

Voltage Stability Investigations in Modern Power System

A Synopsis submitted to Gujarat Technological University

for

The Award of

Degree of Doctor of Philosophy

in

Electrical Engineering

by

Sarika Sanjay Kanojia

Enrollment No: 189999914015

Batch: 2018

(Electrical Engineering)

under the supervision of

Supervisor

Dr. Bhavik N. Suthar

Professor

Electrical Engineering Department,

L. E. College,

Morbi, Gujarat, India

Co-Supervisor

Dr. Ashutosh K. Giri

Assistant Professor

Electrical Engineering Department,

Government Engineering College,

Bharuch, Gujarat, India



Gujarat Technological University Ahmedabad,

Gujarat, India

January 2026

Table of Contents

1	Title: Voltage Stability Investigations in Modern Power Systems.....	4
2	Abstract.....	4
3	Summary of Literature Review.....	7
4	Observation.....	8
5	Motivation of Research.....	9
6	Rationale of Research.....	9
7	Research Gap.....	10
8	Objectives of Research.....	10
9	Original Contribution of Thesis.....	10
10	Thesis Outline.....	11
11	Methodology and Discussion.....	15
11.1	Problem Statement-1.....	13
	11.1.1 Proposed Methodology for Problem Statement-1(Hybrid Optimization method for EVCS Placement.....	13
	11.1.2 Hybrid COA–POA Optimisation.....	13
	11.1.3 Modelling of EV Charging Station.....	14
	11.1.4 Hybrid Optimisation algorithm.....	14
	11.1.5 Results and Discussion on Problem Statement-1.....	17
11.2	Problem Statement-2.....	19
	11.2.1 Proposed Methodology for Problem Statement-2 (RES Optimal Siting Using World Cup Optimization (WCO).....	19
	11.2.2 Solar and Wind Modelling.....	20
	11.2.3 World Cup Optimization Algorithm.....	20
	11.2.4 Result and discussion on problem statement-2 with EVCS and PV only.....	22
	11.2.5 Validation using IEEE-69 Bus System.....	22
	11.2.6 Result and discussion on problem statement-2 with EVCS, PV and Wind System	24
11.3	Problem Statement-3.....	25
	11.3.1 Proposed Methodology for Problem Statement-3 (Advanced Inverter CBF-FLL Control Design for RES Integration to the grid).....	25
	11.3.2 Control Technique.....	26
	11.3.3 Results and discussion on Problem statement-3.....	27
12	Conclusion.....	29
13	Scope of Future Work.....	31
14	List of Publications.....	31
15	References.....	32

List of Table

Table 1 Comparative analysis.....	18
Table 2 Comparative analysis of IEEE 33 and 69 bus system performance.....	3

List of Figure

Figure 1 Flowchart for hybrid COA-POA algorithm.....	17
Figure 2 Voltage profile for 33 bus system for base case, with random EVCS location, and with optimal EVCS location	18
Figure 3: Total Power loss.....	18
Figure 4: Comparison of proposed hybrid algorithm.....	18
Figure 5: Flowchart for WCO algorithm	22
Figure 6: Modified IEEE 33 distribution network	22
Figure 7. Voltage profile	23
Figure 8. Comparison of total losses for IEEE 33 bus system	23
Figure 9: Modified IEEE 69 bus distribution network	23
Figure 10 Voltage profile of IEEE 69 bus for various cases.....	24
Figure 11 Comparison of total losses	24
Figure 12 Voltage profile	25
Figure 13 Comparison of total losses	25
Figure 14 Comparison of proposed algorithm	25
Figure 15 Proposed dual stage solar PV system connected to grid.....	27
Figure 16 Control Structure based on CBF- FLL	27
Figure 17 Response of grid and load side waveforms under (a)weak grid (b) strong grid condition.....	28
Figure 18 Harmonic spectrum under (a)strong grid and (b) weak grid.....	29
Figure 19 Comparative analysis between LMS proposed algorithm.....	29

1. Title: Voltage Stability Investigations in Modern Power System

2. Abstract

The rapid electrification of transportation and the large-scale integration of renewable energy sources have significantly transformed modern power distribution systems. While Electric Vehicle Charging Stations (EVCS) and Distributed Generation (DG) based on solar photovoltaic (PV) and wind energy offer environmental and operational benefits, their uncoordinated integration introduces serious challenges related to voltage stability, power losses, network congestion, and power quality degradation. Maintaining voltage stability under high penetration of EV loads and inverter-interfaced renewable generation has therefore become a critical concern for reliable and secure distribution system operation. A detailed discussion is provided in the succeeding paragraphs/sections of this synopsis. The authors would like to introduce the entire research work carried out as follows.

This research proposes a comprehensive and integrated framework for voltage stability enhancement in electrical distribution networks by jointly addressing the challenges arising from Electric Vehicle Charging Station (EVCS) integration, renewable distributed generation (DG) penetration, and grid-interfacing control strategies. The framework emphasizes the coordinated planning of network assets to ensure reliable and secure operation under increasing load variability and renewable intermittency.

First, a novel hybrid Coati Optimization Algorithm–Pelican Optimization Algorithm (COA–POA) is developed to determine the optimal placement of EV charging stations within the distribution system. The optimization problem is formulated with objectives that include minimization of voltage deviation and enhancement of voltage stability indices, thereby directly targeting the most critical operational constraints of distribution networks. By synergistically combining the strong global exploration capability of COA with the efficient local exploitation ability of POA, the proposed hybrid algorithm effectively overcomes common shortcomings of standalone metaheuristic techniques, such as premature convergence, poor diversity, and entrapment in local optima.

The proposed methodology enables a detailed assessment of the impact of EVCS integration on system voltage profiles, feeder power losses, and overall voltage stability margins. Through systematic simulation studies, the framework demonstrates how optimal EVCS siting can

significantly mitigate adverse effects such as excessive voltage drops and increased losses, while improving network robustness under high EV penetration levels. The results confirm that the hybrid COA–POA approach provides a reliable and efficient solution for planning EVCS deployment in modern distribution networks, contributing to enhanced voltage stability and improved operational performance.

Post-EVCS allocation, Voltage Stability Index (VSI) analysis identifies critical buses exhibiting voltage vulnerability during peak demand periods. Distributed generation (DG) sources are incorporated with EVCS to lessen the impact of EV charging load. Thus, the solar PV and wind based CSs will not only reduce the burden on the existing electrical networks but also provides the sustainable, cost effective and eco-friendly environment.

Further, optimal placement of solar PV and wind-based distributed generation units are achieved using the World Cup Optimization (WCO) technique to enhance voltage profile and VSI viz Fast Voltage Stability Index (FVSI), Line Stability Index (LSI), and Line Stability Factor (LSF) are simultaneously incorporated as objective functions to comprehensively assess and enhance the voltage stability of the distribution network. These indices provide quantitative measures of the system's proximity to voltage collapse by evaluating both bus-level and line-level stability margins, thereby enabling accurate identification of critical buses and weak lines under increased loading conditions caused by renewable energy integration. Unlike conventional approaches that rely on a single voltage stability indicator or focus only on voltage magnitude improvement, the proposed multi-index framework ensures a more robust and reliable stability assessment by capturing diverse aspects of voltage instability behaviour across the network.

Furthermore, although several optimization techniques such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and other nature-inspired algorithms have been widely reported for DG and EVCS placement, the World Cup Optimization (WCO) algorithm has not been previously employed for optimal placement of DG problems in distribution systems considering voltage stability indices. The application of WCO in this work therefore represents a novel contribution, offering a competitive, tournament-based search mechanism that effectively balances global exploration and local exploitation. By integrating FVSI, LSI, and LSF into the WCO framework, the proposed approach efficiently identifies optimal locations for solar PV and wind DG units that significantly improve voltage stability margins, reduce power losses, and enhance overall system performance. This unique combination of multi-

index voltage stability objectives and WCO-based optimization addresses an important research gap and provides a more resilient and scalable solution for modern distribution networks with high penetration of renewable energy sources.

The effectiveness of the proposed methodologies is validated using IEEE 33-bus and IEEE 69-bus distribution test systems through extensive MATLAB/Simulink simulations. The results confirm significant improvements in voltage profile, voltage stability indices, and power loss reduction. Overall, the proposed integrated optimization framework provides a practical and reliable solution for enhancing voltage stability, improving renewable hosting capacity, and enabling the secure integration of EVCS and renewable energy sources in modern distribution networks.

Finally, to effectively address the challenges associated with power quality degradation and grid synchronization in grid-connected renewable energy systems, this research develops a Complex Band-Pass Filter based Frequency Locked Loop (CBPF–FLL) controller for a dual-stage grid-connected solar photovoltaic (PV) system. The proposed controller is specifically designed to achieve robust and accurate synchronization with the utility grid by reliably extracting fundamental frequency and phase information even in the presence of grid voltage distortions, harmonics, frequency deviations, and voltage imbalances.

The CBF–FLL control strategy enables effective voltage regulation and harmonic mitigation by isolating the fundamental positive-sequence components of grid voltage and current, thereby suppressing the influence of non-linear loads connected at the Point of Common Coupling (PCC). This feature is particularly advantageous under weak grid conditions, where low short-circuit ratios and high grid impedance often deteriorate conventional PLL/FLL-based controller performance. By ensuring stable DC-link voltage regulation and fast dynamic response during transient events such as load changes/ unbalancing, and irradiance variations, the proposed controller enhances the overall stability and reliability of the grid-connected PV system.

The effectiveness of the CBPF–FLL controller is validated through extensive simulation studies under diverse operating scenarios, including distorted grid voltages, variable solar irradiance, dynamic load variations, and weak grid environments. Performance evaluation is carried out in terms of total harmonic distortion (THD) of grid voltage and current, DC-link voltage settling time, synchronization accuracy, and transient response. The results

demonstrate that the proposed control strategy maintains THD well within the limits (below 5%) prescribed by IEEE 519 standards, thereby ensuring improved power quality, secure grid interaction, and reliable operation of the solar PV system under practical grid conditions.

The results in MATLAB/Simulink confirm reduced THD, enhanced voltage control, and robust grid synchronization, ensuring reliable and power quality compliant operation of the system.

3. Summary of Literature Review

The fast adoption of electric vehicles (EVs) is transforming the transportation sector by reducing greenhouse gas emissions, while simultaneously increasing electricity demand due to urbanization, industrialization, and population growth. Renewable energy sources (RES) play a vital role in meeting this growing demand, and a significant increase in RES-based generation is expected in the near future [1]. To support sustainable EV growth, the development of efficient electric vehicle charging station (EVCS) infrastructure is essential. However, uncoordinated EVCS placement can lead to voltage deviations, increased power losses, phase imbalance, and transformer overloading in distribution networks. Hence, optimal EVCS placement is necessary to minimize infrastructure costs, maintain grid stability, and ensure reliable system operation.

EV chargers are typically modelled as nonlinear single-phase loads, and their increasing penetration aggravates voltage instability and power quality issues in distribution systems [3]. Several studies have examined the impact of EV integration on distribution networks [4-7], highlighting increased voltage deviations and reduced power efficiency under high EV penetration [8]. Voltage stability analysis is therefore critical for assessing system loading limits and ensuring reliable power supply [9].

Various techniques have been proposed to quantify voltage instability in power systems [10-12]. Voltage instability refers to the inability of the system to maintain acceptable voltage levels following disturbances. Voltage stability indices (VSIs), such as the Fast Voltage Stability Index (FVSI) [13], are widely used to identify weak buses and proximity to voltage collapse. In addition, line stability indices are employed to assess the power transfer capability of lines and detect critical network sections under stressed conditions [14-16]. Optimization-based methods have been successfully applied for voltage stability enhancement and optimal

DG placement [17–22]. However, the problem becomes more complex with increasing penetration of EVCS and RES, and limited studies focus on voltage stability improvement in EVCS-connected distribution systems.

Solar photovoltaic systems are widely adopted due to their scalability, environmental benefits, and declining costs. However, their integration into the grid introduces power quality challenges, particularly under nonlinear loads at the point of common coupling (PCC). Nonlinear loads inject harmonics, increasing total harmonic distortion (THD) and degrading system performance [23]. According to IEEE 519 standards, harmonic mitigation and sinusoidal current injection are essential for safe grid operation [24]. Conventional Phase-Locked Loop (PLL) techniques suffer from poor performance under distorted and weak grid conditions [25–26]. To overcome these limitations, this work adopts an CBF-FLL based synchronization approach, which offers improved robustness and tracking accuracy [27]. CBF-FLL techniques have shown effectiveness in microgrid applications however, their standalone application for grid-connected PV systems remains limited [28–30].

4. Observation:

- Power systems now-a-days are highly complex and heavily loaded.
- Their operation is constrained by the loadability limits.
- They operate very close to the voltage stability limit point.
- So, quantifying the operating boundary becomes important for assessing the system security.

5. Motivation of Research

- Recent major Indian blackouts (2012 National Grid, regional collapses) highlight the critical need for enhanced voltage stability assessment and mitigation frameworks.
- India is rapidly transitioning toward electric mobility and renewable energy, driven by national missions such as FAME, National EV Policy, and 500 GW renewable targets by 2030 and net zero by 2050.
- The large-scale deployment of EV Charging Stations (EVCS) introduces highly variable, impulsive, and location-sensitive loads, which severely impact voltage stability and feeder loading.
- Simultaneously, high penetration of solar and wind generation introduces intermittency, reverse power flows, and reactive power uncertainty, weakening traditional distribution system operation.
- Conventional voltage control using OLTCs, capacitor banks, and fixed compensators is too slow and insufficient for fast EVCS and renewable dynamics.

6. Rationale of research

- Optimal placement of EVCS is essential to prevent localized voltage collapse, thermal overloading, and high losses in urban and semi-urban feeders.
- Simultaneous optimal allocation of PV and wind provides localized voltage support and active-loss minimization, improving grid resiliency.
- With increasing inverter dominance, Grid-Following (GFL) inverters with Frequency Lock Loop (FLL) synchronization provide, fast voltage tracking, stabilize PCC voltage, enhance power quality, robust operation under weak grid and non-linear (EV) loads.
- This coordinated methodology directly supports, distribution system operators (DISCOMs), EV infrastructure planners and renewable energy developers.
- The research uses simulations in MATLAB to assess the strategies performance under different scenarios.
- IEEE 33 bus distribution system is considered for validation of proposed research work.

7. Research Gap

Existing literature on distribution-system planning and control reveals critical shortcomings in the coordinated integration of EV charging infrastructure and renewable energy sources (RES). The proposed research specifically targets and bridges the following key gaps:

- ✓ Absence of Voltage Stability in EVCS Placement: Current studies predominantly focus on power loss minimization and economic factors, neglecting voltage stability constraints critical for high EV penetration scenarios.
- ✓ Limited Multi-Objective Optimization Frameworks: Very few works simultaneously optimize PV -wind placement considering voltage stability using comprehensive multi-objective approaches.
- ✓ Inadequate Robust Inverter Synchronization: Gap persists in adaptive Phase-Locked Loop (PLL) techniques for accurate reference current estimation under grid disturbances and renewable intermittency. Insufficient Weak-Grid Operation Analysis: Weak grid conditions (low Short Circuit Ratio) and low-inertia scenarios remain poorly addressed during RES integration, limiting practical deployment.

8. Objectives of research

Three main objectives addressed in this thesis are:

- ✓ Development of a novel hybrid COA–POA algorithm for optimal placement of EVCS in the IEEE 33-bus distribution system.
- ✓ Application of World Cup Optimization (WCO) for optimal allocation of Solar PV and Wind generators to enhance voltage profile and reduce power losses.
- ✓ Design and implementation of an advanced CBFFLL-based controller for: Real-time voltage regulation, power quality enhancement, fast grid synchronization.

9. Original contribution of the thesis:

The original and significant contributions of the present PhD research are summarized as follows:

- A novel hybrid optimization framework based on Coati Optimization Algorithm (COA) and Pelican Optimization Algorithm (POA) is developed for the optimal placement of Electric Vehicle Charging Stations (EVCS) with direct consideration of voltage stability indices, which is not addressed in existing EVCS planning literature.
- A World Cup Optimization (WCO)-based methodology is proposed for the simultaneous optimal placement of solar PV and wind generation in EVCS-integrated

distribution systems, enabling enhanced voltage security, power loss reduction, and renewable hosting capacity improvement.

- An advanced Complex Band-Pass Filter based Frequency Locked Loop (CBF-FLL) controller designed for reference current estimation in grid-connected inverters is the novelty, which has not been reported in earlier literature. Robust inverter control strategy is developed to ensure stable PCC voltage, fast synchronization under distorted and weak grid conditions, THD compliance with IEEE-519 standards.
- The research provides Indian grid-relevant solutions considering:
 - Electric vehicle charging growth
 - Renewable integration policies
 - Voltage band limits specified in Indian Grid Code
- The thesis offers a comprehensive mitigation framework for voltage instability caused by high EV penetration and renewable intermittency, bridging the gap between distribution planning and real-time voltage control.

10. Thesis Outline

This thesis is arranged into six comprehensive chapters structured with relevant sections, subsections, references, appendices, and a list of research publications. Here's a structured thesis outline presented in a table format:

Chapter 1	This chapter presents the overall research background and motivation, highlighting the emerging challenges in maintaining voltage stability in modern power systems due to high penetration of electric vehicle charging stations (EVCS) and renewable energy sources (RES). This chapter clearly defines the research problem, objectives, scope, and significance of the study. It also outlines the methodological approach adopted and summarizes the key contributions of the thesis.
Chapter 2	Provides a comprehensive review of existing literature related to voltage stability analysis in distribution networks, the impact of EVCS integration, optimal placement of renewable energy sources, and recent advancements in optimization algorithms. It also reviews inverter control and synchronization techniques for grid-connected renewable systems. Based

	on the literature survey, critical research gaps are identified, which form the basis for the proposed work.
Chapter 3	This chapter presents the modeling of EVCS loads in the distribution system, including and voltage stability indices, along with the mathematical formulation of the optimization problem. It introduces the proposed hybrid Coati–Pelican Optimization Algorithm (COA–POA) and its implementation for optimal EVCS placement in the IEEE 33-bus distribution system. The effectiveness of the method is validated through simulations, evaluating voltage deviation, stability indices, and power loss reduction.
Chapter 4	This chapter presents the optimal allocation of photovoltaic and wind generation units using the World Cup Optimization (WCO) technique. The coordinated impact of EVCS, PV, and wind integration on voltage profile, system losses, and stability indices is analyzed and validated on standard IEEE distribution test systems.
Chapter 5	This chapter is dedicated to the design and validation of a Complex Band-Pass Filter–based Frequency Locked Loop (CBF-FLL) controller for a grid-connected photovoltaic system. The controller’s performance is assessed under varying irradiance levels, dynamic load conditions, non-linear loads, and weak grid scenarios, with emphasis on voltage regulation and power quality enhancement.
Chapter 6	This chapter concludes the thesis by summarizing the major findings and contributions of the research work. It also discusses the practical implications of the proposed methodologies and outlines potential directions for future research,

11. Methodology and Discussion

11.1 Problem Statement-1

- The connection of an EVCS to the electricity grid will bring new challenges including a generation-demand mismatch, increased network active power loss, a degradation in voltage profile, and decreased voltage stability margin.
- To overcome the issue, proper integration of electric vehicle charging stations (EVCS) at appropriate locations is essential.
- It has been observed that GA and PSO that are applied by most of the researchers in solving the problem of CS placement.
- The classical optimization techniques can be combined with meta-heuristic techniques for CS placement.

11.1.1 Proposed Methodology for Problem Statement-1

✓ Hybrid Optimization Framework for EVCS Placement

- The proposed research develops an advanced methodology for optimal Electric Vehicle Charging Station (EVCS) allocation in distribution networks through the following key contributions:
- Novel Hybrid Coati Optimization Algorithm (COA) and Pelican Optimization Algorithm (POA): A sophisticated hybrid metaheuristic is formulated by integrating the exploration capabilities of COA (inspired by coati foraging behavior) with the exploitation precision of POA (mimicking pelican hunting strategies), achieving superior convergence and global optima search for complex multi-objective EVCS placement problems.
- Comprehensive Objective Function: Simultaneously optimizes power loss minimization, minimization of voltage deviation and voltage stability enhancement, under high EV penetration scenarios, addressing critical gaps in existing literature.
- Validation on Benchmark Systems: The IEEE 33-bus radial distribution system serves as the primary testbed for rigorous performance evaluation, with comparative analysis against individual algorithm demonstrating superior results in loss reduction and voltage profile improvement.

11.1.2 Hybrid COA- POA Optimisation

- EVCS allocation is a multi-objective non-linear problem: locating a high-demand EV load at the wrong bus worsens voltage stability indices and increases losses.
- COA contributes a high degree of global exploration, ensuring scanning of all possible

bus combinations.

- POA strengthens local exploitation, refining the best candidates for final optimal siting.
- The hybrid approach balances exploration and exploitation, resulting in faster convergence, reduced computational overhead, and more accurate EVCS placement.

11.1.3 Modelling of EV charging station

Reduction in fossil fuels and environmental degradation issues are the primary factors driving the popularity of electric Power system engineers face enormous challenges due to the demand for EV charging; therefore, demand for EVCS also get enhanced. The demand in charging station is based on number of EVs arrived to charge the vehicles. The energy demand is charging station is considered as follows;

$$D = \sum_{n \in N_k} E_{EV} \quad (1)$$

Where D denotes energy demand, E_{EV} indicates total energy required for to EV for N_k number of vehicles [27]. Constraints used in charging stations are as follows;

$$N_{EV} \leq N_C \quad (2)$$

$$P_{\min} \leq P \leq P_{\max} \quad (3)$$

$$SOC_{\min i} \leq SOC_i \leq SOC_{\max i} \quad (4)$$

Where, N_{EV} indicates number of EVs, N_C denotes number of chargers available in charging station, $P_{\min}$ signifies minimum power, $P_{\max}$ represent maximum power, SOC_i indicates SOC of i^{th} EV, $SOC_{\min i}$ denotes minimum SOC, $SOC_{\max i}$ represent maximum SOC [28]. In this work, load demand based on the power limits of EV batteries. The best planning is required to deploy EV charging station where they will best serve consumers with high charging demand. Furthermore, the voltage variation of the power system network must stay within legal bounds and power losses must be maintained as low as feasible. Maintaining a healthy voltage profile at every node is considered the goal, and this is achieved by minimizing voltage variation. These objectives are obtained by optimal allocation of charging station.

11.1.4 Hybrid optimization algorithm for placement of charging station

In this work, hybrid COA and POA method is proposed for selecting optimal location for charging station placement. Voltage deviation and VSI are taken into consideration as an objective in this hybrid method. This method will select the optimal location for

EV charging station with high voltage stability. Main objective of this hybrid method is to minimize average voltage deviation and to increase voltage stability in network. This method will select optimal location based on these objectives. The voltage deviation [29] in the magnitude at all nodes are as follows;

$$f_1 = \frac{1}{N_n} \sum_{n=1}^{N_n} |V_n - 1| \quad (5)$$

Where, N_n indicates number of nodes in IEEE 33 system and V_n denotes n^{th} node voltage. The VSI [30] is evaluated using below equation;

$$f_2 = |V_b|^4 - 4(P_b X_{ab} + Q_b R_{ab})^2 - 4(P_b X_{ab} + Q_b R_{ab})|V_b|^2 \quad (6)$$

Where, V_b denotes node b voltage, P_b indicates active power, X_{ab} signifies reactance in branches, Q_b represent reactive power and R_{ab} denotes resistance between nodes a and b . Considering voltage magnitude of all the buses must be within the acceptable upper and lower limits. Hence, the overall objective function is formulated to reduce voltage deviation index and to maximize VSI. Mathematically, expressed as follows;

$$f = \left(W f_1 + \frac{W}{f_2} \right) \quad (7)$$

$$F = \min(f) \quad (8)$$

This proposed method combines COA and POA into a new algorithm. The exploration of phase of POA algorithm is combined with COA algorithm to obtain better results for placing charging station in an optimal location. Initialization is takes is place by COA algorithm. COA is a new optimization technique, this method mimics the hunting behaviors of coatis [31]. The coatis are a sophisticated animal that can fight and kill iguanas in addition to pursuing and avoiding predators. Random initialization of COA algorithm is as follows;

$$\left. \begin{aligned} C_i: C_{ij} &= L_j + R \cdot (U_j - L_j) \\ i &= 1, 2, \dots, N \\ j &= 1, 2, \dots, m \end{aligned} \right\} \quad (9)$$

Where, m means total decision variables, C_i indicates bus position in i^{th} search space, R specifies random number, C_{ij} denotes j^{th} decision variable and N signify number of bus [32]. Population matrix is evaluated using below equation;

$$C = \begin{bmatrix} C_1 \\ \vdots \\ C_i \\ \vdots \\ C_N \end{bmatrix}_{N \times m} = \begin{bmatrix} C_{1,1} & \cdots & C_{1,j} & \cdots & C_{1,m} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ C_{i,1} & \cdots & C_{i,j} & \cdots & C_{i,m} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ C_{N,i} & \cdots & C_{N,j} & \cdots & C_{N,m} \end{bmatrix}_{N \times m} \quad (10)$$

Bus position is mathematically simulated using the below equation;

$$C_i^{p1}: C_{i,j}^{p1} = C_{i,j} + R \cdot (I_j - I) \cdot C_{i,j} \quad (11)$$

EVCS is placed in a random position in the search space. Coatis random position is simulated using the below equation,

$$C_i^{p1}: C_{i,j}^{p1} = \begin{cases} C_{i,j} + R \cdot (I_j^G - 1 \cdot C_{i,j}), & F_{iguana^G} < F_i \\ C_{i,j} + R \cdot (C_{i,j} - I_j^G), & else \end{cases}, \quad (12)$$

$$C_i = \begin{cases} C_i^{P1}, & F_i^{P1} \\ C_i & else. \end{cases} \quad (13)$$

The updated process results in new position, which is calculated for each increasing value of objective function in equation (12). In exploitation phase, bus position get updated using POA method. Hybridization of COA and POA is done by using the below equation,

$$C_i^{P2} = L_j + R \cdot (U_j - L_j) \quad (14)$$

A random position is generated using the POA methods hunting characteristics [33] to obtain optimal position using (15) and (16).

$$C_{i,j}^{P2} = C_{i,j} + R \left(1 - \frac{t}{T}\right) \cdot C_{i,j} \cdot (2R - 1) \quad (15)$$

$$C_i = \begin{cases} C_i^{P2}, & F_i^{P2} \\ C_i & else. \end{cases} \quad (16)$$

Where, $C_{i,j}^{P2}$ specifies updated position based on POA exploitation phase, t signify iteration counter, T signifies a maximum number of iteration and F_i^{P2} indicates an updated objective function [34]. Iterations get repeated to get the optimal position for placing the EVCS. The minimum voltage deviation and high VSI bus is selected as optimum location based on COA-POA. This process gets stopped when this method obtained finest location in the IEEE 33 bus with specified values. Figure 1 represent the flowchart for hybrid COA-POA.

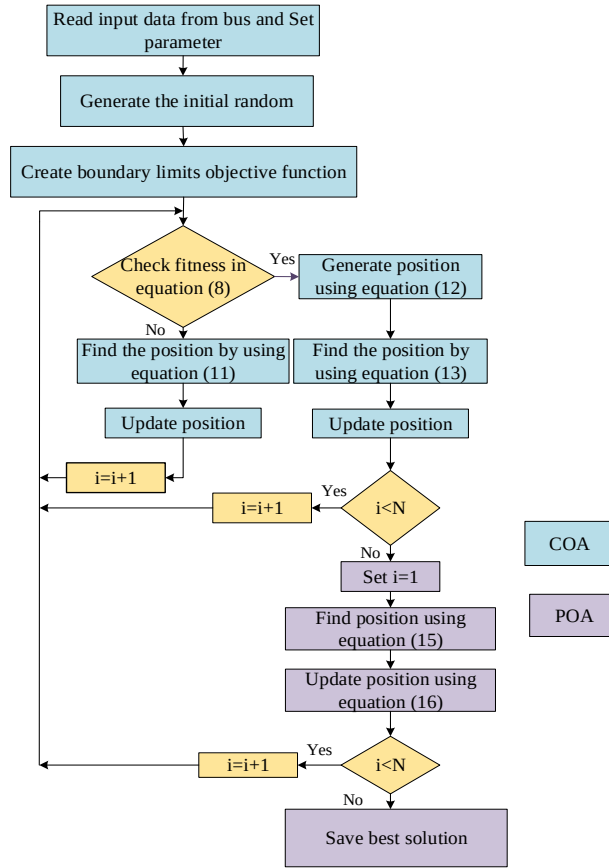


Figure 1: Flowchart for hybrid COA-POA algorithm

11.1.5 Results and Discussion on problem statement-1:

The MATLAB/Simulink platform is used to implement the proposed method. The findings are obtained for voltage profiles based on EV charging demand. Additionally, individual pelican optimization algorithm (POA), coati optimization algorithm (COA) and hybrid coati and pelican algorithm (COA-POA) convergence plots are used for the comparison analysis. The Hybrid COA-POA algorithms are used in this work to allocate EV charging stations in the best possible way. By considering voltage deviation and voltage stability index, this approach will choose bus 27 for the optimal location of the EV charging station in the IEEE 33 bus distribution system.

As EVCS has a power capacity of 770 kW, whenever EV load power exceeds its rated capacity, the grid will supply the excess power to EV. The results of IEEE 33 bus are validated considering 3 cases listed below.

Case 1: Base case, **Case 2:** System with random EVCS placement, **Case 3:** System with Optimal EVCS

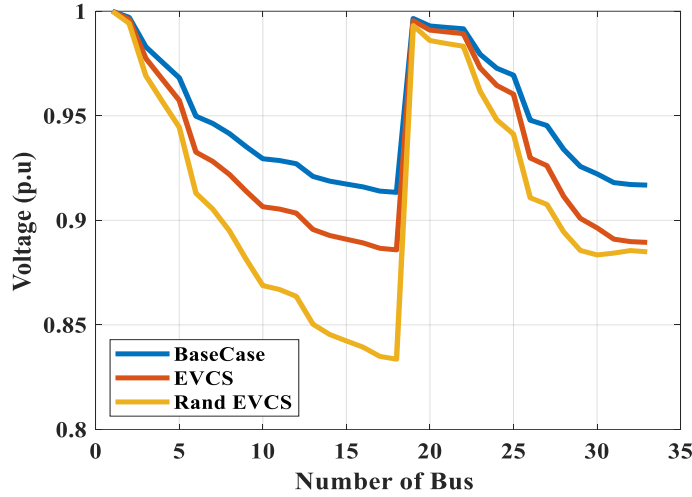


Figure 2: Voltage profile for 33 bus system for base case, with random EVCS location, and with optimal EVCS location

Figure 2 illustrates the voltage profile of the 33-bus system for the different cases listed above. As the charging load increases, the voltage at each bus keeps dropping. Active and reactive power losses in distribution system affect the voltages on each bus. The system is subject to a total real and reactive demand of 3715kW and 2300kVar. After applying the forward-backward approach to execute the distribution power flow algorithm, bus18 shows a minimum voltage of 0.9133p.u at base case. After connecting EVCS at bus 18 and 32 randomly the voltage reduces to 0.8387 p.u. However, when EVCS connected at optimal location i.e at bus 27, the voltage at weak bus increases to 0.8857 pu.

The system's total power loss is 242.6703 kW for base case, its increases to 674.08 kW for random EVCS placement and it reduces to 340.3056 kW while placing EVCS optimally shown in figure 3, which shows the efficacy of the method proposed.

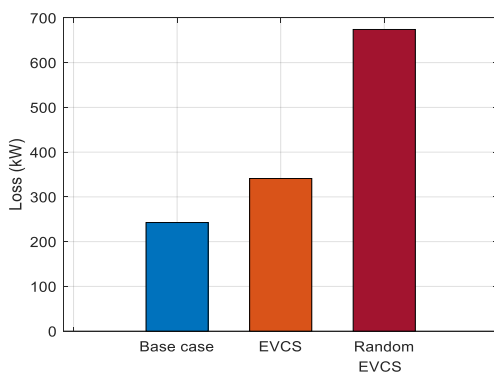


Figure-3: Total Power loss

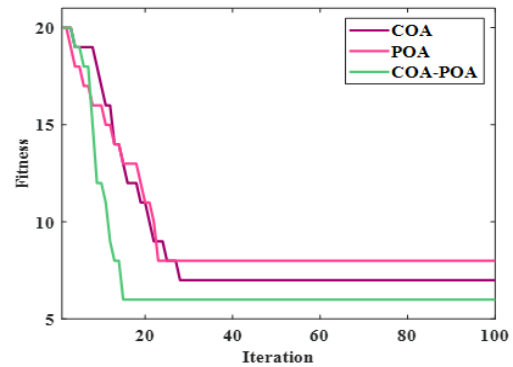


Figure 4: Comparison of proposed hybrid algorithm

Figure 4 illustrates the convergence comparison of the proposed hybrid COA–POA algorithm with the individual COA and POA techniques. The convergence curves demonstrate that the hybrid approach attains a stable optimum in significantly fewer iterations, highlighting its

superior convergence efficiency. The voltage deviation is minimized and VSI is increased as shown in table 1 below.

Table 1: Comparative analysis

System	Cases	Total P (load) kW	Total Q (load) kvar	Voltage (p.u) @ bus 18 (33 bus)	Voltage Deviation Index (VDI)	Voltage stability index (VSI)	Total power Loss (kW)
33	Base case	3715	2300	0.9133	0.05023	0.66716	242.6703
	Random EVCS at bus 18 and bus 32	5255	2300	0.8387	0.05224	0.23486	674.0801
	Optimal EVCS at bus 27	4485	2300	0.8857	0.05082	0.43820	340.3056

11.2 Problem Statement-2

- Voltage Stability Assessment: Post-EVCS allocation, Voltage Stability Index (VSI) analysis identifies critical buses exhibiting voltage vulnerability during peak demand periods.
- Distributed generation (DG) sources are incorporated with EVCS to lessen the impact of EV charging load.
- Charging stations are combined with DG units, increases the motivation to use EVs.
- As the current CSs are fossil fuels based and causing environmental issues which affects the human health through the emission of various gases such as SO_x, NO_x, and carbon monoxides particularly in metropolitan cities of India.
- Thus, the solar PV and wind based CSs will not only reduce the burden on the existing electrical networks but also provides the sustainable, cost effective and eco-friendly environment. In this regard, the feasibility studies of solar PV and wind-based CS are a new research area.

11.2.1 Proposed Methodology for Problem Statement-2

- ✓ **RES Optimal Siting Using World Cup Optimization (WCO)**
- Multi-Objective WCO Application: World Cup Optimization algorithm simultaneously optimizes PV and wind unit locations to maximize VSI margins while minimizing network losses.
- Key Features: WCO's tournament-based exploration-exploitation balance ensures

global optima for hybrid RES configurations.

11.2.2 Solar and wind modelling

In this work, solar and wind turbine are used as an input source for EV charging station. A solar photovoltaic cell (PV) utilizes the photovoltaic effect to convert its solar energy from sunlight into electrical power. Temperature and sun radiation are two examples of physical and environmental elements that have a significant impact on photovoltaic system efficiency. Solar irradiation and PV power output terminal current are almost exactly equivalent. The power generated from PV panel is evaluated using below equation;

$$P_{PV}(t) = A\eta\mu(t) \quad (17)$$

Where, $P_{PV}(t)$ indicates PV power, A denotes area of solar panel placement, η specifies PV panel's efficiency and $\mu(t)$ represent irradiance of solar. Wind turbine converts wind energy into electrical energy, in this work doubly fed induction generator (DFIG) wind turbine model is used. Wind turbine generated power is calculated using below equation;

$$P_{wind}(t) = 0.5C_p\rho Av^3 \quad (18)$$

Where, $P_{wind}(t)$ denotes power obtained from wind turbine in kW, A indicates swept area of wind turbine in m^2 , C_p power coefficient, ρ signifies air density kg/m^3 and v represent wind velocity in m/s [35]. Stability of the system is collapsed while adding these PV and wind sources in the charging station. Thus, solar and wind sources are used for improving it. The optimal placement of these distribution generators is done by using world cup optimization algorithm.

11.2.3 World cup optimization algorithm (WCO)

This optimization algorithm used for selecting the optimal location for placing PV and wind in distribution network by considering FVSI, LSI and LSF. This WCO [36] is inspired from FIFA world cup match to obtain title as an optimal solution. A mathematical model of the team competition process is used to evaluate global optimal solution. In this work, solar and wind are placed in optimal location of IEEE 33 bus system using this WCO. The WCO method starts with a random population to find the global optimal point. Let N indicates variable dimensions (buses) and M denotes total iterations.

$$W = \begin{bmatrix} W_{1,1} & W_{2,1} & \dots & W_{m,1} \\ W_{1,2} & W_{2,2} & \dots & W_{m,2} \\ \vdots & \vdots & \ddots & \vdots \\ W_{i,N} & W_{j,N} & \dots & W_{m,N} \end{bmatrix} \quad (19)$$

Where, W_i specifies bus position and W_{ij} represent ij^{th} variable. Objective function of this algorithm is considered as follows;

$$F = F_r(W_{i,N}, W_{j,N}, \dots, W_{m,N}) \quad (20)$$

The major objective of WCO is to enhance FVSI, LSI and LSF. Hence, objective function of this method is as follows;

A line with has a higher stability value is closer to instability. Root discriminant of the voltage quadratic equation is set to zero to obtain real roots of voltage. Line is at a critical state if index is close to unity. In order to maintain a safe state, index needs to be lower than 1. The equation for line stability index is as follows;

$$F_1 = \frac{4XQ_R}{V_s \sin(\alpha - \beta)^2} \quad (21)$$

Line stability factor must be maintained below 1 to obtain optimal stability of the system. It can evaluate as follows;

$$F_2 = \frac{4X}{V_s^2} \left[\frac{XP_s^2}{V_s^2} + Q_R \right] \quad (22)$$

Fast voltage stability should be near to one, if is not in this value, it causes instability.

$$F_3 = \frac{4Z^2 Q_R}{V_s^2 X} \quad (23)$$

$$F = \text{Max}(F_1 + F_2 + F_3) \quad (24)$$

Where, X indicates inductive reactance, Q_R denotes reactive power, V_s represent sending end voltage, α denotes angle at sending end, β indicates angle at receiving end, P_s signifies active power at sending end and Z denotes line impedance [37]. The ranking of the obtained fitness value is set as follows;

$$R = \frac{\chi \times \sigma + \bar{W}}{2} \quad (25)$$

$$\bar{W} = \frac{1}{n} \sum_{i=1}^n W_i \quad (26)$$

$$\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (W_i - \bar{W})^2} \quad (27)$$

Where, R indicates ranking, χ denotes increasing or decreasing values, σ represent standard deviation, W_i population value, $\bar{W}$ specifies mean value and n indicates number of population. In this WCO method, second best value is evaluated immediately after evaluating the first iterations. Updating the position for next iteration is done using below equation;

$$W_{new} = [W_{best}, W_{Rand}] \quad (28)$$

Where, W_{new} denotes new population matrix, W_{best} indicates best obtained value and W_{Rand} represent random value. W_{best} is obtained as follows;

$$\left(\frac{1}{2} \times A(u - l)\right) < W_{best} < \left(\frac{1}{2} \times A(u + l)\right) \quad (29)$$

Where, A signifies accuracy parameter, u denotes upper bound and l represent lower bound [29]. This process will continue till the best values obtained. The WCO optimally select the bus for PV and wind based on fitness function used in this algorithm. The parameters and the total number of repetitions are randomly initialized, and each parameter's fitness function is estimated. If the limit is reached, change the limit between the optimum ranges and update the position of a parameter. Iteration is repeated till obtaining optimal position for allocation. This optimal allocation will enhance the stability of the distributed system. Figure 5 represent flowchart for WCO algorithm.

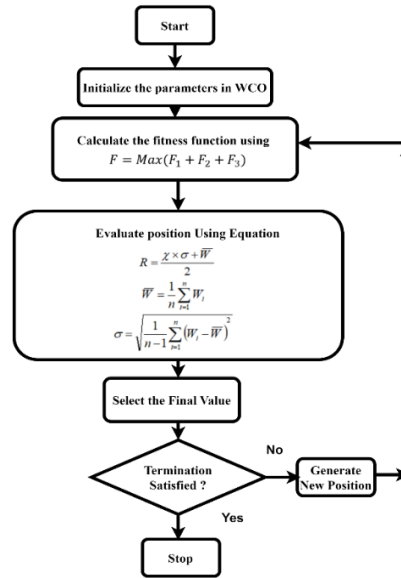


Figure 5: Flowchart for WCO algorithm

The optimal location for solar PV found as 26th bus and for wind is 2nd bus which is shown in figure 6.

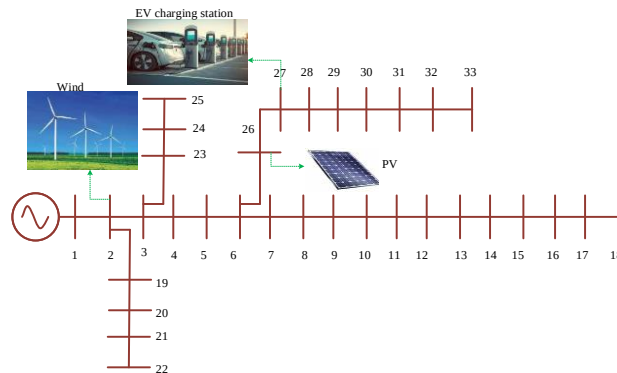


Figure 6: Modified IEEE 33 distribution network

11.2.4 Results and Discussion on problem statement-2 with EVCS and PV only:

The results of IEEE 33 bus distribution system are validated considering 4 cases listed below.

Case 1: Base case, **Case 2:** System with random EVCS placement, **Case 3:** System with Optimal EVCS, **Case 4:** System with optimal EVCS & PV placement

The solar and wind output power rating is 775 kW and 1MW respectively. The Voltage stability is further improved by connecting renewable sources in the system. Here solar PV is connected at bus 26. It has been observed that after placing Solar PV, the voltage profile is further improved and losses are further reduced to 99.47 kW as shown in Figure 7 & 8 respectively. Further, various VSI's are calculated and compared as shown in table 2.

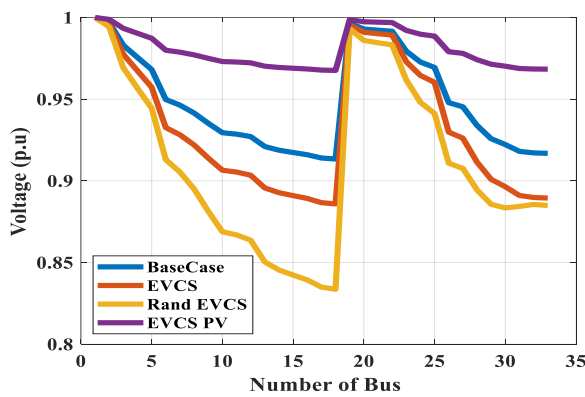


Figure 7 Voltage profile

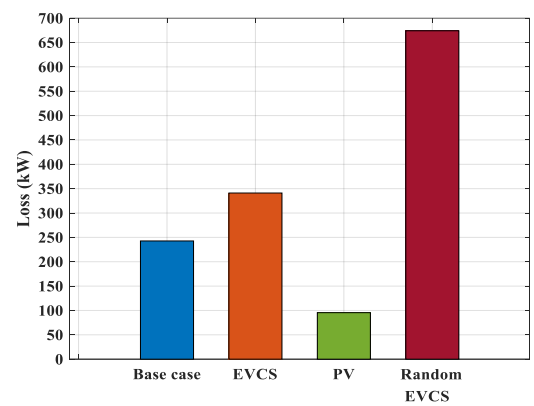


Figure 8 Comparison of total losses for IEEE 33 bus system

11.2.5 Validation using IEEE-69 bus radial distribution system

The IEEE 69 bus test system is shown in Figure 9 where the location of random and optimal located EVCS and PV array is stated. The system is experiencing a total real and reactive demand of 3801.4 kW and 2693.6 kVar. Bus 65 has the most voltage deviation and the worst of all the buses. At bus number 65, the voltage is 0.9102 p.u. The system's total reactive power loss is 102.1647 kVar, while its total active power loss is 224.8807 kW. The comparative analysis of IEEE 33 and 69 distribution system is shown in table-2.

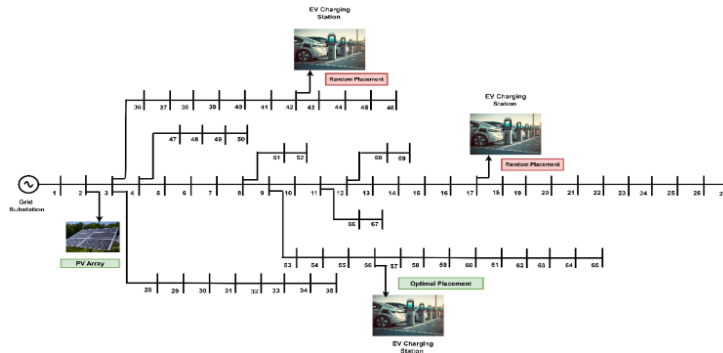


Figure 9: Modified IEEE 69 bus distribution network

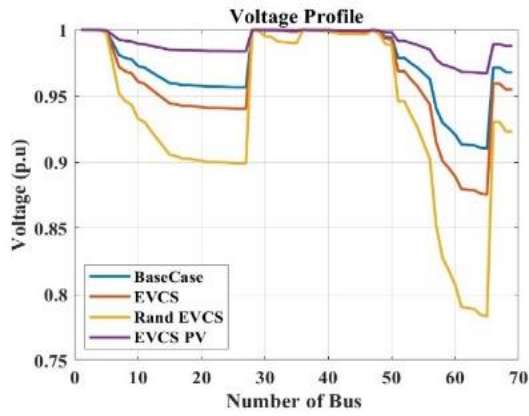


Figure 10: Voltage profile of IEEE 69 bus
for various cases

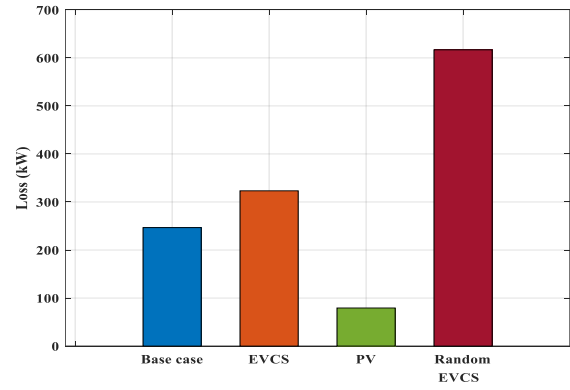


Figure 11: Comparison of total losses

Table 2: Comparative analysis of IEEE 33 and 69 bus system performance

System	Cases	Total P (load) kW	Total Q(load) kvar	Voltage (p.u) @ bus 18 (33 bus) and @ bus 65 (69 bus)	FVSI	LSI	LSF	Total power Loss (kW)
33	Base case	3715	2300	0.9133	0.000302	0.000208	0.06547	242.6703
	Random EVCS at bus 18 and bus 32	5255	2300	0.8387	0.000419	0.001288	0.35515	674.0801
	optimal EVCS at bus 27	4485	2300	0.8857	0.000328	0.000437	0.074547	340.3056
	With optimal EVCS & solar PV	4485	2300	0.9681	0.000156	0.000125	0.054547	99.47897
69	Base case	3801.4	2693.6	0.9102	0.000417	0.000191	0.0136	246.6144
	Random EVCS at bus 17 and bus 52	5341.4	2693.6	0.8025	0.002210	0.001951	0.1204	616.7783
	optimal EVCS at bus 56	4571.4	2693.6	0.8982	0.000528	0.000195	0.01218	323.2390
	With optimal EVCS & solar PV	4571.4	2693.6	0.9695	0.000380	0.000123	0.0124	79.3011

11.2.6 Results and Discussion on problem statement-2 with EVCS, PV and Wind System:

The results show that EVCS alone increases voltage stress and losses. Optimal EVCS placement improves stability, but the coordinated integration of PV and wind provides the best

performance, significantly enhancing voltage profile, stability indices, and loss reduction. The results are taken for following cases:

Case 1: Distribution IEEE 33 Base case

Case 2: Distribution IEEE 33 with EVCS and without DG

Case 3: Distribution system with EVCS and solar PV

Case 4: Distribution system with EVCS and wind turbine

Case 5: Distribution system with solar PV, wind and EVCS.

Case 6: Distribution IEEE 33 with random EVCS placement

Figure 12 shows voltage profile of 33-bus system for various case listed above. It can be seen that with coordinated EVCS-PV and Wind the voltage profile further improves. The comparison of total active loss is shown in Figure 13 which clearly shows that optimally placing EVCS with solar PV and wind generation gives reduced losses against base case and random placement and all other scenarios. It reduced to 53.6286 kW.

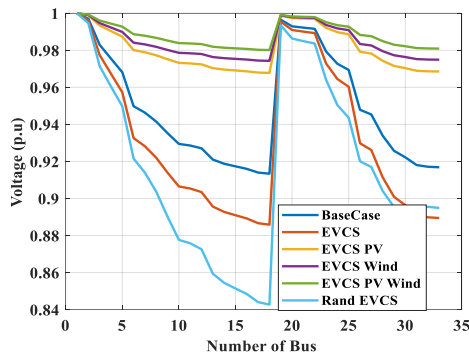


Figure: 12 Voltage profile

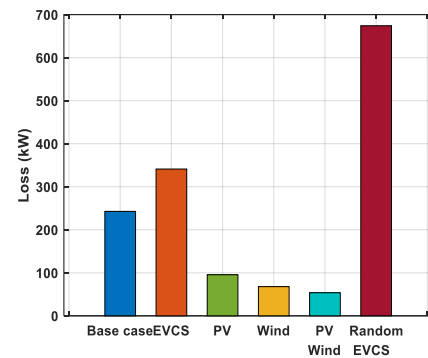


Figure 13: Comparison of total losses

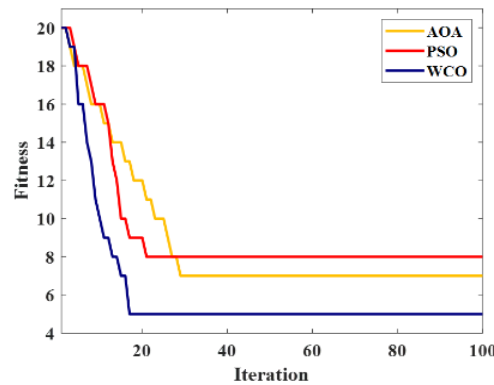


Figure 14: Comparison of proposed algorithm

Figure 14 presents a comparative performance analysis of the proposed algorithm against the existing Arithmetic Optimization Algorithm (AOA) [41] and Particle Swarm Optimization (PSO) [42]. The results demonstrate that the proposed approach converges to a stable optimal solution with significantly fewer iterations. This faster convergence and improved stability

highlight the superior efficiency and effectiveness of the proposed algorithm compared to the benchmark methods.

11.3 Problem statement-3

- Inverter-interfaced DERs and grid-following converters have fast dynamics but lack stabilizing inertia, creating a tradeoff between rapid response and transient stability. As a result, microgrids often face transient performance issues where high-speed control can compromise voltage regulation and power quality.
- The control algorithms are used for enhancing the performance of the microgrids under dynamic/ transient conditions.
- The objective of control technique is used to mitigate the grid currents harmonics, inject the surplus active power into the grid with unity power factor together with compensating the reactive power demand of the load in the grid connected mode.
- Research Needs design of an advanced control for grid-following converters ensuring robust transient stability, voltage regulation, and power quality in inverter-dominated microgrids with RES/EV integration.

11.3.1 Proposed Methodology for Problem Statement-3

✓ **Advanced Inverter CBF-FLL Control Design for RES Integration to the grid.**

With rising inverter dominance in modern grids, the proposed research develops an advanced Complex Band Pass Filter based Frequency Locked Loop (CBF-FLL) synchronization and reference generation technique for Grid-Following (GFL) inverters, delivering:

- Continuous Voltage Support: Real-time voltage regulation ($\pm 5\%$ limits) under intermittent renewable generation and EV charging loads.
- Power Quality Enhancement: Harmonic mitigation and unity power factor operation.
- Robust Performance: Seamless operation during unbalanced conditions and weak grids (low SCR).

Key Innovations:

- Superior frequency/phase tracking compared to conventional PLLs/FLLs.
- Enhanced transient stability addressing inertia-less inverter challenges.
- Grid-supportive features for Indian distribution networks with high RES/EV penetration.

The dual-stage power conversion architecture of the suggested grid-connected solar PV system is intended to provide reliable and effective energy injection into the utility grid. Voltage

support, harmonic reduction, and steady operation under dynamic grid conditions are made possible by the overall system structure, as shown in Figure 15, which permits controlled power exchange with the grid.

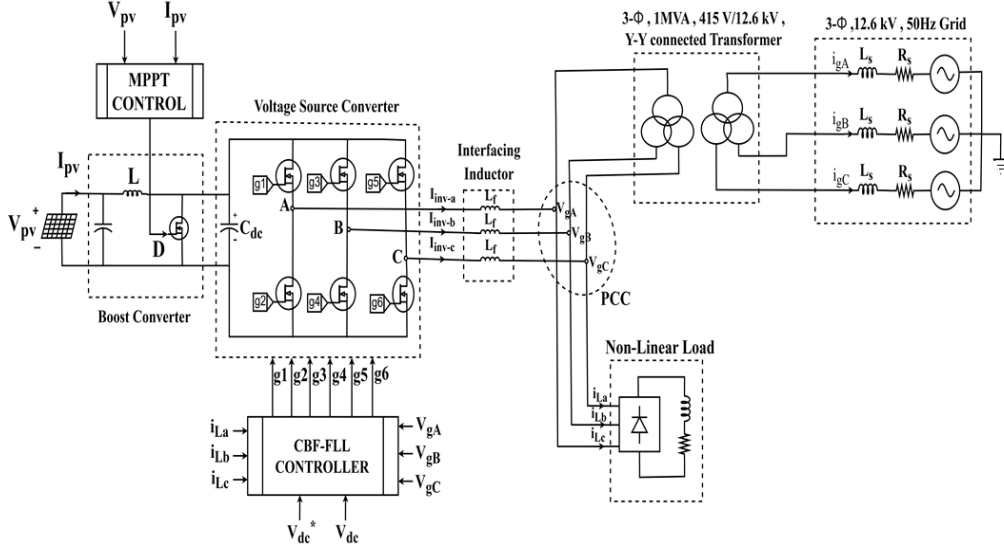


Figure-15 Proposed dual stage solar PV system connected to grid

11.3.2 CBF-FLL Control Technique

To control the Voltage Source Converter (VSC), the control system is divided into three main parts: Unit template generation, the Complex Band-Pass Filter-based Frequency Locked Loop (CBF-FLL), and DC-link voltage regulation using a PI controller. The schematic diagram is shown in figure 16.

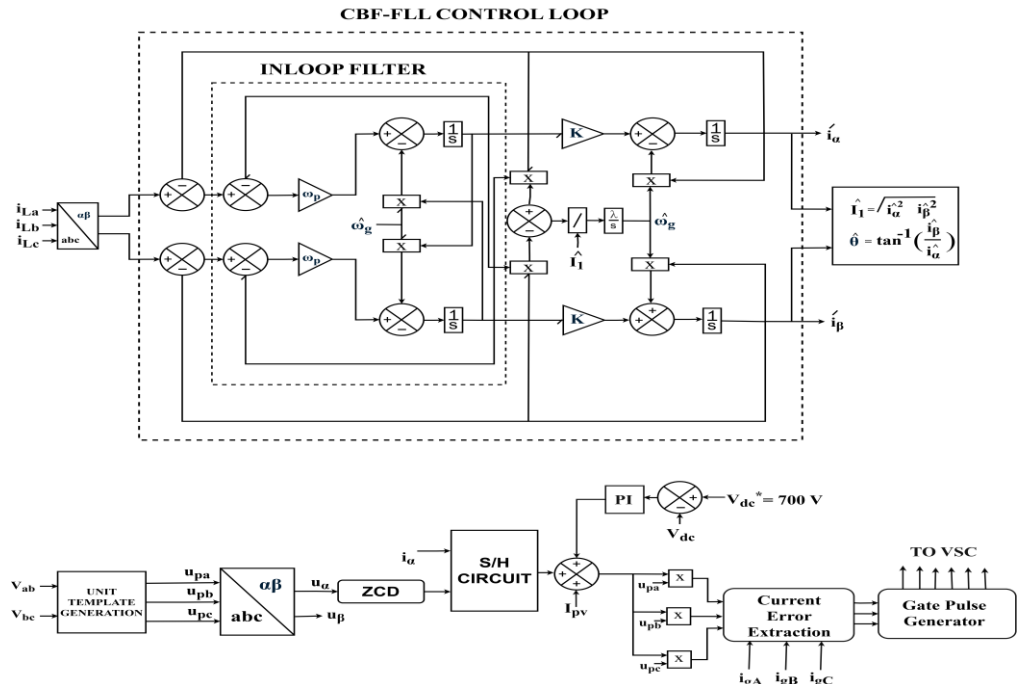


Figure 16 Control Structure based on CBF- FLL

11.3.3 Results and discussion on Problem statement-3:

The proposed double-stage, three-phase grid-connected SPV system is modeled and simulated in MATLAB/Simulink using the SimPowerSystems toolbox. To verify the effectiveness of the developed control strategy, the system is evaluated under a wide range of operating scenarios considering nonlinear load conditions. The performance is further examined during steady-state operation, step changes in irradiance, sudden increases and decreases in load, unbalanced load conditions, and weak-grid scenarios. These test cases collectively demonstrate the robustness of the controller in maintaining voltage stability, ensuring reliable synchronization, and improving overall power quality under practical grid disturbances. The response of grid and load side voltage and current under strong and weak grid condition is shown in figure 17. With these stressed conditions, the controller successfully maintains the PCC voltage by keeping THD below 5% as shown in figure 18.

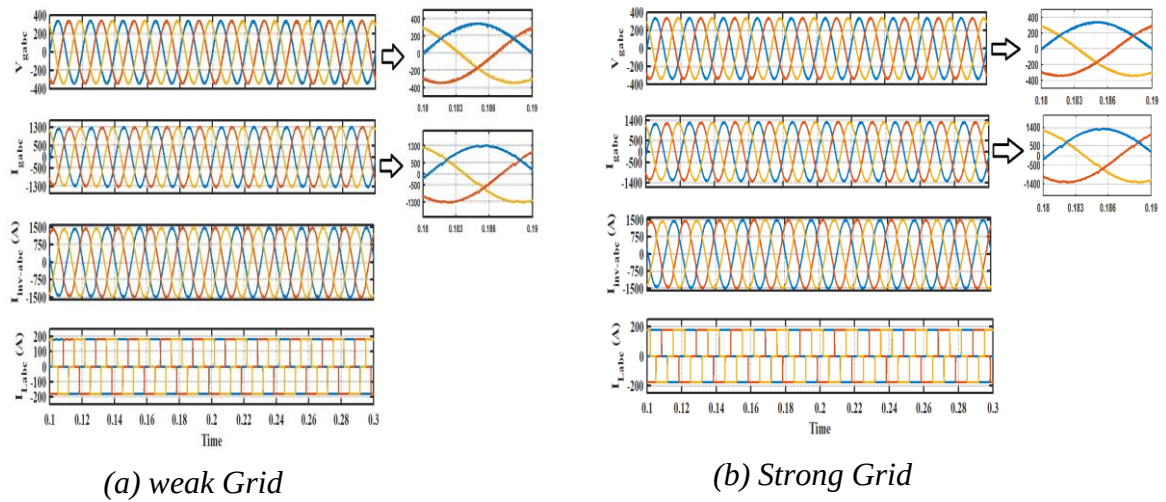
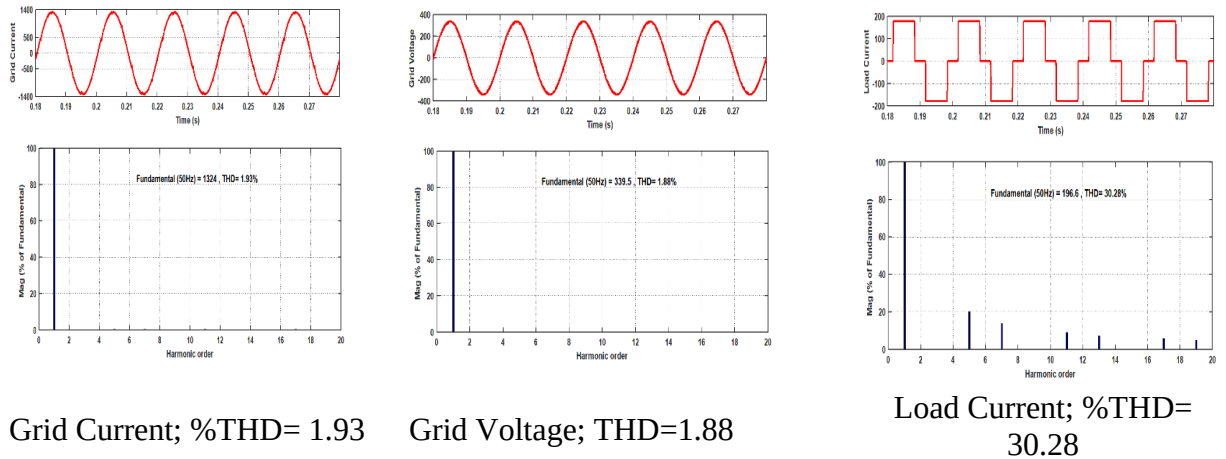
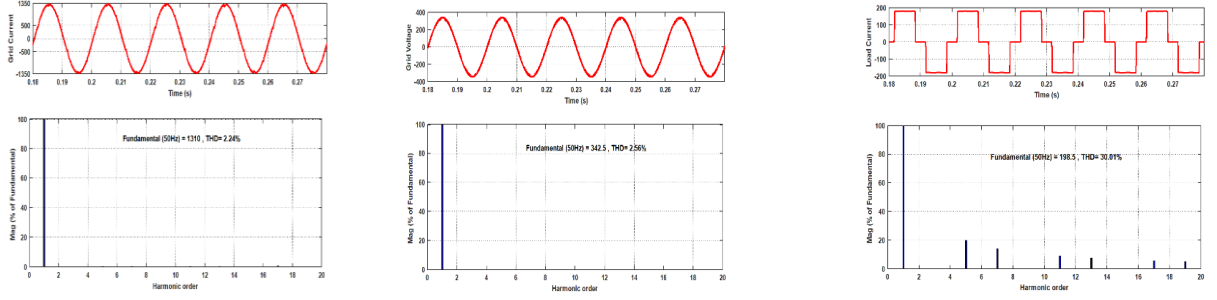


Figure 17 Response of grid and load side waveforms under (a)weak grid (b) strong grid condition





Grid Current %THD= 2.24 Grid Voltage %THD= 2.56 Load Current %THD= 30.01

Figure 18 Harmonic spectrum under (a)strong grid and (b) weak grid

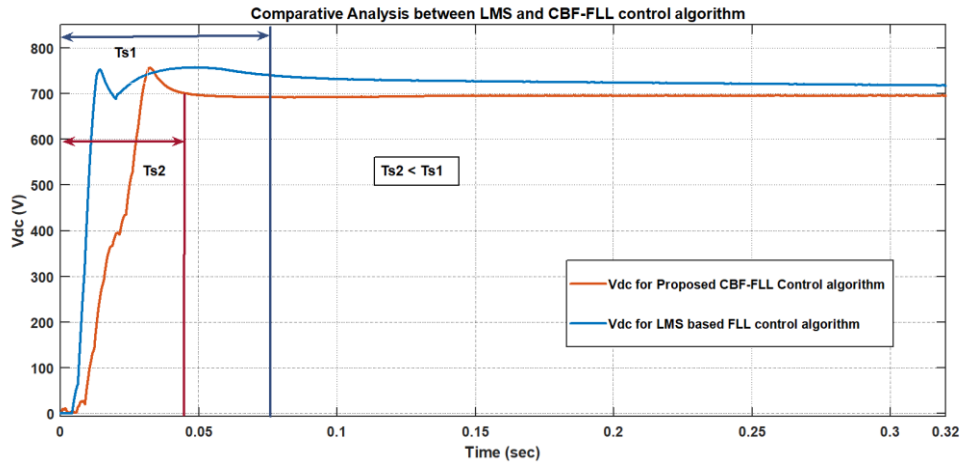


Figure 19 Comparative analysis between LMS proposed algorithm

The DC link voltage (V_{dc}) of CBF-FLL controller is compared with Least mean square (LMS) based FLL as shown in Figure 19. Comparative evaluation offers superior dynamic performance, exhibiting a notably shorter DC-link voltage settling time for the same system conditions. This confirms the enhanced convergence capability and improved synchronization dynamics of the proposed controller.

12. Conclusion

This work develops an integrated framework to enhance voltage stability, power quality, and the ability to handle more renewable and EV load in distribution networks with high RES and EVCS penetration, by jointly addressing optimal EVCS siting, optimal renewable generation allocation, and advanced control for voltage and power quality improvement.

- First, a novel hybrid Coati Optimization–Pelican Optimization Algorithm (COA–POA) was developed for optimal EVCS placement in the IEEE 33-bus system, using

voltage deviation and VSI as objectives. The hybrid strategy achieved an effective exploration–exploitation balance, ensuring faster convergence and superior solution quality. With optimal siting, the VDI is reduced weak 18th bus from 0.05224 to 0.05082 and VSI at the weak 18th bus improved from 0.23486 to 0.4382, feeder losses decreased from 674.0801 kW to 340.3056 kW, and bus voltages remained within limits under high EV penetration. Compared to random placement, the proposed approach significantly minimizes voltage deviation, enhances VSI, and reduces losses, thereby fulfilling the first research objective.

- Next, the World Cup Optimization (WCO) algorithm was employed to determine the optimal placement of PV and wind generation units in the IEEE-33 bus distribution system. The objective was to enhance the voltage profile, minimize active power losses, and strengthen voltage-stability indices (FVSI, LSI, LSF). Due to critically low voltages at weak buses, coordinated integration of PV and wind units was essential to mitigate the loading impact introduced by EV charging stations (EVCS). Six scenarios were evaluated: (i) base case (ii) Random EVCS placement (iii) optimal EVCS, (iv) PV–EVCS, (v) Wind–EVCS, and (vi) combined PV–Wind–EVCS. It has been observed that optimal PV allocation at Bus 26 improved the minimum system voltage from 0.88575 pu to 0.96814 pu, further increased to 0.97460 pu with wind integration, and ultimately reached 0.97974 pu for the coordinated PV–Wind–EVCS case. Voltage-stability indices also showed significant enhancement: FVSI enhanced from 0.00439 to 0.00328 (optimal EVCS), 0.000507 (PV), 0.000418 (Wind), and 0.000305 (PV–Wind–EVCS). LSI enhanced from 0.053916 (random EVCS) to 0.008365 (PV–Wind–EVCS), while LSF improved from 0.6134695 to 0.176835 across the integrated scenarios. Active power losses reduced from 670.0882 kW to 341.0856 kW (optimal EVCS) and further to 53.6286 kW for the combined PV–Wind–EVCS case. Comparative analysis confirmed that WCO consistently outperformed the conventional PSO algorithm, delivering higher-quality, multi-objective solutions with faster convergence and better global search capability. To ensure robustness and generality, the proposed methodology was additionally validated on the IEEE-69 bus distribution system, where similarly satisfactory improvements were obtained across voltage, losses, and stability indices. This cross-system validation underscores the scalability and reliability of the WCO-based optimization framework.
- Finally, an advanced Complex Band-Pass Filter–Frequency Locked Loop (CBF-FLL) controller was developed for a grid-connected dual-stage 775 kW solar PV system to

improve voltage regulation and power quality at the PCC under nonlinear loading. The controller was tested under fixed/variable irradiance, dynamic load changes, and weak-grid conditions, consistently achieving stable synchronization, effective voltage control, and improved power quality. The proposed strategy meets IEEE-519 limits (below 5%), maintaining grid-voltage and grid-current THD as 2.56% and 2.24%, respectively. Compared with an LMS-based FLL, the CBF-FLL achieves a faster DC-link voltage settling time (0.042 s vs. 0.075 s). Overall, the CBF-FLL provides a robust and reliable control solution for the seamless integration of solar PV into grid-connected microgrid systems.

13. Scope of the Future Work

- Future research can extend this work by incorporating techno-economic objectives such as investment cost, operating cost, and tariff structures, as emphasized in recent literature.
- Uncertainty-aware and probabilistic optimization can be adopted to address stochastic EV charging demand and renewable generation variability.
- The framework may be expanded to include fast and ultra-fast EV chargers, V2G operation, and market-oriented models.
- Validation on large-scale and practical distribution networks, along with real-time, adaptive optimization.
- Advanced inverter control features such as grid-code compliance and fault ride-through and hardware-in-the-loop implementation, will further enhance practical applicability. can also be explored.
- Further investigation into advanced control methodologies, including machine learning-based approaches and model predictive control, to enhance performance under dynamic solar and wind conditions.
- The incorporation of energy storage technologies, notably batteries and supercapacitors, serves to augment system reliability and mitigate the challenges associated with fluctuating renewable power generation.

14. List of Publication:

Journal Papers Published

- (1) Kanojia, Sarika S., and Bhavik N. Suthar. "Voltage stability index: a review based on analytical method, formulation and comparison in renewable dominated power

system." *International Journal of Applied power Engineering* 13.2 (2024): 508-520. DOI: 10.11591/ijape.v13.i2.pp508-520. (Scopus indexed journal).

- (2) Kanojia, Sarika S., Bhavik N. Suthar, and Ashutosh K. Giri. "Hybrid Optimization Approach for Optimal Location of Electric Vehicle Charging Station (EVCS) in Distribution Network Considering Voltage Stability." *Smart Grids and Sustainable Energy* 10.2 (2025): 36. IF-1.9. (ESCI -Web of Science and Scopus indexed journal).

Conference Papers / Book chapter Published

- (1) S. Kanojia and B. N. Suthar, "Voltage Stability Analysis in Modern Power System Considering Wind Energy Conversion System," *2023 IEEE IAS Global Conference on Emerging Technologies (GlobConET)*, London, United Kingdom, 2023, pp. 1-7, doi: 10.1109/GlobConET56651.2023.10150149.
(Scopus indexed international conference)
- (2) Kanojia, S.S., Suthar, B.N., Giri, A.K., Singh, M. (2025). Charging Technologies and Infrastructure for EVs: Trends, Technologies, and Integration Strategies for System Stability. In: Giri, A.K., Singh, M. (eds) *Electric Vehicle Charging Infrastructures and its Challenges*. Studies in Infrastructure and Control. Springer, Singapore. https://doi.org/10.1007/978-981-96-0361-9_3. (Book Chapter- Springer Nature).

Patent (Design) accepted and published

- (1) Controller for Solar Microgrid Systems for Enhanced Voltage Regulation and Performance Evaluation.

Journal Papers Communicated

- (1) Kanojia, Sarika S., Bhavik N. Suthar, and Ashutosh K. Giri. "Voltage Stability Enhancement by Optimally Placing DG in radial distribution network: A comparative analysis" submitted to *Journal of The Institution of Engineers (India): Series B (IEIB)*, Springer nature, Reviews completed (*SCOPUS indexed journal*)
- (2) Kanojia, Sarika S., Bhavik N. Suthar, and Ashutosh K. Giri., " Robust Synchronization and Control for DualStage PV Systems: Enhancing Voltage Stability and Power Quality Under Grid Variability," submitted to *International Journal of Ambient Energy-Taylor & Francis*, on date 28th November, 2025. (*SCI-Web of Science, SCOPUS indexed journal*)

15. References:

- [1] P. Kundur, J. Paserba, V. Ajjarapu, G. Andersson, A. Bose, C. Cañizares, N. Hatziaargyriou, D. Hill, A. Stankovic, C. Taylor, T. Van Cutsen, and V. Vittal, "Definition and classification of power system stability," *IEEE Trans. Power Syst.*, vol. 19, no. 3, pp. 1387–1401, May. 2004.
- [2] J. Modarresi, E. Gholipour, and A. Khodabakhshian, "A comprehensive review of the voltage stability indices," *Renew. Sustain. Energy Rev.*, vol. 63, pp. 1–12, 2016.
- [3] Adam, C., Kellen, S.: 'Electric vehicle sales forecast and the charging infrastructure required through 2030', Institute of Electric Innovation, November 2018, pp. 1–16.
- [4] Bilal, M., & Rizwan, M. (2020). Electric vehicles in a smart grid: a comprehensive survey on optimal location of charging station. *IET Smart Grid*, 3(3), 267-279.
- [5] A. M. Kettner and M. Paolone, "A Generalized Index for Static Voltage Stability of Unbalanced Polyphase Power Systems including Thévenin Equivalents and Polynomial Models," *IEEE Trans. Power Syst.*, vol. 34, no. 6, pp. 4630–4639, 2019.
- [6] De Marco CL. A new method of constructing Lyapunov functions for power systems. In: Proceedings of the IEEE international symposium on circuits and systems;1988.p.905–8.
- [7] M. S. Saddique et al., "Solution to optimal reactive power dispatch in transmission system using meta-heuristic techniques -Status and technological review," *Electr. Power Syst. Res.*, vol. 178, no. February 2019, p. 106031, 2020.
- [8] S. Lauria and M. Schembari, "Voltage and reactive power control for maximum utilization of a GW-size EHVAC offshore wind farm interconnection," in *Proc. RPG*, Naples, Italy, 2014, pp. 16.
- [9] K. Mahadevan, P. Kannan, Comprehensive learning particle swarm optimization for reactive power dispatch, *Applied soft computing* 10 (2) (2010) 641–652.
- [10] A.A. El-Ela, A. Kinawy, R. El-Sehiemy, M. Mouwafi, Optimal reactive power dispatch using ant colony optimization algorithm, *Electrical Engineering* 93 (2) (2011) 103–116.
- [11] J. Schmall, S. F. Huang, Y. Li, J. Billo, J. Conto, and Y. Zhang, "Voltage stability of large-scale wind plants integrated in weak networks: An ERCOT case study," in *Proc. Power Energy Soc. Gen. Meeting*, Denver, CO, USA, Jul. 2015, pp. 15.
- [12] Q. L. Guo, H. B. Sun, B. Wang, B. M. Zhang, W. C. Wu, and L. Tang, "Hierarchical automatic voltage control for integration of large-scale wind power: Design and implementation," *Electr. Power Syst. Res.*, vol. 120, pp. 234241, Mar. 2015.
- [13] M. Fischlein, E. J. Wilson, T. R. Peterson, and J. C. Stephens, "States of transmission: Moving towards large-scale wind power," *Energy Policy*, vol. 56, pp. 101113, May 2013.
- [14] Y.-Y. Hong, F.-J. Lin, Y.-C. Lin, F.-Y. Hsu, Chaotic PSO-based VAR control considering renewables using fast probabilistic power flow, *IEEE Transactions on Power Delivery* 29 (4) (2014) 1666–1674.
- [15] M. Ghasemi, M.M. Ghanbarian, S. Ghavidel, S. Rahmani, E.M. Moghaddam, Modified teaching learning algorithm and double differential evolution algorithm for optimal reactive power dispatch problem: a comparative study, *Information Sciences* 278 (2014) 231–249.
- [16] B. Singh, A. Chandra, and K. Al-Haddad, "A review of active filters for power quality improvement," *IEEE Trans. Ind. Electron.*, vol. 46, no. 5, pp. 960–971, Oct. 1999, doi: 10.1109/41.793345.
- [17] [Golestan](#), S., Guerrero, J. M., Vasquez, J. C., Abusorrah, A. M., & Al-Turki, Y. (2018). A study on three-phase FLLs. *IEEE Transactions on Power Electronics*, 34(1), 213-224.
- [18] S. Golestan, J. M. Guerrero and J. C. Vasquez, "Is Using A Complex Control Gain in Three-Phase FLLs Reasonable?", *IEEE Trans. on Ind. Electron.*, vol. 67, no. 3, pp. 2480-2484, March 2020.
- [19] G. G. Pozzebon, A. F. Q. Goncalves, G. G. Pena et al., "Operation of a three-phase power converter connected to a distribution system," *IEEE Trans. on Ind. Electron.*, vol. 60, no. 5, pp. 1810–1818, 2012.
- [20] A. K. Barnes, J. C. Balda, and C. M. Stewart, "Selection of converter topologies for distributed energy resources," in *Proc. IEEE 27th Annu. Appl. Power Elec. Conf. Expo*, Feb. 2012, pp. 1418–1423.
- [21] T. Wu, C. Chang, L. Lin, and C. Kuo, "Power loss comparison of single- and two-stage grid-

- connected photovoltaic systems,” *IEEE Transactions on Energy Conversion*, vol. 26, no. 2, pp. 707–715, 2011
- [22] Giri, A. K. K., Arya, S. R., Maurya, R., & Babu, B. C. (2018). Power quality improvement in stand-alone SEIG-based distributed generation system using Lorentzian norm adaptive filter. *IEEE Transactions on Industry Applications*, 54(5), 5256-5266.
- [23] H. Ritchie, “Renewable-energy,” 2017, Our World in Data, <https://ourworldindata.org/renewable-energy>.
- [24] IEEE Recommended Practice for Monitoring Electric Power Quality,” *IEEE Std 1159-2019* (Revision of IEEE Std 1159-2009), vol., no., pp.1-98, 13 Aug. 2019.
- [25] Saini, M., Khan, S., Sharma, A. K., Chaudhary, S. K., Srivastava, K., Srivastava, P. C., & Saini, S. (2023). Improvement of power quality of a 200 kW grid-connected PV system. *Int J Pow Elec & Dri Syst*, 14(3), 1759-1767.
- [26] Yadav, Varsha, Bhim Singh, and Arunima Verma. "Robust control for improving performance of grid-synchronized solar PV-BES-wind based microgrid." *Sustainable Energy Technologies and Assessments* 64 (2024): 103677.
- [27] Dehghani, Mohammad, Zeinab Montazeri, Eva Trojovská, and Pavel Trojovský. "Coati Optimization Algorithm: A new bio-inspired metaheuristic algorithm for solving optimization problems." *Knowledge-Based Systems* 259 (2023): 110011.
- [28] Trojovský, Pavel, and Mohammad Dehghani. "Pelican optimization algorithm: A novel nature-inspired algorithm for engineering applications." *Sensors* 22, no. 3 (2022): 855.
- [29] Mojiri, Mohsen, and Alireza R. Bakhshai. "An adaptive notch filter for frequency estimation of a periodic signal." *IEEE Transactions on Automatic Control* 49.2 (2004): 314-318.
- [30] Arya, Sabha Raj, Rakesh Maurya, and Talada Appala Naidu. "Amplitude adaptive notch filter with optimized PI gains for mitigation of voltage based power quality problems." *CPSS Transactions on Power Electronics and Applications* 3.4 (2018): 313-323.
- [31] Kundu, Sombir, Madhusudan Singh, and Ashutosh K. Giri. "Synchronization and control of WECS-SPV-BSS-based distributed generation system using ICCF-PLL control approach." *Electric Power Systems Research* 226 (2024): 109919.
- [32] Chaudhary, Priyanka, and M. Rizwan. "Voltage regulation mitigation techniques in distribution system with high PV penetration: A review." *Renewable and Sustainable Energy Reviews* 82 (2018): 3279-3287.
- [33] Nour, Morsy, José Pablo Chaves-Ávila, Gaber Magdy, and Álvaro Sánchez-Miralles. "Review of positive and negative impacts of electric vehicles charging on electric power systems." *Energies* 13, no. 18 (2020): 4675.
- [34] Mohammad, Asaad, Ramon Zamora, and Tek Tjing Lie. "Integration of electric vehicles in the distribution network: A review of PV based electric vehicle modelling." *Energies* 13, no. 17 (2020): 4541.
- [35] Zhang, Meng, Jiazheng Li, Yang Li, and Runnan Xu. "Deep learning for short-term voltage stability assessment of power systems." *IEEE Access* 9 (2021): 29711-29718.
- [36] Razmjoooy, Navid, Vania V. Estrela, Reinaldo Padilha, and Ana Carolina Borges Monteiro. "World cup optimization algorithm: Application for optimal control of pitch angle in hybrid renewable PV/wind energy system." In *Metaheuristics and Optimization in Computer and Electrical Engineering*, pp. 25-47. Cham: Springer International Publishing, 2020.
- [37] Adetokun, Bukola Babatunde, and Christopher Maina Muriithi. "Application and control of flexible alternating current transmission system devices for voltage stability enhancement of renewable-integrated power grid: A comprehensive review." *Heliyon* 7, no. 3 (2021).
- [38] A. Abdollahi, A. Ghadimi, M. Miveh, F. Mohammadi, and F. Jurado, “Optimal power flow incorporating FACTS devices and stochastic wind power generation using krill herd algorithm,” *Electronics*, vol. 9, no. 6, p. 1043, June. 2020.
- [39] Abdul Rahman, Nur Atiqah, Zulkiffli Abdul Hamid, and Nur Ashida Salim. "Optimal placement of distributed generation in distribution network: a review on hybrid techniques." *Journal of Electrical*

and Electronic Systems Research (JEESR) 25.1 (2024): 80-88.

- [40] Vandراس, R. K., Sravana Kumar, B., & Devarapalli, R. (2022). Solar photo voltaic module parameter extraction using a novel Hybrid Chimp-Sine Cosine Algorithm. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 1–20. <https://doi.org/10.1080/15567036.2022.2041768>.
- [41] Palani, V., Gomathi, S., Aruna, P., Veeramani, V. P., & Manathunainathan, V. (2022). Optimal sizing and smart charging abilities of electric vehicle charging station by considering quality of service using hybrid technique. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 1–17. <https://doi.org/10.1080/15567036.2022.2032879>.
- [42] Keleshteri, Sobhan Farjam, et al. "New optimal planning strategy for plug-in electric vehicles charging stations in a coupled power and transportation network." *The Journal of Engineering* 2023.3 (2023): e12252.
- [43] Fathi, Mohammadreza, and Mohammad Ghiasi. "Optimal DG placement to find optimal voltage profile considering minimum DG investment cost in smart neighborhood." *Smart Cities* 2.2 (2019): 328-344.
- [44] Nara K, Shiose A, Kitagawa M, Ishihara T. Implementation of genetic algorithm for distribution systems loss minimum reconfiguration. *IEEE Trans Power Syst* 1992;7(3):1044–51.
- [45] Srinivasa Rao R, Narasimham SVL, Ramalinga Raju M, Srinivasa Rao A. Optimal network reconfiguration of large-scale distribution system using harmony search algorithm. *IEEE Trans Power Syst* 2011;26(3):1080–8. <http://dx.doi.org/10.1109/TPWRS.2010.2076839>.
- [46] Kumar, B. Vinod, and Aneesa Farhan. "Optimal allocation of EV charging station and capacitors considering reliability using a hybrid optimization approach." *Applied Energy* 375 (2024): 124139.
- [47] Kyomugisha, Rebecca, Christopher Maina Muriithi, and George Nyauma Nyakoe. "Performance of Various Voltage Stability Indices in a Stochastic Multiobjective Optimal Power Flow Using Mayfly Algorithm." *Journal of Electrical and Computer Engineering* 2022 (2022).
- [48] Jin, Yuwei, Moses Amoasi Acquah, Mingyu Seo, and Sekyung Han. "Optimal Siting and Sizing of EV Charging Station using Stochastic Power Flow Analysis for Voltage Stability." *IEEE Transactions on Transportation Electrification* (2023).
- [49] Al-Wazni, HS Mohsin, and SS Abdulla Al-Kubragyi. "A hybrid algorithm for voltage stability enhancement of distribution systems." *International Journal of Electrical and Computer Engineering* 12, no. 1 (2022): 50.
- [50] Bilal, M., Rizwan, M., Alsaidan, I., & Almasoudi, F. M. (2021). AI-based approach for optimal placement of EVCS and DG with reliability analysis. *IEEE Access*, 9, 154204-154224.
- [51] Houssein, Essam H., Nagwan Abdel Samee, Noha F. Mahmoud, and Kashif Hussain. "Dynamic coati optimization algorithm for biomedical classification tasks." *Computers in Biology and Medicine* 164 (2023): 107237.
- [52] N. Hatziaargyriou et al., "Definition and classification of power system stability – revisited & extended," *IEEE Transactions on Power Systems*, vol. 36, no. 4, pp. 3271–3281, Jul. 2021, doi: 10.1109/TPWRS.2020.3041774.
- [53] Li, Huan, Kun Li, Nicholas Zafetti, and Jianfeng Gu. "Improvement of energy supply configuration for telecommunication system in remote area s based on improved chaotic world cup optimization algorithm." *Energy* 192 (2020): 116614.
- [54] Singh, Bhim, Chinmay Jain, and Sagar Goel. "ILST control algorithm of single-stage dual purpose grid connected solar PV system." *IEEE Transactions on Power Electronics* 29.10 (2013): 5347-5357.
- [55] Pan, H., Li, Z., & Wei, T. (2019). A novel phase-locked loop with improved-dual adaptive notch filter and multi-variable filter. *IEEE Access*, 7, 176578-176586.