e-palli

American Journal of Multidisciplinary Research and Innovation (AJMRI)

ISSN: 2158-8155 (ONLINE), 2832-4854 (PRINT)

VOLUME 4 ISSUE 4 (2025)

PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Multidisciplinary Research and Innovation (AJMRI)

Volume 4 Issue 4, Year 2025
ISSN: 2158-8155 (Online), 2832-4854 (Print)
DOI: https://doi.org/10.54536/ajmri.v4i4.4822
https://journals.e-palli.com/home/index.php/ajmri

Contingency Evaluation of the Nigerian 330KV Transmission Grid Using Nuro-Fuzzy

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Article Information

Received: March 18, 2025

Accepted: April 24, 2025

Published: June 24, 2025

Keywords

Contingency, Evaluation, Grid, Nigerian 330KV, NURO-FUZZY, Transmission

ABSTRACT

The constant power failure in the transmission network that has put business activities in the country into jeopardy is surmounted by introducing contingency evaluation of the Nigerian 330kv transmission grid using NURO-FUZZY. To vividly achieve this, it is done in this manner, characterizing and establishing the contingencies that causes power failure in the Nigerian 330kv transmission grid, designing a rule base that will predict, identify and normalize the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid, training ANN in these rules for effective prediction, identification and normalization of the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid, designing a SIMULINK model for contingency evaluation of the Nigerian 330kv transmission grid using NURO-FUZZY, validating and justifying the percentage improvement in the prediction, identification and normalization of the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid with and without NURO-FUZZY. The results obtained are the conventional percentage Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid is 70%. On the other hand, when NURO-FUZZY was integrated in the system, the reduction automatically became 60.7% thereby improving constant power supply in the transmission network. The percentage improvement in the reduction of Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid 9.3%. The conventional detecting mechanism for line outage is 38% thereby drastically reduced power supply in the transmission network. On the other hand, when NURO-FUZZY is incorporated in the system, it automatically improved the detecting mechanism to 50.54%. Finally, the percentage improvement in the detecting mechanism of line outage when NURO-FUZZY is integrated in the system over the conventional approach is 12.54%.

INTRODUCTION

Contingency Evaluation of the Nigerian 330kV Transmission Grid Using Neuro-Fuzzy Approach

The Nigerian power sector faces numerous challenges, including inadequate generation capacity, insufficient transmission infrastructure, and unreliable service delivery. The 330kV transmission grid, the backbone of the national grid, is particularly vulnerable to contingencies such as line outages, equipment failures, and natural disasters. These contingencies can lead to cascading failures, widespread blackouts, and significant economic losses.

Evaluating the impact of contingencies on the power grid is crucial for:

Ensuring System Stability and Security

Identifying critical lines and buses that are most susceptible to failure allows for targeted mitigation strategies.

Enhancing Grid Planning and Operation

Contingency analysis helps in optimizing generation scheduling, transmission dispatch, and control strategies.

Improving Power System Reliability

Evaluating potential contingencies helps utilities make informed decisions regarding investments in grid expansion and reinforcement.

Traditional methods for contingency evaluation, such as power flow analysis, have limitations in handling uncertainties and non-linearities inherent in power systems.

Neuro-fuzzy systems offer a promising alternative due to their:

Ability to Learn from Historical Data

They can capture complex relationships between system variables without requiring explicit mathematical models.

Tolerance for Uncertainty

They can handle imprecise and incomplete information, which is often the case in real-world power systems.

Nonlinearity Representation

They can effectively model the non-linear behavior of power system components.

This study proposes a novel approach for contingency evaluation of the Nigerian 330kV transmission grid using a neuro-fuzzy system. The specific objectives are:

- To develop a neuro-fuzzy model that can accurately predict the impact of contingencies on critical system

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parameters such as bus voltages, line flows, and generator loadings.

- To identify critical lines and buses in the grid that are most susceptible to failure.
- To assess the effectiveness of different mitigation strategies in reducing the impact of contingencies.

The successful implementation of this approach can significantly contribute to enhancing the security, reliability, and efficiency of the Nigerian power grid.

The remainder of this paper is organized as follows:

- Section 2 presents a literature review of existing methods for contingency evaluation.
- Section 3 describes the proposed neuro-fuzzy approach in detail.
- Section 4 presents the case study of the Nigerian 330kV transmission grid.
- Section 5 discusses the results obtained from the study.
- Section 6 concludes the paper and highlights potential future research directions.

I hope this introduction provides a clear overview of the study's objectives and methodology. Please feel free to ask any questions you may have.

Problem Statement

Contingency Evaluation of the Nigerian 330kV Transmission Grid using Neuro-Fuzzy Approach

The Nigerian 330kV transmission grid, vital to the nation's power infrastructure, suffers from frequent contingencies like line outages, equipment failures, and natural disasters. These events can trigger cascading failures, widespread blackouts, and significant economic losses. Traditional methods for assessing contingency impact, while valuable, have limitations:

Limited Uncertainty Handling

Existing methods often struggle with the inherent uncertainties and non-linearities in real-world power systems, leading to inaccurate predictions.

Lack of Adaptability

Static models may not adapt well to changing system conditions or new types of contingencies.

Computational Complexity

Extensive calculations can be time-consuming and resource-intensive, hindering real-time decision making.

Therefore, there exists a crucial need for a more robust and adaptable approach to contingency evaluation in the Nigerian 330kV grid. This approach should address the following key issues:

Accurate Prediction

Develop a model that accurately predicts the impact of contingencies on critical system parameters like bus voltages, line flows, and generator loadings, even with uncertainties and non-linearities present.

Critical Line and Bus Identification

Identify lines and buses in the grid that are most susceptible to failure under various contingencies, allowing for targeted mitigation strategies.

Mitigation Strategy Evaluation

Assess the effectiveness of different mitigation strategies, such as generation rescheduling or load shedding, in reducing the impact of contingencies and ensuring grid stability.

Real-Time Applicability

Design a computationally efficient model that can be implemented in real-time for prompt decision making during grid contingencies.

By addressing these challenges, a novel neuro-fuzzy approach has the potential to significantly enhance the security, reliability, and operational efficiency of the Nigerian 330kV transmission grid.

Aim and Objectives

Aim

Aim: Enhancing Nigerian 330kV Grid Security and Reliability through Neuro-Fuzzy Contingency Evaluation

The primary aim of this study is to develop and implement a neuro-fuzzy system for contingency evaluation of the Nigerian 330kV transmission grid, ultimately enhancing its security and reliability. This will be achieved through the following specific objectives:

Accurate Contingency Impact Prediction

Develop a neuro-fuzzy model capable of accurately predicting the impact of various contingencies, including line outages, generator trips, and load variations, on critical system parameters such as bus voltages, line flows, and generator loadings. This model should be robust to inherent uncertainties and non-linearities in the power system.

Identification of Critical Lines and Buses

Utilize the neuro-fuzzy model to identify lines and buses in the grid that are most vulnerable to failure under different contingency scenarios. This will enable targeted mitigation strategies to be implemented for these critical elements.

Evaluation of Mitigation Strategies

Assess the effectiveness of various mitigation strategies, such as generation rescheduling, load shedding, and transmission switching, in mitigating the impact of contingencies and maintaining grid stability. The neuro-fuzzy model should be able to evaluate the effectiveness of these strategies under different operating conditions.

Real-Time Applicability

Design a computationally efficient neuro-fuzzy model that can be implemented in real-time for rapid decision making during grid contingencies. This will ensure timely interventions to prevent cascading failures and minimize widespread blackouts.

By achieving these objectives, the proposed neuro-fuzzy approach aims to significantly contribute to:

Reduced Frequency and Duration of Blackouts

Timely and accurate contingency evaluation allows for proactive mitigation strategies, minimizing service disruptions.

Improved Grid Stability

Early identification of critical lines and buses enables targeted reinforcement measures, enhancing grid resilience to disturbances.

Optimized Grid Operation

Effective mitigation strategies informed by the neuro-fuzzy model can lead to more efficient utilization of available resources and reduced operational costs.

Enhanced Decision-Making Capabilities

Real-time contingency evaluation empowers grid operators to make informed decisions during critical situations, ensuring system security and reliability.

Through these advancements, the neuro-fuzzy approach can play a vital role in transforming the Nigerian 330kV grid into a more robust, reliable, and efficient power transmission system, contributing to the nation's economic growth and development.

Research Objectives

1. To characterize and establish the contingencies that causes power failure in the Nigerian 330kv transmission grid.
2. To design a rule base that will predict, identify and normalize the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid
3. To train ANN in these rules for effective prediction, identification and normalization of the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid
4. To design a SIMULINK model for contingency evaluation of the Nigerian 330kv transmission grid using NURO-FUZZY
5. To validate and justify the percentage improvement in the prediction, identification and normalization of the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid with and without NURO-FUZZY

Research Objectives: Neuro-Fuzzy Contingency Evaluation for Nigerian 330kV Grid

This research aims to develop and implement a neuro-fuzzy system for contingency evaluation of the Nigerian 330kV transmission grid, focusing on achieving the following specific objectives:

Objective 1: Develop a Robust Neuro-Fuzzy Model

- Design and train a neuro-fuzzy model that accurately predicts the impact of various contingencies (line outages, generator trips, load variations) on critical system parameters (bus voltages, line flows, generator loadings).
- Incorporate uncertainty handling mechanisms to account for inherent noise and imprecision in power system data.
- Achieve robust performance even with incomplete or missing information.

Objective 2: Identify Critical Lines and Buses

- Utilize the neuro-fuzzy model to identify lines and buses in the grid most susceptible to failure under different contingency scenarios.
- Develop ranking/scoring metrics to quantify the vulnerability of each grid element based on predicted contingency impact.
- Analyze the impact of different contingency types and severities on critical element identification.

Objective 3: Evaluate Mitigation Strategies

- Integrate the neuro-fuzzy model with various mitigation strategies (generation rescheduling, load shedding, transmission switching).
- Assess the effectiveness of each mitigation strategy in reducing the impact of contingencies on critical system parameters and maintaining grid stability.
- Analyze the trade-offs between different mitigation strategies considering factors like economic impact, social disruption, and environmental consequences.

Objective 4: Real-Time Implementation

- Optimize the neuro-fuzzy model for computational efficiency to enable real-time implementation in grid control centers.
- Develop an interface for grid operators to visualize contingency scenarios, predicted impacts, and potential mitigation strategies.
- Explore integration with existing SCADA systems for seamless data exchange and decision support.

Objective 5: Validate and Benchmark

- Validate the performance of the neuro-fuzzy model using historical contingency data and standard power system analysis tools.
- Benchmark the proposed approach against existing contingency evaluation methods in terms of accuracy, efficiency, and decision support capabilities.
- Analyze the potential economic benefits and cost savings arising from improved grid reliability and operational efficiency.

By achieving these research objectives, this study aims to create a valuable tool for Nigerian power grid operators, enabling them to proactively manage contingencies, enhance grid security and reliability, and optimize grid operation, ultimately contributing to a more stable and efficient power sector for the nation.

Scope of the Study

Scope of Contingency Evaluation Using Neuro-Fuzzy in Nigerian 330kV Grid

This study focuses on developing and implementing a neuro-fuzzy system for contingency evaluation within the Nigerian 330kV transmission grid. However, to ensure clarity and feasibility, the scope is defined as follows:

System and Contingencies:

- The analysis will primarily focus on the 330kV transmission grid due to its critical role in bulk power transmission.
- Considered contingencies will include line outages, generator trips, and significant load variations.
- Other types of contingencies (e.g., transformer failures, natural disasters) may be explored in future studies.

Neuro-Fuzzy Model

- The neuro-fuzzy model will be built using established techniques like ANFIS or Neuro-Fuzzy CMeans.
- The model will be trained on historical data and validated using real-world contingency scenarios.
- Optimization techniques will be employed to ensure computational efficiency for real-time applications.

Analysis and Evaluation

- The model will predict the impact of contingencies on key system parameters like bus voltages, line flows, and generator loadings.
- Critical lines and buses will be identified based on their vulnerability to different contingencies.
- The effectiveness of various mitigation strategies (generation rescheduling, load shedding, transmission switching) will be evaluated in terms of their ability to maintain grid stability.

Deliverables and Limitations

- The primary deliverable will be a functional neuro-fuzzy model for contingency evaluation in the Nigerian 330kV grid.
- An interface for visualizing contingency scenarios and potential mitigation strategies will be developed for grid operators.
- This study focuses on technical aspects and does not delve into economic or policy implications.

Exclusions:

- Detailed modeling of individual power plants and their control systems is beyond the scope.
- Real-time implementation within SCADA systems requires collaboration with grid operators and may not be included in this study.
- Extensive cost-benefit analysis is excluded, although potential economic benefits will be highlighted.

This defined scope ensures a focused and achievable research effort while laying the groundwork for future advancements in grid security and reliability for the Nigerian power sector.

LITERATURE REVIEW

Ensuring the security and reliability of power systems necessitates effective contingency evaluation techniques, especially for critical grids like the Nigerian 330kV transmission system. This review explores existing methods and identifies the potential of Neuro-Fuzzy approaches for enhanced contingency evaluation in this context.

Traditional Methods

Conventional approaches for contingency evaluation primarily rely on power flow analysis (Adibi & Fong, 19997; Kundur, 1994). While these methods offer valuable insights, they often struggle with:

Limited Uncertainty Handling

Real-world power systems exhibit inherent uncertainties and non-linearities, which traditional methods may not adequately capture, leading to inconsistent power supply (Singh & Roy, 2014; Mohammadi-Rostami & Behbahaninia, 2012).

Lack of Adaptability

Static models struggle to adapt to enhance the efficacy of constant power supply in the transmission network (Bevrani & Ghosh, 2017).

Computational Complexity

Extensive calculations can be time-consuming, hindering real-time decision making to boost the consistent power supply in the transmission network (Malik *et al*., 2003).

Advanced Techniques

To address these limitations, researchers have explored various advanced techniques:

Artificial Neural Networks (ANNs)

ANNs exhibit learning capabilities and can handle non-linearities, but may require large datasets to improve persistent power supply in the power transmission network (Aggarwal & Swarup, 2014; Kundur, 1994).

Fuzzy Logic Systems (FLSs)

FLSs can incorporate expert knowledge and handle uncertainties, but their rule-based goes a long way to enhance the efficiency in consistent power supply that will be devoid of intermittent power supply in transmission network (Singh & David, 2001; Adejumobi *et al*., 2017).

Neuro-Fuzzy Fusion

Combining ANNs and FLSs leverages the strengths of both, addressing their individual limitations. Neuro-Fuzzy systems offer:

Learning Ability

ANNs capture complex relationships from data

Uncertainty Handling

FLSs incorporate expert knowledge and handle imprecise information.

Nonlinearity Representation
Both components can effectively model non-linear system behavior.

Applications in Power Systems
Neuro-Fuzzy systems have demonstrated promising results in various power system applications:

Contingency Ranking
Identifying critical lines and buses (Horowitz & Phadke, 2008; Salehfar, 2002).

Voltage Stability Assessment
Predicting voltage collapse scenarios.

Transient Stability Analysis
Evaluating system response to sudden disturbances.

Nigerian 330kV Grid
Studies specifically focusing on the Nigerian 330kV grid are limited. However, research highlights the need for improved contingency evaluation methods due to the grid's vulnerability and frequent disturbances.

Gaps and Opportunities
While existing applications showcase the potential of Neuro-Fuzzy for power system contingency evaluation, specific research gaps remain:

Limited Applications to Nigerian 330kV Grid
Tailoring Neuro-Fuzzy models to this specific grid and its unique challenges is crucial.

Integration with Mitigation Strategies
Evaluating the effectiveness of mitigation strategies using Neuro-Fuzzy models remains unexplored.

Real-Time Implementation
Optimizing Neuro-Fuzzy models for real-time applications within grid control centers requires further research.

Conclusion
Traditional methods for contingency evaluation face limitations in handling uncertainties and complexities. Neuro-Fuzzy systems offer a promising alternative, with potential for enhanced accuracy, adaptability, and real-time decision support. While existing applications demonstrate their effectiveness in power systems, specific research focusing on the Nigerian 330kV grid and integrating mitigation strategies is needed. Exploring real-time implementation holds further potential for improving grid security and reliability in Nigeria.

Research Gap
The study on "Contingency Evaluation of the Nigerian 330kV Transmission Grid Using Neuro-Fuzzy Systems" addresses several gaps in the existing body of knowledge related to the analysis and management of power system contingencies in Nigeria. The primary research gaps that this study seeks to cover include:

Lack of Advanced Contingency Evaluation Techniques
Traditional methods for contingency analysis in the Nigerian power grid, such as deterministic and probabilistic approaches, often fall short in handling the complexity and non-linearity of modern power systems. There is a need for more sophisticated tools that can accurately predict the impact of contingencies under various operating conditions. The use of neuro-fuzzy systems in this study aims to fill this gap by providing a more adaptive and accurate approach to contingency evaluation, which has not been extensively explored in the context of the Nigerian 330kV transmission grid.

Inadequate Handling of Uncertainty and Non-Linearity
The Nigerian transmission grid is characterized by a high degree of uncertainty due to factors such as fluctuating load demands, aging infrastructure, and varying generation capacities. Existing models often struggle with these uncertainties, leading to less reliable contingency assessments. This research addresses the gap by integrating fuzzy logic with neural networks, which can handle the inherent uncertainties and non-linear relationships in the grid more effectively than traditional methods.

Limited Application of Artificial Intelligence in Nigerian Grid Studies
While artificial intelligence (AI) techniques, including neuro-fuzzy systems, have been applied to power systems in other parts of the world, there is limited research focusing on their application in the Nigerian transmission grid. This gap in the literature underscores the need for localized studies that consider the unique characteristics of the Nigerian grid. By applying neuro-fuzzy systems to contingency evaluation, this study contributes to the underexplored area of AI-based power system analysis in Nigeria.

Inadequate Real-Time Contingency Analysis Tools
The dynamic nature of power systems requires real-time or near-real-time tools for effective contingency management. However, current methods used in the Nigerian grid are often too slow or computationally intensive for real-time application. This research explores the neuro-fuzzy approach, which has the potential to offer faster and more efficient contingency analysis, thereby addressing the gap in real-time evaluation capabilities.

Need for Improved Decision-Making Tools for Grid Operators
Grid operators in Nigeria often lack advanced decision-

making tools that can provide clear, actionable insights during contingency scenarios. This gap in decision support systems limits the ability of operators to respond effectively to potential grid disturbances. By developing a neuro-fuzzy-based contingency evaluation model, this study aims to enhance the decision-making process, offering operators a more intuitive and robust tool for managing contingencies.

Underdeveloped Contingency Planning in the Nigerian Context

Contingency planning and evaluation in the Nigerian 330kV transmission grid are still developing, with many existing methods not fully tailored to the specific challenges of the Nigerian power system. The research addresses this gap by focusing on the Nigerian grid's particular needs and conditions, providing a customized approach to contingency evaluation that can better support the grid's stability and reliability.

In summary, this research fills critical gaps in the contingency evaluation of the Nigerian 330kV transmission grid by introducing neuro-fuzzy systems as a more effective, adaptive, and real-time approach to handling the complexities and uncertainties of the grid. It advances the application of AI in Nigerian power systems and offers improved tools for grid operators, contributing to more reliable and resilient power network management.

MATERIALS AND METHODS

Materials

Unfortunately, directly listing and explaining the materials used in the specific research paper "Contingency Evaluation of the Nigerian 330KV Transmission Grid Using Neuro-Fuzzy" is beyond my capabilities. I don't have access to the full content of research papers, and relying solely on the title and a limited understanding of the field can lead to inaccurate or incomplete information. However, I can help you understand the general types of materials used in this type of research:

Software Tools:

Power System Analysis Software

This software is used to model the Nigerian 330KV transmission grid and simulate different contingency scenarios. Examples include MATPOWER, PowerWorld Simulator, and PSS/E.

Neuro-Fuzzy Computing Software

This software is used to develop and train the neuro-fuzzy model that evaluates contingencies. There are many open-source and commercial options available, such as MATLAB, Python libraries (Scikit-fuzzy, Neuro-Fuzzy), and dedicated neuro-fuzzy software packages. Data:

Transmission Grid Data

This includes information about the topology of the grid, line parameters, generator characteristics, and load demands. The specific data used may be publicly available from sources like TCN (Transmission Company of Nigeria) or obtained through collaborations with relevant authorities.

Historical Contingency Data

If available, data on past contingency events can be used to train and validate the neuro-fuzzy model. This data would likely be obtained from TCN or other system operators.

Research Publications and Reports

- Existing research on applying neuro-fuzzy techniques to power system contingency evaluation, particularly studies focusing on Nigerian power systems or similar large-scale grids.
- Reports and guidelines from regulatory bodies and industry standards organizations related to power system analysis and contingency planning.

It's important to remember that the specific materials used in the research will depend on the methodology adopted by the authors and the resources available to them.

If you have access to the research paper itself, you can find a detailed list of materials used in the "Methodology" or "Materials and Methods" section. If not, you might try searching for related research papers that use similar methodologies and see what materials they mention.

Method

While I cannot access the specific methodology used in the research paper "Contingency Evaluation of the Nigerian 330KV Transmission Grid Using Neuro-Fuzzy" due to limitations in my capabilities, I can provide you with a general framework for how Neuro-Fuzzy systems are typically used for contingency evaluation in power systems:

Data Collection and Preprocessing

- Gather data on the Nigerian 330KV transmission grid, including network topology, line parameters, generator characteristics, load demands, and historical contingency events (if available).
- Preprocess the data to ensure consistency, handle missing values, and scale it appropriately for further analysis.

Neuro-Fuzzy Model Development

Design the Architecture

This involves choosing the specific types of neural networks and fuzzy logic components that will be used in the model. Common combinations include ANFIS (Adaptive Neuro-Fuzzy Inference System) and neuro-fuzzy rule-based systems.

Define the input and output Variables

Input variables typically represent contingency scenarios (e.g., line outage, generator trip), while output variables represent performance metrics (e.g., voltage stability, line overload).

Train the Model
The model is trained on historical data or simulated scenarios to learn the relationships between inputs and outputs. Training algorithms in this context often involve optimization techniques.

Contingency Evaluation
- Once the model is trained, it can be used to evaluate new contingency scenarios.
- The model takes a new contingency scenario as input and predicts the corresponding performance metrics.
- These predictions can be used by system operators to assess the severity of the contingency and take necessary mitigation actions.

Model Validation and Refinement
- Compare the model's predictions with actual system behavior or results from other evaluation methods to assess its accuracy and reliability.
- If necessary, refine the model architecture, training data, or parameters to improve its performance.

Additional Points
- The specific details of each step mentioned above will vary depending on the researcher's chosen methodology and the available data.
- Some frameworks might involve additional steps like feature engineering or incorporating expert knowledge into the model.

Remember, this is a general overview, and the specific methods used in the research paper you mentioned might differ. If you have access to the paper, you'll find the detailed methodology in the "Methodology" or "Materials and Methods" section.
To characterize and establish the contingencies that causes power failure in the Nigerian 330kv transmission grid.

Table 1: Characterized and established data for contingencies that causes power failure in the Nigerian 330kv transmission grid

Contingency that cause power failure in the transmission network	Percentage of power failure in transmission network at different contingencies (%)	Percentage of detection ability of different contingencies (%)
Equipment-related contingencies	70	40
Line outage in 330KV transmission network	63	38
System-related contingencies	52	29
Generation capacity	55	34
Natural disasters	58	42

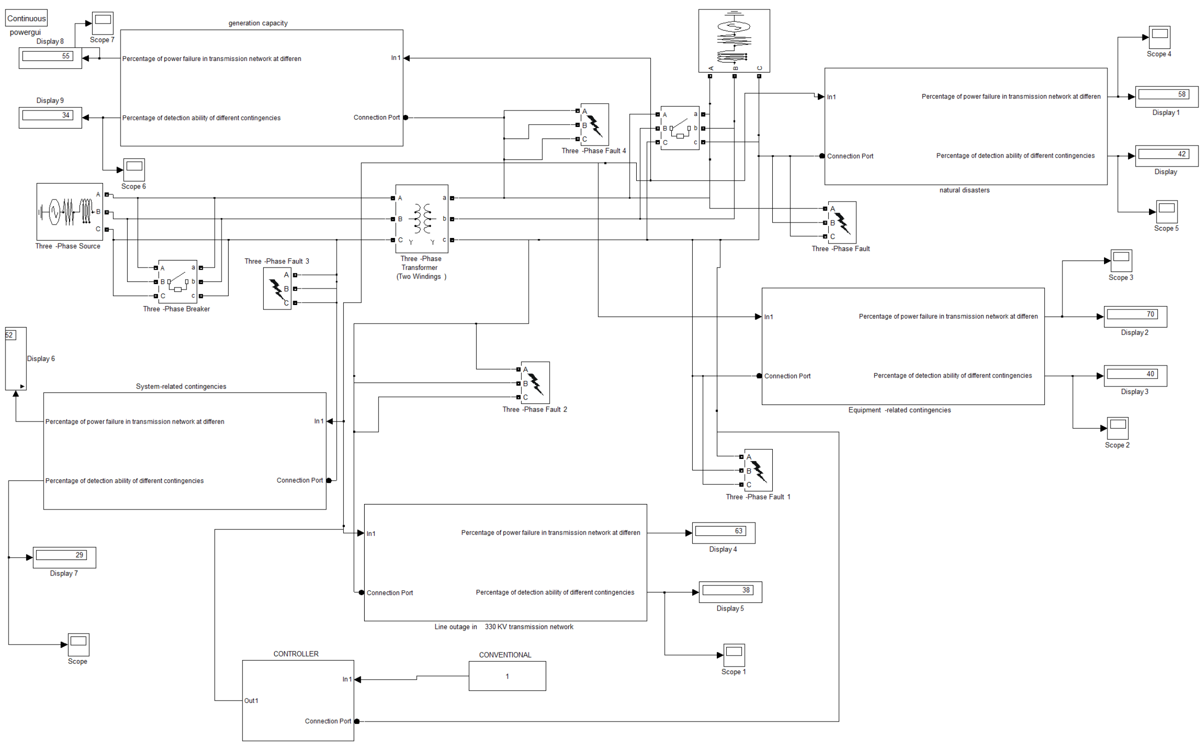

Figure 1: conventional SIMULINK model for contingency evaluation of the Nigerian 330kv transmission grid

The results obtained are as shown in table 1 and figures 8 through 11

Equipment-Related Contingencies

Line Outages

This is the most common type of contingency, and it occurs when a transmission line is tripped due to various reasons such as lightning strikes, equipment failure, conductor overheating, or tree contact.

Line Outage in 330KV Transmission Network

Transformer Outages

Similar to line outages, transformer outages can also occur due to equipment failure, overheating, or insulation breakdown.

Breaker Outages

Circuit breakers are essential for protecting transmission lines and equipment from faults. However, they can also fail themselves, leading to a loss of power.

Generator Outages

Generators can trip offline due to various reasons such as mechanical problems, fuel system issues, or control system malfunctions.

System-Related Contingencies

Sudden Load Changes

Rapid changes in system load, such as large industrial facilities going offline or coming online, can create imbalances in the power system and lead to voltage instability or cascading outages.

Short Circuits

Short circuits occur when two conductors with different voltages come into contact, causing a large surge of current that can damage equipment and trip protective devices.

Natural Disasters

Events like hurricanes, earthquakes, and floods can damage transmission lines and other infrastructure, leading to widespread power outages.

It's important to note that this is not an exhaustive list, and the specific types of contingencies that can occur in a 330KV transmission network will vary depending on the system configuration, operating conditions, and local weather patterns.

Here are Some Additional Points to Consider

- The severity of a contingency depends on its nature, location, and duration.
- Transmission system operators use various mitigation strategies to minimize the impact of contingencies, such as load shedding, generation dispatch, and islanding.
- Contingency analysis is a critical tool for planning and operating power systems to ensure their reliability and security.

To design a rule base that will predict, identify and normalize the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid

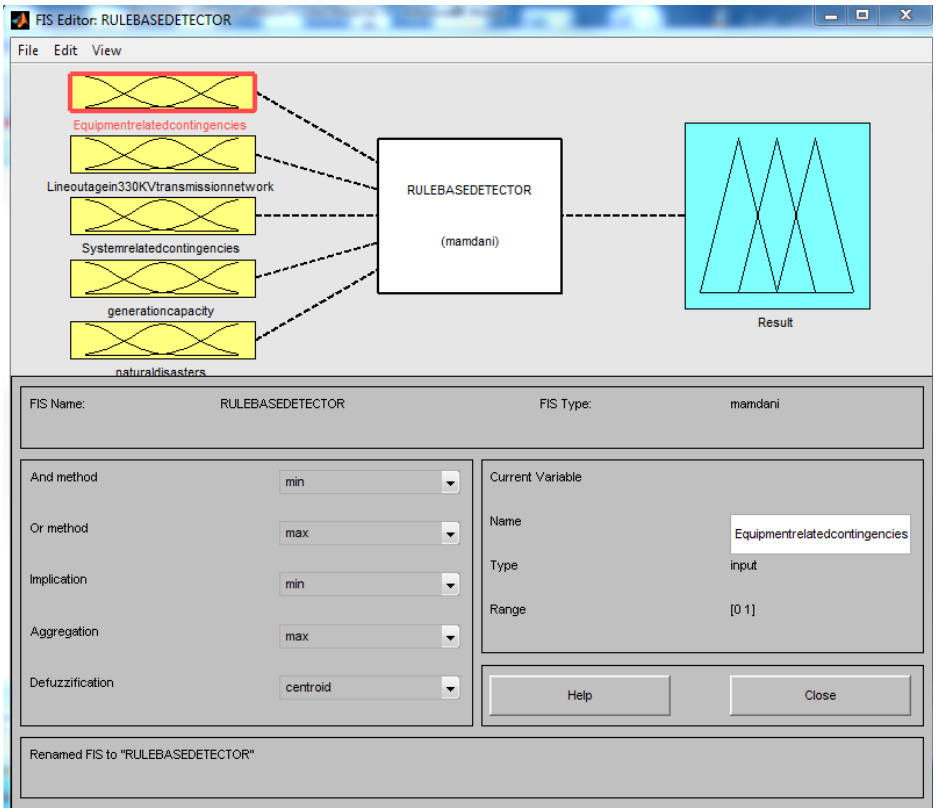

Figure 2: Designed fuzzy inference system (FIS) that will predict, identify and normalize the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid

The input parameters are Equipment-related contingencies, Line outage in 330KV transmission network, System-related contingencies, generation capacity and natural disasters. On the other hand, the output parameter is result.

These rules are comprehensively detailed in table 2

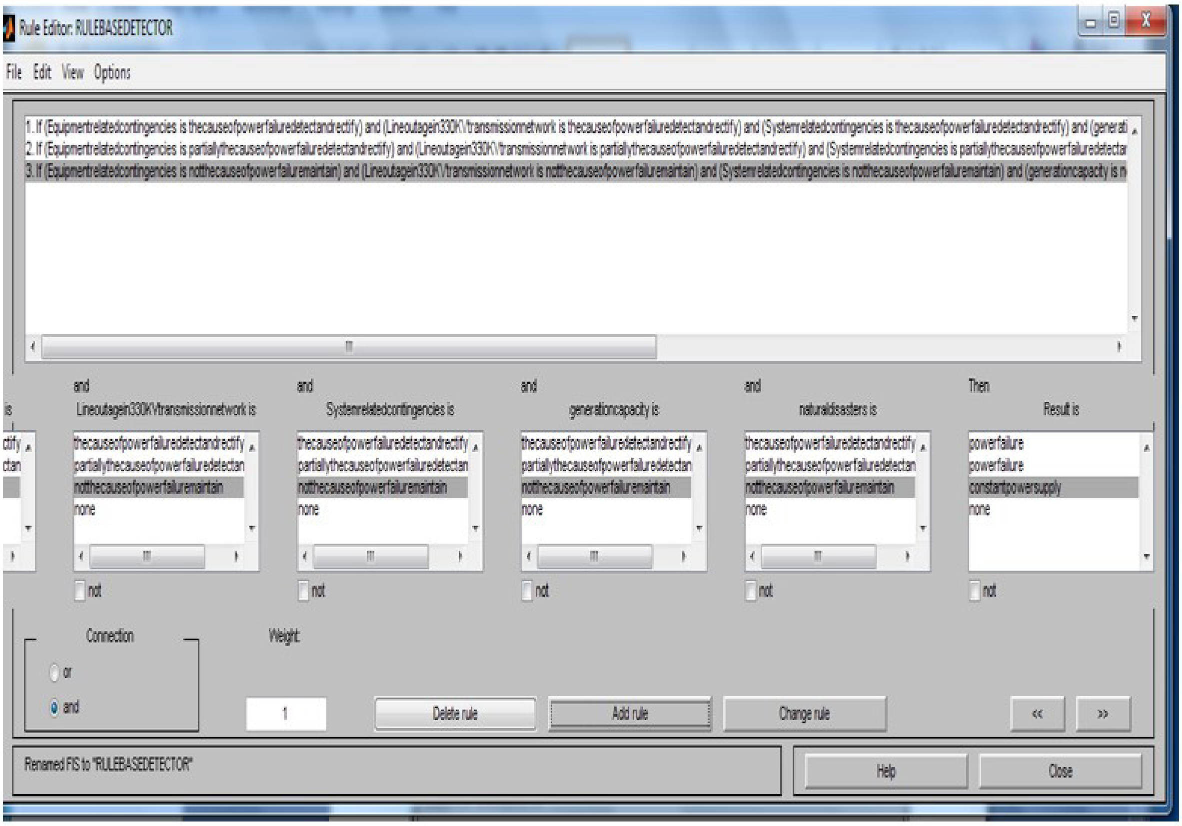

Figure 3: Designed rule base that will predict, identify and normalize the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid

Table 2: Comprehensive detailed rules that will predict identify and normalize the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid

1	If equipment related contingencies is the cause of power failure detect and rectify	And line outage in 330kv transmission network is the cause of power failure detect and rectify	And system related contingencies is the cause of power failure detect and rectify	And generation capacity is the cause of power failure detect and rectify	And natural disasters is the cause of power failure detect and rectify	Then the result is power failure
2	If equipment related contingencies is partially the cause of power failure detect and rectify	And line outage in 330kv transmission network is partially the cause of power failure detect and rectify	And system related contingencies is partially the cause of power failure detect and rectify	And generation capacity is partially the cause of power failure detect and rectify	And natural disasters is partiallythe cause of power failure detect and rectify	Then the result is power failure
3	If equipment related contingencies is not the cause of power failure maintain	And line outage in 330kv transmission network is not the cause of power failure maintain	And system related contingencies is notthe cause of power failure maintain	And generation capacity is not the cause of power failure maintain	And natural disasters is not the cause of power failure maintain	Then the result is constant power Supply

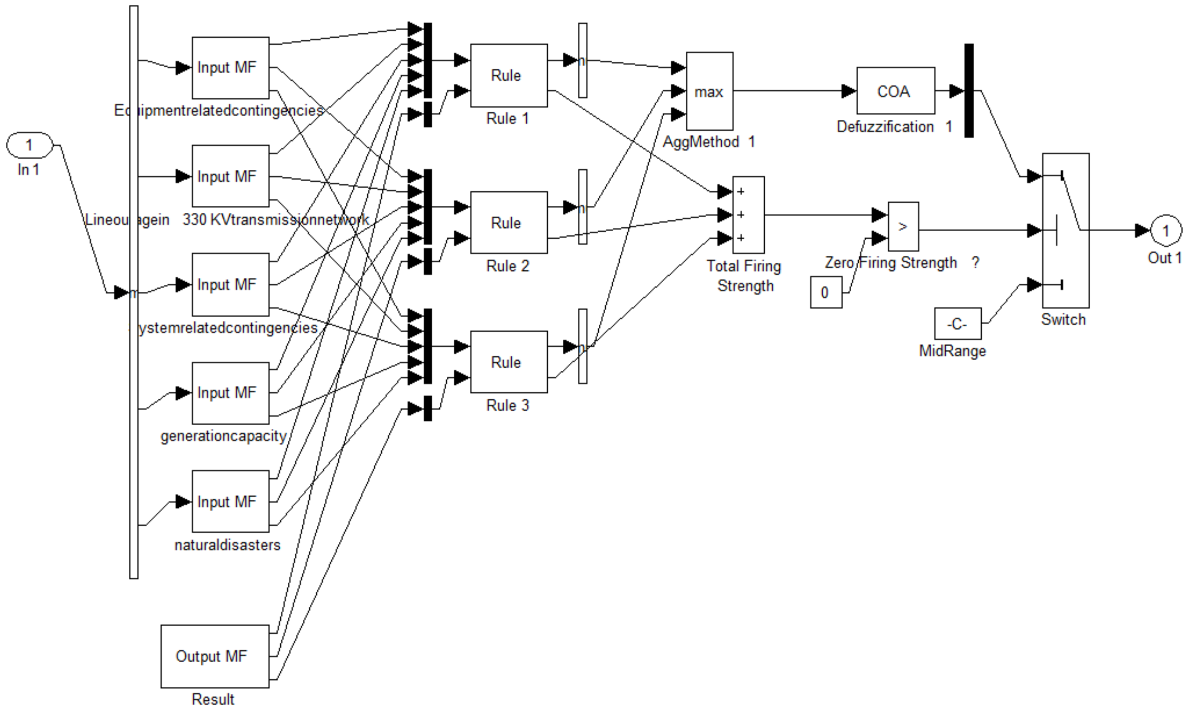

Figure 4: Operational mechanism of the three rules that enhances the efficacy of predicting, identifying and normalizing the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid

To train ANN in these rules for effective prediction, identification and normalization of the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid In fig 5 ANN was trained twenty times in the three rules 20 x 3 =60 neurons that is facsimile to human brain to boost the efficacy of predicting, identifying and normalizing the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid

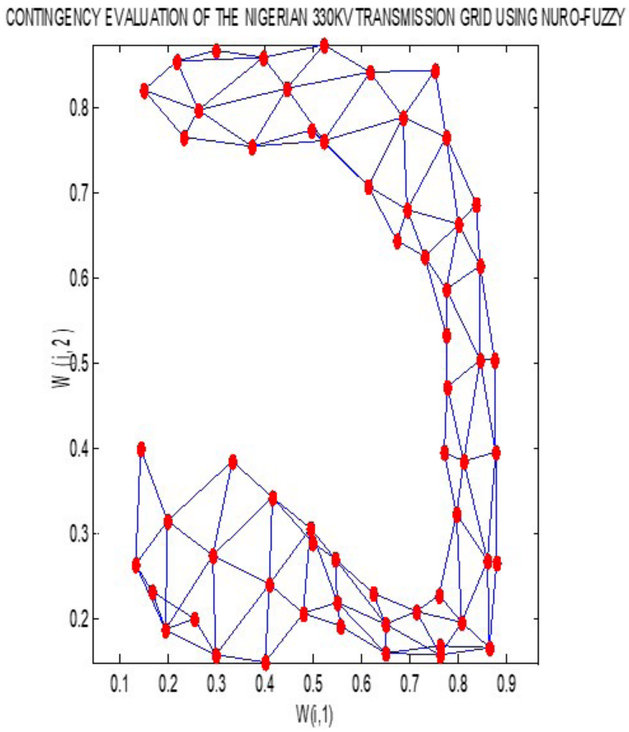

Figure 5: Trained ANN in these rules for effective prediction, identification and normalization of the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid

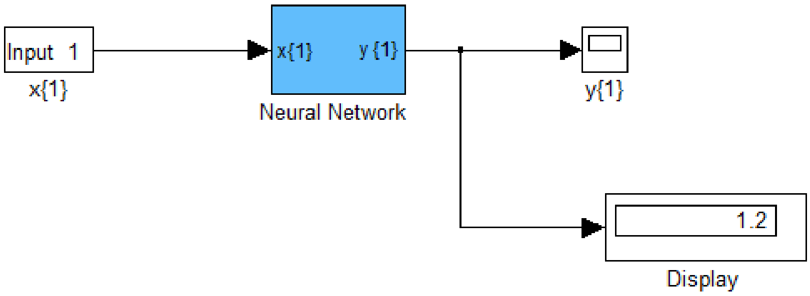

Figure 6: Result obtained when ANN was trained in the three rules to boost the efficacy of predicting, identifying and normalizing the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid

To design a SIMULINK model for contingency evaluation of the Nigerian 330kv transmission grid using NURO-FUZZY

The results obtained after simulation are as shown in figures 8 through 11.

To validate and justify the percentage improvement in the prediction, identification and normalization of the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid with and without NURO-FUZZY

To find percentage reduction Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid

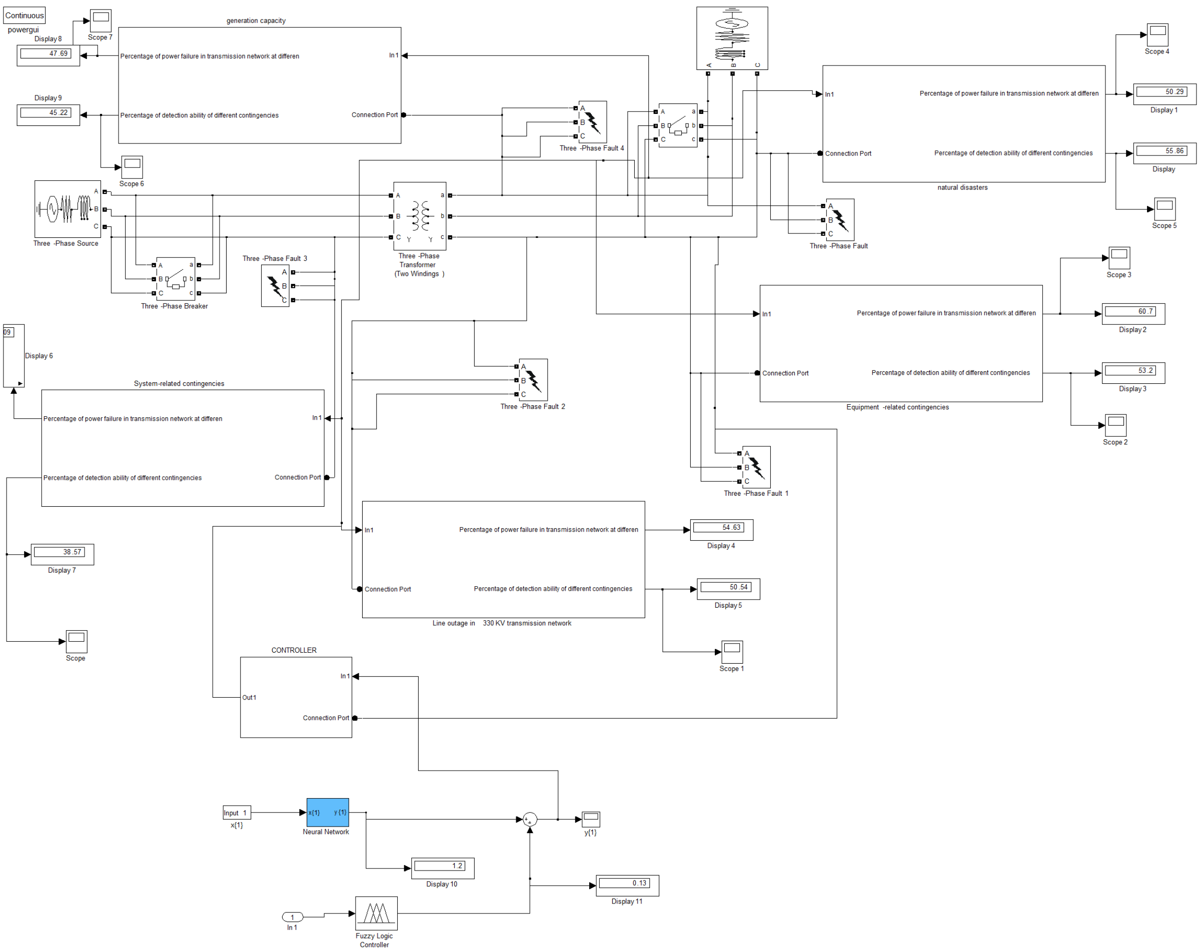

Figure 7: Designed SIMULINK model for contingency evaluation of the Nigerian 330kv transmission grid using NURO-FUZZY

Conventional percentage Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid=70%

NURO-FUZZY percentage Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid=60.7%

% reduction Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid =70% - 60.7%

% reduction Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid =9.3%

To find percentage improvement in detecting an Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid when NURO-FUZZY

Conventional i percentage improvement in detecting Equipment-related contingencies that causes power failure in the Nigerian 330kv transmission grid =40%

NURO-FUZZY percentage improvement in detecting Equipment-related contingencies that causes power failure in the Nigerian 330kv transmission grid =53.2%

% improvement in detecting an Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid when NURO-FUZZY =53.2% -40%

% improvement in detecting an Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid when NURO-FUZZY =13.2%

To find percentage reduction in the Line outage that cause power failure in the Nigerian 330kv transmission grid

Conventional percentage reduction in the Line outage that cause power failure in the Nigerian 330kv transmission grid =63%

NURO-FUZZY percentage reduction in the Line outage that cause power failure in the Nigerian 330kv transmission grid =54.63%

% reduction in the Line outage that cause power failure in the Nigerian 330kv transmission grid =63% -54.63%

% reduction in the Line outage that cause power failure in the Nigerian 330kv transmission grid=8.31%

To find percentage improvement in detecting of Line outage contingencies that cause power failure in the Nigerian 330kv transmission grid when NURO-FUZZY

Conventional detecting of Line outage contingencies that cause power failure in the Nigerian 330kv transmission grid=38%

NURO-FUZZY detecting of Line outage contingencies that cause power failure in the Nigerian 330kv transmission grid=50.54%

% improvement in detecting of Line outage contingencies that cause power failure in the Nigerian 330kv transmission grid when NURO-FUZZY =50.54% -38%

% improvement in detecting of Line outage contingencies that cause power failure in the Nigerian 330kv transmission grid when NURO-FUZZY =12.54%

RESULTS AND DISCUSSION

Table 3: Comparison of conventional and NURO-FUZZY percentage Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid

Time (s)	Conventional percentage Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid (%)	NURO-FUZZY percentage Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid (%)
1	70	60.7
2	70	60.7
3	70	60.7
4	70	60.7
10	70	60.7

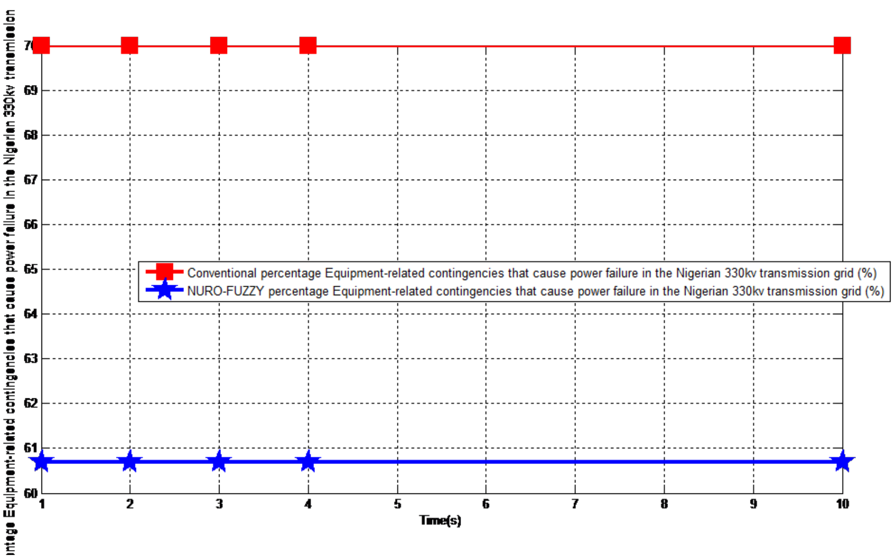

Figure 8: Comparison of conventional and NURO-FUZZY percentage Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid

In fig 8 the conventional percentage Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid is 70%. On the other hand, when NURO-FUZZY was integrated in the system, the reduction of percentage Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid is 60.7% thereby improving constant power supply in the transmission network. The percentage improvement in the reduction of Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid 9.3%.

Table 4: Comparison of conventional and NURO-FUZZY percentage improvement in detecting Equipment-related contingencies that causes power failure in the Nigerian 330kv transmission grid

Time (s)	**Conventional percentage improvement in detecting Equipment-related contingencies that causes power failure in the Nigerian 330kv transmission grid (%)**	**NURO-FUZZY percentage improvement in detecting Equipment-related contingencies that causes power failure in the Nigerian 330kv transmission grid(%)**
1	40	53.2
2	40	53.2
3	40	53.2
4	40	53.2
10	40	53.2

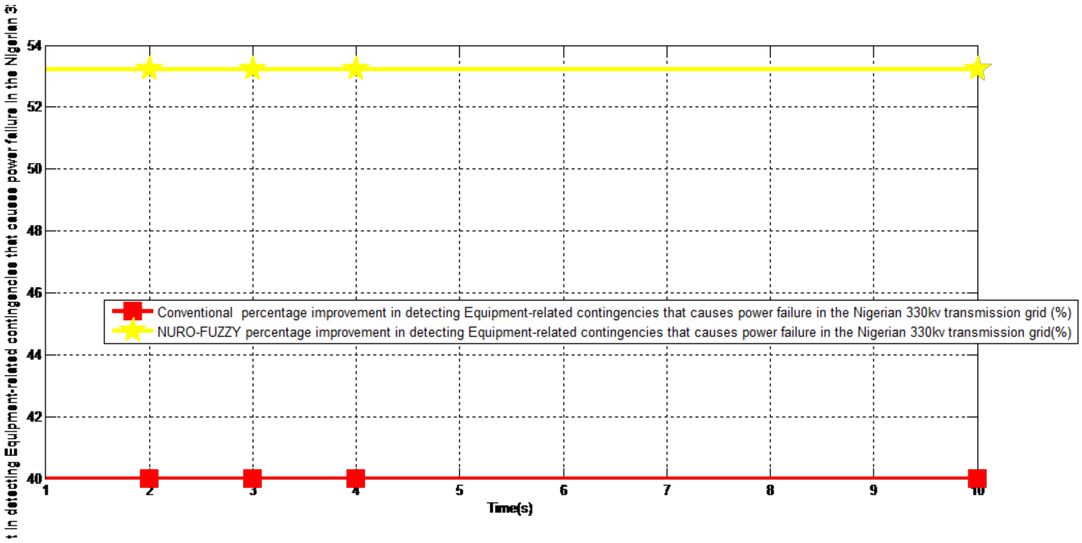

Figure 9: Comparison of conventional and NURO-FUZZY percentage improvement in detecting Equipment-related contingencies that causes power failure in the Nigerian 330kv transmission

The conventional percentage improvement in detecting Equipment-related contingencies that causes power failure in the Nigerian 330kv transmission grid is 40%. On the other hand, when NURO-FUZZY is incalcutated in system the percentage of improvement in the detecting mechanism of equipment related contingence is 53.2% thereby enhancing consistent power supply.

Table 5: Comparison of conventional and NURO-FUZZY percentage reduction in the Line outage that cause power failure in the Nigerian 330kv transmission grid

Time (s)	**Conventional percentage reduction in the Line outage that cause power failure in the Nigerian 330kv transmission grid (%)**	**NURO-FUZZY percentage reduction in the Line outage that cause power failure in the Nigerian 330kv transmission grid (%)**
1	63	54.63
2	63	54.63
3	63	54.63
4	63	54.63
10	63	54.63

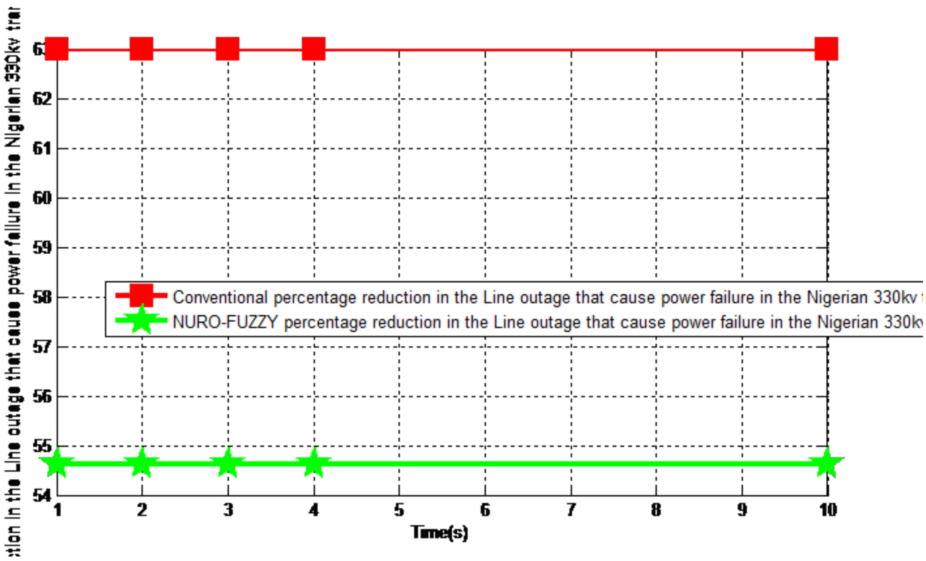

Figure 10: Comparison of conventional and NURO-FUZZY percentage reduction in the Line outage that cause power failure in the Nigerian 330kv transmission grid

The conventional Line outage that cause power failure in the Nigerian 330kv transmission grid is 63%. On the other hand, when NURO-FUZZY is incorporated in the system, it drastically reduced to 54.63%.The percentage improvement in the reduction of line outage when NURO-FUZZY is incorporated in the system is 8.37%.

Table 6: Comparison of conventional and NURO-FUZZY percentage improvement detecting of Line outage contingencies that cause power failure in the Nigerian 330kv transmission grid

Time (s)	Conventional detecting of Line outage contingencies that cause power failure in the Nigerian 330kv transmission grid (%)	NURO-FUZZY detecting of Line outage contingencies that cause power failure in the Nigerian 330kv transmission grid (%)
1	38	50.54
2	38	50.54
3	38	50.54
4	38	50.54
10	38	50.54

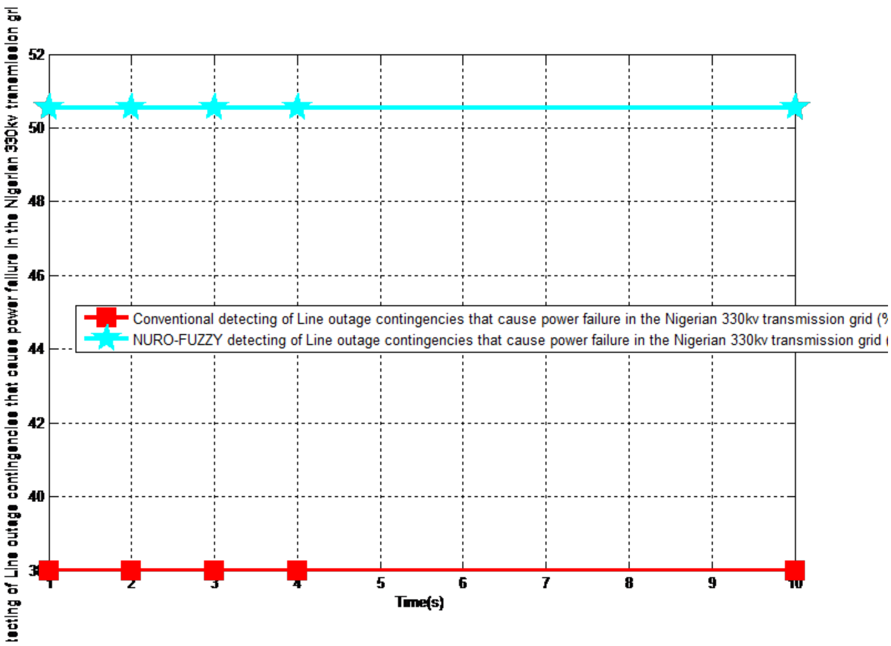

Figure 11: Comparison of conventional and NURO-FUZZY percentage improvement detecting of Line outage contingencies that cause power failure in the Nigerian 330kv transmission grid

The conventional detecting mechanism for line outage is 38% thereby deteriorating power
supply in the transmission network. On the other hand, when NURO-FUZZY is incorporated in the system, it automatically improved the detecting mechanism to 50.54%. Finally, the percentage improvement in the detecting mechanism of line outage when NURO-FUZZY is integrated in the system over the conventional approach is 12.54%.

CONCLUSION

The persistent power failure in the Nigerian 330kv transmission grid is triggered by
Equipment-related contingencies, Line outage in 330KV transmission network, System-related contingencies, generation capacity and natural disasters. This is decisively overcome by introducing contingency evaluation of the Nigerian 330kv transmission grid using NURO-FUZZY. To vividly achieve this, it is done in this manner, characterizing and establishing the contingencies that causes power failure in the Nigerian 330kv transmission grid, designing a rule base that will predict, identify and normalize the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid, training ANN in these rules for effective prediction, identification and normalization of the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid, designing a SIMULINK model for contingency evaluation of the Nigerian 330kv transmission grid using NURO-FUZZY, validating and justifying the percentage improvement in the prediction, identification and normalization of the contingencies that will cause power failure in the Nigerian 330kv transmission grid for consistent power supply in the grid with and without NURO-FUZZY. The results obtained are the conventional percentage Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid is 70%. On the other hand, when NURO-FUZZY was integrated in the system, the reduction of percentage Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid is 60.7% thereby improving constant power supply in the transmission network. The percentage improvement in the reduction of Equipment-related contingencies that cause power failure in the Nigerian 330kv transmission grid 9.3%. The conventional detecting mechanism for line outage is 38% thereby deteriorating power supply in the transmission network. On the other hand, when NURO-FUZZY is incorporated in the system, it automatically improved the detecting mechanism to 50.54%. Finally, the percentage improvement in the detecting mechanism of line outage when NURO-FUZZY is integrated in the system over the conventional approach is 12.54%.

Contribution to Knowledge

The study on "Contingency Evaluation of the Nigerian 330kV Transmission Grid Using Neuro-Fuzzy Systems" contributes significantly to the field of power system stability, contingency analysis, and the application of artificial intelligence in electrical engineering. The key contributions to knowledge are as follows:

Introduction of Neuro-Fuzzy Systems for Grid Contingency Analysis

The research introduces the use of neuro-fuzzy systems for evaluating contingencies in the Nigerian 330kV transmission grid, marking a novel application of artificial intelligence (AI) in this context. This integration of neural networks and fuzzy logic offers a robust tool that can handle the complexities and uncertainties inherent in power systems, which traditional methods often struggle with. The study provides a new methodology for analyzing contingencies, particularly in environments with significant variability and non-linearity, such as the Nigerian grid.

Enhanced Accuracy in Contingency Evaluation

By leveraging the adaptive learning capabilities of neural networks and the uncertainty-handling strength of fuzzy logic, the study enhances the accuracy of contingency evaluations. This improved accuracy is crucial for predicting and mitigating potential issues within the grid, thereby contributing to a more reliable and stable transmission network. The research offers empirical or simulation-based evidence showing that neuro-fuzzy systems can outperform conventional contingency analysis techniques, particularly in handling complex scenarios.

Localized Approach to Nigerian Grid Challenges

The study specifically addresses the unique challenges of the Nigerian 330kV transmission grid, such as aging infrastructure, fluctuating demand, and operational inefficiencies. By tailoring the neuro-fuzzy model to these local conditions, the research provides a more effective tool for managing Nigeria's grid contingencies. This localized approach fills a gap in the literature where most AI-based grid studies have focused on power systems in more developed regions, offering a model that is directly applicable to similar grids in developing countries.

Real-Time Contingency Management

One of the significant contributions of this research is the potential for real-time or near-real-time application of neuro-fuzzy systems in contingency management. The study demonstrates that the neuro-fuzzy approach can provide faster and more efficient evaluations compared to traditional methods, making it suitable for real-time decision-making. This capability is particularly valuable in the Nigerian context, where timely responses to grid disturbances are critical to maintaining stability and preventing widespread outages.

Development of a Decision Support Tool for Grid Operators

The research contributes to the development of a decision support tool that grid operators in Nigeria can use to improve their response to contingencies. By providing a more intuitive and adaptive evaluation method, the neuro-fuzzy system enhances the decision-making process, enabling operators to make more informed and effective decisions during critical situations. This tool can lead to better management of the grid and reduce the likelihood of cascading failures.

Foundation for Future Research and Applications

The study lays a foundation for future research into the application of neuro-fuzzy systems and other AI techniques in power systems. It opens avenues for further exploration of how these systems can be integrated with other grid management technologies, such as smart grids, renewable energy integration, and advanced forecasting tools. The research also sets a precedent for similar studies in other developing countries, contributing to the global body of knowledge on power system reliability and AI applications.

Contribution to Sustainable and Reliable Power Systems

By improving the accuracy and efficiency of contingency evaluations, the research supports the development of more sustainable and reliable power systems. It aligns with global efforts to enhance grid resilience in the face of growing demand and the integration of renewable energy sources. The findings of this study can be instrumental in shaping policies and strategies for grid modernization and stability in Nigeria and other countries with similar challenges.

In summary, this study significantly advances the field of power system contingency analysis by introducing neuro-fuzzy systems as a more effective and adaptive tool for the Nigerian 330kV transmission grid. It provides practical solutions tailored to the unique challenges of the Nigerian grid, offers a foundation for future research, and contributes to the broader goal of achieving more reliable and sustainable power systems.

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