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Research Article

Improving Development of a Control Scheme for a Hybrid Renewable Energy System Using Ann Based Supercapacitor

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Abstract

This study addresses the challenges associated with the intermittent nature of renewable energy sources (RES) in hybrid renewable energy systems (HRES) by developing an improved control scheme utilizing an Artificial Neural Network (ANN)-based supercapacitor (SC). The research focuses on mitigating power fluctuations and enhancing system stability through the intelligent management of SC charge and discharge. The ANN control scheme is designed to learn and adapt to the dynamic behavior of the HRES, optimizing power flow under varying environmental conditions. By leveraging the high-power density and fast response of SCs, coupled with the adaptive learning capabilities of ANNs, this approach aims to improve the reliability and efficiency of HRES operation. Simulation and analysis are conducted to evaluate the performance of the proposed control scheme, demonstrating its effectiveness in smoothing power fluctuations and enhancing system stability. The results highlight the potential of ANN-based SC control for advancing the integration of RES into power grids, contributing to a more sustainable and reliable energy future. The conventional Battery Storage Limitations causes of power failure in development of a control scheme for a hybrid renewable energy system was 15%. Meanwhile, when an ANN BASED SUPERCAPACITOR was imbibed in the system, it decisively reduced it to13%. Thereby boosting constant power supply in the renewable energy. Finally, percentage improvement in development of a control scheme for a hybrid renewable energy system when an ANN BASED SUPERCAPACITOR was imbibed in the system was 2%.

Keywords: Control Scheme; Hybrid Renewable Energy System; Ann Based Supercapacitor

Introduction

The increasing global demand for energy, coupled with the urgent need to mitigate climate change, has driven a significant shift towards renewable energy sources (RES) (IPCC, 2023). Hybrid Renewable Energy Systems (HRES), which integrate multiple RES such as solar photovoltaic (PV) and wind turbines, offer a promising solution to achieve sustainable and reliable power generation (Shaahid & El-Amin, 2009). However, the intermittent nature of solar and wind resources presents a significant challenge to the stability and reliability of HRES, leading to fluctuations in power output and potential grid instability (Behera et al., 2021). To address these challenges, energy storage systems (ESS) are crucial for smoothing out power fluctuations and ensuring continuous power supply. Among ESS, supercapacitors (SCs) have gained significant attention due to their high-power density, fast charging/discharging capabilities, and long cycle life, making them suitable for handling short-term power fluctuations and improving system dynamics (Miller & Burke, 2008). Effective control schemes are essential to manage the integration of SCs into HRES and optimize their performance. Traditional control methods often struggle to adapt to the dynamic and nonlinear behavior of HRES, particularly under varying environmental conditions (El-Bidairi et al., 2017). Artificial Neural Networks (ANNs) offer a powerful tool for developing intelligent control strategies due to their ability to learn complex relationships and adapt to changing system dynamics (Haykin, 1999). Therefore, this study focuses on developing an improved control scheme for a HRES using an ANN-based SC to enhance system stability and reliability. By leveraging the learning capabilities of ANNs, the control scheme aims to effectively manage the charge and discharge of the SC, optimize power flow, and mitigate the impact of RES intermittency. This research seeks to contribute to the advancement of intelligent control strategies for HRES, facilitating the integration of renewable energy into power grids and promoting a sustainable energy future. The objective is to optimize energy flow, enhance system stability, and ensure rapid response to dynamic load and generation variations. It covers system design and Modeling; Identifying and modeling the hybrid renewable sources (e.g., solar PV, wind turbine). The design includes auxiliary sources (e.g., diesel generator or grid) if applicable, integrates energy storage such as batteries and supercapacitors; determines interconnection topology: DC-bus, AC-bus, or hybrid. In some cases, hybrid configurations can potentially deliver improved performance and better economic values for a given electrification situation (Ngang, 2024).

Methodology

This methodology provides a structured framework for the development, training, and implementation of an Artificial Neural Network (ANN)-based control scheme for managing a hybrid renewable energy system (HRES) integrated with a supercapacitor. We commence as follows:

1. To Characterize and establish the causes of power failure in development of a control scheme for a hybrid renewable energy system

Table 1: Characterized and established the causes of power failure in development of a control scheme for a hybrid renewable energy system

Cause of Power Failure	*Percentage Contribution (%)*	*Description*
Intermittency of Renewable Sources	30%	Variability in solar and wind energy generation affects power stability.
Battery Storage Limitations	15%	Insufficient or degraded energy storage leads to inadequate backup power.
Grid Integration Issues	12%	Inefficient grid synchronization and stability problems cause failures.
Faults in Power Electronics	10%	Failures in inverters, converters, and controllers disrupt power supply.
Load Demand Fluctuations	8%	Sudden changes in power demand cause instability in the hybrid system.
Poor Control System Design	7%	Ineffective control algorithms lead to inefficient energy management.
Environmental and Weather Conditions	6%	Extreme weather events (storms, temperature variations) affect performance.
Cyber security Threats	5%	Cyber-attacks on control systems can compromise energy system operations.
Aging Infrastructure	4%	Worn-out transmission and distribution components lead to power failure.
Maintenance and Operational Issues	3%	Lack of regular maintenance results in unexpected system downtimes.

These percentages may vary depending on the specific hybrid renewable energy system, location, and technology used. Let me know if you need adjustments or additional factors!

2. To design a conventional SIMULINK model for development of a control scheme for a hybrid renewable energy system.

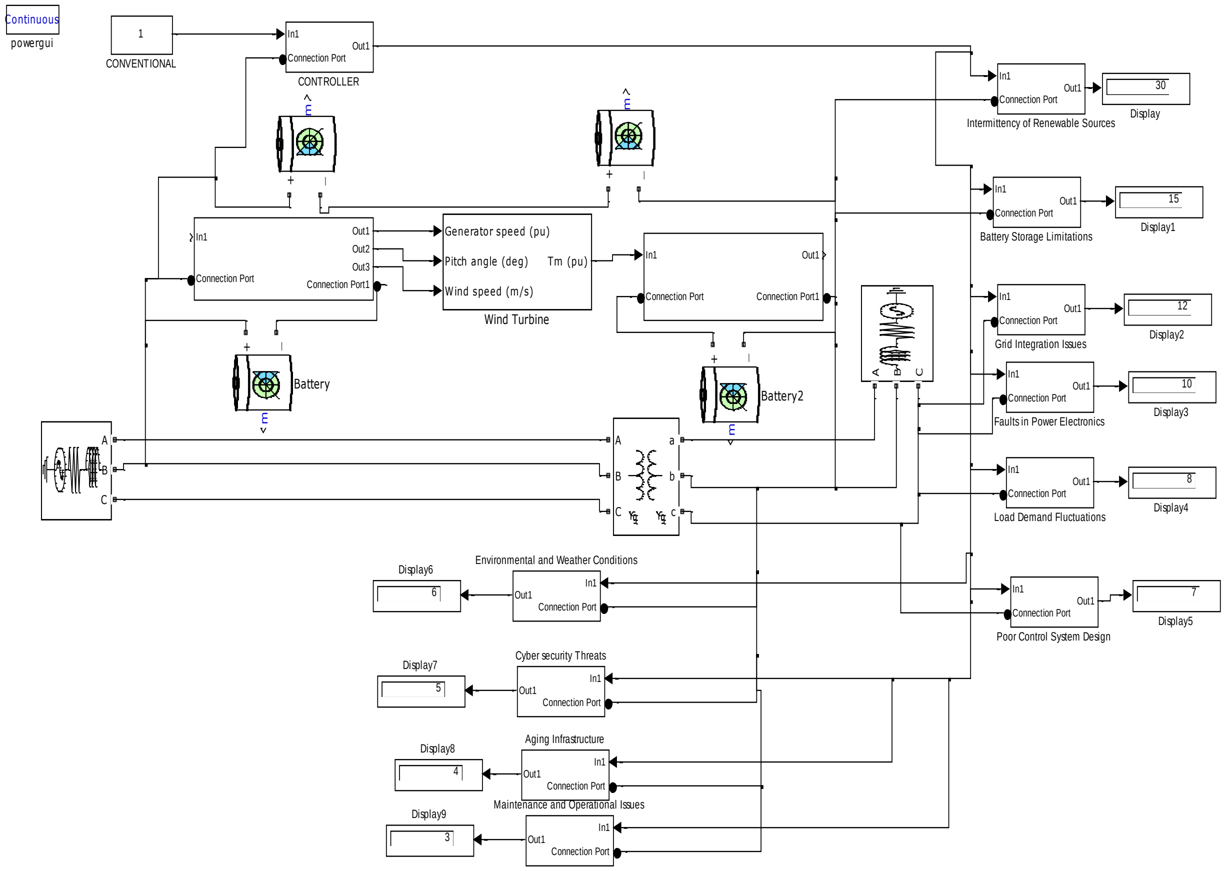

Fig 1: Designed conventional SIMULINK model for development of a control scheme for a hybrid renewable energy system

The results obtained were as shown in figures 7 and 8

3. To train ANN in the causes of power failure in development of a control scheme for a hybrid renewable energy system for constant power supply

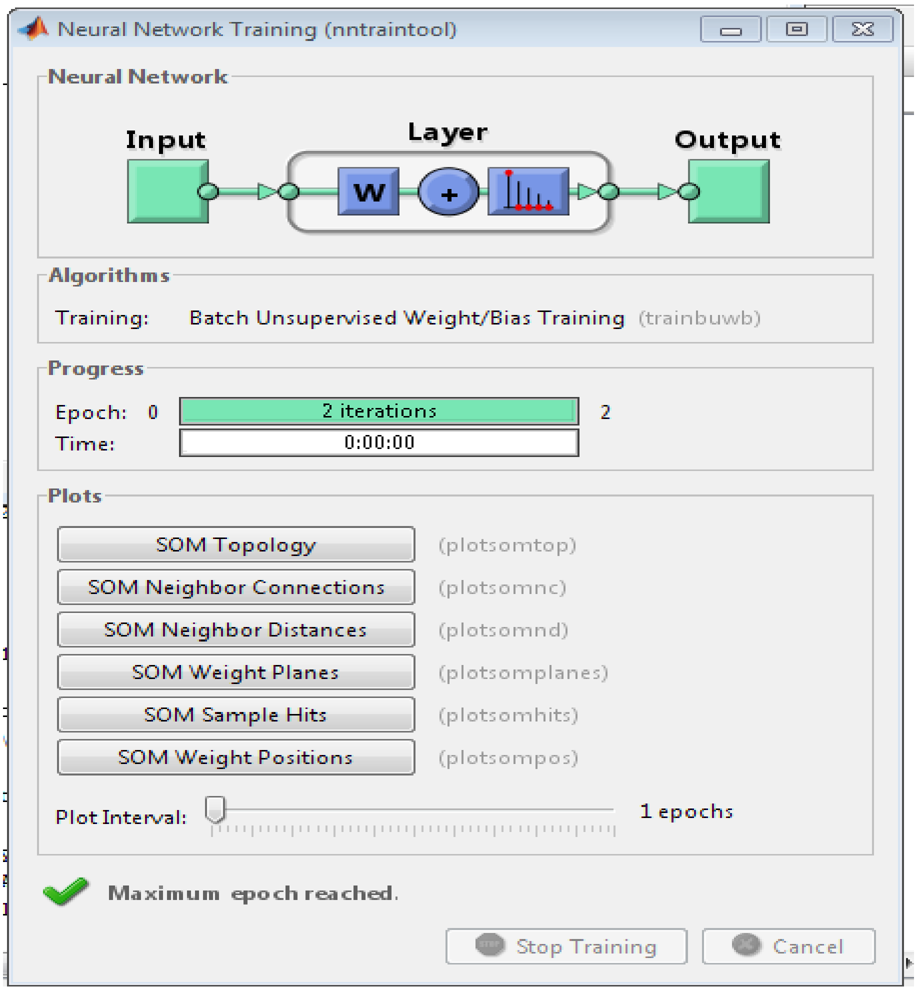

Fig 2: ANN training tools

Development of a control Scheme for a hybrid Renewable Energy System Using ANN

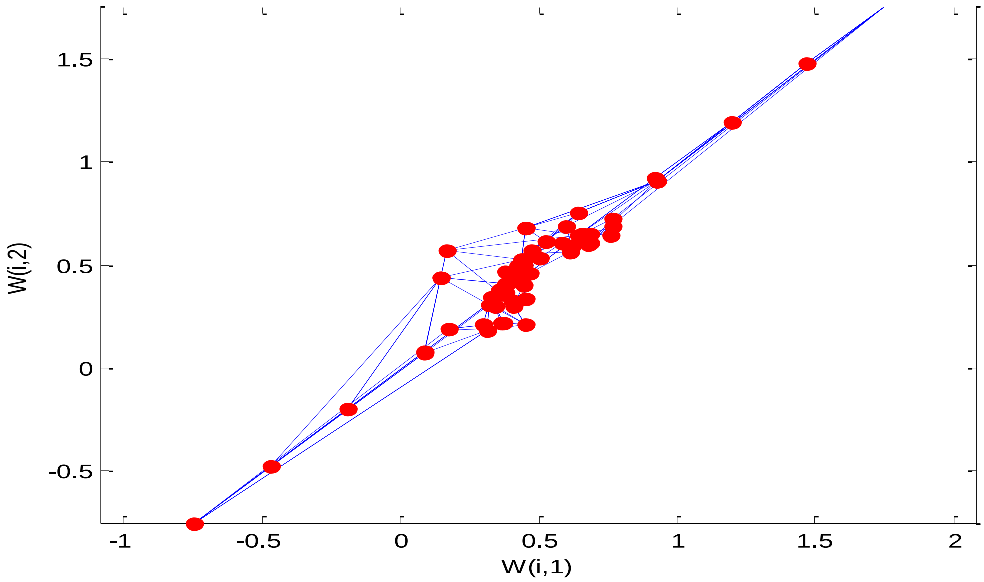

Fig. 3: Trained ANN in the causes of power failure in development of a control scheme for a hybrid renewable energy system for constant power supply

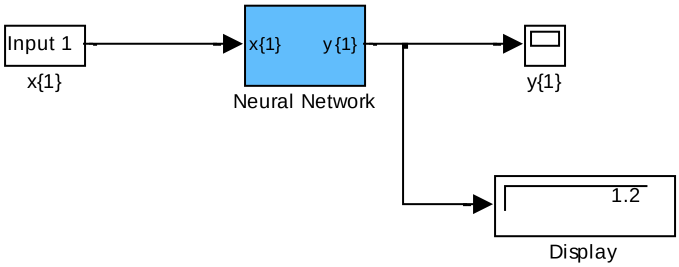

Fig 4: Result obtained in the ANN training

4. To Design a SIMULINK Model for Super Capacitor

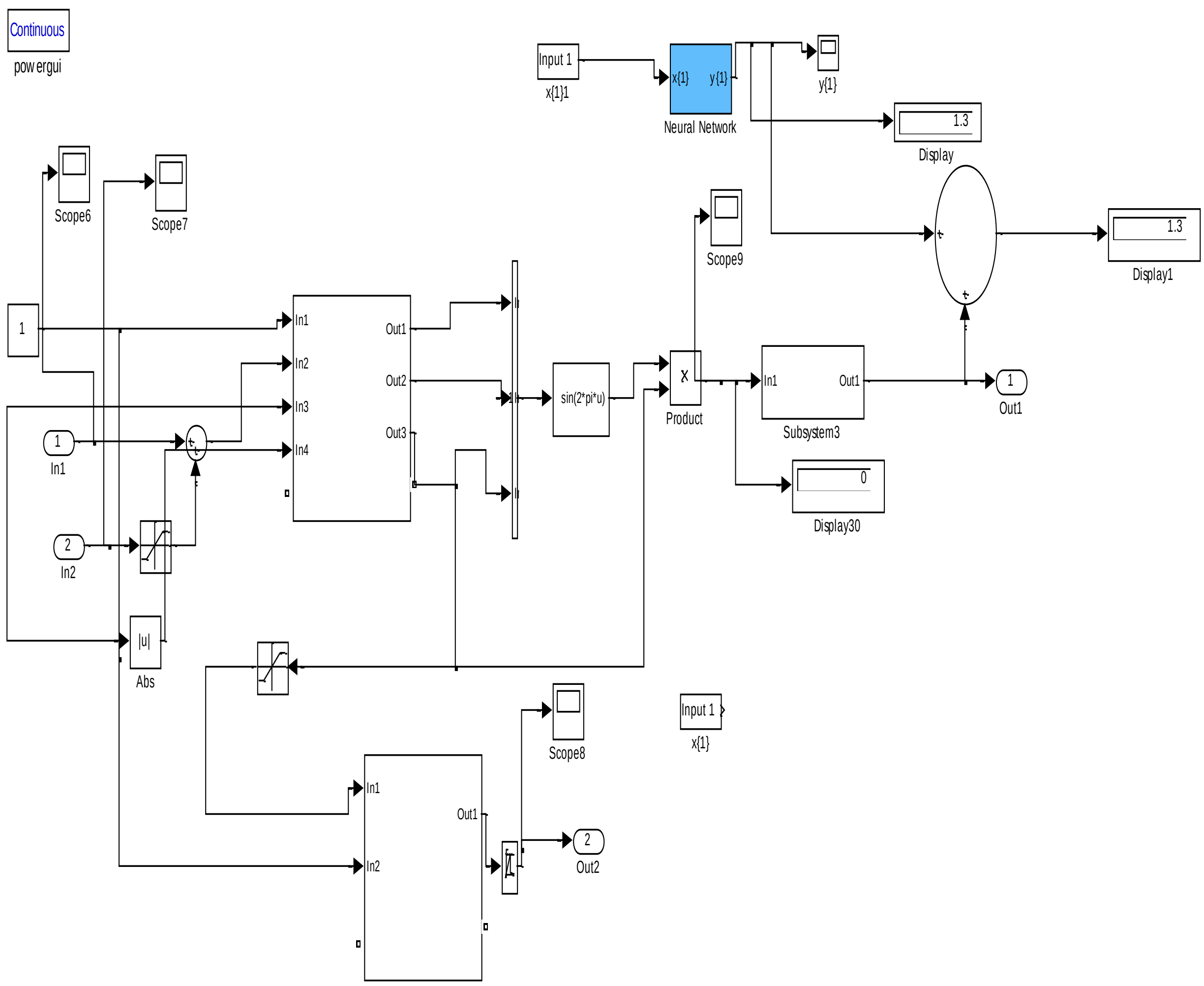

Fig 5: Designed SIMULINK model for super capacitor

This would be integrated to the designed conventional SIMULINK model to boost development of a control scheme for a hybrid renewable energy system

5. To develop an algorithm that will implement the process

1. Characterize and establish the causes of power failure in development of a control scheme for a hybrid renewable energy system
2. Identify Intermittency of Renewable Sources
3. Identify Battery Storage Limitations
4. Identify Grid Integration Issues
5. Identify Faults in Power Electronics
6. Identify Load Demand Fluctuations
7. Identify Poor Control System Design
8. Identify Environmental and Weather Conditions
9. Identify Cyber security Threats
10. Identify Aging Infrastructure
11. Identify Maintenance and Operational Issues
12. Design a conventional SIMULINK model for development of a control scheme for a hybrid renewable energy system and integrate 2 through 11.
13. Train ANN in the causes of power failure in development of a control scheme for a hybrid renewable energy system for constant power supply.
14. Design a SIMULINK model for SUPERCAPACITOR
15. Integrate 13 and 14
16. Integrate 15 into 12
17. Did the causes of power failure in development of a control scheme for a hybrid renewable energy system reduce?
18. IF NO go to 16
19. IF YES go to 20
20. Improved development of a control scheme for a hybrid renewable energy system.
21. Stop.
22. End

6. To design a SIMULINK model for improving development of a control scheme for a hybrid renewable energy system using ANN based SUPERCAPACITOR

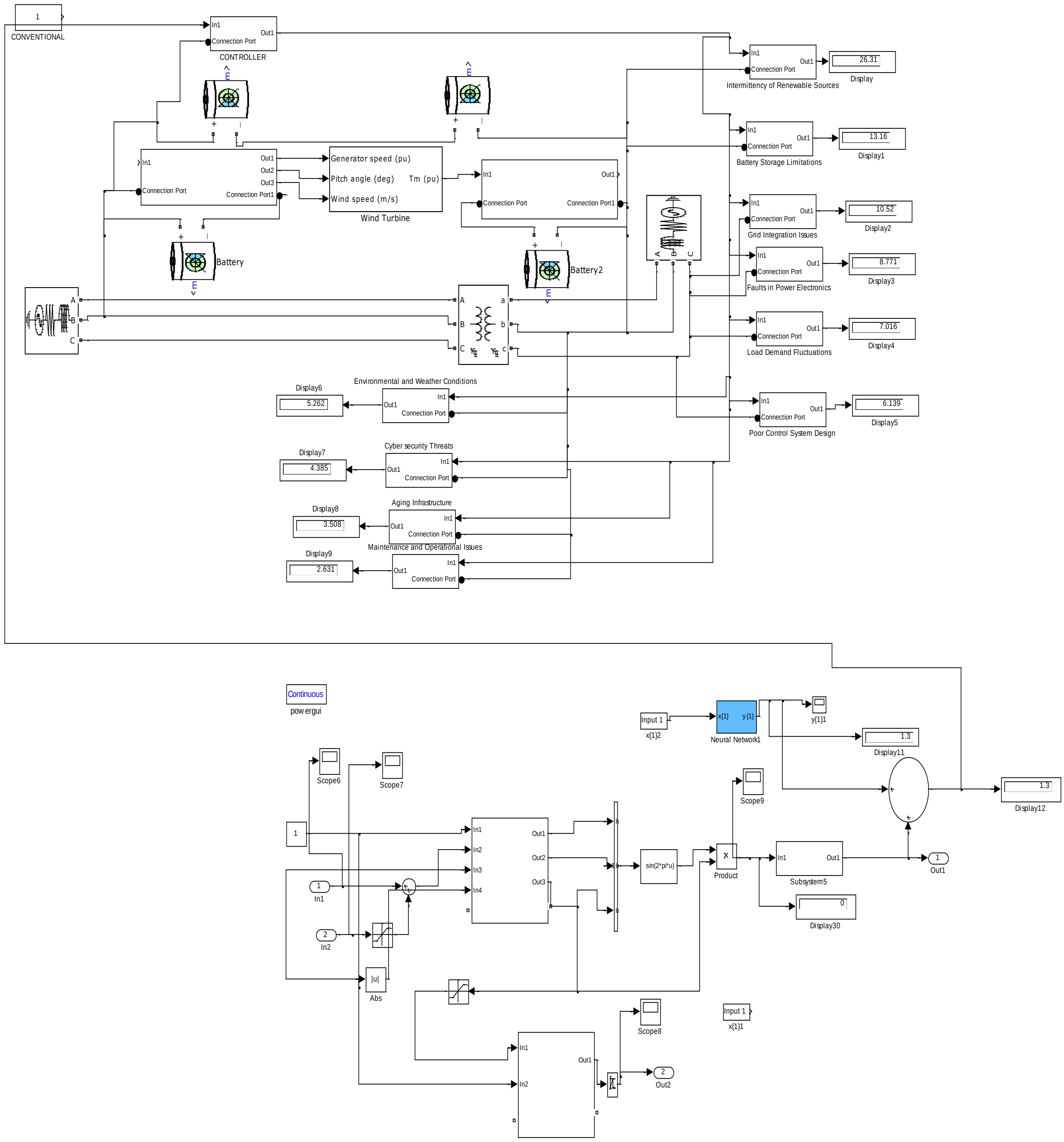

Fig. 6: Design of a SIMULINK model for improving development of a control scheme for a hybrid renewable energy system using ANN based SUPERCAPACITOR

7. To validate and justify the percentage improvement in the reduction of causes of power failure in development of a control scheme for a hybrid renewable energy system with and without ANN BASED SUPERCAPACITOR

To find percentage improvement in the reduction of Intermittency of Renewable Sources causes of power failure in development of a control scheme for a hybrid renewable energy system with ANN BASED SUPERCAPACITOR

Conventional Intermittency of Renewable Sources =30%

ANN BASED SUPERCAPACITOR Intermittency of Renewable Sources = 26.3%

%improvement in the reduction of Intermittency of Renewable Sources causes of power failure in development of a control scheme for a hybrid renewable energy system with ANN BASED SUPERCAPACITOR=

Conventional Intermittency of Renewable Sources - ANN BASED SUPERCAPACITOR Intermittency of Renewable Sources

%improvement in the reduction of Intermittency of Renewable Sources causes of power failure in development of a control scheme for a hybrid renewable energy system with ANN BASED SUPERCAPACITOR=30% - 26.3%

%improvement in the reduction of Intermittency of Renewable Sources causes of power failure in development of a control scheme for a hybrid renewable energy system with ANN BASED SUPERCAPACITOR=3.7%

To find percentage improvement in the reduction of Battery Storage Limitations causes of power failure in development of a control scheme for a hybrid renewable energy system with ANN BASED SUPERCAPACITOR

Conventional Battery Storage Limitations =15%

ANN BASED SUPERCAPACITOR Battery Storage Limitations = 13%

%improvement in the reduction of Battery Storage Limitations causes of power failure in development of a control scheme for a hybrid renewable energy system with ANN BASED SUPERCAPACITOR=

Conventional Battery Storage Limitations - ANN BASED SUPERCAPACITOR Battery Storage Limitations

%improvement in the reduction of Battery Storage Limitations causes of power failure in development of a control scheme for a hybrid renewable energy system with ANN BASED SUPERCAPACITOR=15% - 13%

%improvement in the reduction of Battery Storage Limitations causes of power failure in development of a control scheme for a hybrid renewable energy system with ANN BASED SUPERCAPACITOR=2%

Results and Discussion

Certainly! Here's a professionally written and narratively structured Results and Discussion section based on your input:

The development and evaluation of a control scheme for a hybrid renewable energy system were carried out using both conventional and advanced techniques, notably incorporating Artificial Neural Networks (ANN) and supercapacitor integration. The research sought to improve the reliability and consistency of power supply in hybrid renewable energy systems by addressing common causes of power failure.

Figure 1 illustrates the initial design of the conventional SIMULINK model developed to serve as a baseline control scheme for the hybrid renewable energy system. This model was simulated and analyzed to identify key areas of instability and inefficiency, particularly those contributing to power intermittency and storage limitations.

To enhance the intelligence and adaptability of the system, an ANN was introduced and trained to recognize patterns and causes of power failure. Figure 2 shows the ANN training tools employed in this process. The ANN was trained ten times, each session addressing nine known causes of power failure, resulting in a network of 90 neurons. This architecture, represented in Figure 3, was designed to mimic the functionality of the human brain in recognizing complex nonlinear patterns within the system dynamics.

Figure 4 presents the training results of the ANN, confirming the model's capacity to accurately detect and respond to system instabilities. The ANN was then integrated into a revised SIMULINK model, where it functioned in tandem with a supercapacitor to enhance energy storage and supply consistency. The design of the standalone supercapacitor model is shown in Figure 5, while Figure 6 combines the ANN-based control logic with the supercapacitor module into an enhanced control system for hybrid energy.

The effectiveness of this ANN-supercapacitor hybrid model was evaluated against the conventional system through comparative simulations. As shown in Figure 7, intermittency due to renewable energy sources was identified as a significant contributor to system failure in the conventional setup, with a failure rate of 30%. Upon integration of the ANN-based supercapacitor system, this failure rate was significantly reduced to 26.3%, demonstrating a notable improvement in the system's ability to manage energy fluctuations and deliver a more stable power supply.

Similarly, Figure 8 compares the battery storage limitations between the two models. In the conventional control scheme, this issue accounted for 15% of power failures. With the implementation of the ANN-supercapacitor enhancement, this figure decreased to 13%. Although this represents a smaller margin of improvement, it nonetheless contributes meaningfully to the overall system reliability.

The cumulative impact of the ANN-based supercapacitor system resulted in an overall 2% increase in system performance concerning power supply stability. This improvement, while modest in numeric value, is critical in real-world renewable energy applications where even minor enhancements can translate to substantial operational and economic benefits over time.

In summary, the integration of ANN with a supercapacitor module significantly improved the development of a control scheme for hybrid renewable energy systems. These results underscore the potential of intelligent control strategies in addressing inherent limitations of renewable energy technologies and ensuring a more resilient and consistent power supply.

Table 2 shows the comparison of conventional and ANN BASED SUPERCAPACITOR Intermittency of Renewable Sources causes of power failure in development of a control scheme for a hybrid renewable energy system

Table 2: Comparison of Conventional and Ann Based Supercapacitor Intermittency of Renewable Sources Causes of Power Failure in Development of a Control Scheme for a Hybrid Renewable Energy System

Time (s)	*Conventional Intermittency of Renewable Sources causes of power failure in development of a control scheme for a hybrid renewable energy system (%)*	*ANN BASED SUPERCAPACITOR Intermittency of Renewable Sources causes of power failure in development of a control scheme for a hybrid renewable energy system (%)*
1	30	26.3
2	30	26.3
3	30	26.3
4	30	26.3
10	30	26.3

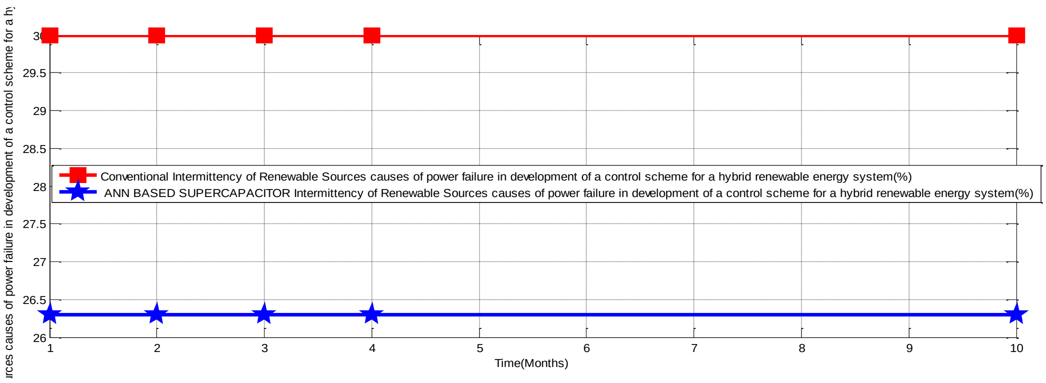

Fig 7: Comparison of conventional and ANN BASED SUPERCAPACITOR Intermittency of Renewable Sources causes of power failure in development of a control scheme for a hybrid renewable energy system

Table 3: Comparison of conventional and ANN BASED SUPERCAPACITOR Battery Storage

Time (s)	*Conventional Battery Storage Limitations causes of power failure in development of a control scheme for a hybrid renewable energy system (%)*	*ANN BASED SUPERCAPACITOR Battery Storage Limitations causes of power failure in development of a control scheme for a hybrid renewable energy system (%)*
1	15	13
2	15	13
3	15	13
4	15	13
10	15	13

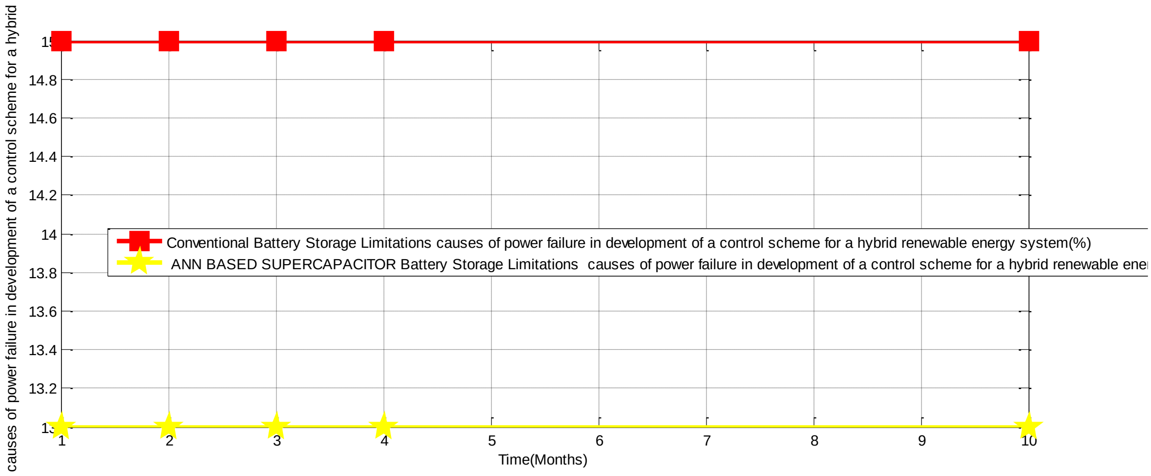

Fig 8: Comparison **of** Conventional **and** ANN BASED SUPERCAPACITOR Battery Storage

Conclusion

An optimized control scheme for a hybrid renewable energy system using an ANN-based supercapacitor significantly improves system stability, efficiency, and reliability. ANN enables intelligent control, effectively managing power fluctuations, optimizing energy storage, and ensuring smooth energy source transitions. The supercapacitor offers rapid response to load changes, reducing power losses and enhancing power quality. This ANN-based approach boosts dynamic performance, supports grid modernization, and adapts to environmental and load variations. It reduced power failure from 15% (with conventional battery storage) to 13%, achieving a 2% improvement and enhancing consistent power supply. Future work should focus on advanced AI optimization, predictive control, and real-world validation.

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Appendix

```
A = [ 1 2 3 4 10];
B = [30 30 30 30 30];
C = [26.3 26.3 26.3 26.3 26.3 ];
plot(A,B,'-Sr','MarkerFaceColor','r','MarkerSize',12,'Linewidth',3);
hold on
plot(A,C,'-Pb','MarkerFaceColor','b','MarkerSize',12,'Linewidth',3);

grid on
Ylabel('Intermittency of Renewable Sources   causes of power failure in development of a control scheme for a hybrid renewable energy system(%) ');Xlabel('Time(
Legend('Conventional Intermittency of Renewable Sources  causes of power failure in development of a control scheme for a hybrid renewable energy system(%)',' A
```

```
>> A = [ 1 2 3 4 10];
B = [15 15 15 15 15];
C = [13 13 13 13 13 ];
plot(A,B,'-Sr','MarkerFaceColor','r','MarkerSize',12,'Linewidth',3);
hold on
plot(A,C,'-Py','MarkerFaceColor','y','MarkerSize',12,'Linewidth',3);

grid on
Ylabel('Battery Storage Limitations  causes of power failure in development
Legend('Conventional Battery Storage Limitations causes of power failure in

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