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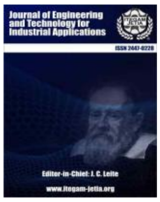

RESEARCH ARTICLE

OPEN ACCESS

A MULTI-OBJECTIVE HUNTER-PREY OPTIMIZATION FOR OPTIMAL INTEGRATION OF CAPACITOR BANKS AND PHOTOVOLTAIC DISTRIBUTION GENERATION UNITS IN RADIAL DISTRIBUTION SYSTEMS

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ABSTRACT

This article put forward the determination of the optimal siting and sizing of capacitor banks and PV-DG (Photo-Voltaic Distribution Generation) units in a radial distribution system. A modern population-based optimization algorithm, Hunter-Prey Optimization (HPO), is applied to determine the optimal capacitor bank and PV-DG placement. This algorithm, HPO, got its motivation from the trapping behaviour of the carnivore (predator/hunter) like lions and wolves towards their target animal like deer. The typical IEEE-33 & 69 test bus systems are scrutinized for validating the effectiveness of the suggested algorithm using MATLAB software R2021b version. The acquired results are collated with the existing heuristic algorithms for the active power loss criterion. The nominal or base values for system losses and voltage profile were considered for the comparison, with the results from HPO. The HPO application has an efficient performance in figuring out the most favourable location and capacity of the capacitor banks and PV DGs compared with the other techniques.

I. INTRODUCTION

I.1 CAPACITOR BANKS

Reactive power flow is observed as the sole basis for the power quality issues like increased power losses, higher voltage drop, and deprivation of power factor in the radial distribution systems [1]. "It is also estimated that of the entire power generation, 13% is dissipated as I2R loss in the distribution networks; hence, the optimal placement of capacitors can enhance the voltage stability and lower the power losses [2]." The entire system control gets endangered by improper placement of the capacitor [3, 4]. Hence, defining the optimal site and size, and the number of capacitors in the radial distribution systems to place a capacitor is necessary. Over the past few years, many algorithms and heuristic methods have been put forward to determine the optimal capacitor location.

The Cuckoo-Search Algorithm (CSA) is presented over the Particle-Swarm Optimization (PSO) technique for the optimal capacitor placement determination in the article [30]. The suggested algorithm is tested on IEEE-33 & 69 buses and then compared to the PSO to prove its superiority. A new technique of Multi-Verse Optimizer (MVO) has been presented in [5] to identify the fair allotment of the capacitor banks tested on IEEE-10, 33 & 69 buses using MATLAB. "Plant Growth Simulation Algorithm (PGSA) in [6] decides the best locations and size of the capacitor to upgrade the voltage profile and bring down the power loss." Tested on IEEE-33, 34 & 69 systems, this algorithm avails loss sensitivity factors to identify the possible locations of the capacitors followed by the algorithm for the prime allocation of the same. [7] Proposes the Flower Pollination Algorithm (FPA) to determine the optimal capacitor positioning tested on IEEE-10, 33 & 69 bus systems in MATLAB. Interior Point (IP) method and Simulated Annealing (SA) methods are proposed in [8] and compared the obtained results with the Gravitational Search Algorithm (GSA), tested on IEEE-33, 69 & 85 bus systems. "New techniques of the Two-stage method, Practical Approach method, and Locust Search method (LS) are proposed in [9,10] for the optimal capacitor placement(OCP), tested in MATLAB for standard IEEE test bus systems." [12] Presents a Plant Growth Simulation Algorithm (PGSA) and a two-stage method for the best placement of the shunt capacitor in the radial distribution systems tested on the IEEE-69 bus system in MATLAB, similarly [13] proposes PSO for optimal capacitor placement. Genetic Algorithm and Heuristic approaches are proposed in the works of [14, 15] to pick out the finest positioning of the capacitor in the radial distribution system.

I.2 DISTRIBUTION GENERATION

The Distribution Generation, shortly DG, is the non/less-pollutant alternative to electricity production. According to [16], DG is the electricity generation nearer to the customer. In that way, the transmission losses are reduced; also, it is an economical option. DG technologies can be classified into traditional and non-traditional types. Micro-turbines and natural gas turbines come under the conventional variety of DG technologies, while fuel cells, PV generation, Wind turbines, flywheels, and batteries fall under non-traditional DG technologies [17]. Of all sorts of DG technologies, solar PV-type DG technology is anticipated to play a vital role in meeting the inevitable requirement [18]. Wind turbines are the other advancement in green energies. Since DG is expounded based on its location [16], it is essential to find its ideal allocation in the distribution network.

The optimal DG allocations may be discovered utilizing a variety of specified heuristic and meta-heuristic approaches. For optimal siting of wind and solar farms, [19] researchers have suggested using a Gray-Wolf Optimizer. The Lagrange multiplier approach is applied to identify the ideal site for PV-DG [20], which was assessed using the IEEE-37 bus system. On common IEEE-118, 85, 69, 33, and 15 test bus systems, the Whale Optimization approach is utilized to calculate the best allotment of DG operating at 0.9pf[21]. For the prime DG placement, [22] recommends a hybrid approach using GA and PSO. "In order to decrease real power losses and enhance voltage profiles, the Ant Lion Optimization (ALO) algorithm for the RE-DG (Renewable Energy based Distribution Generating) was assessed on IEEE-33 & 69 bus systems [23]." A unique backtracking search optimization method (BSOA) is described in [24] to govern the best DG placement implemented on the IEEE-94 and 33 bus systems, pondering various DG kinds. A novel approach of Effective -Analytic Ideal Power Flow (EA-OPF) is examined in [25] to identify the optimal DG placement evaluated on IEEE- 33 and 69bus systems using C ++ considering three kinds of DGs. Through the use of the cutting-edge Ant Bee Colony (ABC) optimization method, the best location of DG is defined in the article [26]. The technique is implemented on an IEEE-33 bus system and tested for four situations with a single DG, two DGs, and three and four DGs with a goal of maximum active power loss curtailment.

The Hunter-Prey Algorithm (HPO), tested on the IEEE-33 and IEEE-69 bus systems, was used in this paper's study to determine the best location for capacitors and the integration of PV-DG. Its effectiveness was proven by comparing it to other previous studies. The subsections of the article are divided into the following groups: 2. Formulation of the mathematical issue; 3. Proposed Hunter-Prey Algorithm (HPO); 4. Results and discussions; and 5. Drawn conclusions.

II. PROBLEM FOMULATION

II.1 POWERFLOW ANALYSIS

The Backward/Forward Sweep (BFS) was taken on to perform the load flow on the IEEE-33 bus system considered due to its analytic performance, and mastery of convergence [27].

The branch currents are calculated using Kirchoff's Current Law (KCL) from the ending node and proceeded back to the first node comprising a backward sweep.

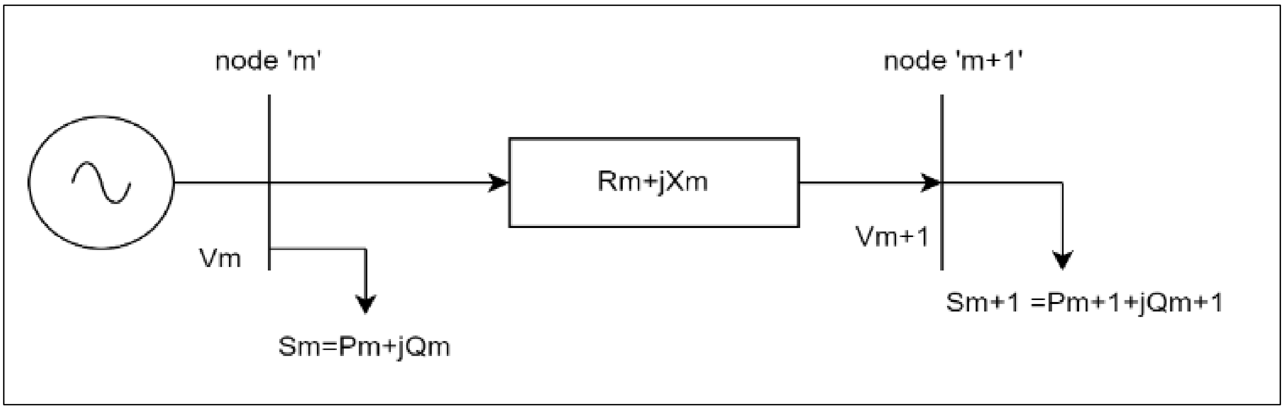

Figure 1: Sample Distribution Network.
Source: Authors, (2023).

$$I_{m+1} = \frac{(P_{l(m+1)} - jQ_{l(m+1)})}{V_{m+1}} \quad (1)$$

From the above equation, one can determine the end bus current from the known load data of the considered system and then the other branch currents are determined moving backward using the KCL. After determining the branch currents the node voltages are determined in the forward sweep.

$$V_{m+1} = V_m - (I_m \times (R_m + jX_m)) \quad (2)$$

The power loss can be calculated as,

$$P_{loss} = \sum_{m=1}^{n} i_m^2 R_m \quad (3)$$

n gives the number of buses of the system taken. For,

$$S_G = V_0 \times \overline{I_0} \quad (4)$$

S_G is the generated Power, V_0 and I_0 are the voltage and the current values at the generating node and

$$S_{load} = \sum_{m=1}^{n}(P_{lm} + jQ_{lm}) \quad (5)$$

S_{loid} is the total load demand which is obtained by summing up all solitary loads at all the buses. The system losses can be determined from

$$S_{losses} = S_G - S_{load} \quad (6)$$

$$S_{losses} = P_{losses} + jQ_{losses} \quad (7)$$

II.1.1 Objective Function

Lessening the true power loss with Voltage Stability improvement is considered as the objective function to estimate the ideal positioning and capacities of the three shunt capacitor banks and three PV-DG units.

$$F_1 = \min(P_{loss}) + max(\text{VSI}) \quad (8)$$

$$S_{loss} = S_{generated} - S_{total\ load} \quad (9)$$

$$P_{loss} = real(S_{loss})\ \&\ Q_{loss} = imag(S_{loss}) \quad (10)$$

$S_{generated}$ is the power fed at the substation and $S_{total\ load}$ is the total load on the distribution system given by

$$S_{generated} = V_1 \times \overline{I_{b1}} \quad (11),$$

Where $V_1$is the generated voltage at the substation and $\overline{I_{b1}}$ is the conjugate of the current through the first bus obtained from the load flow analysis.

$$S_{total\ load} = \sum_{i=1}^{33} P_i + jQ_i \quad (12)$$

Where P_i and Q_i are the active and reactive powers at the 'i^{th}' bus respectively.

II.1.2 System Constraints

1. **Equality Constraints:**

$$S_{generated} - S_{losses} = S_{demand} \quad (13)$$

$$P_{generated} - P_{losses} = P_{demand} \quad (14)$$

$$Q_{generated} - Q_{losses} = Q_{demand} \quad (15)$$

The above equations pertain to the power balance in the considered system.

2. **Inequality Constraints:**

The inequality conditions set the limits for the shunt capacitor capacity, for the safe run of the system.

a. Operating limits of generation:

The generation of active and reactive powers should be within the permissible limits,

$$P_{g\ min} \leq P_g \leq P_{g\ max} \quad (16)$$

$$Q_{g\ min} \leq Q_g \leq Q_{g\ max} \quad (17)$$

Where, $P_{g\ min}$, $P_{g\ max}$, $Q_{q\ min}$, and $Q_{g\ max}$ are the minimum and maximum active and reactive power generation limits

b. Shunt capacitor limits:

$$Q_{min} \leq Q_{size} \leq Q_{max} \quad (18)$$

Where $Qmin$ = minimum capacitor size,
$Qmax$ = maximum capacitor size, and
$Qsize$ = selected capacitor size for reactive power compensation

$$Q_c < Q_{total} \quad (19)$$

Equation (7) states that reactive power injected should be less than the total reactive power load.

c. *Bus Voltage limits*:

$$V_{min} \leq V_i \leq V_{max}\ (i = 1,2, \ldots .n - bus\ number) \quad (20)$$

Usually, the least and crest voltage limits are taken as $V_{min} = 0.95$ & $V_{max} = 1.05$

II.2 MATHEMATICAL PROBLEM FORMULATION FOR SYSTEM LOSSES AND VOLTAGE STABILITY INDEX

Let us consider two nodes of a radial distribution network for the calculation of system losses and the voltage stability index.

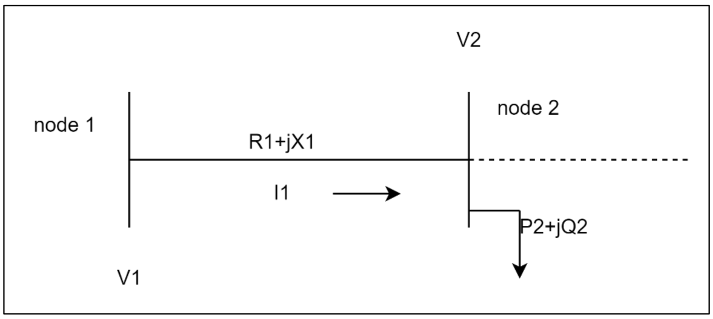

Figure 2: An electrical equivalent network of a radial distribution system considering two nodes.
Source: Authors, (2023).

From the figure we can evaluate I_1 as

$$I_1 = \frac{(V_1 - V_2)}{(R_1 + jX_1)} \quad (21)$$

$Also, we\ have,$

$$S = P_2 + jQ_2 \quad (22)$$

$we\ can\ also\ get\ from,$

$$I_1 = \frac{P_2 - jQ_2}{V_2} = \frac{(P_2 + jQ_2)}{\overline{V_2}} \quad (23)$$

V1 is the voltage at node 1,
V2 is the voltage at node 2, $\overline{V_2}$ is its conjugate.
P2 and Q2 are the real and reactive powers at node 2,
R2 and X2 are the resistance and reactance of the branch bridging the nodes 1 & 2

II.2.1 Active Power Loss Reduction

$$active\ power\ losses, P_{losses} = I^2R, \quad (24)$$

$from$ (3),

$$P_{losses} = (\frac{(P_2+Q_2)}{V_2})^2 \times R_1 \quad (25)$$

$$P_{losses(1)} = \frac{R_1({P_2}^2+{Q_2}^2)}{{V_2}^2} \quad (26)$$

Similarly, we can get the reactive power losses as,

$$Q_{losses(1)} = \frac{X_1({P_2}^2+{Q_2}^2)}{{V_2}^2} \quad (27)$$

For, Plosses (1) and Qlosses (1) are the real and reactive power losses through the branch tieing nodes 1&2,

$$P_{losses(i)} = \frac{R_i({P_{i+1}}^2+{Q_{i+1}}^2)}{{V_{i+1}}^2} \quad (28)$$

$$Q_{losses(i)} = \frac{X_i({P_{i+1}}^2+{Q_{i+1}}^2)}{{V_{i+1}}^2} \quad (29)$$

II.2.2 Voltage stability index

Voltage stability index is proposed to identify the feeble node prior to voltage collapse [28].

Equating (21) and (23),

$$I_1 = \frac{V_1-V_2}{R_1+jX_1} = \frac{P_2-jQ_2}{V_2} \quad (30)$$

$$(P_2 - jQ_2) * (R_1 + jX_1) = (V_1 - V_2) * V_2 \quad (31)$$

taking the voltage angles into consideration we have $V_1\angle\delta 1$ and $V_2\angle\delta 2$

Thus, the above equation becomes,

$$\begin{aligned}(P_2R_1 + Q_2X_1) + j(P_2X_1 - Q_2R_1) &= (V_1\angle\delta 1 - V_2\angle\delta 2) * V_2\angle\delta 2 \\ &= (V_1V_2\cos(\delta 1 - \delta 2) - {V_2}^2) \\ &+ \ j(V_1V_2\sin(\delta 1 - \delta 2))\end{aligned} \quad (32)$$

(Since $x\angle\theta = x(\cos\theta + jsin\theta)$)

Now, equating the real parts and imaginary parts on both sides of the equation, we get,

$$V_1V_2\cos(\delta 1 - \delta 2) - {V_2}^2 = P_2R_1 + Q_2X_1 \quad (33)$$

$$V_1V_2\sin(\delta 1 - \delta 2) = P_2X_1 - Q_2R_1 \quad (34)$$

On squaring and adding on both the equations (33) & (34), (we know$(\cos\theta)^2 + (sin\theta)^2 = 1$)

$${V_1}^2{V_2}^2 = (V_2)^4 + (P_2R_1 + Q_2X_1)\text{^}2 + 2\left({V_2}^2(P_2R_1 + Q_2X_1)\right) + (P_2X_1)^2 + (Q_2R_1)^2 - 2P_2Q_2R_1X_1 \quad (35)$$

On getting the above equation in quadratic equation form,

$${V_2}^4 + {V_2}^2(2P_2R_1 + 2Q_2X_1 - {V_1}^2) + ({P_2}^2 + {Q_2}^2)({R_1}^2 + {X_1}^2) = 0 \quad (36)$$

On comparing it to the standard form of $ax^2 + bx + c = 0$, with roots of $x_1, x_2 = \frac{-b\pm\sqrt{b^2-4ac}}{2a}$

We have,$x = {V_2}^2$ $a = 1, b = (2P_2R_1 + 2Q_2X_1 - {V_1}^2), c = ({P_2}^2 + {Q_2}^2)({R_1}^2 + {X_1}^2)$

Since, the solution is unique as the root term is square, and only positive value is applicable we consider $b^2 - 4ac \geq 0$, thus we get,

$$(2P_2R_1 + 2Q_2X_1 - {V_1}^2)^2 - 4\{({P_2}^2 + {Q_2}^2)({R_1}^2 + {X_1}^2)\} \geq 0$$

On simplifying,

$${V_1}^4 - 4(P_2X_1 - Q_2R_1)^2 - 4(P_2R_1 + Q_2X_1){V_1}^2 \geq 0 \quad (37)$$

Thus, defining Stability Index, in generalized form for ‘i’,

$$VSI(i+1) = {V_i}^4 - 4(P_{i+1}X_i - Q_{i+1}R_i)^2 - 4(P_{i+1}R_i + Q_{i+1}X_i){V_i}^2 \geq 0 \quad (38)$$

The node at which the value of VSI is least, is more feeble and prior to the voltage fall-out.

III. HUNTER-PREY OPTIMIZATION (HPO)

Choosing the hunting and protection mechanisms of various flora and fauna for effective optimization can be termed the Nature Inspired Optimization Algorithm (NIOA). There are many scenarios of animal hunting behaviour considered for optimization algorithms [29]. The Hunter-Prey Optimization (HPO) algorithm mimics the hunting behaviour of carnivorous hyenas, tigers, and lions for their prey like deers and gazelles.

III.1 ALGORITHM

The scheme of the optimization algorithm involves three steps. Step1 initializes of the population arbitarily. Step2 calculates the fitness function (local best solution), constricting the search area or exploration. Step3 is exploitation that mostly involves crucial operations executed amongst the whole population to evolve eminent individuals.

There are two stages to the search process, and they are called "exploration" and "exploitation," respectively. The algorithm's propensity for very erratic behaviors and substantial solution variations is referred to as "exploration." The striking shifts in solutions prompt more exploration of the search space, leading to the identification of previously unexplored potential regions. Once the favorable areas have been located, random behaviors must be reduced so that the algorithm may explore the areas around the bright spots (also known as exploitation).

Step 1: *Population Initialization:*

The population is randomly initialized as$\left(\underset{x}{\rightarrow}\right) = \{\underset{x_1}{\rightarrow} + \underset{x_2}{\rightarrow} + \underset{x_3}{\rightarrow} + \cdots, \underset{x_{n-1}}{\longrightarrow}, \underset{x_n}{\rightarrow}\}$, for each random variable is bounded between lower and an upper limits and thus defining the search space as

$$x_i = rand(1, d) * (ub - lb) + lb \quad (39)$$

Where, ub and lb are the upper and lower boundaries defining the minimum and maximum values, d is the dimension or the number of variables. x_i Is position vector.

For every variable we define, there will be a minimum and a maximum for each, i.e.

$$lb = (lb_1, lb_2, \ldots \ldots lb_d) \text{ And } ub = (ub_1, ub_2 \ldots \ldots ub_d) \quad (40)$$

Step 2: *Calculation of Fitness function/ local minima (Exploration):*

After the initialization of population variables and their respective lower and upper limits, the fitness function is calculated by using the objective function. $O = f(\underset{x}{\rightarrow})$. It is be noted that a search procedure must be repeated numerous times to pilot the search agents to the best position as single run cannot give an optimal solution.

$$x_{m,n}(t+1) = x_{m,n}(t) + 0.5\left[\left(2CZP_{pos(n)} - x_{m,n}(t)\right) + \left(2(1-C)Z\mu_n - x_{m,n}(t)\right)\right] \quad (41)$$

The above equation defines the hunter prey mechanism, which updates the position of hunter at every iteration.

$x_{m,n}(t)$ *is the current position of the hunter* $x_{m,n}(+1)$ *gives the updated position of the hunter for next it* $P_{pos(n)}$ *defines the prey position,*

"μ" is the average (mean) of all position and is given by

$$\mu = \frac{1}{n}\sum_{m=1}^{n} x_i \quad (42)$$

In this algorithm, the hunter targets the prey which is away from the rest of the praise and how the prey reaches its group before getting attacked by the hunter. P is a random vector between [0, 1], Z is an adaptive parameter and C is a balance parameter between the steps 2 &3, i.e., exploration and exploitation.

$$C = 1 - iter\left(\frac{0.98}{Maxiter}\right) \quad (43)$$

Where *iter* is the current iteration and *Maxiter* is the maximum number of iteration user defines; the C value decreased from 1 to 0.02 during the run of iterations.

For R_1 be any random number between [0,1] and R_2 and R_3 be any any random vectors defined within the same range, INX defines the index number of vector R_3 ,the values of P and Z are calculated as

$$Z = (R_1 * INX) + (\vec{R_2} * INX) \quad (44)$$

$$P = \vec{R_3} < C, satisfying\ INX = (P == 0) \quad (45)$$

Step 3: Exploitation:

"We discusses earlier that the prey far from the group is considered by the hunter, but if we consistently suppose the search agent with the longest distance from the average position in each iteration, the algorithm will have a delayed convergence."

$$P_{pos} = x_i|maximum\ of\ (D_{euclid})| \quad (46)$$

$$D_{euclid} = \sqrt{\sum_{n=1}^{d}(x_{m,n} - \mu_n)^{\wedge}2} \quad (47)$$

D_{euclid} is the prey-to-searcher distance as measured by the Euclidean algorithm. When the hunter catches his prey, kills it, and moves on to another target, he solves the problem described by the hunting scenario.

$$kbest = round(C \times N) \quad (48)$$

Using which the position vector is updated as

$$P_{pos} = x_i|maximum\ of\ D_{euclid}(kbest)| \quad (49)$$

, and the search agent equation is updated as

$$x_{m,n}(t+1) = (T_{pos(n)} + CZcos(2\pi R_4) \times (T_{pos(j)} - x_{m,n}(t))) \quad (50)$$

Where T_{ops} is the optimal global position, and R_4 is a random number between [-1, 1].

For the question of how to choose hunter and prey, we define another random number R_5 between [0 and 1] and get it compared with β (a regulator parameter fixed at 0.1);

$$x_m(t+1) = \begin{cases} x_m(t) + 0.5[\left(2CZP_{pos} - x_m(t)\right) + (2(1-c)Z\mu - x_m(t), \ \ for\ R_5 < \beta \\ T_{pos} + CZ\cos(2\pi R_4) \times \left(T_{pos} - x_m(t)\right), \ \ for\ R_5 > \beta \end{cases} \quad (51)$$

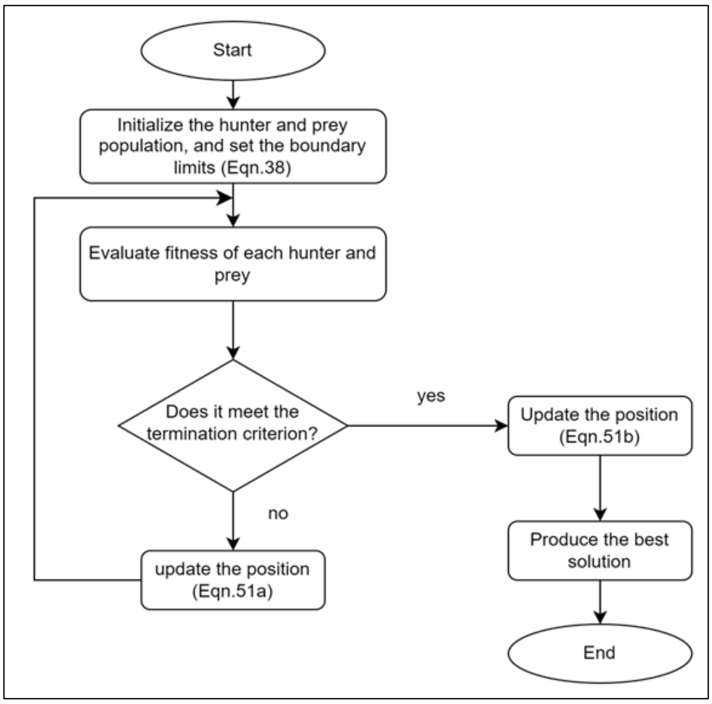

Figure 3: Flowchart of the HPO algorithm.
Source: Authors, (2023).

IV. RESULTS AND DISCUSSIONS

The proposed algorithm of the Hunter-Prey Optimization (HPO) is assayed on typical IEEE-33 and 69 test bus systems using MATLAB2021b. The main aim is the reduction of active power losses by determining the optimal siting and sizing of the capacitor banks and solar DG placement. In this work, the following cases are considered for both 33 and 69 test bus systems to compare and identify the efficiency of the suggested algorithm.

Case1: is the base or nominal case,

Case 2: is the active power loss reduction considering three shunt capacitor allocations,

Case 3: power loss reduction with three PV-Daunts in the considered radial distribution system. And an internal comparison is made within the studied cases for each system. The IEEE-33 and 69 bus systems are considered for the study.

The attained values from the performed algorithm (HPO) are compared with other existing heuristic and meta-heuristic algorithms taking the parameter of active power losses, with a tabulated comparison of the data below.

IV.1 IEEE-33 BUS SYSTEM

IV.1.1 Base or Nominal Case

The load flow analysis is calculated using the Backward-Forward Sweep algorithm and the results are taken into consideration for the comparison. It is to be noted that, for the active loss two values of 202.65kW and 210.8kW are taken into consideration.

Table 1: Nominal values of a 33-bus systems (for 202.65 kW).

Ploss(kW)	Vmin(p.u.)	VSI
202.65	0.8541	0.6821

Source: Authors, (2023).

Table 2: Nominal values of a 33- bus system (for 210.0kW).

Ploss(kW)	Vmin(p.u.)	VSI
210.0	0.9038	0.6685

Source: Authors, (2023).

IV.1.2 Three Shunt Capacitor Banks Allocation

In this case, the system performance with three shunt capacitor bank is analysed using the proposed algorithm of HPO, and the obtained results are compared with that of existing algorithms to highlight the effectiveness of HPO.

Table 3 and 4 gives the comparison among Particle Swarm Optimization (PSO), Cuckoo Search Algorithm (CSA) [30], Multi-Verse Optimizer [5], Plant Growth Simulation Algorithm (PGSA), and Flower Pollination Algorithm (FPA) with the proposed algorithm of Hunter-Prey Optimization (HPO) for the nominal value of active power loss 202.5kW and with Interior Point (IP)[6], Simulated Annealing(SA)[6], Practical Approach[7], Two-Stage method and Locust Search(LS) [8] for nominal active power loss of 210.8kW and the HPO can be found more efficient in loss reduction of other all.

Table 3: Comparitive Analysis for Active power loss for a 33-bus system using HPO and other algorithms.

Parameter	**base case**	**Compensated values**					
		IP [8]	AS [8]	Two-stage method [10]	Practical Approach method [9]	LS [10]	HPO
Active power loss (kW) % loss reduction	210.8 kW	171.78 18.5%	151.75 28.01%	144.04 31.67%	138.61 34.25%	139.23 33.95%	**138.43** **34.33%**
Optimal site (bus number) and size of three capacitor banks (car)		9 450 29 800 30 900	10 450 14 900 30 350	7 850 29 250 30 900	12 500 24 500 30 1000	12 450 25 350 30 900	12 450 24 450 30 1050

Source: Authors, (2023).

Table 4: Comparative Analysis for HPO algorithm with other algorithms for 33-bus system (Extended).

Parameter	**Nominal values**	**Compensated values**					
		PSO [30]	CSA [30]	MVO [5]	PGSA [6]	FPA [7]	HPO
Active power loss (kW)	202.65	133.12	133.0851	132.68	135.40	134.47	**132.37**
%loss reduction		34.31%	34.32%	34.53%	33.18%	33.64%	**34.68%**
The optimal site and size(kVAr) of capacitor banks		14 300 24 600 30 1050	10 600 24 600 30 900	12 450 24 600 30 900	6 1200 28 760 29 200	6 250 9 400 30 950	12 450 24 450 30 1050

Source: Authors, (2023).

Relative Results for IEEE-33-bus system with Capacitor bank allocation

The proposed algorithm of Hunter Prey Optimization is tested for decreasing the active power losses for the standard IEEE-33 bus system. The obtained results of real power loss reduction from 202.6kW to 132.37kW subjecting to 34.68% are compared with other existing algorithms of Particle Swarm Optimization(PSO) [30] for active power loss reduction from 202.6 kW to 133.12 kW with 34.31% reduction, Cuckoo Search Algorithm (CSA) [30] for 34.32% reduction from 202.6kW to 133.08kW, Multiverse Optimizer(MVO) [5]with a loss reduction of 132.68kW from 202.6kW accounting to 34.53%, Plant Growth Simulation Algorithm(PGSA)[6] with 33.18% of active power loss reduction, i.e., real power loss reduced from 202.6kW to 135.4kW and Flower Pollination Algorithm(FPA) [7] lowering losses from 202.6kW to 134.47kW for 33.64%. The variation can be graphically observed as:

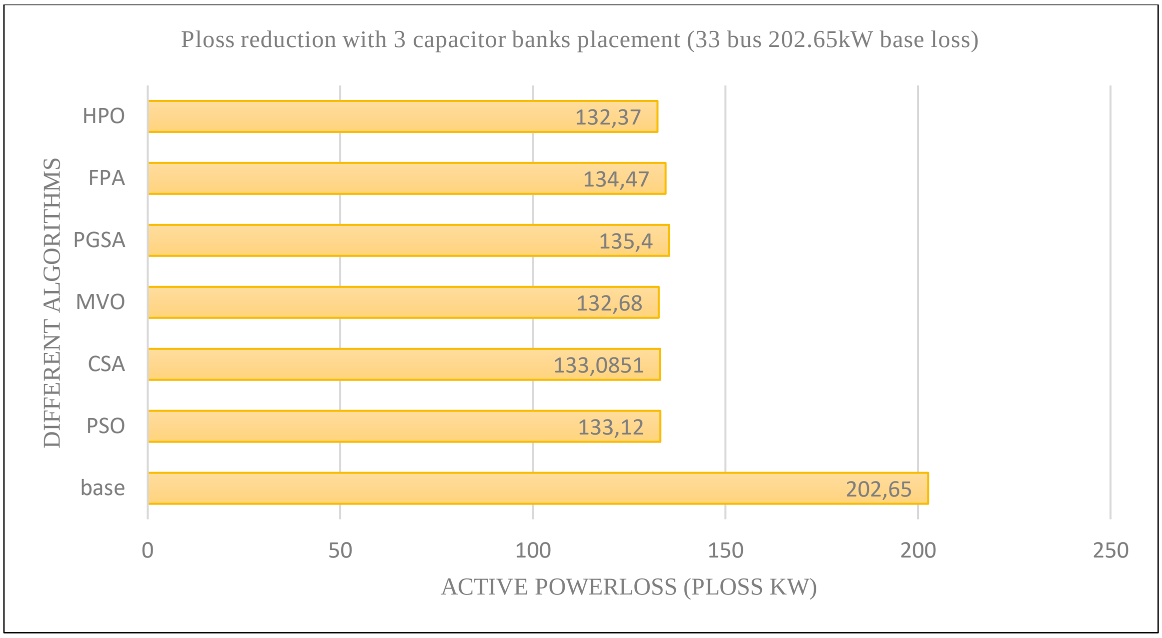

Figure 4: Bar diagram representing active power loss reduction with CB placement (33 bus_202kW).
Source: Authors, (2023).

The comparison is also made with other algorithms of Interior Point (IP)[8,12] for a loss reduction of 171.78kW from 210.8kW (18.5%), Simulated Annealing(SA)[8,10] 151.71 from 210.8kW(28.01%), Two-stage method[11] for deduction of 31.67%,i.e., from 210.8kW to 144.04kW, Practical-Approach[9,10] method reducing the real losses from 210.8kW to 138.61kW(34.25%), Locust Search(LS)[10] algorithm reducing to 139.23kW from 210.8kW(33.95%); while the proposed algorithm reduces the active losses to 138.43kW from 210.8kW accounting to 34.33% reduction proves to be effective in comparison.

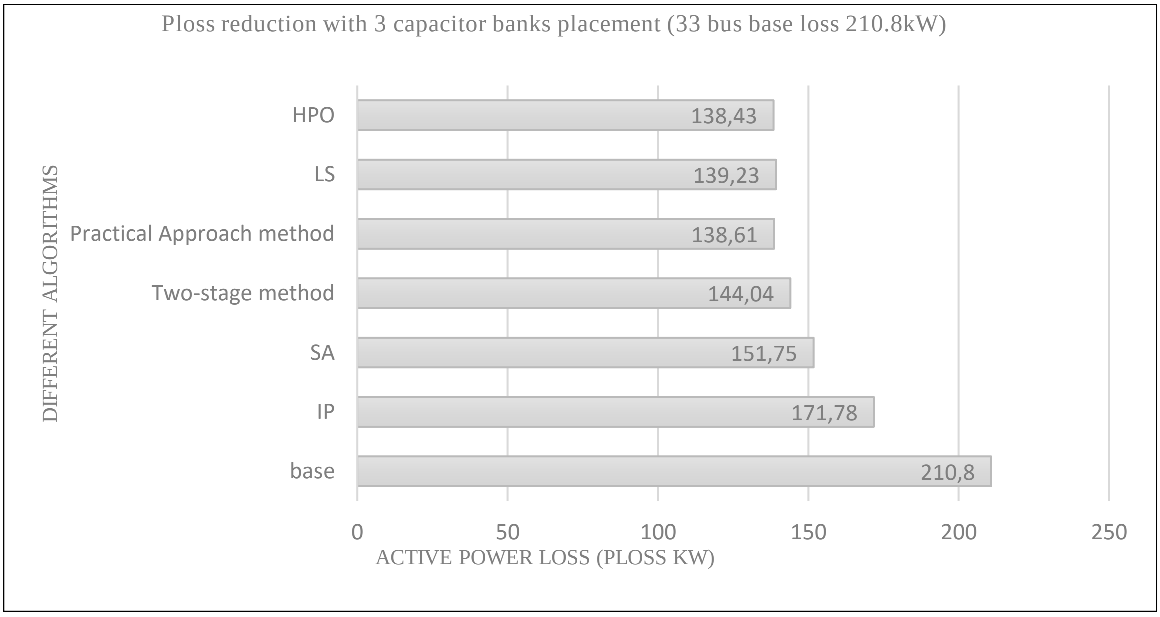

Figure 5: Bar diagram representing active power loss reduction with CB placement (33 bus_210kW).
Source: Authors, (2023).

IV.1.3 Three PV-DG Allocation

The performance analysis of the IEEE-33 bus system with three PV units is considered for this case. Applying the proposed HPO algorithm, the results are obtained of which, the active power losses are compared with the of other algorithms to test the efficiency of the HPO algorithm.

From the tabulated data, it can be noticed that the active power loss reduction using HPO is more, i.e., from 210kW to 71.45kW comprising to 65.97% while GA accounts for 49.38%, PSO for 49.85%, GA-PSO for 50.76%, EA for 65.34%, while EA-OPF and Exhaustive OPF account for 65.33%, upon ABC algorithm there is a loss reduction of 61.08%. Also, we can observe the total DG capacity is also less comparatively with the other algorithms. The sum of the three PV DGs size owing its total capacity using HPO is 2925kW, while it is 2951kW for EA, 2947kW for EA-OPF and Exhaustive-OPF methods, 3114 kW using ABC, 2994 kW using GA and 2988.1kW and 2988kW using PSO and GA-PSO respectively. We can also notice that the total PV-DG capacity is minimum, 2925kW using the HPO algorithm, which is less than that obtained from other algorithms.

Table 5: A comparative Table of active power loss with PV_DG placement within algorithms for 33 bus system.

Parameter	Efficient Method (EA) [25]	Efficient Analytic Optimal Power Flow(EA-OPF)[25]	Exhaustive Power flow method [25]	Ant Bee Colony (ABC) [26]	Genetic Algorithm (GA) [22]	Particle Swarm Optimization (PSO) [22]	GA-PSO [22]	HPO
Active Power loss(kW)	72.78 (65.34%)	72.79 (65.33%)	72.79 (65.33%)	79.26 (61.08%)	106.3 (49.38%)	105.3 (49.85%)	103.4 (50.76%)	**71.45 (65.97%)**
DG site(bus number) and size(kVAr)	13 798 24 1099 30 1054	13 802 24 1091 30 1054	13 802 24 1091 30 1054	6 1756 15 575 25 783	11 1500 29 422.8 30 1071.4	13 981.6 32 829.7 8 1176.8	32 1200 16 863 11 925	14 754 24 1100 30 1071
Total capacity (kVAr)	2951	2947	2947	3114	2994	2988.1	2988	2925

Source: Authors, (2023).

Graphically the comparison among various algorithms for PV placement can be shown as a bar graph.

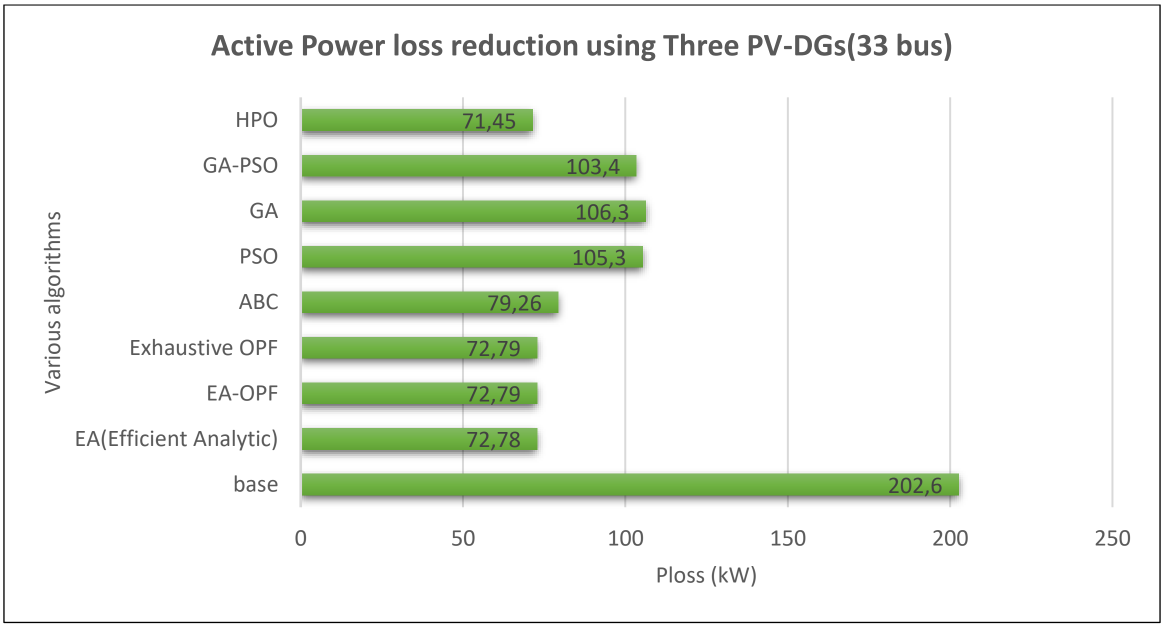

Figure 6: Bar diagram representing comparison among algorithms for PV integration (33 bus) Case.
Source: Authors, (2023).

IV.2 IEEE-69 TEST BUS SYSTEM

IV.2.1 Nominal or Base Case

The Backward-Forward Sweep algorithm is used to evaluate the load flow analysis and the value of active power loss of 225.0kW is taken into consideration for the comparison.

Table 6: Base values of a 69-bus system.

Ploss(kW)	Vmin(p.u.)	VSI
225.0	0.9093	0.6838

Source: Authors, (2023).

IV.2.2 Three Shunt Capacitor Banks Allocation

In this case the performance of the 69-bus radial system is analysed with three capacitor banks allocation and the results derived are compared with the existing algorithms.

The results of the HPO algorithm are compared to that of PSO, PGSA, Fuzzy-GA, Two-Stage method and heuristic approach. Table 7 depicts the comparison for active power losses also the optimal CB locations also noted.

Comparative results for 69 bus system

The preferred algorithm is assessed for 69 bus system and the results are compared for actual power loss with other contemporary algorithms. Particle Swarm Optimization (PSO) [12] with power loss reduction of 32.23% loss reduction from 225.0kW to 152.48kW. Plant Growth Simulation Algorithm (PGSA) proposed in [13] has a loss reduction of 147.40kW from 225.0kW comprising to 34.49%. Two-stage method [13] and Fuzzy-GA in [14] has 33.82% and 32.17% of loss reduction from 225.0kW to 148.91kW and 152.62kW respectively. The losses are decreased from 225.0kW to 148.48 kW comprising 34.01% using Heuristic Approach [15]. The proposed HPO has an active loss reduction of 145.228kW from 225.0kW accounting to 35.43%.

IV.2.3 Three PV-DG Allocation

The proposed HPO algorithm is executed on the IEEE-69 bus system and the active losses derived results are collated to the other existing algorithms of Effective Analytic(EA), EA_OPF(Effective Analytic-Optimal Power Flow), Exhausted Optimal Power Flow algorithm, Particle Swarm Optimization(PSO), Genetic Algorithm(GA), a combined GA-PSO and tabulated in table no. 8.

Table 7: Comparative results of active power loss for 69-bus system for different algorithms with HPO.

Parameter	Nominal values	**Compensated**				
		PSO [12]	PGSA [13]	Two-Stage method [13]	Fuzzy-GA [14]	Heuristic Approach [15]
Active power loss (kW)	225.0	152.48	147.40	148.91	152.62	148.48
%loss reduction		32.23%	34.49%	33.82%	32.17%	34.01%
The optimal site and size(kVAr) of capacitor banks		46 241 47 365 50 1015	57 1200 58 274 61 200	19 225 62 900 63 225	59 1100 61 800 64 1200	8 600 58 150 60 1050

Source: Authors, (2023).

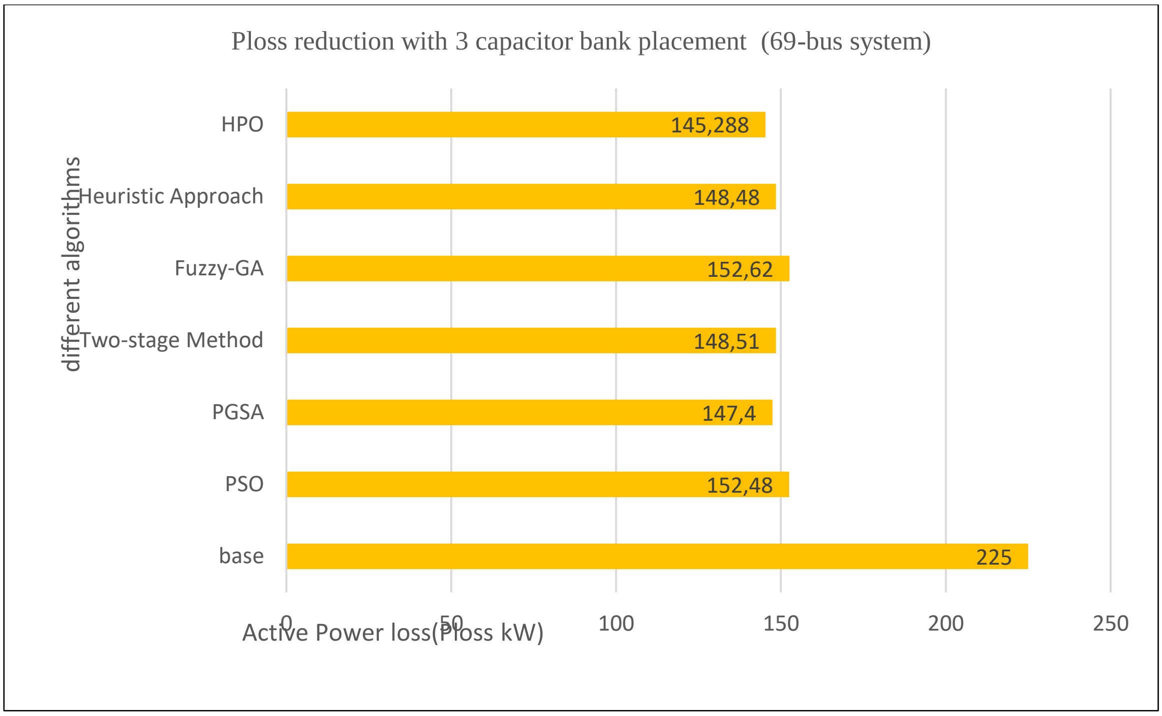

Figure 7: Bar diagram representing comparison among algorithms for CB integration (69 bus).
Source: Authors, (2023).

Table 8: A comparative table of active power loss with PV-DG placement within algorithms for 69 bus system.

Parameter	**Efficient Method (EA) [25]**	**Efficient Analytic Optimal Power Flow(EA-OPF)[25]**	**Exhaustive Power flow method [25]**	**Genetic Algorithm (GA) [22]**	**Particle Swarm Optimization (PSO) [22]**	**GA-PSO [22]**	**HPO**
Active Power loss(kW)	69.62 (69.05%)	69.45 (69.13%)	69.45 (69.13%)	89.0 (60.44%)	83.2 (63%)	81.1 (69.35%)	69.43 **(69.14%)**
DG site(bus number) and size(kVAr)	61 1785 18 380 11 467	61 1719 18 380 11 527	61 1719 18 380 11 527	21 929.7 62 1075.2 64 984.8	61 1199.8 63 795.6 17 992.5	63 884.9 61 1192.6 21 910.5	11 574 18 380 61 1719
Total capacity (kVAr)	2632	2626	2626	2989.7	2987.9	2988	2623

Source: Authors, (2023).

The productivity of the proposed algorithm of HPO is efficient in reduction of active power losses compared to that of other algorithms can be noticed from the table 8. There is a reduction of 69.43kW from 225.0kW comprising to 69.14%. It is 69.05%(69.62kW) using EA, 69.13%(69.45kW) using EA-OPF and Exhaustive OPF,60.44%(89kW) using GA, 63%(83.2kW) using PSO and 63.95%(81.1kW) using GA-PSO. It can also be noted that the total DG capacity (sum of all 3 units) is less when the HPO algorithm is applied, 2623kW using HPO, 2632kW using EA, 2626kW using EA-OPF and Exhaustive-OPF, 2989.7kW using GA, 2987.9kW using PSO and 2988 using GA-

PSO. Also from the last column that gives the DG capacities, we can notice that the total capacity of DGs is minimum using the HPO algorithm comparing with the other optimization technique. The comparison can be graphically depicted as in figure 8.

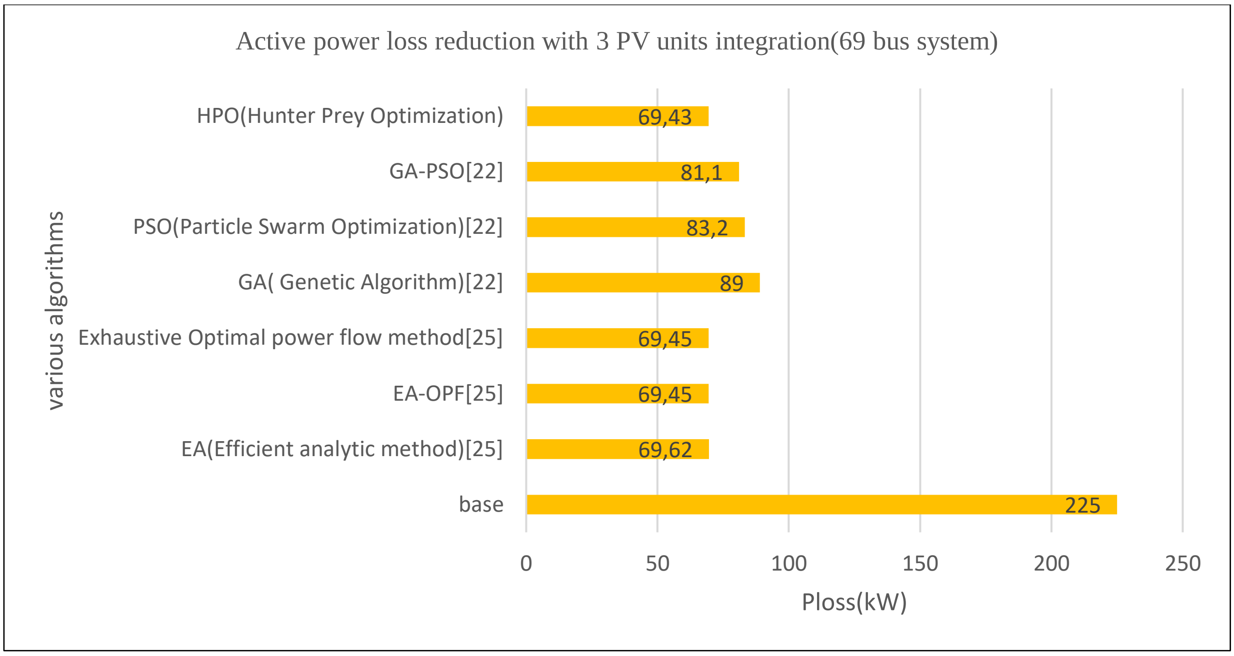

Figure 8: Bar diagram representing comparison among algorithms for PV integration (69 bus).
Source: Authors, (2023).

IV.3 PERFORMANCE ANALYSIS OF HPO FOR IEEE-33 AND 69 BUS SYSTEMS WITH SWITCHED CAPACITOR BANKS, FIXED CAPACITOR BANKS AND PV-DG PLACEMENT

The simulations are done for IEEE 33 and 69 standard test bus systems using the proposed algorithm of HPO (Hunter-Prey Optimization), for the integration with fixed capacitor banks, switched capacitor banks, and solar PV DG integration. Switched capacitors are the automatic capacitors where the kVAr can be varied, while the fixed capacitors supply a constant amount of correction kVAr. The obtained results for each case with loss reduction, both active and reactive power loss reduction and voltage profile improvement are tabulated in tables 9, 10 and 11.

The above tables give results of HPO application which clearly depicts the ease and efficiency of the algorithm. The parameters of active power loss, reactive power loss, minimum voltage and voltage stability index are neffectively varied, with a notable loss reduction and voltage profile amplification. The same can be observed in all three cases of fixed capacitor bank, switched capacitor bank and solar DG integrations in the 33 and 69 bus systems from tables 9, 10 and 11 respectively. The optimal allocation of CBs and DGs are also tabulated.

According to the theory of the algorithm, the prey dies when hunter attacks and kills it and thus the safe position of the hunter will be the best solution. In this context, the bus with minimum number of losses will be the ideal or optimal location for a DG or a CB. The algorithm is found efficient for loss deduction and voltage profile amelioration when compared with other contemporary techniques and nominal values. From the tables of 5 and 8, the total capacity of PV DGs using the algorithm is found minimum but not in case with CBs which could be counted as the limitation of the algorithm.

Table 9: Parameter tabulation of IEEE-33 & 69 bus systems with fixed CBs using HPO.

Parameter-fixed CB (3 units)	33 bus (202 kw loss)	33-bus (210 kW loss)	69 bus
Ploss (kW)	132.4238	137.1657	145.2824
Loss (kVAr)	88.4249	93.4183	67.7404
Vmin p.u.(bus)	0.9362 (18)	0.9309 (18)	0.9308 (65)
VSI(bus)	0.7483 (16)	0.7312 (16)	0.7120(63)
DG site (bus no.)	24 30 11	12 24 30	11 61 18
DG size (kVAr)	450 1050 450	450 450 1050	300 1200 300

Source: Authors, (2023).

Table 10: Parameter tabulation of IEEE-33 and 69 bus systems with switched CBs using HPO.

Parameter-switched CB (3 units)	33- bus (202 kW)	33-bus (210 kW)	69-bus
Ploss (kW)	132.1726	138.2644	145.2876
Qloss (kVAr)	88.3306	94.2155	67.7227
Vmin p.u.(bus)	0.9377 (18)	0.9317 (18)	0.9314 (65)
VSI(bus)	0.7533 (16)	0.7337 (16)	0.7173 (63)
DG site (bus no.)	24 13 30	30 24 13	17 66 61
DG size (kVAr)	544 379 1037	1037 544 388	267 341 1238

Source: Authors, (2023).

Table 11: parameter tabulation of IEEE-33 and 69 bus systems with PV-DG integration using HPO.

Parameter-three units of PV-DG	33-bus (202 kW)	33-bus (210 kW)	69-bus
Ploss (kW)	71.4572	74.0870	69.4284
Qloss (kVAr)	49.3909	51.3923	34.9618
Vmin p.u.(bus)	0.9686 (33)	0.9646 (18)	0.9790 (65)
VSI(bus)	0.8485 (30)	0.8053 (29)	0.8521 (60)
DG site (bus no.)	24 30 14	12 24 31	11 61 18
DG size (kW)	1100 1071 754	932 1101 899	527 1719 380

Source: Authors, (2023).

V. CONCLUSIONS

To determine where and how big capacitor banks and solar DGs should be installed in a radial distribution ssytem, a novel methodology called Hunter- Prey Optimization (HPO) is presented. The fundamental motivation for this optimization approach is the ability to pull a target away from the rest of the pack and strike it in the direction of the pack leader. The algorithm is tested on the IEEE-33 and 69 test bus systems, and the results are compared to those of other popular algorithms to determine where to put the capacitor banks and the PV type DG. For a more thorough evaluation of the radial distribution system's competitiveness, simultaneous installation of PV-DG and capacitor banks may be expanded.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Varaprasad Janamala.
Methodology: Varaprasad Janamala.
Investigation: Varaprasad Janamala.
Discussion of results: Soundarya Lahari Pappu.
Writing – Original Draft: Soundarya Lahari Pappu.
Writing – Review and Editing: Soundarya Lahari Pappu.
Resources: Varaprasad Janamala.
Supervision: Varaprasad Janamala.
Approval of the final text: Soundarya Lahari Pappu and Varaprasad Janamala.

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