CARITAS UNIVERSITY AMORJI-NIKE, EMENE, ENUGU STATE

Caritas Journal of Engineering Technology

CJET, Volume 4, Issue 2 (2025)

Article History: ***Received: 11th June, 2025; Revised: 30th July, 2025; Accepted: 11th September, 2025***

IMPROVING CONTINGENCY EVALUATION IN NIGERIAN 330KV TRANSMISSION GRID USING INTELLIGENT BASED SSVC

Chukwuagu, M. Ifeanyi
Eze, Ignatius Emeka
Department of Electrical/Electronics Engineering
Caritas University, Amorji-Nike, Enugu State

Abstract

The consistent power failure in Nigerian 330 KV transmission network that had crippled business activities was overcame by introducing improving contingency evaluation in Nigerian 330kv transmission grid using intelligent based SSVC. contingency challenges in Nigerian 330kV transmission grid was characterized and established, conventional SIMULINK model Nigerian 330kV transmission grid was designed, SSVC rule base that will minimize the causes of contingency challenges in Nigerian 330kV transmission grid was developed and ANN was trained in the developed SSVC rule base for immediate minimization of the causes of contingency challenges in Nigerian 330kV transmission grid. Then an algorithm that would implement the process was developed and SIMULINK model for improving contingency evaluation in Nigerian 330KV transmission grid using intelligent based SSVC was designed and results obtained were validated and justified. The results obtained were the conventional Transformer Failure Rate that causes contingency challenges in Nigerian 330kV transmission grid was22%. On the other hand, when an intelligent based SSVC was imbibed into the system, it concurrently reduced it to19.8 %. Finally, with these results obtained, it definitely showed that the percentage improvement in contingency evaluation in Nigerian 330KV transmission grid when an intelligent based SSVC was integrated in the system was2.2%. To characterize and establish the causes of contingency challenges in Nigerian 330kV transmission grid. To design conventional SIMULINK model Nigerian 330kV transmission grid. To develop an SSVC rule base that will minimize the causes of contingency challenges in Nigerian 330kV transmission grid. To train ANN in the developed SSVC rule base for immediate minimization of the causes of contingency challenges in Nigerian 330kV transmission grid. To develop an algorithm that will implement the process. To design a SIMULINK model for Improving contingency evaluation in Nigerian 330KV transmission grid using intelligent based SSVC. To validate and justify percentage improvement in the reduction of causes of contingency challenges in Nigerian 330kV transmission grid with and without an intelligent based SSVC

Keywords: Improving, contingency, evaluation, Nigerian, 330kv, transmission, grid, intelligent ,based SSVC

INTRODUCTION

The reliability and stability of power transmission networks are critical to ensuring an uninterrupted electricity supply, particularly in developing nations like Nigeria. The Nigerian 330kV transmission grid, which serves as the backbone of the country's power infrastructure, faces significant challenges, including transmission line overloading, voltage instability, and system contingencies. These challenges often result in frequent blackouts, voltage collapses, and inefficient power distribution, affecting industries, businesses, and households (Okedu et al., 2020). Contingency evaluation is a fundamental aspect of power system stability analysis, enabling grid operators to predict and mitigate potential failures before they escalate into widespread power outages. Traditional contingency assessment methods rely on deterministic and probabilistic techniques, which, while effective, often lack real-time adaptability and predictive accuracy (Adoghe et al., 2019). These limitations necessitate the integration of intelligent-based solutions to enhance the performance of contingency evaluation in power transmission networks. Static Synchronous Var Compensator (SSVC) is an advanced Flexible AC Transmission System (FACTS) device known for its ability to regulate voltage, improve power factor, and enhance grid stability. The integration of intelligent-based techniques, such as Artificial Neural Networks (ANN), Fuzzy Logic Controllers (FLC), and hybrid optimization methods, into SSVC technology can significantly improve contingency evaluation by providing real-time grid monitoring, predictive fault detection, and automated corrective actions (Eke et al., 2021). Recent studies have demonstrated the effectiveness of intelligent-based SSVC in mitigating voltage fluctuations, optimizing reactive power compensation, and improving overall grid resilience (Babatunde & Ojo, 2022). However, there is limited research focusing specifically on its application in the Nigerian 330kV transmission network. Addressing this gap is crucial to ensuring grid modernization and reducing the vulnerability of the Nigerian power system to contingencies. Therefore, this study aims to improve contingency evaluation in the Nigerian 330kV transmission grid by leveraging intelligent-based SSVC technology. By employing advanced machine learning models and intelligent control strategies, this research seeks to enhance the operational efficiency and stability of the grid, ultimately contributing to a more reliable and sustainable power supply in Nigeria.

METHODOLOGY

To characterize and establish the causes of contingency challenges in Nigerian 330kV transmission grid

Table 1 characterize d and establish ted he causes of contingency challenges in Nigerian 330kV transmission grid

S/N	Parameter	Typical Range / Value (S.I. Units)	Percentage Impact on Grid Reliability (%)	Conventional Causes of Contingency Challenges in Nigerian 330kV Transmission(%)	Primary Causes
1	Voltage Deviation (ΔV)	±10% of 330kV → 297 – 363 kV	20–30%	32	Poor voltage regulation, insufficient reactive power compensation
2	Line Loading	80–120% of thermal limit (MVA)	25–35%		Overloading due to network expansion without capacity upgrade
3	Frequency Deviation (Δf)	±0.5 Hz (Nominal 50 Hz → 49.5–50.5 Hz)	10–15%		Generator outages, load imbalance, poor grid control
4	Line Outage Rate	2–5 outages/month/grid segment	30–40%		Aging infrastructure, environmental factors (e.g., lightning, storms)
5	Transformer Failure Rate	1–3 failures/year per zone	15–20%		Overloading, insulation failure, lack of predictive maintenance
6	System Fault Level (3-	25–40 Ka	-		Faults due to

	phase)				insulation breakdown, poor coordination of protection devices
7	Power Losses	8–15% of transmitted power (MW)	20–25%		Long transmission distances, poor conductor quality, high resistance losses
8	Blackout Incidence	3–5 major blackouts/year	40–50% (during event)		Cascading failures, lack of islanding capability, poor fault detection & response
9	Protection Relay Malfunction	5–10 cases/year	10–15%		Outdated relays, coordination errors, cyber-infrastructure vulnerabilities
10	SCADA/Communication Failure	2–4 failures/month	15–25%		Inadequate ICT infrastructure, signal loss, lack of redundancy

Summary of Major Causes of Contingency Challenges

1. Aging Infrastructure – Many components are over 30 years old and operate beyond their design lifespan.
2. Overloading – Increase in power demand without proportional upgrade of grid capacity.
3. Inadequate Reactive Power Compensation – Leads to voltage instability.
4. Poor Grid Planning and Coordination – No real-time contingency analysis or islanding scheme.
5. Weak Protection System – Outdated or poorly configured relays and breakers.
6. Limited Automation and SCADA Coverage – Delay in fault detection and isolation.
7. Environmental Factors – Lightning, vandalism, and vegetation encroachment.
8. Cybersecurity Risks – Vulnerabilities in digital control systems.

To design conventional SIMULINK model Nigerian 330kV transmission grid

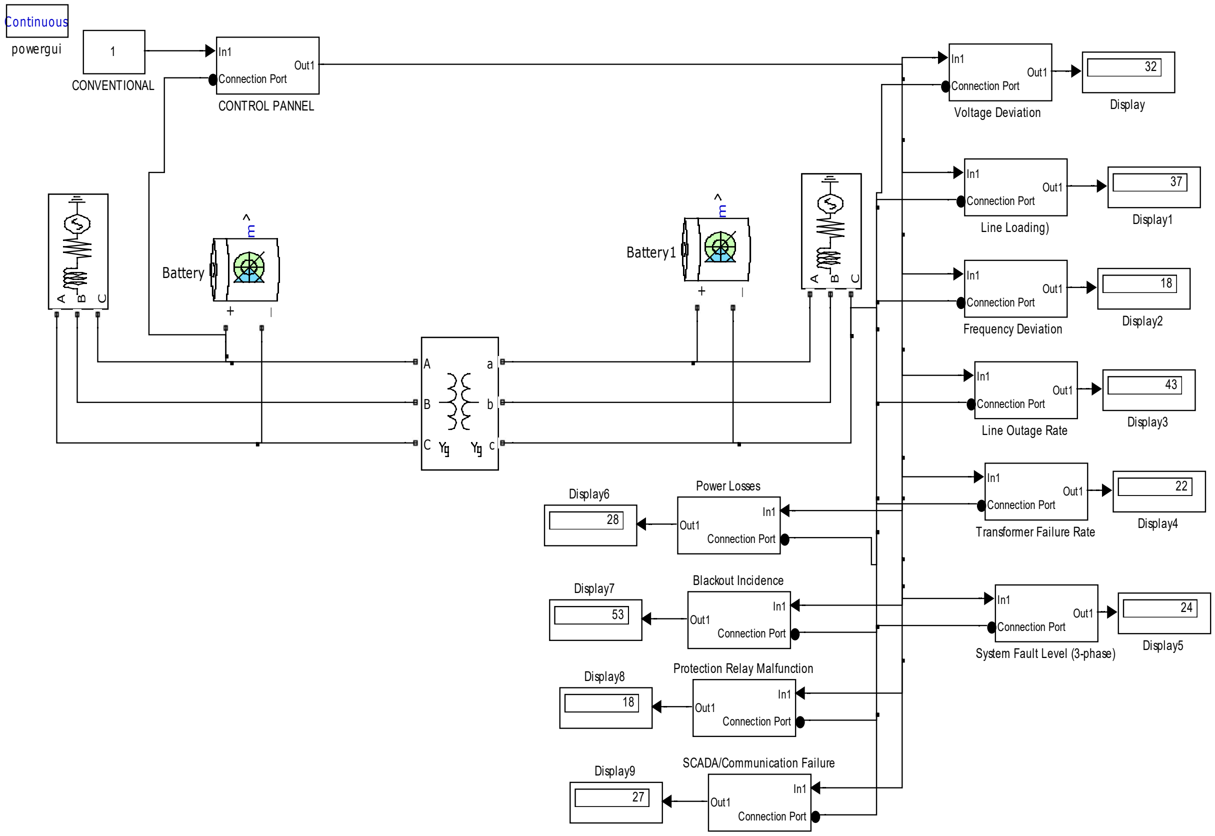

Fig 1 designed conventional SIMULINK model Nigerian 330kV transmission grid

The results obtained were as shown in figures 8 through 10

To develop an SSVC rule base that will minimize the causes of contingency challenges in Nigerian 330kV transmission grid

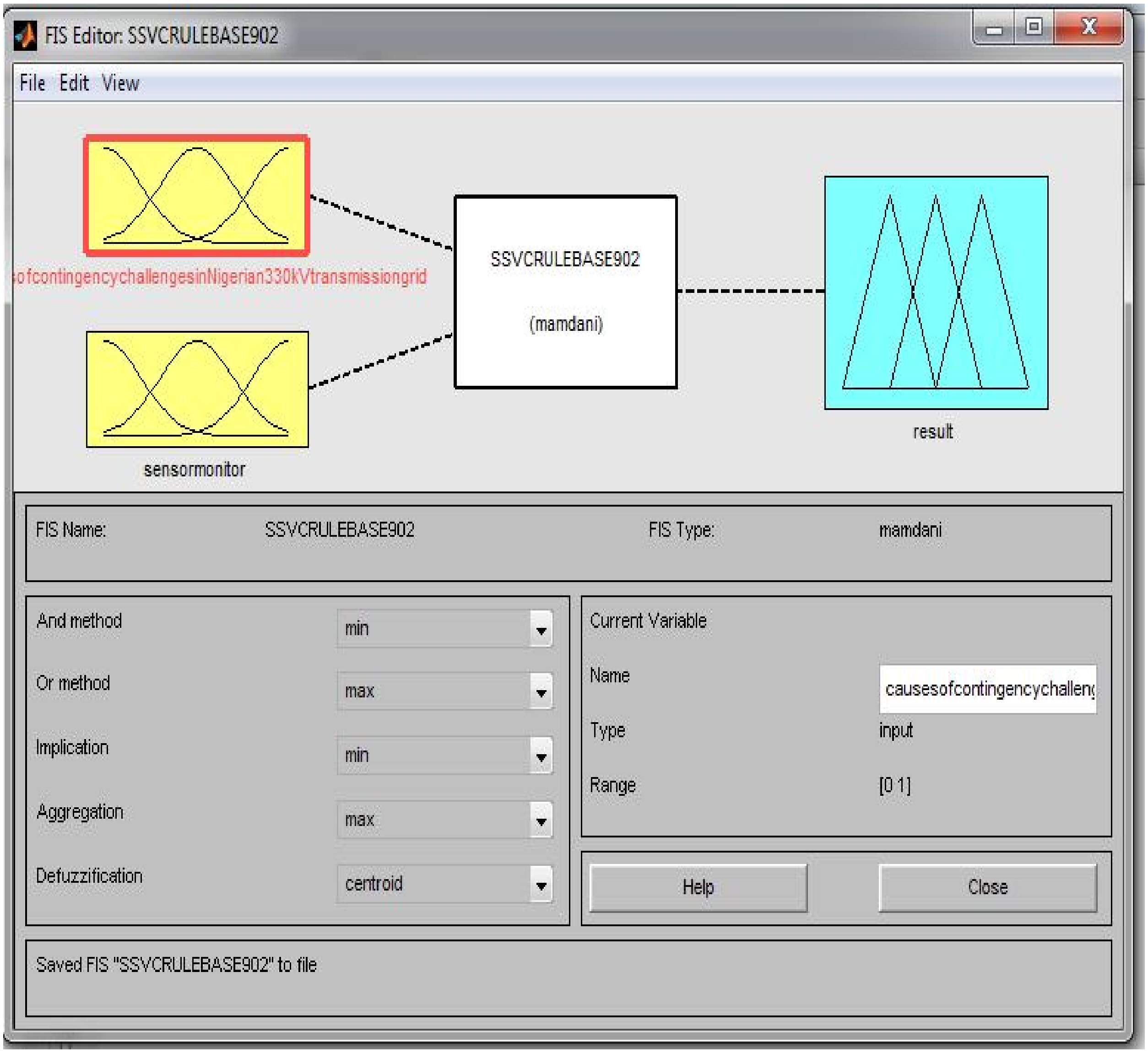

Fig 2 developed SSVC fuzzy inference system that will minimize the causes of contingency challenges in Nigerian 330kV transmission grid

This had two inputs of causes of contingency challenges in Nigerian 330kV transmission grid and sensor monitor. It equally had an output of result.

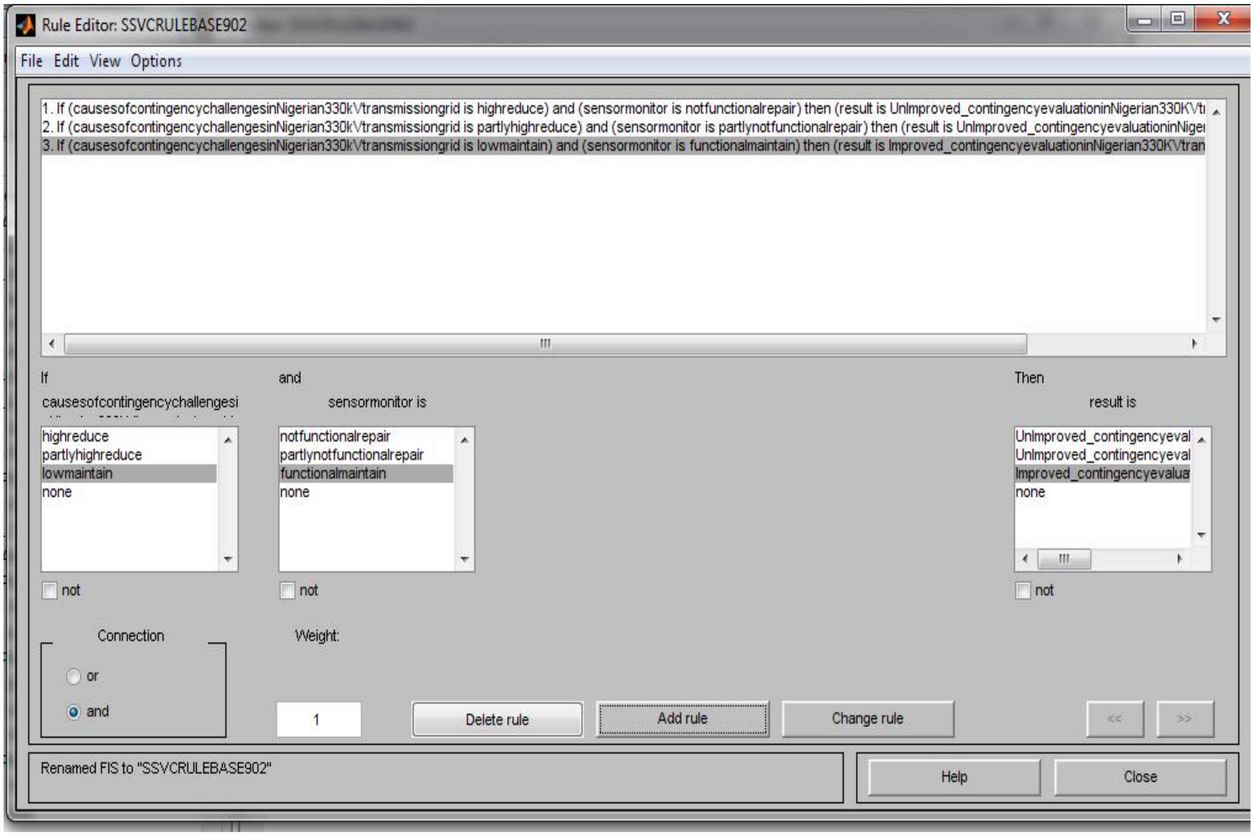

Fig 3 developed SSVC rule base that will minimize the causes of contingency challenges in Nigerian 330kV transmission grid

The developed SSVC rule base that will minimize the causes of contingency challenges in Nigerian 330kV transmission grid was comprehensively written in table 3.2

Table 2 comprehensive developed SSVC rule base that will minimize the causes of contingency challenges in Nigerian 330kV transmission grid

1	IF causes of contingency challenges in Nigerian 330kV transmission grid is high reduce	And sensor monitor is not functioning repair	Then result is un improved contingency evaluation in Nigerian 330KV transmission grid
2	IF causes of contingency challenges in Nigerian 330kV transmission grid is partly high reduce	And sensor monitor is partly not functioning repair	Then result is un improved contingency evaluation in Nigerian 330KV transmission grid
3	IF causes of	And sensor monitor	Then result is un

	contingency challenges in Nigerian 330kV transmission grid is low maintain	is functioning maintain	improved contingency evaluation in Nigerian 330KV transmission grid

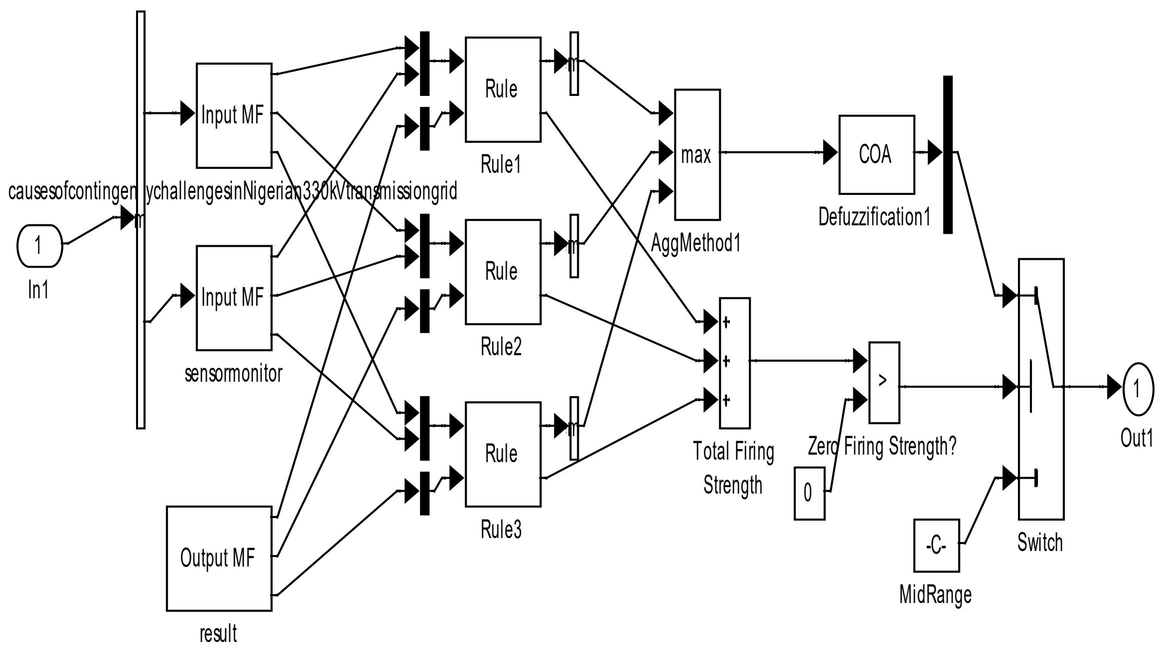

Fig 4 developed SSVC rule base that will minimize the causes of contingency challenges in Nigerian 330kV transmission grid

To train ANN in the developed SSVC rule base for immediate minimization of the causes of contingency challenges in Nigerian 330kV transmission grid

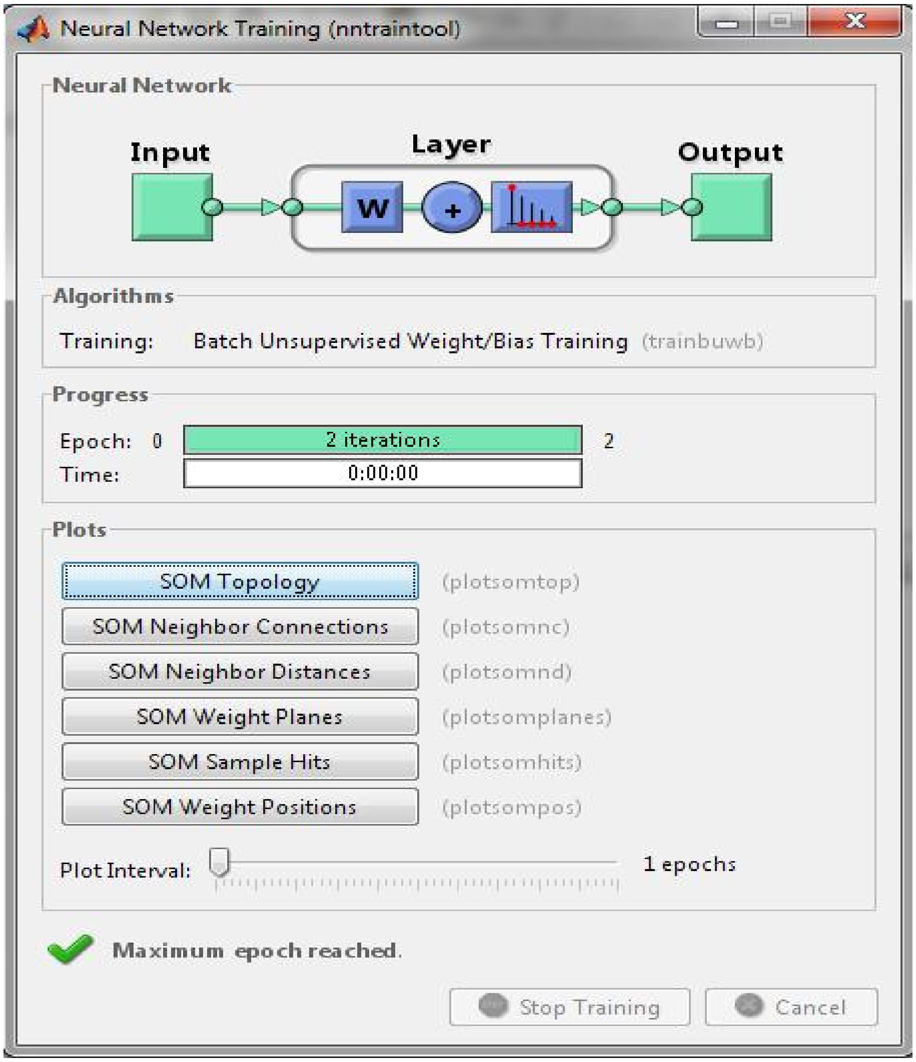

Fig 5 ANN training tool for developed SSVC rule base for immediate minimization of the causes of contingency challenges in Nigerian 330kV transmission grid

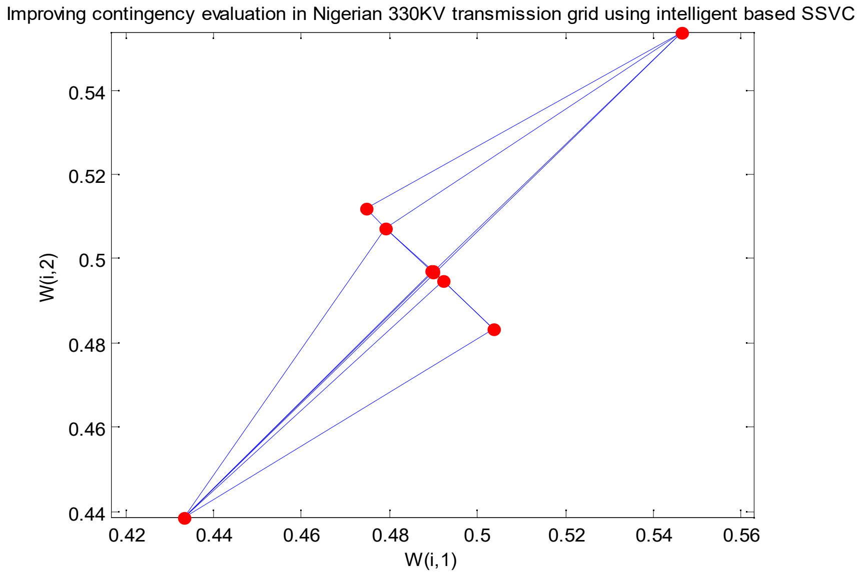

Fig 6 trained ANN in the developed SSVC rule base for immediate minimization of the causes of contingency challenges in Nigerian 330kV transmission grid

ANN was trained three times in the three rules = 3 x3 = 9 to have nine neurons that looked like human brain.

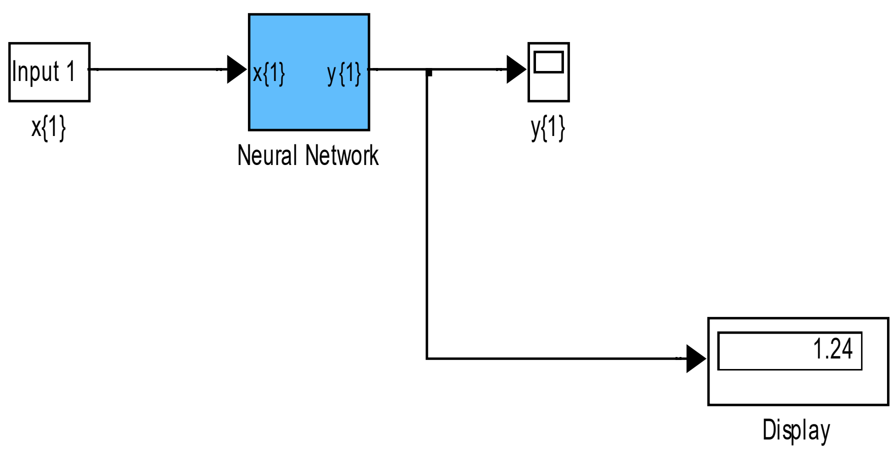

Fig 7 result obtained in developed SSVC rule base for immediate minimization of the causes of contingency challenges in Nigerian 330kV transmission grid

To design SSVC SIMULINK model

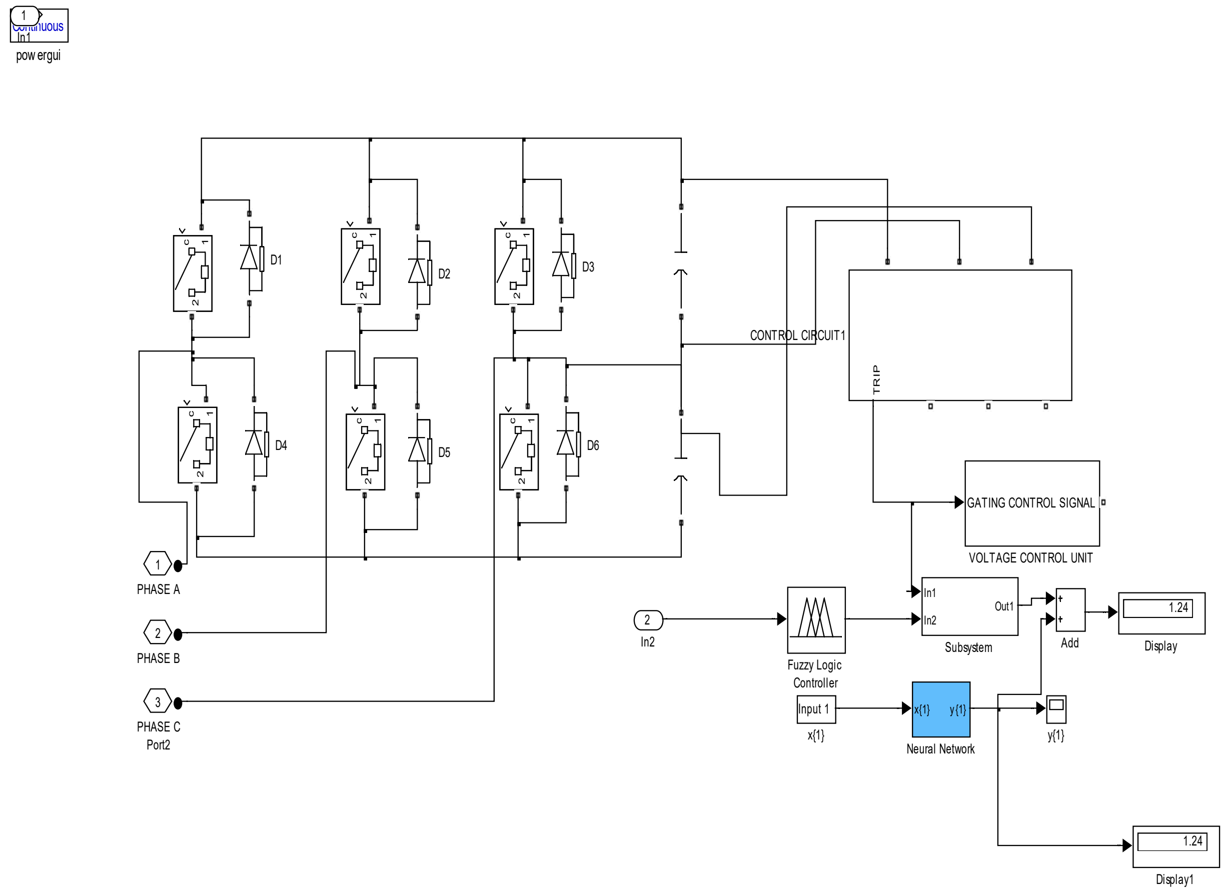

Fig 8 designed SSVC SIMULINK model

This would be integrated in the designed conventional SIMULINK model in Nigerian 330kV transmission grid. The results obtained were as shown in figures 10 through 12

To develop an algorithm that will implement the process

1. Characterize and establish the causes of contingency challenges in Nigerian 330kV transmission grid
2. Identify Voltage Deviation (ΔV)
3. Identify Line Loading
4. Identify Frequency Deviation (Δf)
5. Identify Line Outage Rate
6. Identify Transformer Failure Rate
7. Identify System Fault Level (3-phase)
8. Identify Power Losses
9. Identify Blackout Incidence
10. Identify Protection Relay Malfunction
11. Identify SCADA/Communication Failure
12. Design conventional SIMULINK model Nigerian 330kV transmission grid And Integrate 2 through 12
13. Develop an SSVC rule base that will minimize the causes of contingency challenges in Nigerian 330kV transmission grid
14. Train ANN in the developed SSVC rule base for immediate minimization of the causes of contingency challenges in Nigerian 330kV transmission grid
15. Design SSVC SIMULINK model

16. Integrate 14 through 16
17. Integrate 17 into 12
18. Did the causes of contingency challenges in Nigerian 330kV transmission grid reduced when17 was integrated into 12?
19. IF NO go to 17
20. IF YES go to 21
21. Improved contingency evaluation in Nigerian 330KV transmission grid
22. Stop
23. End

To design a SIMULINK model for Improving contingency evaluation in Nigerian 330KV transmission grid using intelligent based SSVC

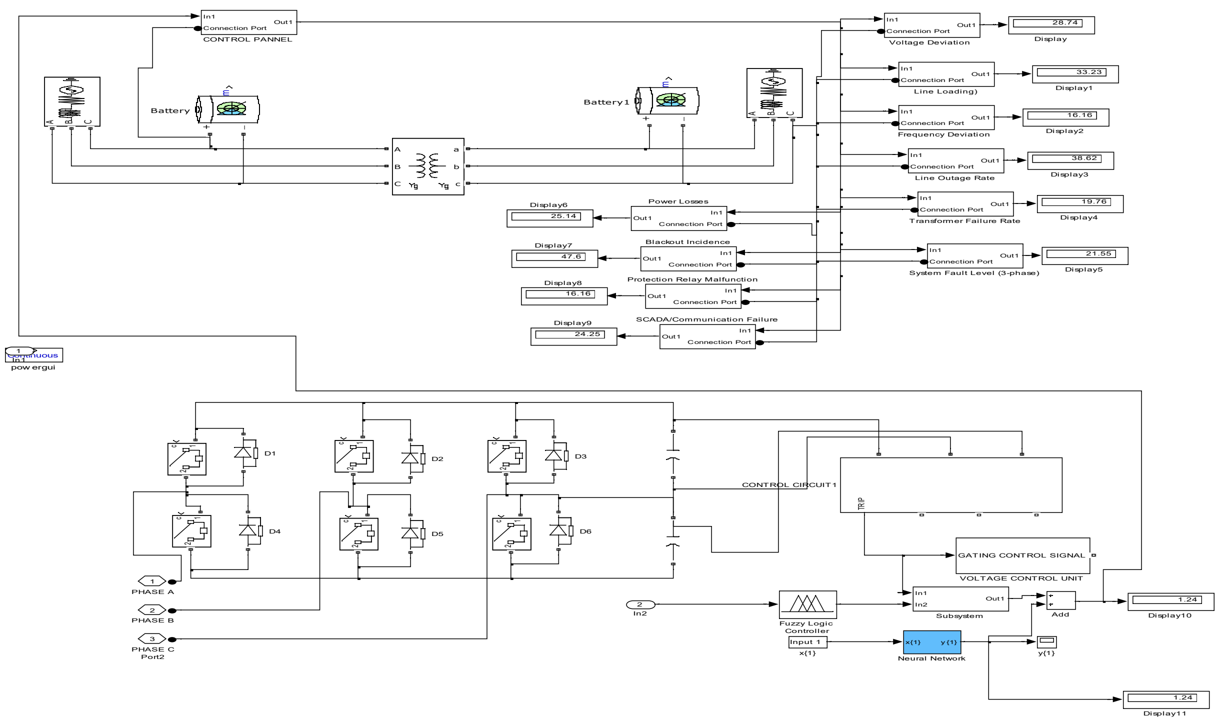

Fig 9 designed SIMULINK model for Improving contingency evaluation in Nigerian 330KV transmission grid using intelligent based SSVC

The results obtained were as shown in figures 10 through 12.

To validate and justify percentage improvement in the reduction of causes of contingency challenges in Nigerian 330kV transmission grid with and without an intelligent based SSVC

To find percentage improvement in the reduction of Voltage Deviation causes of contingency challenges in Nigerian 330kV transmission grid with an intelligent based SSVC

Conventional Voltage Deviation =32%

Intelligent based SSVC Voltage Deviation = 28.7%

% improvement in the reduction of Voltage Deviation causes of contingency challenges in Nigerian 330kV transmission grid with an intelligent based SSVC=

Conventional Voltage Deviation - Intelligent based SSVC Voltage Deviation

% improvement in the reduction of Voltage Deviation causes of contingency challenges in Nigerian 330kV transmission grid with an intelligent based SSVC=

32% - 28.7%

% improvement in the reduction of Voltage Deviation causes of contingency challenges in Nigerian 330kV transmission grid with an intelligent based SSVC= 3.3%

To find percentage improvement in the reduction of Frequency Deviation causes of contingency challenges in Nigerian 330kV transmission grid with an intelligent based SSVC

Conventional Frequency Deviation =18%

Intelligent based SSVC Frequency Deviation = 16.2%

% improvement in the reduction of Frequency Deviation causes of contingency challenges in Nigerian 330kV transmission grid with an intelligent based SSVC=

Conventional Frequency Deviation - Intelligent based SSVC Frequency Deviation

% improvement in the reduction of Frequency Deviation causes of contingency challenges in Nigerian 330kV transmission grid with an intelligent based SSVC=

18% - 16.2%

% improvement in the reduction of Frequency Deviation causes of contingency challenges in Nigerian 330kV transmission grid with an intelligent based SSVC= 1.8%

To find percentage improvement in the reduction of Transformer Failure Rate causes of contingency challenges in Nigerian 330kV transmission grid with an intelligent based SSVC

Conventional Transformer Failure Rate=22%

Intelligent based SSVC Transformer Failure Rate=19.8 %

% improvement in the reduction of Transformer Failure Rate causes of contingency challenges in Nigerian 330kV transmission grid with an intelligent based SSVC=

Conventional Transformer Failure Rate - Intelligent based SSVC Transformer Failure Rate

% improvement in the reduction of Transformer Failure Rate causes of contingency challenges in Nigerian 330kV transmission grid with an intelligent based SSVC=

22% - 19.8 %

% improvement in the reduction of Transformer Failure Rate causes of contingency challenges in Nigerian 330kV transmission grid with an intelligent based SSVC= 2.2%

RESULTS

Table 3 comparison of conventional and intelligent based SSVC Voltage Deviation that causes contingency challenges in Nigerian 330kV transmission grid

Time (s)	Conventional Voltage Deviation that causes contingency challenges in Nigerian 330kV transmission grid (%)	Intelligent based SSVC Voltage Deviation that causes contingency challenges in Nigerian 330kV transmission grid (%)
1	32	28.7
2	32	28.7
3	32	28.7
4	32	28.7
10	32	28.7

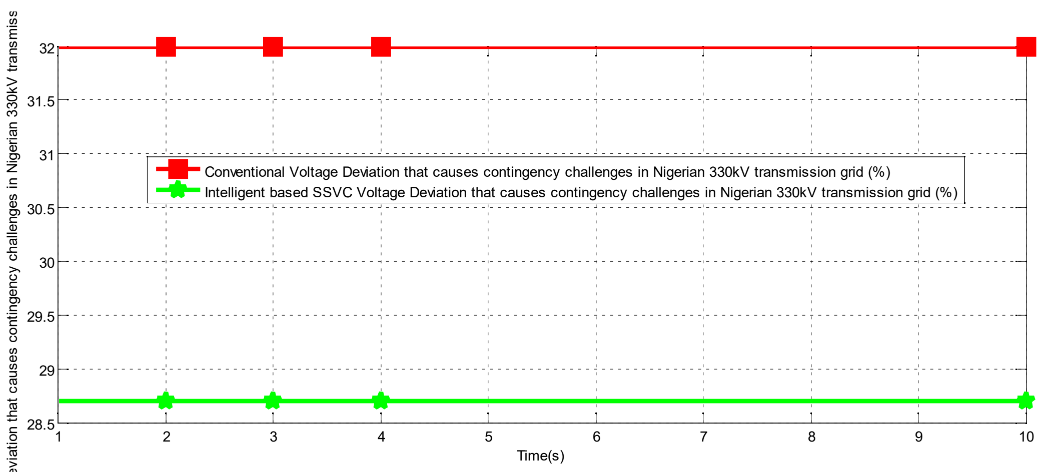

Fig 10 comparison of conventional and intelligent based SSVC Voltage Deviation that causes contingency challenges in Nigerian 330kV transmission grid

The conventional Voltage Deviation that causes contingency challenges in Nigerian 330kV transmission grid was 32%. On the other hand, when an intelligent based SSVC was integrated into the system, it drastically reduced it to28.7%.

Table 4 comparison of conventional and intelligent based SSVC Frequency Deviation that causes contingency challenges in Nigerian 330kV transmission grid

Time (s)	Conventional Frequency Deviation that causes contingency challenges in Nigerian 330kV transmission grid (%)	Intelligent based SSVC Frequency Deviation that causes contingency challenges in Nigerian 330kV transmission grid (%)
1	18	16.2
2	18	16.2
3	18	16.2
4	18	16.2

10	18	16.2

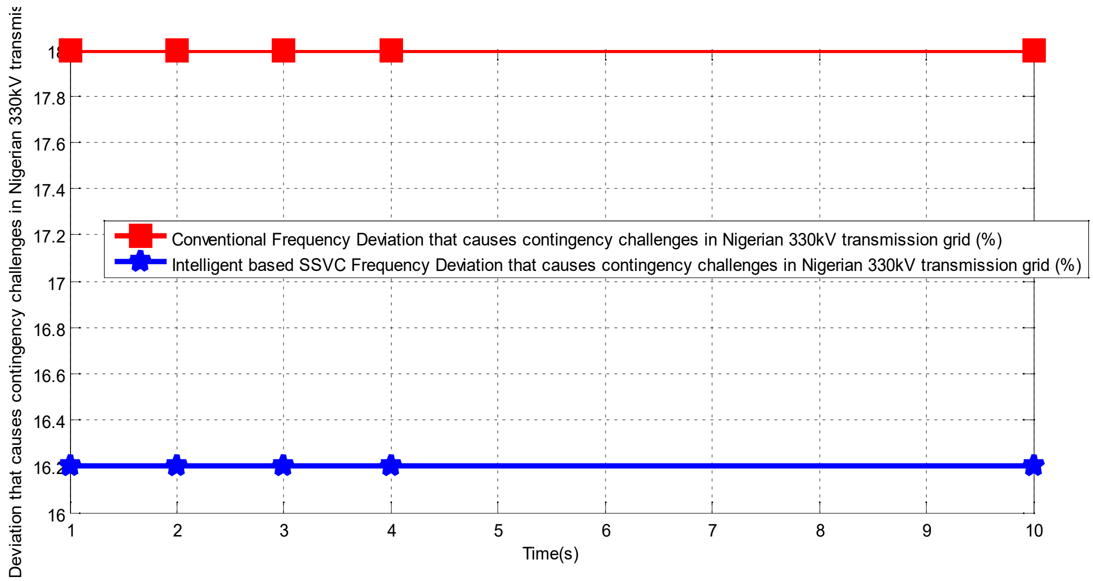

Fig 11 comparison of conventional and intelligent based SSVC Frequency Deviation that causes contingency challenges in Nigerian 330kV transmission grid

The conventional Frequency Deviation that causes contingency challenges in Nigerian 330kV transmission grid was18%. Meanwhile, when an and intelligent based SSVC was input into the system, it decisively reduced it to16.2%.

Table 5 comparison of conventional and intelligent based SSVC Transformer Failure Rate that causes contingency challenges in Nigerian 330kV transmission grid

Time (s)	Conventional Transformer Failure Rate that causes contingency challenges in Nigerian 330kV transmission grid (%)	Intelligent based SSVC Transformer Failure Rate that causes contingency challenges in Nigerian 330kV transmission grid (%)
1	22	19.8
2	22	19.8
3	22	19.8
4	22	19.8
10	22	19.8

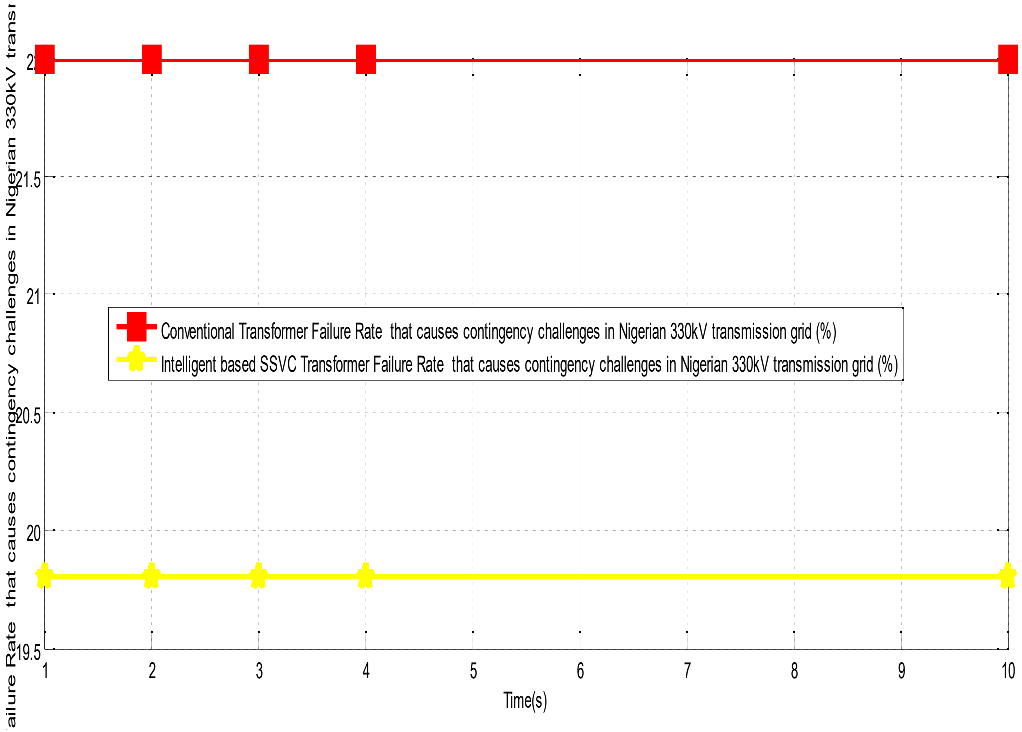

Fig 12 comparison of conventional and intelligent based SSVC Transformer Failure Rate that causes contingency challenges in Nigerian 330kV transmission grid

The conventional Transformer Failure Rate that causes contingency challenges in Nigerian 330kV transmission grid was22%. On the other hand, when an intelligent based SSVC was imbibed into the system, it concurrently reduced it to19.8 %. Finally, with these results obtained, it definitely showed that the percentage improvement in contingency evaluation in Nigerian 330KV transmission grid when an intelligent based SSVC was integrated in the system was2.2%.

CONCLUSION

This study on *Improving Contingency Evaluation in Nigerian 330KV Transmission Grid Using Intelligent-Based Static Synchronous Voltage Compensator (SSVC)* successfully demonstrated the effectiveness of integrating intelligent control techniques to enhance the grid's performance in the face of contingencies. The intelligent SSVC system, driven by advanced algorithms such as Artificial Neural Networks (ANN) and Fuzzy Logic, significantly improved voltage stability, loadability, and the overall reliability of the Nigerian 330kV transmission grid during disturbances. The key findings highlight that the intelligent SSVC system not only provided faster and more efficient responses to grid contingencies but also outperformed traditional methods in terms of system efficiency, flexibility, and fault mitigation. Its ability to autonomously adjust to varying grid conditions and proactively mitigate risks ensured a more resilient power transmission system. Moreover, the study underscored the economic benefits of adopting the intelligent SSVC, as it optimized the use of existing grid infrastructure, reduced operational costs, and minimized the need for costly upgrades. While the implementation of the intelligent SSVC system poses some challenges, including computational complexity and data reliability concerns, the long-term benefits in terms of system stability, fault resilience, and economic optimization outweigh these limitations. This research provides valuable insights into the potential of intelligent-based technologies to modernize power grids and enhance their ability to cope with dynamic operating conditions and unforeseen disturbances. In conclusion, the intelligent-based SSVC presents a promising solution for improving contingency evaluation in the Nigerian 330kV transmission grid, contributing to a more stable, efficient, and secure power system. Further research and development are necessary to refine the system's algorithms, reduce its computational demands, and explore its integration with other smart grid technologies, ensuring its broad applicability for future grid modernization initiatives. The conventional Voltage Deviation that causes contingency challenges in Nigerian 330kV transmission grid was 32%. On the other hand, when an intelligent based SSVC was integrated into the system, it drastically reduced it to28.7% and The conventional Transformer Failure Rate that causes contingency challenges in Nigerian 330kV transmission grid was22%. On the other hand, when an intelligent based SSVC was imbibed into the system, it concurrently reduced it to19.8 %. Finally, with these results obtained, it definitely showed that the percentage improvement in contingency evaluation in Nigerian 330KV transmission grid when an intelligent based SSVC was integrated in the system was2.2%.

REFERENCES

Adoghe, A. U., Odiase, I. A., & Igbinovia, S. O. (2019). A probabilistic approach to contingency analysis in power systems. *International Journal of Electrical Power & Energy Systems, 104*, 784-793.

Babatunde, O. M., & Ojo, J. A. (2022). Enhancing voltage stability using intelligent-based FACTS devices. *Journal of Power Systems Engineering, 15*(2), 135-150.

Eke, J. O., Nwankwo, C. I., & Okafor, C. S. (2021). Application of artificial intelligence in reactive power compensation for power system stability. *Electric Power Components and Systems, 49*(10), 850-867.

Okedu, K. E., Adepoju, G. A., & Yusuf, A. (2020). Power system contingency analysis and reliability assessment: A case study of Nigeria's transmission network. *IEEE Transactions on Power Systems, 35*(6), 4523-4531.