Energy Management And Control Of Dc Micro Grid Wıth Renewable Energy Sources And Dual Energy Storage Devices For EV Chargıng

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ABSTRACT

This paper discusses a DC micro-grid-based electric vehicle (EV) charging system, which is controversial due to the debate on renewable energy and its benefits over AC. The system consists of a sun-directed photovoltaic system (PV) with a supercapacitor (SC) and battery energy storage system (BESS). The goal is to ensure optimal microgrid bus voltage and coordinated power sharing, particularly for EV charging. The strategy considers high-quality energy for DC loading, considering various loads and weather conditions, and solar irradiance. The SC is designed to provide supply during transient periods. The proposed DC microgrid uses two techniques: conventional PID technique and Artificial Neural Network (ANN) controller "feedforward-net" for power flow regulation. SC energy control minimizes voltage variations in the DC bus. An upgraded Maximum Power Point Tracking (MPPT) algorithm based on variable step size incremental conductance (VSSIC) technique is investigated for optimal system performance. A boost DC/DC converter facilitates PV system connection to the microgrid. MATLAB/Simulink is the program that is used considering properly planned task verification of performance.

Keywords: ANN controller, Battery storage system, Modeling renewable sources.

Introductıon

Energy security and sustainability are crucial worldwide, with renewable energy sources like solar, wind, fuel cells, and biomass being preferred over non-renewable sources like oil, natural gas, and coal. The International Energy Agency predicts that fossil fuels will account for around 70% of global electricity generation by 2020. However, non-renewable energy faces environmental concerns, limited resources, and cost competitiveness, leading to a shift towards renewable energy-based power generation [1].

A growing awareness of the need to minimize greenhouse gas emissions and limit human activities' environmental impact is driving a push towards greener power generation. This has led to increased emphasis on technological advancements and reduced demand for fossil fuels, promoting energy independence. However, single renewable sources can have uncertainty, such as solar cells not producing electricity at night or wind turbines requiring sufficient wind flow. Hybrid power generation technology combines multiple sources to meet energy demand, reducing uncertainty and introducing energy storage systems like batteries[2].

1.1. Motivation and approach

Recently, it has been observed that the world surface temperature is rapidly increasing.

Figure 1 depicts the temperature increase from 1880 to 2020. The chart shows that temperature growth is very rapid between 1980 and 2020 [3]. The main contributor to this temperature increase is the release of greenhouse gases like carbon dioxide. The primary producers of these greenhouse gases are power plants, industries, and automobiles. The world is experiencing this phenomenon. Nearly 93 percent of the electricity in Bangladesh is produced using fossil fuels, which produce significant amounts of other greenhouse gases and carbon dioxide. In addition to this, Figure 1 illustrates the total world energy consumption by source. This raises the price of producing electricity. Utilizing renewable energy sources, such as solar power, wind power, etc., will help to solve this issue. This inspires me to create a power generation system based on renewable energy sources.

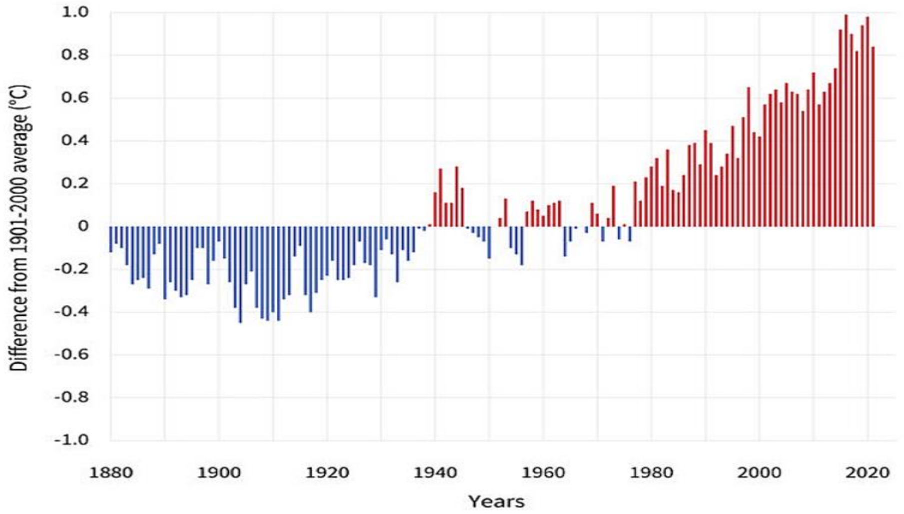

Figure 1. World surface temperature rise over 1880 to 2020 [4]

The author proposes a hybrid power generation system using solar and wind energy to provide a steady supply of electricity for EV charging stations due to the intermittent nature of renewable energy sources.

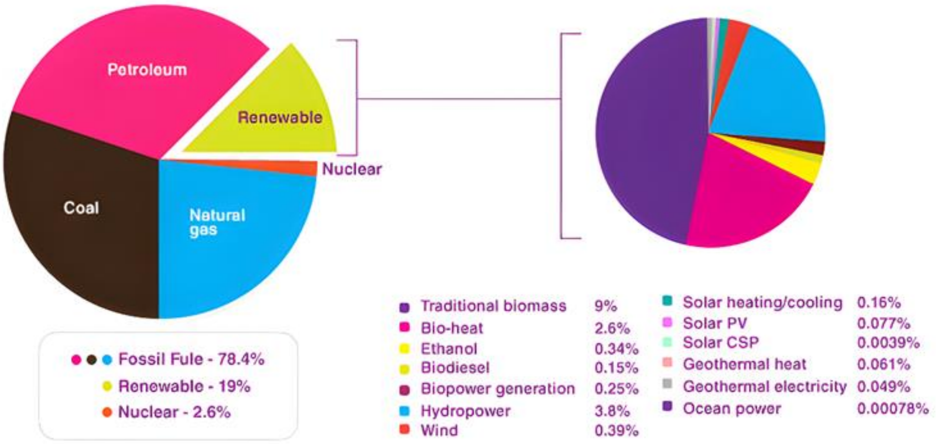

Figure 2. Total world energy consumption by source [5]

Figure 2. illustrates the fossil fuel consumption in the world for electricity production is 78.4% which is a high percentage that is why this thesis used renewable power sources.

1.2. Objectives and Scopes

The primary objectives for this study are-

1) Design and control of photo voltaic (PV), wind turbine model with MPPT control.
2) To design battery and super capacitor model.
3) Design and control of battery storage system for the hybrid system.
4) Modeling a power flow control mechanism for the overall power management.
5) Economic analysis of the proposed model.

2. Methodology

This paper employs a methodology that incorporates photovoltaic (PV) battery storage technologies to investigate the efficacy and potential of a hybrid power generating system. This study's major goal is to evaluate the viability and effectiveness of the hybrid power production system in meeting the needs of various applications for a steady and renewable supply of electricity. The hybrid power generation system's performance under varying operating situations, such as variable weather conditions and load demands, will be evaluated through simulation and analysis. The hybrid power production system's overall cost-effectiveness in comparison to conventional power sources will also be evaluated through economic analysis.

2.1. PV array

The photovoltaic (PV) technology, discovered in the late 19th century, converts light into electricity. It was first used in the 1950s and 1960s for powering satellites and space equipment. Initially, PV systems were large and expensive, limiting their use to specialized applications[6]. However, the 1970s oil crisis and energy independence led to increased research funding and increased efficiency. Residential and small-scale commercial installations began in the 1980s, and the PV industry grew rapidly in the 1990s and 2000s. PV cells, made of semiconducting materials like silicon, convert light into electrical charge, which is collected by electrodes. When connected together, they form a photovoltaic array, capable of powering homes, businesses, and large power plants.

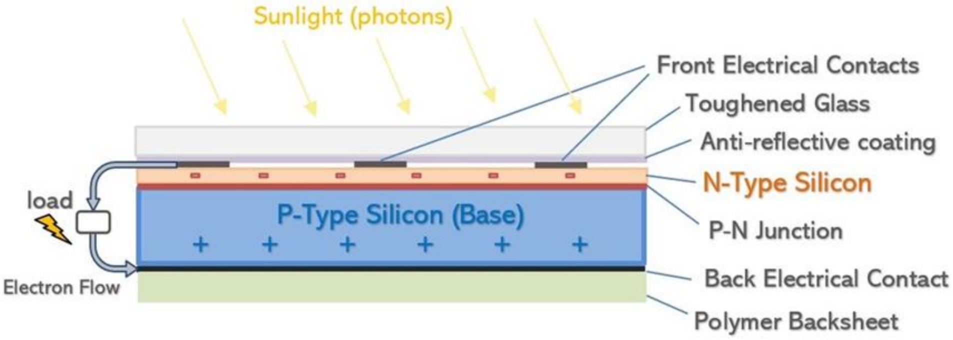

Figure 3: PV cell construction

2.1.1. Maximum Power Point Tracking (MPPT) Design

Maximum Power Point Tracking (MPPT) is a crucial technique for optimizing the energy production of a photovoltaic (PV) system. It ensures that the system operates at its optimal power output, where the voltage and current are balanced. MPPT algorithms monitor these factors at all times, adjusting the duty cycle of the converter feeding the PV array. This technique can significantly improve the overall performance and efficiency of a PV system, especially in rapidly changing environmental conditions. MPPT is used in various applications, including grid-tied and off-grid systems, portable and mobile applications. Control techniques like Perturb and Observe (P&O), Incremental Conductance (IC), and Fractional Open Circuit Voltage (FOCV) are some examples of MPPT control techniques. This dissertation uses the Incremental Conductance (IC) technique[7].

The Incremental Conductance (IC) technique is a simple and effective P&O procedure for locating the highest power point in a photovoltaic (PV) system. It involves manipulating the PV array's voltage and monitoring the resulting current shift. The voltage is adjusted until the maximum power point is reached. The IC method estimates the maximum power point by measuring the incremental conductance of solar cells, which quantifies the rate of change of current over time. This method is popular in residential and commercial solar systems due to its cost, quick reaction time, and ease of installation. It is also used in large-scale photovoltaic systems due to its robustness and high accuracy.Incremental Conductance (IC) method flowchart is illustrated in Figure .4

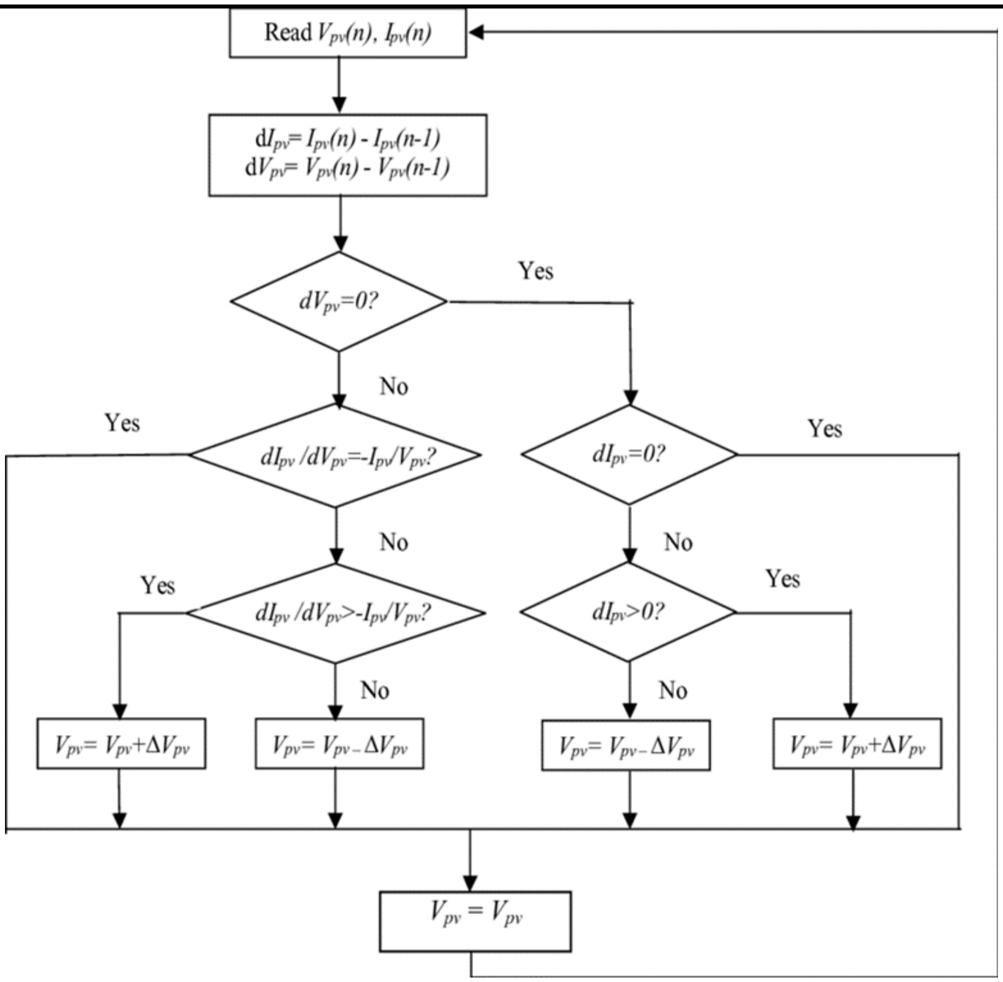

Figure 4. Incremental Conductance (IC) method flowchart

2.2. Wind Energy

A wind turbine consists of a rotor, blades, generator, gearbox, control system, tower, and foundation. The rotor rotates in response to wind, generating kinetic energy. The gearbox raises the generator's speed to extract power. The rotor's kinetic energy is converted into electrical energy by electromagnetic induction. The control system adjusts the blade direction based on wind speed and direction. The tower holds the rotor and generator at a suitable height, while the foundation provides stability. The turbine captures wind energy through aerodynamically designed blades, which are adjusted by the control system for optimal performance and output. Figure 5. represents a wind turbine construction

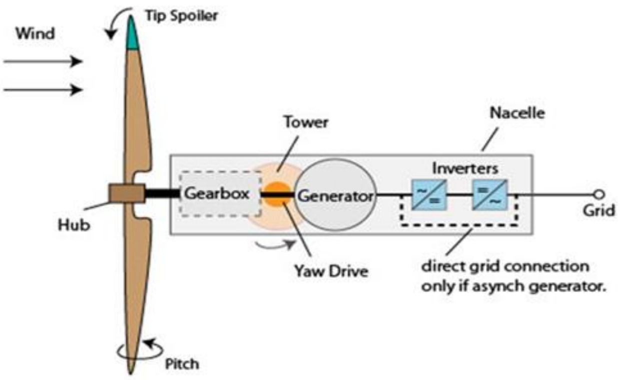

Figure 5. Wind turbine construction

2.2.1. Wind Turbine Modeling

The ratio of the tip speeds of the blades and the pitch angle of the blades are two crucial components of a wind power system and expressed [8]:

$$P_{wt} = \frac{1}{2} C_p(\lambda,\beta) A\rho v_{\omega}3 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad (1)$$

Where P_{wt} = mechanical power extracted, Cp = power coefficient, ρ = air density and A = swept area. λ = tip speed ratio is the ratio of wind speed and blade top portion speed. β = pitch angle blades. v_{ω} = wind speed. Overall, the (λ) tip speed ratio may be expressed the proportion of wind speed to blade tip speed then can be write as:

$$\lambda = \frac{\omega_r R}{\upsilon} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad (2)$$

Where: ω_r is the rotational speed of the rotor in radians/second, and R is the rotor radius in meters. υ is wind speed.

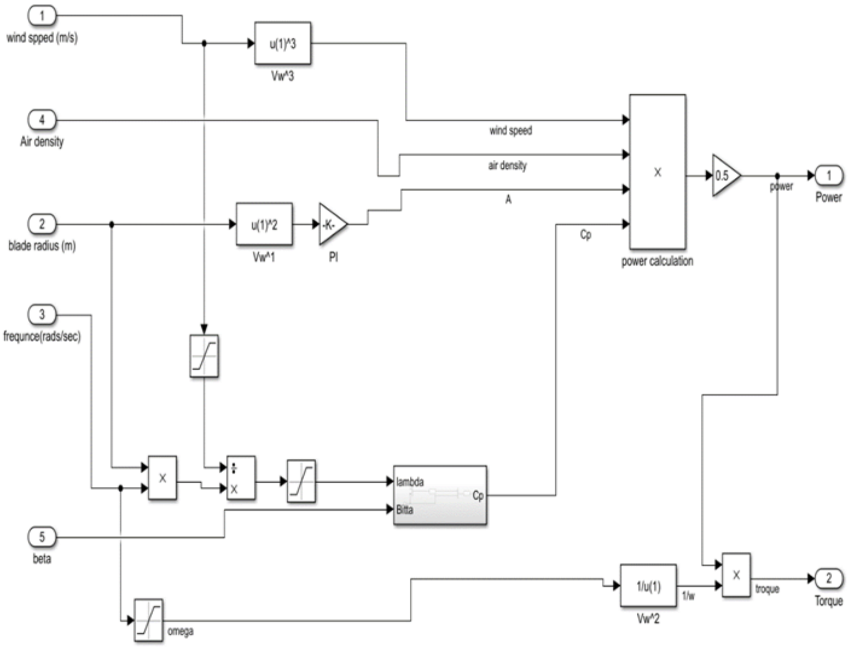

Figure 6. Wind turbine MATLAB Simulink model

Maximum power is harvested from the wind at max Cp in the above equation, which happen for a predetermined top portion speed ratio. Figure 6. represents the Wind turbine's MATLAB Simulink model. Consequently, the control system can ensure that the output power is maximized over a broad range of wind speeds, in accordance with the optimal power output curve.

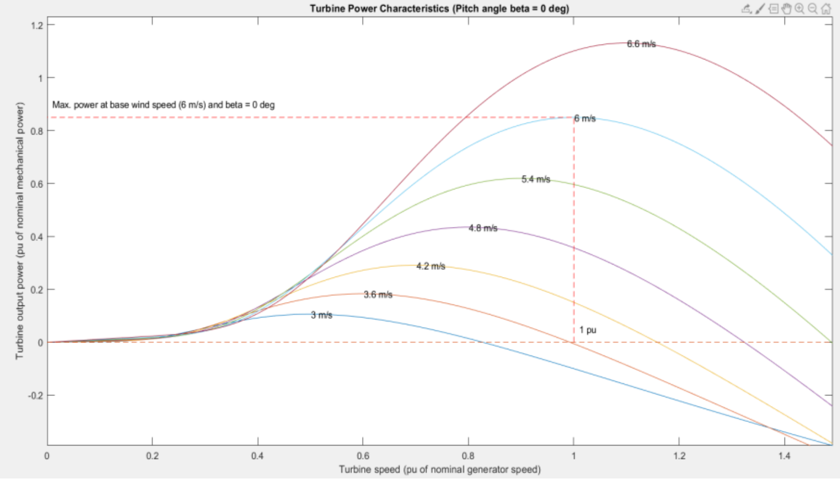

Figure 7. Wind turbine characteristic

This equation is used in wind turbine design and optimization to determine the theoretical maximum power output of a wind turbine. By the proposed model as shown in Figure.7 the wind turbine characteristics can be seen through Figure 7. Where, observed that the power output increases dramatically with even a little increase in wind speed, since the cube of the wind speed is included into the calculation.

Table 1. Parameter of wind turbine

Parameter	Value
Air density	1.08Kg/m^2
Base wind speed	6 m/s
Inertia constant(pu)	4

2.3. Artificial Neural Network

Artificial neural networks (ANNs) are machine learning models trained to identify data structures and extrapolate new information. ANNs consist of three primary parts: the input layer, the hidden layer, and the output layer. The input layer receives data, which is then sent to the hidden layer for weights and biases. The output layer generates the prediction or classification outcome. To train ANNs, it is crucial to tune the model's weights and biases to minimize the difference between expected and actual outputs. Gradient descent and other optimization methods are often used. For example, a deep neural network was used for multi-class classification in a speech recognition system, using input/output layers and two hidden layers[9].

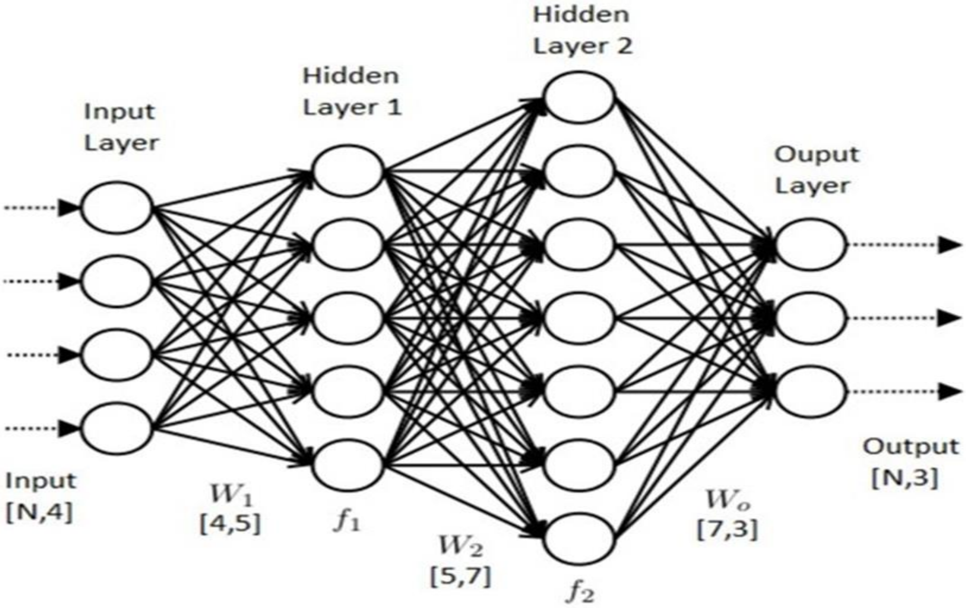

Figure 8. ANN model

The proposed system for training Artificial Neural Networks (ANNs) uses the PID technique to collect input and output data using the "To Workspace" block. The format data is saved as an "Array" for both input and output data. The PID controller is tuned using MATLAB tools through a self-tuning process. The parameters of the ANNs are listed in the next section 2.4. The system is further explained in section 2.4. Moreover, the following parameters of the ANNs are listed below:

1- The training technique is “Levenberg-Marquardt” and the network used is “feedforwardnet” Three hidden layers have been employed, with the neurons of each layer being (50, 10, 10).
2- The training target error (MSE) is 10^{-10}.
3- Data divided, 10% for testing, 10% for validation, and 80% of the data for training.

The procedure for building the ANNs by MATLAB script codes is shown below based on [10].

Create the ANNs model by MATLAB Codes

Step.1: Initialize Network Type is "feedforwardnet"
No. of hidden layers
Neurons of each layer

code. >
```
Network = feedforwardnet([50 10 10]);
```

Step.2: Date Divide To
80% for t training
10% for testing,
10% for validation

code. >
```
Network.divideParam.trainRatio=0.8;
Network.divideParam.testRatio=0.10;
Network.divideParam.valRatio=0.10;
```

Step.3: Set Learning Rate=0.1

code. >
```
Network.trainParam.lr=0.1;
```

Step.4: Set Performance and Gradient goal

code. >
```
Net.trainParam.min_grad=1e-5;
Net.trainParam.goal=1e-10;
```

Step.5: No. of epochs = 600

code. >
```
Network.trainParam.epochs=600;
```

Step.6: Train Network by Input/output Data of PID

code. >
```
Network=train(Network,indata,outdata)
```

Step.7: Export Network to the Simulink Environment

code. >
```
gensim(Network) %% to be used in Simulink model
```

2.4. PID Controller

PID control is a feedback control method used by control engineers to fine-tune the control output to get the system closer to the setpoint. The output is proportional to the error signal, with the integral term accumulating mistakes and the derivative term considering their rate of change. This combination results in a more precise and steady control output. The derivative term foretells future mistakes, while the proportional term corrects existing inaccuracies. PID control offers several benefits, including reliable, precise control over diverse systems with minimal effort and setup time, and a stable control method that adapts well to disturbances and variable system conditions[11].

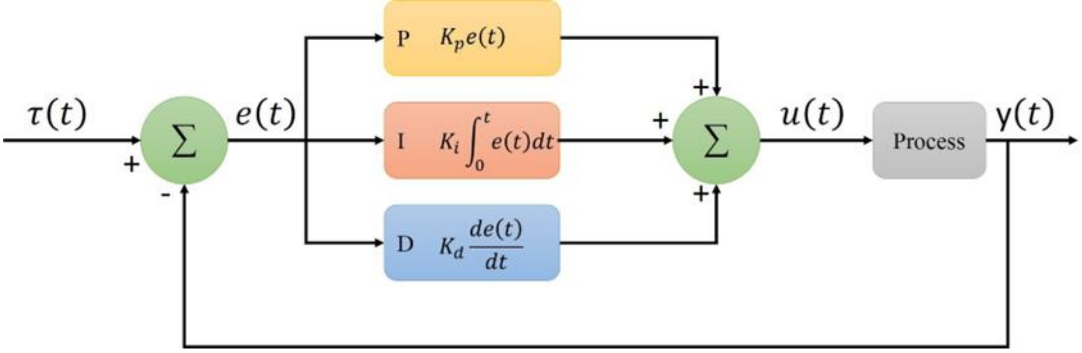

Figure 9. PID controller basic block

PID control is a popular and effective control technique used in fields like process control, robotics, and automation. However, it can be sensitive to system dynamics and requires careful tuning for stable control. It is not suitable for complex systems with nonlinear dynamics. The proposed system uses a PID controller, which is tuned using MATLAB tools called PID autotuner block. The parameters of the PID are Ki (13.7458), Kp (62.6683), and Kd (0.76884).

2.5. Proposed System

A hybrid renewable energy system combining wind and photovoltaic (PV) sources is proposed for research. The system includes a 12.85 kW wind turbine and a 12 kW PV array, with energy stored in a 26.88 kWh battery bank. A 6kW super capacitor will serve as a backup power source during power demands. The control system includes a Maximum Power Point Tracking (MPPT) algorithm to maximize power output, and a state of charge (SOC) algorithm for optimal battery performance. The system will be designed and modeled using simulation software like MATLAB/Simulink, and evaluated under various operating conditions and scenarios. Performance metrics such as energy efficiency, power quality, and reliability will be assessed. The sources are connected in a continuous bus with a voltage of 400V. To ensure sustainable DC bus voltage, the voltage range is determined by the voltage requirements of components like inverter, battery charger, and load. The equipment contains maximum power points to ensure maximum power output and maximum current flow.

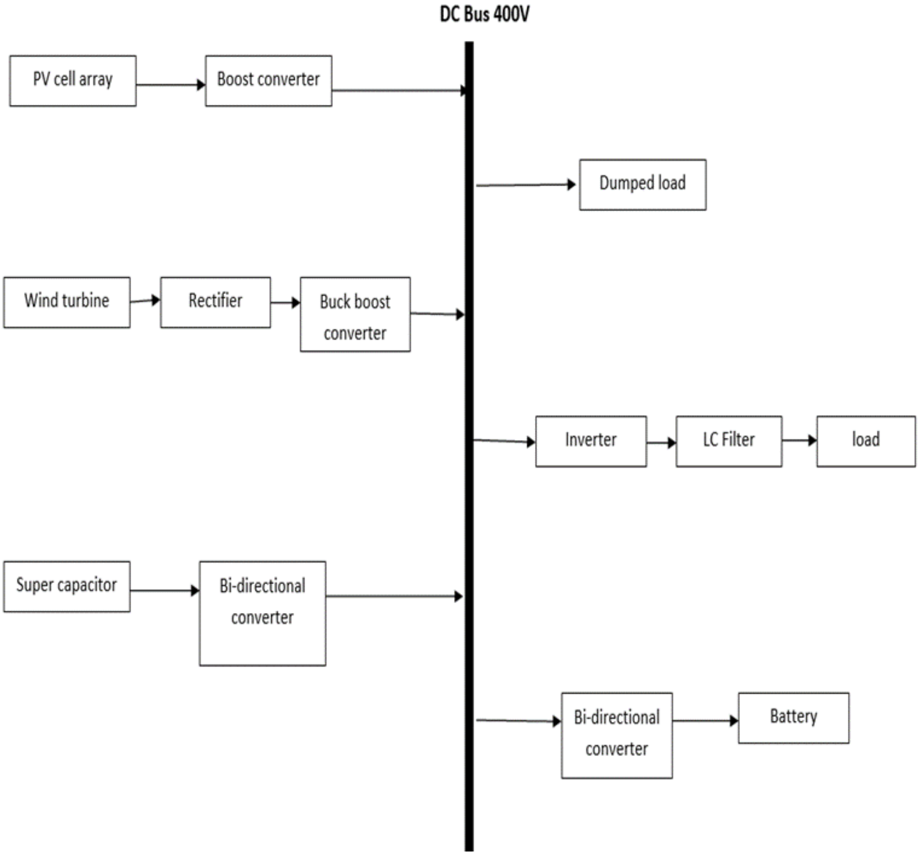

Figure 10. Power flow block diagram

The scenario involves solar photovoltaics and wind as major generators. A DC bus is linked to the PV system using a boost converter, and the generator's output voltage is adjusted based on wind speed changes. A battery storage system is installed for storage, and a supercapacitor is used to maintain electricity during load fluctuations. A power flow diagram is used for management purposes. If the power produced by the PV and WT is less than the load requested or the power differential is greater than zero, the algorithm checks the battery's state of charge (SOC). If SOC is higher than 0.2, the battery is used instead. If SOC is above 0.8, the dumped load is turned on to dump extra power, while the battery is charged. The supercapacitor responds to sudden and rapid load changes, while the battery responds to medium load demand. If the total load for the battery exceeds a threshold, the supercapacitor is turned on to supply power for a short period.

3. RESULTS AND DISCUSSION

3.1. PV Array

The performance of PV arrays is evaluated using varying irradiance, with a total simulation time of 24 seconds. The irradiance figure shows that from 0-5 hours, irradiance is zero, preventing power generation. After morning 6, irradiance increases and output power also increases. A MPPT is connected to ensure maximum power output, which is found at 12 hours at maximum irradiance, almost 12kW. After that, irradiance decreases, affecting power output. At 18 hours, PV output becomes zero, despite sunlight. The output voltage is boosted to 418V for bus connection. A short transient effect is observed in the PV output voltage curve.

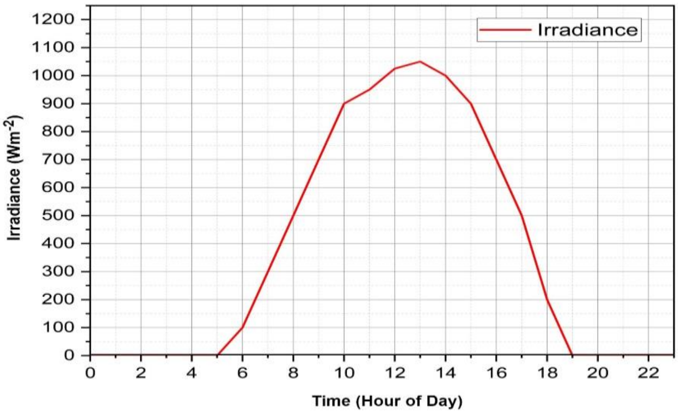

Figure 11. Irradiance

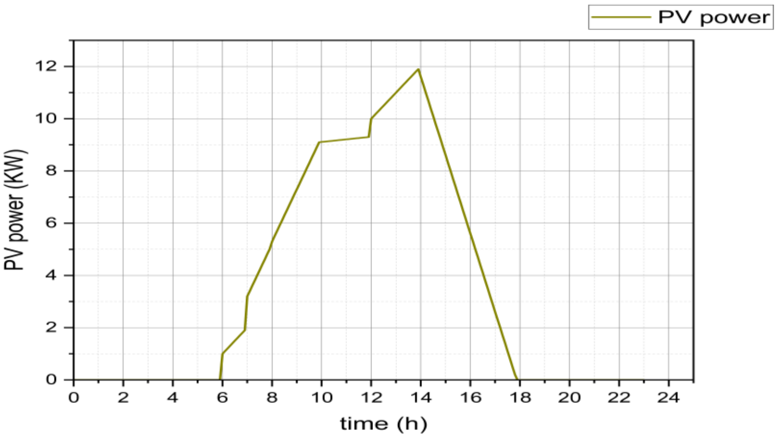

Figure 12. PV power output

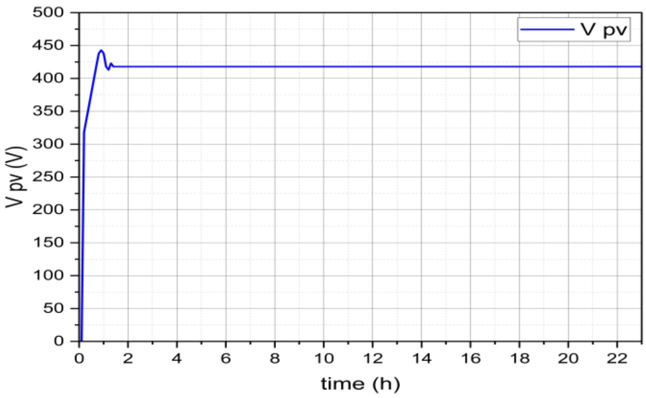

Figure 13. PV output voltage

3.2. Wind Turbine

The wind turbine is analyzed using a constant wind speed of 12m/s, which becomes zero after 10 hours and remains zero after that. The power output of the wind turbine depends on the wind flow speed, so a buck-boost converter is connected to maintain the reference voltage. A permanent magnet synchronous generator (PMSG) is used for electricity generation, with the AC output converted into DC and maintained using the buck-boost converter. The model can deliver a maximum of 11.87 kW of power at the moment of wind flow, but oscillations and power flow due to inertia occur when wind speed becomes zero.From Figure 14. it is seen that at the beginning there is oscillation which is caused by the transient effect.

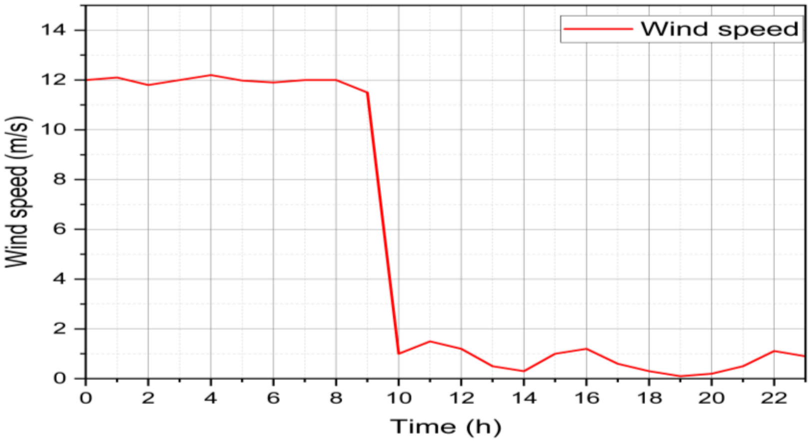

Figure 14. wind speed

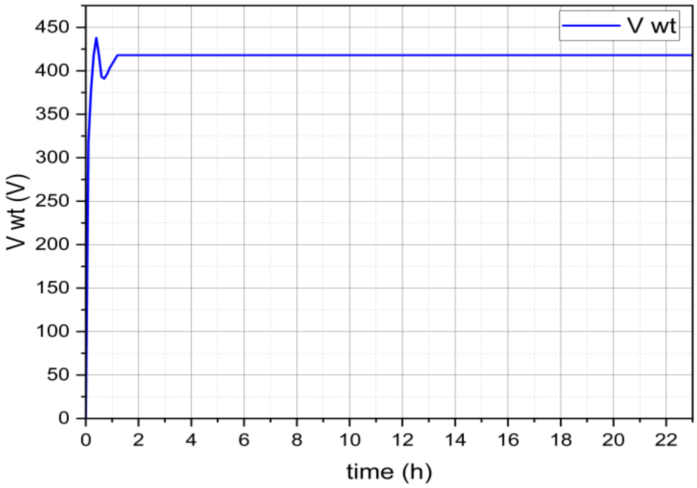

Figure 15. Wind turbine output voltage

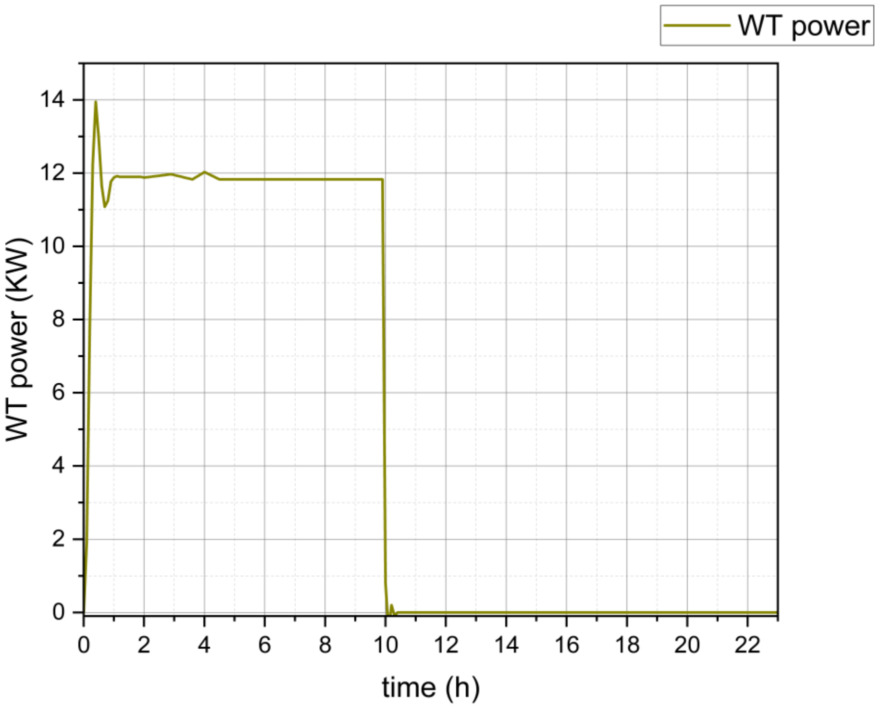

Figure 16. Wind turbine power output

3.3. Overall power management of the proposed system

This study explores two renewable power sources: PV systems and wind turbines. The storage system consists of a battery as the primary storage and a super capacitor as the secondary storage. The super capacitor is used to deliver sudden peak demand when other sources cannot meet it. The load demand peaks at 8KW and the lowest is 5KW, indicating that all sources are trying to meet demand.

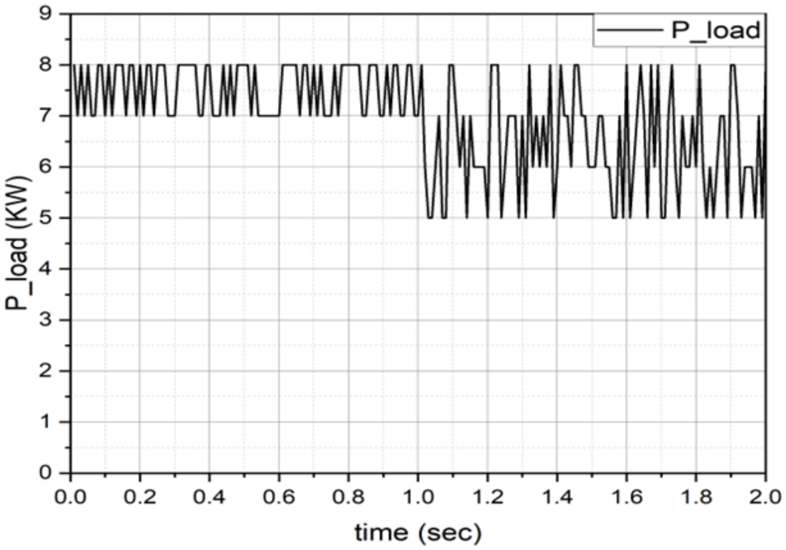

Figure 17. Load curve

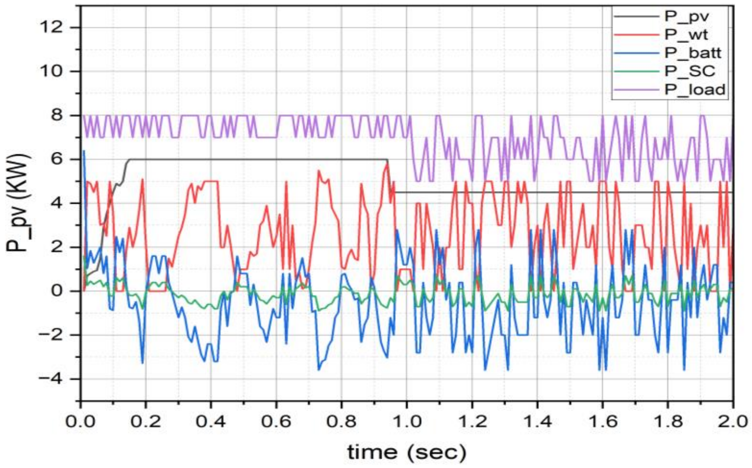

Figure 18. Overall power flow of the proposed system

3.4. Compression between PID and ANN based control

This study compares two control systems: PID controller and ANN controller. PID controller uses three consts to provide high efficiency, but its overall efficiency is near 65% due to energy losses from heat and other sources. ANN controller, on the other hand, uses three hidden layers with 50 nodes, 10 nodes, and 10 nodes. The average power output for ANN-based control is 9.5 KW, while the PID average is 8.1 KW. The study shows that ANN-based control provides significantly better results than PID-based control, providing an average 70% efficiency and a maximum 90% efficiency. The study also shows that ANN-based control can increase power output by almost 30%, with an average power output of 9.5 KW compared to the PID average of 8.1 KW.

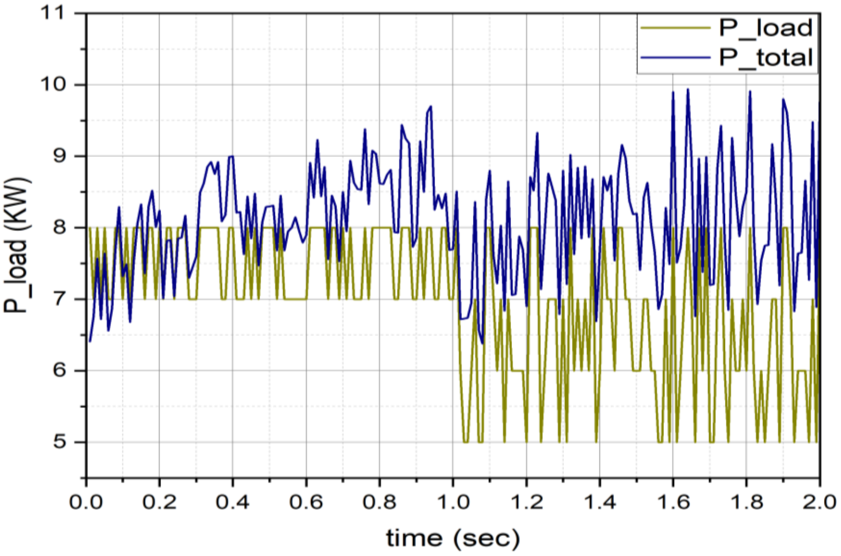

Figure 19. total power output of PID control

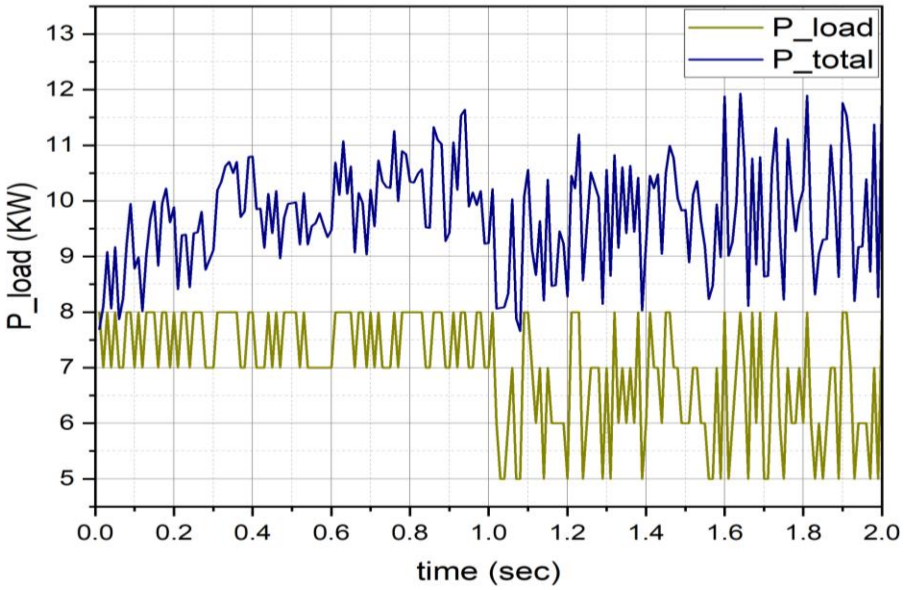

Figure 20. Total power of ANN based control

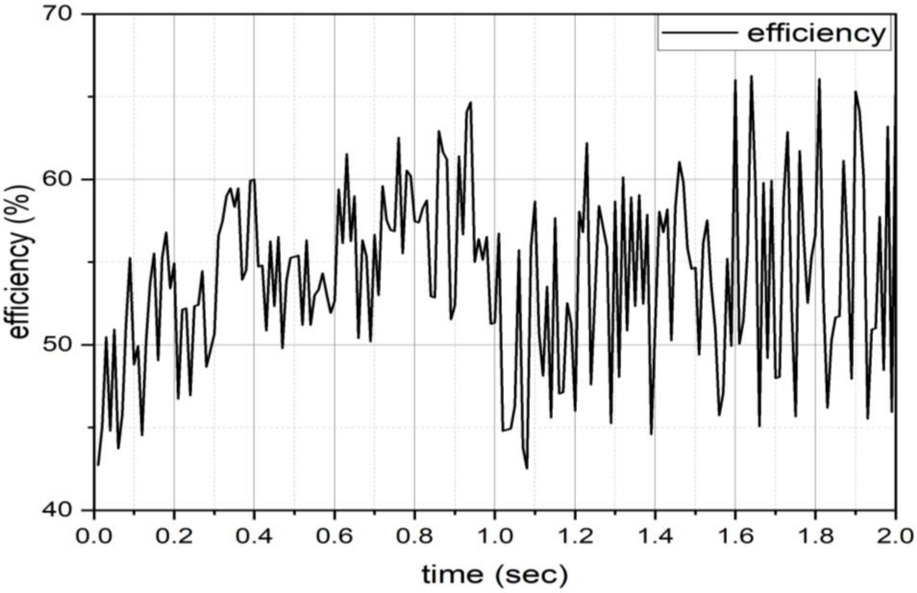

Figure 21. The efficiency of the system with PID Control

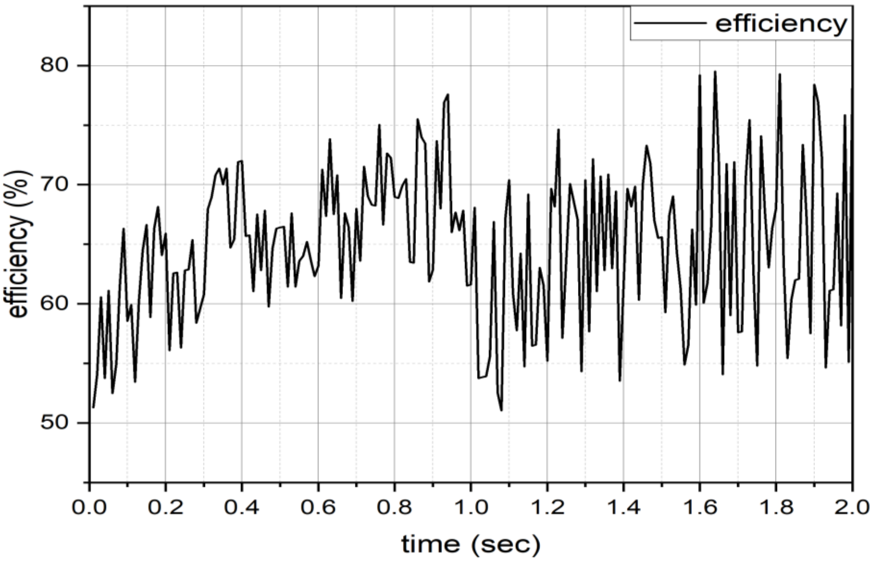

Figure 22. The efficiency of the system with ANN Control

4. Conclusion

The study presents a PV-wind-supercapacitor-battery storage-based EV charging station with PID and ANN-based control systems, demonstrating promising results for efficient and sustainable microgrid operation. The integration of renewable energy sources like solar PV and wind, along with energy storage technologies, offers reduced grid dependence and increased reliability. The study evaluated the performance of PID and ANN control systems, with PID showing satisfactory charging regulation, while ANN-based control system achieved 15% higher efficiency and more power generation.

In conclusion, The PV-wind-supercapacitor-battery storage-based EV charging station with an ANN-based control system is a promising solution for sustainable and efficient charging. Advanced control techniques can improve system performance and energy efficiency. Further research will accelerate the adoption of renewable energy-based charging infrastructure, promoting a cleaner, greener transportation system. The combination of various electrical energy supplies can provide sustainable energy to the system.

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