

RESEARCH ARTICLE

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ENERGY-EFFICIENT SOLAR PV INDUCTION MOTOR DRIVE SYSTEM WITH CIM-SEPIC CONVERTER FOR HIGH-RISE BUILDING APPLICATIONS

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ABSTRACT

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Escorted by the increased insistence of high-rise buildings in developing regions, their construction and maintenance is facing various hazardous situations including severe damages and accidents caused due to increased heights, worker careless and tiredness. Thus, finding a significant solution to reduce these kinds of accidents during high rise building construction such as painting, is considered as highly essential. Henceforth, this paper proposes a novel approach integrating Induction Motor (IM) utilizing Photovoltaic (PV) system as the primary energy source to develop an intelligent device for painting high-rise building. Additionally, to attain highly regulated power output from PV, to meet the desired energy demands of the proposed model, a Coupled Inductor Modified Single Ended Primary Inductor Converter (CIM-SEPIC) is deployed to boost the PV power production. Likewise, to further attain optimum control, a Modified Black Widow Optimized Proportional-Integral (MBWO-PI) controller is implemented to regulate the DC voltage, thus enabling to attain increased stability and optimum power flow. To ensure uniform paint application, the motor drives a specially designed chair-based mechanical arrangement with a painting arm that moves horizontally (from left to right) across the building's surface. Therefore, this proposed approach significantly reduces the requirements of manual labours leading to reduced accidental risks in high-rise building painting operations. Both inverter and converter stages are controlled by a PI controller, which provides precise control of motor's speed. A Node MCU module integrates IoT capability, allowing remote command as well as remote monitoring of system status, including solar output, battery charge level, and motor performance. The proposed model is validated using MATLAB/Simulink implementation which depicts improved efficiency (96%) with enhanced system performance. Thereby, contributing towards highly safe and stable painting process in tall buildings.



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I. INTRODUCTION

Worldwide, building section have been considered as one among the most accident prone industries. Which is mainly caused due to the expanding demand for high-rise building construction leading to increased accidents and life losses [1], [2]. Moreover, the construction of these tall buildings requires substantially increased work force to meet their deadlines while also efficiently maintaining the complexities of the work. Significantly, the risk and hazards of tall building construction are highly increasing, each year the damages caused is surpassing other industries, in terms of severe damages, injuries and even loss of life [3], [4]. Hence, if these type of accidents continues to occur, it leads to severe losses including cost, life and time.



Figure 1: Factors Affecting High-rise Building construction.
Source: Authors, (2026).

As a result, various new topologies are analysed and developed to enhance the safety of workers in building sectors, thereby, to improve efficiency and productivity of the construction site, including the utilization of efficient motors for automatic painting applications [5]. At present there are various types of motors available such as Permanent Magnet Synchronous Motor (PMSM) [6], Switched Reluctance Motor (SRM) [7] and Brushless Direct Current (BLDC) motor [8] which provides enhanced efficiency with minimal maintenance and effective system performance. These motors are utilized for developing an automated system for high-rise building enabling reduced labour requirements and safety risks. However, these motors are still affected by rapid system variations including temperature and fluctuations, which leads to their increased complexity with reduced stability. Therefore, this paper utilizes IM which effectively increases the system performance with improved simplicity, robustness, efficiency, stability, high torque and enhanced safety. In addition to this, Renewable Energy Resources (RES) specifically, PV is integrated to further supply desired power requirements to IM, here PV acts as the primary power source.

However, PV system at first produces lower level output voltages making it essential to utilize DC-DC power converters. Conventionally, there are several types of converters like Boost converter [9], Cuk Converter [10] and Zeta converter [11] which provide enhanced output voltage regulation, high step-up voltage gain, reduced voltage ripples and wide input voltage ranges. Despite this, these converters struggles with increased switching losses, higher current ripples, complex circuit design and increased complexity. To be more specific, the utilization of coupled Inductor boost converter, significantly shows improved performance in terms of achieving improved voltage conversion, higher efficiency, enhanced power handling ability and also improved system stability and reliability, making it highly applicable for PV system [12]. But this converter faces certain issues related to increased component count and losses which makes it less efficient.

Therefore, this paper proposes a novel CIM-SEPIC converter which offers higher voltage gain, enhanced power conversion and increased voltage regulation with reduced losses and ripples, thereby, increasing the effectiveness of PV system. Consecutively, to further improve converter performance and to assure effective functioning, it is essential to utilize optimum control technique. On this basis, PI controller is integrated to perform voltage regulation of the converter, thereby, assuring stable and consistent performance even under varying system circumstances. Despite this, the performance efficiency of PI controller is further enhanced through optimum utilization optimization algorithm including Particle Swarm Optimization (PSO) [13], Falcon Optimization Algorithm (FOA) [14], African Vulture Optimization Algorithm (AVOA) [15] and Coot Bird Metaheuristic Optimizer (CBMO) [16] which are listed in Table 1 along with their merits and demerits.

Table 1: Various Optimization Algorithms for PI controller.

Optimization Algorithm	Merits	Demerits
Particle Swarm Optimization (PSO)	➤ Rapid Convergence speed ➤ Easy and simple integration ➤ Enhanced ability in handling system non-linearity.	➤ Highly impacted by local-optima ➤ Inefficient performance with increased dimensions.
Falcon Optimization Algorithm (FOA)	➤ Improved performance with enhanced problem solving ability. ➤ Enhanced Exploration and Exploitation phase	➤ Reduced convergence speed ➤ Increased sensitivity towards parameters
African Vulture Optimization Algorithm (AVOA)	➤ Improved Stability and reliability ➤ Enhanced Optimization efficiency.	➤ Increased complexity ➤ Reduced stability and reliability ➤ Computationally complex.
Coot Bird Metaheuristic Optimizer (CBMO)	➤ Increased robustness against system deviations ➤ Improved optimization performance	➤ Cannot handle complex problems ➤ Slower convergence speed

Source: Authors, (2026).

From the above listed table regarding the various conventional optimization algorithms utilized for PI controller tuning faces certain limitations including reduced convergence speed, Henceforth, here, Modified Black Widow Optimized PI controller is deployed, which enables increased convergence speed, enhanced global search ability and optimum PI controller tuning, thus, assuring optimal PI controller performance with reduced steady-state errors. Therefore, the overall proposed model achieves improved system performance in terms of increased PV output voltage with optimum control and regulation, enabling to meet the desired power requirements of IM for automated high-rise building painting applications. The major outline and contributions of the proposed model is listed in the following,

- ❖ To implement PV system utilizing a CIM-SEPIC converter for attaining adequate power supply to IM with increased voltage gain and reduced losses.

- ❖ To integrate a Modified Black Widow Optimized PI controller to obtain optimum control with improved voltage regulation and power conversion ability.
- ❖ To attain effective storage and retrieval of excess power using battery through Bi-directional DC-DC converter, enabling seamless charging and discharging.

II. PROPOSED METHODOLOGY

The block diagram of the proposed work utilizing CIM-SEPIC converter and MBWO-PI controller is shown in Figure 1. Initially, the PV system produces energy from sunlight using solar energy, which is primarily low in voltage level in the beginning.

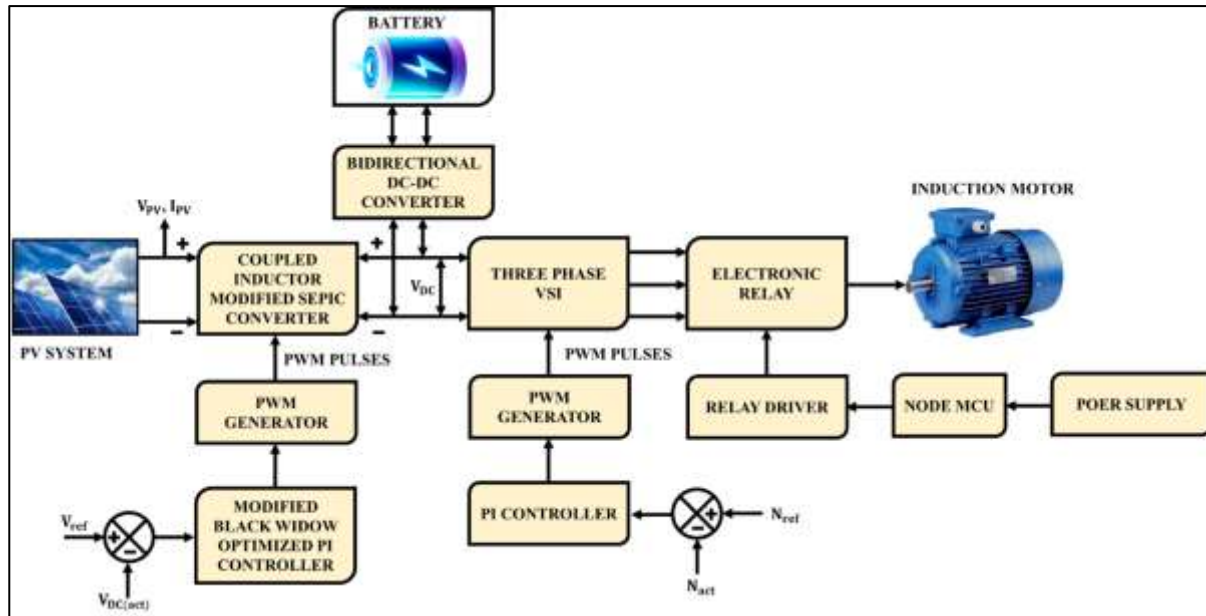


Figure 2: Block Diagram Proposed Painting System.
Source: Authors, (2026).

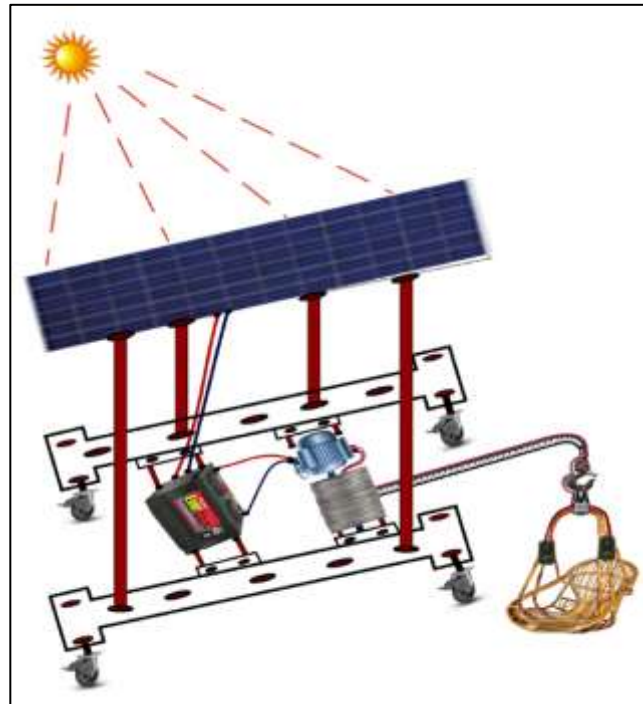


Figure 3: Developed PV Powered Automated Painting System.
Source: Authors, (2026).

Considering this issue, a CIM-SEPIC converter is utilized, which enhances the PV system performance by boosting the output voltage levels, thus generating higher level output voltage with reduced losses. Later, a Modified Black Widow Optimized PI controller is connected to the converter for attaining effective control and voltage regulation. Additionally, a Pulse Width Modulation (PWM) is deployed within the PV system to provide requisite PWM signals for the converter switching performance. Later, the output voltage generated from PV system is fed to the IM through three phase VSI which in turn is controlled using PI controller. The deployment of VSI enables smooth conversion of DC voltage to AC supply, thus making it suitable for IM and here, the motor speed is controlled using the PI controller. In addition to this, Electronic relay and relay driver is attached to IM, which is controlled using the Node MCU, for assuring optimum switching and motor operations. Lastly, the power supply sector provides adequate power supply to the control units.

Despite this, to store the excess power produced by PV system, a Battery unit is attached via Bi-directional converter for attaining seamless charging and discharging of battery, which acts as the supplementary power source during insufficient or excess power requirements. This system works by enabling to paint the high-rise building utilizing the proposed model which is attached to the chair that allows automatic painting using a large handle which moves in left and right directions, thereby achieving smooth and easy painting approaches, shown in Figure 3. Therefore, by implementing and utilizing the proposed converter, controller and motor, assures efficient system performance with enhanced energy conversion, stable and consistent motor operation, thus, enabling effective performance of automated painting application in high-rise building, leading to increased worker safety by preventing unwanted accidents and hazards in construction sites.

II.1 MODELLING OF IM

Electrical energy is converted into mechanical energy using the IM, which is generally utilized for the moving machine applications. The three phase power supply is delivered to the stator that is wound to the three phase winding as represented in Figure 4. Due to which, a rotational magnetic flux is produced at the stator winding. Thus, the produced magnetic flux is distributed to the rotor via the electromagnetic induction effect. Hence, an induced EMF is generated on the rotor side. The mathematical designing of IM is expressed as.

$$V_{ds}^s = i_{ds}^s + L_{ls} \frac{d}{dt} (i_{ds}^s) + \frac{d}{dt} (\psi_{dm}^s) \quad (1)$$

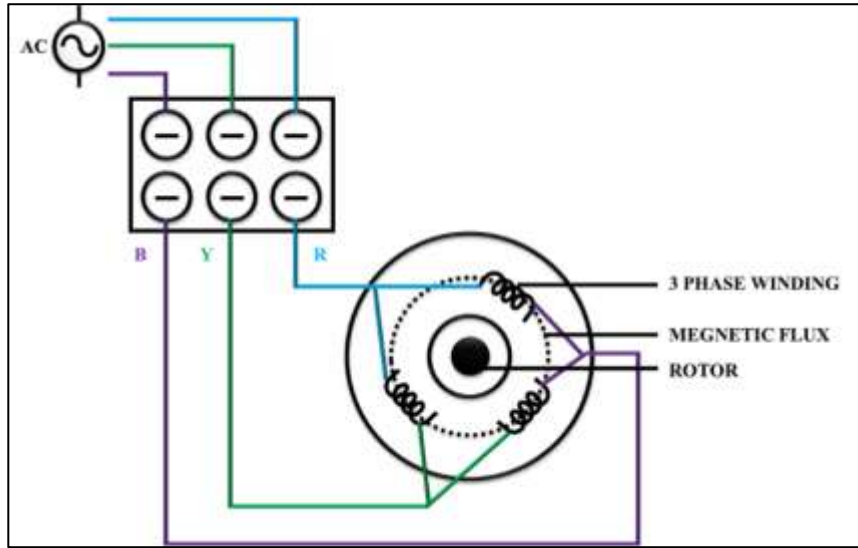


Figure 4: Three Phase Induction Motor
Source: Authors, (2026).

$$V_{ds}^s = \frac{L_m}{L_r} \frac{d}{dt} (\psi_{dr}^s) + (R_s + \sigma L_s S) i_{ds}^s \quad (2)$$

Where, $\sigma = 1 - \frac{L_m^2}{L_r L_s}$

$$\frac{d}{dt} (\psi_{dr}^s) = \frac{L_r}{L_m} V_{ds}^s - \frac{L_r}{L_m} (R_s + \sigma L_s S) i_{ds}^s \quad (3)$$

Likewise,

$$\frac{d}{dt} (\psi_{qr}^s) = \frac{L_r}{L_m} V_{qs}^s - \frac{L_r}{L_m} (R_s + \sigma L_s S) i_{qs}^s \quad (4)$$

$$\frac{d}{dt} (\psi_{dr}^s) = \frac{L_m}{T_r} i_{ds}^s - \omega_r \psi_{qr}^s - \frac{1}{T_r} \psi_{dr}^s \quad (5)$$

$$\frac{d}{dt} (\psi_{qr}^s) = \frac{L_m}{T_r} i_{qs}^s + \omega_r \psi_{dr}^s - \frac{1}{T_r} \psi_{qr}^s \quad (6)$$

Where, $T_r = \frac{L_r}{R_r}$ The rotor speed is calculated using,

$$\omega_r = \frac{d}{dt} \theta_e = \frac{1}{\psi_r^2} \left[\left(\psi_{dr}^s \frac{d}{dt} \psi_{qr}^s - \psi_{qr}^s \frac{d}{dt} \psi_{dr}^s \right) - \frac{L_m}{T_r} (\psi_{dr}^s i_{qs}^s - \psi_{qr}^s i_{ds}^s) \right] \quad (7)$$

The slip speed equation is given as,

$$\omega_{slip} = \frac{(1 + \sigma T_r S) L_s i_{qs}^s}{T_r (\psi_{ds}^s - \sigma L_s i_{ds}^s)} \quad (8)$$

Henceforth, the velocity of IM is depicted as,

$$\omega = \omega_{slip} + \omega_r \quad (9)$$

Furthermore, to provide requisite power supply for optimum motor performance, PV system is deployed to generate adequate power from solar energy. The implementation of PV system supplies consistent and sustainable energy supply for IM.

II.2 MODELLING OF PV SYSTEM

The PV system is implemented to provide adequate power supply to operate IM. The single diode PV equivalent circuit diagram is illustrated in Figure 5.

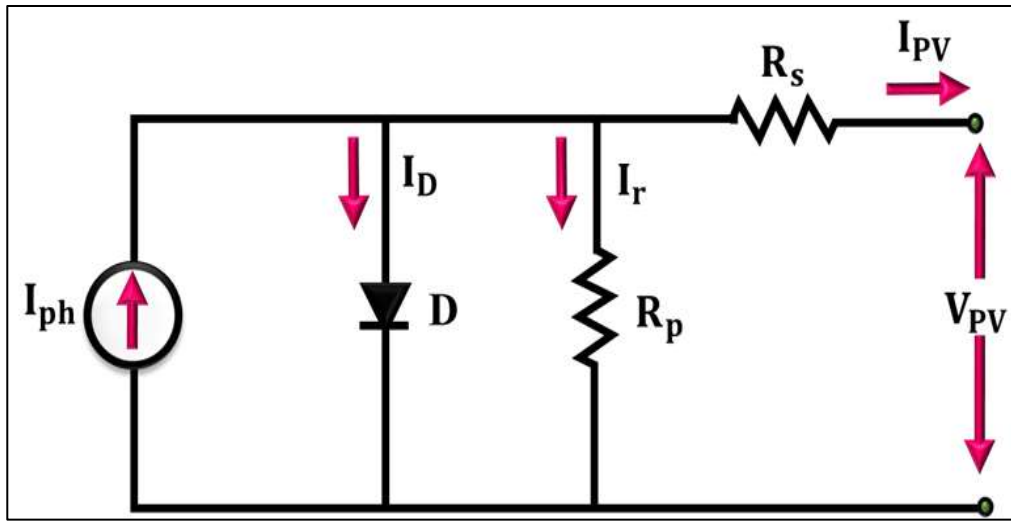


Figure 5: Equivalent Circuit Diagram of PV system.

Source: Authors, (2026).

The PV output current is given by,

$$I_{pv} = I_{ph} - I_d - I_{sh} \quad (10)$$

$$\text{Where, } I_{ph} = G \frac{I_{sc}}{G^8}, I_d = I_0(e^{\frac{V_D}{V_t}} - 1), I_{sh} = \frac{V_D}{R_{sh}}, V_D = V_{pv} + R_s I_{pv}$$

$$I = N_p \left(I_{pv} - I_s \left(e^{\frac{q(V+I R_s)}{a N_s K T}} - 1 \right) \right) - \frac{(V+I R_s)}{R_{sh}} \quad (11)$$

Here, V_t refers to the PV thermal voltage, and N_p and N_s represents the number of cells connected in series and parallel.

II.3 MODELLING OF CIM-SEPIC CONVERTER

The developed CIM-SEPIC converter is shown in Figure 6, which comprises of input inductance L_a , switch S , a coupled inductor, Diodes D_0 , D_a and D_b , and an output capacitor C_0 , capacitors C_a , C_b and C_c . The coupled inductor is significantly equivalent to the magnetising inductance L_m and leakage inductance L_k respectively. The switching waveform of proposed M-SEPIC converter is illustrated in Figure 7.

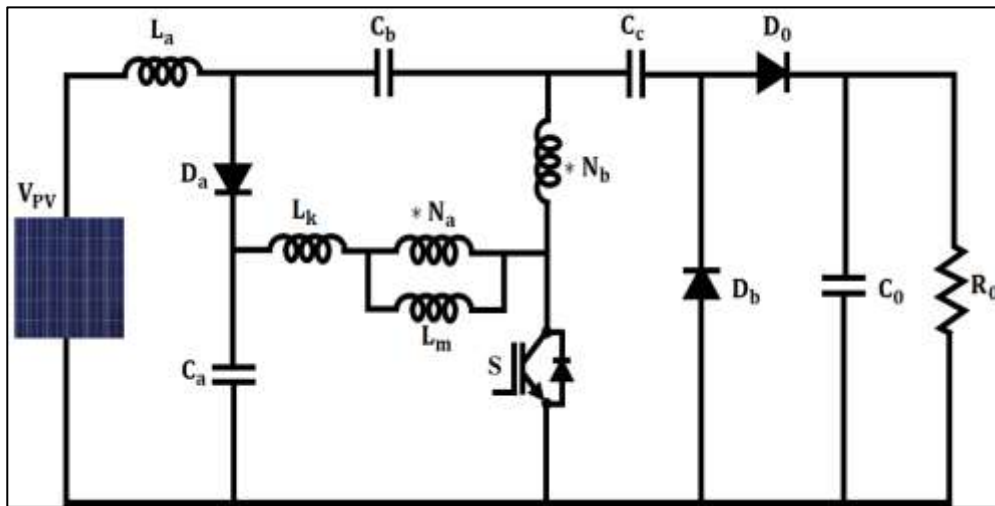


Figure 6: Proposed CIM-SEPIC Converter.

Source: Authors, (2026).

At time $(t_0 - t_1)$, the switch S is in conducting state, with diode D_0 in forward biased condition, whereas the other diodes D_a and D_b are in reversed biased state, depicted in Figure 8(a). The current i_{L_k} , i_{N_b} , i_{D_b} and current across switch increases quickly and the diode current i_{D_0} decreases in linear. Thereby, the load R_0 and C_0 are powered by inductor L_a , magnetizing inductance L_m and capacitor C_b . At instance when $i_{N_b} = 0$, the D_0 is turned OFF and D_b starts conducting. During the interval $(t_1 - t_2)$, the switch is in ON state, with diodes D_0 and D_a in OFF condition, while D_b in forward biased condition, presented in Figure 8(b). In this case C_b discharges and charge L_m . In addition, the input V_{pv} , C_a and N_b supplies energy to L_a in series. Furthermore, C_c charges N_b . The inductor current i_{L_a} shows linear increase and is expressed by

$$i_{L_a}(t) = i_{L_a}(t_1) + \frac{V_{pv} + V_{C_a} + V_{C_c}}{L} (t - t_1) \quad (12)$$

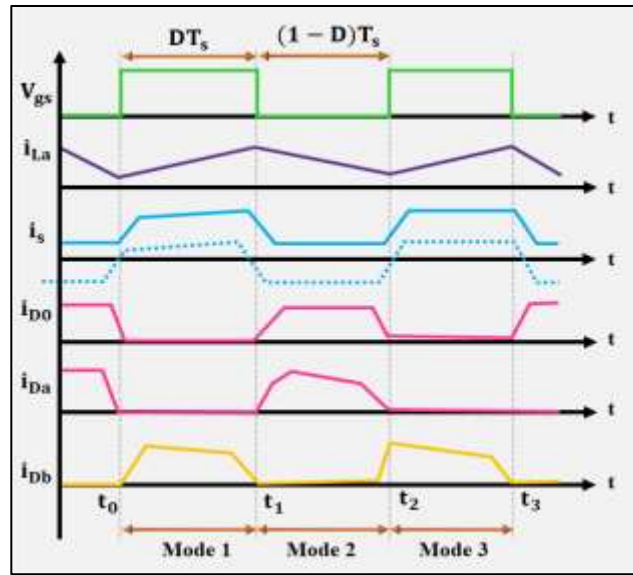


Figure 7: Switching Waveform of CIM-SEPIC Converter.
Source: Authors, (2026).

It is to be noted that, the voltage across L_m and L_k is V_{Cb} , therefore the leakage inductance current i_{Lk} is as follows;

$$i_{Lk} = i_{Lk}(t_1) + \frac{V_{Cb}}{L_k + L_m}(t - t_1) \quad (13)$$

At time interval $(t_2 - t_3)$, the switch is in OFF condition, with D_0 and D_a is turned ON with D_b in reversed bias condition, represented in Figure 8(c). The secondary inductor N_b and magnetizing inductor L_m discharges to C_a . The capacitor C_b gets charged using V_{PV} and L_a . The expression is given by

$$V_{La} = V_{PV} - V_{Cb} \quad (14)$$

$$V_{Cb} = -V_{Nb} - \frac{N_a(L_k + L_m)}{N_b L_m} V_{Nb} \quad (15)$$

$$V_0 = V_{Ca} + V_{Cb} + V_{Cc} \quad (16)$$

The voltage gain is derived as follows:

$$V_{La} = V_{PV} + V_{Ca} + \frac{N_b}{N_a} V_{Lm} \quad (17)$$

$$V_{Lm} = V_{Cb} \quad (18)$$

$$\frac{N_b}{N_a} V_{Lm} = V_{Cc} \quad (19)$$

When switch is in OFF condition,

$$V_{La} = V_{PV} - V_{Cb} \quad (20)$$

$$V_{Ca} = -V_{Lm} - \frac{N_b}{N_a} V_{Lm} \quad (21)$$

$$V_0 = V_{Ca} + V_{Cb} + V_{Cc} \quad (22)$$

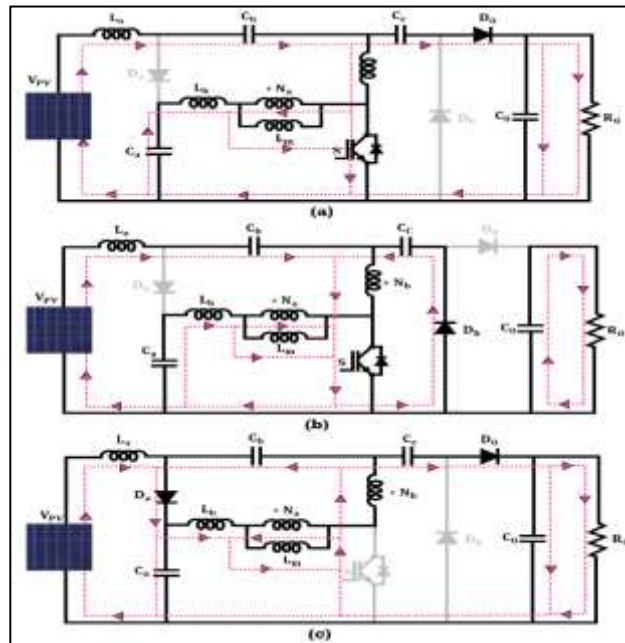


Figure 8: Operating Modes of CIM-SEPIC Converter.
Source: Authors, (2026).

On applying voltage second balance law

$$\int_0^{DT_s} V_{La} dt + \int_{DT_s}^{T_s} V_{La} dt = 0 \quad (23)$$

$$\int_0^{DT_s} V_{Lm} dt + \int_{DT_s}^{T_s} V_{Lm} dt = 0 \quad (24)$$

The voltage across capacitors is expressed by

$$V_{Ca} = \frac{(1+(N_b/N_a))D}{1-2D-(N_b/N_a)D} V_{PV} \quad (25)$$

$$V_{Cb} = \frac{(1-D)}{1-2D-(N_b/N_a)D} V_{PV} \quad (26)$$

$$V_{Cc} = \frac{1+(N_b/N_a)(1-D)}{1-2D-(N_b/N_a)D} V_{PV} \quad (27)$$

The voltage gain of proposed converter is expressed by

$$M = \frac{V_o}{V_{PV}} = \frac{2+(N_b/N_a)}{1-(2+(N_b/N_a))D} = \frac{2+n}{1-(2+n)D} \quad (28)$$

Here, $n = N_b/N_a$, signifying the turn ratio of coupled inductor. Thereby, the proposed converter effectively improves the voltage, but necessitates improved control for better operation.

II.4 MODELLING OF MBWO-PI CONTROLLER

The PI controller is utilized for attaining enhanced converter performance with optimum regulation of PV output voltage. Here, the transfer function of PI is given as,

$$\frac{D(S)}{\Delta I_a(S)} = K_p + \frac{K_i}{s} \quad (29)$$

$$\Delta I_a(S) = I_{ref}(S) - I_{ref}(s) - I_a(s) \quad (30)$$

Where, K_p and K_i are proportional and integral gain of PI controller. However, to further enhance the PI controller performance it is essential to tune K_p and K_i values of PI controller, for which optimization algorithms play an important role. Here, a novel optimization algorithm that is MBWO algorithm is deployed for optimizing K_p and K_i controller parameter and Figure 9 displays the optimized PI controller.

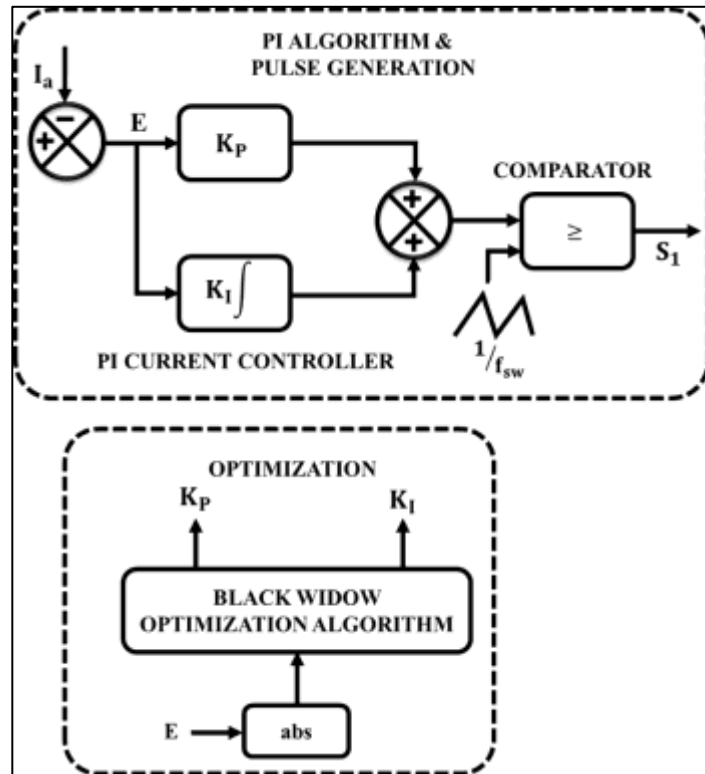


Figure 9: Optimization of PI Controller.

Source: Authors, (2026).

Generally, the algorithm is developed based on natural characteristics of black widow spider. Initially, the female spiders build the nest during night and leave some pheromone behind in order to capture the attention of male spiders for mating. Later, male spiders get attracted by these pheromone and join the net. Significantly, the female spiders later eat the male spider after or during the mating process. Later, the female spider lays egg on net, after, 11 days, these eggs hatch and offspring come out, further these spiders takes place in sibling cannibalism. These baby spiders live for a short period of time in this net during which the mother spider eats some of the baby spiders. The remaining spiders are regarded as the finest spider, based on this behaviour of the spider, the black widow optimization algorithm is developed. Figure 10 illustrates the MBWO-PI controller.

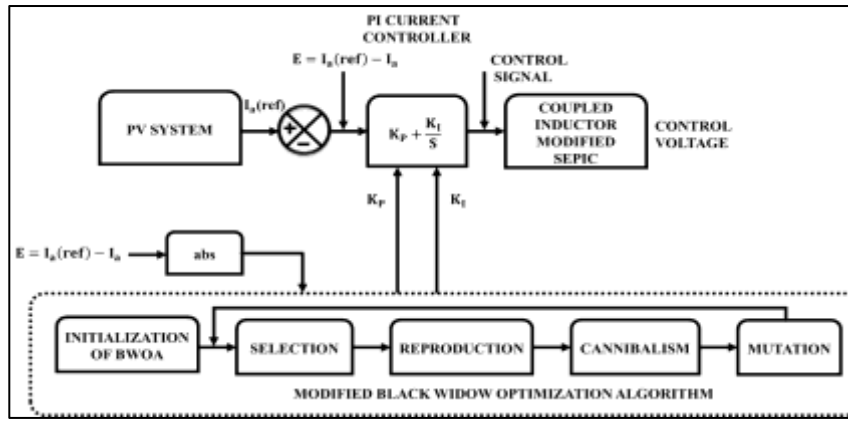


Figure 10: MBWO- PI controller.

Source: Authors, (2026).

The black widow optimization algorithm initially begins with random spider population, where this population basically comprises of male and female offspring for producing the next spider generation. The initial population of these spiders are expressed using,

$$X_{N,d} = \begin{bmatrix} x_{1,1} & x_{1,2} & x_{1,3} & \cdots & x_{1,d} \\ x_{2,1} & x_{2,2} & x_{2,3} & \cdots & x_{2,d} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{N,1} & x_{N,2} & x_{N,3} & \cdots & x_{N,d} \end{bmatrix} \quad lb \leq X_i \leq ub \quad (31)$$

Where, $X_{N,d}$ indicates the black widow population, d denotes the number of decision variables, N implies the total population, lb refers to the lower bound population and ub refers to upper bound population. The objective function that is used for maximising and minimising the potential solution population is given by,

$$Objective\ function = f(X_{N,d}) \quad (32)$$

After initialization process, the next phase is to reproduce offspring from male and female spider mating. Through this process some of the male spiders are eaten by female spiders, For choosing the male spiders for mating process is done using random selection process which is generally expressed as,

$$Y_{i,d} = \beta \times X_{i,d} + (1 - \beta) \times X_{j,d} \quad (33)$$

$$Y_{j,d} = \beta \times X_{j,d} + (1 - \beta) \times X_{i,d} \quad (35)$$

Here, $Y_{i,d}$ and $Y_{j,d}$ implies young spiders considered for reproduction, i and j indicates the randomly chosen number between 1 to N and β refers to the random numbers between 0 and 1 respectively. Significantly, to prevent from random number repetition, the reproduction process is conducted for $d/2$ times.

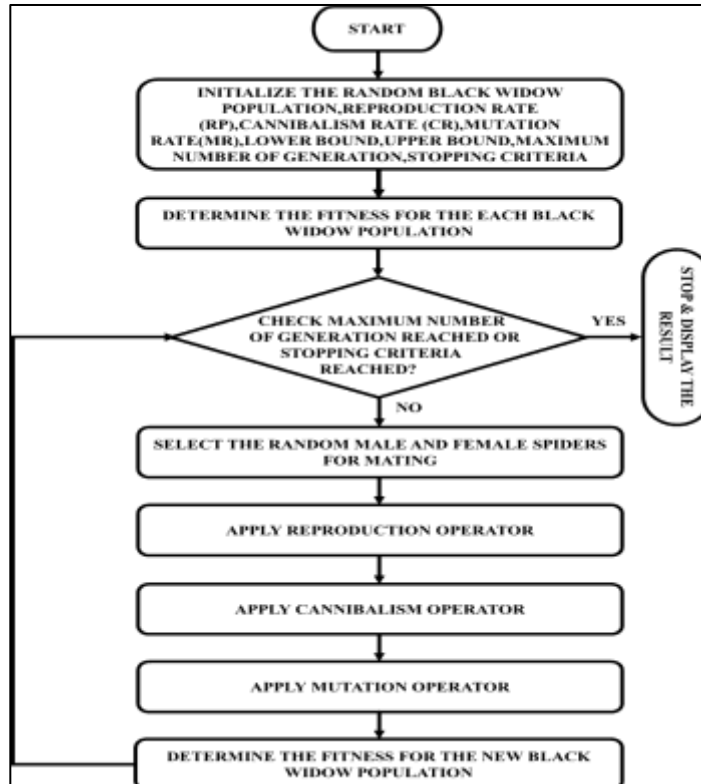


Figure 11: MBWO Flowchart.

Source: Authors, (2026).

Consecutive to the reproduction process, population of mother spiders and young spiders are calculated to determine their fitness value and cannibalism rate. After this the next stage is mutation, where young spiders are chosen on the basis of their mutation value and a minor added value to the young spiders for the mutation process, which is generally depicted as,

$$Z_{k,d} = Y_{k,d} + \alpha \quad (36)$$

Where, $Z_{k,d}$ represents the mutated spider population, $Y_{k,d}$ indicates randomly chosen young spider, k implies random number and α denotes the random mutated value. Considering the black widow optimization, three parameters are highly regarded for their better performance such as Reproduction Rate (RP), Cannibalism Rate (CP) and Mutation Rate (MR). To be specific RP controls the young spider generation, thus enables improved exploration of search space for finding the optimum solution, CP controls the prevent weaker population from passing on to the next generation and allows only the strongest population to the next generation. Finally, MR controls the diversity of the present generation. Figure 11 represents the flow chart of the MBWO.

III. RESULTS AND DISCUSSIONS

The proposed system is implemented using MATLAB/Simulink and their obtained results are discussed in this section along with their comparative analysis to determine the performance efficiency of the developed model against other conventional approaches. Table 2 represents parameter specification of proposed model.

Table 2: Parameter Specification.

Parameters	Values
PV system	
Total Power	10kW
I_{sc}	8.95Amps
I_M	8.35Amps
V_M	29.95 V
V_{oc}	37.25V
No of Panels Connected in series	5
No of Panels Connected in Parallel	7
CIM-SEPIC Converter	
Switching Frequency	10 kHz
L_a, L_k, L_m	4.7 mH
C_a, C_b, C_c	22 μF
C_0	2200 μF

Source: Authors, (2026).

Case 1: Steady State Condition

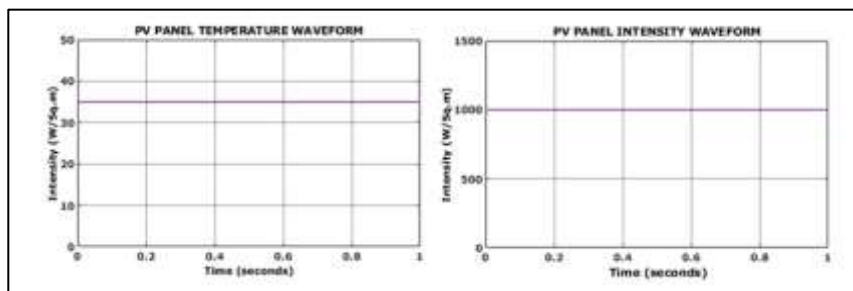


Figure 12: Waveform of PV panel temperature and intensity.

Source: Authors, (2026).

Figure 12 represents PV panel temperature and intensity under case 1 condition, where the first plot shows the temperature of the PV panel remains constant at 35° C throughout the entire depicted time period. Similarly, the intensity of the PV panel is also constantly maintained at 1000 W/Sq-m respectively.

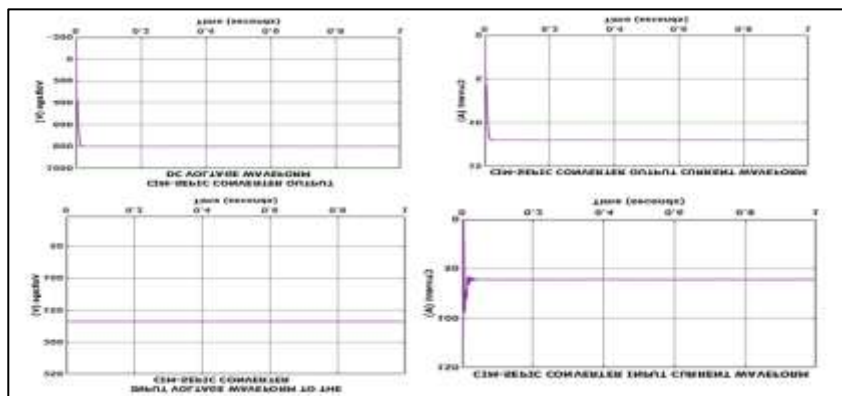


Figure 13: Converter input/output Characteristics Waveform.

Source: Authors, (2026).

Figure 13 indicates the CIM-SEPIC converter input/output current and voltage waveform, in which the first two graphs showcases the converter input voltage and current, where current is constantly maintained at around 160 V for the entire depicted time period of 1 seconds respectively. The input current starts with minor deviations before stabilizing, later is consistently maintained at around 60A. While, converter output voltage and current waveform, depicts similar wave pattern, both the waves progressively rises and later is maintained at that specific voltage 800 V and current 12 A respectively.

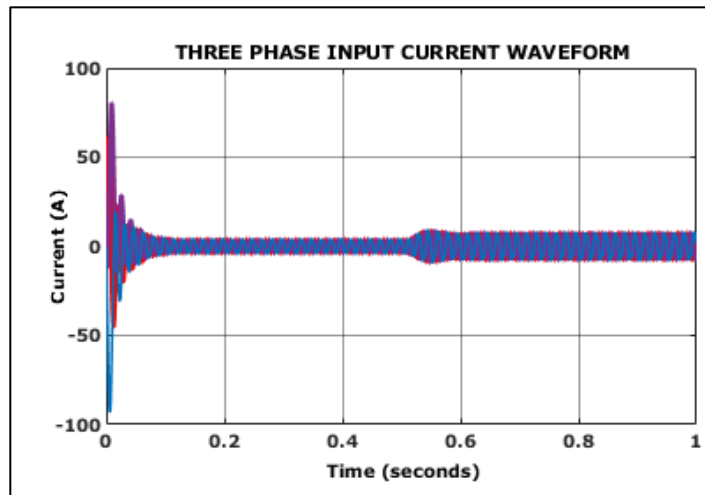


Figure 14: Three Phase Input current waveform.
Source: Authors, (2026).

Figure 14 represents the three-phase input current which initially shows certain fluctuation before stabilizing at around the range of ± 10 A, which after 0.4 seconds shows slight increase, then remains at that specific current value respectively.

Case 2: Varying Temperature and Intensity

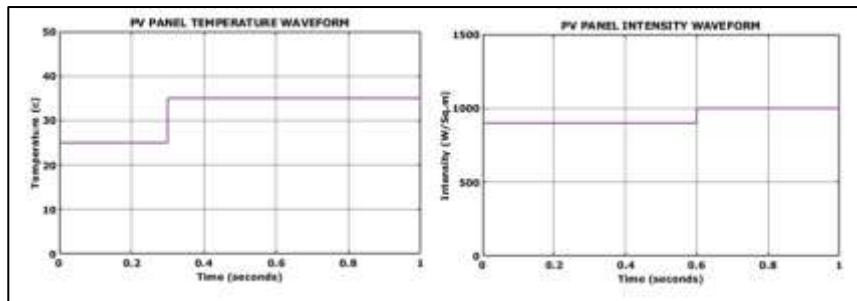


Figure 15: PV panel temperature and intensity waveform.
Source: Authors, (2026).

Figure 15 refers to the PV panel temperature and intensity waveform under case 2 condition, where the first graph displaying temperature initially begins 25°C which after 0.2 seconds rises beyond 30°C to attain 35°C, later is constantly maintained at that temperature throughout the depicted time duration respectively. Significantly, the second graph shows the intensity waveform, which also initially begins below 1000 W/Sq-m, later at 0.6 seconds increases to 1000 W/Sq-m and remains stable respectively.

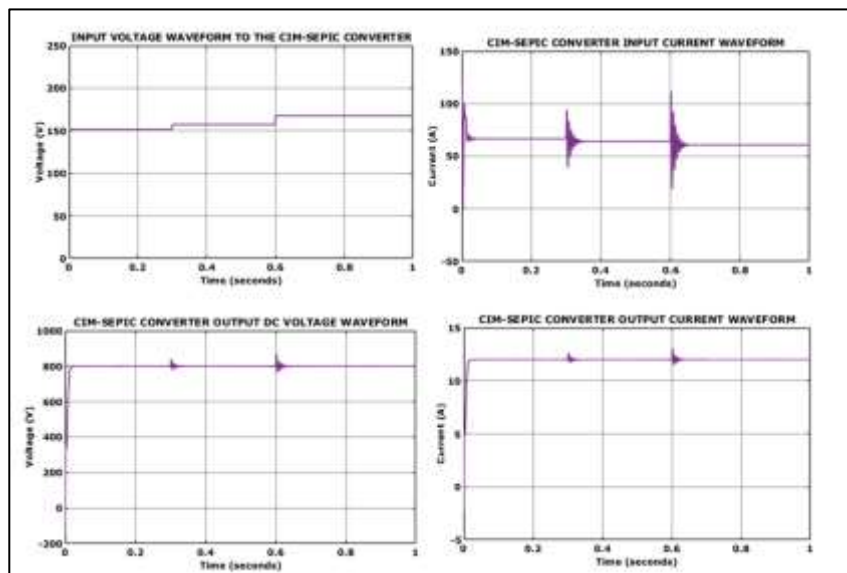


Figure 16: Converter performance waveform.
Source: Authors, (2026).

Figure 16 denotes the converter input voltage/ current and output voltage/current waveform, where the first two graph displays the input voltage and current, where both the current and voltage shows minor fluctuations at regular intervals, later stabilizes around 160 V and 60 A respectively. Similarly, the second two graph comprising of the output current and voltage initially rises and shows minor deviations before stabilizing around 800 V and 12 A respectively.

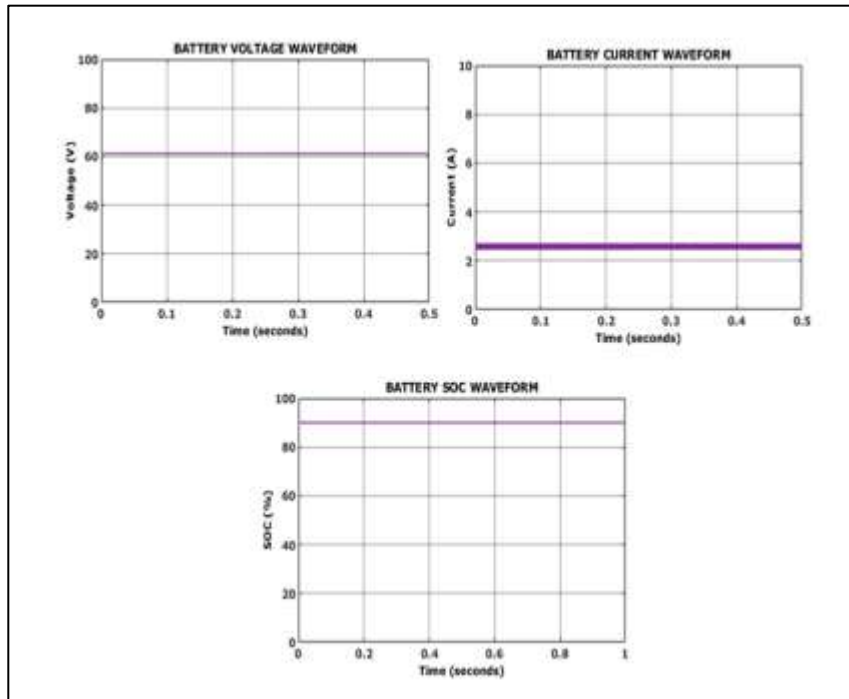


Figure 17: Battery performance waveform.
Source: Authors, (2026).

Figure 17 implies the battery performance waveform, where the first two plots showcases the battery voltage and current waveform, where both current and voltage shows stable performance throughout the depicted time period where the voltage and current is constantly maintained at 62V and 2.5 A respectively. The last graph depicts the battery SOC waveform which is constantly maintained at 90 for the entire time period of 1 seconds respectively.

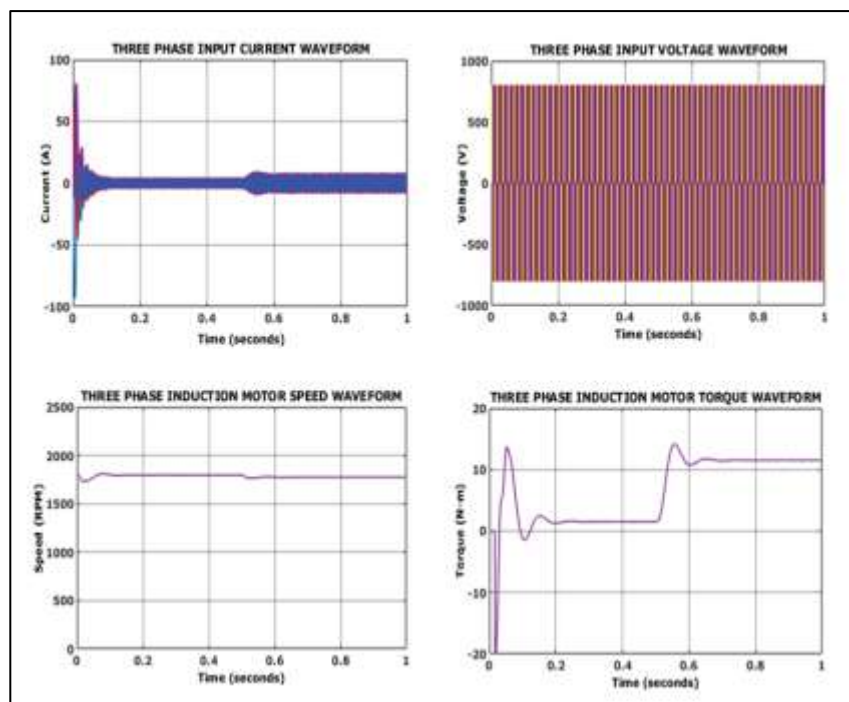


Figure 18: Three Phase input current and voltage waveform and IM speed/torque waveform.
Source: Authors, (2026).

Figure 18 refers to three phase IM performance, where the first two plots showcases the three phase input current and voltage, in which input current shows minor fluctuation while input voltage is constantly maintained between the range of ± 800 V respectively. The third and fourth graph showcases the three phase IM speed and torque, where the speed of the motor constantly maintained with minor deviations. While motor torque shows major deviation in the beginning, later is maintained at around 12 N-m respectively.

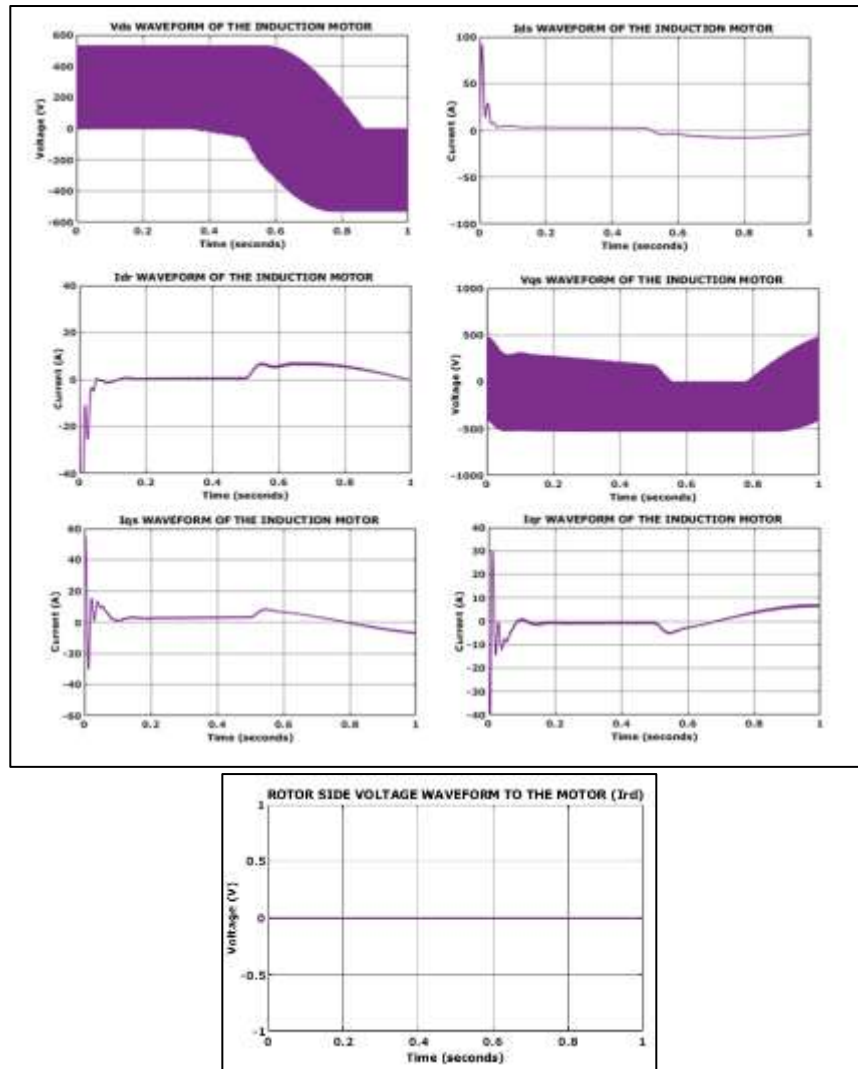


Figure 19: IM performance waveform.
Source: Authors, (2026).

Figure 19 denotes the overall IM performance waveform, the first two graph displays the V_{ds} and I_{ds} waveform, where voltage shows minor fluctuations, while I_{ds} current immediately rises then shows major deviations. The third and fourth graph showcases the I_{dr} and V_{qs} waveform of the IM, where the rotor current depicts minor fluctuations while, V_{qs} shows significantly quite higher fluctuations. The fifth and sixth graph comprises of I_{qs} and I_{qr} waveform, in which both the plots showcases certain fluctuations. Finally, the last graph shows the rotor side voltage waveform, which constantly maintained at null state respectively.

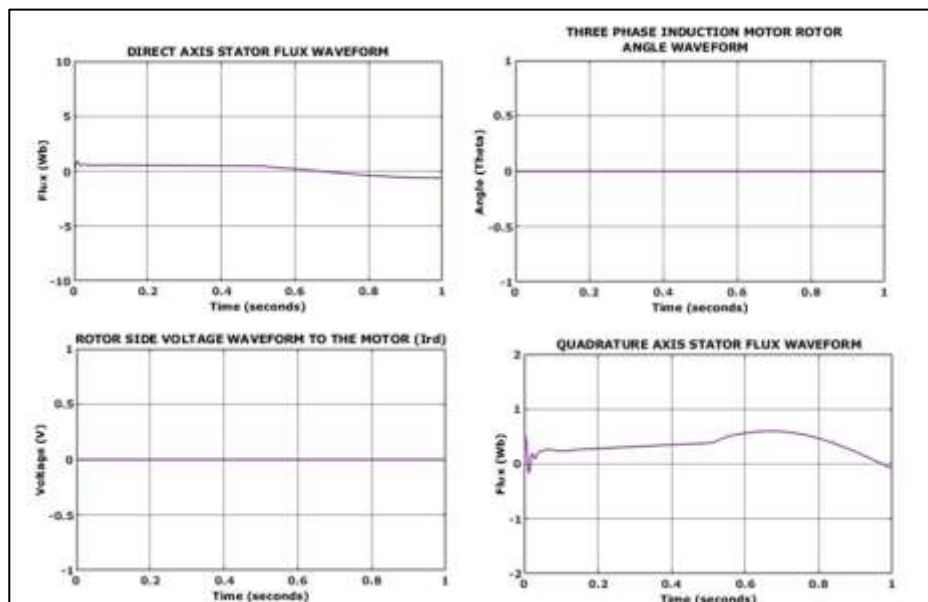


Figure 20: IM direct axis and quadrature axis waveform
Source: Authors, (2026).

In Figure 20 the first graph displays the direct axis current, which initially depicts stabilized performance, then slightly decreases. The second graph shows the three-phase IM rotor angle waveform, which is constantly maintained at null value. The third graph implies the rotor side voltage which is also constantly maintained at null value. Lastly, the final graph showcases the quadrature axis stator flux waveform, which depicts huge fluctuations.

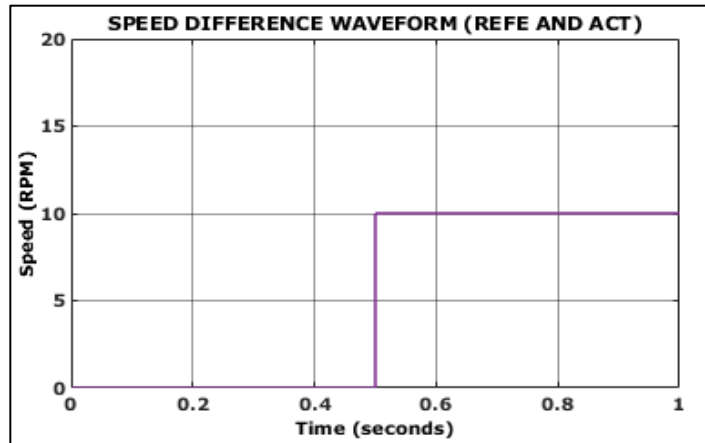


Figure 21: Speed difference waveform.

Source: Authors, (2026).

Figure 21 represents the speed difference waveform (reference and actual) where the x-axis indicates the speed in RPM and the y-axis implies the time in seconds. Initially, the speed is maintained at zero RPM, later after 0.4 seconds, the speed immediately rises to 10 RPM and remains stable throughout the entire depicted time duration respectively.



Figure 22: Hardware setup.

Source: Authors, (2026).

Figure 22 represents the hardware setup of proposed system. The system is powered using root top solar PV system, with the FPGA controller programmed with optimized algorithm. The experimental setup is placed on the top and the building and utilizing IoT setup the chair gets moved left and right for painting.



Figure 23: IoT Display.

Source: Authors, (2026).

The monitored parameters are displayed in the IoT webpage shown in Figure 23. It indicates the PV parameters where PV voltage noticed to be 160 V, PV current of 60 A. The DC-link voltage is 800V, with the Battery SoC revealing 90% and lastly speed of IM is ± 1700 RPM, indicating the left and right movement respectively.

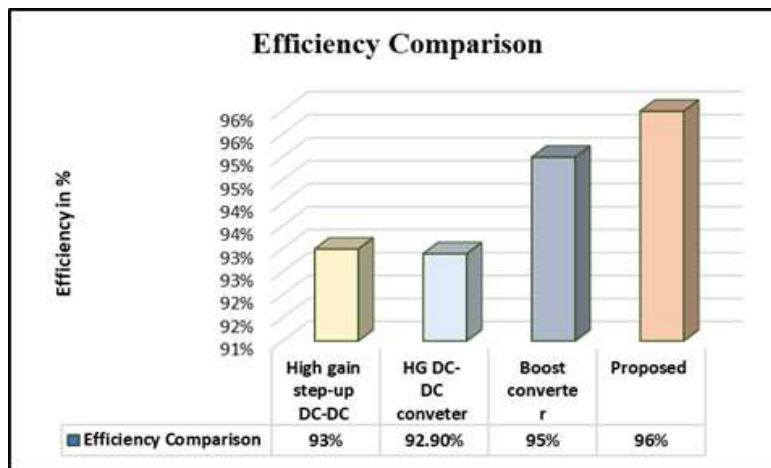


Figure 24: Efficiency Comparison.

Source: Authors, (2026).

Figure 24 represents the Efficiency comparison of the conventional converters and proposed converter. From the above graph it is notable that the proposed converter attained enhanced efficiency of 96% when compared to other conventional converter including High-gain Step-up DC-DC [17], HG DC-DC converter [18] and Boost converter [19] which attained slightly reduced efficiency of 93%, 92.90% and 95%. Indicating enhanced converter performance enabling highly regulated PV power output.

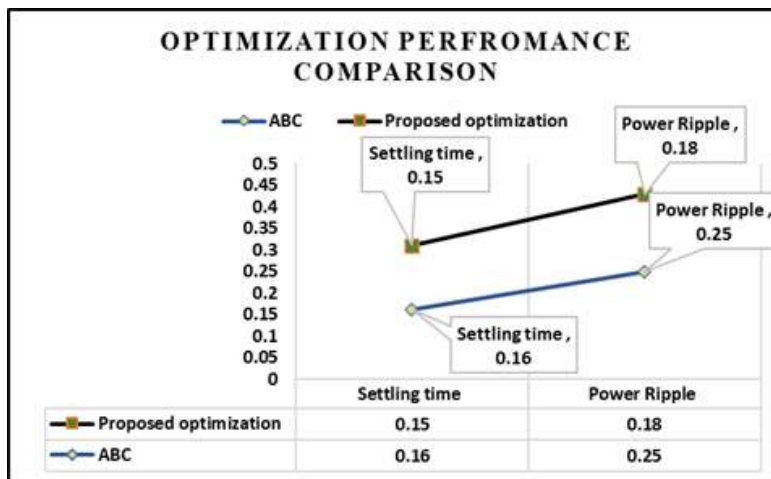


Figure 25: Optimization performance comparison.

Source: Authors, (2026).

Figure 25 indicates performance comparison between the proposed optimized control technique and conventional approach to determine the performance efficacy of the proposed work. From the chart is depicted that proposed optimization based control approach shows enhanced performance when compared to conventional ABC technique [20], referring to improved performance by enabling enhanced converter performance with optimum control.

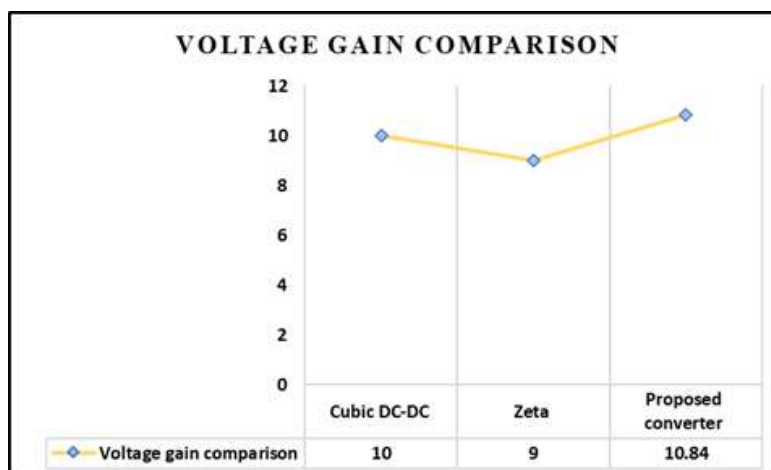


Figure 26: Voltage Gain Comparison.

Source: Authors, (2026).

Figure 26 represents the voltage gain comparison between the proposed converter and conventional converter such as Cubic DC-DC [21] and zeta converter [22] which attained reduced voltage gain of 10 and 9 when compared to proposed AISC which depicts higher voltage gain of 10.64, implying enhanced converter performance.

IV. CONCLUSION

The proposed system integrating PV with IM for reducing the risk of painting high-rise buildings showcases improved system performance in terms of providing enhanced safety and higher performance efficiency. The implementation of PV system assures consistent and sustainable power supply to meet the energy requirements of IM. Similarly, the deployment of CIM-SEPIC converter depicts higher level of PV output voltage with increased voltage gain with reduced power losses and ripples. Moreover, the utilization of the Modified black widow optimized PI controller offers enhanced converter performance by achieving optimum control with highly regulated output voltage. Therefore, the development of the proposed system ensures improved safety with reduced risk and accidents caused by painting high-rise building. The MATLAB/Simulink results demonstrates that the proposed model attained improved efficiency (96%) and voltage gain (10.84), thereby, contributing towards highly safe and secure high-rise building painting work.

VI. REFERENCES

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