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Pelican Optimization Algorithm Based-PI Controller Tuning of Voltage Oriented Control in AC/DC Bi-directional Converter for Hybrid AC/DC Microgrid

Debraj Das, Md. Rifat Hazari, Chowdhury Akram Hossain, Shameem Ahmad and Abir Ahmed

***Abstract*—Hybrid AC/DC microgrids ensure high power quality by combining renewable energy sources (RES) and battery storage systems (BSS), which requires concurrent power sharing and sophisticated power management. In order to accomplish these goals, bidirectional power converters (BPC) are essential. To make power converters more reliable, tuning the PI controller parameters using optimization techniques is very important, as it improves the bidirectional operation of the AC/DC converter and system performance. This work primarily focuses on voltage-oriented control (VOC) combined with active damping (AD) and an inner current control loop (ICCL), utilizing the Pelican Optimization Algorithm (POA) for tuning the parameters of a PI controller to develop a grid-connected bidirectional AC/DC converter (BADC). The suggested 21 kVA system is modeled in MATLAB/SIMULINK. The system provides 7.06% less total harmonic distortion (THD) in case of without an optimization technique that makes it a reliable and effective solution for a hybrid AC/DC microgrid with RES and BSS.**

***Index Terms*— Control strategy, Pelican Optimization Algorithm, bidirectional power flow, bidirectional AC-DC converter, microgrid.**

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I. INTRODUCTION

Hybrid AC/DC microgrids have grown in importance over the past decade, moving from concept to practical implementation due to the combined advantages of integrating both AC and DC microgrids [1]. Hybrid AC/DC microgrids can reduce power losses by avoiding frequent transitions between AC and DC. The DC side Battery Energy Storage System (BESS) is connected by a bidirectional DC-DC converter to control the DC bus voltage [2]. The converter enables energy transmission between the battery bank and the grid to manage grid voltage or rectify power imbalances caused by under or excess [3,4]. The bidirectional AC/DC converter links the DC and AC microgrids to enable energy exchange and improve flexibility between them [5]. The bidirectional converter is expected to perform many tasks in hybrid AC/DC microgrids owing to its several operating modes employing techniques such as active damping coupled with voltage output control and model predictive control. Precise adjustment of PI controller settings is essential for improving the efficacy of bidirectional converters in hybrid AC/DC microgrids. This modification seeks to reduce THD and is the fundamental objective of this study to guarantee the dependability and stability of the suggested systems. [9]

Most hybrid AC/DC microgrids incorporate bidirectional DC/DC converters and grid-connected converters. The design of bidirectional converter controllers in hybrid AC/DC microgrids is challenging [10]. Tricarico et al. [11] developed a control technique for a bidirectional converter in a hybrid AC/DC microgrid to regulate DC microgrid voltage and manage power flow between the two microgrids; however, this strategy does not provide global power sharing. Only DC microgrids utilize it as voltage slack. It does not govern AC microgrid voltage. Nevertheless, it is important to evaluate bidirectional DC/DC converter controller methods. Zolfaghari et al. [12] introduced an enhanced UIPC to improve power distribution in hybrid microgrids. The planned UIPC is incapable of managing AC voltage, and the specifications of the bidirectional dc/dc converter are unspecified. Li et al. [13] employed droop control to integrate bidirectional interlinking converter regulation inside a hybrid AC/DC microgrid. Droop gain requires adjustment for new distributed generators or loads, rendering this strategy impractical for both linear and nonlinear loads. Impedance discrepancies between the DC microgrid and the bidirectional converter hinder precise global power sharing (GPS). A bidirectional DC/DC converter control method must be taken into account. Ali, S. et al. [14] formulated model predictive distributed control for bidirectional converter interconnection in hybrid AC/DC microgrids. The model predictive control approach necessitates a model and parameters. Intricate and labor-intensive. The bidirectional controller requires consideration. Ahmed, M et al. [15] suggested a hybrid AC/DC microgrid with coordinated control between the energy storage system and the interlinking converter. A communication network is essential for synchronized control. No bidirectional DC/DC converter controller or THD control documentation available. To improve voltage and frequency management, Golsorkhi et al. [16] proposed a centralized, unidirectional secondary control layer. A bidirectional dc/dc converter controller is needed to transmit power from the DC subsystem to the AC side to balance the AC microgrid's power. A continuous mixed P-norm technique for iterative learning control (ILC) adaptive regulation was presented by Mohamed et al. [17]. Optimization approaches help tune bidirectional AC/DC/DC converters by determining parameter values that enhance system performance [18]. The aforementioned study and other hybrid AC/DC microgrid research ignore the need of PI controller calibration in the current controller for Total Harmonic Distortion (THD) reduction and voltage regulation.

Bidirectional AC/DC converter current controllers have been studied to increase performance. Particle Swarm Optimization (PSO) was used to regulate a three-phase grid-connected solar system by Waleed et al. [19], improving dynamic responsiveness and reducing steady-state inaccuracy as the core drawbacks of this study. Roslan et al. [20] devised a PSO-based PI inverter controller for grid-connected PV systems, reducing harmonics while emphasizing the processing time needed for real-time applications. Premature convergence of PSO can lead to inferior solutions in complicated system constraints. Thus, there are not mentioned any optimal solutions in case of bi-directional AC/DC converters. Ghazi A. et al. [21] optimized hybrid renewable-energy PI controllers using the African Vulture Optimization Algorithm (AVOA), improving power sharing and system stability. AVOA convergence and computing needs may limit its applicability in time-sensitive situations [22]. However, computational complexity and scalability require additional research into efficient and adaptive tuning approaches specially for bi-directional AC/DC converters for hybrid microgrids. Genetic Algorithm (GA) are often used to tune PI and PID controllers in various settings. A bidirectional converter with a GA-based PID controller by Kumar et al. [23] regulates DC link voltage efficiently under diverse load situations. High computational complexity and convergence concerns restrict real-time GA application. Such research lacked information on the real situation with regard to bi-directional converters [24]. The majority of them emphasized the optimization of one-directional converters, which creates a research deficit in bi-directional converters. Thus, this study aims to enhance the stability and efficiency of bidirectional AC/DC converters by leveraging the POA for optimal PI controller tunning.

This study presents a grid-connected bidirectional AC/DC converter based on current control and capacitor current feedback with active damping control strategy, and optimization of PI controller parameters in the inner current controller loop using POA for hybrid AC/DC MG system. PI controller tuning for hybrid microgrids benefits greatly from the POA, which also improves system performance and stability. A POA-optimized PI controller outperformed other optimization techniques in achieving greater stability in shared power systems, according to different research [9,25]. To improve system performance, POA is used to fine-tune controller parameters, such as for PI controllers, to enhance system performance. In order to provide improved stability, quicker reaction times, and less oscillations.

The proposed technique ensures hybrid AC/DC microgrid stability and equal power sharing under varied operational situations. This work innovates by reducing total harmonic distortion (THD) and improving dynamic performance. Simulations in MATLAB verify the suggested control strategy's performance. This study's main contribution:

- ➢ An optimized controller-based Pelican Optimization Algorithm (POA) has been proposed to determine the optimal parameters of the PI controller. This approach aims to enhance power-sharing quality, stability, and reduce the THD value in the grid-connected bi-directional AC/DC converter system.
- ➢ The validation of the parameters of PI controller using POA, through VOC for enhancing BADC's performance in hybrid AC/DC micro grid.

Necessary The following sections are organized: Section II details the system architecture. Section III offers the recommended control approach, while IV contains all outcomes and analysis. This paper concludes in Section V.

II. SYSTEM ARCHITECTURE

The bidirectional power transfer (BPT) method was essential for the hybrid microgrid and the AC microgrid, which are the microgrid configurations. Bidirectional power converters (BPCs), especially bidirectional AC–DC converters (BADCs), are essential components of AC microgrid (MG) and hybrid MG systems. BADC is a novel approach that combines an inverter and a rectifier into a unified structure to achieve BPT while minimizing the cost, weight, and dimensions of the converter system. An AC/DC hybrid microgrid necessitates a BADC interface to amalgamate both AC and DC microgrids, hence minimizing the stages of AC/DC conversion and the corresponding energy losses seen in Fig. 1.

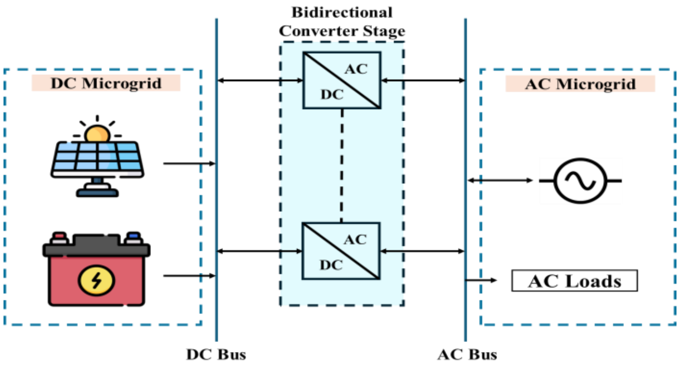


Fig. 1. Configurations of hybrid AC-DC microgrid.

III. PROPOSED CONTROL STRATEGY

The BPT method was essential for the hybrid microgrid and the AC microgrid, which are the microgrid configurations. Bidirectional power converters (BPCs), especially bidirectional AC–DC converters (BADCs), are essential components of AC microgrid (MG) and hybrid MG systems. BADC is a novel approach that combines an inverter and a rectifier into a unified structure to achieve BPT while minimizing the cost, weight, and dimensions of the converter system. Fig. 2 depicts a renewable energy system that integrates a photovoltaic (PV) array with Maximum Power Point Tracking (MPPT) employing the Perturb and Observe (P&O) algorithm and a Voltage Source Converter (VSC). The VSC operates in a dq-frame for precise regulation, employing synchronized feedback and feed-forward signals governed by a control loop [4, 5, 11]. Grid synchronization is achieved by a Phase Locked Loop (PLL), enabling accurate phase and frequency detection for the independent management of active and reactive power.

A Synchronize Reference Frame-based PLL is employed in this work for its straightforward design and fast frequency/phase detection. Phase Detector (PD) produces phase error data. LF is regulating the high-frequency components of output produced by PD. Estimated phase (θ) generated by VOC maintaining tracking of the real phase of the grid voltage [18]. A bidirectional DC-DC converter regulates power transfer between the battery and DC bus, employing switches (Q1, Q2) and an inductor to govern charging and discharging processes [26]. The system assesses battery state-of-charge (SOC) and voltage for optimal performance. The dq components of the VSC-side current are regulated by a decoupled controller, which is integrated with the outputs of the regulator. Sinusoidal Pulse Width Modulation (PWM) produces signals for the IGBT switches, facilitating the effective functioning of the VOC-based control system [27]. Required parameters for microgrid and converter are shown in Table I.

TABLE I
PARAMETERS UTILIZED IN THE PROPOSED STUDY

Parameter	Description	Value
PPV	PV array power	20KW
VBAT	Battery voltage	380V
IBAT	Rated capacity	50Ah
SOC	State of charge	80%
SOCm	Maximum state of charge	95%
VDC	DC bus voltage	800V
Vph(rms)	Rated rms voltage	220V
C	DC link capacitor	1000μF
Srated	Rated power	21KVA
f	Grid frequency	50Hz
fsw	Switching frequency	5kHz
L1	Grid side inductor	3mH
L2	VSC side inductor	6mH
Cf	Filter capacitor	2.65μF

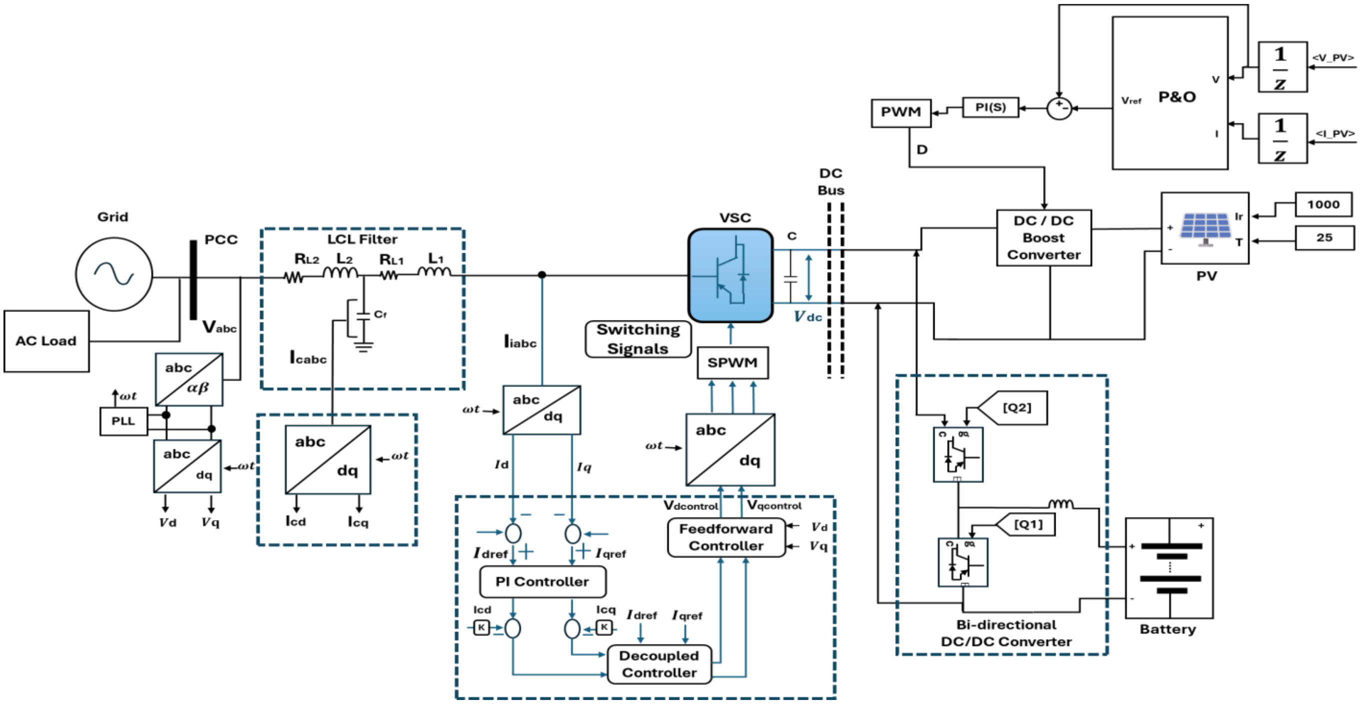


Fig. 2. Structure of the proposed control strategy.

A. *Current reference generator*

This paper's major goal is to evaluate the proposed present controller's control performance in the PQ control mode of operation. The suggested controller can, therefore, function just as well with a voltage controller added; the voltage control loop provides the reference current. The suggested controller can work similarly [26] if a voltage controller is included, and the reference current is derived from the voltage control loop. A current reference generator creates the current reference, though. The dq-reference frame may provide the current references for the ICCL depending on the desired active and reactive power as well as grid voltage [26]. The formulae for active and reactive power are as follows:

$$P_g = \frac{3}{2}\left(V_{gd}I_d + V_{gq}I_q\right) \tag{1}$$

$$Q_g = \frac{3}{2}\left(V_{gq}I_d - V_{gd}I_q\right) \tag{2}$$

While Vgd and Vgq show the active and reactive parts of the grid voltage in the dq-frame [26], Pg and Qg represent the active and reactive power in equations (1) and (2). Id and Iq also signify the active and reactive components of the grid current, respectively. Equation (1) will be as follows in an equilibrium condition when Vgq is zero:

$$P_g = \frac{3}{2}V_{gd}I_{dref} \tag{3}$$

$$Q_g = -\frac{3}{2}V_{gd}I_{qref} \tag{4}$$

In equations (3) and (4), Id ref and Iq ref denote the reference values for the active and reactive components of the ICCL. This investigation examines the ideal state of grid voltage (Vg), characterized by a purely sinusoidal waveform. As a result, the value of Vgd is maintained at a constant level within the dq-frame [17, 26].

B. *Current Controller*

The current controller is set up using the decoupled active (Id) and reactive (Iq) current components in the *dq*-coordinate. Most of the time, Id is regulated to keep the PF near unity and Iq is managed using VDC meant to preserve the active power transfer. Figure 3 uses PI controllers to separate the control of direct-axis (Id) and quadrature-axis (Iq) currents in a synchronous reference frame. Based on PI controllers, the control approach of the LCL-filtered BADC system is based on synchronous dq-coordinate VOC.

$$V_{dcontrol} = V_{gd} + \left(k_p + \frac{k_i}{s}\right)\left(I_{d_{ref}} - I_{id}\right) - kI_{cd} - \omega L_1 I_{iq} \tag{5}$$

$$V_{qcontrol} = V_{gq} + \left(k_p + \frac{k_i}{s}\right)\left(I_{q_{ref}} - I_{id}\right) - kI_{cq} - \omega L_1 I_{id} \tag{6}$$

The VOC system, which is based on the AD-based inner current controller loop (ICCL), uses the control equations (5) and (6). The proposed VOC system, the ICCL, uses these equations to build its control block. Based on them, the present BADC controller configuration was created [26]. The current via the capacitor is shown by an extra block in Fig. 3. This section uses the CCF with a proportional gain k to fix the LCL filter's resonance issue and make sure the system is stable even without a dampening resistor. That is why, to avoid a drastic reduction in converter voltage, k shouldn't be too big. It is common practice to set k such that it is less than 10% of the converter voltage [28]. Considering the values of the PI controller, the grid inductance impact, and the controller time delay, this study considers k = 10 to guarantee the necessary values for the gain margin and phase margin. The recommended ICCL architecture incorporates these capacitor current components into the controller by means of an extra sensor. Using grid voltage in feedforward control allows for a quicker dynamic response. The currents Idref and Iqref are used in place of Id and Iq, respectively, in the VSC current decoupled controller. By taking this fundamental factor into account, the grid current's harmonic content is either improved or reduced, and the grid-connected VSC's dynamic reaction time is accelerated. The effects of inductance are reduced by cross-coupling terms, represented as ω (L1+L2), and the transient response is made more dynamic and smoother by feedforward voltage components, Vd and Vq, respectively [26].

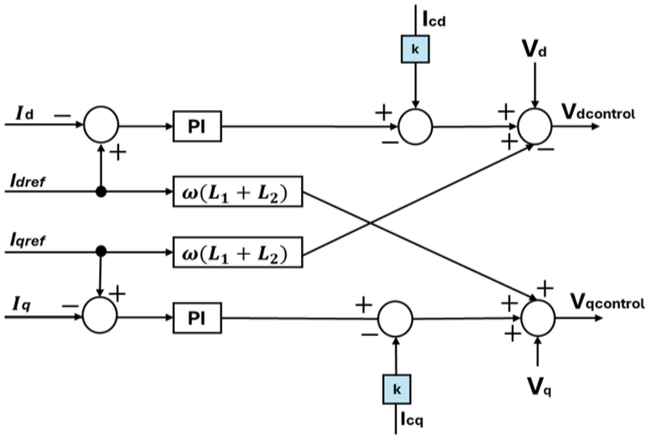


Fig. 3. Design of the current controller in bidirectional AC/DC converter.

C. *Pelican Optimization Algorithm (POA)*

Inspired by nature, Dehghani and Trojovsk [9] developed the POA in 2022. By effectively balancing exploration and exploitation, POA outperforms previous methods and produces faster convergence and more competitive performance [25]. Pelicans are part of the population-based POA method. Every component in population-based algorithms is a possible solution. All population members provided values for optimization problem variables depending on their search space locations. The top and lower limits of the issue restrict equation (7) to haphazardly populate the population.

$$X_{i,j} = l_j + rand.\left(u_j - l_j\right), i = 1.2, \ldots, N, \quad j = 1,2, \ldots, m, \tag{7}$$

The xi, j denotes the jth variable in the ith viable solution. The population size is represented by the sign N. Denoted as m, the number of variables that signify issues. The random number " rand" falls between the range [0, 1]. Lj represents the jth lower bound and jth upper limit of the problem variables, indicated as uj.

$$X = \begin{bmatrix} X_1 \\ \vdots \\ X_i \\ \vdots \\ X_N \end{bmatrix}_{N\times m} = \begin{bmatrix} x_{1,1} & \cdots & x_{1,j} & \cdots & x_{1,m} \\ \vdots & \ddots & \vdots & \iddots & \vdots \\ x_{i,1} & \cdots & x_{i,j} & \cdots & x_{i,m} \\ \vdots & \iddots & \vdots & \ddots & \vdots \\ x_{N,1} & \cdots & x_{N,j} & \cdots & x_{N,m} \end{bmatrix}_{N\times m} \quad (8)$$

While Xi denotes every single pelican, the matrix X shows the pelican population. Given that every POA population member is a pelican, this may be a feasible strategy. Examining every alternative answer helps one to evaluate the objective function of the issue. Equation (9) and a vector called the objective function vector decide the values of the goal function.

$$F = \begin{bmatrix} F_1 \\ \vdots \\ F_i \\ \vdots \\ F_N \end{bmatrix}_{N\times 1} = \begin{bmatrix} F(X_1) \\ \vdots \\ F(X_i) \\ \vdots \\ F(X_N) \end{bmatrix}_{N\times 1} \quad (9)$$

Pelicans hunt in two phases: exploitation and exploration. Exploration involves moving toward prey, whereas exploitation needs flying on the water. Pelicans initially locate and pursue their prey. POA's exploring efficiency improves with unpredictable prey locations. Equation (10) describes the beginning.

$$x_{i,j}^{P_1} = \begin{cases} x_{i,j} + rand.(p_j - l.x_{i,j}), & F_p^1 < F_i; \\ x_{i,j} + rand.(x_{i,j} - p_j), & else, \end{cases} \quad (10)$$

F_p & $x_{i,j}^{P_1}$ denote the prey's goal function, a random number l = 1 or 2, and the ith pelican's new status in the jth dimension from the first phase. Should the goal function value increase there, a new pelican position inside POA is permitted. Effective updating is a technique that stops the algorithm from going into poor areas. Mathematically,

$$X_i = \begin{cases} X_i^{P_1}, & F_i^{P_1} < F_i; \\ X_i, & else, \end{cases} \quad (11)$$

$X_i^{P_1}$ offers the current status of the ith pelican, while, whereas $F_i^{P_1}$ represents the initial goal function value. Pelicans in the second stage of their life cycle spread their wings to drive fish higher, so catching them in their throat bags. This enables pelicans to catch more fish. At this stage, the algorithm identifies improved hunting zone solutions, hence enhancing POA's exploitation potential. The hunting process is as follows::

$$x_{i,j}^{P_2} = x_{i,j} + R.\left(1 - \frac{t}{T}\right).(2.rand - 1).x_{i,j} \quad (12)$$

Where $x_{i,j}^{P_2}$ is the revised condition of the ith pelicans in the jth dimension throughout the second phase. R is 0.2 and $R.(1 - t/T)$ uses t and T variables. The iteration counter t and maximum iteration T define the neighborhood radius of $x_{i,j}$. Equation (13) shows that efficient updating has decided the new pelican position's acceptance or rejection:

$$X_i = \begin{cases} X_i^{P_2}, & F_i^{P_2} < F_i; \\ X_i, & else, \end{cases} \quad (13)$$

Where $X_i^{P_2}$ represents the modified status and goal function value of the ith pelican. The following iteration begins when all population members are updated. Equations (10) to (13) direct a succession of operations until execution is complete. Fig. 4 and Fig. 5 show the POA flowchart and pseudocode respectively.

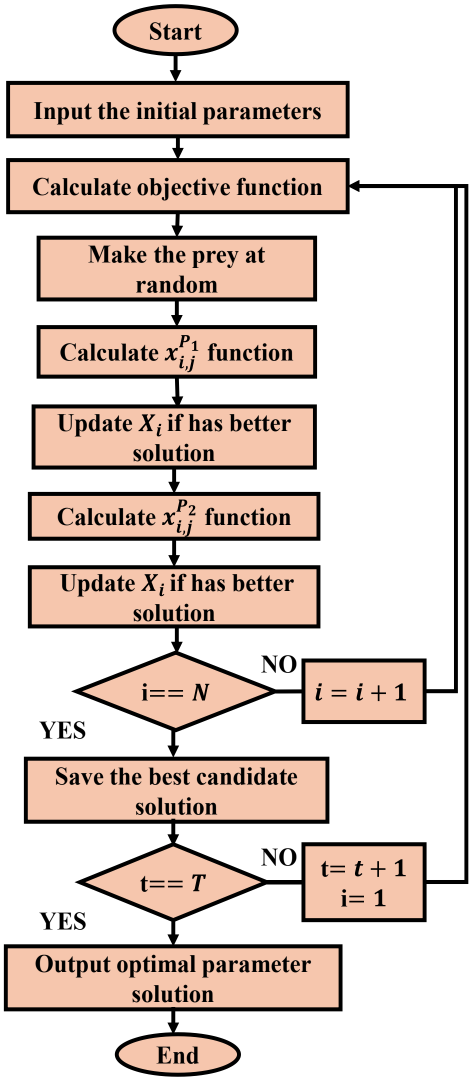
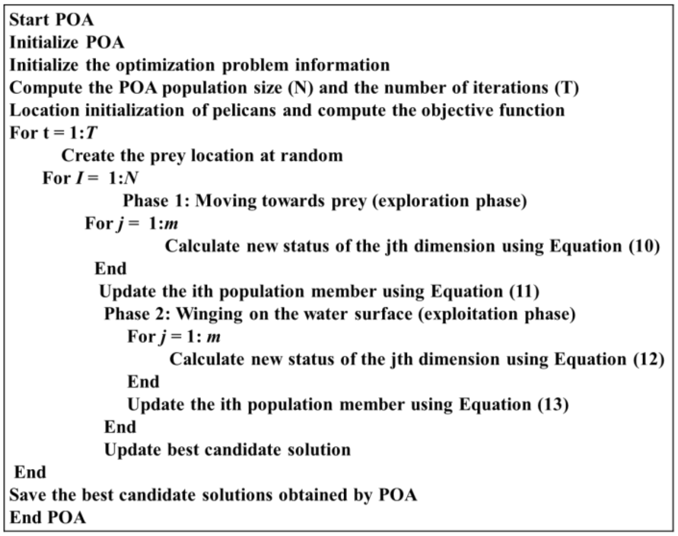


Fig. 4. POA flowchart



```
Start POA
Initialize POA
Initialize the optimization problem information
Compute the POA population size (N) and the number of iterations (T)
Location initialization of pelicans and compute the objective function
For t = 1:T
        Create the prey location at random
    For I = 1:N
            Phase 1: Moving towards prey (exploration phase)
        For j = 1:m
                Calculate new status of the jth dimension using Equation (10)
        End
        Update the ith population member using Equation (11)
        Phase 2: Winging on the water surface (exploitation phase)
            For j = 1: m
                Calculate new status of the jth dimension using Equation (12)
            End
            Update the ith population member using Equation (13)
        End
        Update best candidate solution
End
Save the best candidate solutions obtained by POA
End POA
```

Fig. 5. POA pseudocode.

D. *Proposed POA based PI controller tunning parameter*

The PI controller operates as a feedback control loop, formulated based on a linearized system equation tailored for the bidirectional AC/DC converter employed in hybrid AC/DC microgrid applications. The key factors for choosing a PI controller for the bidirectional converter system encompass optimal control performance, ease of installation, and high reliability. The predominant regulators in AC systems utilize a PI controller for grid current regulation. This research utilizes the POA method to properly configure the parameters of the PI controller. The aim is to optimize Kp and Ki to diminish transient response, minimize overshoot, and reduce THD in the three-phase bidirectional AC/DC converter system. System.

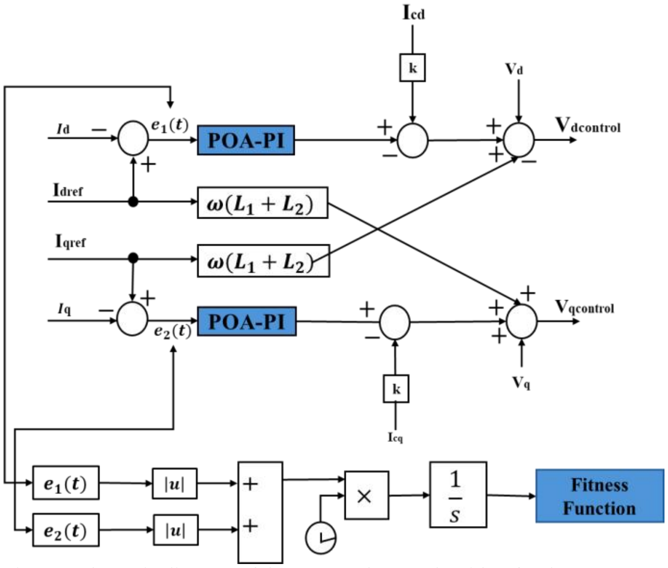


Fig. 6. Schematic diagram of the proposed POA algorithm for the current controller.

The primary objective is to guarantee that the POA algorithm optimization functions well and delivers a quicker response by identifying the optimal values of Kp and Ki. This POA algorithm approach promptly addresses the system's input mistake. Fig. 6 illustrates the suggested current controller for the bidirectional AC/DC converter system utilizing the POA algorithm. Method.

1) *Fitness Function*

The fitness function represents the optimal solution for evaluating the search area, referred to as the objective function. The mean square error serves as the objective function to be minimized for the current controller, facilitating the determination of the optimal PI controller parameters Kp and Ki. The objective function is defined as follows:

$$min\, F(x) = \int_0^T t|e(t)|\, dt \tag{14}$$

In this context, t represents the time variable, e denotes the error value, and T indicates the maximum allowable time.

2) *Problem constraints*

In the hybrid AC/DC microgrid system, the problem constraints involve optimized parameters, which include four parameters of decoupled PI controllers: Kp1, Ki1, Kp2, and Ki2. The comprehensive formulation of the optimal current controller for the three-phase BADC converter system is articulated:

$$min\, F(x) = \int_0^T t|e(t)|\, dt \tag{15}$$

$$l1 \le Kp1 \le u1 \tag{16}$$

$$l2 \le Ki1 \le u2 \tag{17}$$

$$l3 \le Kp2 \le u3 \tag{18}$$

$$l4 \le Kp2 \le u4 \tag{19}$$

In the expression provided, l1, l2, l3, and l4 denote the lower limits of Kp1, Ki1, Kp2, and Ki2, respectively. Additionally, u1, u2, u3, and u4 represent the upper limits of Kp1, Ki1, Kp2, and Ki2. This study proposes the POA algorithm as a solution to the optimization problem..

IV. RESULT ANALYSIS AND DISCUSSION

This section analyzes the performance metrics of the bidirectional AC/DC converter controller developed for the hybrid AC/DC microgrid. The analysis utilizes a voltage source converter functioning in rectifier and inverter modes, implemented through MATLAB/Simulink. This research employs the POA technique to determine the optimal tuning parameters for the controller within the hybrid AC/DC microgrid. The utilized controller's complexity includes the assignment of optimal control parameter settings, which directly affects system performance. Consequently, an effective optimizer is essential for determining optimal values for control parameters. The POA technique integrates and specifies the values of the controller parameters, which function as control variables with established upper and lower limits, to reduce voltage and current errors, thus improving system performance. To validate the system, perform a comparison between the proposed POA-PI and the configuration that lacks the optimization PI controller. Table II presents a comparison of the gains obtained through the implementation of POA optimization methods versus those achieved without such methods in the current control controller of the BADC system. Fig. 7 depicts the convergence curve of the POA concerning the fitness function. The proposed approach's convergence allowed the POA-PI controller to attain the optimal value of the fitness function. The proposed approach achieved the minimum fitness function value during the 13th iteration.

TABLE II.
GAINS VALUE OF PI CONTROLLER WITH AND WITHOUT POA OPTIMIZATION

Approach	Current PI Controller Gains			
	Kp1	Ki1	Kp2	Ki2
Without Optimization	73	500	73	500
With POA Optimization	292.2624543	88.1334497	113.5511656	128.9912878

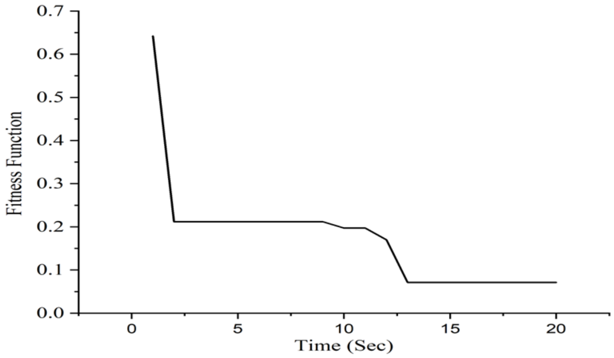


Fig. 7. Convergence curve of the fitness function by proposed POA.

Fig. 8 shows the DC bus voltage performance achieved with and without the POA optimization PI controller. The suggested POA-PI controller of DC bus voltage is seen to be quicker at 0.075 sec and more stable, which reduces the variation relative to without the optimization PI controller. The uncertainty of the PI controller without optimization is causing the voltage to oscillate between 1.1 and 1.2 seconds; the uncertainty of the POA optimization technique is causing the voltage to oscillate between 0.85 and 1.1 seconds. Both methods fluctuate between 1.21 and 1.24 seconds due to the transfer from rectifier to inverter mode, but the proposed HO-PI controller is faster and stable at 1.24 sec, and the conventional PI controller is after 1.2 sec to get a neglect fluctuation overall.

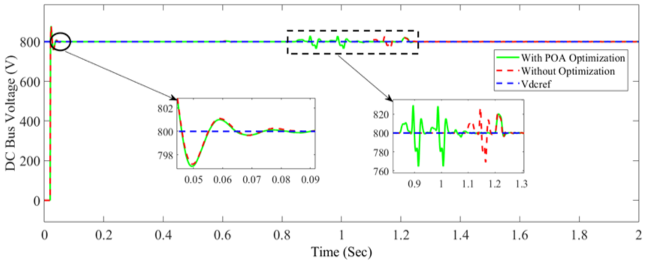


Fig. 8. Performance tracking of DC bus Voltage.

Fig. 9 illustrates the DC bus current of the bidirectional AC/DC converter, as assessed with and without POA optimization of the PI controller. From 0 to 0.6 seconds, the current is 25A; at 0.6 seconds, it decreases to 18.75A, signifying that power is being transmitted from the DC bus to the AC loads. After 1.2 seconds, the DC bus side current becomes negative 25A due to the inverter mode. It is observed that the POA optimization PI controller maintains a stable DC bus current at 0.04 seconds, which is faster than the without optimization PI controller at 0.37 sec. At 1.1–1.2 seconds, the without optimization PI controller fluctuates in a large overshoot, but the with POA optimization PI controller fluctuates in a smaller overshoot between 0.88 and 1.1 seconds. When transferring the inverter mode operation, with POA optimization, the PI controller maintains stability at 1.24 sec, but without optimization, the PI controller maintains stability at 1.55 sec.

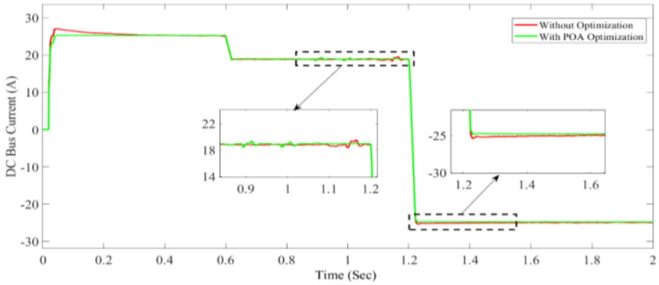


Fig. 9. Performance tracking of DC bus Current.

Fig. 10, represents the tracking of AC bus voltage performance by the with and without POA optimization PI controller. It is observed that all methods attempt to maintain the rated 220V after 0.05 sec.

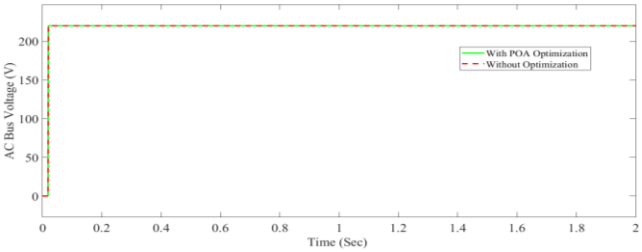


Fig. 10. Performance tracking of AC bus voltage.

In Fig. 11, it displays the tracking of direct current performance using the with and without POA optimization PI controller. Observations indicate that with POA optimization, the PI controller exhibits enhanced performance, sustaining a reference direct current at 0.05, in contrast to the absence of the PI controller, which maintains a reference direct current at 0.37 seconds. With POA optimization, PI controllers cause uncertain neglect fluctuating from 0.9 to 1.01 sec, and also without optimization, fluctuating at 1.16 to 1.2 sec. When transferring to inverter mode operation, the POA optimization maintains a direct current reference at 1.24 sec, but without optimization, maintaining a direct current reference takes time at 1.31 sec.

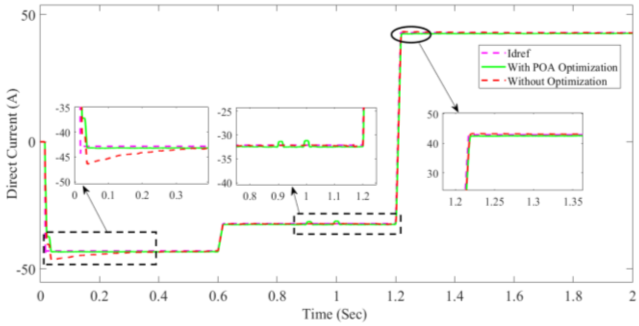


Fig. 11. Direct current (Id) performance tracking.

Fig. 12, illustrates the tracking of quadrature current performance using the with and without POA optimization PI controller. All methods fail to consider the reference quadrature current, the with and without POA optimization PI controller closely follows the Iqref.

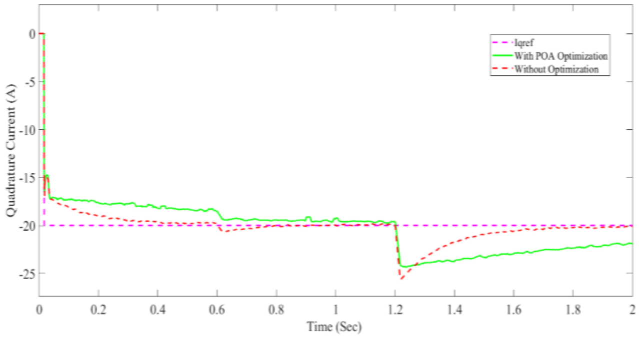


Fig. 12. Quadrature current (Iq) performance tracking.

Fig. 13 presents the active power flow performance tracking obtained with and without the POA optimization PI controller. The active power flow is around 20 kW in rectifier mode from 0 to 0.6 seconds. At 0.6 seconds, a step shift in the current reference results in a modification of the active power flow from 20 kW to 15 kW. After 1.2 seconds, the active power flow is around -20 kW in inverter mode. The POA optimization PI controller demonstrates enhanced performance by maintaining stability at 0.05 seconds, in contrast to the non-optimized PI controller, which exhibits delay stability at 0.3 seconds and unnecessary fluctuations ranging from 1.16 to 1.8 seconds. Additionally, the POA optimization PI controller experiences minor fluctuations from 0.9 to 0.915 and 0.99 to 1.02 seconds, while effectively achieving the desired active power flow.

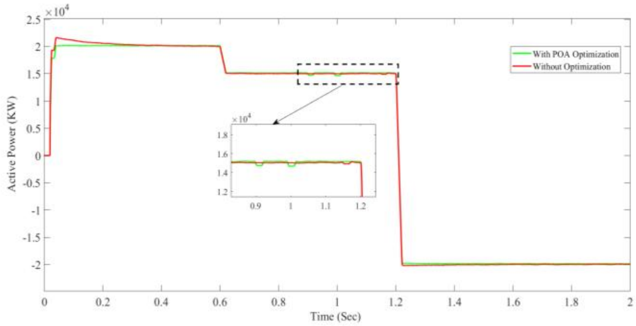


Fig. 13. Monitoring active power performance.

Fig. 14 presents the reactive power flow performance tracking obtained with and without the POA optimization PI controller. It is observed that both methods have neglect fluctuations, but the proposed HO-PI controller has less fluctuation.

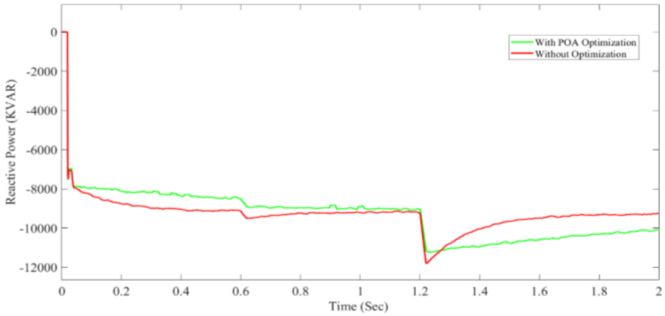
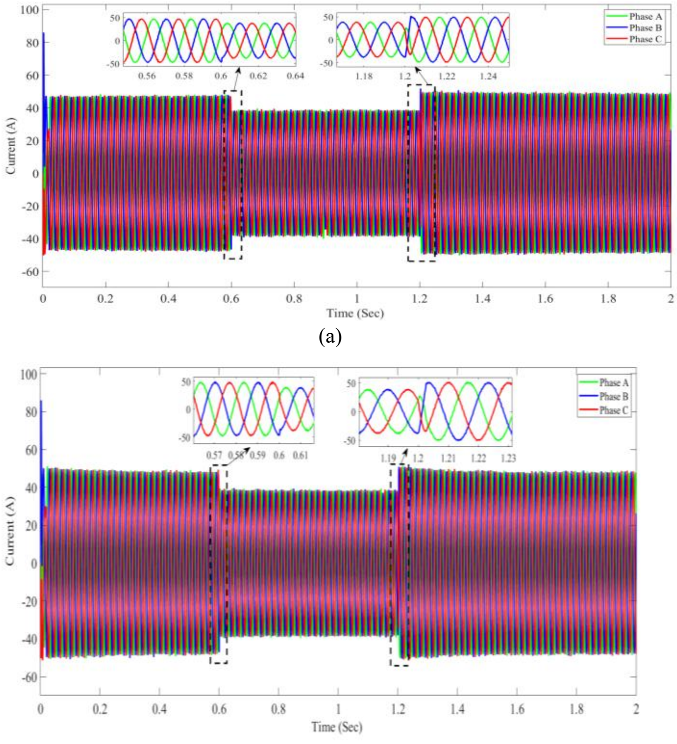


Fig. 14. Monitoring reactive power performance.

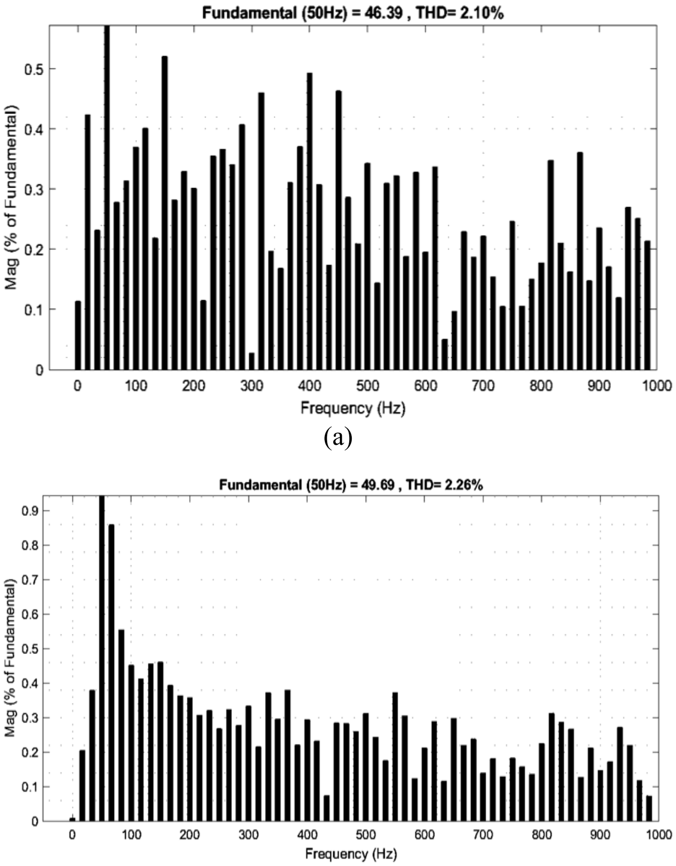
Fig. 15 (a) and (b) illustrates the grid-side current tracking function of the bidirectional controller obtained by the with and without POA optimization PI controller. From 0 to 0.6 seconds, the VSC functions as a rectifier with a nominal current of 48A, and at 0.6 seconds, the AC bus-side current transitions from 42A to 32A with minimal variation. After 1.2 seconds, the VSC transitions performance from the rectifier to the inverter. Simultaneously, the active current reference transitions from -32A to +32A, while the grid-side current exhibits an inverse phase relative to the rated 48A. The suggested POA improvement demonstrated enhanced performance owing to reduced harmonic content in the current, in contrast to the unoptimized PI controller.



(a)

(b)

Fig. 15. Three phase current at AC Bus (a) with and (b) without POA optimization.



(a)

(b)

Fig. 16. Harmonic spectrum (a) with and (b) without POA optimization.

Fig. 16 (a) and (b) depicts the harmonic spectrum acquired with and without the POA optimization PI controller. The THD value with the POA optimization PI controller exceeds 2.10%, but without the optimization PI controller, the THD value above 2.26%. The total harmonic distortion (THD) of the unoptimized version exceeds that of the suggested proportional-integral (PI) controller with POA optimization by 7.6%. The performance of the proposed POA-PI controller is deemed superior to that of the non-optimized PI controller.

Table III presents the results of comparing several controllers depending on the level of harmonic content in the current, measured as Total Harmonic Distortion (THD). The suggested controller technique exhibits enhanced performance, as indicated by a decrease in THD relative to the findings in references [17, 8, 20].

TABLE III
COMPARISON AMONG OTHER CONTROL STRATEGIES

Controller type	THD
VOC with novel active damping [17]	4.56%
Model predictive control (MPC) [8]	4.6%
Particle swarm optimization [20]	2.72%
Proposed controller	2.1%

V. CONCLUSION

This study develops a grid-connected bidirectional AC-DC converter (BADC) using an LCL filter and an efficient control approach based on VOC with active damping (AD) integrated with an inner current control loop (ICCL), PI controller parameter tuning by Pelican Optimization Algorithm (POA) for hybrid AC/DC microgrids. To reduce voltage and current errors and increase system performance, the POA approach assigns controller parameter values, which are controllable variables with upper and lower bounds. Results in different segments are displayed with and without POA optimization. The results show that the suggested POA-PI controller of the 800V DC bus is quicker and more stable, reducing fluctuation compared to without optimization, and 220V was the rated voltage for the AC bus. The VSC works like a rectifier, changing the reference current of 42A to 32A. It switches to inverter mode when the current changes from -42A to +42A, following POA's suggested current levels. The power-sharing system with the suggested POA approach has quicker stable performance and lower steady-state error than without optimization. THD is 2.10% with POA optimization and 2.26% without. This is 7.6% greater than the system without optimization. The suggested method performs well in several segments, demonstrating its dependability in bi-directional AC/DC converters.

Future extension of the work involve enhancing the BADC system integrated with LVRT mode and assessing the system's reliability through various optimization tuning controls, including the Hippopotamus Optimization Algorithm (HOA), Osprey Optimization Algorithm (OOA), Genetic Algorithm, etc., while comparing these with POA to evaluate the system's reliability with greater precision.

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