Planning and operation of EV charging stations by chicken swarm optimization driven heuristics

Sulabh Sachan | Sanchari Deb | Sri Niwas Singh | Pravin Prakash Singh | Desh Deepak Sharma

1 Electrical Engineering Department, MJP Rohilkhand University, Bareilly, India
2 ERCIM, VTT Research Centre, Finland
3 Electrical Engineering Department, IIT Kanpur, India
4 EED, Tallinn University of Technology (TalTech), Estonia

Correspondence
Sulabh Sachan, Electrical Engineering Department, FET, MJP Rohilkhand University, Bareilly 243006, Uttar Pradesh, India.
Email: sulabh.iitr11@gmail.com

Abstract
Successful deployment of electric vehicles demands for establishment of simple reachable charging stations (CSs). Scheduling and action of CSs is a composite problem and that should not affect the smooth operation of the power grid. The present paper attempts to solve the planning and operation of CSs by a novel chicken swarm optimization-based heuristics. The placement of CS is modelled in a multi-objective framework as cost-effective parameters secures the operation of the power grid. Further, the operation of CSs is examined for three scenarios such as uncoordinated charging, coordinated charging, as well as bidirectional vehicle to grid. The proposed approach is tested on IEEE 33-bus, and on a distribution network of Guwahati, India.

1 INTRODUCTION

In recent years, researchers and environmentalists are preoccupied with fossil fuel depletion, degradation of air quality, and energy crisis. Electric vehicles (EVs) are a clean mode of transportation and are viable alternatives to deal with the aforementioned problems. However, successful deployment of EVs calls for enlargement of charging station (CS). The planning and operation of CS are critical aspects. Improper planning and operation of CS may be detrimental to the power grid resulting in voltage instability, degraded reliability, increased power losses, and harmonic distortion [1–5].

Globally, the planning and operation of charging stations have attracted much attention from researchers to deal with various problems [6, 7]. Despite their advantages, EVs are not becoming widespread at the desired level since there are no common charging stations, and the reason for this fear is that the private traditional vehicles are on the road [8, 9]. To alleviate this problem, it is assumed that car parks can be used as charging places. Normally, the EVs are not used for a long time as they are often left in parking lots. For this reason, these long times can be measured as a prospect to recharge EVs in smart car parks [10]. The focus of this technology is to prevent damage to the grid by multiple EVs and HEVs being charged simultaneously. The aim of this paper is to ensure the satisfaction of EV and HEV users while eliminating the negative effects [11]. There is a need for a control mechanism to control the power supplied to parked vehicles which is fed from the grid as well as by other forms of electricity production [12–14].

The operation of charging stations signifies the charging strategy that will be adopted in the charging stations such as uncoordinated charging, coordinated smart charging etc. In [15, 16], authors have analysed the advantages of smart charging schemes and found that coordinated charging is beneficial. In [17], authors provided a DR strategy of EV CS by using dynamic programming. In [18], the authors presented a two-stage linear programming-based approach for the operation of charging stations. In [19], authors have proposed an adaptive strategy to manage EV charging load. Further, in [20], the authors presented a load management strategy in EV charging stations in the presence of renewable energy sources.

Researchers have made significant attempts to improve energy efficiency of CSs. In a category, researchers have considered different technologies such as renewable energy sources, ESS and DR programs in studying the operation of energy systems in the presence of EVs. The authors have proposed a
multi-objective model for a PV-based, intelligent electric-vehicle CS in connection with a demand–response program in [21] to satisfy both the environmental and economic issues of CSs. A multi-agent approach for coordination of EVs, combined with a renewable-based micro grid, is proposed in [22] for providing vehicle-to-home service. The multi-agent coordination is performed by exchanging information among various control elements. The authors, in [23], have presented a self-supporting model for smart grids to minimise costs during outages by using EV batteries to fulfil the demands of the grid. Accordingly, a multi-agent scheme consisting of a micro grid, home, and EV is designed for managing outages in the smart grid. Also, the penetration of fuel cell technology as a hydrogen-storage system and electrolyze, along with time-of-use DR, have been investigated [24] in conjunction with optimal scheduling of CSs.

A summary of research works on planning and operation of charging stations is presented in Table 1. From Table 1, it is observed that most of the research works have dealt with placement and operation of charging stations separately. This work considers planning and operation of charging stations under a single framework. Thus, the major contributions of this work are:

- A robust framework has been considered regarding placement and operation of charging stations;
- Multi-objective modelling of charging infrastructure planning has been considered using economic factors as well as the secure operation of power grid;
- A novel chicken swarm optimization (CSO)-based heuristics has been used to solve the planning and operation of charging station problem; and
- Three scenarios such as uncoordinated charging, coordinated charging, as well as bidirectional V2G are examined for the operation of charging stations.

2 | PROBLEM FORMULATION

The charging station scheduling problem is mainly concerned with two activities such as location and operation of CS. The
### Table 2 Summary of the nodes of the proposed BN

| Node name                     | Type     | States               |
|-------------------------------|----------|----------------------|
| VSF                           | Parent   | {High (H), Medium (M), Low (L)} |
| Charging demand               | Parent   | {Peak (P), Off Peak (OP)} |
| Failure probability           | Parent   | {High (H), Low (L)}   |
| Probability of being candidate location | Child    | {High (H), Low (L)}   |

### Algorithm 1 Pseudo-code for computation of the VSF [25]

1. Input the bus data and line data;
2. Run distribution load flow for base case by forward backward method;
3. For \( i = 1: \text{total number of bus} \);
   - \( VSF_{base}(i) = \frac{dV(i)}{dp(i)} \);
   - \( k = 1; \)
4. While \( k < \text{Realistic loading margin} \);
   - Increase load in steps;
   - Run distribution load flow by forward backward sweep algorithm;
   - If load flow converges
     - \( k = k + 1; \)
   - else
     - Compute VSF for critical loading;
   - End if else
5. End while

### Algorithm 2 Pseudo-code for computing for charging demand [26, 27]

1. Input historical feature data and corresponding charge of EVs;
2. Step the input charging amount data;
3. Extract \( n \) training samples by Bootstrap;
4. Repeatedly extract \( k \) training sets;
5. Build decision tree based on the Cart algorithm;
6. If training set traversal is completed
   - Random forest forecast is completed and input the corresponding feature to forecast;
7. Calculate the average output of the forest;
8. Output amount of charge during the period;
9. Else, build decision tree based on the Cart algorithm;
10. end

The placement and operation problem reported in Section 2 is solved by a novel CSO-based heuristics approach elaborated in [31]. CSO is a bio-stimulated procedure that mimics the work. The details of the objective function are given in Table 3. It is depicted as:

\[
F = \min(\cos t) + \min(VRP \text{ index}) + \max(Accessibility \text{ index}) + \max(\text{waiting time}),
\]

Subject to:

\[
F_{\min} < F_p \leq F_{\max} \quad \text{and} \quad f_{\min} < f_p \leq f_{\max},
\]

\[
S_{\min} < S_p \leq S_{\max} \quad \text{and} \quad s_{\min} < s_p \leq s_{\max},
\]

\[
P_{di} - P_{di} - V_i \sum_{j=1}^{N_D} V_j Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) = 0,
\]

\[
Q_{di} - Q_{di} - V_i \sum_{j=1}^{N_D} V_j Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) = 0.
\]

System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI) are the typical power distribution network reliability indices [28].

2.2 Charging strategy

Three charging strategies via uncoordinated charging, coordinated charging, as well as bidirectional vehicle to grid (V2G) are examined in this work. An overview of the aforementioned charging strategies is provided in Table 4.

3 METHODOLOGY

The placement and operation problem reported in Section 2 is solved by a novel CSO-based heuristics approach elaborated in [31]. CSO is a bio-stimulated procedure that mimics the
food searching phenomenon of chicken in a swarm. The swarm is divided into dominant roosters that lead the food searching process, hens following the roosters, and chicks following the mother hen. The algorithm also mimics the competition between hens in the quest for food. The main advantage of CSO is that it utilises the intelligence of chicken swarm in an effective manner and maintains a good balance between randomness and determinism while finding the optimal solution. A multi-objective modelling considering economic and security issues jointly has made the problem more complex. However, the proposed model is more realistic and considers planning and operation of charging stations simultaneously. The CSO-based heuristics proposed in the work has the capacity to take into account the computational burden of the proposed model by sustaining a stability among exploration and manipulation. The detailed solution procedure is shown in Figure 2.

4  NUMERICAL ANALYSIS

The proposed formulation is validated on IEEE 33-bus and distribution network of Guwahati as depicted in Figures 3 and 4, respectively. The bus, line, outage data of the two test systems shown in Figures 3 and 4 can be found in [4, 32, 33]. As elaborated in Section 2, the first step of the placement problem

| TABLE 3  | Objective functions |
|----------|---------------------|
| **Objective function** | **Significance** | **Formulation** |
| Cost | This takes into account the installation (Cost_installation), operating (Cost_operation) and maintenance (Cost_maintenance) cost of charging stations | $\text{Cost} = \text{Cost}_{\text{installation}} + \text{Cost}_{\text{operation}} + \text{Cost}_{\text{maintenance}}$ |
| $\text{Cost}_{\text{installation}}$ | $\left\{ \left( \sum_{j=1}^{m} f_j x_j \right) \times C_{\text{fast}} \right\} + \left\{ \left( \sum_{j=1}^{m} s_j x_j \right) \times C_{\text{slow}} \right\}$ |
| $\text{Cost}_{\text{operation}}$ | $\left\{ \left( \sum_{j=1}^{m} f_j x_j \right) \times C_{P_{\text{fast}}} \right\} + \left\{ \left( \sum_{j=1}^{m} s_j x_j \right) \times C_{P_{\text{slow}}} \right\} \times P_{\text{elec}}$ |
| $\text{Cost}_{\text{maintenance}}$ | $\left\{ \left( \sum_{j=1}^{m} f_j x_j \right) \times C_{M_{\text{fast}}} \right\} + \left\{ \left( \sum_{j=1}^{m} s_j x_j \right) \times C_{M_{\text{slow}}} \right\} \times P_{\text{elec}}$ |
| Voltage stability index | Voltage stability index (VSI) is regarded as a tool for evaluating the proximity of a given operating point to voltage instability | $V = \frac{\text{VSI}_{\text{base}}}{\text{VSO}}$ |
| $\text{VSI}_{\text{base}}$ | $\sum_{j=1}^{n} 21 V_j^2 + 21 V_{p+1}^2 \left( P_{p+1} + Q_{p+1} \right) - \left| q \right|^2 \left( P_{p+1}^2 + Q_{p+1}^2 \right)$ |
| $\text{VSI}$ | $\sum_{j=1}^{n} 21 V_j^2 + 21 V_{p+1}^2 \left( P_{p+1} + Q_{p+1} \right) - \left| q \right|^2 \left( P_{p+1}^2 + Q_{p+1}^2 \right)$ |
| Reliability | The probability of a system under which it operates satisfactorily is termed as reliability | $R = \frac{1}{S\text{AID}_{\text{base}}} + \frac{1}{S\text{AID}_{\text{medium}}} + \frac{1}{S\text{AID}_{\text{high}}}$ |
| Power loss | Power loss refers to the $PR$ losses of the system | $P = \frac{P_{\text{elec}}}{V_{\text{base}}}$ |

| TABLE 4  | Overview of charging strategies |
|----------|---------------------|
| Strategy | Description | ToU tariff | Bi-directional flow | Control system requirement | Complexity |
| Uncoordinated charging | Under uncoordinated scheme, the batteries of the EVs take power immediately when arrived at stations and plugged in (even during peak hours) | • | • | • |
| Coordinated charging | In coordinated charging, the EV charging can be shifted to off peak time. EVs participate in this scheme by adapting the rate of power at which the battery is charged | • | • | • |
| V2G | In V2G, EVs can provide grid services by sending power back to the grid, by bidirectional power flow | • | • | • | • | • | • |
involves screening of candidate locations for charging station allocation by BN with voltage sensitivity factor (VSF), charging demand, and failure probability as the parent nodes. The VSF of the two test systems are evaluated by Algorithm 1 and depicted in Figures 5 and 6. Also, it is observed that bus 14 and bus 19 are the weakest buses of test system 1 and test system 2, respectively. The charging demands of the test systems are computed by Algorithm 2 and depicted in Figures 7 and 8. The failure probability of test system 1 can be found in [4] and the failure probability of test system 2 is taken from the logbook of substations.

The probabilities of being candidate locations for the placement of charging stations computed by BN are depicted in Figures 9 and 10. It can be observed that locating the
FIGURE 3 Test system 1 [4]

FIGURE 4 Test system 2 [32, 34]

FIGURE 5 VSF of all the buses for IEEE 33-bus distribution network

FIGURE 6 VSF of all the buses for distribution network of Guwahati

FIGURE 7 Charging demand for IEEE 33-bus distribution network

FIGURE 8 Charging demand for distribution network of Guwahati
charging stations at various buses is better than concentrating on few buses which will create voltage deviation, reliability problem and increased losses. If any node has no space for charging the vehicles, the neighbouring bus can be selected. Accordingly, another favourable position for appropriating the charging station is making the charging station available to a bigger number of EVs handling in various routes. This will decrease the congestion of the particular routes in which charging stations are concentrated.

The set of candidate locations having probability more than 0.6 is shown in Table 5. The optimization problem reported in Section 2 is solved by CSO. The input parameters of the optimization problem are same as in [31]. The general as well as algorithm-specific parameters of CSO are also taken from [31]. The optimization yielded six non-dominant solutions (NDSs) as reported in Tables 6 and 7. The selection of the best plan among the six alternatives depends upon user requirements. Further, three charging scenarios namely uncoordinated charging, coordinated charging and V2G are compared based on VRP index proposed in [4]. A novel index named VRP index taking into account the voltage stability, reliability and power loss is also formulated. The novelty of VRP index lies in the fact that it has the capability of considering voltage stability, power loss, and reliability together under a common frame. The VRP indices for two test systems in case of the three aforementioned scenarios are shown in Figures 11 and 12, respectively. The advantages of coordinated charging and V2G
over uncoordinated charging are prominent from the simulation results.

5 | CONCLUSION

In recent years, both limited fossil fuels and environmental factors have forced automotive manufacturers to produce more efficient and greener vehicles. In this context, the production and use of hybrid and electric vehicles are increasing rapidly. With this rapid change in vehicle technology, user habits have raised important issues, such as the need to increase the numbers of charging stations, updating the electricity grid and increasing their capacities. It will, therefore, become inevitable that existing traditional car parks and fuel stations will have to be equipped with charging units and smart energy management algorithms will have to be developed to ensure their effective use. The formulations consider economic factors as well as secure operation of the power network. Further, the framework compares three charging strategies such as uncoordinated charging, coordinated charging and V2G. The solution methodology is based on a CSO driven heuristics. The simulation consequences indorse the efficacy of the anticipated framework and the advantages of coordinated charging and V2G over uncoordinated charging. The important issues such as quantitative analysis of charging strategies, operation of V2G enabled CSs, techno-economic analysis of smart charging as well as V2G will be addressed in future work.

NOMENCLATURE

Abbreviations

EV Electric vehicle  
CS Charging station  
DR Demand response  
BN Bayesian network  
CSO Chicken Swarm Optimization  
V2G Vehicle to Grid  
ESS Energy storage system  
VSF Voltage Sensitivity Factor  
VRP Voltage stability, Reliability & Power loss (VRP) index

Decision variables

\[ p \] Cite for the placement of CS  
\[ F_{fp}, S_{fp} \] fast/slow CS at location \( p \)  
\[ f_{p}, s_{p} \] fast/slow servers at location \( p \)  
\[ P_{ loss } \] Base value of power loss  
\[ F_{max}, s_{max} \] number of fast CS and sockets  
\[ S_{max}, s_{max} \] number of slow CS and sockets  
\[ F_{min}, s_{min} \] Min fast CS and charging points  
\[ S_{min}, s_{min} \] Min slow CS and charging points

Constant parameters

\[ C_{fast} \] fast CS cost  
\[ C_{slow} \] slow CS cost  
\[ CP_{fast} \] fast CS capacity  
\[ CP_{slow} \] slow CS capacity  
\[ CM_{fast} \] Maintenance cost  
\[ P_{elec} \] Per-unit cost of electricity  
\[ VSI_{base} \] voltage stability index  
\[ SAIFI_{base} \] (SAIFI)  
\[ SAIDI_{base} \] (SAIDI)  
\[ CAIDI_{base} \] (CAIDI)

Variables

\[ P_{gi} \] Active power at \( i^{th} \) bus  
\[ P_{di} \] demand at \( i^{th} \) bus  
\[ Q_{gi} \] Reactive power at \( i^{th} \) bus  
\[ V_{j} \] Voltage of \( j^{th} \) bus  
\[ Y_{ij} \] admittance matrix  
\[ \theta_{ji} \] Angle of \( Y_{ji} \)  
\[ \delta_{ji} \] angle of \( i^{th} \) bus  
\[ \delta_{ji} \] angle of \( j^{th} \) bus

ACKNOWLEDGEMENTS

The authors are thankful to TEQIP-III, govern by NPIU, MHRD India for CRS ID-1–5742567271.

ORCID

Sulabh Sachan https://orcid.org/0000-0003-0309-5001

REFERENCES

1. Dubey, A., Santoso, S.: Electric vehicle charging on residential distribution systems: Impacts and mitigations. IEEE Access 3, 1871–1893 (2015)
2. Deb, S., Kalia, K., Mahanta, P.: Review of impact of electric vehicle charging station on the power grid. In: 2017 International Conference on Technological Advancements in Power and Energy (TAP Energy), pp. 1-6 (2017). https://doi.org/10.1109/TAPENERGY.2017.8397215
3. Deb, S., Kalia, K., Mahanta, P.: Impact of electric vehicle charging stations on reliability of distribution network. In: 2017 International Conference on Technological Advancements in Power and Energy (TAP Energy), pp. 1-6 (2017). https://doi.org/10.1109/TAPENERGY.2017.8397272
4. Dharmakeerthi, N.M., Saha, T.K.: Impact of electric vehicle fast charging on power system voltage stability. Int. J. Electr. Power Energy Syst. 57, 241–249 (2014)
5. Esmaili, M., Goldoust, A.: Multi-objective optimal charging of plug-in electric vehicles in unbalanced distribution networks. Int. J. Electr. Power Energy Syst. 73, 644–652 (2015)
6. López, M.A., et al.: Demand-side management in smart grid operation considering electric vehicles load shifting and vehicle-to-grid support. Int. J. Electr. Power Energy Syst. 64, 689–698 (2015)
7. Shareef, H., Islam, M.M., Mohamed, A.: A review of the stage-of-the-art charging technologies, placement methodologies, and impacts of electric vehicles. Renew. Sust. Energ. Rev. 64, 403–420 (2016)
8. Sachan, S., Kishor, N.: Optimal location for centralized charging of electric vehicles in distribution network. In: 2016 18th Mediterranean Electrotechnical Conference (MELECON), pp. 1–6 (2016)
9. Janic, A.: Two-step algorithm for the optimization of vehicle fleet in electricity distribution company. Int. J. Electr. Power Energy Syst. 65, 307–315 (2015)
10. Yao, W., et al.: A multi-objective collaborative planning strategy for integrated power distribution and electric vehicle charging systems. IEEE Trans. Power. Syst. 29(4), 1811–1821 (2014)
11. Zhao, J., et al.: Robust distributed generation investment accommodating electric vehicle charging in a distribution network. IEEE Trans. Power Syst. 33(5), 4654–4666 (2018)
12. Rahmani-Anbedili, M., et al.: Planning and operation of parking lots considering system, traffic, and drivers behavioral model. IEEE Trans. Syst. Man Cybern. Syst. 49(9), 1879–1892 (2018)
13. Zhang, Y., et al.: GIS-based multi-objective particle swarm optimization of charging stations for electric vehicles. Energy. 169, 844–853 (2019)
14. Parastvand, H., et al.: A graph automorphic approach for placement and sizing of charging stations in EV network considering traffic. IEEE Trans. Smart Grid 11, 4190–4200 (2020)
15. Sachan, S., Deb, S., Singh, S.N.: Different charging infrastructures along with smart charging strategies for electric vehicles. Sustain. Cities Soc. 60, 102238 (2020)
16. Sachan, S., Adnan, N.: Stochastic charging of electric vehicles in smart power distribution grids. Sustain. Cities Soc. 40, 91–100 (2018)
17. Wu, Y., et al.: Demand side energy management of EV charging stations by approximate dynamic programming. Energy Convers. Manag. 196, 878–890 (2019)
18. Faridpak, B., et al.: Two-step I.P approach for optimal placement and operation of EV charging stations. In: 2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), Bucharest (2019)
19. Wang, B., et al.: Adaptive operation strategies for electric vehicle charging stations. In: 2019 IEEE Industry Applications Society Annual Meeting, Baltimore (2019)

How to cite this article: Sachan, S., et al.: Planning and operation of EV charging stations by chicken swarm optimization driven heuristics. Energy Convers. Econ. 2, 91–99 (2021). https://doi.org/10.1049/enc2.12030