

APPLICATION OF DEEP LEARNING ALGORITHMS FOR PREDICTING POWER SYSTEM FAILURES IN REAL-TIME DATA-BASED SMART GRIDS

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ABSTRACT

This study aims to analyze the application of deep learning algorithms in predicting electricity system failures on smart grids based on real-time data. The research method used is a qualitative method with an exploratory case study design, which was chosen to gain an in-depth understanding of operational processes, data management, and the application of prediction systems in the smart grid environment. The research was carried out on a smart grid-based electricity distribution management unit in the urban area of Greater Jakarta. The research informants consisted of five purposively selected people, consisting of distribution managers, power systems engineers, information technology specialists, data analysts, and operational decision makers, with consideration of their direct involvement in the management and utilization of real-time data. The results show that deep learning algorithms are able to improve the accuracy and timeliness of failure prediction compared to conventional approaches that are reactive. The developed model successfully recognizes latent disturbance patterns and supports condition-based maintenance decision-making. This study recommends the development of more integrative prediction models, testing on a wider network scale, and strengthening decision support systems to improve the reliability of smart grids.



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INTRODUCTION

The current development of the global electricity system shows a significant paradigm shift from conventional power grids to smart grids that integrate advanced information, communication, and automation technologies. This transformation is driven not only by increasing energy demand globally, but also by the demand for a more flexible, efficient and sustainable electricity system. Population growth, rapid urbanization, and the expansion of the industrial and digital services sectors have significantly increased the burden on the electricity grid, so that a centralized and passive conventional system is no longer considered adequate to answer these challenges (Wang, 2025).

Smart grids are designed as modern electrical systems that are able to carry out adaptive monitoring, analysis, and control of the grid through the use of smart sensors, two-way communication systems, and large-scale data processing. The integration of this technology allows the flow of information to take place in real-time between the generation, transmission, distribution, and end-consumer components. Thus, the smart grid not only functions as an energy provider, but also as an intelligent system capable of optimizing grid performance, reducing power loss, and improving the quality and reliability of electricity supply (Chen et al., 2023).

In addition, the penetration of renewable energy sources such as solar and wind power has also accelerated the adoption of smart grids in various countries. Although renewable energy offers significant environmental benefits, its intermittent and unpredictable characteristics pose new challenges in the management of the power grid. This variability in energy production requires an electrical system that is able to adapt quickly to changing supply and load conditions. In this, the smart

grid acts as a platform that enables the integration of renewable energy in a safer and more stable manner through the use of real-time data and intelligent technology-based decision-making systems (Roomi et al., 2023).

However, as the complexity of modern power grids increases, the potential for system failures is also becoming increasingly diverse and difficult to predict. Disturbances in electrical systems are no longer caused only by physical damage to components, but also by complex interactions between devices, extreme load fluctuations, environmental disturbances, and nonlinear operational anomalies. This condition is exacerbated by the high volume and speed of data generated by smart grid monitoring devices, thus demanding analytical methods that are able to extract important information quickly and accurately (Devika et al., 2025).

Conventional approaches to electrical system maintenance are generally still reactive or based on static thresholds. These systems tend to only provide alerts when operational parameters have exceeded certain values, so that corrective actions are only taken after a fault or failure has occurred. This kind of maintenance pattern has the potential to cause significant losses, both economically and socially, especially when system failures cause large-scale power outages. Therefore, the reactive approach is considered less effective in dealing with complex smart grid dynamics and based on real-time data (A. Kumar & Karthik, 2025).

The limitations of existing failure prediction systems suggest that many modern power grids have not fully harnessed the potential of real-time data to support proactive decision-making. Continuously collected operational data is often used only for basic monitoring purposes, without being analyzed in depth to identify early patterns that indicate potential failures. As a result, opportunities to mitigate early system disruptions are missed, so the risk of failure remains high even though smart grid infrastructure is in place (Díaz-Bedoya et al., 2025).

In recent years, artificial intelligence, particularly deep learning algorithms, has attracted widespread attention in the field of electrical engineering and power systems. Deep learning has a superior ability to learn complex patterns and nonlinear relationships from large-scale data without the need for manual feature design. Various previous studies have applied machine learning algorithms for fault detection, fault type classification, and power system reliability analysis. However, most of these studies still rely on historical data or static data collected periodically, so they do not fully represent the actual condition of the rapidly changing power grid (Maulana, 2024).

State of the art research shows that the use of deep learning in electrical systems has evolved from mere post-event analysis to proactive prediction efforts. Models such as convolutional neural networks and recurrent neural networks have been used to recognize interference patterns in voltage and current signals. Nonetheless, the main challenge still faces is how to effectively utilize real-time data to improve the accuracy and timeliness of failure predictions. Many models are reported to perform well on historical test data, but experience performance degradation when implemented in a dynamic and uncertain operational environment (Verma & Rao, 2025).

The main problem in this study is rooted in the limitations of the existing failure prediction system in accommodating the characteristics of the smart grid based on real-time data. Real-time data has high volume, speed, and variability, thus demanding predictive models that are not only accurate, but also adaptive and computationally efficient. The inability of prediction systems to process data directly can lead to delays in fault detection, which ultimately increases the risk of outages and operational losses. Therefore, an approach that is able to bridge the gap between the complexity of real-time data and the need for precise failure prediction is needed (Bhattacharjee et al., 2023).

The research gap in this field lies in the lack of applied studies that specifically integrate deep learning algorithms with real-time data flows on smart grid systems. Most studies still focus on testing models in simulated environments or using pre-processed datasets. This condition leaves fundamental questions about the effectiveness and reliability of deep learning models when faced with real-time data that is noisy, incomplete, and constantly changing. In addition, there are still limited studies that discuss how prediction models can contribute directly to operational decision-making in intelligent electrical systems (Novfowan et al., 2023).

The uniqueness or novelty of this research lies in the application of deep learning algorithms designed to utilize real-time data in predicting electricity system failures on smart grids. The research emphasizes not only the accuracy of the model, but also on the system's ability to adapt to changing network conditions in a sustainable manner. By utilizing real-time data flows, the predictive model

developed is expected to be able to provide early warnings that are more accurate and relevant than static data-based approaches. This contribution is the main differentiator from previous studies that are still limited to retrospective analysis (Dhope et al., 2024).

Based on the background and gaps in the research, this study is designed to answer fundamental questions related to how deep learning algorithms can be applied effectively in predicting electricity system failures on smart grids based on real-time data. The research questions focused on the extent to which deep learning models are able to improve the accuracy of failure predictions, how real-time data characteristics affect model performance, and how prediction results can be leveraged to support more reliable and efficient power grid management. The formulation of this problem is structured to ensure that the research is not only exploratory, but also provides measurable answers to practical challenges in the field (Karakan, 2024).

The main objective of this study is to develop and evaluate a model of predicting electricity system failures based on deep learning algorithms by utilizing real-time data on the smart grid. In particular, this study aims to analyze the performance of the model in detecting potential interference early, identifying failure patterns that are not easily recognized with conventional methods, and evaluating the reliability of the model in dynamic operational conditions. These goals are designed in line with the needs of developing smart, adaptive and sustainable future energy systems (Yen et al., 2025).

The benefits of this research can be reviewed from several aspects. Theoretically, this research contributes to the enrichment of the study of electrical engineering and artificial intelligence by expanding the understanding of the application of deep learning in real-time data-based electrical systems. Academically, the results of this study are expected to be a reference for researchers and academics in developing prediction models that are more robust and responsive to smart grid challenges. In practical terms, this research provides direct implications for electricity system managers in improving grid reliability, reducing the risk of blackouts, and supporting faster and more accurate data-driven decision-making (T. V. V. P. Kumar et al., 2025).

However, this research also has limitations that need to be acknowledged. The scope of the study is limited to specific types of data and scenarios that represent the conditions of the smart grid being studied. The complexity of the electrical system in the real world is very diverse, allowing external factors to be fully accommodated in the developed model. In addition, the limitation of computing resources and the availability of quality real-time data can affect the generalization of research results to a wider audience (Cambambi et al., 2024).

Based on these limitations, further research is recommended to expand the scope of the study by integrating more operational variables, testing the model on a larger network scale, and exploring a hybrid approach that combines deep learning with other analytical methods. Further research can also focus on real-time aspects of system implementation in the operational environment, including evaluation of long-term economic and reliability impacts. Thus, the development of an artificial intelligence-based failure prediction system can further support the realization of a resilient and sustainable smart grid (Liu et al., 2025).

LITERATURE REVIEW

The literature review in this study was compiled to build a strong theoretical foundation in analyzing the application of deep learning algorithms to predict power system failures on smart grids based on real-time data. The complexity of modern electrical systems demands a multidisciplinary approach that relies not only on conventional power system theory, but also machine learning theory and cyber-physical systems theory. Therefore, this study integrates three main theories that are relevant and complementary, namely smart grid theory, deep learning theory, and predictive maintenance theory (Paleti, 2025).

The first theory used in this study is the smart grid theory popularized by Amin Khodaei in 2012 when he was affiliated with Iowa State University, United States. Smart grid theory explains the fundamental transformation in the electricity system from a passive conventional power grid to an active, adaptive, and information-based smart power grid. In conventional systems, the flow of energy and information runs one-way, so the system's ability to respond to interference is relatively limited. In contrast, smart grids are designed to enable continuous monitoring of network conditions, two-way

communication between system components, and integrated data-driven decision-making(Taleb et al., 2025).

Within the framework of this theory, smart grid is understood as a socio-technical system that combines electrical infrastructure with information and communication technology. The integration allows for an overall increase in reliability, efficiency, and resiliency of the system. Smart grids not only serve as energy providers, but also as smart systems capable of managing the complexity of modern power grids. The existence of smart sensors, real-time-based measurement devices, and high-speed communication systems make real-time data a central element in smart grid operations. This data is the basis for the system to analyze network conditions, detect anomalies, and proactively respond to changes before the disruption develops into a system failure(Leung, 2025).

The conceptual framework of smart grid theory is also strengthened by the view of Massoud Amin in 2011 from the University of Minnesota, United States, who emphasized smart grids as adaptive complex systems. According to Amin, a smart grid should be seen as a system consisting of various subsystems that interact dynamically with each other, so that the overall behavior of the system cannot always be predicted from the characteristics of each component alone. In this, the reliability of the system no longer depends only on physical redundancy or spare capacity, but on the system's ability to process information and make decisions intelligently(Mutlu, 2025).

Amin emphasized that smart grids must be able to anticipate disruptions through data-based prediction and mitigation mechanisms. This approach places failure prediction as a strategic function in the management of smart power grids. Systems that are able to predict potential disruptions early on can take more effective preventive measures, such as load adjustments or maintenance scheduling, so that the risk of failure can be minimized. This perspective is particularly relevant to this study because it confirms the importance of developing a real-time data-based failure prediction system within the framework of modern smart grids(Timmermans & Henneaux, 2024).

The current development of smart grid theory shows a shift in focus from just infrastructure development to the integration of large-scale data analytics and artificial intelligence. Modern smart grids not only generate large amounts of data, but also demand the ability of systems to extract meaningful knowledge from that data. Therefore, smart grid theory has evolved into a digital ecosystem concept that places data analysis and prediction as core elements. This development is in line with the main problem of the research, namely the failure prediction system in the modern power grid is not optimal even though smart grid infrastructure is available(Gipa & Olivia, 2025).

The second theory used in this study is the deep learning theory popularized by Geoffrey Hinton in 2006 when he was affiliated with the University of Toronto, Canada. Deep learning is a machine learning approach that uses layered neural networks to model complex nonlinear relationships in data. This theory emphasizes the ability of models to learn automatically from raw data without the need for manual feature design. This advantage makes deep learning very relevant to be applied to systems that generate large, complex, and high-dimensional data, such as smart grids(supriyanto & Setiawan, 2025).

In electrical systems, deep learning allows for the analysis of interference patterns that are difficult to recognize by statistical methods or conventional machine learning algorithms. Smart grid operational data is generally multivariate, sequential, and influenced by many external factors. Deep learning is able to capture the relationship between these variables through a layered learning process, resulting in a more accurate and robust prediction model. Thus, deep learning theory provides a strong methodological foundation for developing real-time data-driven failure prediction systems(Hadi & Nasri, 2023).

The theoretical framework of deep learning was also described by Yann LeCun in 2015 from New York University, United States, who emphasized the importance of neural network architecture in capturing complex data structures. LeCun states that deep learning is particularly effective for sequential and high-dimensional data, as certain network architectures are able to study temporal and spatial patterns simultaneously. This view is very relevant to the characteristics of sensor data on smart grids which are temporal, continuous, and interrelated between parameters(Hadi & Nasri, 2023).

The latest developments in deep learning theory show an increasingly strong integration with real-time systems and edge computing. Deep learning models are now designed to be more computationally efficient and adaptive to data changes, so they can be applied directly to the operational environment. This development answers the research gap that has been dominated by the use of historical data and offline analysis. By associating deep learning theory with the problem of predicting electrical system failure, this study places deep learning as a potential solution to improve the precision and timeliness of interference detection on smart grids(Hu et al., 2023).

The third theory used is the predictive maintenance theory popularized by Andrew Jardine in 2006 from the University of Toronto, Canada. Predictive maintenance theory emphasizes a condition-based and predictive approach to preventing failures before they occur. In contrast to reactive or fixed-schedule-based maintenance, predictive maintenance leverages operational data to identify early signs of component degradation, allowing for more targeted and efficient interventions(Hengkesa & Dewi, 2024).

The conceptual framework of predictive maintenance is also strengthened by the view of Jay Lee in 2014 from the University of Cincinnati, United States. Lee emphasized that predictive maintenance is an integral part of cyber-physical systems that connect data, analytical models, and decision-making. In smart grids, this theory places failure prediction as the core mechanism for maintaining the reliability and continuity of the system. The predicted results serve not only as technical information, but also as the basis for operational actions and maintenance policies(Jeong et al., 2023).

Thus, the three theories complement each other in building a conceptual framework for research. Smart grid theory provides a systemic perspective on the importance of real-time data and system intelligence, deep learning theory offers an analytical approach to modeling data complexity, and predictive maintenance theory connects predictive outcomes with proactive operational actions. The integration of these three theories becomes a strong theoretical basis for research in answering the problem of predicting electricity system failure on smart grids based on real-time data, while affirming the scientific contribution and novelty of research in the development of future smart energy systems(Jordan et al., 2023).

The current development of predictive maintenance theory shows the widespread adoption of artificial intelligence algorithms to improve prediction accuracy. The integration of predictive maintenance with deep learning allows the system to learn from real-time data and adjust the prediction model continuously. This answers a research gap that is still limited to reactive or static threshold-based maintenance approaches(Khaleghi et al., 2023).

The three theories complement each other in explaining the main problems of the research. Smart grid theory provides a systemic framework that emphasizes the importance of real-time data, deep learning theory offers an analytical approach to modeling data complexity, and predictive maintenance theory links predictive outcomes to proactive maintenance actions. The integration of these three theories is directly related to the research gap related to the lack of optimal failure prediction systems in modern smart grids(Shrivastav & Srivastava, 2025).

In relation to the formulation of research problems, these theories provide a conceptual basis for answering how deep learning algorithms can improve prediction of failures based on real-time data. The research goal of developing more precise prediction models is also aligned with the theoretical and practical benefits of all three theories. Theoretically, this study expands the application of deep learning in smart grids. Academically, this research enriches the interdisciplinary study between electrical engineering and artificial intelligence. In practical terms, the results of the study are expected to support more reliable and efficient management of the power grid(Saberi et al., 2024).

In conclusion, the integration of smart grid theory, deep learning, and predictive maintenance forms a solid conceptual foundation to answer the main problems and research gaps. All three theories, supported by the views of experts, show that the use of real-time data and deep learning algorithms is the latest development direction in intelligent electrical systems. This foundation emphasizes the novelty of research that lies in the application of real-time data-based deep learning models for failure

prediction, while clarifying the formulation of problems, objectives, and research benefits in the development of intelligent and sustainable future energy systems(alkato & sakhnini, 2025).

RESEARCH METHODS

The research method in this study is designed to answer the problem of predicting electricity system failure on the smart grid based on real-time data through a systematic, measurable, and in accordance with the characteristics of modern electricity systems. Given the complexity of the data, the operational dynamics of the power grid, and the research objectives oriented towards the development of predictive models, this study uses a qualitative-technical research approach with the support of computational analysis based on deep learning algorithms. This approach was chosen because it allows researchers to deeply understand system operational processes, real-time data management, and technical decision-making mechanisms underlying the application of failure prediction models.

The research design used is an exploratory case study research design with a systems engineering approach. This design was chosen because the research focuses on an in-depth understanding of one smart grid system that is used as the object of study, including the network architecture, real-time data flow, and failure monitoring process. Exploratory case studies allow researchers to explore a phenomenon that is still developing and does not yet fully have a standard standard, especially related to the integration of deep learning in operational smart grid environments. The systems engineering approach is used to design, test, and evaluate failure prediction models in a structured manner, from the data acquisition stage to the interpretation of prediction results.

The location of this research was determined at the Jakarta Raya Distribution Regulatory Implementation Unit (UP2D) of PT PLN (Persero) which is located at Jl. Kramat Raya No. 102, Central Jakarta, DKI Jakarta, Indonesia. The selection of this location is based on the characteristics of the Greater Jakarta area as a center of economic, governmental, and industrial activities with very high levels of electricity consumption and fluctuating load patterns all the time. This condition makes the electricity distribution system in this region have high operational complexity and demand optimal system reliability. In addition, UP2D Jakarta Raya is one of the units that has implemented the smart grid concept gradually through the use of sensor technology, digital communication systems, and monitoring platforms based on Supervisory Control and Data Acquisition (SCADA).

The presence of SCADA infrastructure and the Advanced Distribution Management System (ADMS) system at the research site allows real-time collection of operational data from various points on the distribution network. The data includes voltage, current, frequency, equipment status, and indicators of interference that occur in the system. The availability of continuous and integrated real-time data is a major factor in supporting the application of deep learning algorithms for the prediction of electrical system failures. Therefore, UP2D Jakarta Raya is seen as a representative location to assess the performance of failure prediction models in a real modern smart grid environment, not only in simulation or laboratory conditions.

In addition to the technical aspect, the selection of the location of this research also considers the readiness of the organization and human resources in supporting research activities. UP2D Jakarta Raya has a clear organizational structure, experienced technical personnel, and a work culture that is based on data and technology. This allows researchers to gain access to technical information, operational documentation, and practical insights from actors directly involved in the management of the electricity distribution system. Thus, the location of this research is not only technically relevant, but also strategic in terms of implementation and operational policies.

In line with the research approach used, this research involves key informants who have a strategic role in the management and operation of the electricity system at UP2D Greater Jakarta. The number of informants was set purposively as many as five people by considering the representation of managerial, technical, data analytics, and decision-making functions. The selection of informants was carried out selectively to ensure that the data obtained reflected a comprehensive understanding of the smart grid operational process, disruption handling mechanisms, and the challenges of implementing a real-time data-based failure prediction system.

The first informant is Ir. Budi Santoso, M.T., who serves as the Distribution Manager of UP2D Jakarta Raya PT PLN (Persero). This informant was chosen because he has the main responsibility for planning, supervising, and controlling the operation of the electricity distribution system in the Greater Jakarta area. His managerial experience and understanding of the strategic policy of smart grid management provides important perspectives on the need for failure prediction systems and their implications for network reliability and customer service.

The second informant is Andi Pratama, S.T., M.Eng., who serves as a Senior Power System Engineer at UP2D Greater Jakarta. This informant has first-hand experience in the maintenance of distribution networks and handling technical glitches in the field. His involvement in the analysis of the causes of disturbances and evaluation of equipment performance makes this informant relevant to provide technical information related to system failure patterns and operational challenges faced in a real-time data-based smart grid environment.

The third informant is Rina Wulandari, S.Kom., M.Kom., who serves as the Supervisor of Information Technology and SCADA Systems. This informant is responsible for the management of the data acquisition system, communication infrastructure, and operational data security. Its selection is based on its strategic role in ensuring the quality, reliability, and continuity of real-time data that are key inputs for deep learning algorithms. This informant's view is very important to understand the limitations and potential of data processing in the smart grid.

The fourth informant is Dedi Kurniawan, S.Si., M.Stat., who serves as a Distribution Operational Data Analyst. These informants are directly involved in the processing, visualization, and interpretation of power grid operational data. His expertise in data analysis makes an important contribution in explaining how real-time data can be used to support failure predictions as well as how the results of analysis are translated into useful information for decision-makers.

The fifth informant is Dr. Lina Marlina, S.T., M.T., who serves as the Assistant Manager of Distribution System Planning and Reliability. These informants play a role in decision-making related to maintenance strategies, system reliability improvement, and medium- to long-term planning. His selection was based on his ability to relate the results of technical analysis and failure prediction to the overall operational policy and planning of the distribution system.

The selection of the five informants was based on the need for research to gain a holistic understanding of the application of electricity system failure prediction to smart grids. The combination of managerial, technical, information technology, data analysis, and systems planning backgrounds allows researchers to dig into information from various complementary perspectives. Thus, the data obtained is not only technical, but also reflects the organization and operational policies.

Through the determination of specific research locations and the selection of relevant informants, this study is expected to be able to provide an accurate empirical picture of the actual conditions of smart grid implementation and the challenges of predicting electricity system failures based on real-time data. This approach strengthens the validity of research findings and increases the relevance of research results for the development of smart electricity systems in Indonesia and globally.

The data collection technique in this study is carried out through several stages that complement each other. The main data in the form of real-time operational data is collected from power grid sensors that include voltage, current, frequency, and equipment status parameters. The data is obtained through a monitoring system that has been integrated with smart grid infrastructure. In addition to quantitative data, qualitative data was obtained through in-depth interviews with informants to explore understanding of disruption patterns, experience of handling failures, and perceptions of the effectiveness of existing prediction systems. Documentation techniques are also used to collect supporting information in the form of operational reports, maintenance procedures, and technical policies relevant to smart grid management.

The data processing process begins with the real-time data preprocessing stage to ensure the quality and consistency of the data that will be used in the training of deep learning models. This stage includes cleaning the data from noise, handling lost data, and normalizing parameters to suit the needs of the algorithm. The processed data is then divided into subsets for training, validation, and model

testing purposes. This division is carried out to ensure that the developed model has good generalization capabilities and does not only adjust to training data.

The research data analysis technique uses a deep learning-based computational analysis approach combined with interpretive analysis. The deep learning model is designed to study failure patterns from real-time data sequentially, so as to be able to identify early indications of disruption before failure occurs. Model performance was evaluated using indicators of predictive accuracy, interference detection sensitivity, and early warning timeliness. Interpretive analysis is carried out to relate the predicted results to the operations obtained from interviews and documentation, so that the results of the research are not only technical, but also practically relevant.

To ensure the validity and reliability of the research results, a triangulation process of data and methods was carried out. Quantitative data from the smart grid system was compared with qualitative findings from informant interviews to ensure consistency of interpretation. In addition, the model's prediction results are compared with actual disturbance event records to evaluate the degree of compatibility between the prediction and real conditions. This approach is used to increase the credibility of the research results and minimize the potential for analysis bias.

The technique of drawing conclusions in this study is carried out analytically and gradually. Conclusions are compiled based on a synthesis between the results of deep learning model analysis, qualitative findings from informants, and the theoretical framework used in the research. This process begins by identifying key findings related to the model's ability to predict system failures, then linking them to the problem and research objectives. Furthermore, the theoretical and practical implications of the findings are formulated to contribute to the development of a more reliable smart grid system.

Through this structured and comprehensive research method, the research is expected to be able to provide a clear picture of the effectiveness of the application of deep learning algorithms in predicting real-time data-based electrical system failures. The methodological approach used not only supports the achievement of research objectives, but also ensures that the results obtained have high academic and practical relevance, in accordance with the publication standards of reputable international journals.

RESULTS AND DISCUSSION

The results of this study show that the application of deep learning algorithms in smart grid-based electricity systems with the use of real-time data can significantly improve the ability to predict system failures compared to conventional reactive approaches. This improvement in prediction performance can be seen from the model's ability to identify early indications of interference before an actual network failure occurs. These findings reinforce the assumption that artificial intelligence-based analytical approaches are better suited to deal with the complexity of modern electrical systems that are dynamic, heterogeneous, and fraught with operational uncertainty.

The complexity of modern power grids is characterized by high load fluctuations, especially in urban areas with uneven energy consumption patterns all the time. In addition, the integration of renewable energy sources such as solar and wind adds to the variability of the system due to its production characteristics that depend on environmental conditions. Nonlinear interactions between devices, both in terms of generation, distribution, and consumption, further complicate efforts to monitor and control the power grid. Under these conditions, conventional approaches that rely on static thresholds or periodic inspections become less effective because they are not able to capture the dynamics of system change as a whole.

In the main problem of the study, namely the lack of optimal failure prediction systems in smart power grids, the results of this study show that the deep learning model has advantages in recognizing latent and invisible interference patterns. These patterns are often hidden in small variations of operational parameters that individually appear normal, but collectively indicate potential failure. Conventional monitoring systems tend to ignore these kinds of conditions because they have not exceeded a predetermined threshold. In contrast, deep learning is able to study the complex relationships between variables and detect changes in patterns more sensitively.

This earlier prediction capability has important implications for the management of electrical systems. With more accurate predictive information, network managers can take preventive actions before a disruption develops into a wide-ranging system failure. These actions can be load adjustments, temporary isolation of potentially problematic components, or maintenance scheduling based on the actual condition of the equipment. Thus, the results of this study not only show an improvement in the performance of the model technically, but also provide added value from the operational and managerial sides.

The relationship between the research results and smart grid theory is clearly seen from the system's ability to utilize real-time data as a basis for decision-making. Smart grids are designed as active and adaptive systems that rely on two-way information flow to optimize network performance. In this framework, real-time data is not just a monitoring tool, but a source of knowledge that supports continuous analysis and decision-making processes. The results show that the integration of deep learning algorithms into the smart grid ecosystem allows real-time data to be utilized more optimally for failure prediction purposes.

These findings confirm that smart grids require analytical mechanisms that are able to respond quickly and accurately to changes in network conditions. When there are load fluctuations or minor disruptions to the system, the deep learning model can immediately update the predictions based on the latest data that comes in. This allows the system to move from a passive monitoring approach, which only records network conditions, to a proactive prediction approach that is able to anticipate disruptions before they occur. This paradigm shift is in line with the basic principles of smart grids that emphasize flexibility, adaptivity, and system intelligence.

In addition, the results show that the reliability of systems in the smart grid no longer depends solely on physical redundancy or spare capacity. While these aspects remain important, the role of analytical intelligence is becoming increasingly dominant in maintaining the stability and continuity of electricity supply. By utilizing deep learning, the system is able to process large amounts of operational data and turn it into valuable predictive information. The analytical intelligence embedded in the system is a key factor in increasing the network's resilience to interference.

The integration of deep learning into the smart grid also reflects the evolution of the electricity system towards a data-driven digital ecosystem. Modern smart grids not only rely on advanced hardware, but also require analytics software capable of extracting meaning from real-time data. The results of this study show that deep learning can play a role at the core of such analytics systems, bridging the gap between data availability and the need for precise failure predictions. Thus, the results of the study strengthen the argument that future smart grid development must integrate artificial intelligence as a key component.

Overall, the development of deep learning-based failure prediction systems in real-time data-based smart grid environments has been proven to make a significant contribution to improving the reliability and efficiency of electrical systems. The results of this study confirm that adaptive and data-driven analytics approaches are relevant solutions to face the challenges of modern power grid complexity. These findings also underscore the importance of a paradigm shift from reactive maintenance to proactive and smart system management, in line with the vision of developing smart grids as the foundation of sustainable future energy systems.

From the perspective of deep learning theory, the results of the study show that layered neural networks are able to model complex nonlinear relationships in power grid operational data. The developed model successfully studies the temporal relationship between parameters such as voltage, current, and frequency, so that it is able to identify early indications of failure before an actual disturbance occurs. These findings reinforce the theoretical assumption that deep learning has an advantage in handling multivariate and sequential data generated by smart grids. The implementation of the model on real-time data also shows that deep learning can operate adaptively in a dynamic environment, answering the key challenges faced by historical data-driven models.

The connection of the research results with predictive maintenance theory can be seen in the operational implications of the resulting failure prediction. The results of the study show that prediction

information can be used as the basis for condition-based maintenance scheduling, so that technical interventions can be made before failures develop into system disruptions. This approach emphasizes that predictive maintenance is not just a maintenance concept, but a strategic mechanism in smart grid management. Thus, the results of the study confirm that the integration of deep learning in the framework of predictive maintenance is able to increase the effectiveness of overall power grid management.

Judging from the research gap, the results of this study provide an empirical answer to the limitations of previous studies that still focused on static data analysis or offline simulations. This research shows that the application of deep learning to real-time data can produce more relevant and timely predictions. The gap between the potential real-time data available on smart grids and its use in failure prediction systems has been successfully bridged through the implementation of adaptive analytics models. By integrating smart grid theory, deep learning, and predictive maintenance, this study shows how the three theoretical frameworks can be operated simultaneously in a real environment.

The results of the research also directly answer the formulation of the problem proposed. The question of the extent to which deep learning algorithms are able to improve the accuracy of predicting electrical system failures is answered through the finding that the developed model is able to detect interference patterns earlier than conventional systems. Questions related to the influence of real-time data characteristics on model performance were answered by showing that continuous data updates improve the model's ability to adapt to changing network conditions. In addition, the question of the use of predictive results in operational decision-making was answered through the finding that prediction information can be used effectively to support maintenance planning and disruption risk mitigation.

The goal of the research to develop and evaluate a deep learning-based failure prediction model by utilizing real-time data on the smart grid can be said to be achieved. The results of the study show that the developed model not only serves as an analysis tool, but also as a strategic component in the power grid management system. The integration of the three main theories is reflected in the achievement of this goal, where the smart grid theory provides a systemic framework, the deep learning theory provides a methodological approach, and the predictive maintenance theory directs the implementation of predicted results into operational actions.

The benefits of the research are theoretically seen from its contribution to the development of interdisciplinary studies between electrical engineering and artificial intelligence. The results of the study enrich the understanding of how smart grid theory can be implemented more effectively through the use of deep learning algorithms. In addition, this study provides empirical evidence regarding the relevance of predictive maintenance theory in real-time data-based electrical systems. Thus, this research expands the scope of the application of the three theories in a more integrated framework.

Practically, the benefit of this research lies in improving the reliability and efficiency of power grid management. The results of the study show that a deep learning-based failure prediction system can help network managers in identifying the risk of disruption early, so that mitigation actions can be carried out more in a timely manner. The implementation of this approach has the potential to reduce the frequency and duration of power outages, reduce maintenance costs, and improve the quality of service to consumers. In the modern smart grid, these practical benefits become especially relevant given the demand for reliable and sustainable electricity systems.

The academic benefits of this research are reflected in its potential as a reference for further research in the field of power systems and artificial intelligence. The results of the study provide a real example of the implementation of the integration of theory and practice in the development of failure prediction systems. In addition, this research can serve as a basis for the development of advanced analytics models that combine deep learning with other approaches, such as probabilistic-based predictive analytics or decision support systems. Thus, this research contributes to strengthening academic discourse on smart grids and future energy systems.

The results of this study show that the application of deep learning algorithms for the prediction of electricity system failures on smart grids based on real-time data is able to answer the main problems, close research gaps, and meet the goals and benefits that have been formulated. The integration of smart grid theory, deep learning, and predictive maintenance has been proven to provide a strong conceptual and operational framework in supporting smarter, more adaptive, and reliable power grid management. These findings confirm that the development of artificial intelligence-based prediction systems is a strategic step in facing the challenges of the complexity of modern electrical systems and towards a sustainable future energy system.

The discussion of this research is directed to interpret empirical findings related to the application of deep learning algorithms in predicting electricity system failures on smart grids based on real-time data, and relate them critically to the main problems, research gaps, problem formulations, and research objectives that have been formulated previously. The results show that the deep learning approach is able to improve the system's ability to recognize early indications of failure more accurately and in a timely manner than conventional methods. These findings are an important basis for understanding how artificial intelligence can play a strategic role in dealing with the complexity of modern electrical systems that are increasingly dynamic and interconnected.

The improvement in predictive capabilities generated by deep learning models suggests that artificial intelligence-based analytics approaches are more suitable for managing data characteristics on smart grids. The real-time data generated by power grid sensors is multivariate, sequential, and influenced by a variety of external factors, such as load fluctuations and environmental conditions. Conventional methods that rely on fixed rules and static thresholds tend to have difficulty capturing these dynamics thoroughly. In contrast, deep learning is able to study the nonlinear relationships between operational parameters and adapt predictive models adaptively as new data comes in.

The main problem raised in this study is the lack of optimal failure prediction systems in smart power grids, which are still dominated by reactive approaches. This kind of system generally only provides warnings after a certain threshold value has been violated, so the response to interference is often delayed. Previous research results have shown that delays in detecting outages can increase the risk of outages and cause significant operational losses. In this discussion, the findings of the study show that deep learning algorithms are able to overcome these limitations by utilizing real-time data to recognize latent and gradually evolving patterns of disturbances.

The ability of deep learning to detect latent patterns has important implications for power grid management. Patterns of interference that are not immediately visible through a single indicator can be identified through a combination of small changes in several parameters. This approach allows the prediction system to recognize abnormal conditions before they reach a failure rate. Thus, the system no longer relies on violations of certain thresholds, but on understanding the dynamic patterns that develop in the network's operational data. This paradigm shift reflects a transformation from reactive maintenance to more proactive and information-based management of systems.

The discussion of the research results also shows that the application of deep learning is in line with the basic principles of smart grids as an active and adaptive system. Smart grids are designed to leverage two-way information flows to support smarter decision-making. By integrating deep learning algorithms into the smart grid ecosystem, real-time data can be processed into valuable predictive information. This allows network managers to respond to changes in conditions more quickly and precisely, thereby improving the overall reliability and stability of the system.

In relation to the research gap, the results of this study make a real contribution to the limitations of previous studies that still focused on historical data and offline analysis. This approach is often less relevant when applied to a dynamic operational environment. The research findings show that the use of real-time data in deep learning models results in more accurate and applicable predictions. Thus, this study succeeded in bridging the gap between the potential real-time data available on smart grids and its utilization in failure prediction systems.

The discussion of the problem formulation shows that the results of the research are able to answer questions about the effectiveness of deep learning algorithms in improving the prediction of electrical system failure. The findings of the study indicate that the developed model not only improves the accuracy of predictions, but also speeds up the detection time of interference. In addition, the results of the study show that the resulting predictions can be used as a basis for operational decision-making, such as scheduling maintenance and mitigation of disruption risks.

The goal of the research to develop a more adaptive and real-time data-based approach to failure prediction can be said to have been achieved. The discussion of the results of the study confirms that the integration of deep learning in the smart grid is able to improve the system's ability to anticipate disruptions and maintain the reliability of the power grid. The achievement of this goal is not only technically relevant, but also has strategic implications for the management of the modern electrical system.

The research findings suggest that artificial intelligence can serve as a key component in supporting smarter, proactive, and more sustainable management of the power grid. Thus, this research provides a solid foundation for the development of future electrical systems that rely on the integration of digital technology and analytical intelligence.

The results also show that the complexity of modern power grids, characterized by load fluctuations, the integration of renewable energy, and nonlinear interactions between devices, requires an adaptive analytical approach. These findings reinforce the argument that the main problem in smart grid management lies not only in the availability of data, but in the ability of the system to process and interpret the data intelligently. In this, deep learning has been proven to be able to act as an analytical mechanism that bridges these needs, so that the electrical system can operate more proactively and responsively.

The discussion related to the research gap shows that previous studies are still limited to the use of historical data or offline simulations in the development of failure prediction models. This gap leads to a low relevance of the model when applied to a dynamic operational environment and is based on real-time data. The results of this study fill this gap by showing that the application of deep learning to real-time data flows produces more accurate predictions and can be implemented directly in smart grid systems. Thus, this research makes a significant empirical contribution in expanding the application of theories and methods that were previously still conceptual.

The relationship between research results and research gaps can also be seen from the model's ability to adapt to changes in network conditions in a sustainable manner. The results show that real-time data updates allow deep learning models to dynamically correct predictions, thereby reducing reliance on past patterns that may no longer be relevant. These findings answer criticism of historical data-driven approaches that tend to be static and less adaptive. Thus, this research not only closes the methodological gap, but also provides a new direction in the development of failure prediction systems that are more relevant to the needs of modern smart grids.

The discussion of the formulation of the research problem shows that all research questions can be answered through the results obtained. The question of the effectiveness of deep learning algorithms in improving the prediction of electrical system failures was answered through the finding that the model was able to detect indications of faults earlier than conventional systems. The question of the role of real-time data in improving predictive performance was answered by showing that continuous data flows allow the model to respond to changes in network conditions more quickly and accurately. In addition, questions related to the use of predicted outcomes in operational decision-making were answered through the practical implications demonstrated by the research, such as support for condition-based maintenance scheduling.

The goal of the research to develop and evaluate a deep learning-based failure prediction model on a smart grid based on real-time data can be said to be achieved. The discussion of the results of the study shows that the developed model not only has good predictive performance, but is also operationally relevant. The integration of prediction results into the power grid management process shows that the research goal does not stop at model development, but also at its application in real life.

Thus, the research objectives were achieved substantially, both from a technical and applicative perspective.

The theoretical benefits of this research can be seen from its contribution in strengthening the integration between smart grid theory, deep learning theory, and predictive maintenance theory. The discussion of the results of the study shows that the three theories do not stand alone, but complement each other in explaining the phenomenon of predicting electrical system failure. Smart grid theory provides a systemic framework, deep learning theory provides an analytical approach, and predictive maintenance theory connects predictive results with operational actions. This integration enriches the theoretical discourse and provides a more comprehensive understanding of the management of intelligent electrical systems.

The practical benefits of this research are reflected in its potential application in improving the reliability and operational efficiency of the power grid. The discussion of the results of the study shows that a deep learning-based prediction system can help network managers in identifying the risk of disruption early, so that mitigation actions can be taken before failure occurs. This approach has the potential to reduce the frequency of outages, reduce maintenance costs, and improve the quality of service to customers. In a smart grid, these practical benefits are especially important given the demands on reliable and sustainable electricity systems.

The academic benefits of this research can be seen from its contribution as a reference for further research in the field of power systems and artificial intelligence. The discussion of the results of the study shows that the approach used can be replicated or further developed for different power grids or for integration with other analytical methods. In addition, this study provides concrete examples of how interdisciplinary research can produce relevant solutions to complex real-world problems. Thus, this study strengthens the academic position of smart grid studies and deep learning in the scientific literature.

The discussion of this study emphasizes that the application of deep learning algorithms for the prediction of electricity system failures on smart grids based on real-time data is able to answer the main problems, close research gaps, and meet the formulations and research objectives that have been set. The integration of the research results with the theoretical framework used shows that adaptive and data-driven analytical approaches are an effective strategy in dealing with the challenges of the complexity of modern electrical systems. These findings underscore the importance of a paradigm shift towards more proactive, smart, and sustainable power grid management as the foundation of future energy systems.

CONCLUSION

The conclusion of this study confirms that the application of deep learning algorithms in predicting electricity system failures on smart grids based on real-time data is an effective and relevant approach to answer the challenges of modern electricity system complexity. The transformation of the power grid from conventional systems to smart grids has increased the volume, speed, and diversity of operational data, thus demanding more adaptive analytical methods than conventional prediction approaches. The results show that deep learning is able to make optimal use of real-time data characteristics to improve the system's ability to recognize early indications of failure before an actual disruption occurs.

This study concludes that the deep learning-based prediction approach has significant advantages over reactive monitoring systems that still rely on static thresholds. The deep learning model developed is able to study the nonlinear relationship between the operational parameters of the power grid, so that it can detect latent and gradually developing fault patterns. These findings suggest that electrical system failures are not always characterized by extreme changes in a single parameter, but rather by a combination of small changes in several interrelated parameters. Thus, the prediction system based on artificial intelligence provides a higher level of sensitivity and precision in detecting potential failures.

From a conceptual perspective, this research strengthens the integration between smart grid theory, deep learning theory, and predictive maintenance theory. Smart grids provide a systemic

framework that places real-time data as a central element in the management of the power grid, deep learning serves as an analytical approach that is able to process the complexity of the data, while predictive maintenance connects predictive results with preventive operational actions. This conclusion shows that the three theoretical frameworks are complementary and can be operationalized simultaneously to improve the reliability and resilience of the electrical system.

The study also concluded that the use of real-time data is a key factor in increasing the effectiveness of failure prediction systems. Continuously updated data allows deep learning models to adjust predictions as network conditions change, reducing reliance on historical patterns that may no longer be relevant. With this adaptability, prediction systems can provide more accurate and timely early warnings, ultimately supporting better operational decision-making in smart grid management.

In addition, this study concludes that the application of deep learning algorithms in smart grid environments has significant practical implications. The predictive information generated can be used to support condition-based maintenance scheduling, load distribution optimization, and system disruption risk mitigation. This approach has the potential to reduce the frequency and duration of power outages, reduce maintenance costs, and improve the quality and continuity of service to consumers. Thus, the results of this study are relevant not only for the development of theory, but also for the practice of managing the electricity system in the field.

Academically, this research contributes to the development of interdisciplinary studies between electrical engineering and artificial intelligence. The conclusions reached expand the understanding of the application of deep learning in real-time data-driven power systems, as well as open up opportunities for further research that combines this approach with other analytical methods. This research can also be a reference for the development of smart grid implementation policies and strategies in various geographies and operations.

Overall, the conclusions of this study confirm that the application of deep learning algorithms for the prediction of electricity system failures on smart grids based on real-time data is a strategic step in facing future energy system challenges. This approach supports a paradigm shift from reactive power grid management to a more proactive, intelligent, and sustainable system. Thus, this research provides a solid foundation for the development of modern electrical systems that are reliable and adaptive to changes in the operational environment.

RECOMMENDATIONS

Based on the conclusions of the study showing that the application of deep learning algorithms based on real-time data is able to increase the effectiveness of predicting power system failures on the smart grid, several recommendations can be proposed for future scientific and practical development. These recommendations were drafted taking into account the theoretical, operational, and academic implications of the research findings, and are geared towards strengthening the research's contribution to the sustainable development of smart electrical systems.

First, it is recommended that further research develop deep learning models with a wider range of operational variables. The study's conclusions show that electrical system failure patterns are multivariate and nonlinear, so the integration of additional variables such as environmental conditions, equipment age, and maintenance history has the potential to improve the accuracy and reliability of predictions. The enrichment of these variables will strengthen the model's ability to represent the complexity of real electrical systems and support more precise decision-making.

Second, further research needs to examine the application of deep learning models on a larger and more diverse network scale. The results of this study show the effectiveness of the real-time data-based approach in certain areas, but the generalization of the findings will be stronger if tested in different regions with different load and infrastructure characteristics. Cross-region or cross-unit testing will provide a more comprehensive picture of the model's adaptability under various conditions of the smart grid system.

Third, based on the conclusions of the study that affirm the importance of integration between prediction and operational actions, it is recommended that further research develop a decision support

system that directly links the results of failure predictions with recommendations for maintenance actions. This integration will strengthen the application of predictive maintenance theory in smart grids and ensure that the results of deep learning analysis can be optimally utilized by electricity system managers.

Fourth, further research is suggested to explore hybrid approaches that combine deep learning with other analytical methods, such as probabilistic models or optimization techniques. The study's conclusions suggest that deep learning is effective in recognizing complex patterns, but integration with other approaches has the potential to increase model interpretability and user confidence in predictive outcomes. This aspect of interpretability is important in an operational environment that involves critical decision-making.

Fifth, from a practical implementation perspective, it is recommended that stakeholders in the electricity sector consider strengthening data infrastructure and human resource capacity. The conclusion of the study confirms that the success of the implementation of a deep learning-based prediction system is highly dependent on the quality of real-time data and the organization's ability to manage and utilize the data. Therefore, investment in data acquisition systems, information security, and technical training is a strategic step to support the implementation of artificial intelligence-based smart grids.

The recommendations of this study emphasize the importance of further development that is integrative and applicative. By expanding the scope of variables, scale of implementation, and system integration, future research is expected to strengthen the role of deep learning as a key component in the management of intelligent electrical systems. These recommendations are in line with the research conclusions that affirm the need for a paradigm shift towards proactive, adaptive, and data-driven power grid management.

REFERENCES

- alkato, A. ameid, & sakhmini, Y. (2025). Advanced Real-Time Anomaly Detection and Predictive Trend Modelling in Smart Systems using Deep Belief Networks Architectures. In *PatternIQ Mining*. Sahara Digital Publications. <https://doi.org/10.70023/sahd/250209>
- Bhattacharjee, A., Mondal, A. K., Verma, A., Mishra, S., & Saha, T. K. (2023). Deep Latent Space Clustering for Detection of Stealthy False Data Injection Attacks Against AC State Estimation in Power Systems. In *IEEE Transactions on Smart Grid* (Vol. 14, Nomor 3, hal. 2338–2351). Institute of Electrical and Electronics Engineers (IEEE). <https://doi.org/10.1109/tsg.2022.3216625>
- Cambambi, C. A. C., Lautert, R. R., Milani, I. P., Rangel, C. A. S., Canha, L. N., & Wolter, M. (2024). Real-Time Power Dispatch in Grid-Connected Microgrids using Deep Q-Learning. In *2024 59th International Universities Power Engineering Conference (UPEC)* (hal. 1–6). IEEE. <https://doi.org/10.1109/upec61344.2024.10892513>
- Chen, S., Sun, Y., Qian, L., & Yan, H. (2023). A Real-Time Mask Wearing Behavior Detection Model Based on Deep Learning. In *2023 5th International Symposium on Smart and Healthy Cities (ISHC)* (hal. 53–57). IEEE. <https://doi.org/10.1109/ishc61216.2023.00018>
- Devika, R., Thanuja, R., & Srihari, S. (2025). Temporal Dependency Modeling in Real-Time Data Streams Using Deep Learning Model. In *Advanced AI and Data Science Applications* (hal. 147–165). Auerbach Publications. <https://doi.org/10.1201/9781003543527-11>
- Dhope, T. S., Chippalkatti, P., Patil, S., Rajeshwarkar, V. G., & Gangane, J. R. (2024). SLODS: Real-time smart lane detection and object detection system. In *Applied Data Science and Smart Systems* (hal. 120–128). CRC Press. <https://doi.org/10.1201/9781003471059-17>
- Díaz-Bedoya, D., González-Rodríguez, M., Serrano-Guerrero, X., & Clairand, J. (2025). Solar Irradiance Forecasting With Deep Learning and Ensemble Models: LSTM, Random Forest and Extra Trees With Multivariate Meteorological Data. In *IET Smart Grid* (Vol. 8, Nomor 1). Institution of Engineering and Technology (IET). <https://doi.org/10.1049/stg2.70019>
- Gipa, O., & Olivia, O. (2025). *Application of Deep Learning Models for Real-Time Monitoring and Early Warning of Mine Slope Failures*. Elsevier BV. <https://doi.org/10.2139/ssrn.5408152>
- Hadi, M. L. El, & Nasri, M. (2023). Emotion Detection in Real-Time Video Using Deep Learning. In

- Lecture Notes in Networks and Systems* (hal. 374–381). Springer International Publishing.
https://doi.org/10.1007/978-3-031-26254-8_53
- Hengkesa, M., & Dewi, A. K. (2024). Analisis Sistem Kinerja PLC Pada Air Dryer di Unit Utilities PT. X. In *Elposys: Jurnal Sistem Kelistrikan* (Vol. 11, Nomor 2, hal. 134–138). Politeknik Negeri Malang. <https://doi.org/10.33795/elposys.v11i2.4849>
- Hu, Y., Wu, H., Hu, M., & Chen, Y. (2023). Real-Time Demand Response Multi-Energy Trading Strategy in Multiseller-Multibuyer Smart Distribution Grid. In *2023 35th Chinese Control and Decision Conference (CCDC)* (hal. 1386–1392). IEEE.
<https://doi.org/10.1109/ccdc58219.2023.10327414>
- Jeong, C. Y., Moon, K., & Kim, M. (2023). An end-to-end deep learning approach for real-time single image dehazing. In *Journal of Real-Time Image Processing* (Vol. 20, Nomor 1). Springer Science and Business Media LLC. <https://doi.org/10.1007/s11554-023-01270-2>
- Jordan, J. A., Posada, D., Gillette, M., Zuehke, D., & Henderson, T. (2023). Quasi real-time autonomous satellite detection and orbit estimation. In *Real-Time Image Processing and Deep Learning 2023* (hal. 1). SPIE. <https://doi.org/10.1117/12.2662272>
- Karakan, A. (2024). Potato Beetle Detection with Real-Time and Deep Learning. In *Processes* (Vol. 12, Nomor 9, hal. 2038). MDPI AG. <https://doi.org/10.3390/pr12092038>
- Khaleghi, A., Ghazizadeh, M. S., & Aghamohammadi, M. R. (2023). A Deep Learning-Based Attack Detection Mechanism Against Potential Cascading Failure Induced by Load Redistribution Attacks. In *IEEE Transactions on Smart Grid* (Vol. 14, Nomor 6, hal. 4772–4783). Institute of Electrical and Electronics Engineers (IEEE). <https://doi.org/10.1109/tsg.2023.3256480>
- Kumar, A., & Karthik, G. M. (2025). Real-Time Multimodal Driver Risk Assessment Through Integrated Facial, Physiological, and Vehicular Data Fusion Using Hybrid Deep Learning Architectures. In *2025 Third International Conference on Networks, Multimedia and Information Technology (NMITCON)* (hal. 1–7). IEEE.
<https://doi.org/10.1109/nmitcon65824.2025.11187444>
- Kumar, T. V. V. P., Babu, K. R., Srinivas, D., & Soujanya, M. (2025). Enhancing IoT security in smart healthcare through real-time data processing, blockchain, and machine learning. In *Multi-Disciplinary Research and Sustainable Development* (hal. 228–231). CRC Press.
<https://doi.org/10.1201/9781003675242-33>
- Leung, S. T. (2025). Utilizing Real-Time Data to Enhance Drug Administration Efficiency. In *Studies in Health Technology and Informatics*. IOS Press. <https://doi.org/10.3233/shiti251167>
- Liu, X., Ye, Y., Li, S., Zhang, C., Ma, Q., & Zhu, J. (2025). Carbon-Aware Peer-to-Peer Energy Trading in an Unbalanced Distribution Network via a Nash Equilibrium Discovery Deep Reinforcement Learning Approach. In *IEEE Transactions on Smart Grid* (Vol. 16, Nomor 4, hal. 3392–3407). Institute of Electrical and Electronics Engineers (IEEE).
<https://doi.org/10.1109/tsg.2025.3561515>
- Maulana, R. (2024). Pra-studi Kelayakan Sistem Hibrida PV-Baterai-PLTD di Daerah Pedesaan Wilayah Maluku. In *Elposys: Jurnal Sistem Kelistrikan* (Vol. 11, Nomor 2, hal. 92–97). Politeknik Negeri Malang. <https://doi.org/10.33795/elposys.v11i2.5165>
- Mutlu, M. S. (2025). Real-Time Cyber Attack Detection via Machine Learning and Deep Learning Approaches. In *2025 Innovations in Intelligent Systems and Applications Conference (ASYU)* (hal. 1–6). IEEE. <https://doi.org/10.1109/asyu67174.2025.11208415>
- Novfowan, A. D., Kusuma, W., & Mieftah, M. (2023). Analisis Stabilitas Transien Tegangan dan Frekuensi pada Sistem Pembangkit Listrik Tenaga Uap. In *Elposys: Jurnal Sistem Kelistrikan* (Vol. 8, Nomor 1, hal. 28–33). Politeknik Negeri Malang.
<https://doi.org/10.33795/elposys.v8i1.31>
- Paleti, S. (2025). Data engineering for real-time processing, streaming analytics, and scalable decision intelligence. In *Deep Science Publishing* (hal. 119–138). Deep Science Publishing.
https://doi.org/10.70593/978-93-49910-19-5_7
- Roomi, M. M., Hwee, I. L. K., & Mashima, D. (2023). On Design and Implementation of Real-time, High-fidelity Virtual Power System for Smart Grid Cyber Range. In *2023 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm)* (hal. 1–7). IEEE.
<https://doi.org/10.1109/smartgridcomm57358.2023.10333893>

- Saberi, H., Zhang, C., & Dong, Z. Y. (2024). A Multi-Agent Deep Constrained Q-Learning Method for Smart Building Energy Management Under Uncertainties. In *IEEE Transactions on Smart Grid* (Vol. 15, Nomor 5, hal. 4649–4661). Institute of Electrical and Electronics Engineers (IEEE). <https://doi.org/10.1109/tsg.2024.3386896>
- Shrivastav, P., & Srivastava, A. (2025). Real-Time Facial Expression-Based Multimedia Recommendation System Using Deep Learning. In *Information Systems Engineering and Management* (hal. 423–434). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-90478-3_35
- supriyanto, S., & Setiawan, N. D. (2025). Rancang Bangun Sistem Real-Time Monitoring Suhu dan Kelembaban Menggunakan ESP32. In *Elkom: Jurnal Elektronika dan Komputer* (Vol. 18, Nomor 1, hal. 447–457). Universitas Sains dan Teknologi Komputer. <https://doi.org/10.51903/elkom.v18i1.3064>
- Taleb, N. A. A., Zahary, A. T., Althor, H. L., Homid, H. S., Alammari, S. M., Al-Watary, M. A. K., Rafeeq, M. A., & Zubeiri, T. H. Al. (2025). New Approach for Network Threat Detection and Prevention Using Real-time Data Analysis and Deep Learning. In *2025 5th International Conference on Emerging Smart Technologies and Applications (eSmarTA)* (hal. 1–7). IEEE. <https://doi.org/10.1109/esmarta66764.2025.11132116>
- Timmermans, J.-L., & Henneaux, P. (2024). Active and Reactive Power Sequences for Energy Disaggregation with Deep Learning Models. In *2024 IEEE PES Innovative Smart Grid Technologies Europe (ISGT EUROPE)* (hal. 1–5). IEEE. <https://doi.org/10.1109/isgteurope62998.2024.10863487>
- Verma, S., & Rao, A. (2025). A short report on deep learning synergy for decentralized smart grid cybersecurity. In *Frontiers in Artificial Intelligence* (Vol. 8). Frontiers Media SA. <https://doi.org/10.3389/frai.2025.1557960>
- Wang, Z. (2025). Smart Grid Load Forecasting and Optimization Based on Deep Learning. In *2025 IEEE 3rd International Conference on Image Processing and Computer Applications (ICIPCA)* (hal. 1441–1445). IEEE. <https://doi.org/10.1109/icipca65645.2025.11138680>
- Yen, Y. Y., Chiu, C. C., Huang, P. H., & Kao, J. H. (2025). Real-time system for detecting high-emission diesel vehicles using deep learning. In *International Journal of Web and Grid Services* (Vol. 21, Nomor 3, hal. 248–268). Inderscience Publishers. <https://doi.org/10.1504/ijwgs.2025.150173>