



RESEARCH ARTICLE

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OPTIMIZED CONTROL AND INTEGRATION OF RENEWABLE ENERGY SOURCES IN ADN USING HIGH GAIN SEPIC CONVERTER AND ADAPTIVE GRASSHOPPER-PI CONTROLLER

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ABSTRACT

In recent years, incorporating renewable energy into Active Distribution Networks (ADNs) significantly reduces greenhouse gas emissions by replacing fossil fuel-based generation with clean energy sources. Hence, this study explores an ADN configuration featuring a Photovoltaic (PV) system and a Doubly-Fed Induction Generator (DFIG)-based wind energy conversion system (WECS). A high gain improved Single-Ended Primary Inductor Converter (SEPIC) is utilized to boost the PV voltage into required level for ADN. The SEPIC converter's operation is precisely regulated by an Adaptive Grasshopper Optimization Algorithm (AGOA) tuned Proportional-Integral (PI) controller, ensuring optimal performance and efficiency. In parallel, the DFIG-based WECS is connected to a Pulse Width Modulation (PWM) rectifier, which is managed by a PI controller. To enhance the system's resilience and stability, a bidirectional converter is integrated with a battery storage system, allows for efficient energy management in which excess energy generated by the RES during peak production periods is stored in the battery. The performance of the developed system is validated through MATLAB/Simulink and the outcomes establishes that the developed converter together with control approach outperform in higher efficiency of 95% with minimal settling time and convergence speed.



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I. INTRODUCTION

Traditionally, power distribution systems are primarily passive, as the networks use transmission lines to obtain electricity from conventional generators [1], [2]. On the other hand, ADN produce electricity through the usage of contemporary distribution networks. In this context, the need for RES to meet electricity demands is driven by the rapidly depleting fossil fuels, rising load demands and aims to create a pollution-free atmosphere [3], [4]. In this circumstance, HRES system such as solar and wind energy systems are employed by active distributed generation due to their abundance and lack of pollution [5]. PV generation has emerged as one of the world's fastest-growing energy sources due to its clean and sustainable nature [6]. Nonetheless, PV output is unpredictable and correlated, greatly affects ADN operation and makes dispatching more difficult [7]. In order to solve this, traditional Boost, Cuk, Single Ended Primary Inductor Converter (SEPIC) [8-10], and other converters are typically utilized to achieve a High Voltage Gain. However, these classical converters has several drawbacks, including lower efficiency from higher duty cycles owing to increased losses in parasitic resistances of diodes, capacitors, and inductors [11], [12]. As a result, the High gain Improved SEPIC converter is developed in this study, which efficiently improves the lower amount of energy from PV module to satisfy the need of ADN with better performance. The development of controller that handle system uncertainties while maintaining system stability is necessary [13]. Thus PI controller is utilized to achieve this and also tuning PI controller's parameters is essential for attaining higher performance. Hence, various classical metaheuristic algorithms such as Genetic Algorithm (GA) [14] and Particle Swarm Optimization (PSO) [15] approaches are employed.

The GA's attains great degree of flexibility and ability to handle functions that are nonlinear, non-differentiable and have a large number of parameters. However, because of poor fitness processes that produce poor chromosomal blocks and unable to tackle variation optimization problems [16]. In comparison to the previously described procedure, PSO algorithm is recommended as a leader among the most beneficial and prospective methods for optimizing the converter since it locates the optimal solution employing the global optimum. Nevertheless, poor convergence and higher settling time and overshoot issues leads to worsen the effectiveness of the developed system [17], [18]. Henceforth, the proposed system utilizes Adaptive GOA, which fine tune the parameters of PI controller by producing stabilized output with better settling time and quick convergence speed. By the aim of overcoming the issues associated with recently presented works, the proposed work introduces a novel HRES based converter with optimized approaches and the topmost contributions of the proposed work are specified as follows.

- Incorporating High gain Improved SEPIC converter in ADN for engendering higher amount of energy from PV into the required level of grid system with superior voltage gain and minimized switching losses.
- Implementing Adaptive GOA-PI controller for ensuring the stabilized output by controlling the converter with minimized settling time and overshoot issues,
- Employing PWM rectifier in DFIG based Wind energy system for efficiently convert AC output into DC.
- Integrating Battery with Bidirectional converter for managing power demand by handling charging and discharging process efficiently.

II. PROPOSED METHODOLOGY

The goal of study is to develop a novel approach to improve the economy and stability of the active distribution network with RES, energy storages. Hence, the proposed topology introduces HRES based converter and control approach with battery setup for ADN as represented in Figure 1.

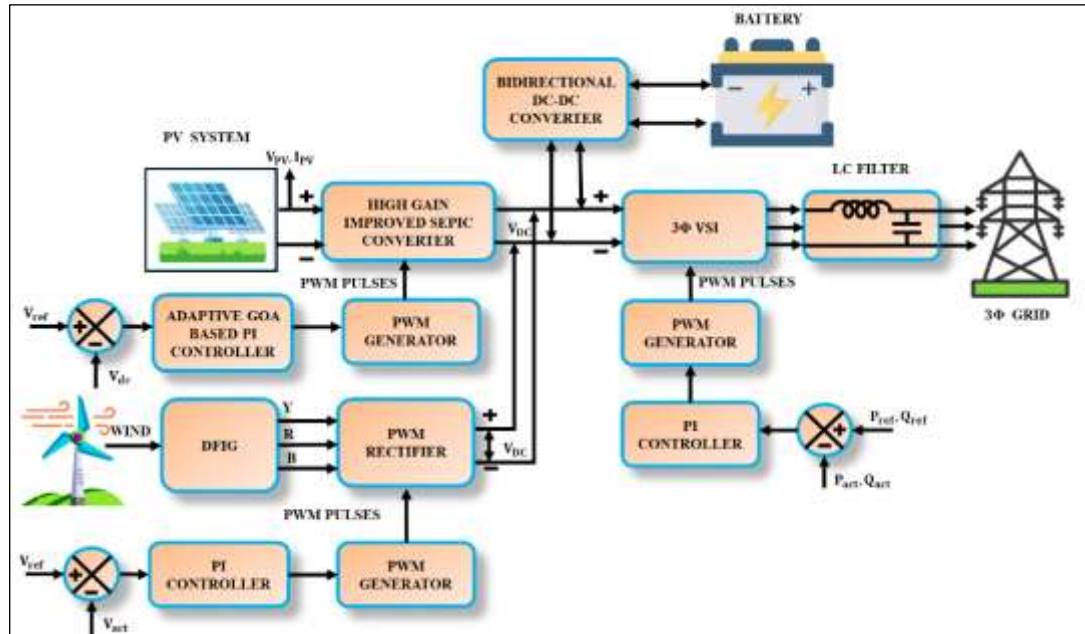


Figure 1: Block diagram of the proposed work.

Source: Authors, (2026).

The minimal output generated by the PV module is given to High gain Improved SEPIC converter for improving the voltage into higher level desired for grid system. Also, for stabilizing the output of high gain converter, adaptive GOA-PI controller is utilized that delivers the controlled output to PWM generator for producing pulses for the functioning of designed converter. One of the other RES is DFIG based WECS, the supply from DFIG is AC that converts into DC with the assistance of PWM rectifier and regulated by the PI controller. The supply from HRES (DC) is given to three phase grid system over VSI, which convert DC-AC and gets controlled by the PI controller. Despite this, storage battery is employed for storing surplus energy generated by HRES and gives power back to three phase grid during inadequate energy from HRES. Also, the bidirectional converter performs charging and discharging process according to the battery requirement. Thereby the performance of proposed system is enhanced by producing adequate power with better efficiency.

II.1 MODELLING OF PV SYSTEM

PV system utilized as the main component for producing sustainable solutions by capturing sunlight and changes into usable electricity. Figure 2 shows the circuit for an identical PV module, which deals with the parallel connection of the current source and diode. The relationship between PV and voltage-current in an arithmetic equation is expressed as follows,

$$I_{PV} = I_L - I_D \left[\exp \left(\frac{q \cdot V_{PV} + q \cdot I \cdot R_s}{A \cdot k \cdot T} \right) - 1 \right] \quad (1)$$

Here, I_D indicates saturation current, q denotes charge of electron, I_{PV} and V_{PV} refers voltage and current of PV, k shows Boltzmann constant and T represent absolute temperature, R_s shows series resistor correspondingly.

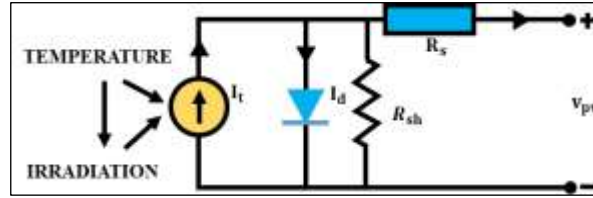


Figure 2: Equivalent Circuit Diagram of PV array.
Source: Authors, (2026).

However, the output energy generated by the PV array is minimal that is unable to satisfy the need of grid system, hence High gain Improved SEPIC converter is designed in this work for supplying uppermost power to ADN as discussed in the below section.

II.2 MODELLING OF HIGH GAIN IMPROVED SEPIC CONVERTER

The developed High gain Improved SEPIC converter is depicted in Figure 3, where the normal SEPIC converter is Improved by adding the components of capacitor and inductor from the normal SEPIC converter for improving the efficiency with reduced losses. Additionally, this designed converter operates under two modes as illustrated in Figure 4 and its associated timing diagram of ON and OFF condition is shown in Figure 5.

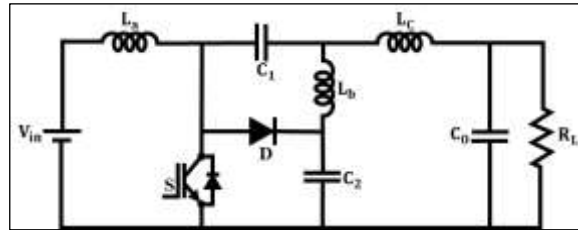


Figure 3: Circuit diagram of designed High gain Improved SEPIC converter.
Source: Authors, (2026).

Mode 1: In this phase, the switch S is in conduction state, while the diode remains non magnetized condition. The Inductors L_a and L_c stores energy obtain from the input and L_b discharges its energy and charge C_2 in this phase, at the same time C_1 and C_o are discharge and deliver supply to the load.

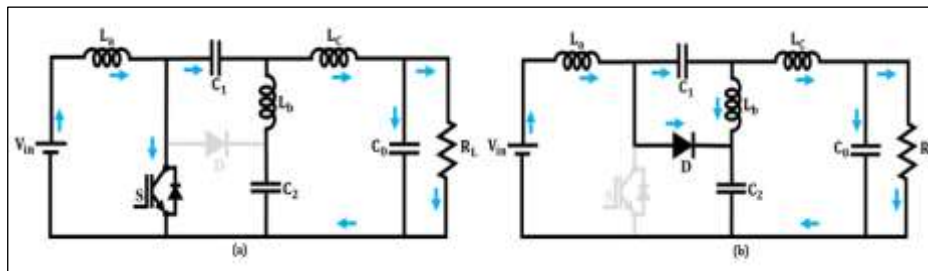


Figure 4: Modes of Operation of High gain Improved SEPIC converter.
Source: Authors, (2026).

Mode 2: In this condition, when the switch S is turned OFF, the diode D becomes forward biased. The stored energy in inductors L_a and L_c as well as capacitor C_2 gets discharged in this state and charge the inductor L_b and capacitors C_1 and C_o . Thereby, the load gets supplied by inductor L_c respectively.

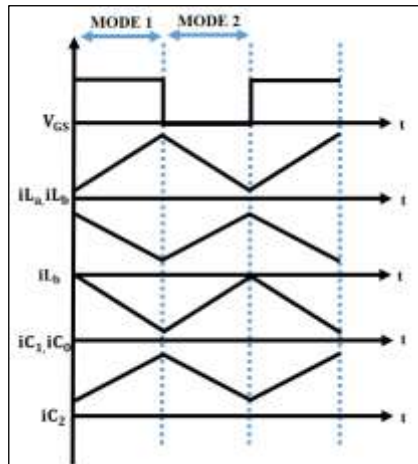


Figure 5: Switching state of developed High gain Improved SEPIC converter.
Source: Authors, (2026).

The developed converter's static gain is reliant upon the steady-state average inductance voltage at zero. Equation (2) presents the duty cycle relation while considering continuous conduction mode.

$$D = \frac{(V_{out}-V_{in})}{(V_{out}+V_{in})} \quad (2)$$

The following equation shows the static gain (q) as,

$$q = \frac{V_{out}}{V_{in}} \quad (3)$$

The average amount of current that flows to be equal to the output current converters:

$$I_o = \frac{P_o}{V_o} \quad (4)$$

The switch voltage V_s is defined by the below equation (5),

$$V_s = \frac{V_i}{1-D} \quad (5)$$

Following equation is utilized for finding the value of inductors,

$$L_1 = L_2 = L_3 = \frac{V_i \times D}{\Delta i_L \times f} \quad (6)$$

$$I_L = \frac{V_o \times I_o}{V_i} \quad (7)$$

By utilizing the below equation, C_1 and C_2 is obtained,

$$C_1 = C_2 = \frac{I_o}{\Delta V_c \times f} \quad (8)$$

$$C_o = \frac{I_o \times D}{\Delta V_o \times f} \quad (9)$$

The voltage gain equation for the developed converter is defined as,

$$\frac{V_{out}}{V_{in}} = \frac{D}{1-D} \quad (10)$$

The minimal output voltage from PV gets efficiently stepped upto the required level of grid with the assistance of designed High gain converter. Despite this, the control approach has to be implement for producing stabilized output with minimized settling time and overshoot problems, hence Adaptive GOA optimized PI controller is integrated in this study as follows.

II.3 MODELLING OF ADAPTIVE GRASSHOPPER OPTIMIZED PI CONTROLLER

Tuning the parameters of PI controller utilizing Adaptive GOA is crucial for improving the performance of control system. In contrast, AGOA enhances the conventional approach by incorporating adaptive mechanisms that alter the parameters dynamically in the period of optimization process. AGOA adequately modify key parameters such as attraction and repulsion strengths based on real time feedback from the search environment. Additionally, the movement of grasshoppers are influenced by both gravity and wind that represents attraction to better solutions and simulating random disturbances. This dual influence allows for more effective navigation of the search space, with movement strategies based on solution density.

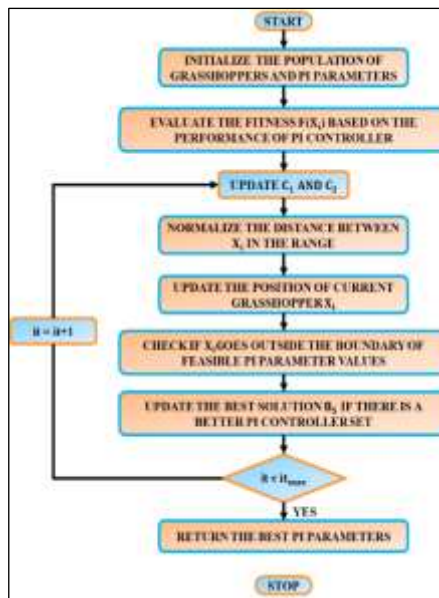


Figure 6: Flowchart representation of AGOA-PI controller.
Source: Authors, (2026).

Exploration and exploitation are the two steps of the search process. The exploitation stage deals with the sudden and long-range swarming nature of the adult phase, while the exploitation stage deals with the gradual and small-step swarming nature of the larval phase. The simulated activity of grasshoppers mimics these two stages with food objectives. The following is the mathematical model used in GOA. The following factors affects the position of k th grasshopper, gravity force G_k , social impact S_k and wind advection A_k ,

$$X_k = S_k + G_k + A_k \quad (11)$$

To ensure randomness, Equation (11) incorporates three randomly distributed numbers r_i , which are uniformly distributed, and is provided in Equation (12).

$$X_k = r_1 S_k + r_2 G_k + r_3 A_k \quad (12)$$

In order to represent the social impact component, the strength of social forces consider together with the distance between the k th and i th positioned grasshoppers $(\overline{d_{ik}})$ and a directional unit vector $(\overline{a_{ik}})$, as provided by Equation (13).

$$S_k = \sum_{\substack{i=1 \\ \neq k}}^N S(\overline{d_{ik}})(\overline{a_{ik}}) \quad (13)$$

Here, $\overline{a_{ik}} = \frac{(\overline{d_{ik}})}{|\overline{d_{ik}}|}$, $\overline{d_{ik}} = x_i - x_k$ and N denotes the number of grasshoppers. Following equation (14) is used to defined social force function s as,

$$0s(r) = fe^{\frac{-r}{l}} - e^{-r} \quad (14)$$

Where l denotes the attractive length scale and f specifies attraction strength. There are two possible social forces: attraction and repulsion. Several social forces are formulated by varying f and l . Likewise, wind advection and gravity force are considered by the following equation (15),

$$G_k = -g\bar{e}_g \text{ And } A_k = u\bar{e}_w \quad (15)$$

Here, $\bar{e}_g$ and $\bar{e}_w$ shows the unit vectors over the center of earth and in the direction of wind respectively. Equation (16) is written by expanding the equation of (12) by substituting equation (13) to equation (15),

$$X_k = \sum_{\substack{i=1 \\ \neq k}}^N S(\overline{d_{ik}})(\overline{a_{ik}}) - g\bar{e}_g + u\bar{e}_w \quad (16)$$

Nevertheless, as grasshoppers rapidly find their comfort zone and do not converge to precise spots, the swarming behavior of grasshoppers as represented in Equation (16) not be well suited to directly solve optimization problems. This is addressed by slightly altering Equation (16) as specified in Equation (17).

$$X_k^d = c \left\{ \sum_{\substack{i=1 \\ \neq k}}^N \left(\frac{ub_d - lb_d}{2} \right) S(\overline{d_{ik}})(\overline{a_{ik}}) \right\} + \bar{T}_d \quad (17)$$

Here, ub_d and lb_d shows upper and lower limits in the D th dimension, optimal solution identified thus far for the target value in the D th dimension is $\bar{T}_d$ and c specifies adaptive parameter, or decreasing inertia coefficient, to reduce the comfort, repulsion, and attraction zones is represented by Equation (18).

$$c = (c_{max} - 1) \left[\frac{it(c_{max} - c_{min})}{it_{max}} \right] \quad (18)$$

Improved inertia weight is introduced in adaptive GOA given in Equation (19) to maximize local search ability, boost accuracy, and need minimal processing time.

$$c = c_{max} - (c_{max} - c_{min}) (it / it_{max})^{1/it} \quad (19)$$

Where it_{max} denotes maximum number of iterations respectively. By utilizing this novel AGOA-PI controller, the stabilized form of output is attained within rapid settling time and convergence speed.

II.4 MODELLING OF DFIG BASED WECS

II.4.1 Wind Turbine Model

The wind turbine is the central part of a wind energy conversion system. In this, the gearbox is employed to connect the DFIG and WT and to reduce disturbances, improve stability as well as maximize system quality, the generated electricity is then incorporated into an electrical grid via a control system. Equation (20) describes the quantity of output power of a wind turbine because it is a nonlinear function as it depends on wind velocity.

$$P_m = \frac{1}{2} \rho A C_p(\lambda, \beta) V^3 \quad (20)$$

Furthermore, λ is defined as the ratio of the wind velocity to the linear velocity at the wind rotor blade tip, and it can be expressed as follows in Equation (20).

$$\lambda = \frac{\omega R}{V} \quad (21)$$

Here, A shows area covered by wind turbine blades, R specifies sweep of turbine blades, V denotes wind velocity, C_p represents power coefficient, ρ shows air density. Following equation (21) defines evolution of torque as,

$$T_a = \frac{\rho}{\omega_t} = \frac{1}{2\lambda} \rho \pi R^3 V^3 \omega C_p(\lambda, \beta) \quad (22)$$

II.4.2 DFIG Model

DFIG is the vital component of the wind power production system since it transforms mechanical energy into electrical energy. According to the Park reference, the global mathematical formulae for the DFIG's active/reactive powers, voltages, and flux are as follows. The mathematical equation for stator and rotor is given as follows,

$$\begin{cases} V_{sd} = R_s i_{sd} + \frac{d}{dt} \phi_{sd} - \omega_s \phi_{sq} \\ V_{sq} = R_s i_{sq} + \frac{d}{dt} \phi_{sq} + \omega_s \phi_{sd} \\ V_{rd} = R_r i_{rd} + \frac{d}{dt} \phi_{rd} - (\omega_s - \omega_r) \phi_{rq} \\ V_{rq} = R_r i_{rq} + \frac{d}{dt} \phi_{rq} + (\omega_s - \omega_r) \phi_{rd} \end{cases} \quad (23)$$

Here, R_s, R_r, ω_s and ω_r refers stator resistance, rotor resistance, stator pulsation, rotor pulsation correspondingly.

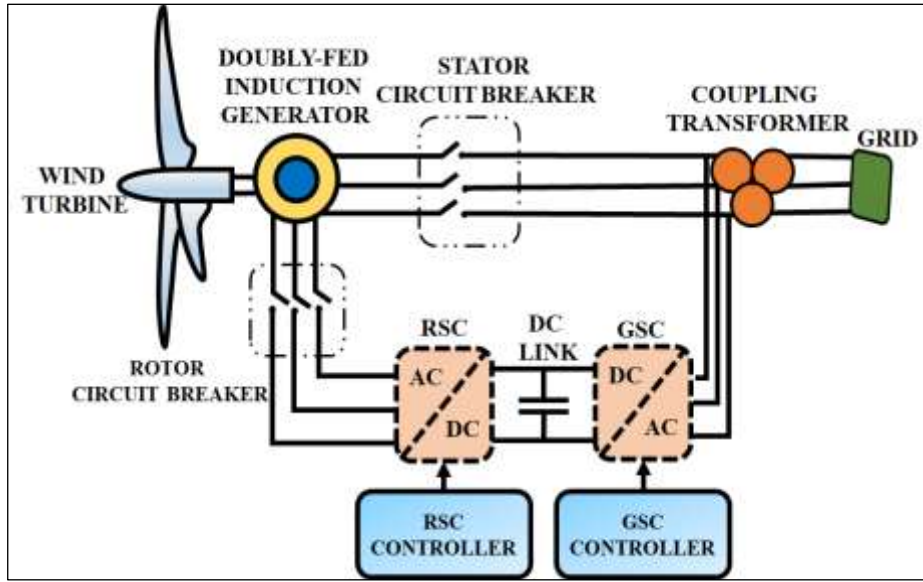


Figure 7: Architecture of DFIG based WECS.
Source: Authors, (2026).

Following equation (24) denotes stator and rotor flux as,

$$\begin{cases} \phi_{sd} = L_s i_{sd} + L_m i_{dr} \\ \phi_{sq} = L_s i_{sq} + L_m i_{qr} \\ \phi_{rd} = L_r i_{rd} + L_m i_{ds} \\ \phi_{rq} = L_r i_{rq} + L_m i_{qs} \end{cases} \quad (24)$$

Here, $\phi_{rd}, \phi_{sq}, \phi_{rd}$ and ϕ_{sq} denotes rotor and stator fluxes, L_r, L_s specifies inductance of rotor and stator, i_{rd}, i_{rq} shows the rotor currents and L_m denotes mutual inductance respectively. Additionally, the obtained energy from DFIG is AC that converts into DC with the aid of PWM rectifier, which gets regulated by the PI controller. Despite this, the battery system is performs for storing additional energy generated by the HRES and the charging and discharging process are handled with the assistance of Bidirectional converter. The stored energy from the battery generates power back to grid in the event of unavailable power from HRES, thereby the grid system gets continuous power without any disturbances.

III. RESULTS AND DISCUSSION

This section deals with the outcomes obtained from MATLAB/Simulink for the proposed High gain Improved SEPIC converter, AGOA-PI controller with battery system. The attained findings are compared with the other recently utilized conventional converters and optimized control approaches for screening the effectiveness of developed system. The following Table 1 showcase the specification for developed system.

Table 1: Parameter Specification for the proposed system.

Parameters	Ratings
PV and DFIG	
Open circuit Voltage	37.25V
Peak power	10kW
Cell linked in Series	36
Short circuit current	8.95A
No. of turbine	1
Switching frequency	10kHz
Power	10kW
High gain SEPIC converter	
Switching Frequency	10kHz
C_1, C_2	22 μ F
L_a, L_b, L_c	4.7mH
C_0	2200 μ F

Source: Authors, (2026).

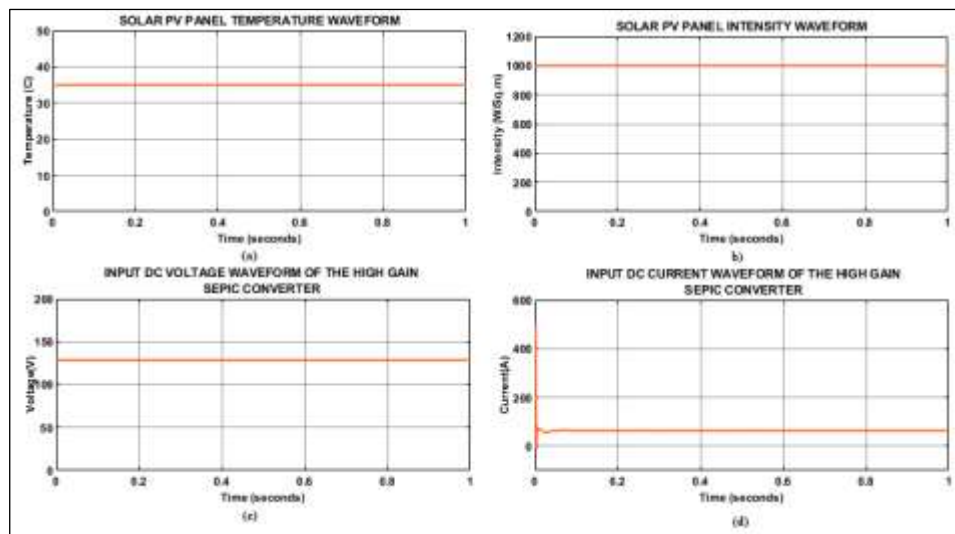
Case 1 Under constant Temperature and Intensity

Figure 8: Solar panel waveforms for case 1 condition.

Source: Authors, (2026).

The solar panel temperature is constantly maintained under 35°C as indicated in Figure 8(a) and Intensity waveform in Figure 8(b) shown that the constant irradiance is maintained at 1000(W/Sq.m) throughout the period of time. Additionally, solar array output voltage is given as input to the High gain converter, the voltage gets continued at 130V as specifies in Figure 8(c). Similarly, the input current waveform for the converter is constantly sustained at 60A respectively under constant condition.

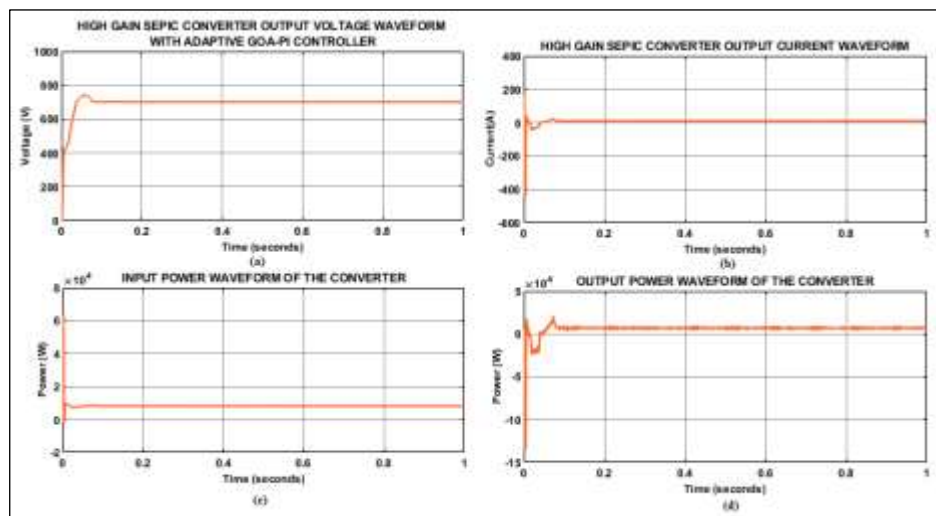


Figure 9: High gain SEPIC Converter with control technique Waveforms.

Source: Authors, (2026).

The output converter voltage gets fluctuated in initial period and after 0.1s, it continually maintained at 705V through the aid of adaptive GOA-PI controller as shown in Figure 9(a). Alike, the High gain converter's output current waveform in Figure 9(b) states that current is continues at 10.5A throughout the period of time. Furthermore, the input power waveform in Figure 9(c) specifies that the power is stabilized at 7800W without any oscillations. Identically, the converter output power shows that after 0.1s the constant power is maintained at 7402W as indicated in Figure 9(d) respectively.

Case 2 Varying Temperature and Intensity

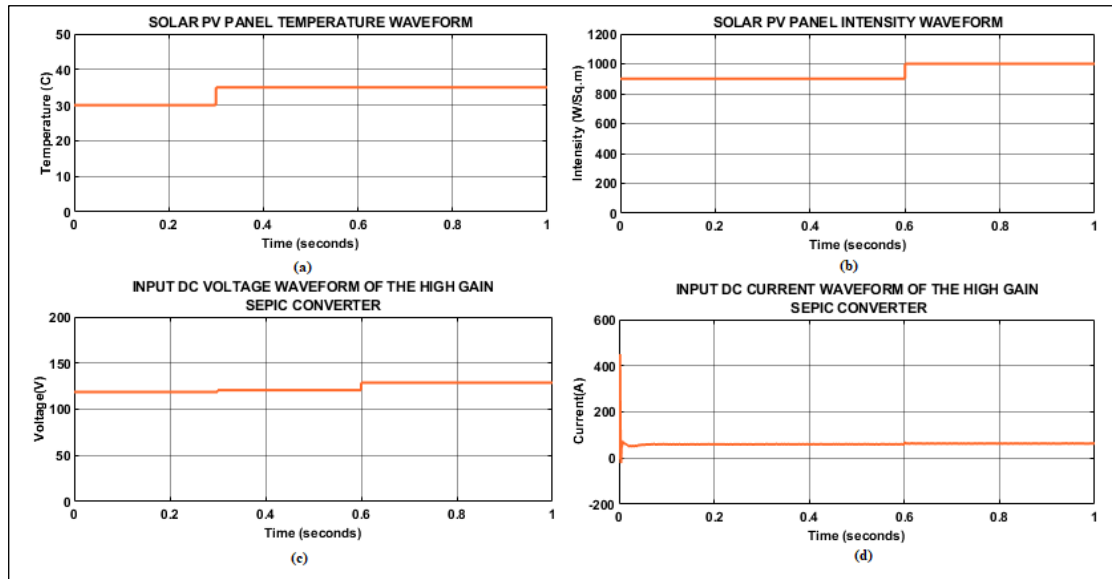


Figure 10: Solar panel waveforms for case 2 condition.

Source: Authors, (2026).

As indicated in Figure 10 (a), the solar panel temperature gets stable at 35°C after facing slight distortions in starting period. Also, irradiance of solar module in Figure 10(b) illustrates the stable performance is attained at 1000(W/Sq.m) after the duration of 0.6s under varying condition. Similarly, input DC voltage of High gain Improved SEPIC converter face slight deviations under the period of 0.6s as specified in Figure 10(c), after that it maintained at 130V. In Figure 10(d), the input current waveform for the converter illustrate that the current is constantly preserved at 60A after the time period of 0.6s correspondingly.

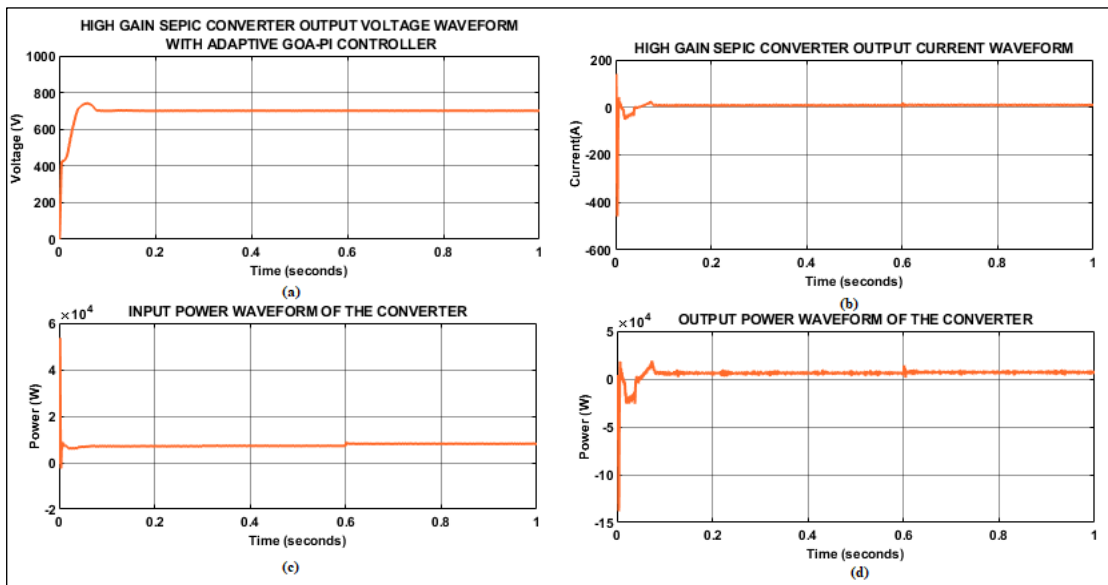


Figure 11: Converter Waveforms for case 2.

Source: Authors, (2026).

As shown in Figure 11(a), the output converter voltage fluctuates during the initial period and after it gets constantly maintained at 705V with the assistance of the adaptive GOA-PI controller. Figure 11(b) shows that the output current of the high gain converter that remains at 10.5A continuously after facing slight oscillations upto 0.1s. According to Figure 11(c), the converter input power gets oscillations till 0.6s and gets stabilized at 7800W. Similarly, Figure 11(d) indicates that after 0.1s, the converter output power stabilizes at 7402W without any deviations.

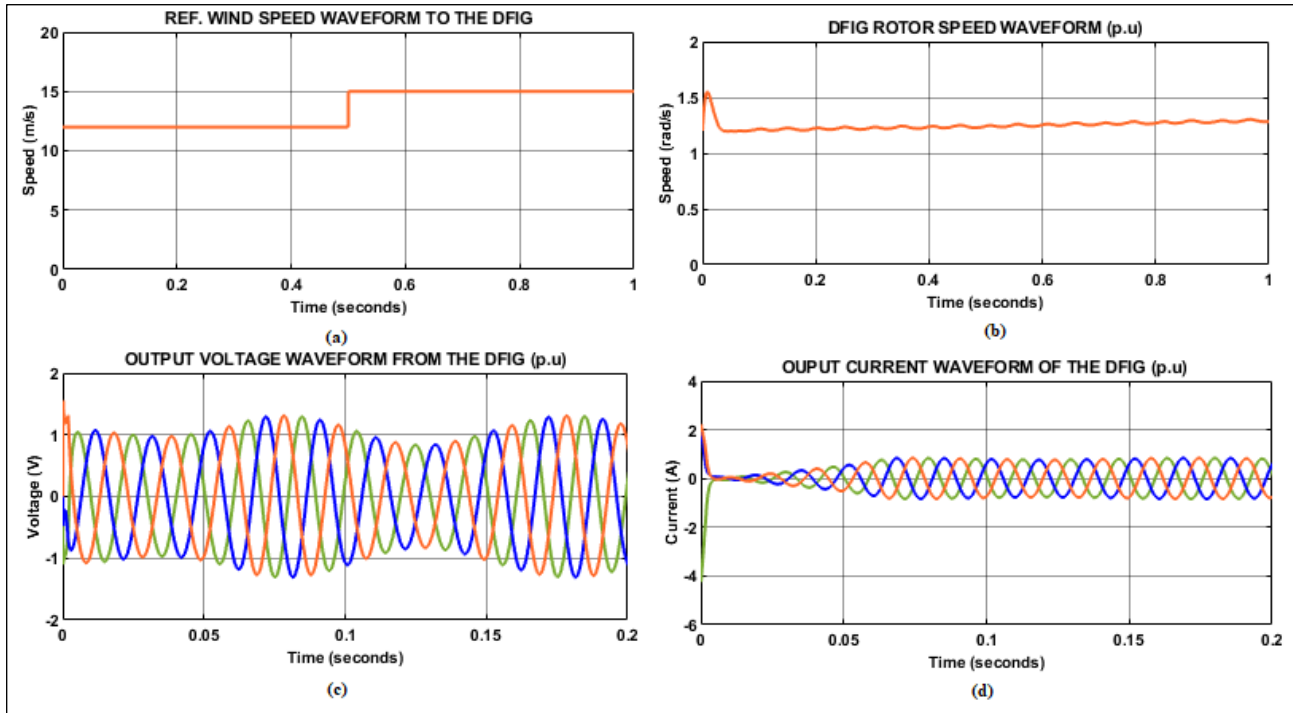


Figure 12: DFIG based WECS waveforms.

Source: Authors, (2026).

The reference wind speed waveform to the DFIG in Figure 12(a) states that the wind speed to DFIG gets minimal distortion upto the period of 0.5s after that the speed is stabilized at 15(m/s). Also, the rotor speed is highly raised upto 1.6 radius and it slightly slow down and maintains at 1.3radius with minimal deviations as shown in Figure 12(b). In Figure 12(c), the output voltage of DFIG is maintained after the time duration of 0.15s. Alike, the output current waveform in Figure 12(d) indicates that initially its face fluctuations upto 0.1s and after the stable output at 0.9A is maintained respectively.

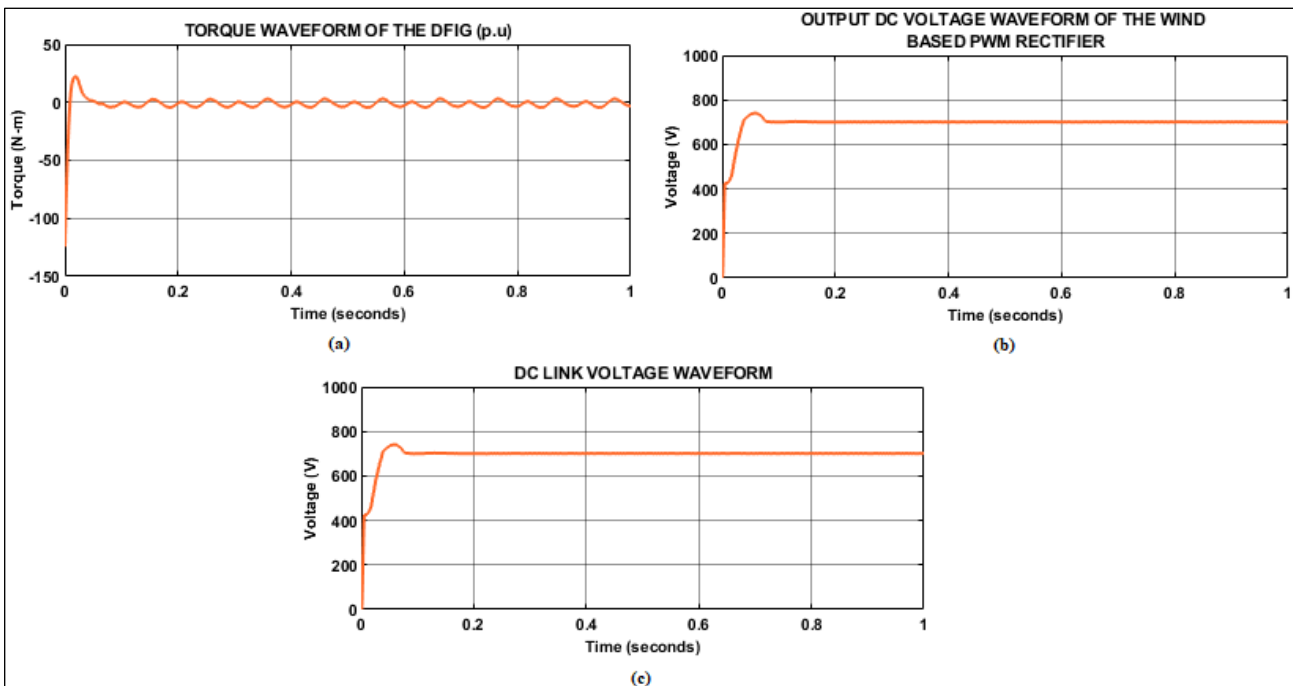


Figure 13: Waveforms of DFIG Torque, output DC of wind based PWM rectifier and DC link voltage.

Source: Authors, (2026).

The DFIG torque waveform in Figure 13(a) specifies that torque is highly minimized after 0.2s and output DC of wind based PWM rectifier gets stabilized output at 700V after the duration of 0.1s. Similarly, the DC Link voltage is slightly raised and face oscillation till 0.1s, after that a constant output at 700V is maintained throughout the period of time as specified in Figure 13(c).

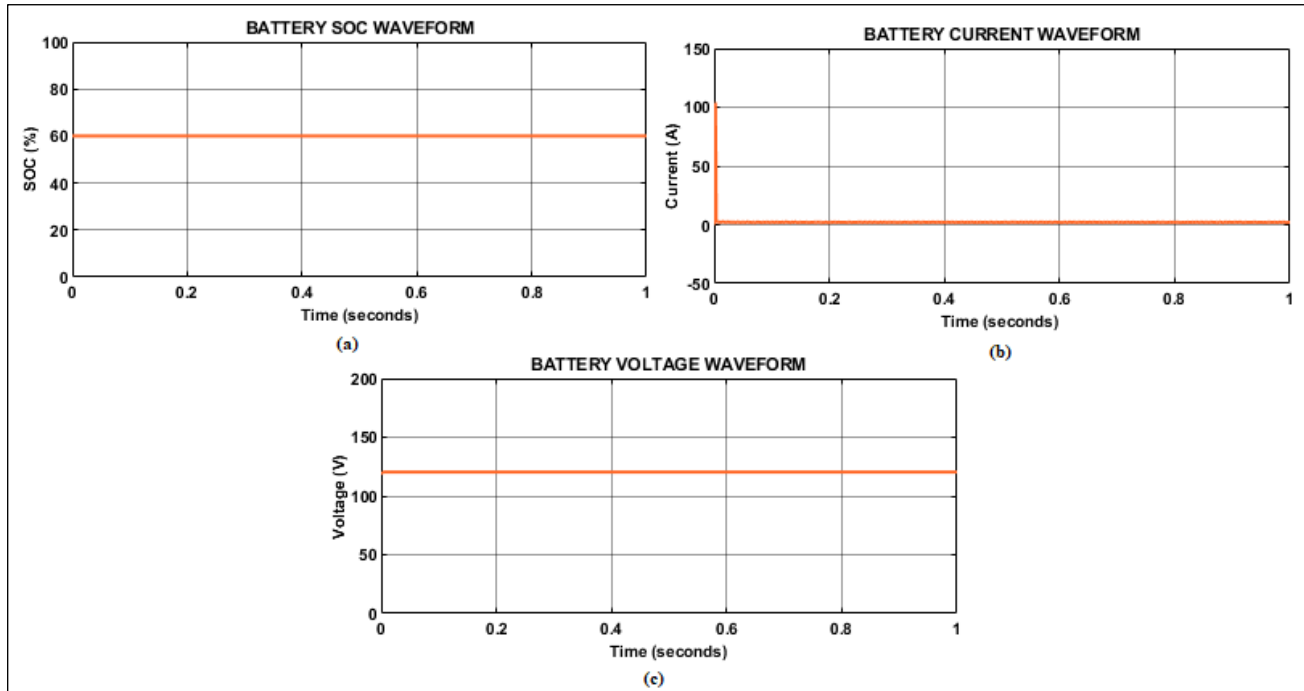


Figure 14: Waveforms of battery.

Source: Authors, (2026).

The waveform in Figure 14(a) shows the SOC of battery is constantly preserved at 60% and the current of battery is highly increased upto 100A and suddenly decreases upto 2A and maintained continually as indicated in Figure 14(b). Likewise, the battery voltage waveform in Figure 14(c) specifies that the stabilized output at 120V is maintained throughout the period of time.

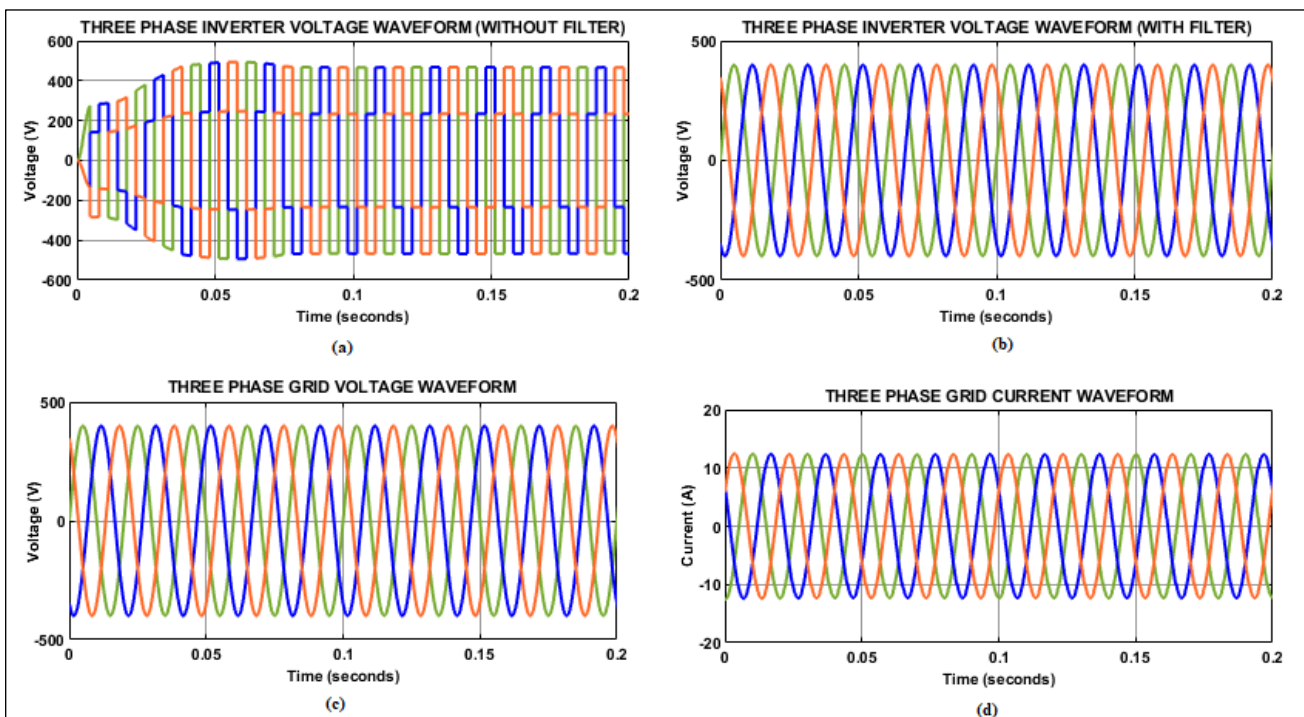


Figure 15: Waveforms of grid and inverter voltage without LC filter.

Source: Authors, (2026).

In Figure 15(a), the inverter without filter waveform indicates that it fluctuates in initial period and maintains 415V in the form of square wave without using LC filter. The inverter voltage waveform in Figure 15(b) states that constant voltage is maintained continually at 500V in the form of sinusoidal after utilizing LC filter. Three phase grid voltage waveform proves that it maintains a stabilized output at 415V without any oscillations as shown in Figure 15(c). Similarly, the current waveform in Figure 15(d) states that a constant current at 12A is continuously preserved over the time period.

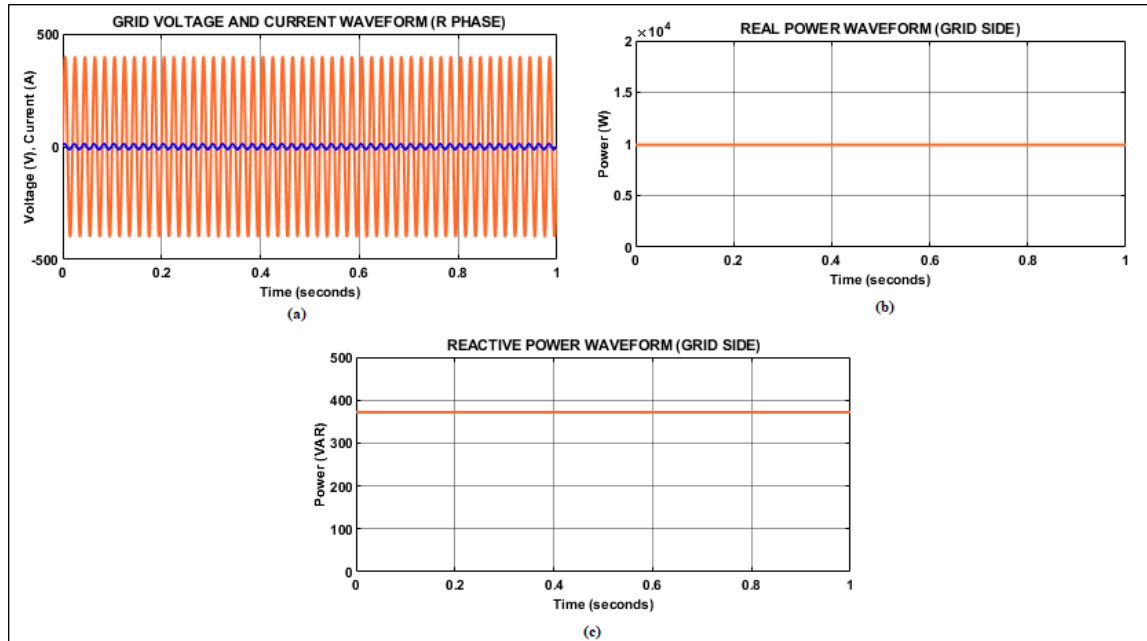


Figure 16: Waveforms of three phase inverter voltage with LC filter, Real and Reactive power.
Source: Authors, (2026).

The in phase voltage and current waveform shown a stabilized form of voltage and current is frequently maintained at 415 and 12A as represented in Figure 16(a). Also, the stabilized real and eliminated reactive power is attained with the assistance of proposed system as indicated in Figure 16 (b and c).

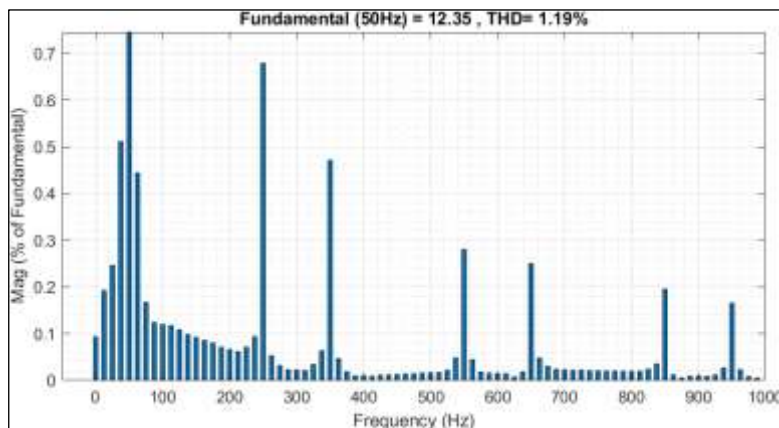


Figure 17: THD Output.
Source: Authors, (2026).

The THD waveform for the proposed system is stated in Figure 17, which shown that with the aid of developed converter and optimized approach, the minimized value of 1.19% is achieved.

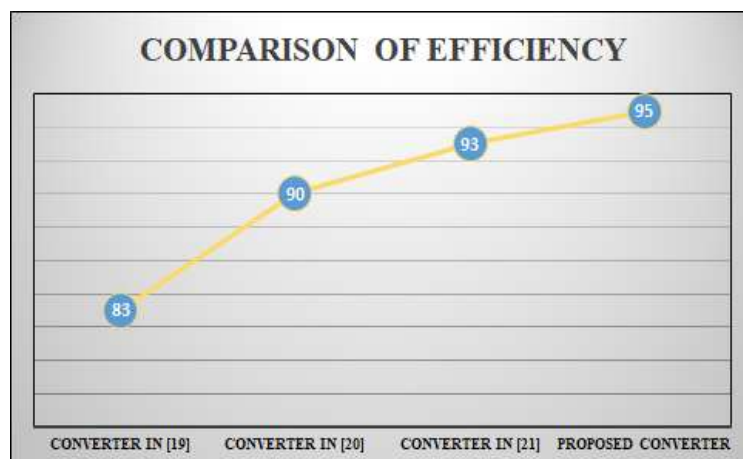


Figure 18: Comparative analysis of converter's efficiency.
Source: Authors, (2026).

The conventional converters that is referred in [19-21] are compared with the proposed converter for showing the development of proposed system. From the graph in above Figure 18 denotes that the proposed high gain improved SEPIC converter attains higher efficiency of 95% with the aid of optimized controller compared to the traditional approaches.

Table 2: Comparison of settling time.

Approaches	Settling time(s)
Modified Seagull [22]	21.4s
PSO [23]	21.6s
Proposed AGOA	0.1s

Source: Authors, (2026).

The various optimization approaches are compared with the traditional topologies as shown in Table 2, which indicates that the utilized GOA optimized PI controller performs minimized settling time of 0.1s compared to the other optimization topologies.

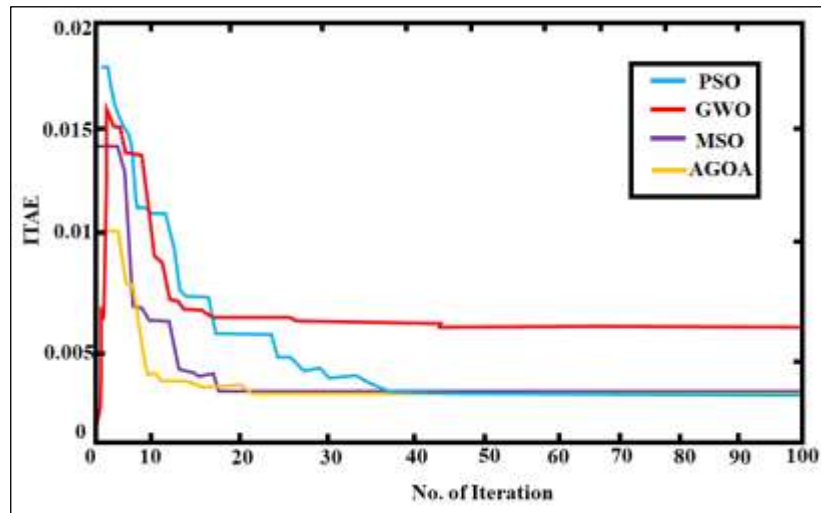


Figure 19: Comparison of Optimization approach.

Source: Authors, (2026).

Various Optimization algorithms are compared with the other classical approaches as shown in Figure 19, from the graph it is known that the utilized AGOA approach attains minimized ITAE, thereby the convergence speed is also enhanced.

IV. CONCLUSION

The proposed research develops a novel HRES based converter with optimized control and battery system for ADN topology. In this, the PV system voltage is outperforms by employing High gain Improved SEPIC converter, which step up the output voltage of PV to satisfy the load requirement. Also, the voltage gets stabilized without any oscillations by regulating the converter performance through the use of GOA-PI controller. Despite this, during the lacking period of energy to supply enough power to grid system, the stored energy in battery during excess power generation from HRES is proficiently generated power supply to grid, thereby the energy management is attained. Additionally, the outcomes obtained by the MATLAB/Simulink demonstrates that the designed converter approach attains higher efficiency value of 95% and AGOA control approach attains superior in terms of minimized settling time with ITAE when compared to the other currently utilized topologies. Thereby, the proposed system proves that by utilizing the proposed topology, an efficient power is delivered to the ADN with superior performance.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Siddheswar Kar, Manish Jain and Murali Matcha.

Methodology: Siddheswar Kar and Manish Jain.

Investigation: Siddheswar Kar and Manish Jain.

Discussion of results: Siddheswar Kar, Manish Jain and Murali Matcha.

Writing – Original Draft: Siddheswar Kar.

Writing – Review and Editing: Siddheswar Kar and Manish Jain.

Resources: Manish Jain.

Supervision: Manish Jain and Murali Matcha.

Approval of the final text: Siddheswar Kar, Manish Jain and Murali Matcha.

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