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OPTIMIZING SOLAR-WIND HYBRID ENERGY SYSTEM USING ARTIFICIAL NEURAL NETWORK

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ABSTRACT: This paper shows a Boost Converter for a Hybrid Solar Wind System (HSWS) for an AC and DC load using a battery energy storage simulation model using Artificial Neural Network(ANN). Simulation results conducted in MATLAB/Simulink environment validate the system's effectiveness .The growing environmental concerns and the rapid growth in the energy demand, led to an alternative for the currently used conventional energy resources. Renewable energy technology is the best option, but they are uncontrollable and unpredictable in nature, because of which steady output cannot be obtained. Therefore, MPPT techniques are used to maximize power extraction in hybrid generation. Common MPPT techniques used in hybrid systems are Perturb and Observe method, Incremental conductance, fuzzy logic and ANN- based MPPT techniques. Among the various MPPT techniques available, the Artificial Neural Network (ANN) method is preferred due to its superior accuracy and rapid tracking performance. The ANN-based controller demonstrates superior performance in tracking maximum power point under varying environmental conditions compared to conventional MPPT techniques.

Keywords : AC Microgrid, Hybrid Energy System, Neural Network, PV generation , Renewable Energy Source

I. INTRODUCTION

The increasing global energy demand and growing concerns over environmental sustainability have prompted significant interest in Hybrid Renewable Energy Systems (HRES), especially for powering domestic appliances in areas with inconsistent grid access. By combining Solar PhotoVoltaic(PV) and Wind Energy Sources with Battery Storage, provide a stable and sustainable power supply while improving energy independence and reducing carbon emissions [1], [7]. The use of Boost DC-DC converters is essential in these systems to elevate the inherently low and fluctuating voltage levels from PV and Wind inputs to meet the required operating levels of domestic loads [3], [5].To efficiently manage the power generated from these intermittent sources, DC-DC Boost Converters are employed to regulate and elevate the low voltage output from PV panels and Wind generators to a higher, stable DC bus level. This step is crucial for maintaining voltage consistency required by household electrical appliances [3], [5]. The inclusion of a battery backup further enhances the system's reliability by storing excess energy during peak generation periods and supplying power during periods of low renewable availability [2], [4].

A major challenge in Hybrid systems is ensuring maximum energy extraction from fluctuating sources. Traditional MPPT (Maximum Power Point Tracking) techniques often fall short under rapidly changing environmental conditions. To overcome this, Artificial Neural Networks (ANNs) have been increasingly adopted due to their adaptive learning capabilities and nonlinear mapping features. ANN-based MPPT controllers dynamically adjust converter duty cycles to track the optimal operating point of PV and Wind systems, resulting in improved tracking speed, accuracy and overall system efficiency [12], [20], [22]. In addition, ANN controllers enhance battery management by optimizing charge/discharge cycles, extending battery life and ensuring stable load supply [6], [21].

In this paper, a Boost Converter-based PV-Wind Hybrid Energy System with Battery backup is proposed and modeled using ANN-based MPPT controllers. The system is designed specifically for domestic applications, where reliability, efficiency and seamless energy delivery are essential. The proposed architecture intelligently coordinates multiple energy sources and storage, maintaining stable AC power output through an inverter for household use. The system aims to address practical challenges in renewable integration, including variability, energy loss, and response time, through the application of ANN based intelligent control strategies.

II. SYSTEM ARCHITECTURE

Fig.1 shows the proposed system architecture integrates Solar PhotoVoltaic (PV) panels and a Wind turbine with a Battery storage unit to supply uninterrupted power to domestic appliances. Both the PV and Wind subsystems are connected to individual Boost DC-DC Converters, which step-up their respective low and variable DC outputs to a common DC bus level [3], [5]. An Artificial Neural Network (ANN) controller is implemented to perform Maximum Power Point Tracking (MPPT) by adaptively adjusting the converter duty cycles for both sources based on real-time Climatic factors like solar irradiance and wind velocity are considered as input parameters [12], [20], [22].

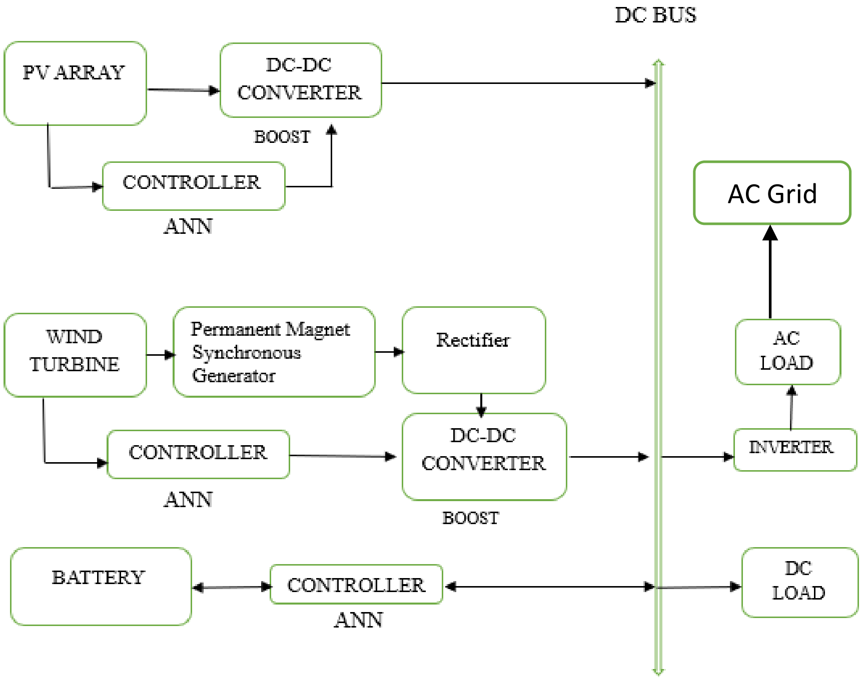

Fig. 1 Block diagram of a Hybrid Energy System

The battery bank, managed by a bidirectional converter, stores excess energy and supplies power during low-generation periods to improve system reliability [2], [4], [6]. The regulated DC output from all sources is then fed into a DC-AC inverter, which delivers a stable AC supply suitable for domestic loads. This intelligent and modular architecture ensures efficient power extraction, reliable energy management and consistent performance under variable operating conditions [7], [21], [23].

A. Hybrid Energy System

The proposed Hybrid Energy System consists of a Solar PhotoVoltaic (PV) array, a Wind turbine generator and a Battery backup unit, all integrated to form a coordinated Renewable Energy Source. The PV array captures solar irradiance and produces a variable DC output, which is stepped up using a Boost DC-DC converter controlled by an ANN-based MPPT algorithm to ensure maximum power extraction under varying sunlight conditions [3], [12], [20]. Simultaneously, the Wind subsystem, comprising a turbine coupled to a Permanent Magnet Synchronous Generator (PMSG), generates variable AC power, which is rectified to DC and further regulated by a separate Boost converter. This is also governed by an ANN-based MPPT to adapt to changing wind speeds [2], [5], [21]. A Battery storage unit is connected via a bidirectional DC-DC converter, allowing it to store excess energy and supply power during periods of low generation or high demand. The ANN controller also manages the charge and discharge cycles of the battery to improve energy efficiency and ensure system stability [4], [6], [22]. This integrated Hybrid configuration ensures continuous, optimized Renewable Energy availability regardless of environmental variations.

B. Boost Converter

Fig.2 shows Elementary Circuit Of Boost Converter. It is a high-efficiency DC-DC power electronic converter used to step up the low-voltage output from renewable sources like PV panels and Wind turbines to a higher, regulated DC voltage suitable for domestic appliances [4]. Hybrid system, the Boost Converter plays a crucial role by maintaining voltage stability despite input fluctuations [18]. It interfaces with the battery and load, ensuring continuous power delivery and enabling efficient energy storage and extraction [5].

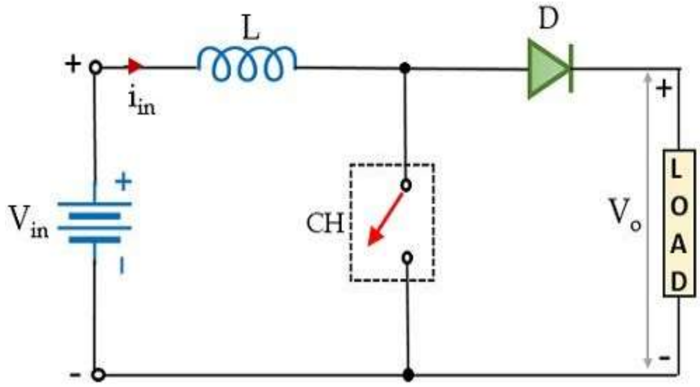

Fig. 2 Elementary Circuit Of Boost Converter

The Boost Converter is a step-up DC-DC converter used to increase the input voltage from renewable sources such as solar panels or wind turbines to a higher, regulated DC output suitable for domestic loads [4]. As shown in the circuit diagram, it consists of an inductor (L), a switch (CH), a diode (D), and an output capacitor, which work together to efficiently transfer and regulate energy [18]. During the switch ON period (Ton), current flows through the inductor, storing energy in its magnetic field while the diode remains reverse-biased. When the switch is turned OFF (Toff), the inductor releases this energy through the diode to the capacitor and load, resulting in a boosted output voltage [18]. The corresponding waveforms illustrate the switching process, where the inductor current increases during Ton and decreases during Toff, enabling stable output voltage with reduced ripple. This high-gain conversion stage is crucial in hybrid renewable systems, and when integrated with ANN based control techniques, it significantly enhances efficiency under variable operating conditions [13], [22].The Fig.3 represents waveform of Boost Converter.

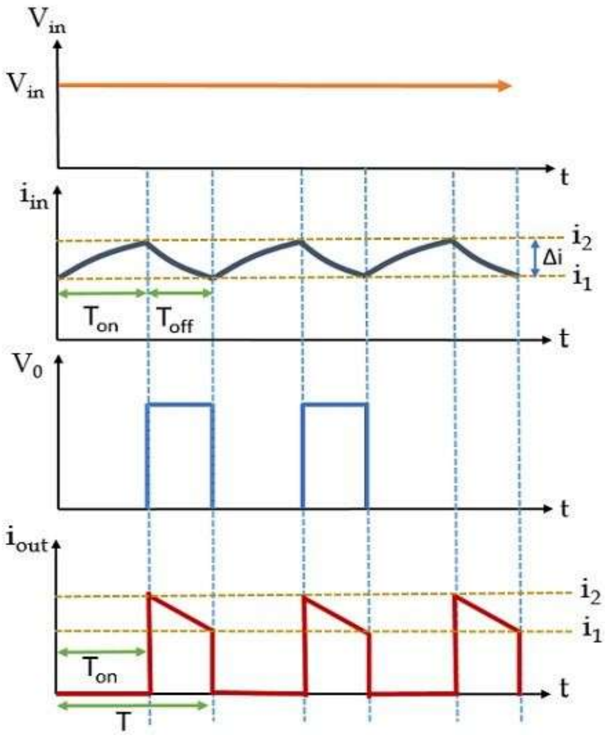

Fig.3 Waveform representation of Boost Converter

C. ANN-Based Control System

In the proposed Hybrid Energy System, the Artificial Neural Network (ANN) plays a key role in the control architecture by enhancing system performance under dynamic environmental conditions. ANN is employed to perform intelligent control of Maximum Power Point Tracking (MPPT), ensuring optimal energy extraction takes place from both PV and Wind sources even during rapid fluctuations in irradiance or wind speed [13]. Unlike conventional methods, ANN uses a trained dataset to predict the operating point, enabling faster response and better adaptability to non-linear and variable source behaviors [22]. Its integration into the system allows for real-time decision-making to regulate the Boost Converter's switching duty cycle, thereby stabilizing the output voltage and improving power quality for domestic appliances [21], [23]. This intelligent control technique improves overall system reliability, efficiency and responsiveness, making it highly suitable for Hybrid Renewable applications [13].

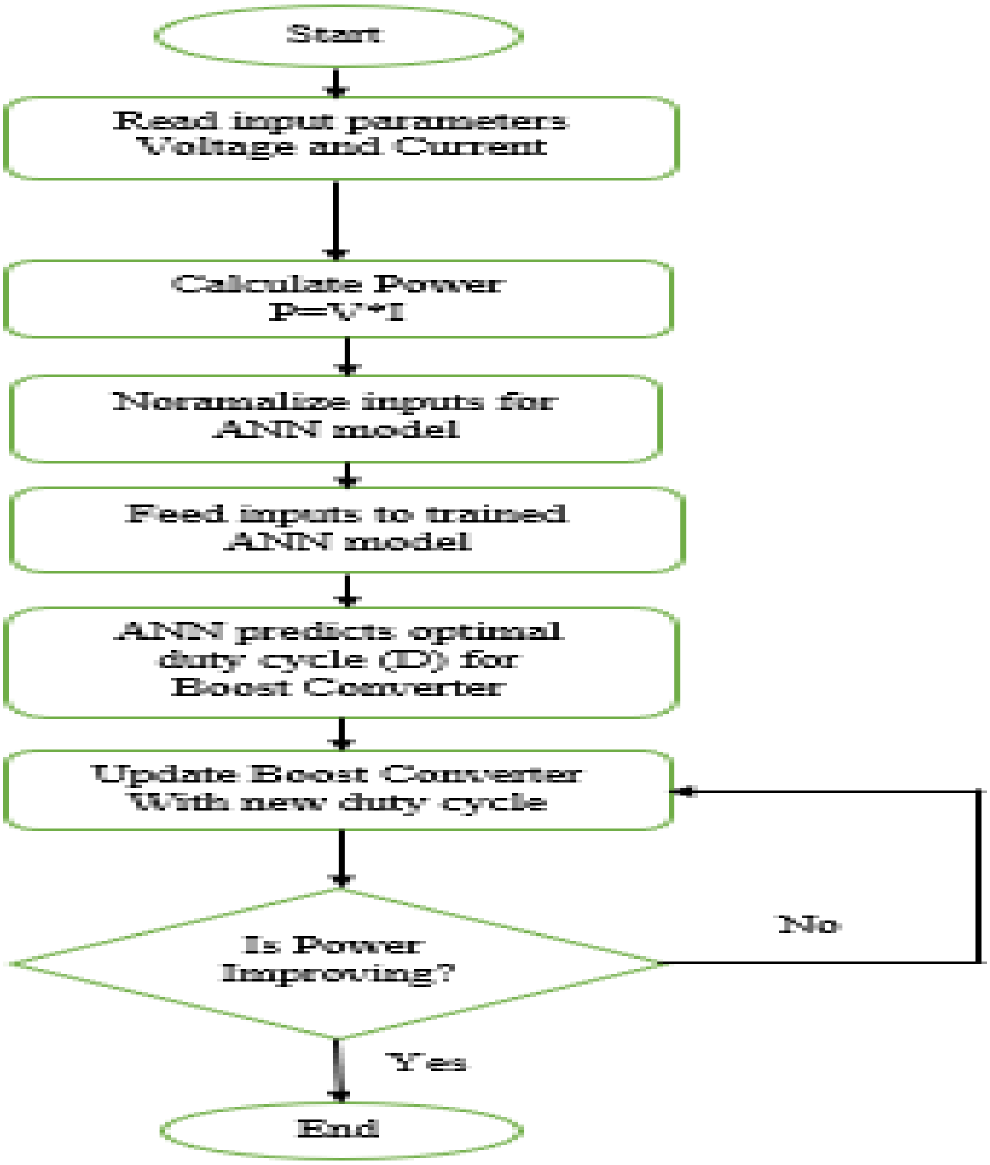

Fig. 4 Flowchart of ANN model

Fig.4 represents an ANN-based control strategy for Maximum Power Point Tracking (MPPT) in a Hybrid PV Wind system. Initially, the system acquires real-time input parameters such as PV voltage, current and Wind speed [13], [21]. These inputs are used to calculate instantaneous power, which is then normalized and fed into a trained Artificial Neural Network (ANN). The ANN, having learned the nonlinear characteristics of the system during training, predicts the optimal duty cycle for the Boost Converter to ensure maximum power extraction [22]. This control signal regulates the converter, adjusting the output voltage and enhancing overall system efficiency under dynamic environmental conditions [13], [23]. The system continually monitors output performance and adjusts accordingly, making the ANN an effective intelligent controller in Renewable Energy Systems [21].

III. MATHEMATICAL MODELLING

The output of a PV cell is given by the single-diode model:

$$V = \frac{nkT}{q} \ln \left(\frac{I_{ph} - I + \frac{V}{R_{sh}}}{I_0} + 1 \right)$$

$$I = Iph - I_0 \left(\frac{e^{nkTq}}{V+IR_s} - 1 \right) - \frac{V+IR_s}{IR_{sh}}$$

$$P_{pv} = V*I \text{ ………………………...(1)}$$

The mechanical power extracted from wind by a turbine is given by ,

$$P_w = \frac{1}{2} \rho ACp(\lambda,\beta)V^3 \text{ …………….(2)}$$

The battery output power is given by,

$$P_b = V_b \cdot I_b \text{ ....(3)}$$

Total output power $P_T = P_{pv}+P_w+P_b-P_{loss}$

Boost Converter:

Output Voltage Equation : $V_o = \frac{V_{in}}{1-D}$

Duty Cycle (D) : $D = 1 - \frac{V_{in}}{V_o}$

Inductor Value (L) : $L = \frac{V_{in} \cdot D}{f_s \cdot \Delta I_L}$

Output Capacitor (C) : $C = \frac{I_o \cdot D}{f_s \cdot \Delta V_o}$

Output Current : $I_o = \frac{P_o}{V_o}$

Input Current : $I_{in} = \frac{I_o}{1-D}$

Efficiency : $\frac{P_o}{P_{in}} = \frac{V_o \cdot I_o}{V_{in} \cdot I_{in}}$

Table – I: Specifications of Proposed Model

Parameters	**Value**	**Units**
Solar Photovoltaic Array		
Rated Power	3000	KWatts
Open Circuit Voltage	135.96	Volts
Short Circuit Current	9.24	Amps
Vmp	112.10	Volts
Imp	8.89	Amps
Wind Turbine		
Rated Power	3000	Kwatts
Rated Speed	2	Rad/sec
DC/DC Boost Converter 1 (for solar)		
Rated Capacity	3000	Kwatts
L1	0.3	μHenry
C1	20	μFarad
Switching Frequency	50	KHz
Vin	118	Volts
Vout	330	Volts
Iout	9.09	Amps
DC/DC Boost Converter 2 (for wind)		
Rated Capacity	3000	Kwatts
L1	0.27	μHenry
C1	18.4	μFarad
Switching Frequency	50	KHz
Vin	110	Volts
Vout	330	Volts

Iout	9.09	Amps
Battery		
Nominal Voltage	48	Volts
Series Connected Batteries	4	-
SOC	50	%
Rated Capacity	150	Ah

IV. SIMULATION MODEL

The system consists of a Solar PV array, a Wind turbine coupled with a PMSG and a Battery Storage System, all integrated using ANN-based control logic [1]. Each source is connected through a dedicated boost or bidirectional converter to regulate and stabilize the output voltage to a common DC bus [4]. The PV module feeds a boost converter, which is controlled by an ANN-based MPPT algorithm for maximum energy harvesting under changing irradiance and temperature [13]. Likewise, the Wind turbine output is rectified and passed through a Boost Converter governed by an ANN controller trained on Wind speed and generator data [1].

A Bidirectional DC-DC Converter connects the battery, allowing it to charge and discharge based on system needs, thus ensuring load continuity and DC bus stability [5]. ANN controllers provide faster and more accurate tracking than traditional P&O or INC methods, especially under rapidly changing environmental conditions [14]. Furthermore, the ANN-based control enhances system adaptability and learning by continuously responding to input variations without requiring manual retuning. The converters dynamically adjust duty cycles to maintain a stable DC link, ensuring both AC and DC loads which are supplied without interruption. The simulation results validate the system's ability to reduce power losses, maintain voltage stability and efficiently balance source and storage contributions. The proposed architecture also supports grid integration or islanded operation, making it suitable for remote or semi-urban applications where energy reliability and autonomy are critical [3], [8].

The incorporation of battery energy storage managed through a bidirectional converter significantly improves the system's energy management flexibility. During periods of high renewable energy generation, the surplus energy is effectively stored in the battery, preventing over-voltage on the DC bus. Conversely, during low generation or peak load conditions, the battery discharges, ensuring uninterrupted power delivery to the loads. This dynamic energy flow maintains a balanced power profile across the system, reducing dependence on grid supply and enhancing system reliability. The ANN-based controller continuously monitors the system parameters such as PV irradiance, wind speed, load demand, and battery state of charge (SOC), enabling real-time decisions for converter operation. This proactive control minimizes energy wastage and ensures the system operates at its maximum efficiency point.

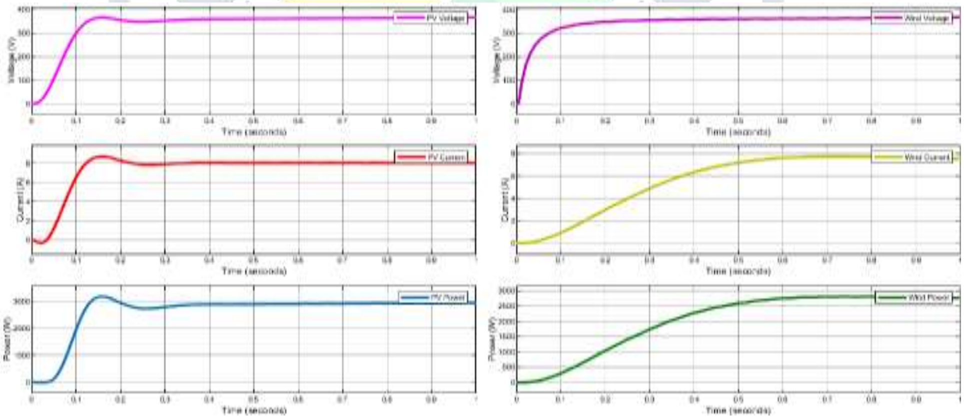

Fig.5 Output waveforms of PV and Wind Generation

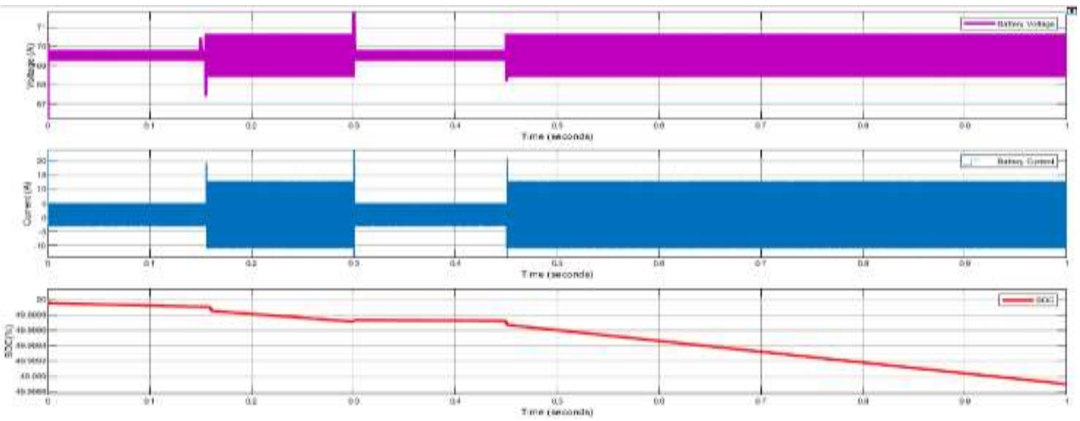

Fig.6 Output waveforms of Battery

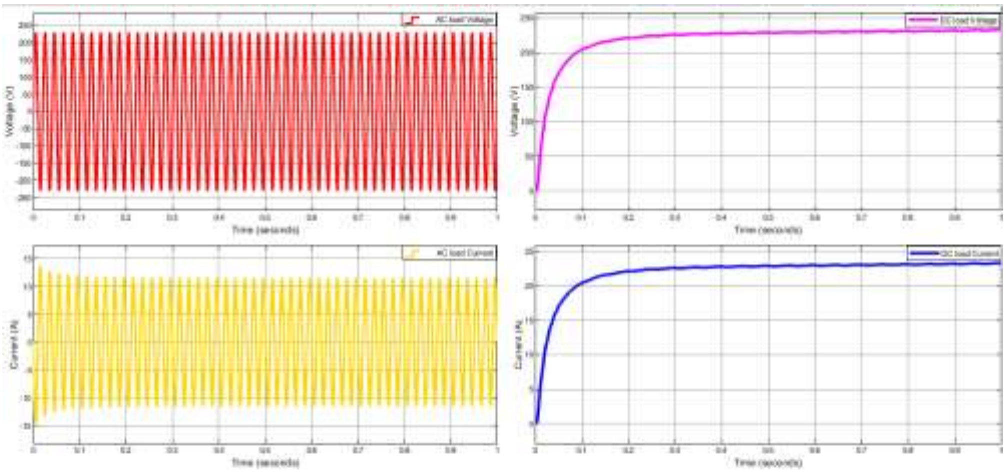

Fig. 7 Output waveforms of AC and DC loads

The simulation results Fig. 5, Fig. 6 & Fig.7 demonstrate a well-coordinated Hybrid Energy System integrating PV, Wind, Battery and AC/DC loads. The PV and Wind subsystems show fast voltage rise and power stabilization, indicating effective MPPT tracking. The Battery operates in a controlled manner, responding to the system's dynamic load conditions with appropriate voltage, current, and minor SOC variations, suggesting proper charge/discharge behavior. Regulated power with consistent voltage and current levels is delivered to both AC and DC loads, demonstrating the effective operation of the converters and control mechanism. Overall, the Hybrid System maintains steady performance under varying generation and demand conditions, achieving balanced energy flow and reliable supply to domestic loads.

VI. CONCLUSION

This proposed system successfully demonstrates the modeling and optimization of a Solar-Wind Hybrid Energy System integrated with battery storage using an ANN-based MPPT controller. The system is designed to supply both DC and AC loads reliably, with a DC load demand of 220 V at 23 A and an AC load demand of 230 V at 11 A. A Boost Converter is employed to step up the voltage from the Renewable Sources to 330 V, delivering a stable output of 8 A. The ANN controller efficiently tracks the maximum power point under varying environmental conditions, ensuring maximum energy extraction and improved system efficiency. Battery backup further enhances system reliability, allowing uninterrupted power supply during periods of low generation or peak load. Overall, the proposed Hybrid model proves to be an effective and intelligent solution for sustainable and stable energy delivery.

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