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ENHANCING CONSTANT POWER SUPPLY BY INTEGRATING SOLAR TO THE MICROGRID USING ANN BASED SUPERCAPACITOR

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Abstract

The quest for a constant and reliable power supply remains a pressing challenge, particularly in regions where conventional grid infrastructure is constrained by generation shortfalls, transmission inefficiencies, and growing energy demand. Solar photovoltaic (PV) systems integrated into micro grids offer a viable pathway toward sustainable energy solutions; however, the intermittent and variable nature of solar power necessitates effective energy storage and management strategies. This study proposes the integration of an artificial neural network (ANN)-based super capacitor energy storage system into a solar-powered microgrid to enhance supply stability, efficiency, and adaptability. The ANN controller is designed to process real-time data on load demand, solar irradiance, and state-of-charge, enabling predictive and adaptive charge–discharge management of the super capacitor. This intelligent approach mitigates the effects of solar generation fluctuations, reduces system losses, and optimizes energy dispatch to maintain a steady power output. Simulation results demonstrate improved voltage stability, reduced downtime, and enhanced energy utilization compared to conventional control methods. The findings highlight the potential of ANN-based super capacitor systems as a robust solution for achieving constant power supply in solar-integrated microgrids, thereby contributing to energy sustainability and supporting the global transition to clean energy. The results obtained were the conventional reduction of rapid irradiance fluctuation that will enhance consistent power supply in integrating solar to the micro grid was220 w/m^2. on the other hand, when an ANN based super capacitor was integrated into the system, it automatically reduced to200 w/m^2 and the conventional Frequency deviation/ instability that will enhance consistent power supply in integrating solar to the micro grid was42Hz. It could not attain the threshold of 50Hz thereby causing inconsistent power failure in integration of solar to the micro grid.. Meanwhile, when an ANN based super capacitor was imbibed into the system, it simultaneously increased it to 50Hz thereby making it to attain the threshold. Finally, with these results obtained, It meant that the percentage enhancement of constant power supply by integrating solar to the micro grid when an ANN based super capacitor was integrated into the system was19%.

Keywords: generation shortfalls, transmission inefficiencies, rowing energy demand and Solar photovoltaic (PV)

1.0 INTRODUCTION

The provision of constant and reliable power supply is a fundamental requirement for economic growth, industrial productivity, and social development. However, in many developing nations, including Nigeria, the national grid is plagued by generation shortfalls, transmission bottlenecks, and increasing energy demand, leading to frequent blackouts and unstable supply (Akinbulire et al., 2021). To address these challenges, microgrids have emerged as a viable solution for localized power generation and distribution. Microgrids can operate autonomously or in conjunction with the main grid, enabling the integration of renewable energy sources such as solar photovoltaic (PV) systems to reduce dependency on fossil fuels and improve supply sustainability (Kabalci, 2020). Solar PV technology is widely recognized for its environmental benefits and ability to harness abundant solar energy. However, its inherent intermittency, caused by weather variability and diurnal cycles, poses a significant obstacle to ensuring constant power delivery (Mekhilef et al., 2022). To mitigate these fluctuations, energy storage systems (ESS) are employed to store surplus energy during peak generation and release it during low or no sunlight periods. Among various ESS technologies, supercapacitors stand out for their high power density, rapid charge–discharge rates, and long operational lifespans, making them ideal for stabilizing short-term power variations and supporting grid voltage regulation (Bai et al., 2021). The performance of supercapacitor-based storage in microgrids can be significantly enhanced through intelligent control strategies. Artificial Neural Networks (ANN), inspired by biological neural processes, have proven effective in handling nonlinear, dynamic, and uncertain systems (Kou et al., 2019). When applied to supercapacitor management in a solar-integrated microgrid, ANN controllers can process real-time data on load demand, solar irradiance, and state-of-charge to predict fluctuations and make adaptive charge–discharge decisions. This predictive capability improves system efficiency, reduces energy losses, and ensures a more stable power supply (Okedu et al., 2022). In regions like Nigeria, where grid instability is a major hindrance to socio-economic development, integrating solar energy into micro grids supported by ANN-based super capacitors offers a promising pathway toward achieving the United Nations' Sustainable Development Goal 7 (SDG 7) on affordable and clean energy (United Nations, 2023). Despite the potential benefits, challenges remain in optimizing system design, developing efficient ANN models, and ensuring cost-effectiveness. Therefore, research on ANN-based super capacitor integration in solar-powered micro grids is crucial for advancing constant power supply solutions and supporting the global transition to sustainable energy systems.

2.0 METHODOLOGY

To characterize and establish the causes of intermittent power supply by integrating solar to the micro grid

Table 1 characterized and established the causes of intermittent power supply by integrating solar to the micro grid

CAUSE	CHARACTERIZATION OR WHAT HAPPENED	THRESHOLD VALUES	Conventional causes of intermittent power supply by integrating solar to the micro grid
Rapid irradiance Fluatuation	sudden drop or spike PV irradiance causing fast PV output changes	Irradiance drop > 200 W/m^2	220 W/m^2
Dumal and seasonal low irradiance	Prolong low solar resource reduces PV generation	Irradiance <200W/m^2	197 W/m^2
PV output ramp rate slow/fast	PV power changes over minutes affecting balance	>0.00033 P.U/s for a 1P.U system	0.00036 P.U/s
Module temperature affects	High module temperature reduces PV efficiency and voltage	Cell module temperature >55^{0}C.	57^{0}C
Voltage sags/swells on micro grid bus	Grid side disturbances or large sudden loads	<230V	191V

Frequency deviation/ instability	Supply/demand imbalance	<50HZ	42HZ

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

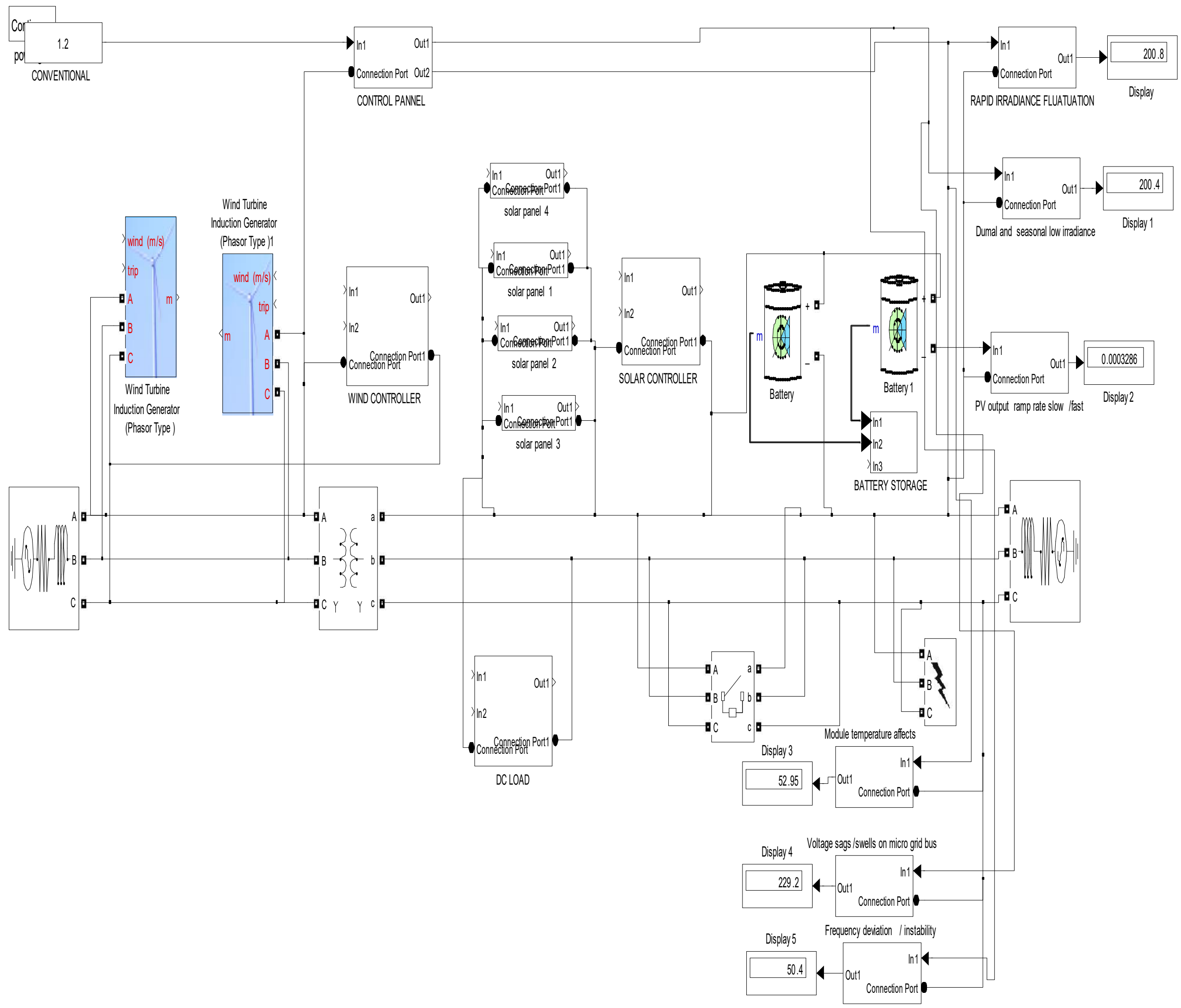

Fig1 designed conventional SIMULINK model for integrating solar to the micro grid

The results obtained were as shown in figures 6 and 7.

To train ANN in the causes of intermittent power supply by integrating solar to the micro grid for effective consistent power supply.

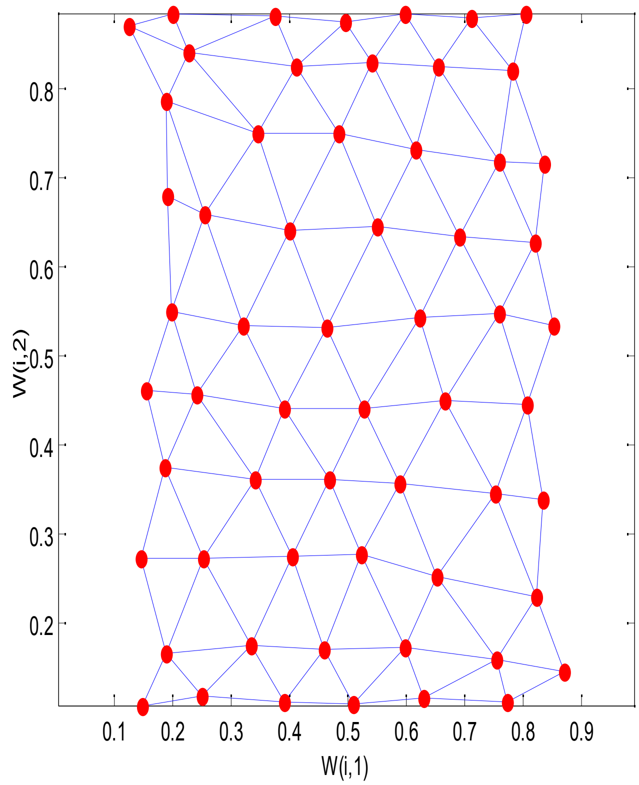

Fig 2 trained ANN in the causes of intermittent power supply by integrating solar to the micro grid for effective consistent power supply

In fig 2 ANN was trained 10 times in the 6 causes of intermittent power supply by integrating solar to the micro grid 10 x 6 = 60 neurons that looked like human brain and performed duties allocated to it.

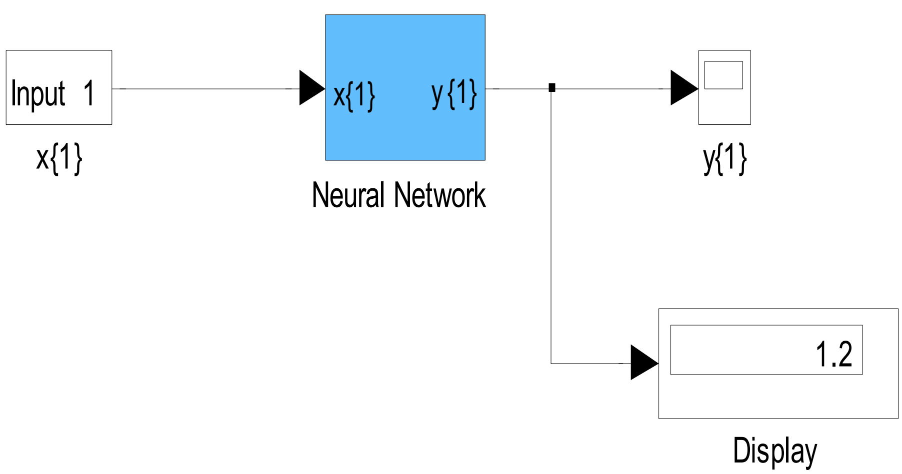

Fig 3 results obtained from the trained ANN in the causes of intermittent power supply by integrating solar to the micro grid for effective consistent power supply

To design a SIMULINK model for SUPERCAPACITOR

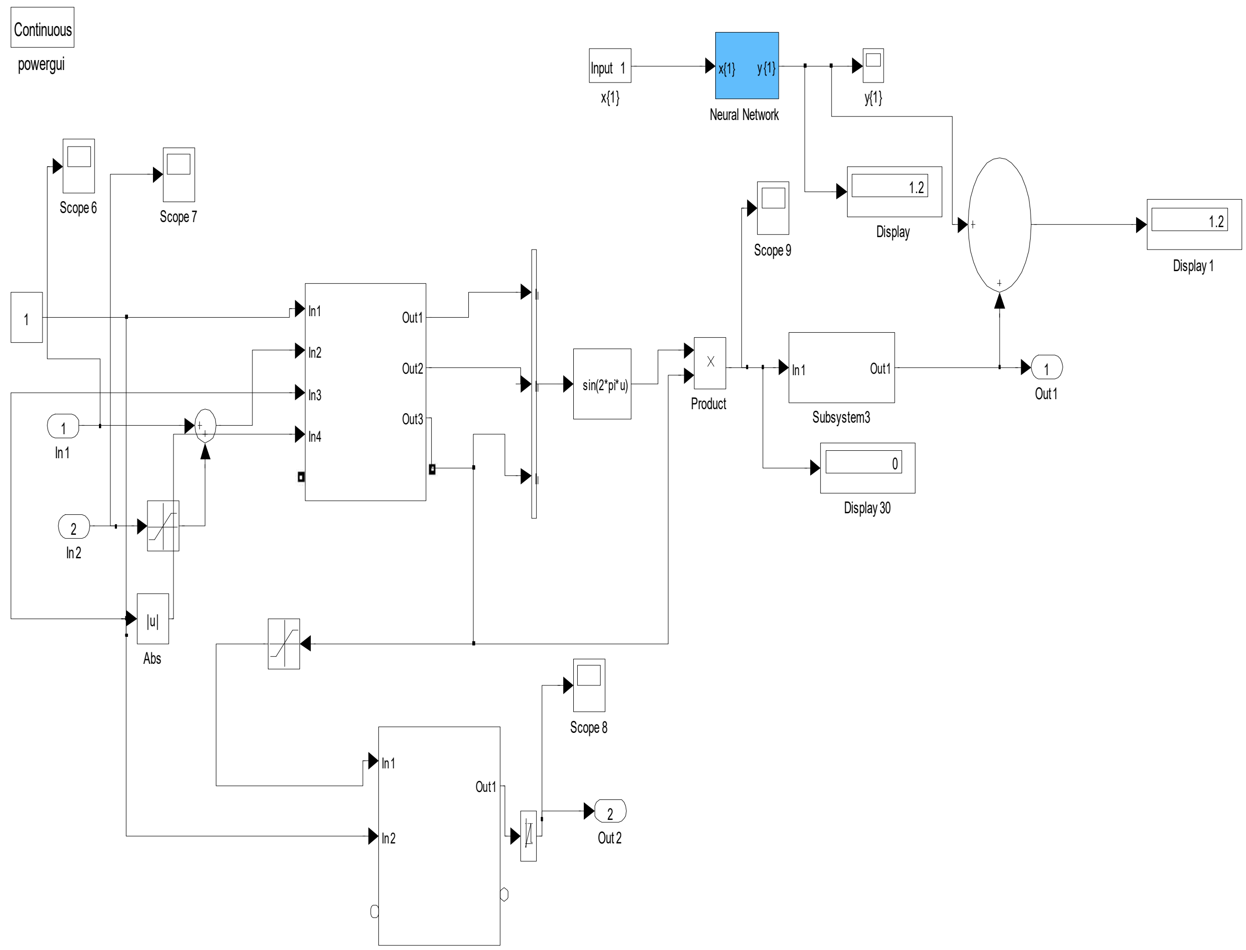

Fig 4 designed SIMULINK model for SUPERCAPACITOR

This would be integrated to the designed conventional SIMULINK model for integrating solar to the micro grid to obtain the results shown in figures 6 and 7.

To develop an algorithm that would implement the process

1. Characterize and establish the causes of intermittent power supply by integrating solar to the micro grid
2. Identify rapid irradiance fluctuation
3. Identify dumal and seasonal low irradiance
4. Identify PV output ramp rate slow/fast
5. Identify module temperature affects
6. Identify voltage sags/swells on micro grid bus
7. Identify frequency deviation/ instability
8. Design a conventional SIMULINK model for integrating solar to the micro grid and integrate 2 through 7.

9. Train ANN in the causes of intermittent power supply by integrating solar to the micro grid for effective consistent power supply.
10. Design a SIMULINK model for super capacitor
11. Integrate 9 and 10
12. integrate 11 into 8
13. Did the causes of intermittent power supply by integrating solar to the micro grid reduce when 11 was integrated into 8?
14. IF NO go to 12.
15. IF YES go to 16
16. Enhanced constant power supply by integrating solar to the micro grid
17. Stop
18. End

To design a SIMULINK model for enhancing constant power supply by integrating solar to the micro grid using ANN based super capacitor

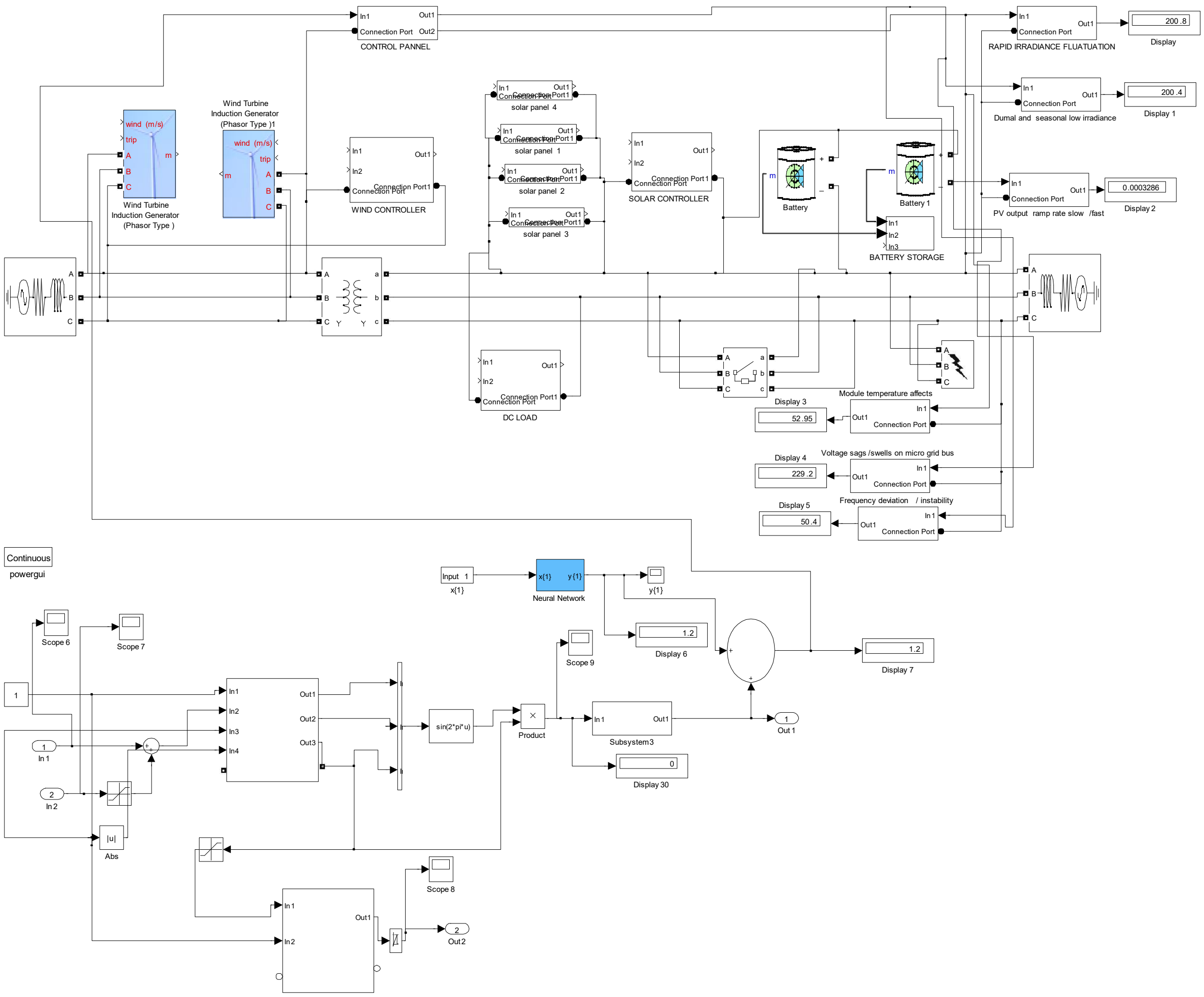

Fig 5 designed SIMULINK model for enhancing constant power supply by integrating solar to the micro grid using ANN based super capacitor

The results obtained were as shown in figures 6 and 7.

To validate and justify the percentage enhancement in consistent power supply in integrating solar to the micro grid

With and without ANN based super capacitor

To find percentage improvement in the reduction of rapid irradiance fluctuation to enhance consistent power supply in integrating solar to the micro grid with ANN based super capacitor

Conventional rapid irradiance fluctuation =220 W/m^2

ANN based super capacitor rapid irradiance fluctuation=200 W/m^2

%improvement in the reduction of rapid irradiance fluctuation to enhance consistent power supply in integrating solar to the micro grid with ANN based super capacitor =

$$\frac{\text{Conventional rapid irradiance fluctuation - ANN based super capacitor rapid irradiance fluctuat}}{\text{Conventional rapid irradiance fluctuation}} \times \frac{100\%}{1}$$

%improvement in the reduction of rapid irradiance fluctuation to enhance consistent power supply in integrating solar to the micro grid with ANN based super capacitor =

$$\frac{220\ W/m^2 - 200\ W/m^2}{220\ W/m^2} \times \frac{100\%}{1}$$

%improvement in the reduction of rapid irradiance fluctuation to enhance consistent power supply in integrating solar to the micro grid with ANN based super capacitor =9.1%

To find percentage improvement of Frequency deviation/ instability to enhance consistent power supply in integrating solar to the micro grid with ANN based super capacitor

Conventional Frequency deviation/ instability =42HZ

ANN based super capacitor Frequency deviation/ instability =50 HZ

%improvement in the reduction of Frequency deviation/ instability to enhance consistent power supply in integrating solar to the micro grid with ANN based super capacitor =

$$\frac{\text{ANN based super capacitor Frequency deviation-Conventional Frequency deviation}}{\text{Conventional Frequency deviation/ instability}} \times \frac{100\%}{1}$$

%improvement in the Frequency deviation/ instability to enhance consistent power supply in integrating solar to the micro grid with ANN based super capacitor =

$$\frac{50\ HZ - 42HZ}{42HZ} \times \frac{100\%}{1}$$

%improvement in the Frequency deviation/ instability to enhance consistent power supply in integrating solar to the micro grid with ANN based super capacitor =19%

3.0 RESULTS AND DISCUSSION

Table2 comparison of conventional and ANN based super capacitor reduction of rapid irradiance fluctuation that will enhance consistent power supply in integrating solar to the micro grid

Time (days)	Conventional reduction of rapid irradiance fluctuation that will enhance consistent	ANN based super capacitor reduction of rapid irradiance fluctuation that will enhance

	power supply in integrating solar to the micro grid(W/m^2)	consistent power supply in integrating solar to the micro grid(W/m^2)
1	220	200
2	220	200
3	220	200
4	220	200
10	220	200

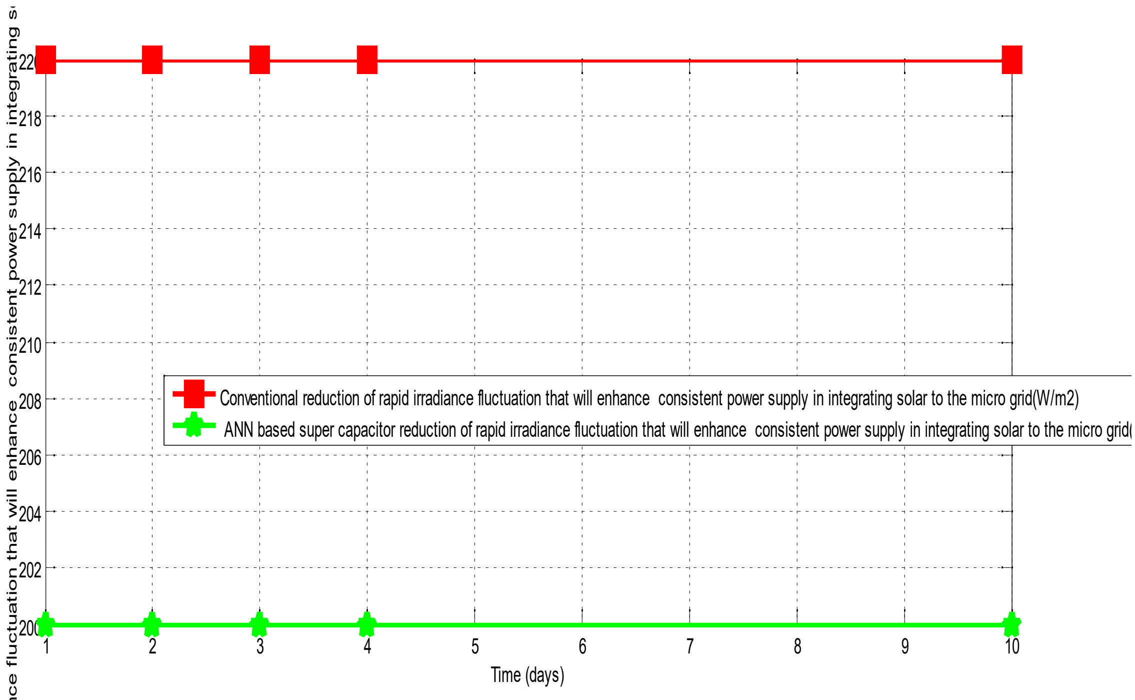

Fig 6 comparison of conventional and ANN based super capacitor reduction of rapid irradiance fluctuation that will enhance consistent power supply in integrating solar to the micro grid

The conventional reduction of rapid irradiance fluctuation that will enhance consistent power supply in integrating solar to the micro grid was220 W/m^2. On the other hand, when an ANN based super capacitor was integrated into the system, it automatically reduced to200 W/m^2.

Table3 comparison of conventional and ANN based super capacitor Frequency deviation/ instability that will enhance consistent power supply in integrating solar to the micro grid

Time (days)	Conventional Frequency deviation/ instability that will	ANN based super capacitor Frequency deviation/

	enhance consistent power supply in integrating solar to the micro grid(HZ)	instability that will enhance consistent power supply in integrating solar to the micro grid(HZ)
1	42	50
2	42	50
3	42	50
4	42	50
10	42	50

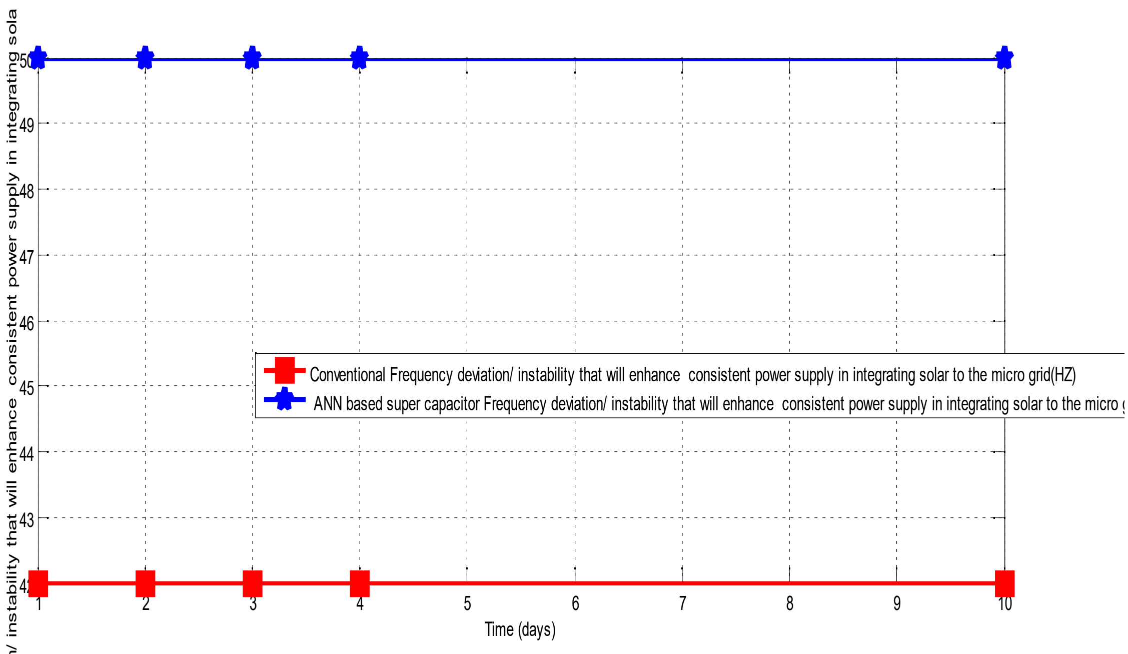

Fig 7 comparison of conventional and ANN based super capacitor Frequency deviation/ instability that will enhance consistent power supply in integrating solar to the micro grid

The conventional Frequency deviation/ instability that will enhance consistent power supply in integrating solar to the micro grid was42Hz. It could not attain the threshold of 50Hz thereby causing inconsistent power failure in integration of solar to the micro grid.. Meanwhile, when an ANN based super capacitor was imbibed into the system, it simultaneously increased it to 50Hz thereby making it to attain the threshold. Finally, with these results obtained, It meant that the percentage enhancement of constant power supply by integrating solar to the micro grid when an ANN based super capacitor was integrated into the system was19%.

4.0. CONCLUSION

This study underscores the potential of integrating solar photovoltaic (PV) systems with artificial neural network (ANN)-based super capacitor energy storage to achieve a more reliable and constant power supply in micro grid applications. The combination of renewable solar energy and intelligent storage management addresses the dual challenges of generation intermittency and grid instability, particularly in regions with weak or underdeveloped power infrastructure. By leveraging the predictive and adaptive capabilities of ANN, the system can optimize the charging and discharging cycles of the super capacitor, ensuring efficient energy utilization, minimizing fluctuations, and maintaining voltage stability. The findings highlight that ANN-based control offers superior performance compared to conventional storage management strategies, resulting in improved system resilience, reduced downtime, and enhanced power quality. Furthermore, this approach supports global clean energy objectives, particularly the United Nations' Sustainable Development Goal 7 (SDG 7) on affordable and clean energy. The integration of intelligent-based super capacitors in solar microgrids therefore represents a practical and scalable solution for sustainable energy supply, with significant implications for both rural electrification and urban energy resilience. Future work should focus on large-scale implementation, cost optimization, and hybrid integration with other renewable sources to further improve reliability and economic viability. The results obtained were the conventional reduction of rapid irradiance fluctuation that will enhance consistent power supply in integrating solar to the micro grid was220 w/m^2. on the other hand, when an ANN based super capacitor was integrated into the system, it automatically reduced to200 w/m^2 and the conventional Frequency deviation/ instability that will enhance consistent power supply in integrating solar to the micro grid was42Hz. It could not attain the threshold of 50Hz thereby causing inconsistent power failure in integration of solar to the micro grid.. Meanwhile, when an ANN based super capacitor was imbibed into the system, it simultaneously increased it to 50Hz thereby making it to attain the threshold. Finally, with these results obtained, It meant that the percentage enhancement of constant power supply by integrating solar to the micro grid when an ANN based super capacitor was integrated into the system was 19%.

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