Optimal allocation of EV charging station in Distribution Network

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Abstract—**Electric vehicles (EVs) are one of the alternatives to conventional car's negative environmental impact. Construction of electric vehicle charging station (EVCS) emerged from the development of EVs. Distribution system power loss increases and the voltage decreases during charging of EVs. To keep the power loss as low as possible and the voltage profile healthy, proper placement of the charging station is required. In this paper, the IEEE 33 bus distribution system has been taken for finding the ideal location for EVCS placement. In order to provide EV charging in a separate area, each charging stations are allocated at three different locations. Soft Computing techniques Particle Swarm Optimization (PSO) and Symbiotic Organism Search (SOS) has been applied to find optimal placement of EVCS. The optimized results obtained by Symbiotic Organism Search (SOS) & Particle Swarm Optimization (PSO) have been compared.**

Keywords—***Distribution System, EVCS, Power Loss Minimization, PSO, SOS.***

I. INTRODUCTION

Pollution and the problem of mineral fuel is a major cause for the attraction of electric vehicles (EVs). Because of EVs offering low-pollution and stable structures, many nations see them as one of their national tactical measures to combat pollution and the fossil-fuel issue [1]-[4]. The need to charge the EV creates major challenges for power system engineers. The placement of the charging station in the right place is an essential requirement for EV users and the health of the power system.

On the IEEE 33 bus system, a comprehensive EVCS configuration was achieved in [5]. The authors in [6] followed a variety of approaches, objective tasks, and problem-solving constraints. In addition, EV load modelling, uncertainty, vehicle-to-grid strategy, distributed generation integration, charging types, development strategies, and sensitivity analysis are studied. The Newton Raphson approach uses the Loss Sensitivity Factor (LSF) and power flow to approve full EVCS deployment. The LSF was determined by various buses taking into account the electrical capacity of the system, the load (real and efficient power), and the system losses by various Meta-Heuristic strategies [7]. The author of [9], [10] used Symbiotic Organism Search (SOS) to find the size, location, and number of Distributed Generations (DG) in distribution networks. Author in [10], [11] discovered the whole distribution of EVCS using the PSO approach. In many research work, the charging station has been allocated at adjacent location, which makes the vast area uncover with EVCS service.

In this work, IEEE 33 bus distribution network has been used to locate the ideal EVCS location. Providing universal EV charging service, the distribution network has been separated into three parts [13]. Vehicle to Grid (V2G) is a remarkable feature of EV to stabilize the power system condition. Along with the charging ability of EVCS, facility of V2G has been also taken in measured [14]. EVCS placement was obtained using the soft computing technique SOS, where the objective function was to reduce actual power losses. The PSO has also been used to find the results of the same problem and the results obtained with two soft computing techniques has been compared.

II. PROBLEM OPTIMIZATION

A. Mathematical Construction

Objective to minimize power loss has been structured as follows:

Let br^{th} be the branch of a distribution system [13].

$I_{br}=br^{th}$ branch current.

$Z_{br}=br^{th}$ branch impedance.

$R_{br}=br^{th}$ branch resistance.

$X_{br}=br^{th}$ branch reactance.

Impedance Z_{br} can be labeled as:

$$Z_{br}= R_{br} + jX_{br} \tag{1}$$

The over-all apparent power loss i.e., S_{br} has been labeled as

$$S_{br}=(I_{br})^2 \times Z_{br} \tag{2}$$

The over-all system load has been calculated as

$$T_{LD}=\sum_{bus=1}^{Nbus}(L_{ex}^{bus} + L_{cs}^{bus}) \tag{3}$$

Here, T_{LD} denotes the system's overall load. $Nbus$ is the entire bus in the system, L_{ex}^{bus} is the current load at bus^{th} bus. L_{cs}^{bus} is extra load because of EV connected at Charging station at bus^{th} bus.

$$L_{cs}^{bus}= (EV_{G2V} \times R_C) – (EV_{V2G} \times R_D) \tag{4}$$

EV_{G2V} is the number of EV linked with charging station in G2V manner and EV_{V2G} is the number of EV linked with charging station in $V2G$ manner. R_C is the charging rate, while discharging rate is R_D. The extra load caused by EV charging would only be applied to the bus where the charging station is located.

Over-all active power loss can be labelled as

$$P_{Loss}=\sum_{br=1}^{tbr} P_{LD}^{br} \tag{5}$$

Here, P_{Loss} denotes the network's over-all active power loss, P_{LD}^{br} denotes the active power loss of br^{th} branch, and tbr

is the over-all number of branches. The objective to minimize power loss can be expressed as:

$$min\ (f)=min\ (P_{Loss}) \tag{6}$$

B. Limitations

1) Load balancing limits: The total amount of power provided must equal to the sum of demand and loss [13],[14].

$$P^{SB}=\sum_{bus}^{tbus}(P_{LD}^{bus})+P_{Loss} \tag{7}$$

where,
P^{SB} = power delivered from substation.
P_{LD}^{bus} = load at bus^{th} bus.
$tbus$ = over-all number of buses.

2) Voltage limitation: To maintain the bus voltage within limits [13],[14].

$$V_{min} \leq V_{bus} \leq V_{max},\ for\ bus = 1\ to\ tbus \tag{8}$$

Here, V_{min} and V_{max} denotes the lowest and highest voltage limits respectively and V_{bus} denotes the bus voltage at the bus^{th} bus.

3) Current flow limitation: To maintain the current flow of the branch within the limits [13],[14].

$$I_{min} \leq I_{br} \leq I_{max},\ for\ br=1\ to\ tbr \tag{9}$$

Here, I_{min} and I_{max} denotes the lowest and highest current limits respectively. I_{br} is the current passing on br^{th} branch. *tbr* is the over-all number of branches.

III. Optimization Tools

According to reference [15], [16] Dr. Eberhart and Dr. Kennedy proposed PSO algorithm in 1995, which is a population-based stochastic optimization method. PSO algorithm has been applied in the present work to obtain the proper EVCS allocation. The SOS algorithm was introduced by Cheng and Progogo to better address the numbers and challenges of engineering design [17]. In this present work, SOS has been used for the same work to determine the appropriate locations of the EVCS to set and compare relevant results obtained with two algorithms.

A. SOS Algorithm

Cheng and Prayer created SOS in 2014, a meta-heuristic algorithm based on symbiotic connections between two unique species in the ecosystem [17]. The SOS algorithm has found three symbiotic relationships: mutualism, commensalism, and parasitism.

1) Mutialism Phase: The symbiotic interaction between two separate species have been demonstrated in this phase, in which both species takes advantage from each other. From reference (10),(11) E_i^{New} and E_j^{New} were constructed.

$$E_i^{New} = E_i + rand\ (0,1) \times (E^{best} - M_{\_vector} \times BF_1), \tag{10}$$

$$E_j^{New} = E_j + rand\ (0,1) \times (E^{best} - M_{-vector} \times BF_2), \tag{11}$$

$$\mathrm{M}_{\_\mathrm{vector}} = \frac{\mathrm{BF1+BF2}}{2} \tag{12}$$

E_i is the ecosystem's i^{th} species, while E_j is a randomly selected ecosystem species that interacts with species E_i. *"rand (0,1)"* in eq. (10) and (11) is a random number chosen between 0 and 1. *BF1* and *BF2* are two vectors of advantage and the value can be 1 or 2. The mutual correlation between the two species E_i and E_j is represented by $M_{\_Vector}$ in eq. (12).

2) Commensalism Phase: Two distinct species have a symbiotic relationship in which one species take advantage from the other while the other is unaffected. To generate new species E_i^{New}, species E_j is selected at random from the ecosystem in collaboration with species E_i. The relationship is advantageous to species E_i but has no effect on species E_j.

$$E_i^{New} = E_i + rand\ (-1,1) \times (E^{best} - E_j) \tag{13}$$

Here $(E^{best} - E_j)$ is a valuable advantage supplied by species E_i with the assistance of E_j, increasing its chances of survival to the maximum level in the ecosystem up to E^{best}.

3) Parasitism Phase: The ecosystem's species E_i is chosen, and E_i is duplicated to create Parasite Vector, an artificial species. E_j is a species chosen at random from the ecosystem and will function as a parasite host. If Parasite Vector has a higher capability value than E_j, Parasite Vector will usurp E_j's place in the ecosystem; if not, E_j will take its place and live.

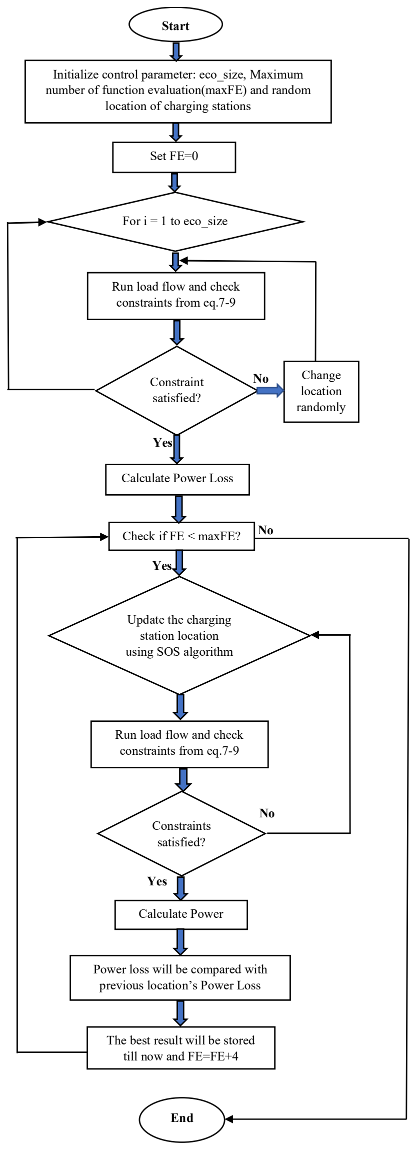

Fig. 1. Flow diagram for finding the correct EVCS location using SOS.

In Fig.1, the flow diagram for finding the correct EVCS location by applying SOS has been shown. In this operation, three randomized nodes of the charging station are detected, and the objective function is calculated by means of the backward/forward sweep load flow of radial distribution network. The location of the charging station will be updated according to the SOS update method.

IV. Results and Discussion

In this paper, the IEEE 33 bus distribution test system, with a capacity of 3715 kW and 2300 kVAr respectively, 33 buses and 32 lines has been adopted. The base voltage is 11 kV and base power is 100 MVA [18]. For Load flow analysis of IEEE 33 bus radial distribution test system, the backward/forward Sweep algorithm has been used to calculate the power loss and voltage of the system [19],[20].

The AC fast-charging rate on grid-to-vehicle (G2V) manner is 19 kW [21] and with a discharge rate of 8 kW Vehicle-to-grid (V2G) manner [22] has been considered. It is presumed that 10% of total EV connected at charging station can work on V2G manner [14]. Two cases were executed in the present work. In Case-1, allocation of EVCS has been determined without dividing the distribution network and in Case-2, EVCS has been allocated by dividing the distribution network into three areas to provide better EVCS service. Three scenarios have been considered. 1) Firstly, a total of 10 EVs connected to the charging points, 2) Secondly a total of 20 EVs connected to the charging points and 3) Thirdly a total of 30 EVs connected to the charging points [13]. At a moment number of EVs connected cannot be more than 30 EVs in the system. In this study, charging stations have been assigned based on these scenarios.

The extra load caused by EV charging would only be applied to the bus where the charging station is located. Load at the charging station be contingent on the number of EVs associated via G2V and V2G manner and also depending on the charging and discharging level.

A. Allocation of EVCS using PSO and SOS without area division (Case-1)

TABLE I. *Placement of EVCS for Case-1 using PSO*

Number of EV	*Optimum Location*			*Min. Voltage*	*Power Loss(kW)*	*Elapsed Time(sec)*
10	2	19	20	0.9027	212.0823	467.347
20	2	19	20	0.9017	213.3071	440.684
30	2	19	20	0.9007	215.1908	526.217

Table-I shows the optimal allocation, losses and minimum voltage for Case-1 applying PSO for three different scenarios.

TABLE II. Placement of EVCS for Case-1 using SOS

Number of EV	*Optimum Location*			*Min. Voltage*	*Power Loss(kW)*	*Elapsed Time(sec)*
10	2	19	20	0.9035	212.0209	582.672
20	2	19	20	0.9030	213.1758	389.491
30	2	19	20	0.9023	214.9422	469.470

Table-II shows the optimal allocation of EVCS, losses and minimum voltage at three different scenarios using SOS algorithm. Fig. 2-4 depicts the voltage profile of Case-1 for three scenarios using SOS algorithm. Very small difference has been noticed as the charging station location is very close to the substation.

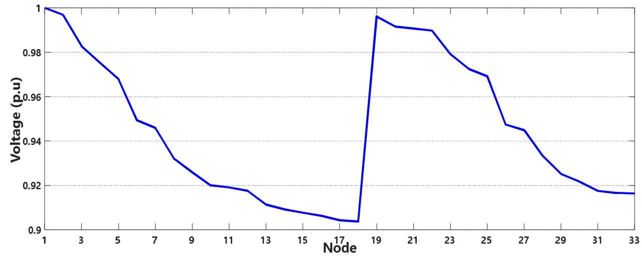

Fig. 2. Voltage profile for Case-1 with 10 EV using SOS

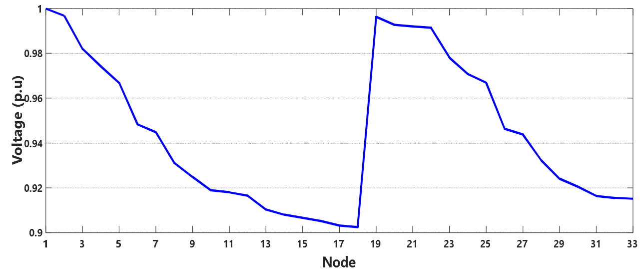

Fig. 3. Voltage profile for Case-1 with 20 EV using SOS

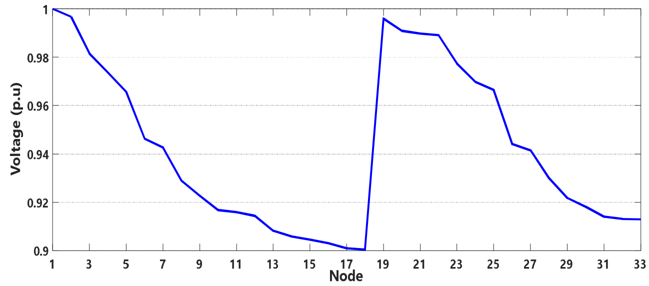

Fig. 4. Voltage profile for Case-1 with 30 EV using SOS

Fig.5-7 shows the convergence curve of PSO and SOS optimization techniques for three scenarios i.e., with 10, 20 and 30 EV (Case-1).

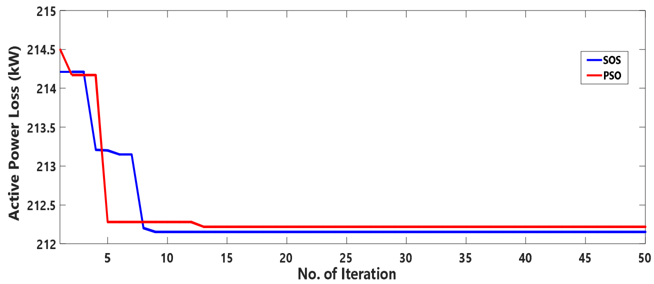

Fig. 5. PSO and SOS-based convergence curve for Case-1 with 10 EV

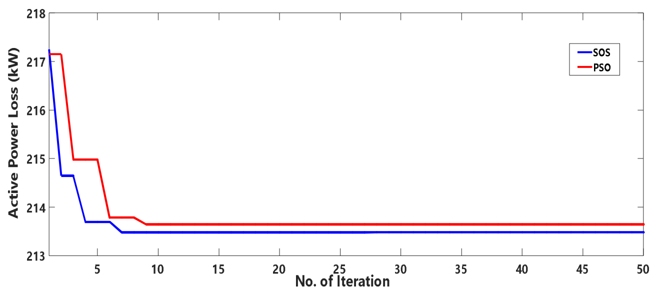

Fig. 6. PSO and SOS-based convergence curve for Case-1 with 20 EV

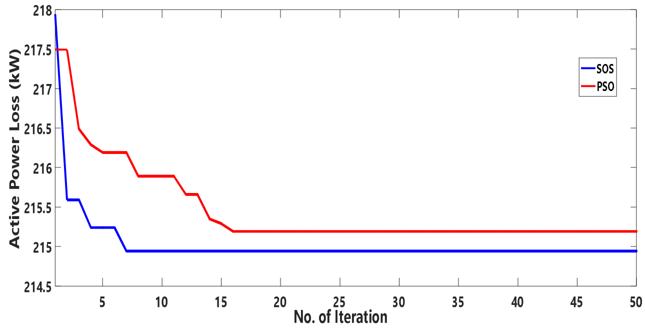

Fig. 7. PSO and SOS-based convergence curve for Case-1 with 30 EV

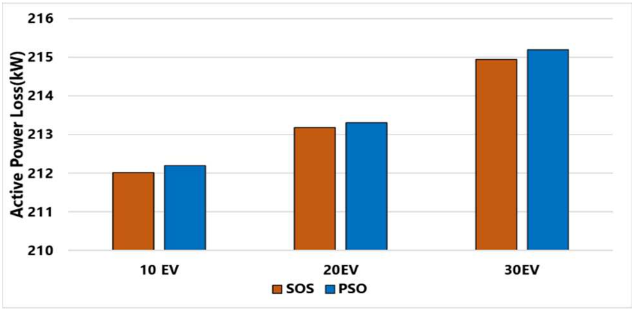

Fig. 8. Comparison of active power loss obtained by PSO and SOS for Case-1

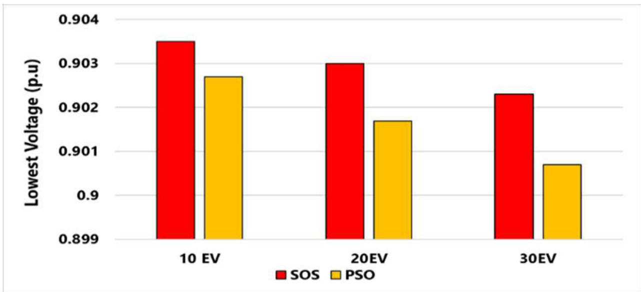

Fig. 9. Comparison of lowest voltage obtained by PSO & SOS for Case-1

Fig.8 shows a comparison of active power loss derived using PSO and SOS. Here, for the same number of EV active power loss obtained by SOS is less than the PSO. The distribution network's lowest voltage is shown in Fig.9. From Fig 9, it indicates that SOS performed better than PSO in detecting the voltage profile.

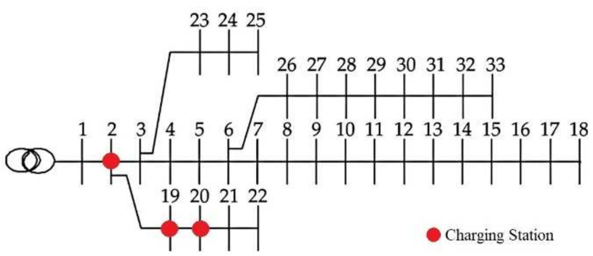

Fig. 10. Optimal location of charging station for Case-1

Fig.10 shows the ideal location of EVCS for Case-1. It has been seen that the optimal locations are close to each other, this makes the vast area uncover with EV charging service. EV owners must drive a considerable distance to charge their vehicles. Moreover, three charging stations are not required to be placed so close to each other as obtained in Case-1. For these reasons the idea of distributing the network into three sectors comes as Case-2.

B. Allocation of EVCS using PSO and SOS after area division (Case-2)

The distribution network has been separated into three sectors in this case. Fig.11 shows the sector division of distribution network. The division of sectors has been founded on the presumed populated area and charging demand.

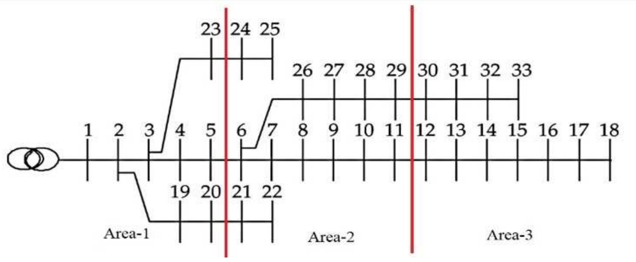

Fig. 11. IEEE 33 test distribution system area division [13].

TABLE III. PLACEMENT OF EVCS FOR CASE-2 USING PSO

Number of EV	*Optimum Location*			*Min. Voltage*	*Power Loss(kW)*	*Elapsed Time(sec)*
10	2	21	30	0.9029	216.5809	321.6532
20	2	21	30	0.9019	222.3529	504.8454
30	2	21	30	0.9007	236.0101	954.9501

Table-III shows the optimal location, power losses and minimum voltage for Case-2 applying PSO for three scenarios.

TABLE IV. PLACEMENT OF EVCS FOR CASE-2 USING SOS

Number of EV	*Optimum Location*			*Min. Voltage*	*Power Loss(kW)*	*Elapsed Time(sec)*
10	2	21	30	0.9032	215.6521	351.4549
20	2	21	30	0.9021	221.3964	599.8226
30	2	21	30	0.9008	234.6043	136.9639

Table-IV shows the optimal location of EVCS, losses and minimum voltage at three different scenarios using SOS algorithm for Case-2. Fig. 12-14 depict the voltage profile obtained by SOS of Case-2 under three scenarios. Voltage drops increases with the proportion of EVs in G2V mode.

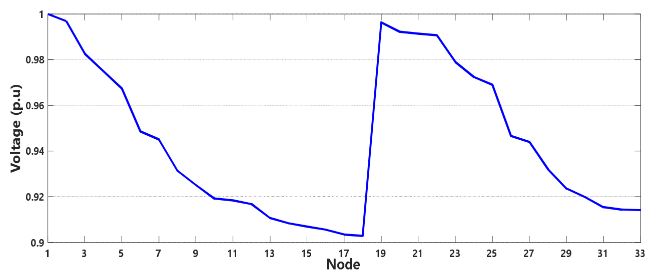

Fig. 12. Voltage profile for Case-2 with 10 EV using SOS

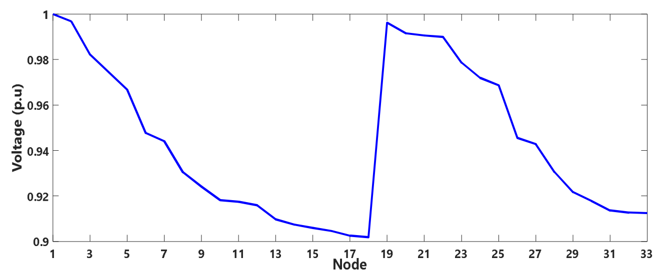

Fig. 13. Voltage profile for Case-2 with 20 EV using SOS

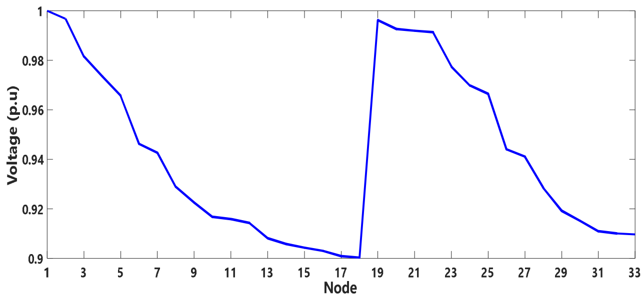

Fig. 14. Voltage profile for Case-2 with 30 EV using SOS

Fig.15-17 show the convergence graphs obtained by PSO and SOS optimization techniques for three scenarios i.e., 10, 20 and 30 EV connected to charging station (Case-2).

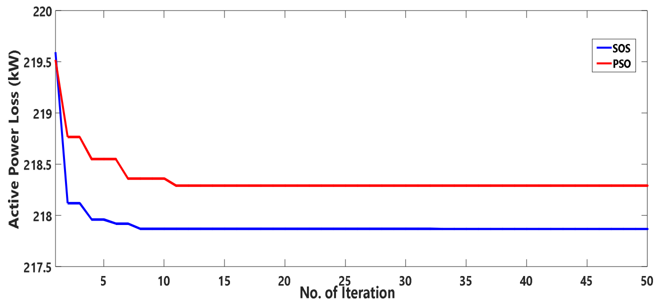

Fig. 15. PSO and SOS-based convergence curve for Case-2 with 10 EV

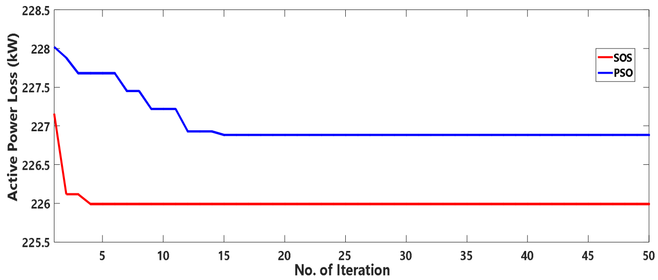

Fig. 16. PSO and SOS-based convergence curve for Case-2 with 20 EV

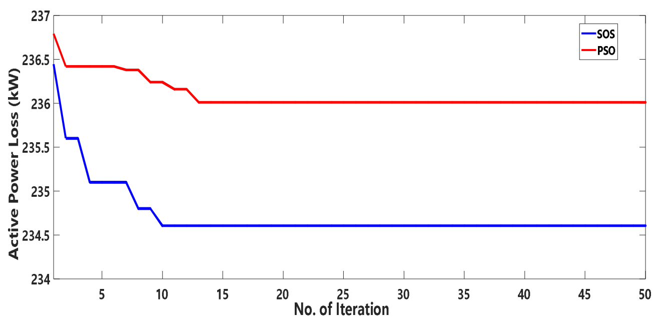

Fig. 17. PSO and SOS-based convergence curve for Case-2 with 30 EV

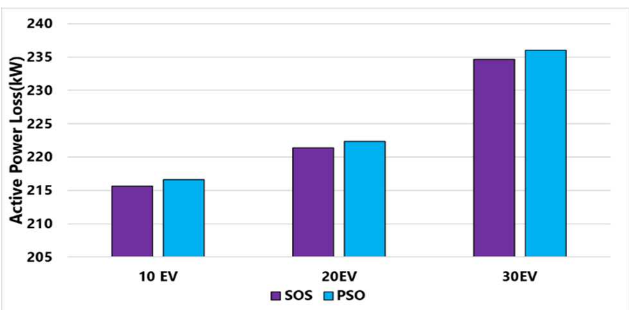

Fig. 18. Comparison of active power loss obtained by PSO and SOS for Case-2.

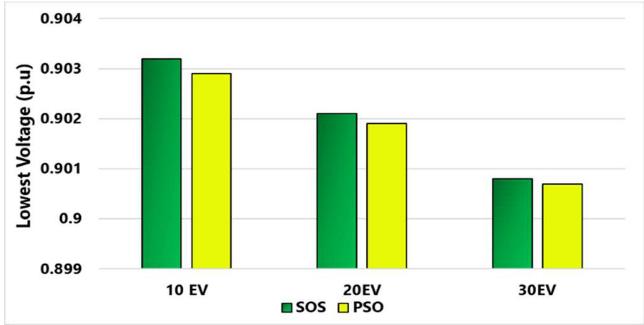

Fig. 19. Comparison of lowest voltage obtained by PSO and SOS for Case-2.

Fig.18 depicts a comparison of active power loss determined by using PSO and SOS. For the same number of EV, active power loss obtained by SOS is less than PSO.The comparision of minimum voltage in the distribution network has been depicted in Fig.19. From Fig.19, it appears to be the voltage profile obtained by SOS is better than that acquired by PSO.

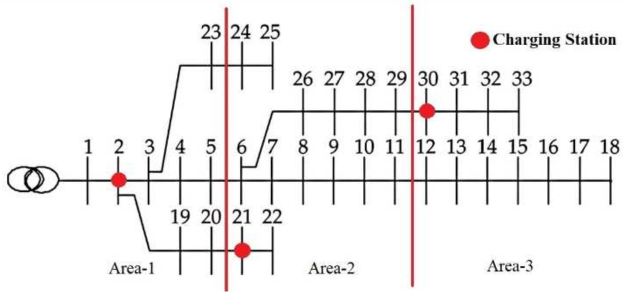

Fig. 20. Optimal location of charging station for Case-2

Fig-20 depicts the optimal charging station position following area partitioning. The placement of EVCS is now more distributed which will be more convenient for EV owners to access the service.

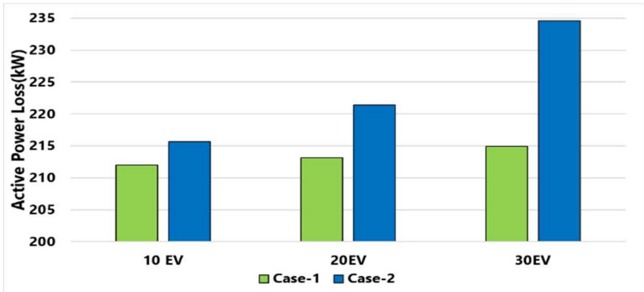

Fig. 21. Active power loss valuation between two Cases obtained by SOS.

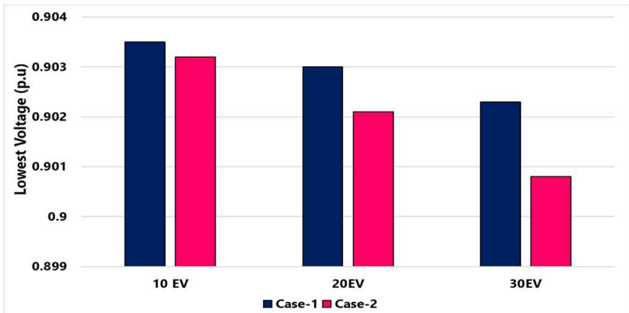

Fig. 22. Minimum voltage valuation between two Cases obtained by SOS.

Fig.21 and 22 represent the comparison of active power loss and lowest voltage obtained for both cases by applying SOS for the same number of EV. From Fig.21 it is observed that power loss obtained in Case-1 is less than Case-2, whereas the minimum voltage value of Case-2 is less than the value of Case-1 as shown in Fig.22. Case-1 uses an optimization strategy that analyzes the entire distribution network for the best node among all of them, resulting in improved outcomes. But in Case-2, the optimization technique searches area wise and give compromised result for power loss and voltage to provide more realistic and better service to EV users.

CONCLUSION

The distribution system's power loss has been significantly influenced by EVCS allocation. So correct allocation of EVCS is required for reduction of active power loss. In this paper, SOS and PSO algorithms have been implemented for allocating the EVCS in IEEE 33 radial distribution network for minimizing power loss of the network. The findings of both algorithms were compared to get the best outcomes. It's worth mentioning that SOS performs considerably better than PSO. Though area wise division has a negative effect on power loss and voltage drop, but area wise division makes EV owners to access EVCS service without travelling long distance.

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