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Artificial Neural Network with 3-Port Dc-Dc Converter Based Energy Management Scheme in Sustainable Energy Sources

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Abstract: *In micro grids, energy management is referred to as an information and control system that offers the essential functionality to ensure that the energy supply from the generation and distribution systems occurs at the lowest possible operational cost. Energy management systems (EMS) support distributed energy resource utilization in micro grids, especially when variable generation and pricing are present. In this paper, an Artificial Neural Network (ANN)-based energy management approach for a hybrid wind, solar and Battery Storage System (BSS) is presented. To sustain the DC voltage, a 3 Port DC-DC Converter is also proposed. While renewable energy systems have numerous advantages, one of the challenges they face is the intermittency of power generation, leading to fluctuations in the power supply to the grid. Therefore, EMS aims to reduce these variations. Another goal is to maintain the battery state of charge (SOC) within the allowed ranges to extend the battery life. The implementation is carried out in Simulink/Matlab platform. To demonstrate the efficacy of the suggested approach, we compare the Total Harmonic Distortion (THD) of the proposed controller (1.52%) with that of conventional controllers, including the ZSI-based PID controller (3.05%), PI controller (4.02%), and FO-PI (3.32%) controller.*

Keywords: *Artificial Neural Network, Battery Energy System, Energy Management System, State of Charge.*

I. INTRODUCTION

Solar and wind energy are cheap, abundant sources of energy that can provide a country's needs. However, in the absence of a supplemental power generating system or/an ESS, these resources are intermittent, leading to instability in the power generation systems. Integrating numerous renewable energy technologies can increase the system's efficiency without relying on supplementary power systems. Numerous studies have indicated that wind and Photovoltaic (PV) systems might work together effectively to improve system efficiency through better demand-supply coordination. However, the PV/wind hybrid system remains inefficient without an additional power production system or ESS.

Having an energy source that can consistently provide electricity to encounter the load requirement is of utmost importance [1]. A promising approach to achieving safe, dependable, ample, and eco-friendly power generation infrastructure is the merging of wind and PV. These hybrid power systems can replace conventional power plants, lowering greenhouse gas emissions and preserving the planet for future generations.

To effectively counteract Renewable Energy Sources (RES) disturbances in an economically dependent power network, ESS should ideally possess an optimal operational period, high power density, high energy density, and an optimal reaction time [2]. Battery Energy Storage Systems (BESS) are frequently used due to their superior efficiency and energy density. However, their technological limitations prevent optimal adjustment to transient power variations, resulting in a negative impact on the BESS life cycle. As a result, BESS may deteriorate more quickly in such circumstances, significantly reducing its economic significance. Combining various energy storage systems into hybrids allows users to tap into the specific qualities of each ESS [3].

Wind and solar systems are more prevalent energy sources that can be combined as a hybrid power system (HPS) to provide steady power. However, the outputs of these renewable energy sources depend on uncertain environmental variables. The mismatch of actual and reactive powers between the sources and the load can cause problems with power quality and stability when renewable resources are integrated with microgrids [4]. To address these issues, microgrids require appropriate EM control techniques.

Hence, this article proposes an ANN-based controller as an EMS for standalone hybrid power systems (HPS). The primary objective of developing this algorithm is to enhance the efficiency of power transfer between the load and energy sources. The study incorporates PV and wind energy systems along with a battery as the energy sources. By training the ANN network with renewable energy inputs, it generates load power, battery SOC, and target reference power for the storage devices.

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Through this approach, the suggested method effectively generates control signals for different system components to manage energy flow within the HPS, adapting to load variations. The article is structured as follows: Section 2 provides an overview of previous related works. Section 3 describes the proposed energy management process. Section 4 presents the experimental findings, which are then discussed and concluded in Section 5.

II. LITERATURE SURVEY

By combining Artificial Intelligence approaches with multi-objective optimization based on linear programming, Chaouachi et al. [6] presented a generalized paradigm for intelligent energy management in a microgrid. To predict load demand, wind and solar generation 24 hours in advance, they utilize a synthetic Neural Network Ensemble (NNE). The distinguishing features of the suggested machine learning approach are its increased learning model and generalization capacity. The results demonstrate a significant decrease in operating costs and emission levels compared to prior microgrid EMSs that rely on opportunity charging and probability-based battery management.

Hamzeh et al. [7] introduced a decentralized self-adjusting reactive power controller to enable remote monitoring of a multi-bus medium voltage microgrid. The primary goal of the recommended control method for each distributed generation (DG) unit is to distribute reactive power while accounting for the reactive power of the unit's local loads. The suggested management strategy includes an improved droop controller with parameters tuned to the reactive power of the local loads. In terms of the voltage profiles of the microgrid buses, the suggested approach significantly outperforms traditional droop methods. Arcos-Aviles et al. [8] proposed a low-complexity Fuzzy Logic Control (FLC) based EM strategy for a grid-connected residential microgrid incorporating RES and ESS. The proposed method regulates grid power based on battery SOC and microgrid power forecast error. A simulation comparison with previous EMSs demonstrates the advantages of suggested strategy, which reduces fluctuations and power peaks in the power profile transmitted into the grid while keeping the energy stored in ESS within safe bounds.

Solanki et al. [9] proposed Microgrid EMS architecture with a model predictive control method that produces optimal dispatch decisions for dispatchable producing units, ESSs, and controllable load peak demand. A Neural Network (NN) load estimator was used to determine smart loads as a function of the environment's temperature, time of day, pricing at the point of consumption, and the microgrid operator's enforced peak demand. The outcomes demonstrate the viability and advantages of the suggested models and methodology. In the instance of a microgrid on an island, Moussa [10] introduced a new angle droop approach for distributing power among parallel inverters in the situation of an islanded microgrid. However, this approach leads to changes in the system frequency and voltage. To address this, a secondary loop is incorporated in the droop control to optimize power sharing and restore the frequency and voltage to their nominal levels. In some instances, a communication link is established between a centralized controller and each linked droop control. A one-loop flatness-based control is used to accurately manage the output voltage of inverters with low THD and high bandwidth.

To prevent the DC voltage changes of the converters with droop control exceeding their limits during critical stages, and to keep the overall multi-terminal direct current (MTDC) system's high power-sharing capabilities, Wang *et al.* [11] presented an adaptive Voltage Droop Method (VDM) strategy. This approach ensures that the overall MTDC system maintains its power-sharing capacity while also keeping each converter's DC voltage and power loading rate within safe operating ranges during major disruptions. For power sharing amongst DC sources, Azizi*et al.* [12] have proposed droop-based control methods, Energy management strategies, on the other hand, use communication networks to monitor demand, renewable energy production, and energy levels in storage containers in order to run energy sources more effectively. Simulations were conducted to assess the feasibility and efficacy of the suggested technique, and validated the results. In microgrids with islanded resistive low voltage, a unique control technique for parallel inverters was introduced by Razi*et al.* [13]. By employing an appropriate feed forward term, this technique mitigates the impact of innate inverter impedance. The findings support the suggested control strategy's applicability even in the presence of multiple inverters and local loads.

More prevalent energy sources include wind and solar systems, which can be combined as a HPS to produce steady power. However, the outputs of these RES depend on uncertain environmental variables, leading to mismatches between actual and reactive powers when integrated with microgrids, causing issues with power quality and stability [5].

III. PROPOSED METHODOLOGY

Fig.1 shows the architecture of suggested methodology. The two RES used in this strategy are Wind and PV. Solar energy is harnessed during daytime hours, while wind energy remains continuously available throughout the day, with no fixed period of availability. However, there are instances where night-time wind energy surpasses that of daytime. Hence, the two energy sources are integrated to enhance the microgrid's dependability and sustainability while reducing the ESS size. Thus, the proposed system comprises of a three-port DC-DC converter coupled with solar, wind, and batteries. The hybrid RES generates the input DC electricity. A PV array made up of three parallel stings makes up the solar energy system. Each string consists of modules. A wind turbine is mechanically linked to a 3-kilowatt Permanent Magnet Synchronous Generator (PMSG) to form the wind system. The AC electricity generated by the wind energy system is converted to DC using a rectifier circuit. The batteries are connected to the suggested bidirectional DC-DC converter, while the PV and wind power systems are connected to the planned three-port DC-DC converter.

During excess electricity production by the solar and wind power sources, the batteries charge, and they degrade when the power generated is insufficient to meet the load requirement. For the proposed hybrid system, the ANN controller is proposed to be in either a charging or discharging state to attain the appropriate SOC value. The bidirectional converter connects the battery cells to the DC bus, typically using a DC/DC converter. Furthermore, the PV and wind systems are linked to the shared DC bus through a three-port DC-DC converter, enabling bidirectional power delivery. The battery storage is already connected to this bus through a bidirectional DC-DC converter to facilitate power flow in both directions.

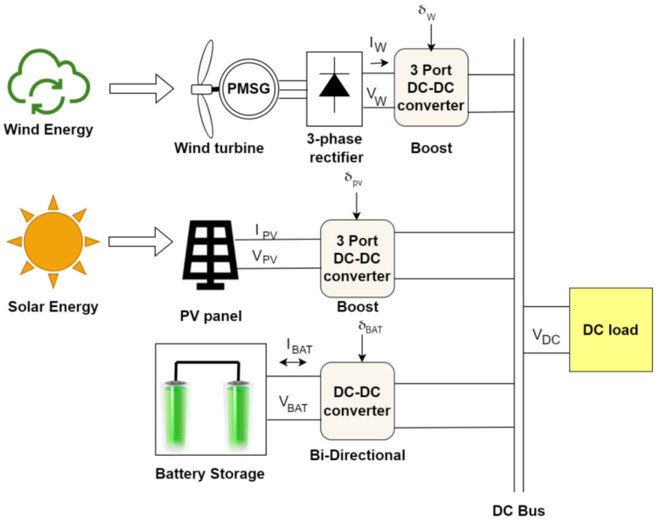

Fig.1. Structure of proposed method

A. Solar Energy

The single-diode PV model is chosen for modeling the PV module because along with its accuracy and simplicity, which is displayed in Fig.2 as the equivalent circuit. The following expression can be used to describe the PV module's non-linear current-voltage characteristic [14].

$$I = I_{PV} - I_0\left[\exp\left(\frac{v + R_S I}{\alpha V_t}\right) - 1\right] - \frac{V + R_S I}{R_P} \qquad (1)$$

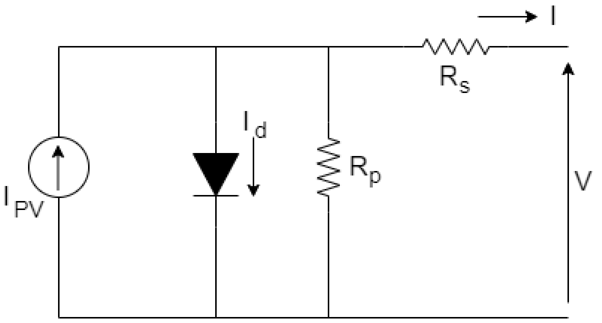

Fig. 2. Equivalent circuit of PV model

Where, the diode ideality factor is denoted as α , PV current is I_{PV} , the reverse bias current is I_0 , parallel, and series resistances are R_P and R_S thermal voltage is V_t respectively.

B. Wind Energy

The mechanical power through wind P_m mathematical model is expressed by Eq. (2),

$$P_m = 0.5\rho\pi R^2 V_w^3 C_p(\lambda,\beta) \qquad (2)$$

Here, air density is ρ [kg/m3], blade radius R [m], wind speed is V_w [m/s], tip speed ratio is λ , the blade pitch angle is β , and power coefficient is C_P . These parameters are evaluated by following Eq. (3),

$$C_p = 0.5(\lambda_i - 0.022\beta^2 - 5.6)e^{-0.17\lambda_i} \qquad (3)$$

$$\text{Where, } \lambda = \frac{\omega_B R}{V_w} \text{ , } \lambda_i = \frac{3600R}{1609\lambda}$$

Where, rotational blade speed is denoted into ω_B [rad/s].

C. Battery Storage System

The BSS is made up of a buck-boost bidirectional DC-DC converter and a lead acid battery. This converter is in charge of keeping the DC bus voltage via an ANN controller. According to the SOC [14],

$$SOC = 100 + \left(1 + \frac{\int I_{bat}dt}{Q}\right) \qquad (4)$$

Here, I_{bat} and Q is denoted as battery current and capacity, respectively.

The battery operates in two different ways, charging and discharging, depending on how much energy the sun and the wind generate. Due to the energy restrictions set by the SOC limitations, the battery typically functions in these two modes.

$$SOC_{\min} \le SOC \le SOC_{\max} \qquad (5)$$

D. Three Port DC-DC Converter

Fig. 3 depicts the proposed three port DC-DC converter. The suggested EMS approach utilizes 3-port DC-DC converter which is designed to function as a stand-alone unit. The power switches (S1, S2, and S3) and the diodes (D4 and D5) that are connected to them provide the bidirectional path. The majority of the components share characteristics in many operating modes, according to the structure [15]. The channel provides a unidirectional or bidirectional path to transfer power between the input source, battery, and load, depending on the switching method. The converter has the capability to regulate incoming power and output voltage using two separate duty cycles, depending on the employed switching strategy. The typical independent converter operates in three modes, which are executed by the two duty cycles. The duty cycles of the suggested converter are divided, enabling independent regulation of input power and output voltage. One duty cycle is responsible for battery charging and discharging modes (d2). Furthermore, the analysis assumes the components to be ideal and employs continuous conduction mode for evaluation.

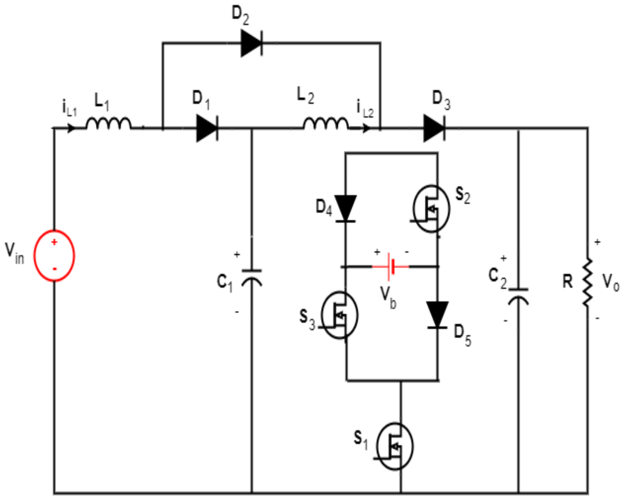

Fig. 3. Proposed 3-port DC-DC converter

The PV source and storage port are considered as a DC source with constant power and a lead-acid battery is used to supply the load. The input power and battery state have an impact on the converter operation modes. There is no need to use more battery power or more power to recharge the battery when the highest input power and load power are equal. When the highest input power and load power are equal, there is no need to use more battery power or more power to recharge the battery. The converter's default operating mode is depicted when it functions as a quadratic boost converter. In scenarios where the maximum input power exceeds the output power, the second operating mode is configured for high input power situations. In this mode, the input source powers the load while also charging the battery. However, when the output power surpasses the power generated in the input port, the battery's capacity proves insufficient to meet the demand. In such cases, the third operating mode is activated to address this circumstance.

E. ANN-Based Energy Management Scheme

A computational model called ANN is based on the components and operations of biological neural networks. ANN's internal structure is modified in response to input and output. When the complicated relationships between input and output are modeled, ANN is a nonlinear statistical data. The layers of an ANN contain numerous interconnected nodes, sometimes stated to as neurons. Here, the ANN is trained using the back propagation approach.

ANN which combines poor-level computational ability with superior-level reasoning has evolved as a hybrid soft computing technology. An effective adaptive network, or ANN, may represent complicated, nonlinear systems with fewer input parameters and the desired output parameters. Like the human brain, the ANN controller functions which is displayed in Fig.4. ANN has a number of synthetic neurons that function like those in the human brain. The reference tracking error information is provided as input to the ANN in order for it to generate the control pulses for the converter.

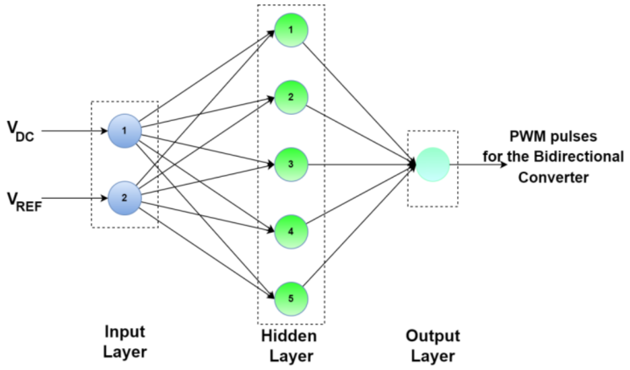

Fig. 4. Structure of ANN

In both online and offline modes, a stable operating frequency is attained to control the three-port DC-DC converter. The ANN controller is designed through the knowledge of the converter's functional behavior. Fig.5 illustrates the ANN controller for implementation.

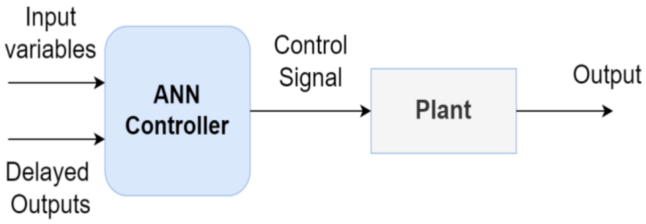

Fig. 5. Scheme for controller implementation

While controlling the PV, WGS, and batteries shown in Fig. 6, the recommended method enhances the power exchange between the source and load sides.

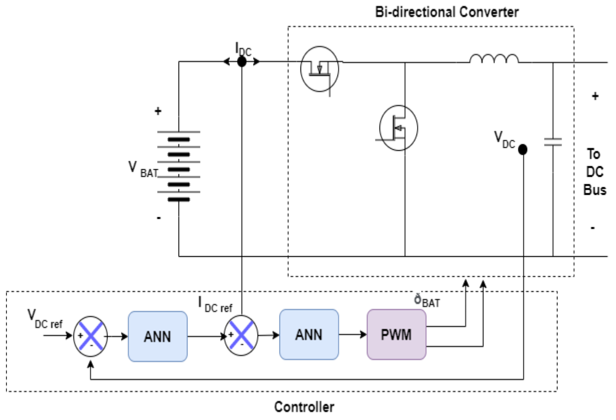

Fig. 6. BES system with ANN controller

The EMS control mode serves as the basis for the functioning of all converter controllers discussed in the preceding sections. Depending on the power generated, the boost converter in the solar energy conversion system can operate in either MPPT or off-MPPT mode. The DC-DC boost converter in the wind energy conversion system operates in boost mode, while the bidirectional converter for the battery remains in charging or discharging mode, maintaining a constant DC bus voltage. Balancing the power in the microgrid is essential under various conditions of renewable energy output and load consumption. The power balance Eq. (6),

$$P_w + P_{pv} = P_L + P_{bat} \quad (6)$$

Where, wind, PV, load, and battery power is denoted as P_w, P_{pv}, P_L, and P_{bat} respectively.

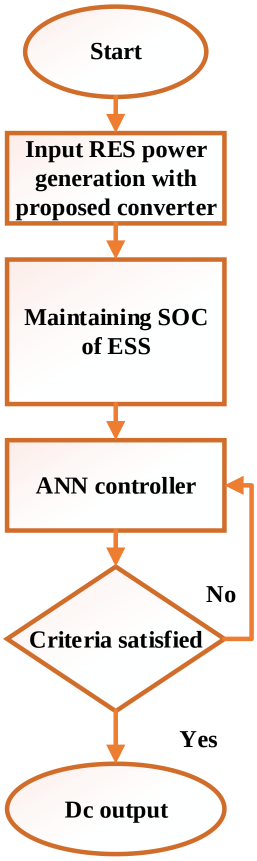

Fig.7. Flow chart of the proposed method

Fig. 7 illustrates the flow chart of the proposed method. The EMS operates in four modes, with each mode of operation influenced by two variables: the electricity generation capacity and the battery's charge level. The first mode occurs when the electricity generated by solar and wind sources exceed the load's power requirements. During this operation, the battery is charged up to its maximum (SOC max). If the battery's SOC reaches SOC max, the MPPT controller switches to off-mode, limiting solar power generation to prevent excess power generation beyond the load's demand. The surplus power is not used to recharge the battery; instead, the battery supplies any additional power needed by the load. However, when the battery's SOC falls to the minimum SOC (SOC minimum), the power supply cannot meet the load demand, requiring load shedding to maintain power equilibrium. This situation arises when the energy demand from the load surpasses the combined energy production from wind and PV energy sources.

IV. RESULTS AND DISCUSSION

The suggested system was created using the 2023 online version of the MATLAB/Simulink platform on an Intel Core i5 processor-based workstation with 4 GB of RAM. Fig. 8 depicts the Simulink model of the proposed system.

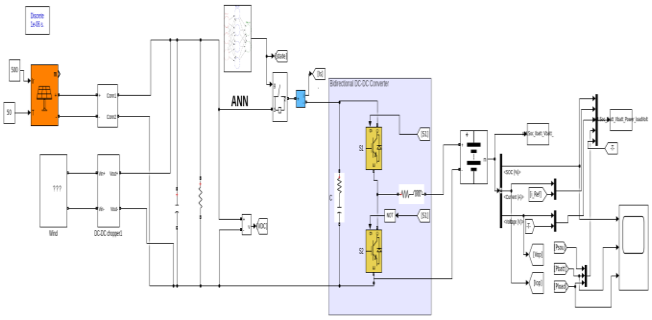

Fig. 8. Simulink Model of Proposed Work

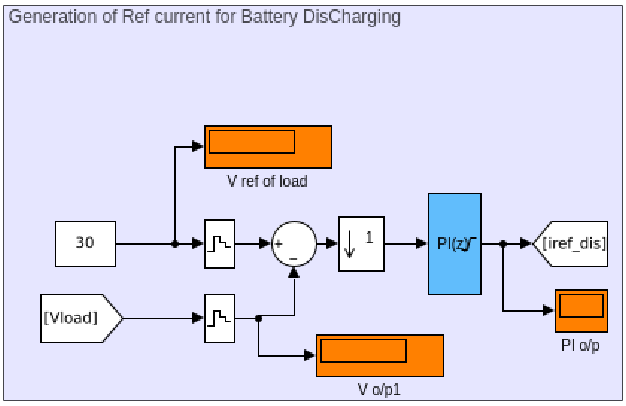

Fig. 9. Generation of Ref current for battery discharging

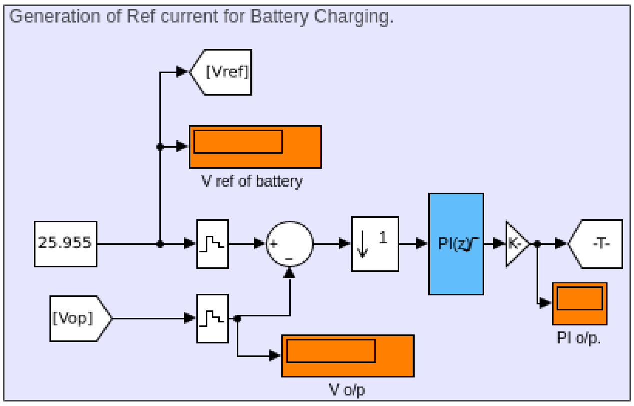

Fig. 10. Generation of Ref current for battery charging

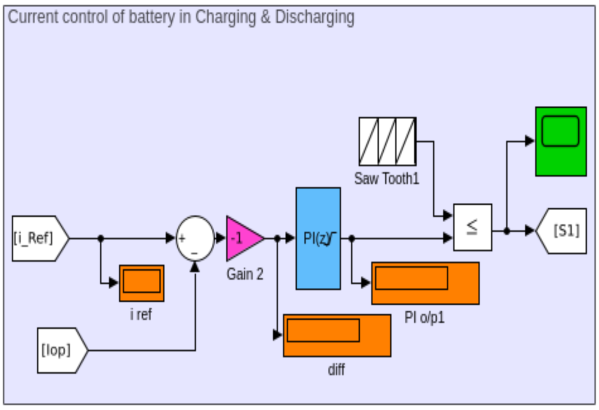

Fig. 11. Current control of battery

Fig. 9 and Fig. 10 shows simulation blocks of reference current generation for battery discharging and charging, respectively.

Fig. 11 shows the simulation block of current control of battery in the process of charging and discharging.

The PV voltage output is displayed in Fig. 12. The PV output current is depicted in Fig. 13. The PV output power is 83V. The PV current is 4.8A. The solar energy system produces a total power of 398.4 watts.

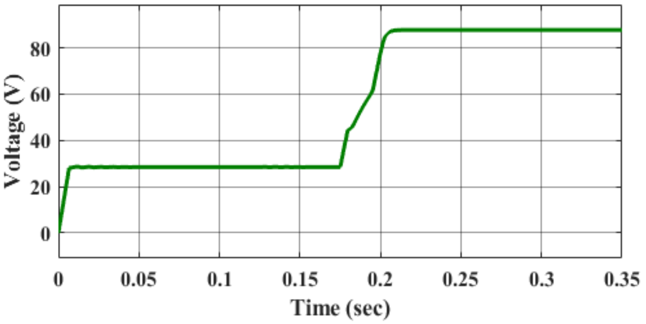

Fig. 12. Simulation Output for PV Voltage

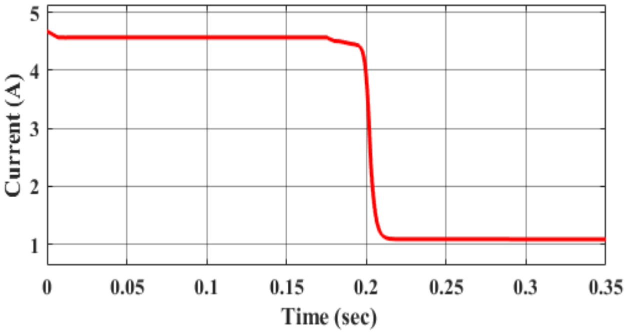

Fig. 13. Simulation Output for PV Current

However, since weather conditions are always shifting, the variations in sun irradiance and wind speed are essentially step fluctuations that never happen in the real world. To evaluate the system's functionality for these variations, these values are chosen so that they fluctuate between the PV panel and wind turbine potential maximum and lowest operating ranges. The load must be kept constant to evaluate the effectiveness of the renewable energy conversion systems and the battery storage system for changes in the power supplied by RES. This assessment would be difficult if the load is constantly changing. The wind power simulation output is displayed in Fig. 14.

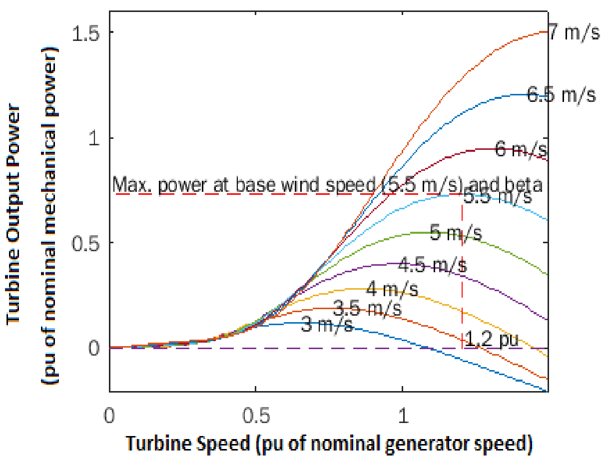

Fig.14. Simulation Output for Wind Power

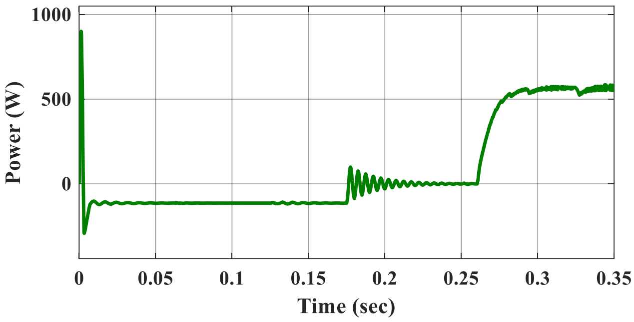

Fig. 15. Simulation Output for Battery Power

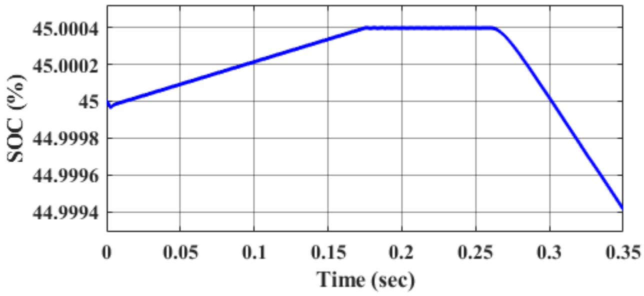

Fig. 16. Simulation Output for SOC

Fig.15 displays the battery's power. When electricity from RES is reliable, the EMS maintains a power balance for both decreased load requirements and higher load demands. The batteries are charged for smaller loads and drained for heavier loads. Fig.16 illustrates these fluctuations in the battery's SOC.

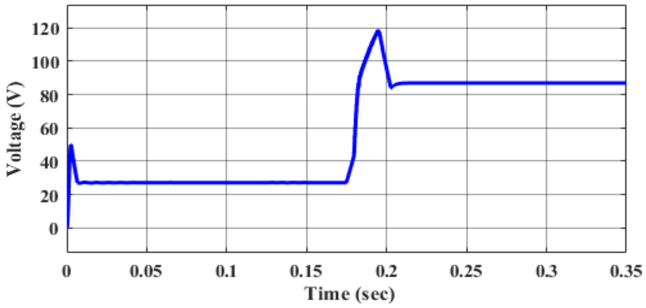

Fig. 17. Simulation Output for Converter Voltage

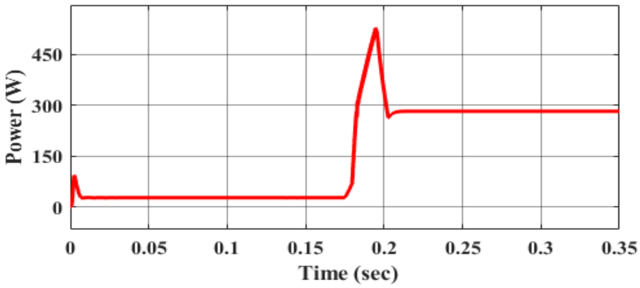

Fig. 18. Simulation Output for Load Power

ESS maintains a constant DC bus voltage of 180V to accomplish power balance, as illustrated in Fig. 17. As observed from Fig. 18, the power generated by wind and PV energy conversion devices exceeds the load requirement for the first 10 seconds, and the excess power charges the battery.

After that, discharging begins, and the discharge level varies depending on changes in the power deficit from RES at different periods.

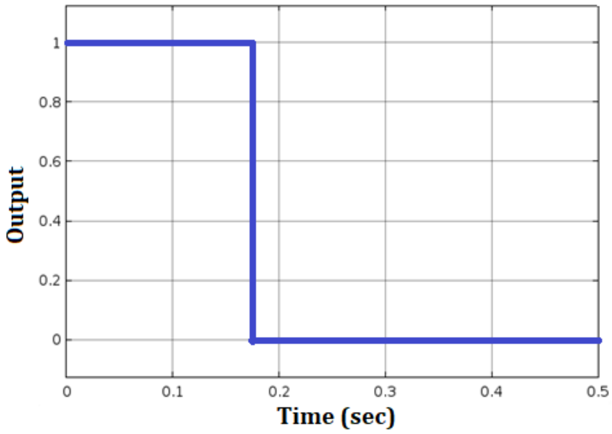

Fig. 19. Simulation Output for ANN

The suggested ANN-based energy management plan detects the required power and the available energy generation while setting the reference power levels for the storage devices. In situations where wind and solar energy sources cannot produce the required power due to insufficient inputs, the proposed control technique efficiently manages load demand. The findings shown in this part make it abundantly evident that the suggested energy management scheme effectively handles the load with renewable power sources and power from storage devices without any shedding. It also efficiently controls the power flow from storage devices. The control pulse generated by ANN is depicted in Fig. 19.

Table-1: Comparison of Total Harmonic Distortion

Methods	THD (%)
Proposed 3 port-ANN	1.52%
ZSI based PID [16]	3.05%
ZSI based PI [17]	4.02%
FO-PI [18]	3.32%

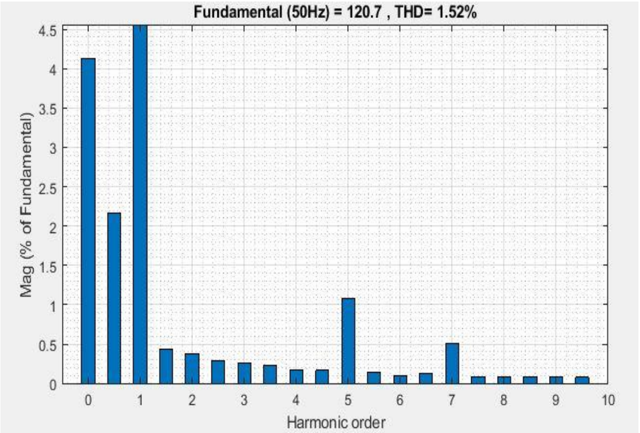

Fig. 20. Investigation of current THD

Table 1 shows the Total Harmonic Distortion (THD) evaluation. Fig.20 shows the proposed method of THD evaluation. The corresponding table comparison gives the THD values of the existing and proposed method. The proposed 3 port DC-DC converter with ANN controller exhibits 1.52% of THD. ZSI-based PID controller gives 3.05% THD, PI controller produce 4.02% distortion value, and high gain multi-level inverter-based FO-PI controller gives 3.32% of distortion. The level of distortion is reduced by the 3-portDC-DC converter with ANN.

V. CONCLUSION

A load-connected hybrid system that consists of batteries and RES (PV, wind) has been constructed using an ANN-based energy management system. By utilizing an ANN controller, the battery SOC is kept at the desired level to extend battery life and conserve excess power generated by solar panels and wind turbines. Whether the initial value of the SOC is low or high, the battery's SOC can be maintained at a set level by the suggested converter system with ANN controller. The performance of the ANN controller can be enhanced by tweaking the weights and future work will implement a novel optimization method for ANN controllers. To show the effectiveness of the proposed methodology, a potential driver THD (1.52%) is compared with existing controllers such as the ZSI-based PID controller (3.05%), PI controller (4.02%), and FO-PI (3.32%) controller. The level of distortion is reduced by the 3-portDC-DC converter with ANN. In future work, the battery SOC is regulated using an advanced machine learning approach with soft computing techniques like metaheuristic optimization algorithms.

DECLARATION

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Ethical Approval and Consent to Participate	No, this article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	No, it does not relevant.
Authors Contributions	All authors having equal contribution for this article.

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