

Energy Management in a Hybrid PV and Wind Based Landsman Converter for Three-Phase Grid Applications

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ABSTRACT: The effective management of energy in distribution systems has established a lot of attention in recent years. Effective control of both solar-wind generation and demand essential in achieving energy savings and reducing overall energy costs. This study explores the integration of Hybrid Renewable Energy System (HRES) combining Photovoltaic (PV) and wind-based sources for stable grid operation. The proposed structure employs a Landsman converter with Adaptive Neuro-Fuzzy Inference System (ANFIS) Maximum Power Point Tracking (MPPT) for efficient voltage and power extraction from the PV system. Additionally, a Doubly Fed Induction Generator (DFIG)-based Wind Energy Conversion System (WECS) is utilized, controlled by a Pulse Width Modulation (PWM) rectifier for harvesting alternate energy from the wind. A bidirectional buck-boost converter is incorporated for managing the charging and discharging of hybrid energy storage devices. The proposed structure implemented by MATLAB/Simulink, with results showing a proposed converter achieve high efficiency of 96.5%, providing stable voltage for grid applications.

Keywords: PV, ANFIS, MPPT, DFIG, WECS, PWM rectifier.

1. Introduction

Conventional energy sources, like fossil fuels, are gradually diminishing due to the increasing need for electricity, which causes a rise in energy consumption [1]. This situation has led to the demand for power generation through alternative energy sources, such as Renewable Energy Sources (RES) [2]. RES provide various advantages over traditional energy sources, such as being environmentally sustainable and economical. However, their intermittent nature causes less consistent power production [3]. To address this issue and improve the energy generation from renewable sources, HRES have been developed [4].

HRES, which integrate various energy sources, leverage the benefits of one to compensate for the limitations of another. Solar panels and wind

turbines are commonly used RES owing to their simple implementation and low cost-to-power ratio, with no need for fossil fuels in electricity generation [5-6]. Solar power's dependence on weather conditions make a challenges of provide required level of voltage. Therefore, solar converters assist in adjusting and optimizing the voltage for grid integration [7-8].

Nabil Driantama *et al* (2023) have introduced a modified Cuk converter reduces ripple in the output voltage and current by using mutual inductance, which helps minimize current ripple and improves the converter's performance. However, mutual inductance helps reduce ripple, it has little impact on the voltage drop, which restrict its application in certain situations [9]. B. Jyothi *et al* (2023) have developed a Modified SEPIC Converter (MSC) for PV-powered DC

microgrids to improve efficiency, voltage output, and constant output current, particularly for domestic applications. However, it operates with only one controlled switch, which limit flexibility in certain applications [10]. Faris Hassan Taha Aldabbagh *et al* (2024) have introduced a PV-connected Zeta converter system for solution to the problems of voltage fluctuations and highest overshoot. However, Zeta converter is more difficulty in control and design system [11]. Therefore proposed work employed a landsman converter for overcome these limitations and significantly increase the voltage level.

Further, Multiple MPPT algorithms are employed to extract peak power from solar panels [12-13]. Bikash Gyawali *et al* (2024) developed a MPPT controller with perturb and observe (P&O) algorithm for effectual, quicker, and decreasing load of the controller. However, this controller struggle to achieve the MPP when production with multiple PV panels [14]. Avinash Kumar Pandey *et al* (2024) have developed a Fuzzy Logic (FL)-based MPPT method, utilizing PV array is to enhance accurateness of MPPT algorithm. This system enhances tracking performance for all environmental conditions, particularly during low irradiance. However, this controller involves increased complexity, that possible to make difficult implementation in certain applications [15]. Pradeep Kumar *et al* (2023) have developed Incremental Conductance (InC) based MPPT to improve power quality and mitigate harmonics in the grid under linear and non-linear loading conditions. However, a slow convergence speed of the MPPT algorithm, which leads to significant fluctuation in steady-state operation [16]. Thus, to overcome these challenges, ANFIS MPPT is used

to provide a flexible solution which manages environmental fluctuations efficiently. The contributions of this works are,

- To convert sunlight into electricity, a PV system is utilized.
- To enhance higher voltage level from PV system, a Landsman converter is employed.
- To get the most power from PV, an ANFIS-MPPT controller is employed.
- To control wind turbine's speed and provide stable power, a DFIG is implemented.
- To change AC power from wind into DC power, a PWM rectifier is utilized.
- To adjust voltage levels between the energy sources, battery, and the grid, a Bidirectional buck-boost converter is employed.

2. Proposed System Description

The proposed system Figure 1 integrates HRES, including a PV system and a WECS, with a common DC bus. The PV system generates DC power, which is stepped up to the required voltage by a Landsman Converter. The PWM generator control this conversion process, aiding efficient power transfer to the DC bus. To maximize power extraction, an ANFIS-MPPT controller adjusts the functioning point of PV system based on fluctuating environmental conditions. Simultaneously, the WECS operates with a wind turbine that drives a DFIG, producing adaptable AC power. A PWM rectifier converts this AC power into DC to integrate with the common DC bus. A Proportional-Integral (PI) controller ensures stable DC voltage by adjusting the rectifier based on the reference and actual voltage values.

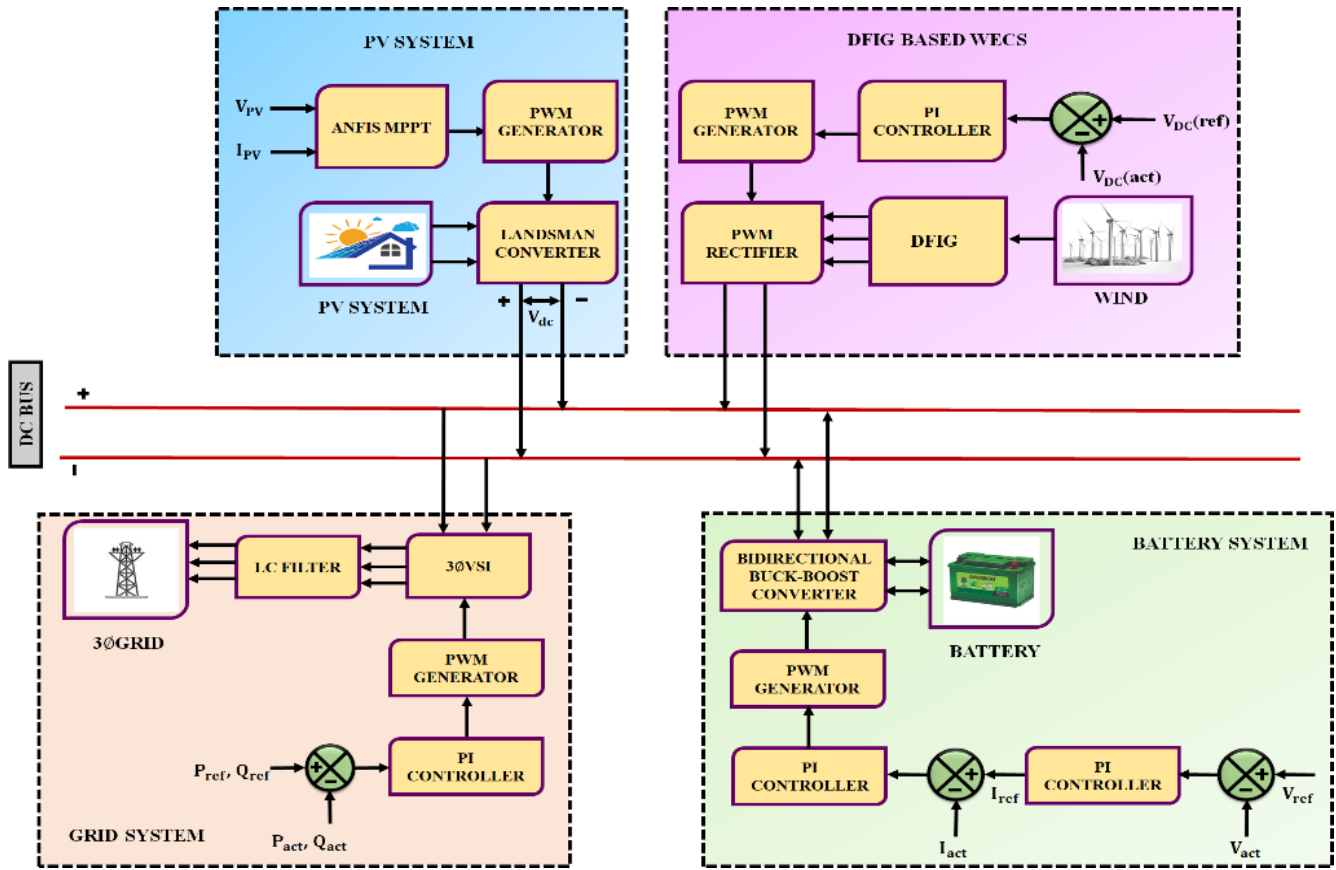


Figure 1: Energy management system using hybrid PV-wind system.

Also, the system incorporates energy storage via a battery coupled to DC bus over a bidirectional buck-boost converter, which handles both charging and discharging. PI controllers manage current and voltage regulation, ensuring stable battery operation. Finally, surplus energy is supplied to the grid via a Three-Phase Voltage Source Inverter, controlled via a PWM generator for efficient modulation. An LC filter smooths out harmonics, ensuring high power quality, although a PI controller regulates active and reactive power flow to maintain grid synchronization. This integrated system optimizes renewable energy usage, enhancing overall efficiency and stability.

3. System Modelling

3.1 PV Cell

PV cells are a crucial component of a PV panel, with electrical properties like current, voltage, and resistance changing with light intensity to provide power to a load refer to Figure 2.

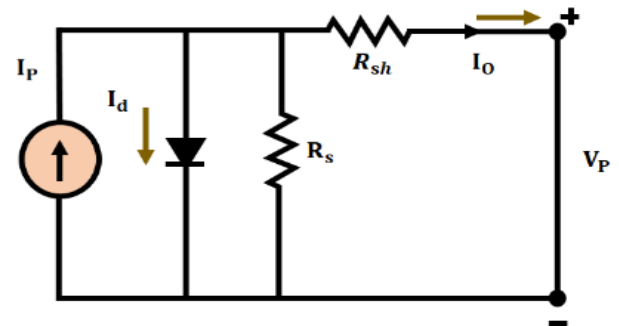


Figure 2: PV cell model

The mathematical representation of the parameters of PV cells expressed,

$$I_p = I_l - I_o \left\{ e^{\left[\frac{q(V_p + I_p R_s)}{A k T_c} \right]} - 1 \right\} - \frac{(V_p + I_p R_s)}{R_{sh}} \quad (1)$$

Here, current denotes I_l and saturation denotes I_o current of diode. q stands magnitude electron charge. R_s represents series resistance. A and k represents ideality factor and Boltzmann's constant respectively. T_c represents temperature of cell. Due to the weather condition, converter is employed for increase voltage level. The proposed converter is discussed below.

3.2 Landsman Converter

The Landsman converter act as a DC-DC converter which utilized in Continuous Conduction Mode (CCM). The PV array's output is frequently unsteady due to variations in solar radiation levels. Figure 3 shows the Landsman converter, which functions in two different modes: mode 1, as illustrated in Figure 4 (a), and mode 2, as seen in Figure 4 (b).

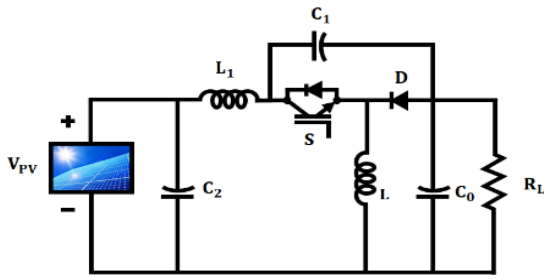


Figure 3: Landsman converter circuit diagram

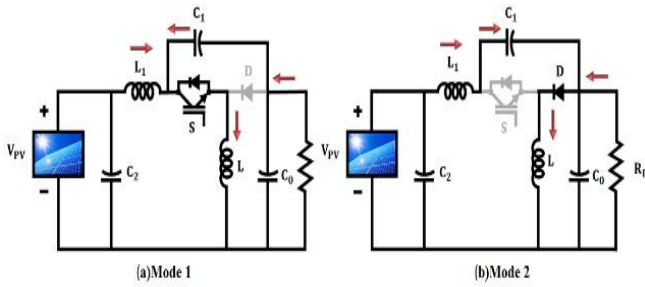


Figure 4: Landsman converter (a) mode 1 (b) mode 2

Mode 1: When switch S is turned on, diode D becomes reverse biased. Current I_L flowing through the inductor also passes over the switch S . The voltage across the intermediate capacitor v_{C_1} , shows its potential. If v_{C_1} exceeds the output voltage V_{DC} , the capacitor C_1 discharges through switch S into inductor L , transferring energy to the output. This causes the voltage across C_1 to decrease while inductor current I_L increases. As consequence, input energy supplies to input inductor L_1 .

Mode 2: Diode D becomes forward biased when switch S is opened. I_L , the inductor's current, flows via the diode, transferring stored energy from inductor L to the output. In this phase, capacitor C_1 is charged with the energy stored in both the input and inductor L_1 . As a result, the voltage v_{C_1} across

the intermediate capacitor rises, while the current through the inductor, I_L , decreases.

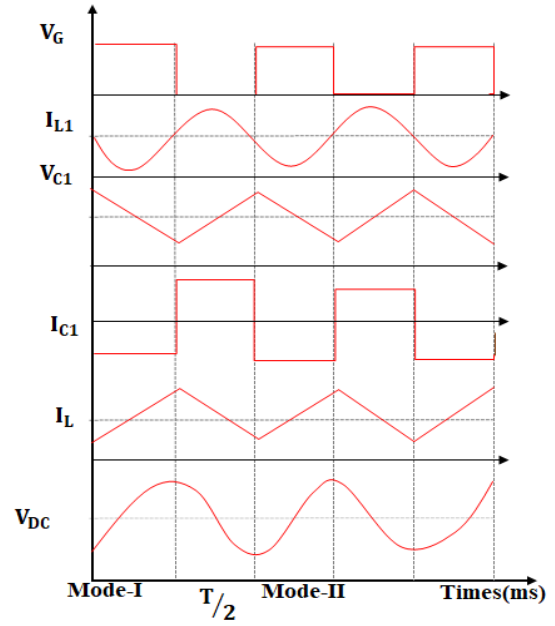


Figure 5: Waveform of Landsman converter

3.2.1 Design of Landsman converter

The Timing diagram of Landsman converter is displayed in Figure 5. In CCM, the ripples in inductor current I_{L_1} flow through capacitor C_1 . The shaded region in the v_{C_1} waveform represents an additional flux $\Delta\Phi$. As a result, the formula for the peak-to-peak ripple current ΔI_{L_1} is given by:

$$\Delta I_{L_1} = \frac{\Delta\Phi}{L_1} = \frac{\Delta v_{C_1} T}{L_1 2 \times 2 \times 2} \quad (2)$$

Turning off the switch makes the electricity to pass through C_1 to be

$$i_{C_1} = I_{L_1} = C_1 \frac{\Delta v_{C_1}}{(1-D)T} \quad (3)$$

Here, D indicates the duty ratio and T indicates the switching duration. To calculate the voltage v_{C_1} ripple, use the formula

$$\Delta v_{C_1} = \frac{I_{L_1}}{C_1} (1-D)^T \quad (4)$$

By substituting Δv_{C_1} from (2) in (4),

$$\Delta I_{L_1} = \frac{I_{L_1}}{L_1 2 \times 2 \times C_1} (1-D)^T \frac{T}{2} \quad (5)$$

$$\Delta I_{L_1} = \frac{1}{8L_1C_1} \frac{I_{L_1}(1-D)}{f_{sw}^2} \quad (6)$$

It is normalized as

$$\frac{\Delta I_{L_1}}{I_{L_1}} = \frac{1}{8L_1C_1} \frac{(1-D)}{f_{sw}^2} \quad (7)$$

From the input-output relation,

$$I_{L_1} = \frac{D}{1-D} I_{dc} \quad (8)$$

where current output I_{dc} of Landsman converter exchange formula (8) in (6),

$$L_1 = \frac{DI_{dc}}{8C_1\Delta I_{L_1}} \quad (9)$$

To ensure a consistent and reliable DC power supply, the Landsman converter is employed in proposed PV system. Next, to tract maximum power from PV, ANFIS-MPPT controller is employed and its discussed below.

3.3 ANFIS MPPT

ANFIS is a hybrid of Artificial Neural Networks (ANN) and FL systems. ANFIS utilized to control MPPT which consist of two parts input involves error (e) and error variance (Δe). Duty cycle value is the result of this calculation. ANFIS, which is an Artificial Condition Network, requires prior training with input-output data pairs. Figure 6 shows the ANFIS structural Model. Figure 7 depicts the flowchart layout of an ANFIS-based MPPT control developed using the MATLAB/Simulink design.

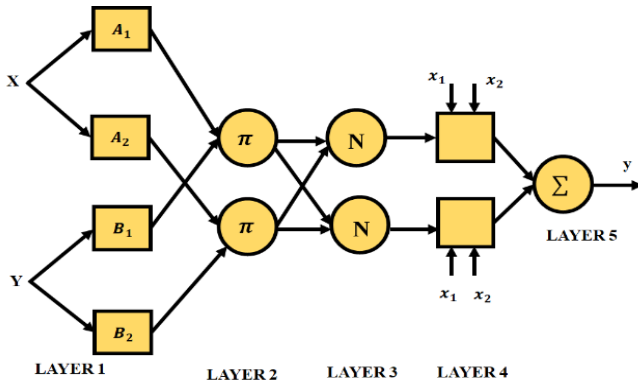


Figure 6: Design of ANFIS

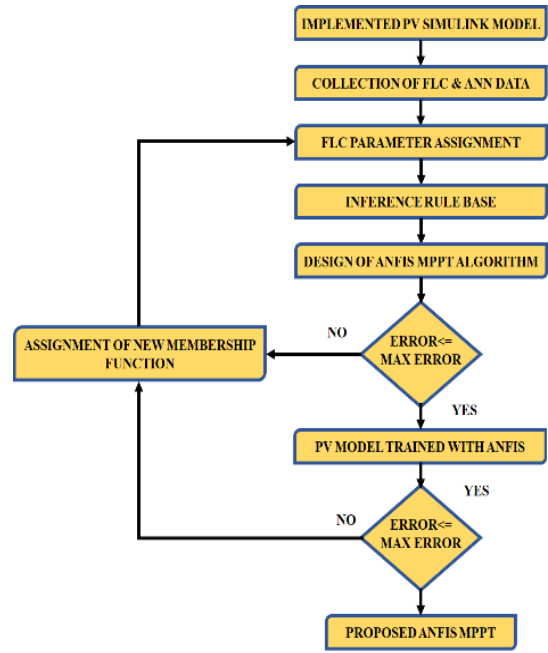


Figure 7: Flowchart for ANFIS-MPPT

The Neuro-Fuzzy system consists of five processing levels, each with its own set of equations and functions for operation.

Layer 1- Fuzzification; Let o_1, i denote the output for every node in layer 1. In this layer, node i stands for the value of the node, where the output is calculated as

$$o_1, i = A_i(x), \quad i = 1, 2 \quad (10)$$

$$o_1, i = B_i(y), \quad i = 3, 4 \quad (11)$$

$$f(x, a, b, c) = \frac{1}{1 + \left(\frac{x-c}{a}\right)^{2b}} \quad (12)$$

Layer 2- Product Layer; This layer performs multiplication of all received signals and then transmits the outcomes after layer 1 requires processed the information. The output of the product layer is expressed as

$$o_2, i = \mu A_i(x) \times \mu B_i(y) = W_i \quad (13)$$

Layer 3- Normalization Layer; this layer contains the output from previous product layer. The output expressed as

$$o_3, i = \frac{W_i}{W_1 + W_2} \quad (14)$$

Layer 4- Defuzzification Layer; this layer contains a naturally occurring adaption. Equation 15 is

utilized to calculate this layer's defuzzification output.

$$o_{4,i} = o_3, i(\alpha_i x + \beta_i y + \gamma_i) \quad (15)$$

Layer 5- Output Layer; at this layer, the fixed function Equation 16 is utilized to generate the data provided from layer 4 and return all output.

$$o_{5,i} = \frac{\sum w_i y_i}{\sum} \quad (16)$$

The PV system's power output provides a source factor for MPPT control. The ANFIS's training data, which is utilized in both control systems, is generated by simulation outcomes that employ the fuzzy algorithm. The ANFIS model forecasts the maximum power output of PV module based on temperature and solar irradiance. The actual power output is measured and compared with the predicted value from the ANFIS model. The error

(difference) is then utilized by the FL power controller to generate a control signal. This signal modifies the duty cycle of Landsman converter via PWM, ensuring PV module operates at its MPP for efficient energy generation. Also, DFIG based WESC utilized to converter wind energy. The detail discussion provide below.

3.4 DFIG Based WECS

DFIG-based wind turbines as shown Figure 8 are highly regarded for their ability to operate at varying speeds with reduced expenses. This feature is made possible by the use of slip rings, which connect the rotor circuit to an external power supply. Additionally, DFIG provides advantages such as smaller inverter sizes, cost savings, improved efficiency, and better power factor correction.

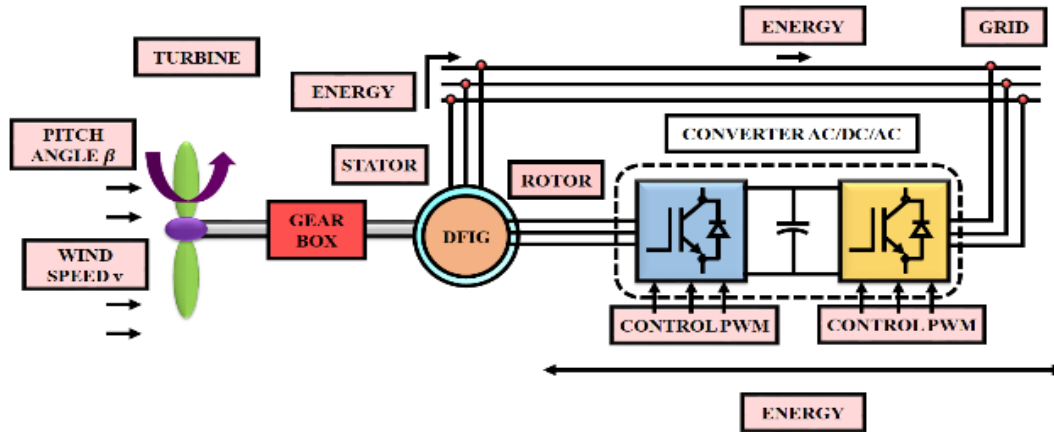


Figure 8: Diagram of DFIG based WECS

The space vector electrical equation of DFIG within the dq reference frame is expressed as

$$V_{sd} = R_s I_{sd} + \frac{d\phi_{sd}}{dt} - \omega_s \phi_{sq} \quad (17)$$

$$V_{sq} = R_s I_{sq} + \frac{d\phi_{sq}}{dt} + \omega_s \phi_{sd} \quad (18)$$

$$V_{rd} = R_r I_{rd} + \frac{d\phi_{rd}}{dt} - \omega_r \phi_{rq} \quad (19)$$

$$V_{rq} = R_r I_{rq} + \frac{d\phi_{rq}}{dt} + \omega_r \phi_{rd} \quad (20)$$

In this case, I_{rd} represents rotor current flowing in the direction of the d axis, I_{rq} the rotor current flowing in the direction of the q axis, I_{sd} the stator current flowing in the direction of the d axis, and I_{sq} the rotor current flowing in the direction of the

q axis. The electrical synchronous speed is represented by ω_s , and the rotor electrical speed by ω_r . The resistances of the stator and rotor windings are denoted by R_s and R_r . The stator and rotor flux is provided as:

$$\phi_{sd} = L_s I_{sd} + M I_{rd} \quad (21)$$

$$\phi_{sq} = L_s I_{sq} + M I_{rq} \quad (22)$$

$$\phi_{rd} = L_r I_{rd} + M I_{sd} \quad (23)$$

$$\phi_{rq} = L_r I_{rq} + M I_{sq} \quad (24)$$

In this case, ϕ_{sd} and ϕ_{sq} —represent the stator flow in the d and q axes, respectively. ϕ_{rd} and ϕ_{rq} represent rotor flux in d and q axes, correspondingly. The stator and rotor leakage

inductances are denoted by L_s and L_r , respectively. The mutual inductance is denoted by M . The definition of the stator's active and reactive powers is

$$P_s = V_{ds}I_{ds} + V_{qs}I_{qs} \quad (25)$$

$$Q_s = V_{qs}I_{ds} + V_{ds}I_{qs} \quad (26)$$

The torque equation for DFIG is expressed as:

$$T_{em} = \frac{pM}{L_s}(I_{rd}\varphi_{sq} - I_{rq}\varphi_{sd}) \quad (27)$$

In a DFIG-based WECS, the rotor side generates variable frequency power that is convert DC power by PWM rectifier. The DC voltage is then sent to a three-phase VSI, which converts it into AC voltage suitable for grid connection. Additionally, the bidirectional buck-boost converter captures and stores any excess voltage produced by the system. The following section provides a detailed explanation.

3.5 Bidirectional Buck-Boost Converter

The bidirectional buck-boost converter configuration consists of an inductor, two capacitors, and a pair of switching transistors. The role of the diode within the switching transistor is crucial in the circuit design, facilitating flow of current in both directions between DC link and battery storage unit. Figure 9 displays the circuit diagram of bidirectional Buck-Boost converter. By analyze switching states of the converter when ON and OFF, the dynamic state-space equations derived.

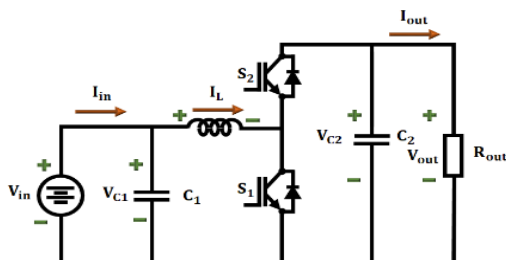


Figure 9: Circuit diagram of the bidirectional Buck-Boost converter

The equations for Bidirectional Buck-Boost converter presented in equations (28) to (30).

$$\frac{dI_L}{dt} = \frac{V_{C1}}{L} - \frac{V_{C2}}{L} \cdot (1 - S) \quad (28)$$

$$\frac{dV_{C1}}{dt} = \frac{I_{in}}{C_1} - \frac{I_L}{C_1} \quad (29)$$

$$\frac{dV_{C2}}{dt} = \frac{I_L}{C_2} (1 - S) - \frac{V_{C2}}{C_2 \cdot R_{out}} \quad (30)$$

In these formulas, S represents binary state of the switch, I_L denotes current flowing via inductor L . V_{C1} refers to the voltage across the battery capacitor C_1 , while V_{C2} indicates voltage through capacitor C_2 . V_{in} and I_{in} correspond to battery's voltage and current, individually. R_{out} stands for equivalent resistance. The bidirectional Buck-Boost converter allows for various charging modes for the energy storage devices.

4. Results and Discussion

This work presents an energy management system for integrating HRES, utilizing Landsman converters and an ANFIS-MPPT controller to enhance grid stability and power quality. The developed system is implemented using MATLAB simulation, with the results provided in the following section. Table 1 also outlines the parameter specifications of the proposed system.

Parameters	Specifications
PV System	
Rated Power	10kW
Open Circuit Voltage	37.25 V
Short Circuit Voltage	8.95 A
Series connected solar PV cell	3
Parallel connected solar PV cell	15
Maximum Power Voltage	29.95 V
DFIG_WECS	
Power	10kW
Voltage	600V
No. of Turbines	1
Landsman Converter	
Switching Frequency	10KHz
L_1 & L_2	4.7mH
C_1 & C_2	22μF
C_0	2200 μF

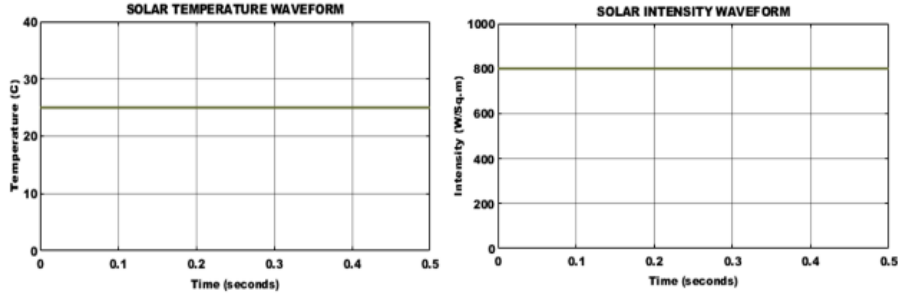


Figure 10: Solar Temperature & Intensity Waveform

Figure 10 shows solar temperature & intensity Waveform that the image shows solar temperature maintain a constant flow at 25°C over 0.5s and

solar intensity maintain a constant flow at 800 W/m² over the same time period.

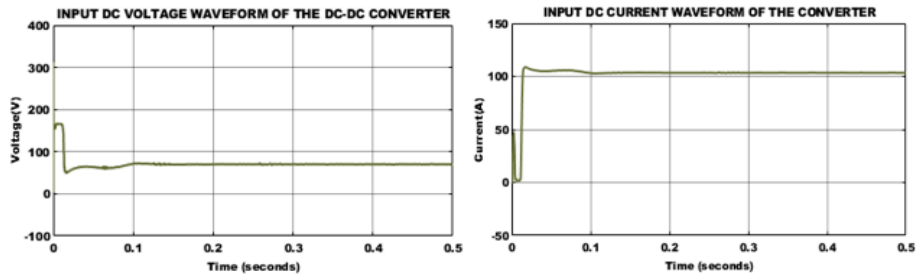


Figure 11: Converter Input Voltage & Current Waveform

Figure 11 represents waveform of converter input voltage & current. It shows the input DC voltage

keeps a constant waveforms at 80V and input current at 105A after 0.1s.

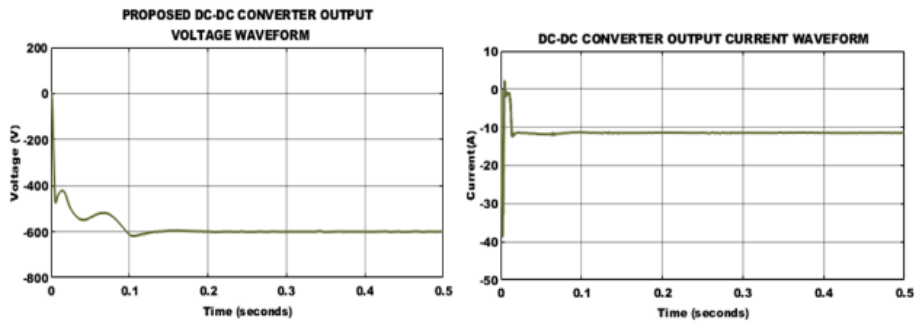


Figure 12: Waveform of Converter Output Voltage & Current

Figure 12 represents the waveforms of converter output voltage & current. It shows output voltage which is maintain -600V after 0.1s and output

current waveform, keep constant flow at -12A after 0.1s.

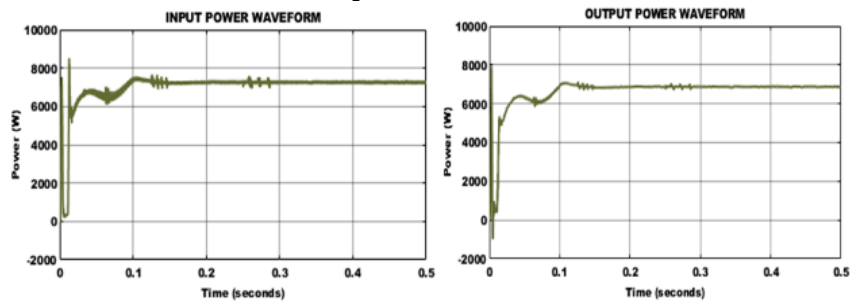


Figure 13: Input & Output Power Waveform

Figure 13 represents the waveforms of input & output power that shows input power fluctuate between 500W to 8500W over 0.5s output power ranging from -1000W to 8000W over 0.5s.

Figure 14 shows a wind speed waveform over a 0.5s period, where the wind speed remains steady at around 12 m/s.

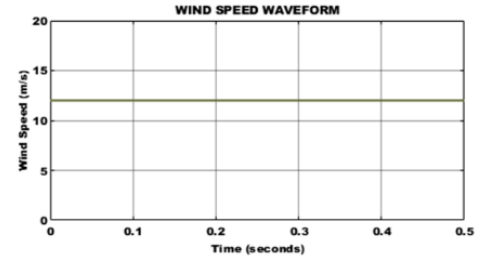


Figure 14: Wind Speed Waveform

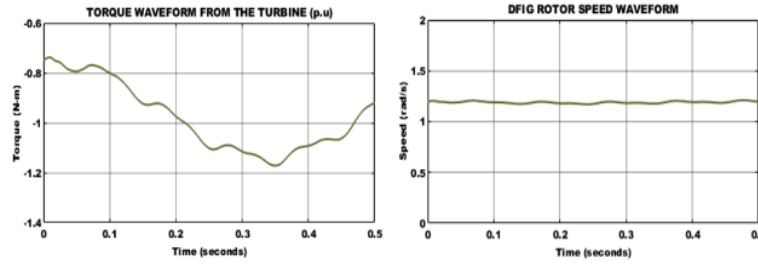


Figure 15: Torque and Rotor Speed Waveform

Figure 15 shows torque waveform from the turbine fluctuates between $-0.7 \text{ N} \cdot \text{m}$ to $-1.2 \text{ N} \cdot \text{m}$ over 0.5s and rotor speed waveform of the

DFIG fluctuates between 1.2 rad/s and 1.4 rad/s .

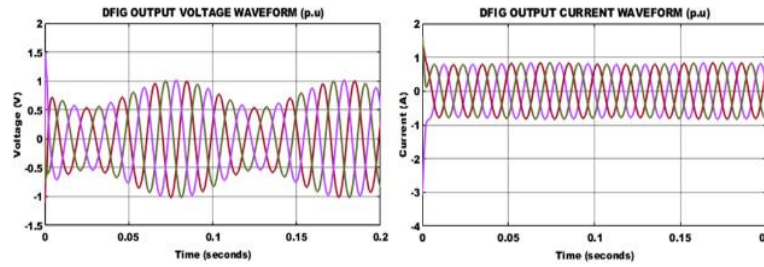


Figure 16: DFIG Output Voltage & Current Waveform

Figure 16 shows the output voltage and current of a DFIG system over a 0.2s time period. The voltage waveform fluctuates between -1.5 p.u. and 1.5 p.u. over 0.2s. The current waveform ranges from -3 p.u. to 2 p.u. over 0.2s.

Figure 17 shows waveform of output voltage fluctuates between -600 V and 600 V over 0.5s, illustrating the dynamic behavior of the DFIG system's output voltage

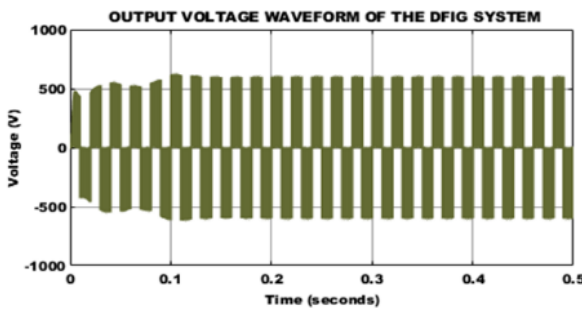


Figure 17: DFIG System Output Voltage Waveform

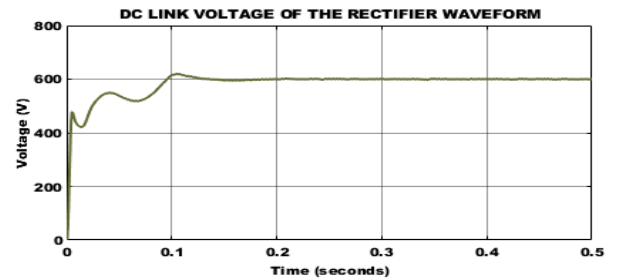


Figure 18: DC Link Voltage of the Rectifier Waveform

Figure 18 illustrates the dynamic behavior of the rectifier's DC link voltage, which fluctuates minimally around 600 V after 0.1s.

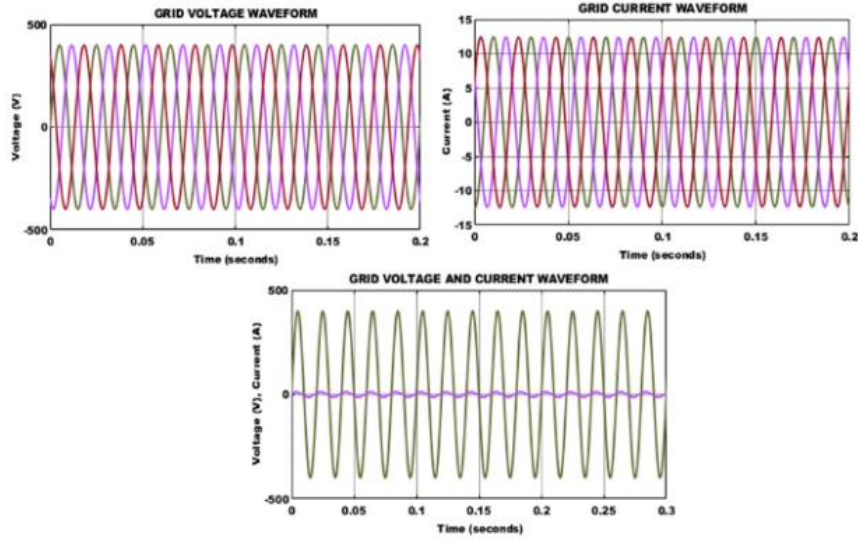


Figure 19: GRID Voltage & Current Waveform

Figure 19 shows the grid voltage fluctuating between -500V and 500, and the current varying from -15A to 15A over a 0.2s.

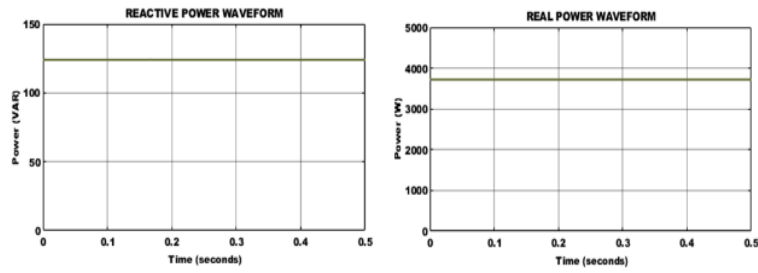


Figure 20: Real & Reactive Power Waveform

Figure 20 shows the reactive power maintain constant flow at 130VAR, and the real power

maintain a constant flow at 3700W over a 0.5s time period.

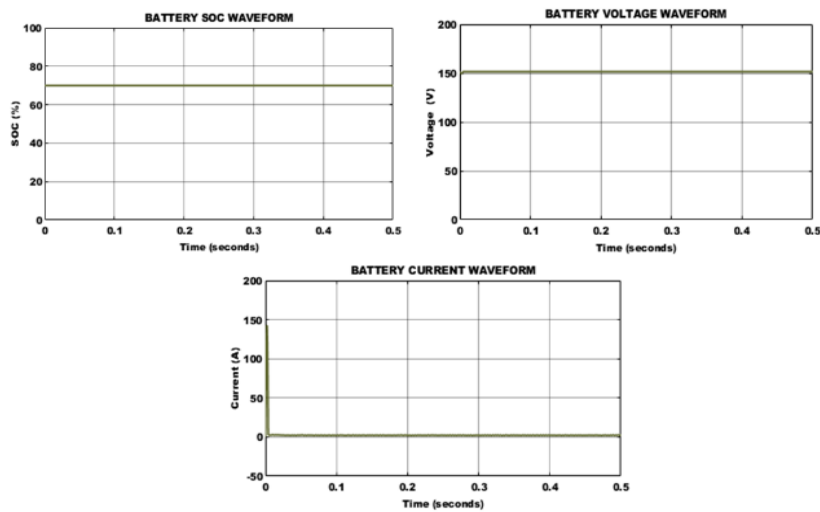


Figure 21: Battery Waveform

Figure 21 shows the battery State-of-Charge (SOC) constant in beginning of operation at 70%,

voltage maintain constant at 150 V, and current maintain at 5A over a 0.5s.

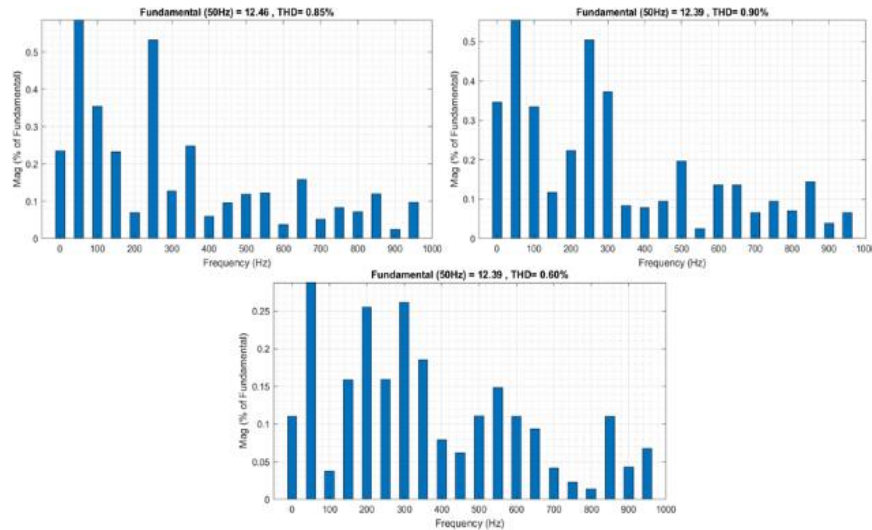


Figure 22: THD Waveform

Total harmonic distortion (THD) values for three phases are depicted in the Figure22 as follows: B phase has a THD of 0.85%, R phase has a THD of 0.90%, and Y phase has a THD of 0.60%.

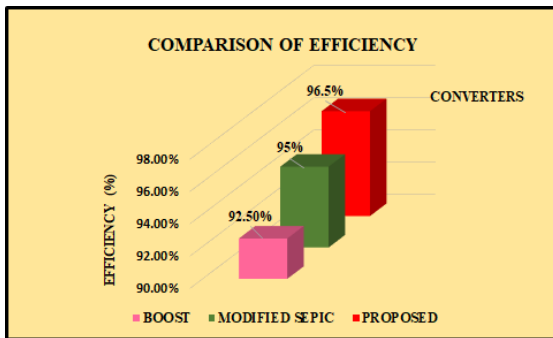


Figure 23: Converter's comparison of efficiency

Figure 23 presents a comparison of the efficiency of various converters, where the proposed Landsman converter exceeds the efficiencies of the boost [16] (92.5%) and modified Sepic [17] (95%) converters, achieving an efficiency of 96.5%.

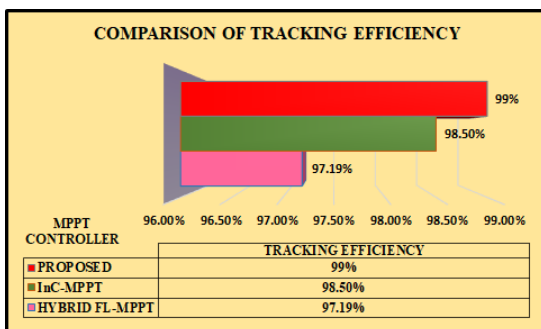


Figure 24: MPPT controller's comparison of tracking efficiency

Figure 24 presents a comparison of the tracking efficiency of various MPPT controllers, where the proposed Landsman converter exceeds the efficiencies of the hybrid FL [18] (97.19%) and InC [19] (98.50%) converters, achieving an efficiency of 99%.

5. Conclusion

The presented study focuses on energy management in a hybrid PV and wind-based system for three-phase grid applications, utilizing a high-gain Landsman converter. This approach offers several advantages, including enhanced efficiency, reduced switch voltage stress, and the incorporation of an optimized MPPT controller to maximize energy extraction from both the solar and wind energy sources. Furthermore, a bidirectional buck-boost converter efficiently manages the energy flow between the grid and the hybrid system. MATLAB/Simulink simulations demonstrate an efficient solution for integrating RES with grid applications, achieving a notable efficiency of 96.5%. This work contributes to growth of more sustainable and effective energy management systems for hybrid PV-wind grid integration, promoting clean and consistent energy use.

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