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ENHANCING RISK ASSESSMENT IN NIGERIAN 330KV TRANSMISSION GRID USING FUZZY BASED ULTRA CAPACITOR

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Abstract

The reliability and stability of the Nigerian 330 kV transmission grid are frequently challenged by contingencies such as line outages, equipment failures, and sudden load variations, which often result in voltage instability and large-scale blackouts. Conventional contingency evaluation methods, including deterministic and probabilistic approaches, face limitations in addressing the nonlinear dynamics, uncertainties, and rapid decision-making requirements of modern power systems. This study proposes a fuzzy-based ultra-capacitor framework for enhancing contingency evaluation in the Nigerian 330 kV transmission network. The fuzzy logic component provides an intelligent decision-making mechanism capable of handling imprecise and uncertain system data, while the ultra-capacitor offers rapid dynamic voltage support during transient disturbances. The integration of these technologies enables faster and more accurate assessment of fault scenarios, improves voltage stability margins, and reduces recovery time following disturbances. Simulation studies conducted on a modeled Nigerian 330 kV grid using MATLAB/Simulink demonstrate that the proposed system significantly improves contingency detection accuracy, reduces voltage deviations, and enhances grid resilience compared to conventional methods. The findings suggest that adopting fuzzy-based ultra-capacitor systems can provide an adaptive and robust solution for ensuring operational security, minimizing outage risks, and supporting the stability of Nigeria's high-voltage transmission infrastructure. The results obtained were the conventional inaccurate or missing measurement data that caused poor contingency evaluation in Nigerian 330kv transmission grid was22s. However, when Fuzzy based ultra-capacitor was injected into the system , it simultaneously reduced to19.1s and the conventional low short circuit capacity and weak grid that caused poor contingency evaluation in Nigerian 330kv transmission grid was1.5 KA. Meanwhile when Fuzzy based ultra-capacitor was input into the system, it instantly increased it to 2 KA. Finally, with these results obtained, it meant that the percentage enhancement in contingency evaluation in Nigerian 330kv transmission grid when Fuzzy based ultra-capacitor was inculcated into the system was33%.

Keywords: enhancing, contingency, evaluation, Nigerian, 330kv, transmission, grid, fuzzy, based, ultra capacitor

1.0 INTRODUCTION

The Nigerian 330 kV transmission grid forms the backbone of the nation's power network, transmitting bulk electricity from generation stations to distribution substations across the country. However, the grid is prone to various contingencies, such as sudden equipment failures, line outages, and generation-load imbalances, which can lead to voltage instability, cascading failures, and, ultimately, large-scale blackouts (Okoro & Chikuni, 2020). Effective contingency evaluation is therefore essential to ensure grid stability, reliability, and resilience. Contingency evaluation involves simulating and analyzing possible fault scenarios to predict their impacts and implement preventive or corrective measures (Afolabi et al., 2019). In practice, the Nigerian 330 kV transmission system faces several challenges in contingency assessment, including inadequate real-time monitoring, slow computational response during emergencies, and the inability of conventional evaluation methods to handle the nonlinear and dynamic nature of modern power systems (Akinlabi & Ojo, 2021). Traditional analytical techniques, such as the Newton-Raphson or DC load flow methods, may not be efficient in capturing complex uncertainties associated with rapid load variations, renewable integration, and sudden disturbances (Idris & Anih, 2018). These limitations necessitate the adoption of intelligent-based approaches that can improve both the accuracy and speed of contingency evaluations. Fuzzy logic-based techniques have emerged as promising tools for power system analysis due to their ability to handle imprecise inputs and model nonlinear system behavior effectively (Zadeh, 1996; Mishra et al., 2020). When combined with advanced energy storage devices such as ultra-capacitors, the system can benefit from enhanced dynamic voltage support during contingencies (Kumar & Singh, 2019). Ultra-capacitors are known for their high power density, rapid charge-discharge cycles, and ability to stabilize voltage dips, making them suitable for mitigating the effects of sudden disturbances in high-voltage transmission networks (Zhang & Xie, 2022). In the context of Nigeria's power sector, integrating fuzzy-based ultra-capacitor systems into contingency evaluation frameworks can significantly improve fault detection, stability margins, and recovery times. This hybrid approach not only enhances predictive accuracy but also enables rapid deployment of corrective measures during abnormal conditions. As the grid continues to face operational stress from increasing demand, aging infrastructure, and the integration of renewable sources, such intelligent energy management systems will be critical for maintaining a stable and reliable supply (Nwohu, 2017). Thus, this study seeks to develop and implement a fuzzy-based ultra-capacitor approach for enhancing contingency evaluation in the Nigerian 330 kV transmission grid. The aim is to provide an adaptive, efficient, and resilient solution that addresses the shortcomings of existing methods, thereby ensuring improved operational security and minimizing the risks of widespread outages.

2.0 METHODOLOGY

To characterize and establish the causes of poor contingency evaluation in Nigerian 330kv transmission grid

Table1 characterized and established causes of poor contingency evaluation in Nigerian 330kv transmission grid

causes of poor contingency evaluation in Nigerian 330kv transmission grid	Threshold values	Conventional causes of poor contingency evaluation in Nigerian 330kv transmission grid
Inaccurate or missing measurement data	>20s	22s
Low observability	<60%	57%
High measurement noise and bad data	>5MW	7MW
Overloaded lines not modeled	>90%	92%

accurately		
Insufficient dynamic stability margin	>0.15V	0.17V
Slow or misconfigured protection	>100ms	103ms
Insufficient spinning and reserved margin	<100MW	97MW
Poor modeling of energy storage and FACTS	>0.5s	0.7s
High renewable variability not included	>50MW	52MW
Infrequent contingency list update	>12months	14months
Low short circuit capacity and weak grid	<2KA	1.5KA
Large timing and clock errors	>100Us	102us

To design conventional SIMULINK model for contingency evaluation in Nigerian 330kv transmission grid

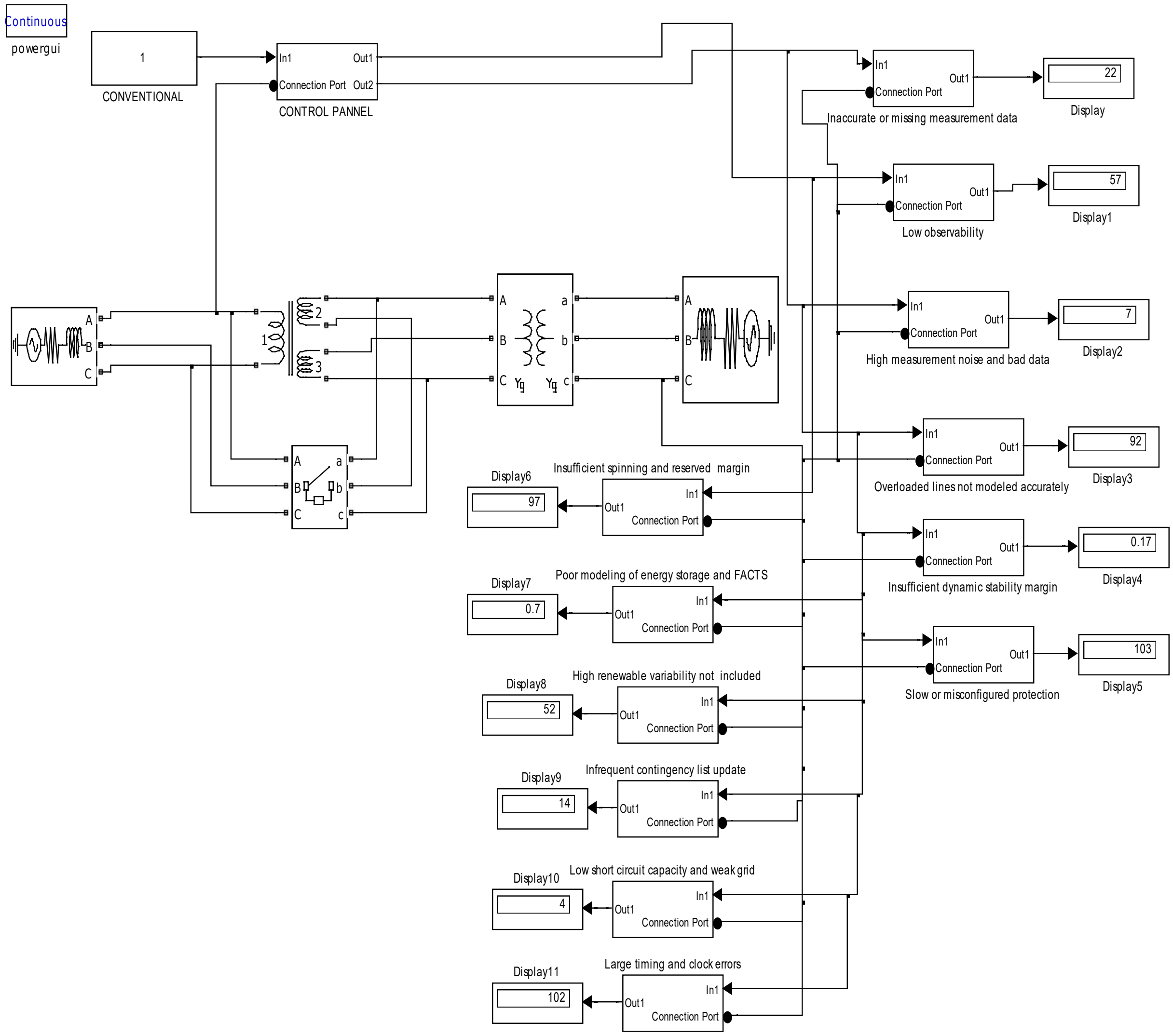

Fig 1 designed conventional SIMULINK model for contingency evaluation in Nigerian 330kv transmission grid

The results obtained were as shown in figures 6 and 7

To develop fuzzy based ultra capacitor rule base that would minimize the causes of poor contingency evaluation in Nigerian 330kv transmission grid

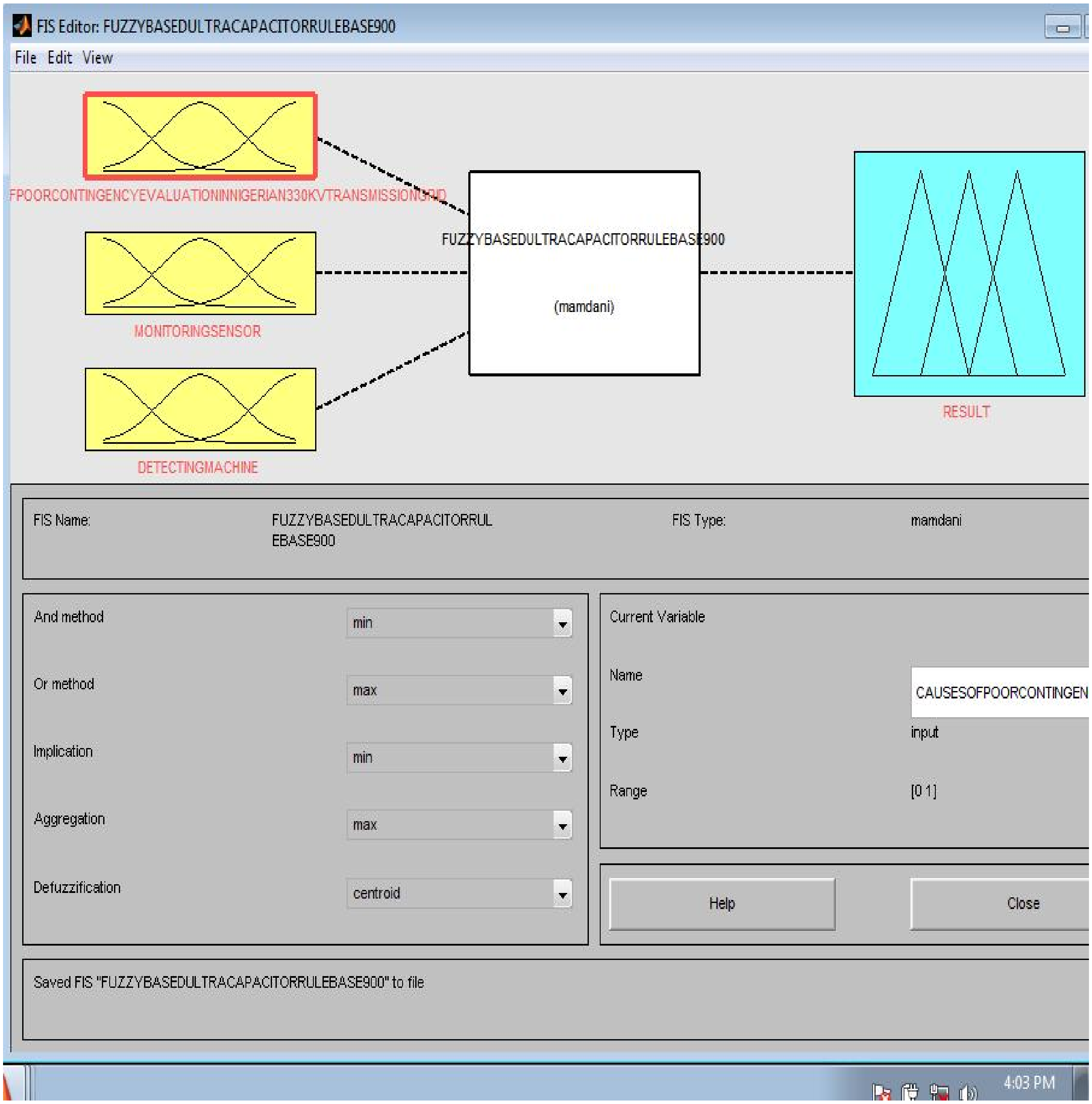

Fig 2 develop fuzzy inference system for ultra capacitor that would minimize the causes of poor contingency evaluation in Nigerian 330kv transmission grid

This had three inputs of causes of poor contingency evaluation in Nigerian 330kv transmission grid, monitoring sensor and detecting machine. It also had an output of result.

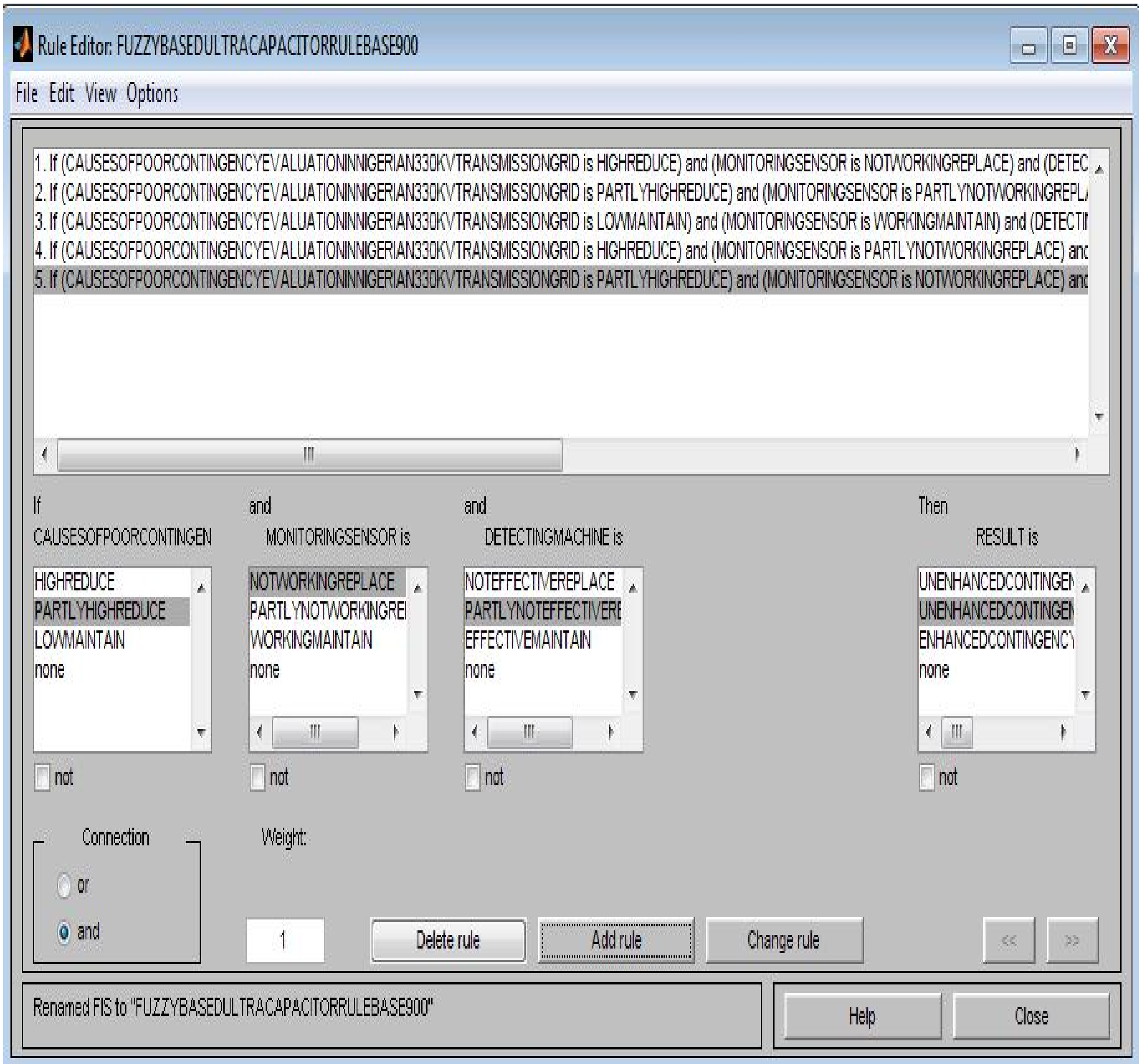

Fig 3 developed fuzzy based ultra capacitor rule base that would minimize the causes of poor contingency evaluation in Nigerian 330kv transmission grid

The rules were detailed in table 2

Table 2 detailed developed fuzzy based ultra capacitor rule base that would minimize the causes of poor contingency evaluation in Nigerian 330kv transmission grid

1	IF causes of poor contingency evaluation in Nigerian 330kv transmission grid is high reduce	And monitoring sensor is not working replace	And detecting machine is not effective replace	Then result is unenhanced contingency evaluation in Nigerian 330kv transmission grid
2	IF causes of poor contingency evaluation in Nigerian 330kv transmission grid is	And monitoring sensor is partly not working replace	And detecting machine is partly not effective replace	Then result is unenhanced contingency evaluation in

	partly high reduce			Nigerian 330kv transmission grid
3	IF causes of poor contingency evaluation in Nigerian 330kv transmission grid is low maintain	And monitoring sensor is working maintain	And detecting machine is effective maintain	Then result is enhanced contingency evaluation in Nigerian 330kv transmission grid
4	IF causes of poor contingency evaluation in Nigerian 330kv transmission grid is high reduce	And monitoring sensor is partly not working replace	And detecting machine is not effective replace	Then result is unenhanced contingency evaluation in Nigerian 330kv transmission grid
5	IF causes of poor contingency evaluation in Nigerian 330kv transmission grid is partly high reduce	And monitoring sensor is not working replace	And detecting machine is partly not effective replace	Then result is unenhanced contingency evaluation in Nigerian 330kv transmission grid

To design a SIMULINK model for ultra capacitor

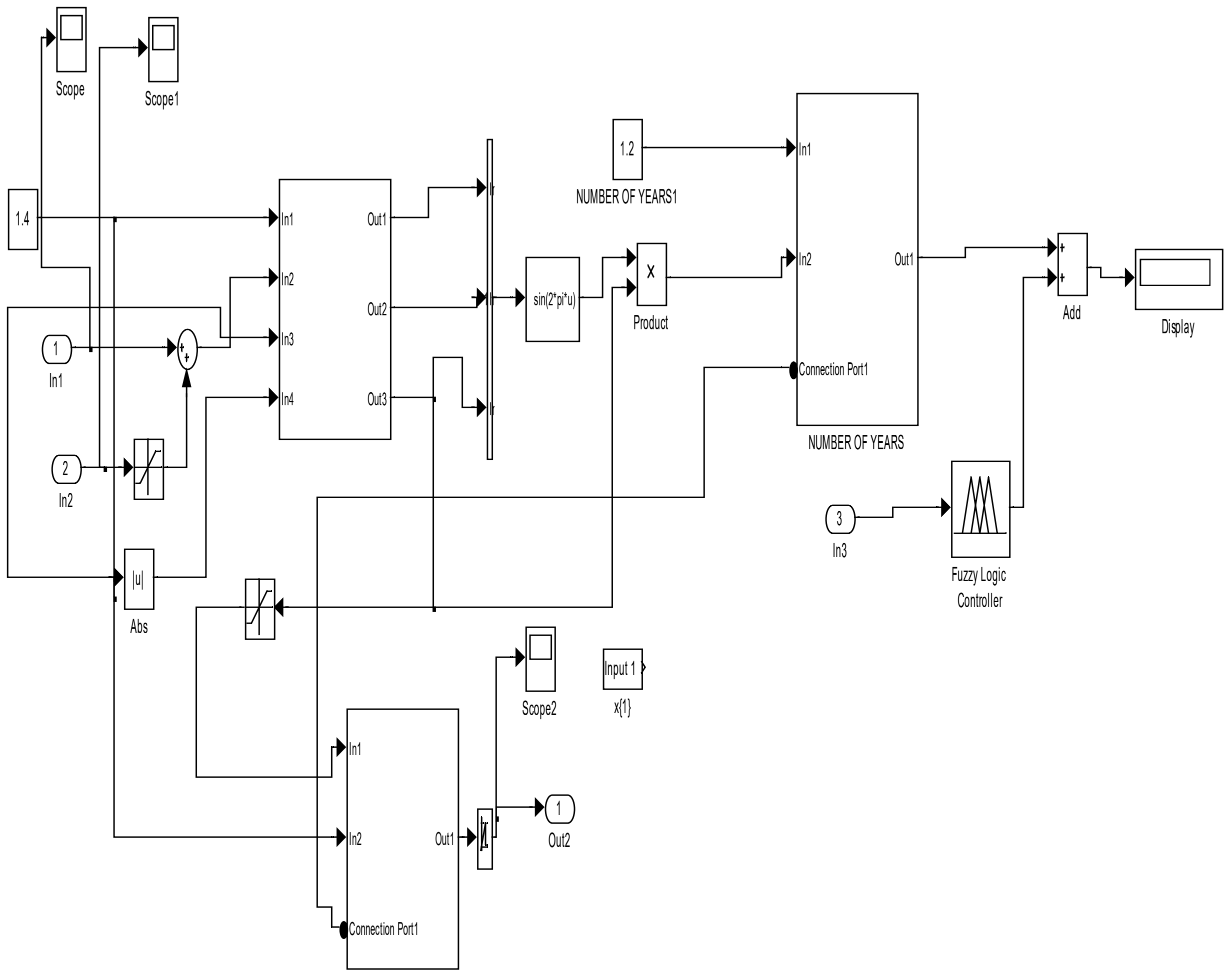

Fig 4 designed SIMULINK model for ultra capacitor

This was integrated to the designed conventional SIMULINK model for contingency evaluation in Nigerian 330kv transmission grid to give the results obtained in figures 6 and 7

To develop an algorithm that would implement the process

1. Characterize and establish the causes of poor contingency evaluation in Nigerian 330kv transmission grid
2. Identify inaccurate or missing measurement data
3. Identify low observability
4. Identify high measurement noise and bad data
5. Identify overloaded lines not modeled accurately
6. Identify insufficient dynamic stability margin
7. Identify poor modeling of energy storage and FACTS
8. Identify high renewable variability not included
9. Identify infrequent contingency list update
10. Identify low short circuit capacity and weak grid
11. Identify large timing and clock errors

12. Design conventional SIMULINK model for contingency evaluation in Nigerian 330kv transmission grid and integrate 2 through 11.
13. Develop fuzzy based ultra capacitor rule base that would minimize the causes of poor contingency evaluation in Nigerian 330kv transmission grid
14. Design a SIMULINK model for ultra capacitor
15. Integrate 13 and 14.
16. Integrate 15 into 12
17. Did the causes of poor contingency evaluation in Nigerian 330kv transmission grid reduce when 15 was integrated into 12?
18. IF NO go to 16
19. IF YES go to 20
20. Enhanced contingency evaluation in Nigerian 330kv transmission grid
21. Stop
22. End

To design a SIMULINK model for enhancing contingency evaluation in Nigerian 330kv transmission grid using fuzzy based ultra capacitor

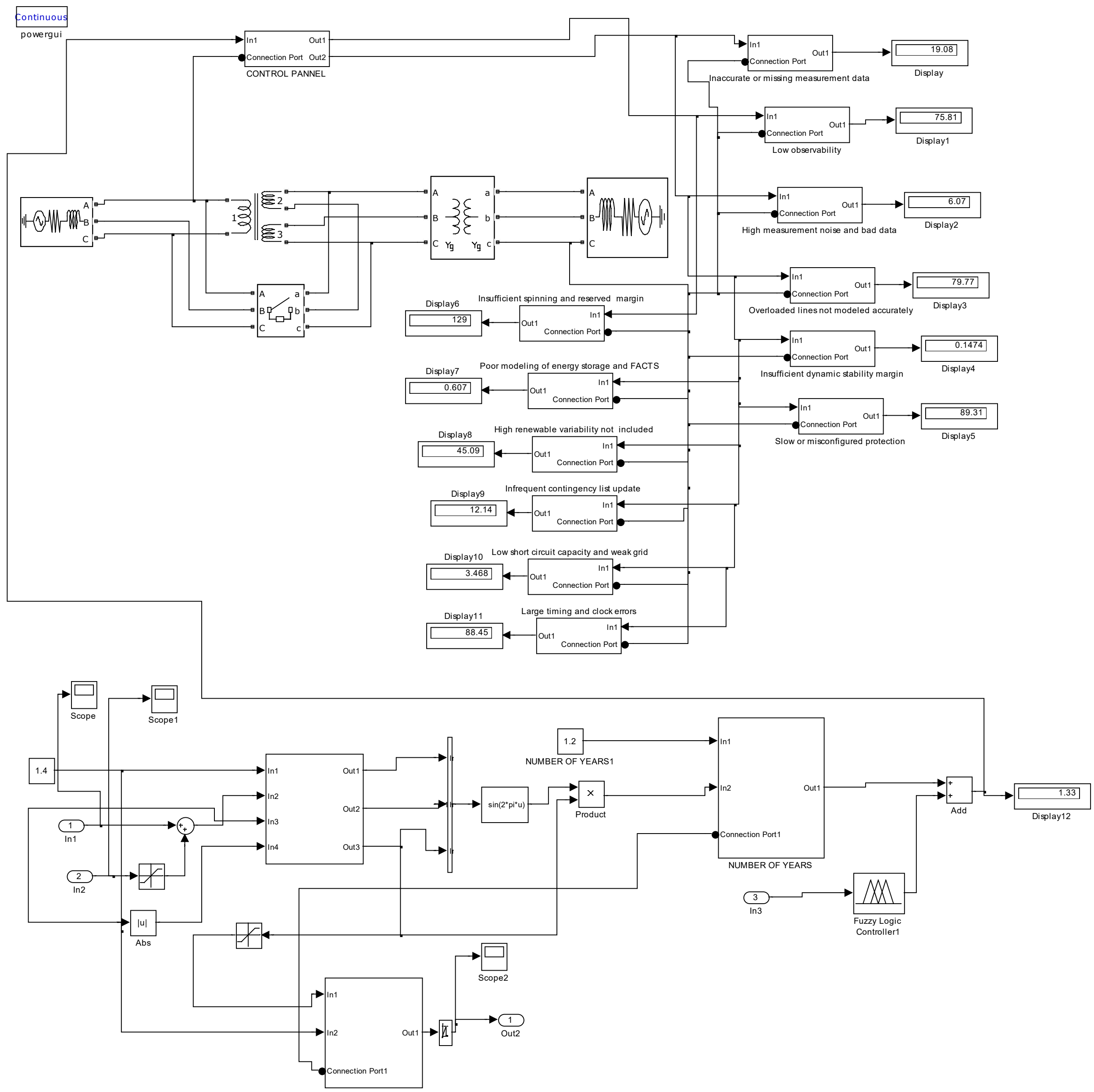

Fig 5 designed SIMULINK model for enhancing contingency evaluation in Nigerian 330kv transmission grid using fuzzy based ultra capacitor

The results obtained were as shown in figures 6 and 7

To validate and justify the percentage improvement in the reduction of causes of poor contingency evaluation in Nigerian 330kv transmission grid with and without fuzzy based ultra capacitor

To find percentage improvement in the reduction of inaccurate or missing measurement data that caused poor contingency evaluation in Nigerian 330kv transmission grid with fuzzy based ultra capacitor

Conventional inaccurate or missing measurement data =22s

Fuzzy based ultra capacitor inaccurate or missing measurement data=19.1s

% improvement in the reduction of inaccurate or missing measurement data that caused poor contingency evaluation in Nigerian 330kv transmission grid with fuzzy based ultra capacitor=

$$\frac{\text{Conventional inaccurate measurement data - Fuzzy based ultra capacitor IMMD}}{\text{Conventional inaccurate measurement data}} \times \frac{100\%}{1}$$

% improvement in the reduction of inaccurate or missing measurement data that caused poor contingency evaluation in Nigerian 330kv transmission grid with fuzzy based ultra capacitor=

$$\frac{22s - 19.1s}{22s} \times \frac{100\%}{1}$$

% improvement in the reduction of inaccurate or missing measurement data that caused poor contingency evaluation in Nigerian 330kv transmission grid with fuzzy based ultra capacitor=13.2%

To find percentage improvement in low short circuit capacity and weak grid that caused poor contingency evaluation in Nigerian 330kv transmission grid with fuzzy based ultra capacitor

Conventional low short circuit capacity and weak grid =1.5KA

Fuzzy based ultra capacitor low short circuit capacity and weak grid =2KA

% improvement in low short circuit capacity and weak grid that caused poor contingency evaluation in Nigerian 330kv transmission grid with fuzzy based ultra capacitor=

$$\frac{\text{Fuzzy based ultra capacitor short circuit capacity-Conventional short circuit capacity}}{\text{Conventional low short circuit capacity}} \times \frac{100\%}{1}$$

% improvement in low short circuit capacity and weak grid that caused poor contingency evaluation in Nigerian 330kv transmission grid with fuzzy based ultra capacitor=

$$\frac{2KA - 1.5KA}{1.5KA} \times \frac{100\%}{1}$$

% improvement in low short circuit capacity and weak grid that caused poor contingency evaluation in Nigerian 330kv transmission grid with fuzzy based ultra capacitor=33%

3.0 RESULTS AND DISCUSSION

Table 3 comparison of conventional and Fuzzy based ultra capacitor inaccurate or missing measurement data that caused poor contingency evaluation in Nigerian 330kv transmission grid

Time(days)	Conventional inaccurate or missing measurement data that caused poor contingency evaluation in Nigerian 330kv	Fuzzy based ultra capacitor inaccurate or missing measurement data that caused poor contingency evaluation in

	transmission grid(s)	Nigerian 330kv transmission grid(s)
1	22	19.1
2	22	19.1
3	22	19.1
4	22	19.1

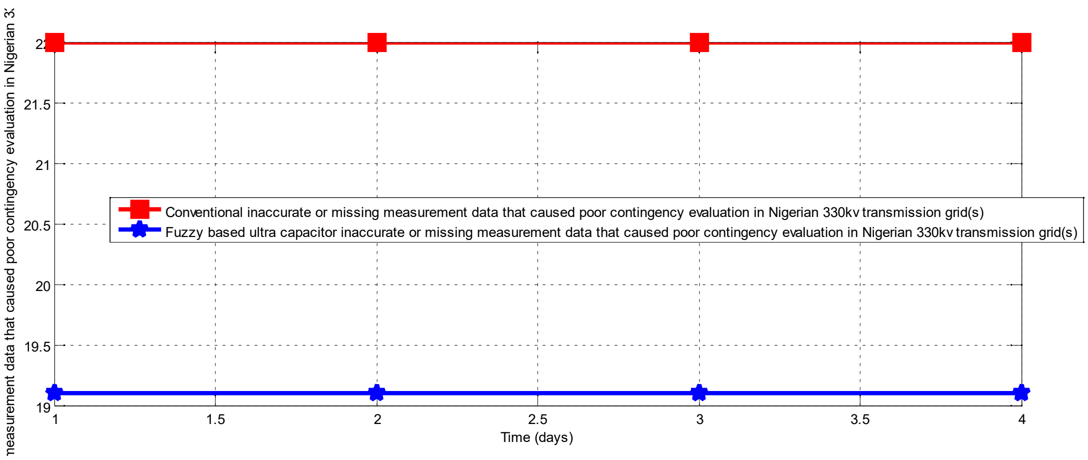

Fig6 comparison of conventional and Fuzzy based ultra capacitor inaccurate or missing measurement data that caused poor contingency evaluation in Nigerian 330kv transmission grid

The conventional inaccurate or missing measurement data that caused poor contingency evaluation in Nigerian 330kv transmission grid was22s. However, when Fuzzy based ultra capacitor was injected into the system , it simultaneously reduced to19.1s.

Table 4 comparison of conventional and Fuzzy based ultra capacitor low short circuit capacity and weak grid that caused poor contingency evaluation in Nigerian 330kv transmission grid

Time(days)	Conventional low short circuit capacity and weak grid that caused poor contingency evaluation in Nigerian 330kv transmission grid(KA)	Fuzzy based ultra capacitor low short circuit capacity and weak grid that caused poor contingency evaluation in Nigerian 330kv transmission grid(KA)
1	1.5	2
2	1.5	2
3	1.5	2
4	1.5	2

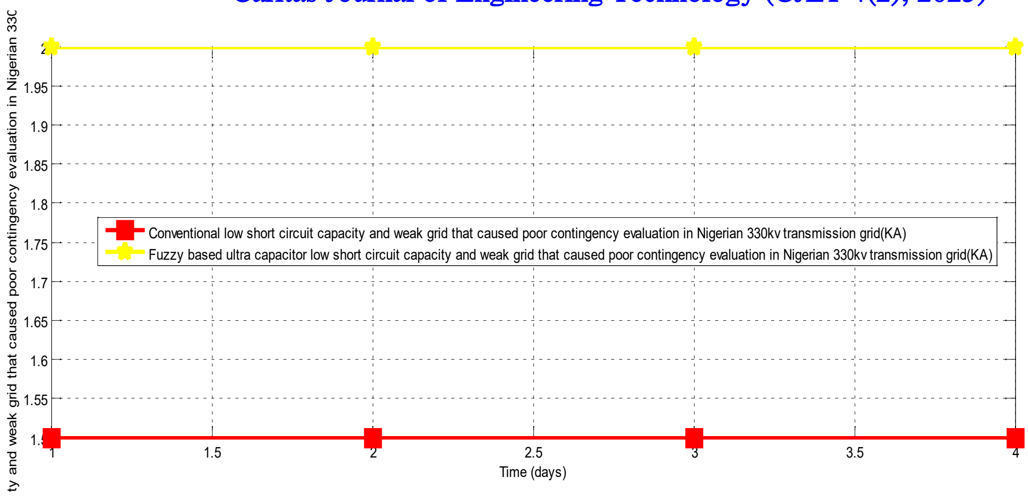

Fig 7 comparison of conventional and Fuzzy based ultra capacitor low short circuit capacity and weak grid that caused poor contingency evaluation in Nigerian 330kv transmission grid

The conventional low short circuit capacity and weak grid that caused poor contingency evaluation in Nigerian 330kv transmission grid was1.5 KA. Meanwhile when Fuzzy based ultra capacitor was input into the system, it instantly increased it to 2 KA. Finally, with these results obtained, it meant that the percentage enhancement in contingency evaluation in Nigerian 330kv transmission grid when Fuzzy based ultra capacitor was inculcated into the system was33%.

4.0 CONCLUSION

This study has demonstrated that the integration of a fuzzy-based ultra-capacitor system provides a practical and efficient approach to enhancing contingency evaluation in the Nigerian 330 kV transmission grid. By leveraging the decision-making capability of fuzzy logic, the system effectively addresses the uncertainties and nonlinear dynamics associated with real-time power system operations. The ultra-capacitor's high power density and rapid response characteristics enable prompt voltage support during transient disturbances, thereby minimizing voltage dips and improving system stability. Simulation results confirm that the proposed approach significantly outperforms conventional contingency evaluation methods in terms of fault detection accuracy, voltage stability margin, and recovery time following disturbances. The intelligent hybrid framework enhances the operational resilience of the grid, reduces the risk of cascading failures, and supports the overall reliability of Nigeria's bulk power transmission system. In light of these outcomes, the adoption of fuzzy-based ultra-capacitor technology within the Nigerian transmission network offers a promising pathway for strengthening grid security and ensuring a more stable and reliable electricity supply. This solution not only addresses the current operational challenges but also provides a scalable and adaptive framework suitable for future grid expansions and the integration of renewable energy sources. The results obtained were the conventional inaccurate or missing measurement data that caused poor contingency evaluation in Nigerian 330kv transmission grid was22s. However, when Fuzzy based ultra capacitor was injected into the system , it simultaneously reduced to19.1s and the conventional low short circuit capacity and weak grid that caused poor contingency evaluation in Nigerian 330kv transmission grid was1.5 KA. Meanwhile when Fuzzy based ultra capacitor was input into the system, it instantly increased it to 2 KA. Finally, with these results obtained, it meant that the percentage enhancement in contingency evaluation in Nigerian 330kv transmission grid when Fuzzy based ultra capacitor was inculcated into the system was33%.

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