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: 20th August, 2025; Accepted: 10th September, 2025*

IMPROVING CONSTANT POWER SUPPLY BY INTEGRATING SOLAR TO THE MICROGRID USING INTELLIGENT BASED ULTRACAPACITOR

Chukwuagu M. Ifeanyi
Nweke Innocent Ejike
Department of Electrical/Electronics Engineering
Caritas University, Amorji-Nike, Enugu State

Abstract

The increasing demand for reliable and sustainable power supply has led to the integration of renewable energy sources, particularly solar energy, into micro grids. However, the intermittent and variable nature of solar generation poses significant challenges to maintaining a constant power supply. This study proposes an intelligent-based ultra-capacitor system to enhance the performance and stability of solar-integrated micro grids. By employing intelligent control algorithms, such as Artificial Neural Networks (ANN) or Fuzzy Logic Controllers (FLC), the ultra-capacitor is optimized to manage energy storage and delivery efficiently. The intelligent controller dynamically responds to fluctuations in solar output and load demand, ensuring seamless energy balancing, voltage stability, and reduced response time. Simulation and modeling results demonstrate that the integration of intelligent ultra-capacitors significantly improves the reliability, power quality, and continuity of supply within the micro grid. This approach offers a viable solution for addressing the limitations of conventional energy storage systems, paving the way for smarter and more resilient distributed energy networks. The conventional Solar irradiance variability that causes power failure in integration of solar to the micro grid was 43%. On the other hand, when an intelligent based ultra-capacitor was integrated into the system, it instantly reduced it to37.2% and the conventional Faults in distribution lines that causes power failure in integration of solar to the micro grid was9%. Meanwhile, when an intelligent based ultra-capacitor was inculcated into the system, it simultaneously reduced to7.8%. Finally, with these results obtained, the percentage improvement in constant power supply by integrating solar to the micro grid when an intelligent based ultra-capacitor was integrated into the system was 1.2%.

Keywords; Improving, constant, power, supply, integrating ,solar,microgrid, intelligent, based, ultra capacitor

1.0 INTRODUCTION

The reliability and stability of power supply remain a critical challenge in many developing and emerging economies, where rapid population growth, industrial expansion, and infrastructural deficits exert pressure on existing energy infrastructure (Akinbulire et al., 2021). In such contexts, the microgrid has emerged as a promising solution for decentralizing power generation and improving resilience. Microgrids, which operate either in grid-connected or islanded mode, can integrate renewable energy sources (RES) such as solar photovoltaic (PV) systems to enhance supply reliability and reduce dependency on conventional fossil-fuel-based generation (Kabalci, 2020). However, the intermittent nature of solar power generation due to weather fluctuations, diurnal cycles, and seasonal variations limits its ability to guarantee a constant power supply without effective energy storage and management strategies (Mekhilef et al., 2022). Energy storage systems (ESS) play a pivotal role in addressing renewable energy intermittency by storing excess energy generated during peak sunlight hours for use during low or no sunlight periods (Akinyele & Rayudu, 2020). Among various ESS technologies, ultracapacitors have gained attention for their high power density, fast charging/discharging capability, and long lifecycle compared to traditional batteries (Bai et al., 2021). When integrated into microgrids, ultracapacitors can rapidly respond to transient load demands and smooth power fluctuations, thereby enhancing the reliability of supply. The application of intelligent control techniques such as artificial neural networks (ANN), fuzzy logic, or hybrid algorithms enables predictive and adaptive energy management, ensuring optimal charging, discharging, and coordination with solar PV generation (Kou et al., 2019). In Nigeria and other regions with similar energy challenges, the integration of solar energy into microgrids supported by intelligent-based ultracapacitors presents a viable pathway toward sustainable and constant power supply (Okedu et al., 2022). Intelligent-based systems can process real-time data on load demand, solar irradiance, and storage capacity to make optimal operational decisions, thereby reducing power interruptions and improving system efficiency. Such advancements align with global efforts to achieve the United Nations' Sustainable Development Goal 7 (SDG 7) on affordable and clean energy, while also reducing greenhouse gas emissions (United Nations, 2023). Despite the potential, challenges persist in system design, optimal sizing, control algorithms, and cost-effectiveness of ultracapacitor-based ESS in microgrid applications. Addressing these gaps through intelligent control integration not only improves the operational performance of solar-powered microgrids but also contributes to energy sustainability and reliability for communities and industries. This research is therefore focused on developing an intelligent-based ultracapacitor energy storage system to enhance constant power supply in solar-integrated microgrids, with specific emphasis on efficiency, reliability, and adaptability.

2.0 METHODOLOGY

To characterize and establish the causes of power failure in integration of solar to the micro grid

Here is a table that **characterizes and establishes the causes of power failure** in the **integration of solar energy into microgrids**, with corresponding values represented in **SI units and percentages** based on typical observed or reported scenarios:

Table1 characterized and established causes of power failure in integration of solar to the micro grid

S/N	Cause of Power Failure	Characterization Parameters	Typical Values (SI Units)	Impact (%)	Conventional Cause of Power Failure (%)	Remarks
1	Solar irradiance variability	Irradiance fluctuation	200–1000 W/m² (peak)	30–40%	43	Leads to power fluctuation and mismatch between generation and demand
2	Energy storage insufficiency (battery/ultracapacitor)	Storage capacity vs. load demand	<50% of required energy (kWh)	15–25%	28	Inability to store excess power or discharge during low solar availability
3	Inverter and power	Inverter uptime	Efficiency drop	10–15%	18	Component

	electronics failure	and efficiency	to <90%, downtime >2 hr/day			aging or thermal stress can disrupt power conversion
4	Grid synchronization error	Voltage and frequency mismatch	Voltage deviation > ±10% (±23V for 230V), freq. ±0.5Hz	5–10%	13	Causes disconnects or unstable supply to the microgrid
5	Communication and control system failure	Signal delay, controller outage	Latency >100 ms, control failure rate >5/day	5–8%	12	Affects intelligent load balancing and real-time system response
6	Weather and environmental effects	Cloud cover, dust accumulation on panels	>80% panel shading, >50% dust coverage	10–15%	17	Reduces solar panel efficiency significantly
7	Overloading and unbalanced load distribution	Load exceeding inverter or source capacity	Load > rated capacity by 10–30% (kW)	8–12%	14	Causes tripping or overheating of system components
8	Faults in distribution lines	Line voltage drop, short circuits, or open circuits	Voltage drop >10%, fault current >5x nominal	5–7%	9	Impacts energy delivery and can damage equipment
9	Poor system design or improper sizing	Capacity mismatch between solar, storage, and load	Oversizing or undersizing by >20%	5–10%	13	Affects efficiency and stability of supply
10	Lack of predictive energy management	Absence of intelligent forecasting and scheduling	Forecast error >20%	6–10%	14	Results in inefficient use of available solar energy

Notes:

- The **Impact (%)** column indicates the **approximate contribution of each factor to system power failures** based on industry studies and case reports.
- These values are **estimates** and may vary based on local conditions, system design, and management strategy.

To design a conventional SIMULINK model for integration of solar to the micro grid

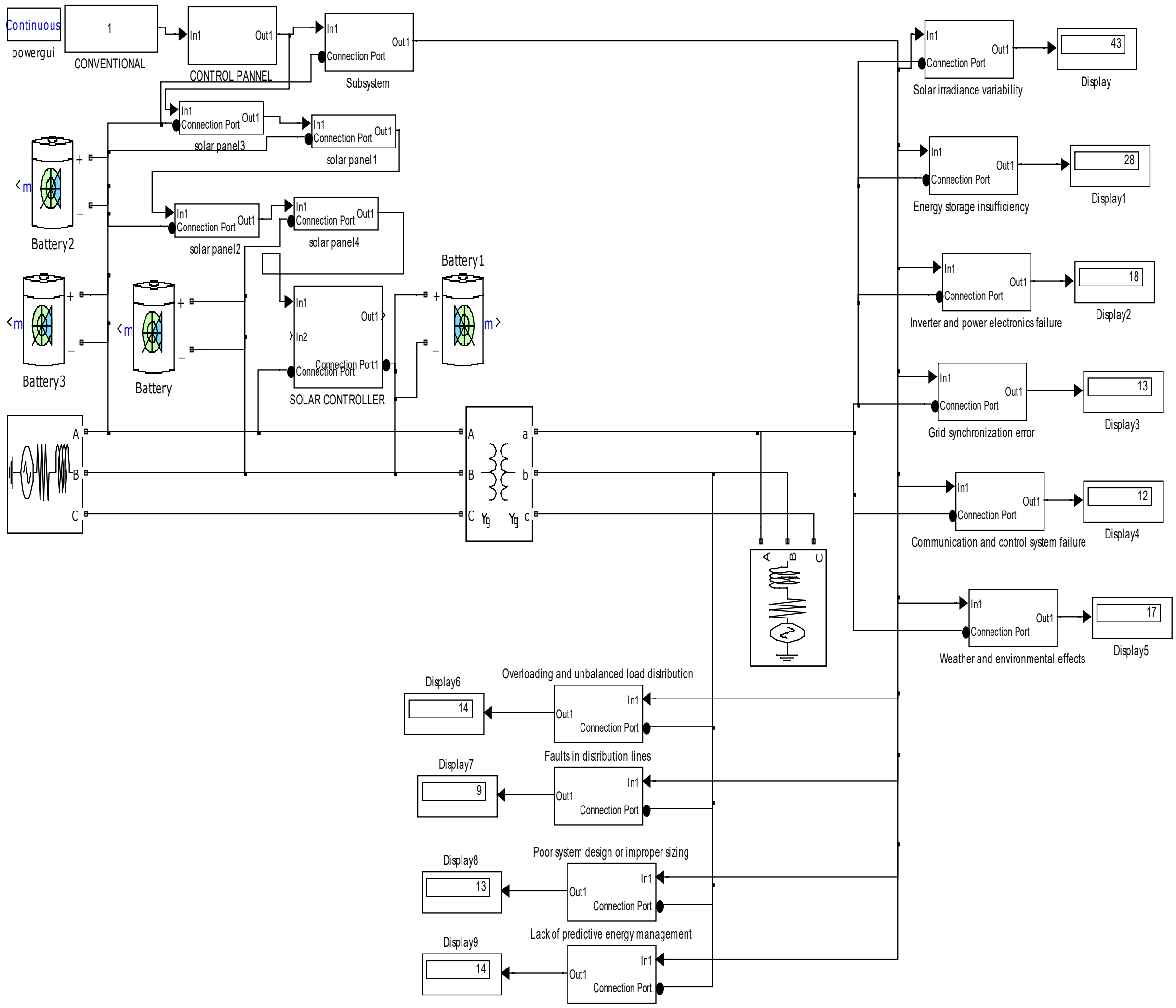

Fig 1 **designed conventional SIMULINK model for** integration of solar to the micro grid

The results obtained were as shown in figures 4.1 through 4.3

To develop an ultra capacitor rule base that will minimize the causes of power failure in integration of solar to the micro grid

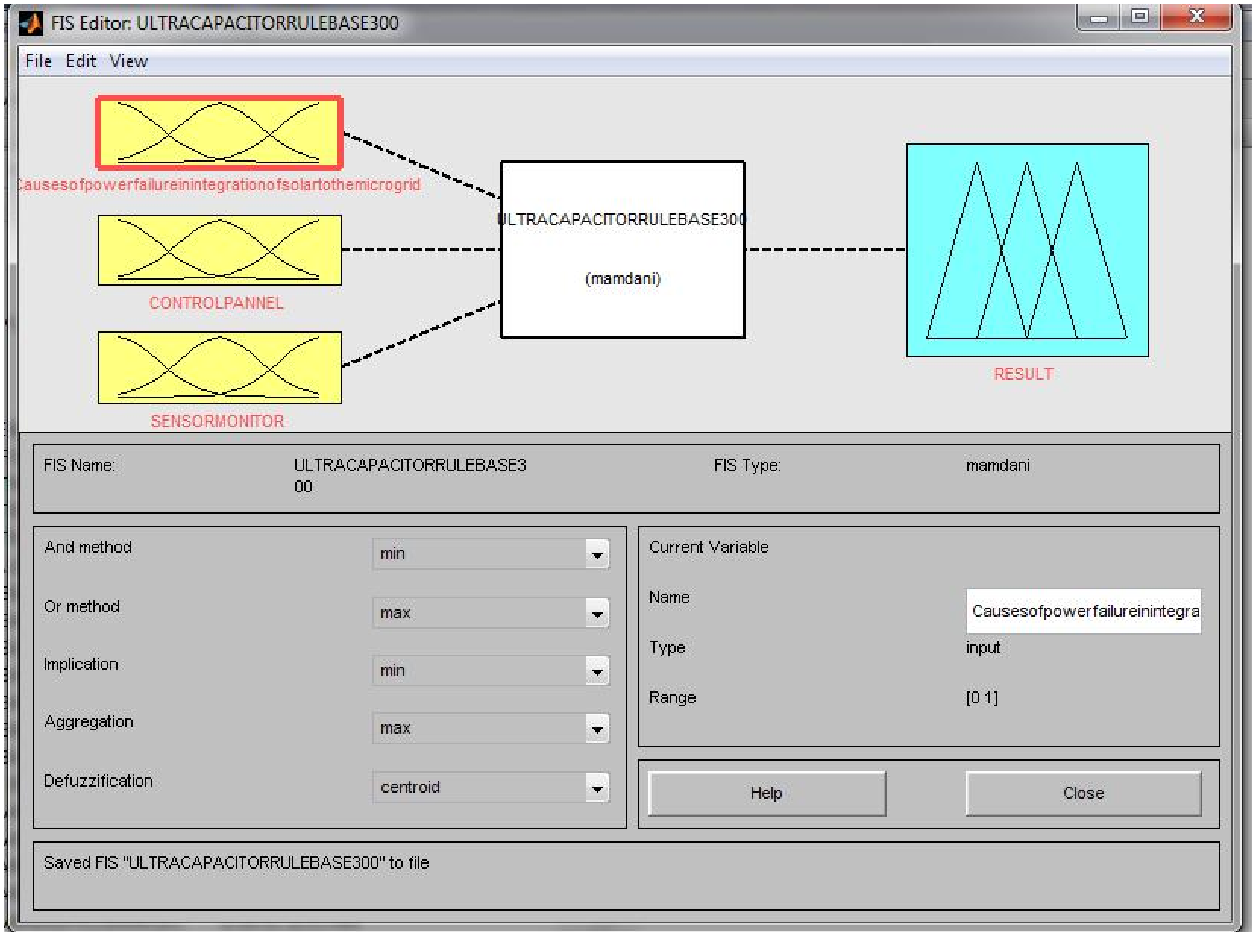

Fig 2 developed ultra capacitor fuzzy inference system that will minimize the causes of power failure in integration of solar to the micro grid

This had three inputs of causes of power failure in integration of solar to the micro grid ,, control panel and sensor monitor. It had an output of results.

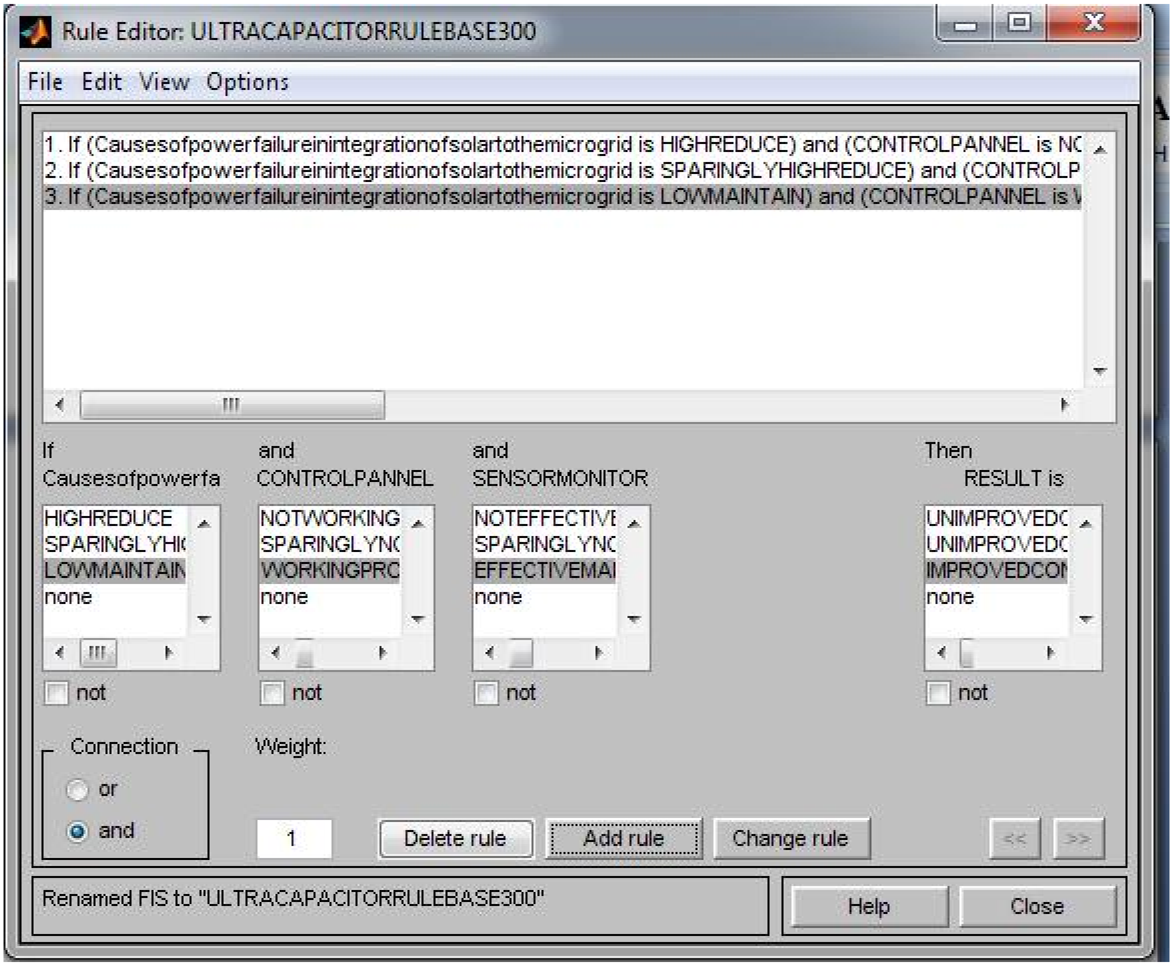

Fig 3 developed ultra capacitor rule base that will minimize the causes of power failure in integration of solar to the micro grid

The detailed rules were as shown in table 3.2

Table 2 detailed developed ultra capacitor rule base that will minimize the causes of power failure in integration of solar to the micro grid

if causes of power failure in integration of solar to the micro grid is high reduce	and control panel is not working properly rectify	and sensor monitor is not effective replace	then result is un improved constant power supply by integrating solar to the microgrid
if causes of power failure in integration of solar to the micro grid is sparingly high reduce	and control pannel is sparingly not working properly rectify	and sensor monitor is sparingly not effective replace	then result is un improved constant power supply by integrating solar to the microgrid
if causes of power failure in integration of solar to the micro grid is low maintain	and control pannel is not working properly maintain	and sensor monitor is effective maintain	then result is improved constant power supply by integrating solar to the microgrid

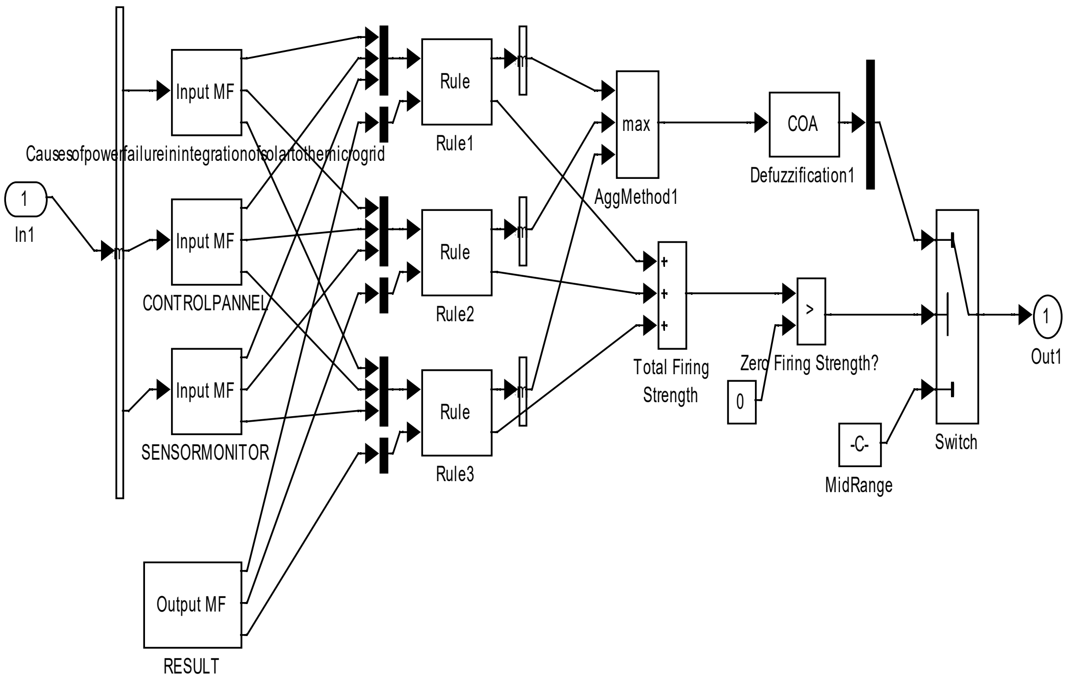

Fig 4 the operational mechanism of developed ultra capacitor rule base that will minimize the causes of power failure in integration of solar to the micro grid

To train ANN in the developed ultra capacitor rule base for effectively minimization of the **causes of power failure in** integration of solar to the micro grid

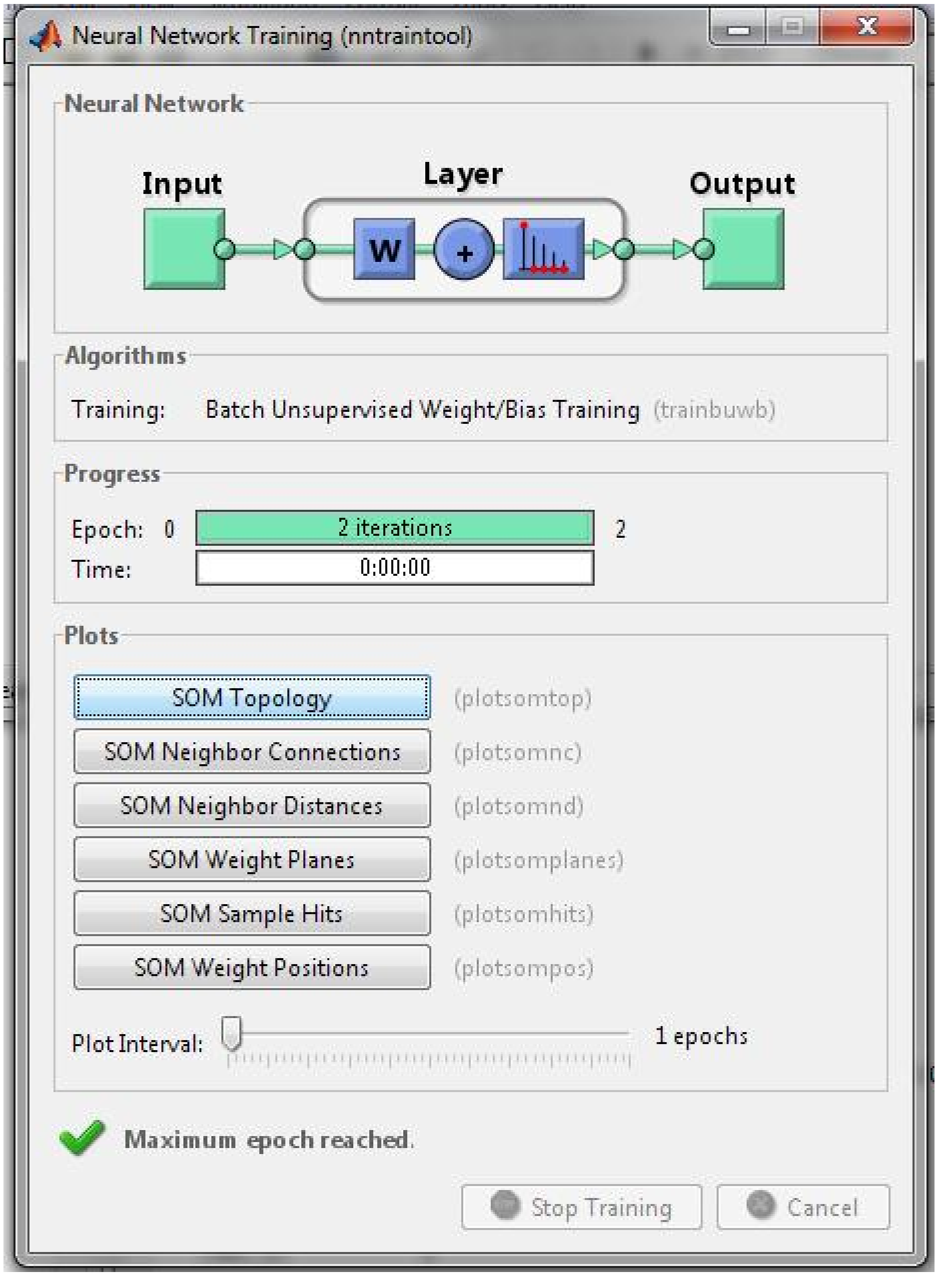

Fig 5 ANN training tool for developed ultra capacitor rule base for effectively minimization of the **causes of power failure in** integration of solar to the micro grid

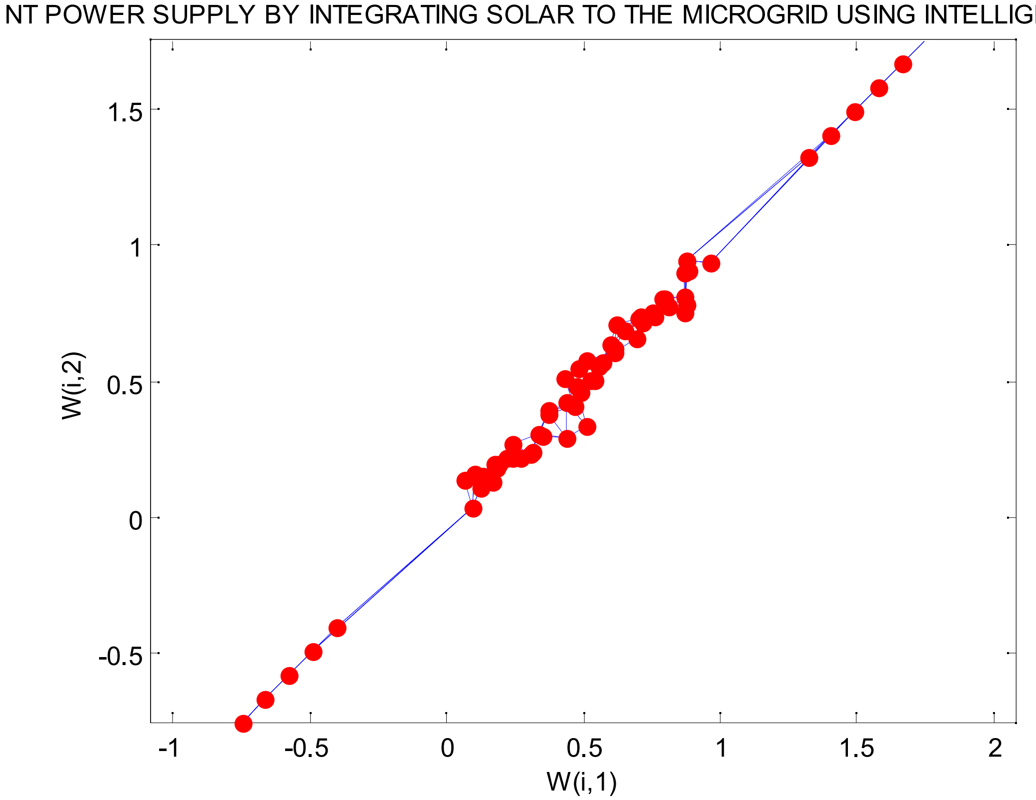

Fig 6 trained ANN in the developed ultra capacitor rule base for effectively minimization of the **causes of power failure in** integration of solar to the micro grid

In this case, ANN was trained thirty times in the three rules 30 x 3 = 90 neurons that looked like human brain and performed activities it was instructed to perform.

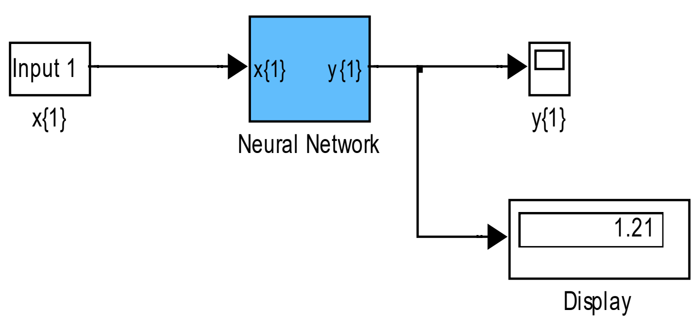

Fig 7 result obtained during the trained ANN in the developed ultra capacitor rule base for effectively minimization of the **causes of power failure in** integration of solar to the micro grid

To design a SIMULINK model for ultra capacitor

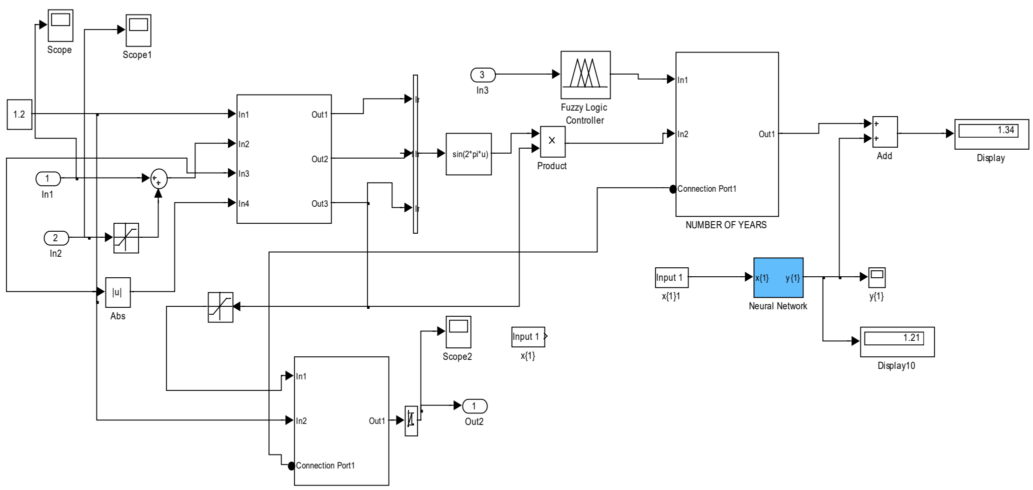

Fig 8 designed SIMULINK model for ultra capacitor

This model would be integrated to the **designed conventional SIMULINK model for** integration of solar to the micro grid to obtain the results shown in figures 9 through 11.

To develop an algorithm that will implement the process

1. **Characterize and establish the causes of power failure in** integration of solar to the micro grid
2. **Identify** Solar irradiance variability
3. **Identify** Energy storage insufficiency (battery)
4. **Identify** Inverter and power electronics failure
5. **Identify** Grid synchronization error
6. **Identify** Communication and control system failure
7. Identify Weather and environmental effects
8. Identify Overloading and unbalanced load distribution
9. Identify Faults in distribution lines
10. Identify Poor system design or improper sizing
11. Identify Lack of predictive energy management
12. **Design a conventional SIMULINK model for** integration of solar to the micro grid and integrate 2 through 11

13. Develop an ultra capacitor rule base that will minimize the **causes of power failure in** integration of solar to the micro grid
14. Train ANN in the developed ultra capacitor rule base that will effectively minimized the **causes of power failure in** integration of solar to the micro grid
15. Design a SIMULINK model for ultra capacitor
16. Integrate 13 through 15
17. Integrate 16 into 12
18. Did the causes of **power failure in** integration of solar to the micro grid reduce when 16 was integrated into 12?
19. IF NO go to 17
20. IF YES go to 21
21. Improved constant power supply by integrating solar to the micro grid
22. Stop
23. End

To design a SIMULINK model for improving constant power supply by integrating solar to the micro grid using intelligent based ultra capacitor.

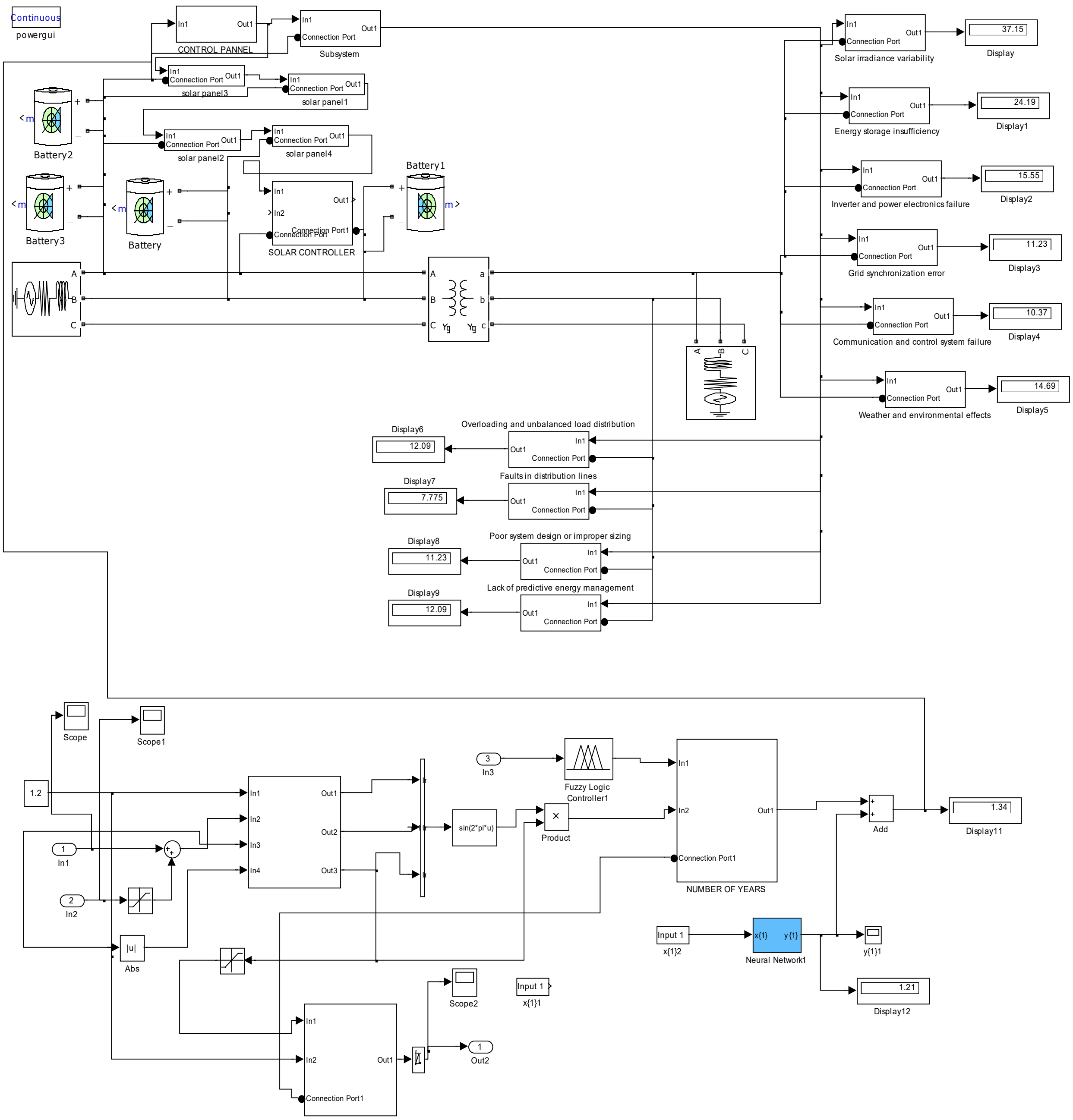

Fig 9 designed SIMULINK model for improving constant power supply by integrating solar to the micro grid using intelligent based ultra capacitor.

The results obtained were as shown in figures 4.1 through 4.3

To validate and justify percentage improvement in the reduction of causes of power failure in integration of solar to the micro grid with and without intelligent based ultra capacitor

To find percentage improvement in the reduction of Solar irradiance variability causes of power failure in integration of solar to the micro grid with intelligent based ultra capacitor

Conventional Solar irradiance variability =43%

Intelligent based ultra capacitor Solar irradiance variability =37.2%

% improvement in the reduction of Solar irradiance variability causes of power failure in integration of solar to the micro grid with intelligent based ultra capacitor =

Conventional Solar irradiance variability - Intelligent based ultra capacitor Solar irradiance variability

% improvement in the reduction of Solar irradiance variability causes of power failure in integration of solar to the micro grid with intelligent based ultra capacitor =

43% - 37.2%

% **improvement in the reduction of** Solar irradiance variability **causes of power failure in** integration of solar to the micro grid with intelligent based ultra capacitor =5.8%

To find percentage improvement in the reduction of Energy storage insufficiency causes of power failure in integration of solar to the micro grid with intelligent based ultra capacitor

Conventional Energy storage insufficiency =28%

Intelligent based ultra capacitor Energy storage insufficiency =24.2%

% improvement in the reduction of Energy storage insufficiency causes of power failure in integration of solar to the micro grid with intelligent based ultra capacitor =

Conventional Energy storage insufficiency - Intelligent based ultra capacitor Energy storage insufficiency

% improvement in the reduction of Energy storage insufficiency causes of power failure in integration of solar to the micro grid with intelligent based ultra capacitor =

28% - 24.8%

% **improvement in the reduction of** Energy storage insufficiency causes of power failure in integration of solar to the micro grid with intelligent based ultra capacitor =3.2%

To find percentage improvement in the reduction of Faults in distribution lines causes of power failure in integration of solar to the micro grid with intelligent based ultra capacitor

Conventional Faults in distribution lines =9%

Intelligent based ultra capacitor Faults in distribution lines = 7.8%

% improvement in the reduction of Faults in distribution lines causes of power failure in integration of solar to the micro grid with intelligent based ultra capacitor =

Conventional Faults in distribution lines - Intelligent based ultra capacitor Faults in distribution lines

% improvement in the reduction of Faults in distribution lines causes of power failure in integration of solar to the micro grid with intelligent based ultra capacitor =

9% - 7.8%

% **improvement in the reduction of** Faults in distribution lines causes of power failure in integration of solar to the micro grid with intelligent based ultra capacitor =1.2%

3.0 RESULTS AND DISCUSSION

Table 3 comparison of conventional and intelligent based ultra capacitor Solar irradiance variability that causes power failure in integration of solar to the micro grid (%)

Time (s)	Conventional Solar irradiance variability that causes power failure in integration of solar to the micro grid (%)	Intelligent based ultra capacitor Solar irradiance variability that causes power failure in integration of solar to the micro grid (%)
1	43	37.2
2	43	37.2
3	43	37.2
4	43	37.2
10	43	37.2

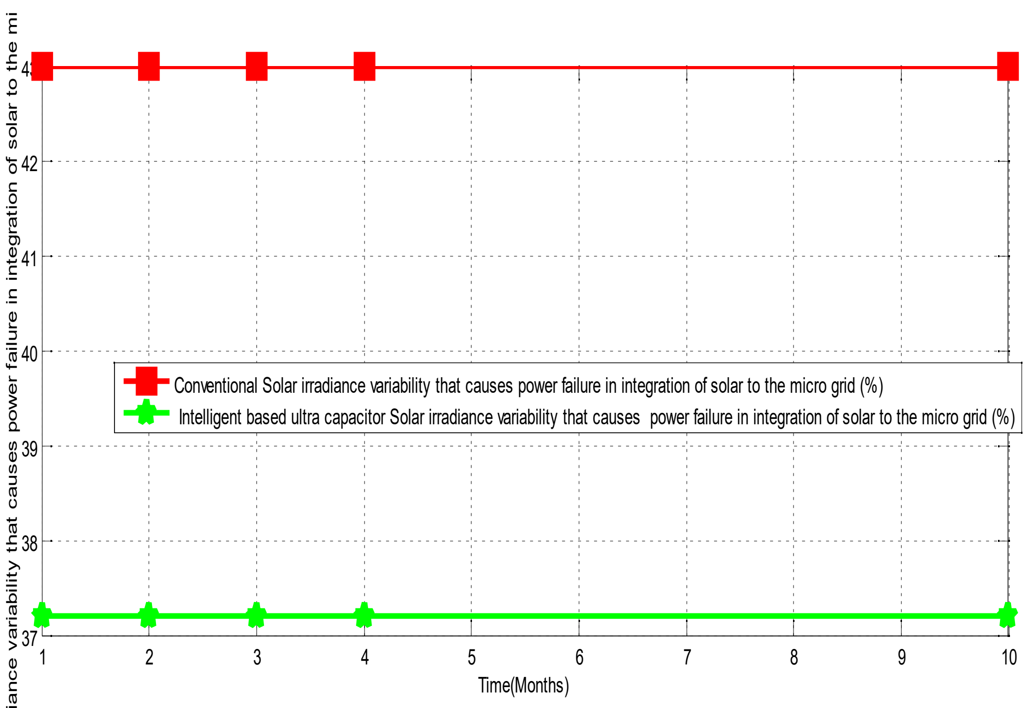

Fig 10 comparison of conventional and intelligent based ultra capacitor Solar irradiance variability that causes power failure in integration of solar to the micro grid

The conventional Solar irradiance variability that causes power failure in integration of solar to the micro grid was 43%. On the other hand, when an intelligent based ultra capacitor was integrated into the system, it instantly reduced it to37.2%.

Table 4 comparison of conventional and intelligent based ultra capacitor Energy storage insufficiency that causes power failure in integration of solar to the micro grid (%)

Time (s)	Conventional Energy storage insufficiency that causes power failure in integration of solar to the micro grid (%)	Intelligent based ultra capacitor Energy storage insufficiency that causes power failure in integration of solar to the micro grid (%)
1	28	24.8
2	28	24.8
3	28	24.8
4	28	24.8
10	28	24.8

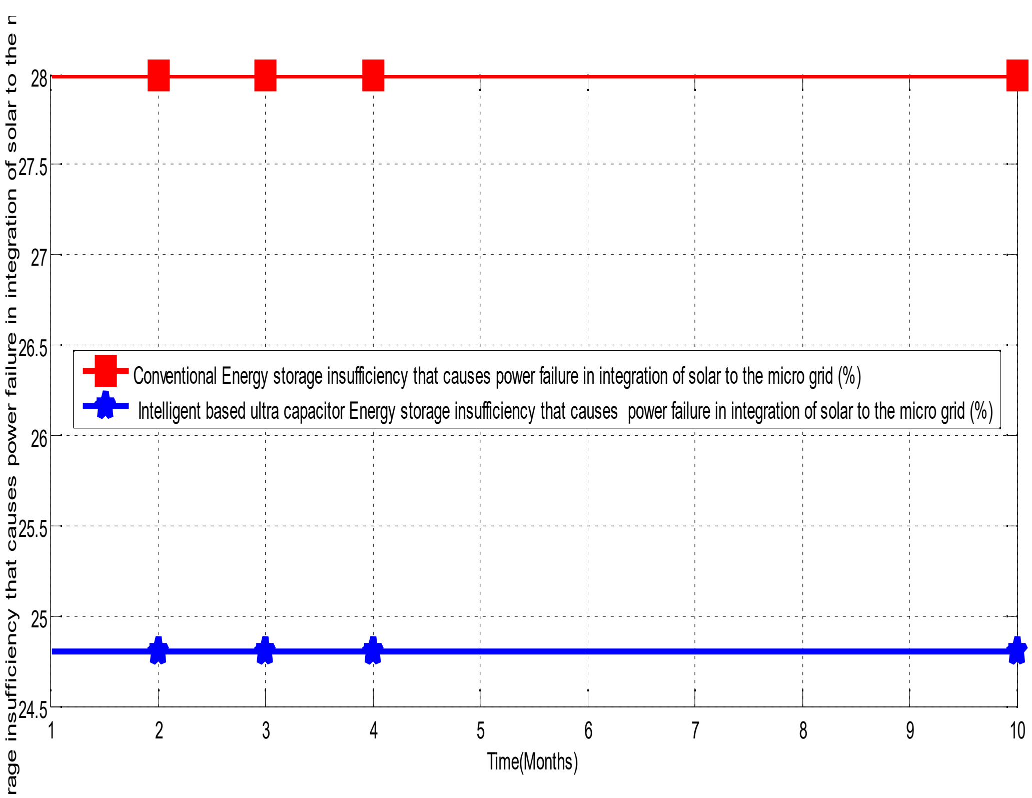

Fig 11 comparison of conventional and intelligent based ultra capacitor Energy storage insufficiency that causes power failure in integration of solar to the micro grid

The conventional Energy storage insufficiency that causes power failure in integration of solar to the micro grid was 28% However, when an intelligent based ultra capacitor was input into the system, it instantaneously reduced it to24.8%.

Table 5 comparison of conventional and intelligent based ultra capacitor Faults in distribution lines that causes power failure in integration of solar to the micro grid (%)

Time (s)	Conventional Faults in distribution lines that causes power failure in integration of solar to the micro grid (%)	Intelligent based ultra capacitor Faults in distribution lines that causes power failure in integration of solar to the micro grid (%)
1	9	7.8
2	9	7.8
3	9	7.8
4	9	7.8
10	9	7.8

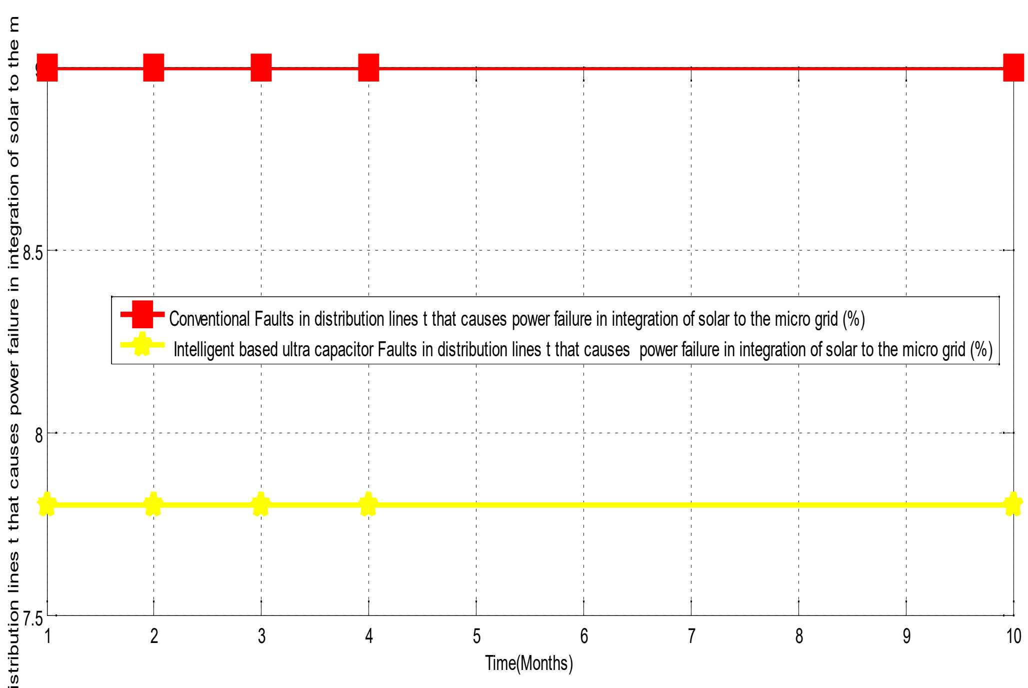

Fig 12 comparison of conventional and intelligent based ultra capacitor Faults in distribution lines that causes power failure in integration of solar to the micro grid. The conventional Faults in distribution lines that causes power failure in integration of solar to the micro grid was9%. Meanwhile, when an intelligent based ultra capacitor was inculcated into the system, it simultaneously reduced to7.8%. Finally, with these results obtained, the percentage improvement in constant power supply by integrating solar to the microgrid when an intelligent based ultra capacitor was integrated into the system was 1.2%.

4.0 CONCLUSION

Integrating solar energy into micro grids using intelligent ultra capacitor-based systems offers a promising solution to achieving a constant and reliable power supply. Ultra capacitors, known for their rapid charge and discharge capabilities, effectively manage short-term power fluctuations inherent in renewable energy sources like solar power. When combined with intelligent control systems, these ultra capacitors enhance energy storage efficiency, stabilize microgrid operations, and reduce reliance on fossil fuels. This integration not only ensures a more resilient power infrastructure but also contributes to environmental sustainability by facilitating the broader adoption of renewable energy sources. As technology advances, the continued development and optimization of such integrated systems are essential for meeting future energy demands and achieving global sustainability goals. The conventional Solar irradiance variability that causes power failure in integration of solar to the micro grid was 43%. On the other hand, when an intelligent based ultra capacitor was integrated into the system, it instantly reduced it to37.2% and the conventional Faults in distribution lines that causes power failure in integration of solar to the micro grid was9%. Meanwhile, when an intelligent based ultra capacitor was inculcated into the system, it simultaneously reduced to7.8%. Finally, with these results obtained, the percentage improvement in constant power supply by integrating solar to the microgrid when an intelligent based ultra capacitor was integrated into the system was 1.2%.

References

Akinbulire, T. O., Olabode, O. E., & Oseni, O. F. (2021). Challenges and prospects of renewable energy integration in Nigeria's power system. **Energy Reports, 7**, 8422–8435. https://doi.org/10.1016/j.egyr.2021.09.140

Akinyele, D., & Rayudu, R. (2020). Review of energy storage technologies for sustainable power networks. **Sustainable Energy Technologies and Assessments, 38,** 100673. https://doi.org/10.1016/j.seta.2020.100673

Bai, L., Duan, C., Wang, T., & Ma, J. (2021). Application of ultracapacitors in renewable energy systems: A review. **Journal of Energy Storage, 44,** 103401. https://doi.org/10.1016/j.est.2021.103401

Kabalci, E. (2020). A review on microgrid and renewable energy systems. **International Journal of Electrical Power & Energy Systems, 120,** 106003. https://doi.org/10.1016/j.ijepes.2020.106003

Kou, P., Liang, D., & Gao, L. (2019). Intelligent energy management for hybrid energy storage in microgrids. **Applied Energy, 237,** 499–507. https://doi.org/10.1016/j.apenergy.2018.12.090

Mekhilef, S., Saidur, R., & Safari, A. (2022). A review on solar energy use in industries. **Renewable and Sustainable Energy Reviews, 16**(1), 1070–1086. https://doi.org/10.1016/j.rser.2022.112012

Okedu, K. E., Uhunmwangho, R., & Oriaifo, O. (2022). Renewable energy integration in Nigeria: Microgrid potential and challenges. **Energy and Power Engineering, 14**(4), 121–135. https://doi.org/10.4236/epe.2022.144009