

Improvement of the Distribution System Voltage Profile and Net Profit by the Integration of Capacitors with EVCS

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Abstract- Electric vehicles must be used to reduce the amount of greenhouse gases and other hazardous gases that are emitted by traditional engine-driven vehicles. Facilities for charging electric vehicles are essential to their broad use. Utility operators and electrical networks have problems when Electric Vehicle charging stations (EVCS) are placed inappropriately. In this work, a new technique for finding the best places for EVCS is presented. Additionally, the charging station has reactive power compensation to handle power outages and keep the distribution network reliable. The suggested technique is Honey Badger Algorithm (HBA). Its capacity for exploration and extraction is well-balanced. To maximize net profit and minimize actual power loss, the recommended technique is applied on the IEEE-33 bus distribution network. Additionally, the results obtained with the expected method are comparable to traditional Advanced Grey Wolf Particle Swarm Optimization (AGWOPSO), GWO and PSO. Compared to AGWOPSO, GWO, and PSO, the recommended approach maximizes net profit by 5764.45\$, 6907.36\$, and 7324.89\$ and reduces loss by 3.34%, 4.62% and 5.06% for the 33-bus system. The collected outcomes illustrate the supremacy of the suggested method over AGWOPSO for identifying the locations of reactive power sources and charging stations in radial distribution systems.

Keywords- Electric Vehicle charging stations, Radial Distribution System, Active Power Loss, Voltage Profile, Honey Badger Algorithm.

1. Introduction

The environment is affected by the transportation sector's reliance on fossil fuels, which results in dangerous carbon dioxide (CO₂) releases. Using electric vehicles (EVs) will promote active travel and improve public transport in greener communities. In addition to their outstanding performance and financial benefits, EVs also have a good environmental impact by lowering the hazardous releases that come from transportation. Thus, in order to create an affordable and easily accessible EVCS facilities for the future development of the EV sector, tactical planning is necessary. Moreover, the correct position of EVCS on the distribution network is essential for extensive EV integration. An unbalance between generation and demand, rise

in actual energy loss, a weak voltage profile, and ultimately a decline in the degree of voltage stability can all result from incorrect positioning of EVCSs. Integrating EV charging stations (CSs) in strategic places is crucial to reducing all of these issues. EVCS establishment affects the Radial Distribution System's (RDS) stability and efficiency. EVCS installation has increased the strain on the distribution network. This work proposes optimum design of EVCS in presence of capacitors (CAP) to reduce this issue.

An approach utilizing PSO is suggested to find out the ideal spot for EVCS and the best CS capacity for URDS [1]. Different hybrid energy system topologies are discussed in [2] to fulfil the energy needs of the EVCS placed in Delhi, India's northwest. A method for the best placement and

the capacity of fast CSs (FCSs) that takes build-up costs, grid power loss, and delivery loss into account is presented [3]. A new method [4] for placing EVCS properly in a distribution network while preserving system efficacy is put forth. This article clarifies how to create a test place with V2G functionality. An innovative technique for EV charging station location is put forth, taking into account both the electrical grid's loss minimization and the power loss experienced by EVs while travelling to charging stations [5]. EVCS deployment is proposed in [6] within a radial distribution network that is layered on top of a road network. The weighting of various locations has been taken into account based on charging demand, which varies depending on the supermarket, intersections, homes, etc. A methodology is proposed to ensure stability conditions while determining the ideal charging point placement and capacity in a distribution network [7]. In [8], a new rapid charging station site planning approach is provided to optimize the power grid, drivers, vehicles, operators, and traffic. In order to achieve the concurrent quantity and positioning of FCSs and DGs with limitations like the quantity of EVs in every zone and the optimum quantity of FCSs depending on the electricity lines and roads in the suggested system, a multi-objective optimization issue is addressed in [9].

In [10], the best way to plan FCSs and DGs while taking into consideration the current and projected rise in the quantity of EVs is presented. The best way to deploy PEVCS in a DN with DG in large quantities and at specific buses is to utilize a hybrid GA-PSO, as recommended in [11]. To distribute EVCSs and RESs as efficiently as possible, a multi-objective allocation approach [12] is suggested. In order to maximize the technological, financial, and environmental advantages of a distribution network, a new complete planning process for the distribution of BESS units, DGs, and EVCS facilities is described in [13]. A more sustainable energy destiny depends on the widespread use of EVs and the installation of RES. Utilizing locally produced renewable energy to charge EVs is the concept behind incorporating GRDG-based electric vehicle charging points into imbalanced distribution systems [14]. Additional actual power is drawn from the distribution

substation when EVCS and EVBSSs are added to the RDS. To determine the ideal position of EVBSSs/EVCS in the RDS, a unique approach is presented [15]. In [16], the optimal positioning of EVCS in combination with Distributed Generation (DG) is examined in order to lessen network loss.

This work suggests a new intelligent approach for the ideal positioning of EVCS, which is inspired by the existing research on the most efficient way to place EVCS. The suggested method maintains the voltage profile, maximizes net profit, minimizes active energy loss, and enhances dependability by using capacitors. The recommended method's efficacy is put into practice in MATLAB, and its efficiency is examined against the existing approaches.

2. Problem Formulations

Efficient deployment of EVCS is crucial for both electric utility companies and their customers. Every electric vehicle has a restricted range; therefore, recharging is necessary several times while driving. Electric vehicle charging stations (EVCS) are a usual source of power loss due to the enormous strain they place on distribution networks. Therefore, the ideal placement of EVCS is essential for a minor rise in energy loss. The impact of adding EVCS to the distribution network is mitigated by installing capacitors, which enhance the voltage profile and minimize power loss.

2.1 An Analysis of the Objective Parameters

Finding the ideal location for EVCS and capacitors inside the distribution network is the primary goal of this work. The insertion of EVCS within the distribution network gives in a growth of system energy losses and a deterioration of the voltage profile. To efficiently minimize power losses, capacitors are strategically positioned at the best spots in the distribution system. The voltage profile is efficiently kept within predetermined bounds by the capacitor allocation mechanism. Thus, without going against the topic limitations, the target function is made to decrease power outages, which ultimately lowers

the total yearly energy loss costs, enhances net profit, and enhances distribution system dependability. The mathematical illustration of the objective functions for the suggested issue is as follows.

Overall active loss of power $P_{T,loss} =$

$$\sum_{j=1}^{N_{br}} P_{loss,j}(m, n) \quad (1)$$

Optimize net profit = Benefit from decreased energy loss – the expense of assembling the parts of the system – running expenses for system parts

Benefit from decreased energy loss =

$$K_{ep} * (P_{T,loss} - P_{T,loss}^{cap}) * T \quad (2)$$

The expense of assembling the parts of the system =

$$\beta \left[c_i^{cap} * N_{cap} + C_i^{EVCS} * N_{EVCS} + K_{cp} * \sum_{i=1}^{N_{cap}} Q_{cap}(i) \right] \quad (3)$$

Running expenses for system parts =

$$C_0^{cap} * N_{cap} + C_0^{EVCS} * N_{EVCS} \quad (4)$$

In order to upgrade electrical distribution networks to meet current and ever-increasing loads, reliability study is needed under diverse operating instances. In order to assess the dependability of the system, energy not supplied (ENS) is considered as an indication. To estimate the annual cost of unsupplied energy, one may follow these steps:

$$C_{ENS} = \sum_{j=1}^{N_{br}} \left(\sum_{t=1}^{T=365} \left(\sum_h \left(\frac{E^d(h)}{T} F_h R_h \right) P C_t \right) \right) \quad (5)$$

The variation between the cost of electricity that was not delivered before and after adding EVs may therefore be used to define the reliability enhancement benefit, which can be expressed as follows:

$$C_{RE} = C_{ENS} - C_{ENS,V2G} \quad (6)$$

Here, $P_{T,loss}^{cap}$ is the overall actual energy loss subsequent to the integration of capacitors, K_{ep} represents the price of energy incurred per kilowatt-hour (kWh), T shows the duration in

hours, The depreciation factor is expressed by β , capacitor and EVCS installation costs for each site are c_i^{cap} and C_i^{EVCS} , respectively, N_{EVCS} and N_{cap} represent the quantities of charging stations and capacitors, K_{cp} represents the capacitor buying price per kVAR, C_0^{cap} and C_0^{EVCS} are the running expense of capacitors and EVCS, respectively, Bus bs^{th} 's reactive power injection quantity is denoted by $Q_{cap}(bs)$, At hour h , the average energy demand is denoted by $E^d(h)$, F_h represents the failure percentage at hour h , At hour h the outage duration is R_h , the penalty for not providing energy on day t in \$/kWh is denoted by PC_t .

2.2 Explanation of Operational Constraints

In order to enhance the simulated objective functions, the following constraints are considered.

Load flow constraints

The distribution network's limitations with regard to load flow are given below:

$P_{substation} =$

$$\sum_{j=1}^{N_{br}} P_{loss}^j(m, n) + \sum_{bs=1}^{N_{bus}} P_{avail,bs} + P_{EVCS}^{bs} \quad (7)$$

$$Q^{substation} + \sum_{bs=1}^{N_{bus}} Q^{cap}(bs) = \sum_{j=1}^{N_{br}} Q_{loss}^j(m, n) + \sum_{bs=1}^{N_{bus}} Q_{avail,bs} \quad (8)$$

Bus voltage tolerance

Every bus's voltage, indicated as $V(bs)$, must to be between the lowest possible V_{bs}^{min} and highest possible V_{bs}^{max} limits.

$$V_{bs}^{min} \leq V(bs) \leq V_{bs}^{max} \quad bs = 1, 2, 3, \dots, N_{bus} \quad (9)$$

Transmission line tolerance

Every line $PF(j)$ power flow must be within the bounds of the maximum value PF_j^{max} has mentioned.

$$PF(j) < PF_j^{max} \quad (10)$$

Capacitor count restriction

This limitation is intended to minimize the quantity of capacitor positionings. The quantity of installed capacitors N_{cap} must be equal or below to the maximum permissible capacitors N_{cap}^{max} .

$$N_{cap} \leq N_{cap}^{max} \quad (11)$$

Capacitor size limit

There should be no more than the allowed maximum Q_{cap}^{max} and lowest Q_{cap}^{min} values for the reactive power injection Q_{cap} .

$$Q_{cap}^{min} \leq Q_{cap} \leq Q_{cap}^{max} \quad (12)$$

Capacitor's maximum compensation limit

Capacitor Q_{cap}^{total} total reactive energy injection must either be equal or less than load $Q_{avail,bs}^{total}$ total reactive energy.

$$\sum_{p=1}^{N_{cap}} Q_{cap}(p) \leq \sum_{bs=1}^{N_{bus}} Q_{avail,bs} \quad (13)$$

Substation bus active power is indicated as $p_{substation}$ and reactive power as $Q_{substation}$. Valves at the bs^{th} bus might be as low as V_{bs}^{min} and as high as V_{bs}^{max} . For the j^{th} branch, $PF(j)$ indicates the power flow. The injected reactive power's lowest and highest are indicated by Q_{cap}^{min} and Q_{cap}^{max} . At bus bs^{th} , there is a reactive power load of $Q_{avail,bs}$.

3. Proposed Method

The present work offered the HBA, a unique and successful metaheuristic-improvement method to aid in the most effective distribution of EVCSs and Capacitors in RDS. Inspired by honey badgers' ingenious foraging plans, Hashim et al. [17] built a potential algorithm. HBA is superior at seeking because of two separate stages, called the honey

stage and the excavating stage, which are also called the quest and pillage phases. It is an excellent optimization strategy for resolving tough, mixed-integer, and non-linear optimization problems [18-19].

3.1 Use of the HBA approach to the Problem of Capacitor and EVCSs Placement

Using the HBA technique, the following procedures are used to solve the MOVSO problem by allocating EVCSs and capacitors optimally.

1. Examine the planned 33-node test system's bus, line, load data, and EV and CS features.
2. Utilizing the accurate loss equation for the base case, perform the distribution energy flow and compute the loss.
3. Set how many EVCSs and capacitors, how many charging points (CPs), and how many charged CPs in the radial distribution system will be utilized.
4. Configure the HBA's dimension, population, upper and lower boundaries, and highest quantity of iterations.
5. Put the iteration number at 1.
6. Assess the suitability of each digging phase, taking into account network power outages and the best places for capacitors and EVCSs.
7. Evaluate the multi-objective functions for every digging and honey stage.
8. The array's highest fitness scores should be stored after the digging and honey phases' positions have been updated.
9. Determine the current digging and honey stage positions.
10. Make sure that every restriction has been fulfilled; if not, proceed to step 6; if not, proceed to the following step.
11. Continue to the next stage if the amount of iteration processes is equal to the highest number of iterations. Go on to step 5 if not.
12. The program ends when the worldwide best solution for net profit, AVDI, VSI, power loss, and voltage profile are shown.

4. Results and Discussions

The dominance of the recommended HBA is examined at enhancement of voltage stability, improve the net profit and minimize the power loss of several distribution systems. The recommended technique has been executed on

the 33-node RDS with EVCS and capacitor banks. Simulation is carryout using MATLAB 14.0 platform which is implemented on a computer having 4210U processor, i5 Intel Core, 8 GB of RAM and up to 2.5 GHz. The test systems are analyzed with different case studies and simulated results are numerically and graphically reported. Comparative study also made to prove the performance of projected HBA approach.

Test system: 33-node RDS

This test system has one main feeder, three network laterals, thirty-three buses and thirty-two transmission lines. The system's overall reactive and actual power loads are 2300 KVAR and 3715 kW, respectively. Figure 1 displays the one-line schematic for the 33-node test setup. The reference [20] provides the line and bus details and proposed test system analyzed by two separate test cases; those are

Case 1: Base case with no compensating devices

Case 2: EVCS and Capacitor placement

Initially capacitors and EVCS are not considered and do the load flow study using distribution power flow which is consider as case 1. Here, decides the actual and reactive power flow, voltage profile, voltage violations and active & reactive energy losses. The obtained outcomes are shown in Table 1. The minimum VSI and minimum voltage is 0.6951 (p.u) and 0.9131 (p.u) respectively. The actual energy loss for the base case power flow is 201.870 kW. From the base case study identified the week busses, voltage violations and deviations, power flows and power losses of the proposed system.

Capacitors and EVCS are installed to boost the voltage profile and net profit of the system and considered as case 2. The four capacitors with rating of 0 - 2 MVAR and two EVCS are charged with power rating of 975 kW are taking into account power flow study. An effective successful optimization tool of HBA approach is performed to recognize and locate the ideal location and sizing of Capacitors also find the best position of EVCS. The parameter setting of HBA is population size = 40, random number = 0 to 1, number of variables =8 and maximum number of iterations = 300 respectively. The HBA resourcefully tuned the

variables such as locations of EVCS are 18 and 22. Further, the best optimal location and sizing of capacitors are 8, 30, 4, 26 and 294 KVAR, 540 KVAR, 207 KVAR, 426 KVAR respectively. The EVCS and capacitors are installed in the 33 nodes with beat location with optimized values.

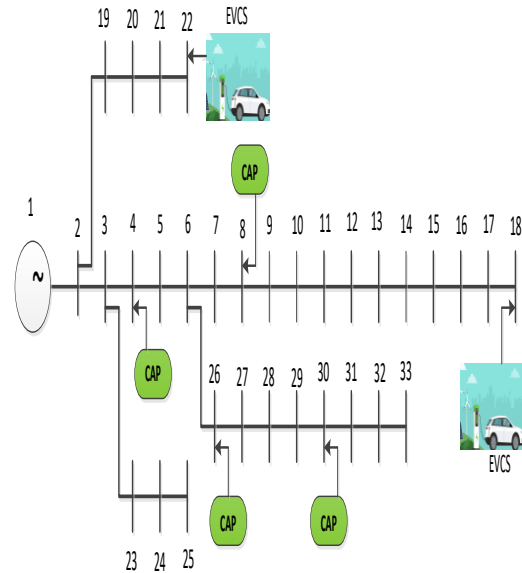


Figure 1. A one-line schematic of a 33-node radial distribution system with EVCS and capacitors

The distribution load flow with HBA technique is conducted and gets the improved solutions which are better voltage and VSI at every bus, reduced network loss and voltage deviations, maximized net profit of the system and are given in Table 1. Minimum Voltage (p.u) and minimum VSI (p.u) is 0.93809 and 0.74194, Power loss and net profit is 135.26 KW and 19123 \$ respectively. The power loss is 32.99% superior to the base case approach. The minimum voltage level improved 2.73% higher than the base case approach. The power loss minimization is 5.06%, 4.62% and 3.34% improved than the existing approaches of PSO, GWO and AGWOPSO. Also, net profit of RDS is 38.30%, 36.06%, and 30.14% improved then the existing methods. The EVCS and capacitors are allocated with optimal size in the RDS using HBA and run distribution power flow for enhancing the voltage profile and net profit. The improved voltage profile is evaluated under various test cases such as base case, capacitor placement only, EVCS and Capacitor placement. The obtained voltage at each bus for their different test cases is graphically reported in Figure 2. Minimum node

voltage and minimum voltage stability index has been computed as 0.93809 (p.u) and 0.74194 (p.u) respectively.

The outcomes of the proposed IEEE-thirty-three bus test system with various test cases using HBA method is represented in Table 1. It displays the simulation results of Base case and EVCS and capacitor positioning. Also include Real Power loss in kW, Energy loss reduction benefit,

Table 1. Simulation results of 33 bus test system with different cases

Parameters	Base Case (Case 1)	EVCS and Capacitor placement (Case 2)
Open switches	-	-
Tie-line switches	-	-
Optimal location and size of EVCS	-	18(975 kW), 22((975 kW)
Optimal location and size of Capacitor	-	8 (294 KVAR), 30(540 KVAR) 4(207 KVAR), 26 (426 KVAR)
Minimum Voltage (p.u)	0.9131	0.93809
Minimum Voltage stability index (p.u)	0.6951	0.74194
Real Power loss (kW)	201.870	135.26
Total capacitor cost (\$)	-	1406
Installation cost of system components (\$)	-	10883
Energy loss reduction benefit (\$)	-	32806
Operating cost of system components (\$)	-	2800
Net Profit (\$)	-	19123
Convergence time in seconds	-	32

Efficiency	-	84
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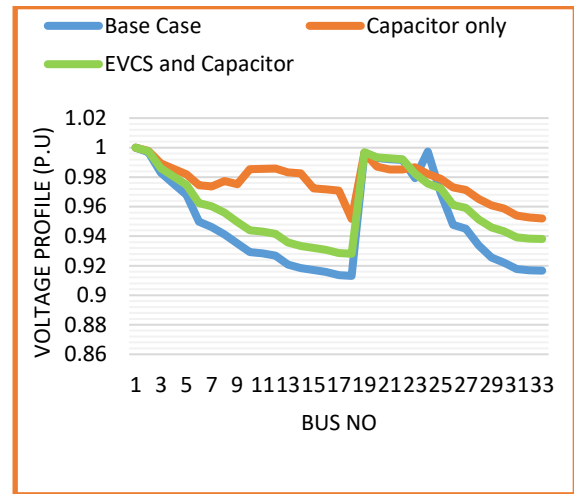


Figure 2. Comparing the 33-node RDS's voltage profile with various cases

Operating cost of system components, Total capacitor cost, Installation cost of system components, and net profit of RDS. The minimized actual power loss is 135.26 kW. The net saving cost of the system is Rs 19123.00. The Convergence time and efficiency is 32 seconds and 84 % respectively. The obtained outcomes are contrasted with other existing approaches such as PSO, GWO and AGWO-PSO and presented in Table 2. From the table, the proposed HBA approach effectively minimizes the actual energy loss and maximizes the net profit of the RDS when compared with other recently developed soft computing methods of PSO, GWO and AGWO-PSO. The power loss of various approaches with proposed HBA algorithm is graphically reported in Figure 3. Form the graph, the HBA effectively minimizes 32.99 % of power loss than the base case method. The minimum voltage and VSI for two different cases are graphically compared and shown in Figure 4.

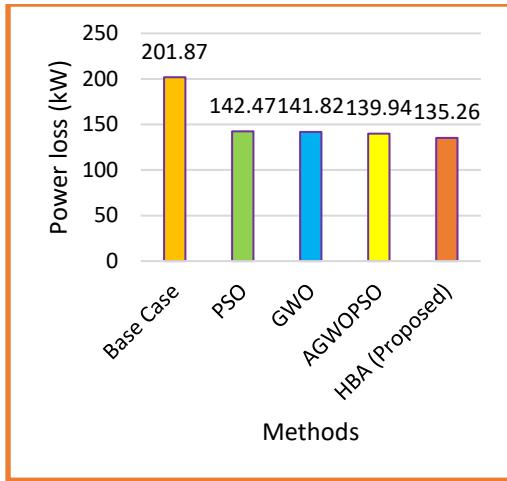


Figure 3. Comparison of power loss of proposed with existing methods for 33 node system

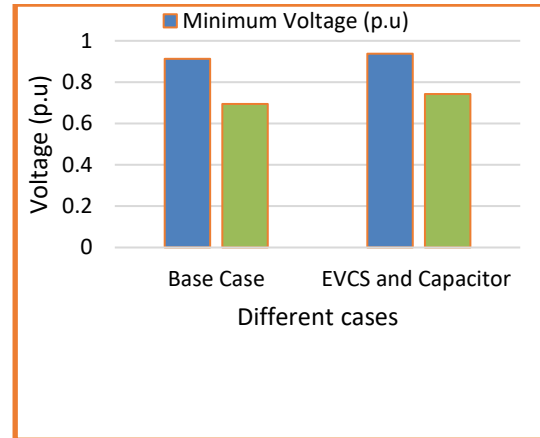


Figure 4. Comparison of minimum voltage and minimum VSI for case 1 and case 2 for 33-node test system

Table 2. Comparative analysis of proposed with existing methods for 33-node test system

Parameter	Base Case	HBA (Proposed)	AGWOPSO [21]	GWO [21]	PSO [21]
Active power loss (kW)	201.870	135.26	139.940	141.820	142.470
Total count of EVs	-	100.00	100.00	100.00	100.00
Optimal nodes for EVCS	-	18, 22	2,19	2,19	2,19
Optimal nodes for capacitor	-	8, 30, 4, 26	7, 18, 30, 32	7, 18, 30, 32	9, 16, 27, 32
Capacitor sizes (KVAR)	-	294, 540, 207, 426	371.7, 473.7, 220.59, 608.13	425.18, 494.5, 353.8, 710.2	450.12, 519.45, 425.32, 740.56
Total KVAR	-	1467	1674.120	1983.680	2135.450
Energy loss cost (\$)	106102.870	32806	73552.460	74540.590	74882.230
% loss reduction in energy loss cost	-	69.08	30.670	29.740	29.420
Net profit (\$)	-	19123.00	13358.550	12215.640	11798.110
Efficiency	-	84.00	81.50	75.10	74.50

The convergence curve of case 2 is shown in Figure 5. The HBA takes 80 to 120 iterations to achieving the best solutions with computational time period of 30 to 32 sec. The net profit of the recommended method is compared with other available methods using a bar chart and shown in Figure 6. From the chart, the proposed HBA with EVCS and capacitors provides the maximum profit compared to other methods. The net profit is

30.14%, 36.06%, 38.30% improved than the other intelligent algorithms of AGWO-PSO, GWO, and PSO. Therefore, the proposed HBA approach is a promising optimization tool for solution of non-linear and constrained voltage stability problems in RDS.

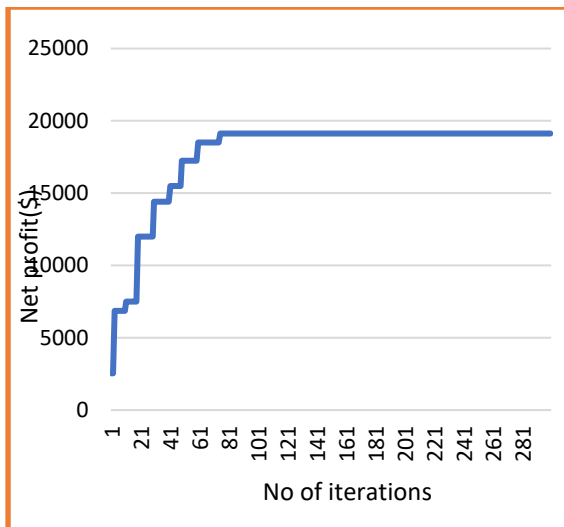


Figure 5. Convergence curve of 33-node RDS for case-2

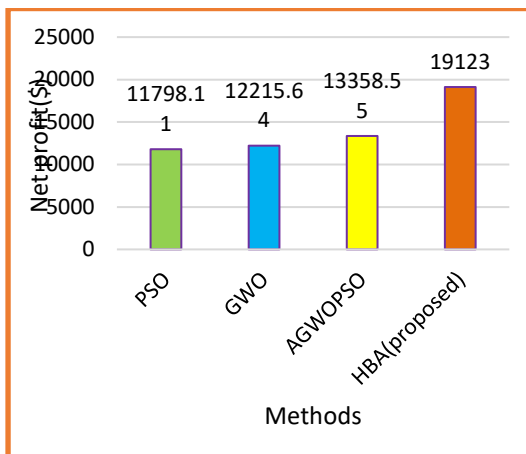


Figure 6. Comparison of net profit of proposed with existing methods for 33-node system

5. Conclusions

This study used the HBA approach, a potent and innovative optimization tool, to examine how EVCS affected Radial Distribution Networks (RDN). The proposed HBA installing capacitors and EVCS for achieving optimal solutions (improving the system voltage profile, maximize the net profit and reduce the active energy loss). To examine the performance of the suggested HBA for a 33-node test system, two distinct scenarios are taken into account. The case studies are base case without compensating devices, EVCS and capacitor positioning. In contrast to the other scenarios, the results indicate that the installation of

capacitors and EVCS is more successful in lowering active power loss and voltage variations, optimizing net profit while raising the value of VSI. Additionally, the usefulness of the recommended HBA

technique is assessed by contrasting the outcomes with those of AGWOPSO, GWO, and PSO. The following are the main findings of this work:

- The outcomes demonstrated that the HBA method had superior convergence, best outcomes and less computational time than the other soft computing techniques.
- The approach yields the improved voltage profile, VSI and reduced active power loss (minimizes 32.99 % of power loss for 33-node than the base case method)
- Also, the HBA technique provides the best solutions in terms of cost-effectiveness, such as energy loss reduction benefit, installation and operating cost of system components, and net profit of RDN.

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