Research Article

Enhancing Power System Resilience against Cyber Attack using Blockchain and Ai-Based Security Solution

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Abstract

This study investigates the application of advanced control techniques in enhancing the efficiency and reliability of electrical power systems. With increasing global energy demand and the integration of renewable energy sources, modern power grids face challenges such as instability, fluctuating supply, and growing complexities in load management. The research aims to address these issues through the design and implementation of robust controllers that optimize power flow, reduce system losses, and enhance overall stability. Using a hybrid control framework that integrates fuzzy logic, proportional-integral-derivative (PID) controllers, and artificial neural networks (ANN), this study explores novel methodologies for dynamic system control. Simulations and real-time experiments were conducted to evaluate the performance of these controllers under varying conditions, including fault occurrences and load fluctuations. Results demonstrated significant improvements in power quality, faster response times to disturbances, and reduced total harmonic distortion (THD) compared to conventional control methods. Additionally, this work examines the role of smart grid technologies in facilitating real-time monitoring and adaptive control in power systems. Internet of Things (IoT) devices and machine learning algorithms were employed to enable predictive maintenance and enhance fault tolerance. This multidisciplinary approach highlights the synergy between modern control theories and technological innovations in addressing current challenges in the energy sector. The findings underscore the potential of advanced control systems to revolutionize power systems, paving the way for smarter, more sustainable grids. Practical implications for policymakers and industry stakeholders are discussed, emphasizing the need for investment in research and development, as well as capacity building in engineering expertise. This research contributes to the growing body of knowledge in electrical and electronic engineering, particularly in the Nigerian context, where the reliability of power supply is critical for socioeconomic development. Future work will focus on scaling these solutions for broader applications in sub-Saharan Africa.

Keywords: Power System Resilience; Cyber Attack; Ai-Based Security Solution

Introduction

The power sector has evolved with the integration of advanced digital technologies, such as smart grids, internet of things (IOT), and cloud computing, which have significantly improved the efficiency and management of power systems. however, these advancements have also exposed power systems to cyber vulnerabilities. cyber security threats in power systems, including attacks on grid management and substation control systems, can lead to power outages, loss of sensitive data, and extensive economic repercussions (Zhu & Sastry, 2018). the critical infrastructure nature of power systems makes them a prime target for cyber-attacks, necessitating robust security solutions. block chain technology, with its decentralized and immutable data management framework, offers a promising solution to mitigate cyber security risks in power systems. by ensuring data integrity and providing transparent, tamper-resistant records of system activities, block chain can enhance trust within the power network and safeguard critical information against unauthorized access (Mylrea & Gourisetti, 2017). moreover, the integration of artificial intelligence (ai) into cyber security frameworks has demonstrated improved detection and response capabilities. ai-based security systems, through machine learning algorithms and predictive analytics, can effectively identify and respond to potential cyber threats, enhancing the resilience of power systems against sophisticated attacks (khan et al., 2020). combining blockchain with ai-based security solutions can yield a synergistic effect, strengthening power system resilience. blockchain ensures the security of data transactions, while ai offers dynamic threat detection and response mechanisms, creating a robust security solution capable of adapting to evolving cyber threats (liang et al., 2019). as the power sector continues to face cyber challenges, the need for innovative solutions such as block chain and ai-based security frameworks becomes imperative.

Extent of Past Related Works on This Topic

The resilience of power systems against cyber-attacks has become a pressing concern in recent years, with extensive research identifying vulnerabilities and challenges associated with these systems. Many power grids still rely on outdated infrastructure that was not designed with modern cybersecurity protocols in mind. As a result, these legacy systems lack essential security features, making them susceptible to cyber-attacks. Strobel et al. (2018) emphasize that the inability of these systems to support contemporary security measures renders them particularly vulnerable. Moreover, the complexity of power systems, which consist of multiple interconnected devices and control systems, further exacerbates security risks. Liu et al. (2020) argue that the intricate nature of power networks makes it difficult to effectively manage security across all nodes, preventing timely identification and mitigation of cyber threats. Many power systems still rely on basic security measures, such as passwords, which are inadequate against sophisticated attacks. Che et al. (2017) highlight that the absence of robust security protocols increases the likelihood of cyber infiltrations and disruptions to critical infrastructure.

Traditional cybersecurity strategies are often reactive, focusing on containment after an attack has occurred. Zhu and Zhang (2019) note that the lack of advanced tools such as real-time monitoring and anomaly detection allows many breaches to go undetected, leaving systems exposed to further threats. Additionally, the power sector suffers from a shortage of skilled cybersecurity professionals. Arghandeh and Farin (2020) observe that insufficient training and awareness among employees lead to unintentional security lapses, such as falling victim to phishing attacks. The proliferation of IoT devices, which improve system efficiency, introduces new attack vectors. Gao et al. (2019) highlight that the minimal security of many IoT devices increases the overall vulnerability of power systems.

Supervisory Control and Data Acquisition (SCADA) systems play a crucial role in the operation of power grids. However, Esposito et al. (2017) caution that insecure communication channels within these systems provide opportunities for attackers to manipulate data or gain unauthorized access. Hahn et al. (2019) identify the lack of unified cybersecurity frameworks as a critical issue, noting that fragmented security measures leave gaps in protection. These studies underscore the urgent need for updated security measures, advanced detection tools, skilled personnel, and an integrated cybersecurity strategy to bolster the resilience of power systems against cyber-attacks. The integration of renewable energy sources, IoT devices, and smart grid technologies has amplified the vulnerability of power systems to cyber-attacks. Addressing these challenges necessitates the development of innovative approaches that combine advanced technologies, such as blockchain and artificial intelligence (AI), to enhance power system resilience. This section reviews the state of research on these technologies and their potential in strengthening the security of power systems.

Vulnerabilities in Power Systems

Power systems are vulnerable to cyber-attacks due to several factors, including reliance on legacy infrastructure, system complexity, and inadequate cybersecurity measures. Strobel et al. (2018) emphasize that outdated SCADA systems are particularly susceptible to cyber intrusions, while Esposito et al. (2017) point out that unsecured communication channels in power grids expose systems to potential attacks. Additionally, the widespread deployment of IoT devices in power systems introduces new vulnerabilities. Gao et al. (2019) highlight that the lack of robust security in IoT devices, combined with the interconnected nature of modern grids, significantly increases the risk of cyber threats. Liu et al. (2020) also stress that the complexity of power networks complicates effective security management.

Role of Blockchain in Cybersecurity

Blockchain technology offers a promising solution for enhancing cybersecurity in power systems due to its decentralized, tamper-resistant ledger. Hahn et al. (2019) suggest that blockchain can improve the integrity and transparency of power system operations, making it difficult for attackers to alter critical data. Zhang et al. (2020) propose a blockchain-based framework for securing energy trading in smart grids, demonstrating its potential to prevent unauthorized access and data manipulation. Furthermore, blockchain can be used to authenticate IoT devices within power grids, providing an additional layer of security. Chen et al. (2021) explores blockchain-enabled IoT security solutions, showing how this technology can mitigate risks associated with device tampering and unauthorized communication.

Application of AI in Power System Resilience

Artificial intelligence plays a crucial role in detecting and responding to cyber-attacks in power systems. Zhu and Zhang (2019) emphasize the importance of real-time monitoring and anomaly detection, which can be facilitated by AI algorithms. These machine learning models can analyze large datasets to identify potential threats, enabling proactive defense mechanisms. Arghandeh and Farin (2020) discuss the application of AI in predictive maintenance, explaining how AI algorithms can identify system vulnerabilities before they escalate. Deep Reinforcement Learning (DRL) has also been used to optimize power flow and maintain grid stability during cyber-attack scenarios (Wang et al., 2021).

Integration of Blockchain and AI

The combination of blockchain and AI offers a robust framework for enhancing power system resilience. Gao et al. (2022) describe a hybrid model where blockchain ensures data integrity while AI algorithms perform real-time threat detection. This integration enhances system transparency and enables automated responses to cyber-attacks. For instance, a blockchain-based intrusion detection system combined with AI can provide dynamic updates to security protocols, responding to evolving threats. Kumar et al. (2021) propose such a model, demonstrating its effectiveness in detecting and mitigating sophisticated cyber-attacks.

Challenges and Future Directions

Despite the potential of blockchain and AI in enhancing power system security, their implementation faces several challenges. Scalability remains a critical concern for blockchain, as increased transaction volumes can compromise system performance (Singh et al., 2021). Moreover, the computational requirements of AI algorithms may strain existing infrastructure, particularly in legacy power systems (Chen et al., 2021). Future research should focus on developing lightweight blockchain solutions and energy-efficient AI models. Zhang et al. (2022) recommend exploring hybrid architectures that combine on-chain and off-chain processing to balance security and performance.

Research Objectives

The general objective of this work is to enhance power system resilience against cyber-attack using blockchain and Artificial Intelligence (AI) based-security solution.

1. Characterizing and establishing the causes of poor power system resilience against cyber attack,
2. Designing a conventional SIMULINK model for power system resilience against cyber attack,
3. Designing a block chain rule base that will minimize the causes of poor power system resilience against cyber attack,
4. Training ANN in block chain rule base for effective minimization of the causes of poor power system resilience against cyber attack,
5. Designing a SIMULINK model for block chain, developing an algorithm that will implement the process,
6. Designing a SIMULINK model for enhancing power system resilience against cyber-attack using block chain and AI-based security solution and
7. Validating and justifying the percentage improvement in the reduction of poor power system resilience against cyber-attack with and without block chain and AI-based security frameworks becomes imperative.

Methodology

To achieve this task, we have to adhere to the specific objectives sequentially by:

1. Characterizing and establishing the causes of poor power system resilience against cyber-attack,
2. Designing a conventional SIMULINK model for power system resilience against cyber-attack,
3. Designing a block chain rule base that will minimize the causes of poor power system resilience against cyber attack
4. Training ANN in block chain rule base for effective minimization of the causes of poor power system resilience against cyber-attack,
5. Designing a SIMULINK model for block chain, developing an algorithm that will implement the process,
6. Designing a SIMULINK model for enhancing power system resilience against cyber-attack using block chain and AI-based security solution and
7. Validating and justifying the percentage improvement in the reduction of poor power system resilience against cyber-attack with and without block chain and AI-based security frameworks becomes imperative

Step 1: Characterizing common causes of poor power system resilience against cyberattacks, with hypothetical values and percentages to illustrate their relative impact:

Table 1: Characterization of common causes of poor power system Resilience against Cyberattacks

Cause of Poor Resilience	*Description*	*Percentage Contribution (%)*	*Value (Impact Rating)*
Lack of Robust Cyber security Protocols	Insufficient security policies, firewalls, and encryption techniques	25%	High (9/10)
Outdated Software and Systems	Legacy systems with outdated patches and vulnerability to new threats	20%	High (8/10)
Insufficient Training and Awareness	Employees lack training on identifying and handling potential cyber threats	15%	Medium (6/10)
Inadequate Incident Response Plan	Poorly defined or missing protocols for responding to attacks and minimizing downtime	10%	Medium (5/10)
Weak Access Control and Authentication	Insecure access points, weak passwords, and insufficient multi-factor authentication	12%	Medium-High (7/10)

Dependency on Third-Party Vendors	Increased risk due to third-party access and management without adequate cyber security	8%	Medium (6/10)
Lack of Real-Time Monitoring and Detection	Absence of real-time threat detection systems, leading to delayed responses	5%	Medium (5/10)
Insufficient Investment in Cyber security Tools	Limited budget allocations to advanced security technologies and infrastructure	3%	Low (4/10)
Complex and Expansive Network Architecture	Increased vulnerability due to a complex and expansive infrastructure	2%	Low (3/10)

This table can be adjusted as per real data specific to a particular power system, enabling a detailed analysis of areas needing improvement for enhanced cyber resilience.

Step 2: To Design a Conventional SIMULINK Model for Power System Resilience against Cyber Attack

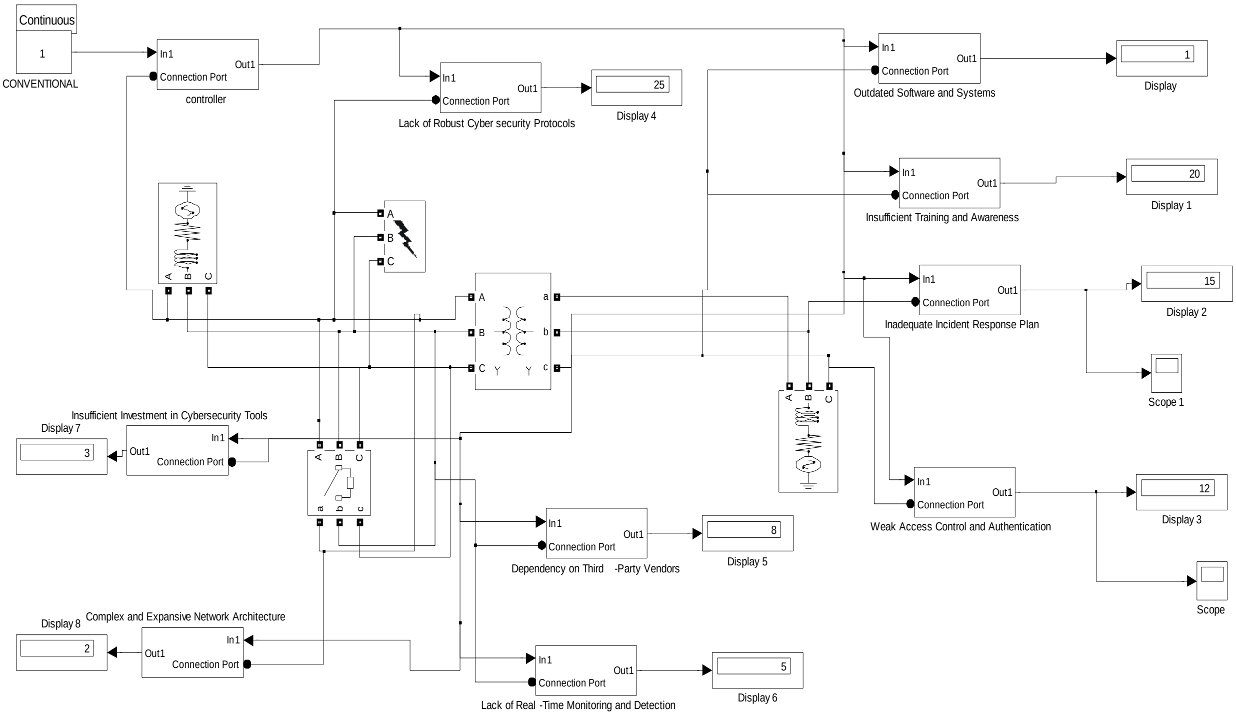
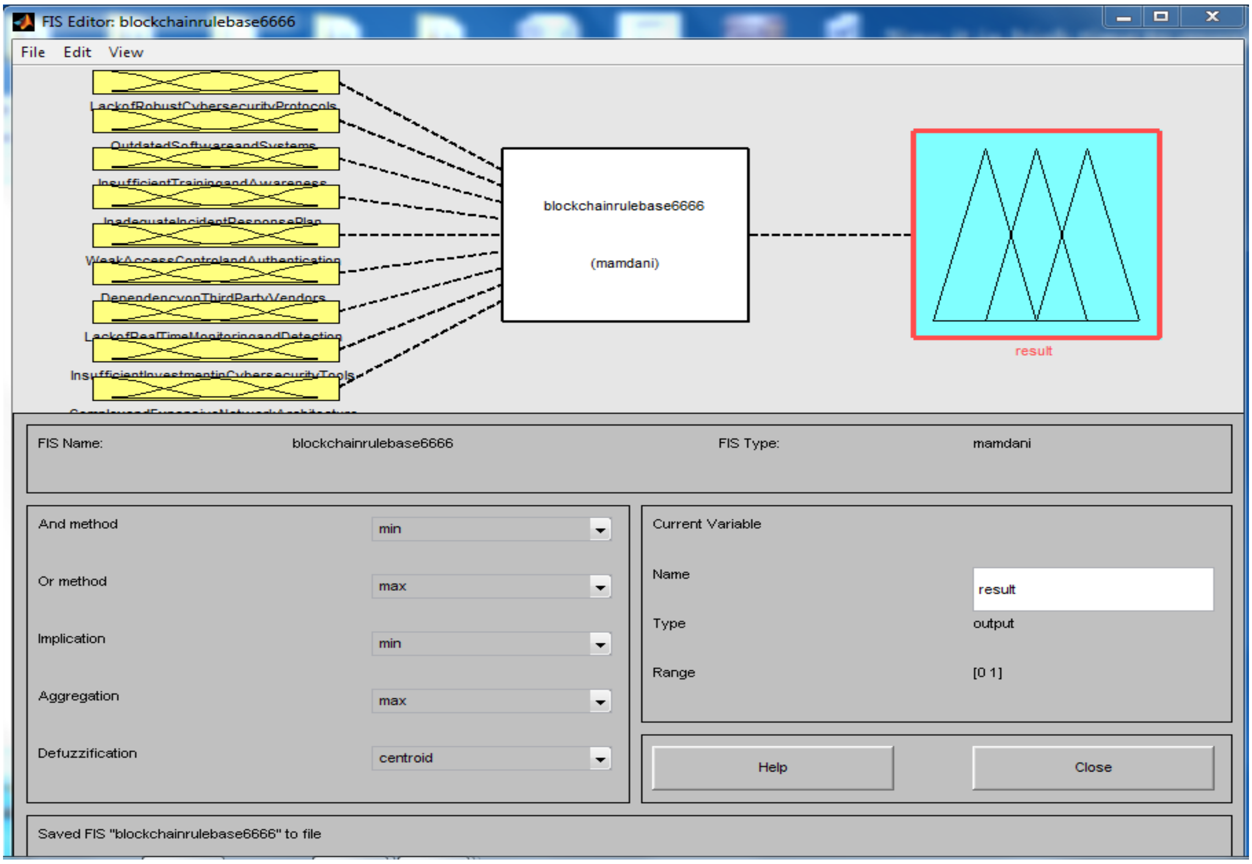

Continuous
1
CONVENTIONAL
In1
Out1
Connection Port
controller
Lack of Robust Cyber security Protocols
25
Display 4
Outdated Software and Systems
1
Display
Insufficient Training and Awareness
20
Display 1
Inadequate Incident Response Plan
15
Display 2
Scope 1
Weak Access Control and Authentication
12
Display 3
Scope
A
B
C
a
b
c
Insufficient Investment in Cybersecurity Tools
Display 7
3
Dependency on Third -Party Vendors
8
Display 5
Complex and Expansive Network Architecture
Display 8
2
Lack of Real -Time Monitoring and Detection
5
Display 6

Fig. 1: Conventional SIMULINK model for enhancing power system resilience against cyber-attack.

The results obtained were as shown in figures 10 through 12

Step 3: To design a block chain rule base that will minimize the causes of poor power system resilience against cyber-attack


FIS Editor: blockchainrulebase6666
File
Edit
View
LackofRobustCybersecurityProtocols
OutdatedSoftwareandSystems
InsufficientTrainingandAwareness
InadequateIncidentResponsePlan
WeakAccessControlandAuthentication
DependencyonThirdPartyVendors
LackofRealTimeMonitoringandDetection
InsufficientInvestmentinCybersecurityTools
ComplexandExpansiveNetworkArchitecture
blockchainrulebase6666
(mamdani)
result
Help
Close

FIS Name: blockchainrulebase6666

FIS Type: mamdani

And method: min

Or method: max

Implication: min

Aggregation: max

Defuzzification: centroid

Current Variable

Name: result

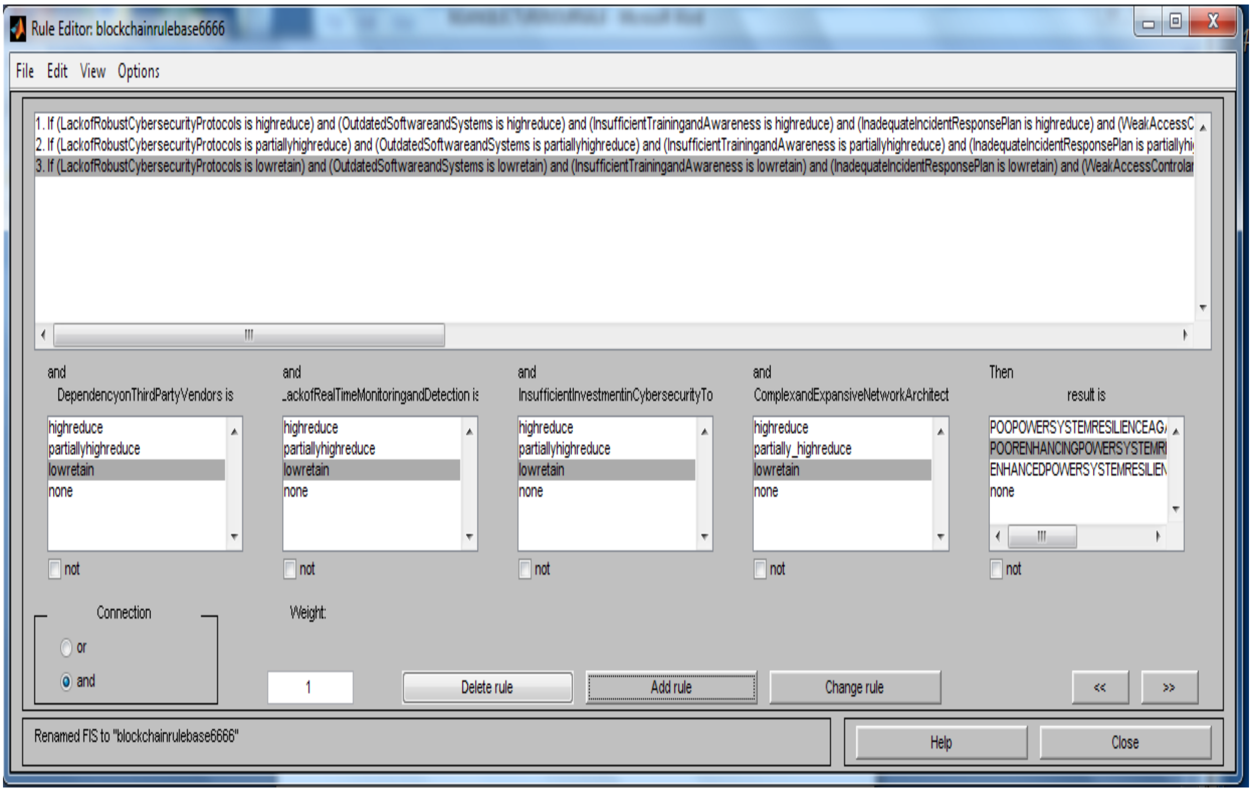
Type: output

Range: [0 1]

Saved FIS "blockchainrulebase6666" to file

Fig. 2: Design block chain fuzzy inference system (FIS) that will minimize the causes of poor power system resilience against cyber-attack.

This has nine inputs of lack of robust cyber security protocols, outdated software and systems, insufficient training and awareness, inadequate incident response plan, weak access control and authentication, dependency on third-party vendors, lack of real-time monitoring and detection and insufficient investment in cyber security tools. It also has an output of result.



1. If (LackofRobustCybersecurityProtocols is highreduce) and (OutdatedSoftwareandSystems is highreduce) and (InsufficientTrainingandAwareness is highreduce) and (InadequateIncidentResponsePlan is highreduce) and (WeakAccessC
2. If (LackofRobustCybersecurityProtocols is partiallyhighreduce) and (OutdatedSoftwareandSystems is partiallyhighreduce) and (InsufficientTrainingandAwareness is partiallyhighreduce) and (InadequateIncidentResponsePlan is partiallyhi
3. If (LackofRobustCybersecurityProtocols is lowretain) and (OutdatedSoftwareandSystems is lowretain) and (InsufficientTrainingandAwareness is lowretain) and (InadequateIncidentResponsePlan is lowretain) and (WeakAccessControlar

Renamed FIS to "blockchainrulebase6666"

Fig 3: Designed block chain rule base that will minimize the causes of poor power system resilience against cyber attack

The comprehensive detail of the rules was as shown in table 3

Table 2: Comprehensive detail of designed block chain rule base that will minimize the causes of poor power system resilience against cyber attack

if lack of robust cyber security protocols is high reduce	and outdated software and systems is high reduce	and insufficient training and awareness is high reduce	and inadequate incident response plan is high reduce	and weak access control and authentication is high reduce	and dependency on third-party vendors is high reduce	and lack of real-time monitoring and detection is high reduce	and insufficient investment in cyber security tools is high reduce	and complex and expansive network architecture is high reduce	then result i poor power system resilience against cyber-attacks
if lack of robust cyber security protocols is partially high reduce	and outdated software and systems ispartially high reduce	and insufficient training and awareness is partially high reduce	and inadequate incident response plan is partially high reduce	and weak access control and authentication is partially high reduce	and dependency on third-party vendors is partially high reduce	and lack of real-time monitoring and detection is partially high reduce	and insufficient investment in cyber security tools is partially high reduce	and complex and expansive network architecture is partially high reduce	then result i poor power system resilience against cyber attack
if lack of robust cyber security protocols is low retain	and outdated software and systems is low retain	and insufficient training and awareness is low retain	and inadequate incident response plan is low retain	and weak access control and authentication is low retain	and dependency on third-party vendors is low retain	and lack of real-time monitoring and detection is low retain	and insufficient investment in cyber security tools is low retain	and complex and expansive network architecture is low retain	then result is enhanced power system resilience against cyber attack

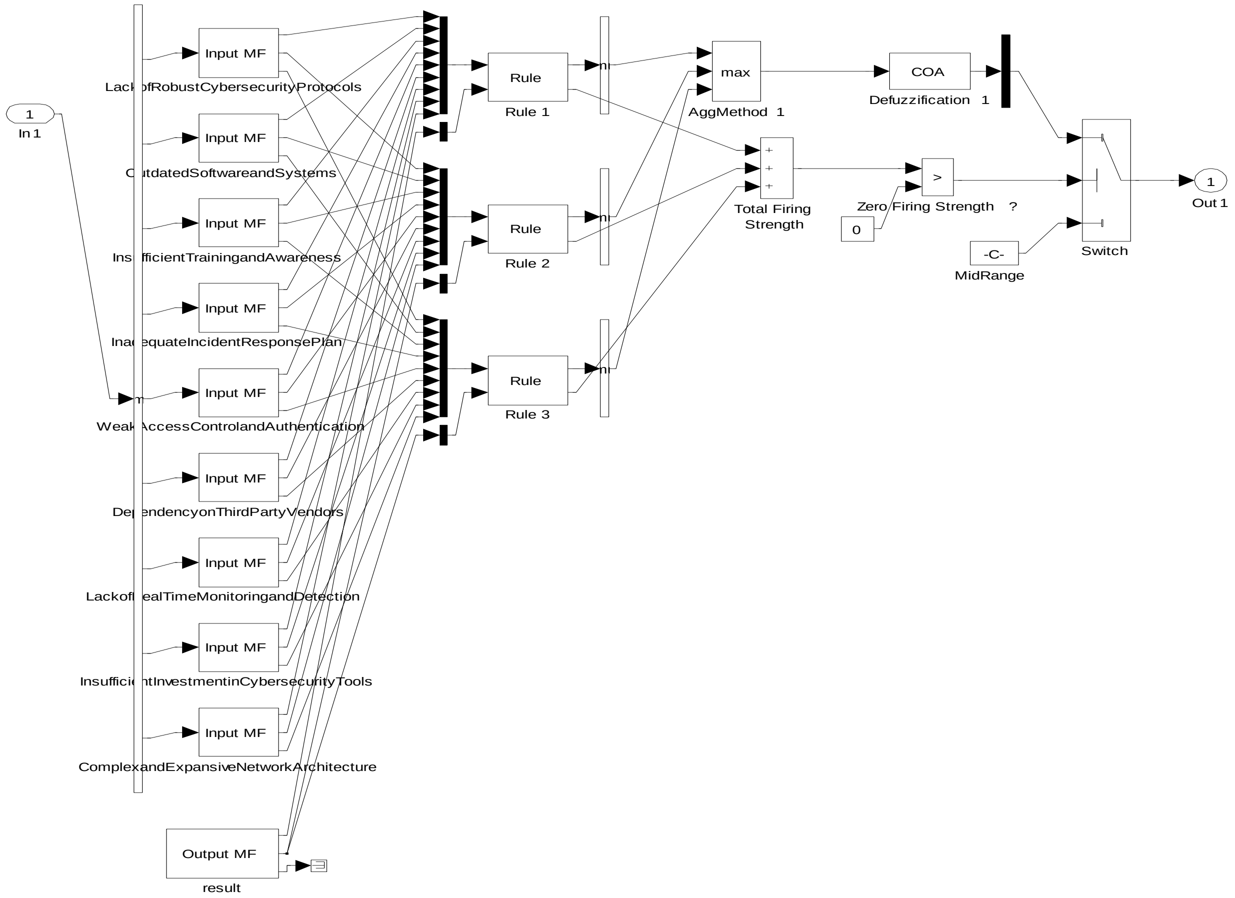

1
In 1
Input MF
LackofRobustCybersecurityProtocols
Input MF
OutdatedSoftwareandSystems
Input MF
InsufficientTrainingandAwareness
Input MF
InadequateIncidentResponsePlan
Input MF
WeakAccessControlandAuthentication
Input MF
DependencyonThirdPartyVendors
Input MF
LackofRealTimeMonitoringandDetection
Input MF
InsufficientInvestmentinCybersecurityTools
Input MF
ComplexandExpansiveNetworkArchitecture
Output MF
result
Rule
Rule 1
Rule
Rule 2
Rule
Rule 3
max
AggMethod 1
COA
Defuzzification 1
Total Firing Strength
>
Zero Firing Strength ?
0
-C-
MidRange
Switch
1
Out 1

Fig 4: The operational mechanism of designed block chain rule base that will minimize the causes of poor power system resilience against cyber attack

Step 4: To train ANN in block chain rule base for effective minimization of the causes of poor power system resilience against cyber attack

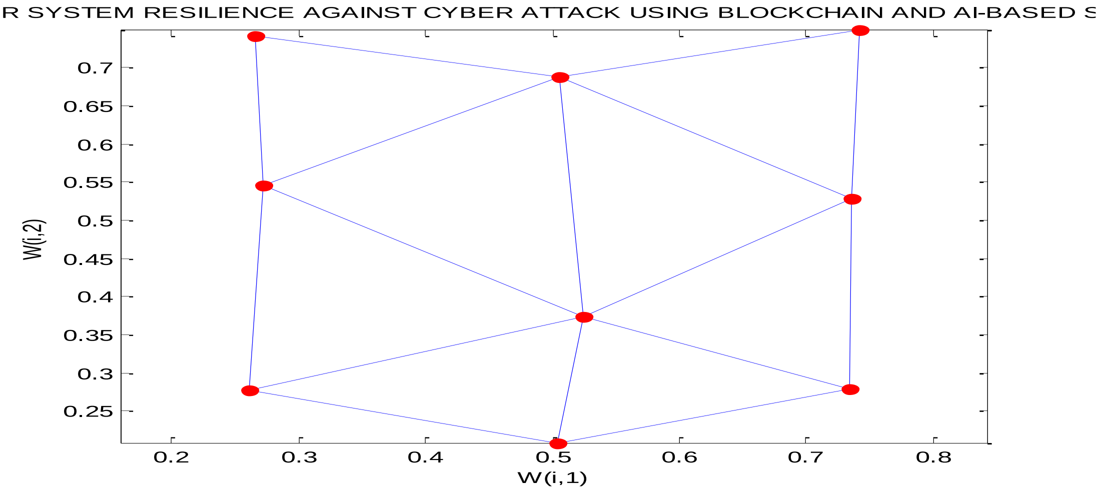


Fig 5: Trained ANN in block chain rule base for effective minimization of the causes of poor power system resilience against cyber attack

ANN was trained three times in the three rules of block chain rule base for effective minimization of the causes of poor power system resilience against cyber-attack 3 x 3 =9 to give nine neurons that looks similar to human brain, and performs exactly what it was instructed to do.

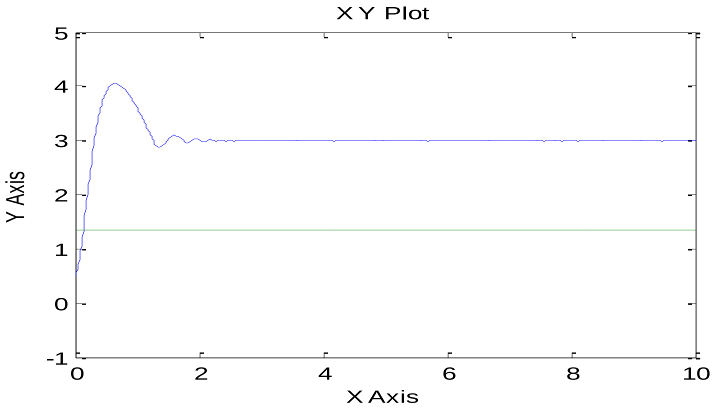


Fig 6: Number of times ANN was trained in the rules

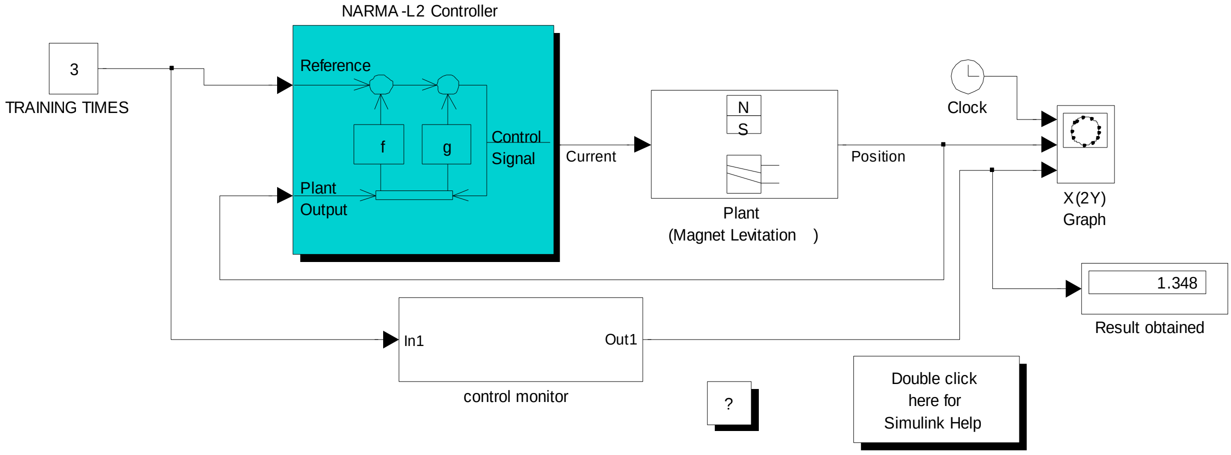


Fig 7: Result obtained during the course of the training

Step 5: To design a SIMULINK model for block chain

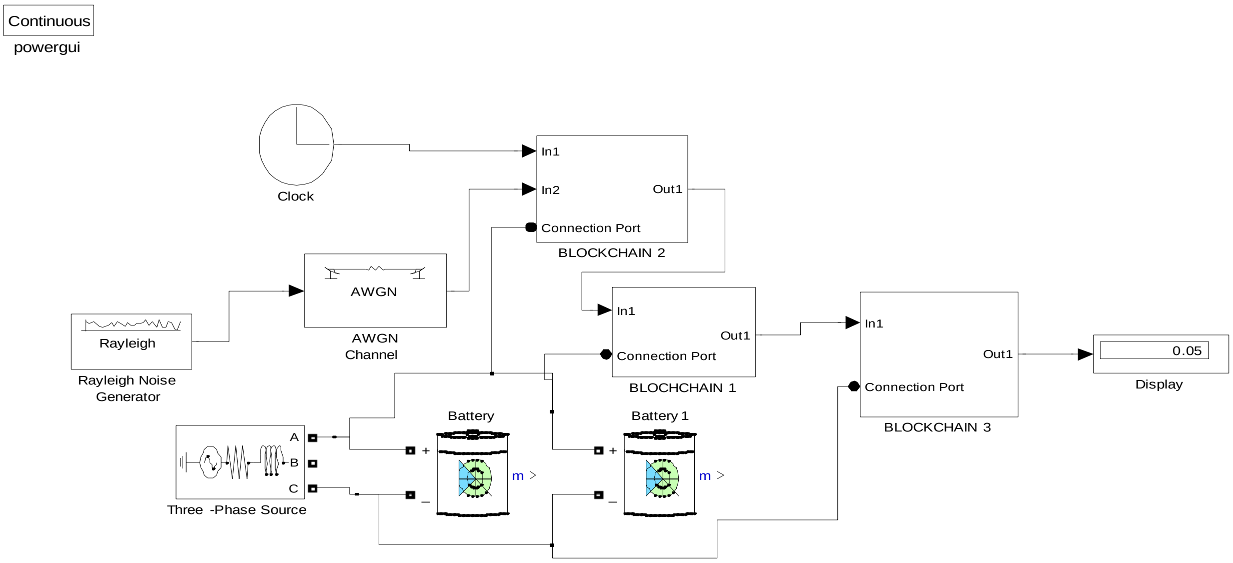


Fig 8: Designed SIMULINK model for block chain

This will be integrated to the result obtained during the course of the training.

Algorithm that will implement the process

1. Characterize and establish the causes of poor power system resilience against cyber attack.
2. Identify lack of robust cyber security protocols
3. Identify Outdated Software and Systems
4. Identify Insufficient Training and Awareness
5. Identify Inadequate Incident Response Plan
6. Identify Weak Access Control and Authentication
7. Identify Dependency on Third-Party Vendors
8. Identify Lack of Real-Time Monitoring and Detection
9. Identify Insufficient Investment in Cyber security Tools
10. Identify Complex and Expansive Network Architecture
11. Design a conventional SIMULINK model for power system resilience against cyber attack and integrate 2 through 10.
12. Design a block chain rule base that will minimize the causes of poor power system resilience against cyber attack.
13. Train ANN in block chain rule base for effective minimization of the causes of poor power system resilience against cyber attack.
14. Design a SIMULINK model for block chain
15. Integrate 12 through 14
16. Integrate 15 in 11.
17. Did the causes of poor power system resilience against cyber attack reduce when 15 was integrated in 11?
18. IF NO go to 16
19. IF YES go to 20
20. Enhanced power system resilience against cyber attack
21. Stop
22. End

Step 6: Design a SIMULINK model for enhancing power system resilience against cyber attack using block chain and AI-based security solution

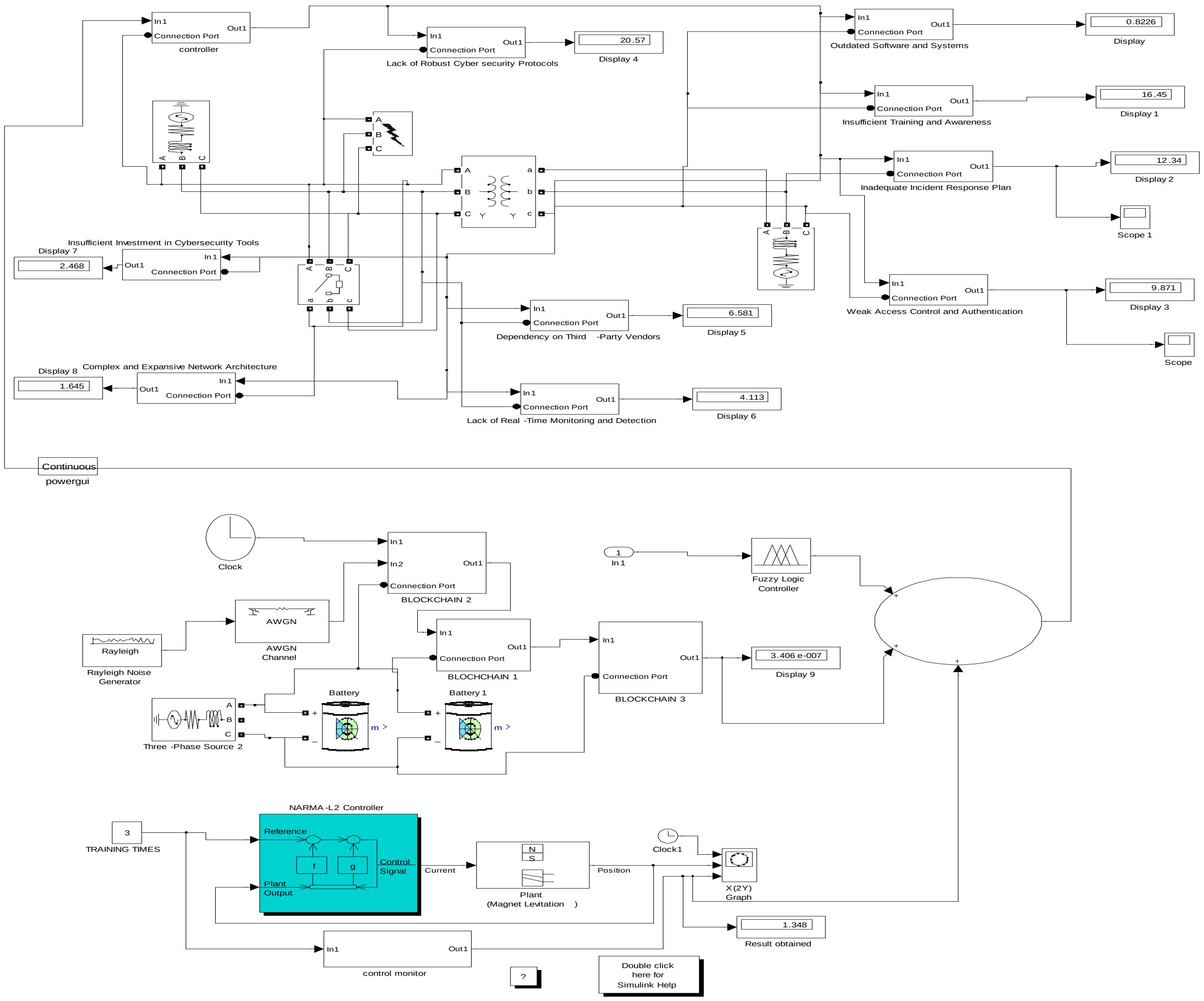


Fig 9: Designed SIMULINK model for enhancing power system resilience against cyber attack using block chain and AI-based security solution

The results obtained were as shown in figures 10 through 12

Step 7: To validate and justify the percentage improvement in the reduction of cause of poor power system resilience against cyber-attack with and without block chain and AI-based security frameworks becomes imperative

To find percentage improvement in the reduction of lack of robust cyber security protocols cause of poor power system resilience against cyber-attack with and without block chain and AI-based security frameworks becomes imperative.

Conventional robust cyber security protocols = 25%

Block chain and AI-based robust cyber security protocols = 20.57%

% improvement in the reduction of lack of robust cyber security protocols cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative = Conventional robust cyber security protocols - Block chain and AI-based robust cyber security protocols

% improvement in the reduction of lack of robust cyber security protocols cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative = 25% - 20.57%

% improvement in the reduction of lack of robust cyber security protocols cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative =4.43%

To find percentage improvement in the reduction of lack of Outdated Software and Systems cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative.

Conventional Outdated Software and Systems = 20%

Block chain and AI-based Outdated Software and Systems = 16.46%

% improvement in the reduction of Outdated Software and Systems cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative = Conventional Outdated Software and Systems - Block chain and AI-based Outdated Software and Systems

% improvement in the reduction of Outdated Software and Systems cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative = 20% - 16.46%

% improvement in the reduction of Outdated Software and Systems cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative =3.54%

To find percentage improvement in the reduction of Lack of Real-Time Monitoring and Detection cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative.

Conventional Lack of Real-Time Monitoring and Detection =5%

Block chain and AI-based Lack of Real-Time Monitoring and Detection =4.1 %

% improvement in the reduction of Lack of Real-Time Monitoring and Detection cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative = Conventional Lack of Real-Time Monitoring and Detection - Block chain and AI-based Lack of Real-Time Monitoring and Detection

% improvement in the reduction of Lack of Real-Time Monitoring and Detection cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative = 5% - 4.1%

% improvement in the reduction of Lack of Real-Time Monitoring and Detection cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative =0.9%

To find percentage improvement in the reduction of Lack of Insufficient Investment in Cyber security Tools cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative.

Conventional Insufficient Investment in Cyber security Tools = 3%

Block chain and AI-based Insufficient Investment in Cyber security Tools = 2.46 %

% improvement in the reduction of Insufficient Investment in Cyber security Tools cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative = Conventional Insufficient Investment in Cyber security Tools - Block chain and AI-based Insufficient Investment in Cyber security Tools

% improvement in the reduction of Insufficient Investment in Cyber security Tools cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative = 3% - 2.46%

% improvement in the reduction of Lack of Real-Time Monitoring and Detection cause of poor power system resilience against cyber attack with and without block chain and AI-based security frameworks becomes imperative = 0.54%

Table 3: Comparison of conventional and block chain and AI-based robust cyber security protocols cause of poor power system resilience against cyber attack

Time (s)	*Conventional robust cyber security protocols cause of poor power system resilience against cyber attack (%)*	*Block chain and AI-based robust cyber security protocols cause of poor power system resilience against cyber attack (%)*
1	25	20.57
2	25	20.57
3	25	20.57
4	25	20.57
10	25	20.57

To 20.57% thereby improving constant power supply devoid of cyber attack.

Table 4: Comparison of conventional and block chain and AI-based lack of Outdated Software and Systems cause of poor power system resilience against cyber attack

Time (s)	*Conventional lack of Outdated Software and Systems cause of poor power system resilience against cyber attack (%)*	*Block chain and AI-based robust cyber security protocols lack of Outdated Software and Systems cause of poor power system resilience against cyber attack (%)*
1	20	16.46
2	20	16.46
3	20	16.46
4	20	16.46
10	20	16.46

Table 5: Comparison of conventional and block chain and AI-based Lack of Real-Time Monitoring and Detection cause of poor power system resilience against cyber attack

Time (s)	*Conventional Lack of Real-Time Monitoring and Detection cause of poor power system resilience against cyber attack (%)*	*Block chain and AI-based Lack of Real-Time Monitoring and Detection cause of poor power system resilience against cyber attack (%)*
1	3	2.46
2	3	2.46

3	3	2.46
4	3	2.46
10	3	2.46

Results and Discussion

Figure 1 is a Conventional SIMULINK Model for Enhancing Power System Resilience Against Cyber Attacks. This figure illustrates the traditional SIMULINK model developed to enhance the resilience of power systems against cyber-attacks.

Figures 10–12 are the Results Obtained. The results derived from the experiments are presented in Figures 10 through 12, showing the effectiveness of the model in improving system resilience.

Figure 2 depicts the Blockchain-based Fuzzy Inference System (FIS) Design to Minimize the Causes of Poor Power System Resilience Against Cyber Attacks. The FIS model incorporates nine inputs, which represent critical factors contributing to the vulnerability of power systems. These include: Lack of robust cybersecurity protocols; Outdated software and systems; Insufficient training and awareness; Inadequate incident response plans; Weak access control and; authentication measures; Dependency on third-party vendors; Lack of real-time monitoring and detection; Insufficient investment in cybersecurity tools; the system processes these inputs to generate an output result, which aims to minimize vulnerabilities.

Figure 3 shows Blockchain Rule Base Design to Minimize the Causes of Poor Power System Resilience Against Cyber Attacks. This figure depicts the rule base for the blockchain system, which is designed to address the identified causes of poor resilience. The rules governing the system are detailed in Table 3.

Figure 4 presents the Operational Mechanism of the Designed Blockchain Rule Base to Minimize Causes of Poor Power System Resilience Against Cyber Attacks. This diagram outlines how the blockchain rule base operates to mitigate factors contributing to poor power system resilience against cyber threats.

Figure 5 shows the trained Artificial Neural Network (ANN) in the Blockchain Rule Base for Effective Minimization of Vulnerabilities. The ANN was trained three times within the framework of the blockchain rule base. This training process covers the three blockchain rules, resulting in nine neurons that function similarly to the human brain, carrying out specific instructions to optimize system performance.

Figure 6 is the Number of Times the ANN Was Trained in the Rules. This figure shows the frequency with which the ANN was trained across the different rules within the blockchain framework.

Figure 7 is the Results Obtained During the ANN Training Process. The results obtained during the training phase of the ANN are shown in this figure, demonstrating the effectiveness of the training process.

Figure 8 depicts the Designed SIMULINK Model for Blockchain. This figure presents the SIMULINK model created for the integration of blockchain technology to enhance power system resilience.

While Figure 9 displays the SIMULINK Model for Enhancing Power System Resilience Against Cyber Attacks Using Blockchain and AI-Based Security Solutions. This model integrates the results of the previous training with both blockchain and AI-based security solutions to enhance resilience against cyber threats. The results are reflected in Figures 10 through 12.

The combination of blockchain and AI in these models demonstrates significant potential in minimizing vulnerabilities and improving the overall security and resilience of power systems.

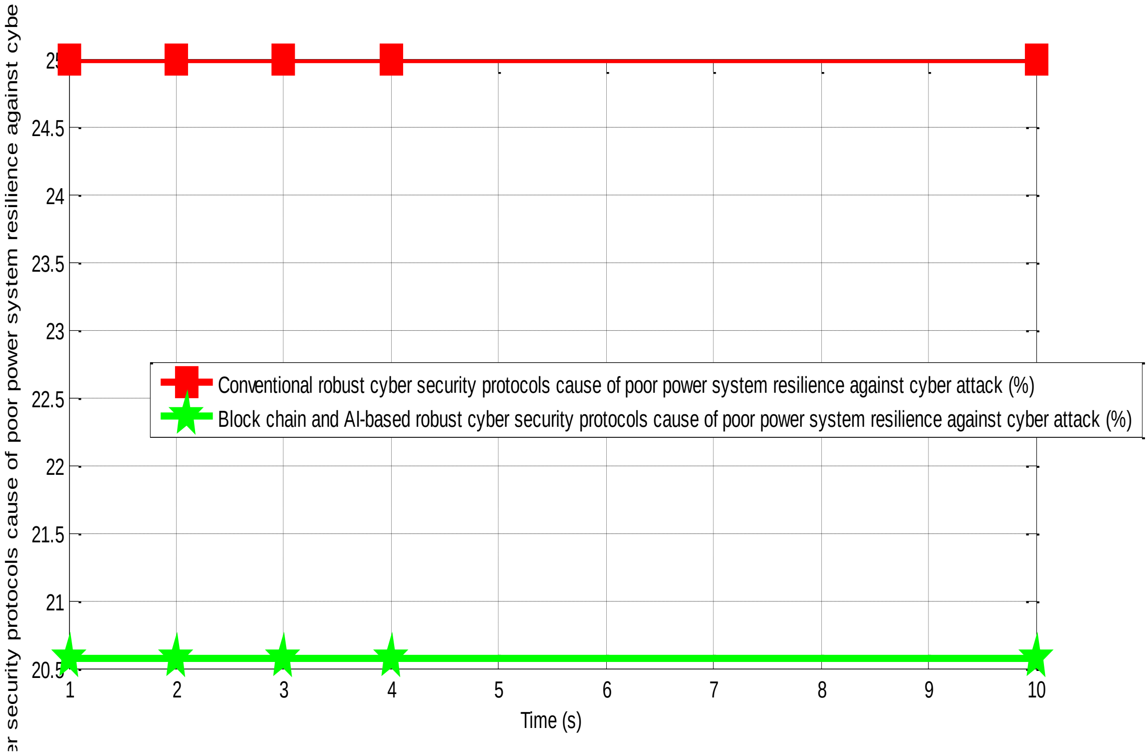


Fig 10: Comparison of conventional and block chain and AI-based robust cyber security protocols cause of poor power system resilience against cyber attack

The conventional robust cyber security protocols cause of poor power system resilience against cyber-attack was 25%. On the other hand, when block chain and AI-based was integrated in the system, it drastically reduced the robust cyber security protocols cause of poor power system resilience against cyberattack.

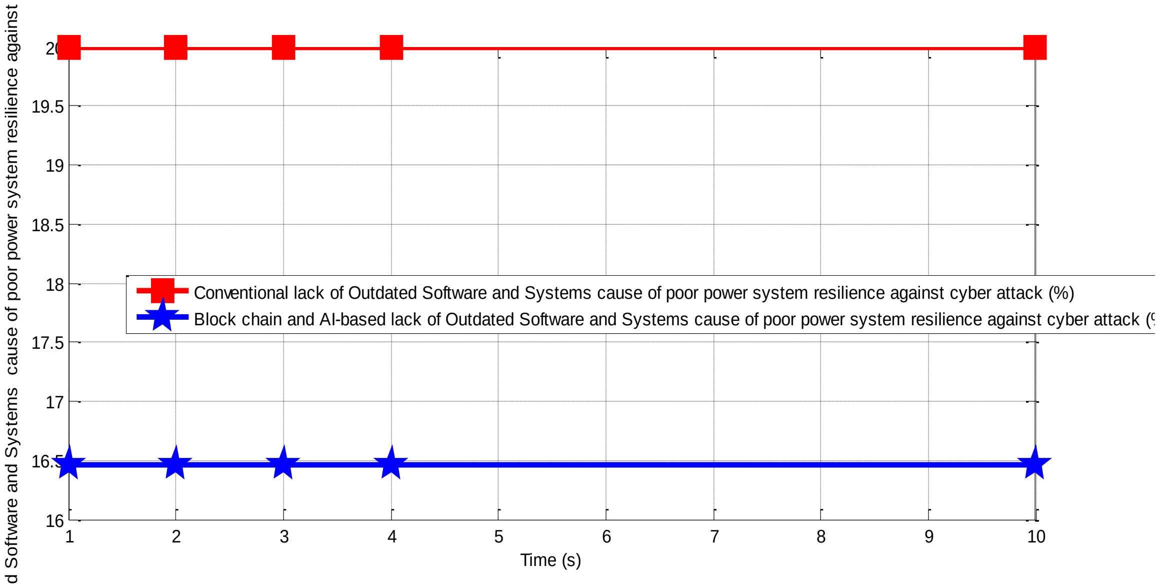


Fig 11: Comparison of conventional and block chain and AI-based lack of Outdated Software and Systems cause of poor power system resilience against cyber attack

The conventional lack of Outdated Software and Systems cause of poor power system resilience against cyber attack was 20%. Meanwhile, when block chain and AI-based was incorporated in the system, it vehemently reduced lack of Outdated Software and Systems cause of poor power system resilience against cyber attack to 16.46% thereby simultaneously improved consistent power supply with minute cyber attack.

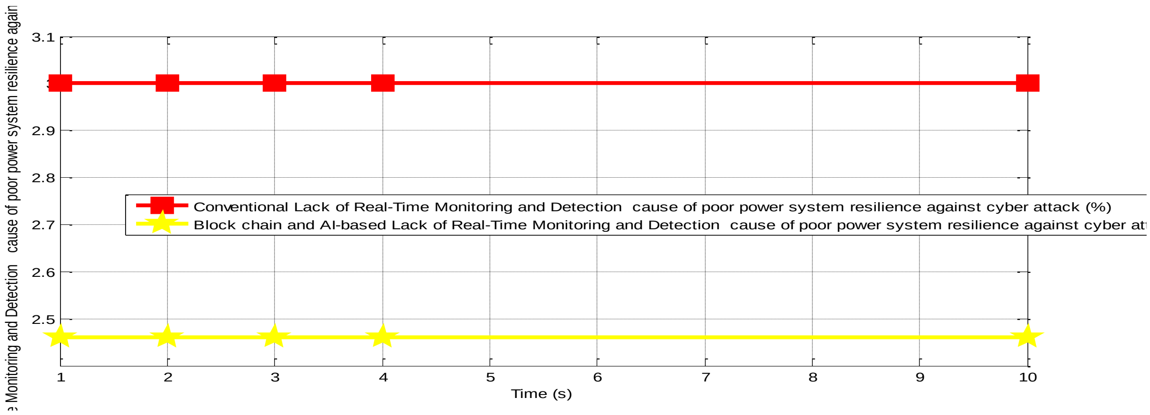


Fig 12: Comparison of conventional and block chain and AI-based Lack of Real-Time Monitoring and Detection cause of poor power system resilience against cyber attack

The conventional Lack of Real-Time Monitoring and Detection cause of poor power system resilience against cyber-attack was 3%. However, when block chain and AI-based was imbibed in the system, it decisively reduced it to 2.46%. finally, with these results obtained, it definitely shown that the percentage enhancement of power system resilience against cyber attack is 0.54%.

Conclusion

The integration of blockchain and AI presents a transformative approach to improving the resilience of power systems against cyber-attacks. By addressing vulnerabilities, enabling real-time threat detection, and ensuring data integrity, these technologies can significantly enhance the security and reliability of modern power grids. Continued research and collaboration will be essential to overcoming implementation challenges and realizing the full potential of these advanced solutions.

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