SRIP IIT Gandhinagar 2021

Optimal placement of Charging Stations for Electric Vehicles in Indian urban transportation networks

Yamini Sharma

(NIT Hamirpur, Electrical Engineering)

Raavi Patel

(IIT Gandhinagar, Civil Engineering)

Vaibhav Gupta

(IIT Delhi, Mechanical Engineering)

July, 2021

Under the guidance of,

Prof Udit Bhatia

Department of Civil Engineering, IIT Gandhinagar

Table of Contents

ABSTRACT

In this project, we aimed to find out the candidate locations for EV charging stations keeping in mind the Indian transportation and distribution networks. The problem has become critical nowadays as the global issue of pollution has caused the focus of the government to incline towards sustainable ways of system operation. As the transportation sector is found to be the major culprit behind the circumstances, global leaders have discovered the importance of electrification of the sector lately. A major focus on adoption of EVs for the Indian roads is also made by the Indian Government and steps are being taken in this direction. Our work aims to provide a solution to making the urban infrastructure ready for the future EV market.

The charging station placement is a complex optimization problem involving power distribution network and road network and thus its solution must superpose the considerations of both the systems. Therefore, in order to find an optimal solution to this problem, multistage multi-objective solution approach is followed.

Stage I aims at determining the candidate locations based on parameters like voltage stability factor, distance between nodes of traffic and distribution networks and congestion. Furthermore, in stage II optimization of the candidate locations based on cost of installations, system up-gradation, penalties, range anxiety etc.is carried and trade off solutions are obtained.

Initially, analysis is done on a 25-node transport network superposed on a 33-bus radial distribution network. Thereafter, the proposed model is applied to real networks viz Indian cities like Chandigarh, Delhi, Ahmedabad

INTRODUCTION

The problem of optimal placement of charging stations is addressed as below:

Interface	Criteria for siting and designing
Urban network	• Proximity to Traffic: Large-scale traffic patterns determine viability of locations for most commercial operations, thus this data could be used to place a charging station • Proximity to building entrances: Placement of the EVCS is determined by its visibility and accessibility, typically with respect to priority parking spaces.
Power network	• Electrical capacity: Connecting EVCS to a power source will require evaluation of existing electrical capacity. This has two parts: the electrical system at the location of the EVCs installation, and the capacity of neighborhood systems to support charging many EVs at once. • Construction cost & proximity to power system: The cost differential for EVCS installation is represented by the power interface. Considering a site’s power sources and capacity will help plan for lower-cost installations and operations along with system upgrades.

Compared to the existing works, the present work has following contributions:

- Two stage planning model has been laid for the optimal placement of EV charging station. In first stage, candidate locations are found followed by the optimization to get the best results. Furthermore, distribution network is analyzed to place the DGs effectively.
- The charging station placement problem is modelled in the context of Indian urban cities like Delhi, Chandigarh and Ahmedabad. These cities will be having large EV users, hence, there will be a necessity of sustainable charging infrastructure.
- This work focuses on placing the EV charging station taking into account both the traffic and electric grid parameters.

PROBLEM FORMULATION

The optimal placement of charging station is typical planning problem that requires the interaction of both the transport and distribution networks. It is a multifaceted problem with a number of decision variables, objective functions and constraints. We have formulated the charging station placement problem as a multi-variable, multi-objective and non-linear optimization problem. One of the salient features of the multi-objective formulation of this problem is inclusion of cost, power loss, waiting time as the objective functions, thereby taking into consideration the drivers' perspective.

Brief of solution approach along with the objective functions and constraints is presented.

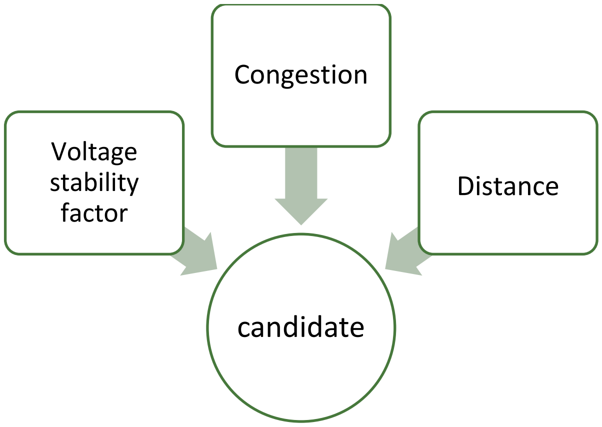
ASSUMPTIONS:

- Urban setting
- Large EV penetration
- High utilization ratio
- Focus on FCS
- Sustainable solutions

STAGE I: SELECTION OF CANDIDATE LOCATIONS

In the first stage, the potential locations for the placement of charging stations are determined using a probabilistic approach based on Bayesian network. It is often assumed that charging stations may be placed at the meeting points of distribution and road network, thereby making them the candidate locations. However, some of these nodes may have high traffic intensity while there is chance of some of these nodes being vulnerable points of the grid in terms of voltage stability, reliability etc.

Therefore, here we consider distance of the road network nodes from the nearest bus of the distribution network, congestion and grid stability as the key factors for finding the candidate sites for placing the charging stations.



The Bayesian network has 3 parent nodes viz VSF, congestion and distance. Candidate is the child node.

Parameter	State
VSF	Low, Medium, High
Congestion	Low, High
Distance	Low, Medium, High
Candidate	Yes, No

P (candidate = yes) = P (candidate| VSF, congestion, distance) ×P(VSF) × P(congestion) × P(distance)

UNDERSTANDING ABOVE PARAMETERS:

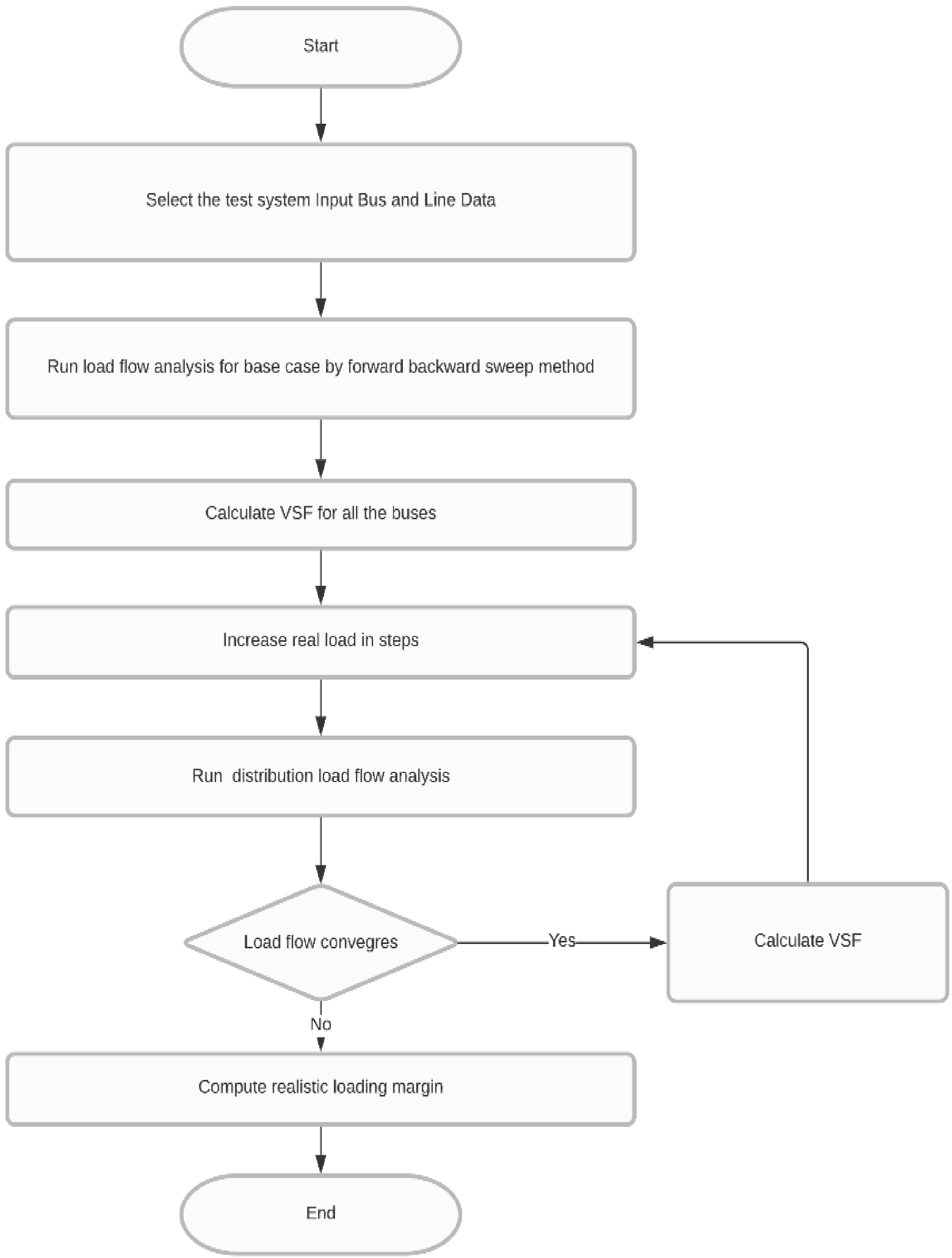
<u>Calculation of VSF:</u>

Voltage sensitivity factor (VSF):

It will help us to determine the weak and the strong buses of the distribution network. A high VSF value indicates that even for a small change in loading, there is a considerable voltage drop, thereby signifying weakness of the bus.

VSF is defined as the ratio of variation in voltage and variation in load. Mathematically,

$$VSF = \left|\frac{dV}{dP}\right| \quad \forall P < P_{\max}$$


Start
Select the test system Input Bus and Line Data
Run load flow analysis for base case by forward backward sweep method
Calculate VSF for all the buses
Increase real load in steps
Run distribution load flow analysis
Load flow convegres
Yes
Calculate VSF
No
Compute realistic loading margin
End

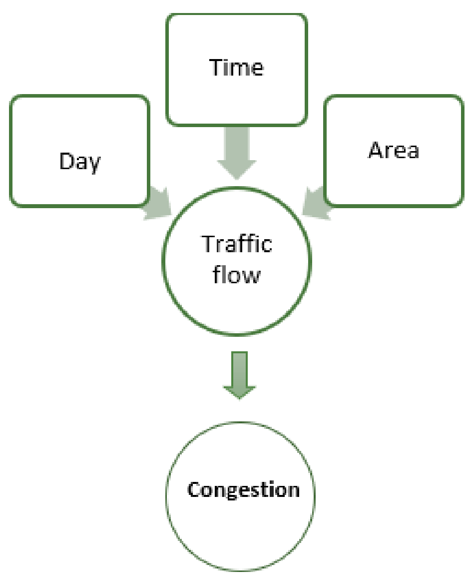
CONGESTION PROBABILITY

A probabilistic approach based on Bayesian network is utilized to find the probability of congestion of the nodes of the road network. The probability of a road network being congested depends on the traffic flow which in turn depends on day of the week, time of the day, and area covered by the road.

Root node	States
Day	Weekday, weekend
Time	AM Peak, Work, PM Peak, Leisure, Rest
Area	Residential (R), Office (O), Market (M), School (Sc)

Child node	States
Congestion	High, low

The probability of congestion being high or low is computed by bucket elimination algorithm.



STAGE II: OPTIMIZATION

The second stage of the proposed methodology involves finding the optimal locations for the placement of charging stations from the set of candidate locations.

This is formulated as a multi-objective optimization problem with cost, power losses, penalties and waiting time at the charging stations as objective functions.

Here is an overview of the multi-objective formulation with objective functions and constraints.

OBJECTIVE FUNCTIONS

1. Cost

   The objective function represents the gross investment cost of joint planning project (cost of installation and operation cost) and the penalty on voltage deviation and AENS.

$$C_{installation} = \{(\sum_{i=1}^{m}(F_i \times f_i) \times C_{fast}\}$$

$$C_{operation} = \{(\sum_{i=1}^{m}(F_i \times f_i) \times CP_{fast}\} \times P_{elec}$$

$$F_1 = \min\,(C_{installation} + C_{operation})$$

2. Cost of penalty

   The second optimization function that has been considered is the cost of penalties to be paid by the utility.

$$C_{penalty} = VD_{penalty} + AENS_{penalty}$$

$$VD_{penalty} = P_{VD} \times \sum_{i=2}^{N_D} VD_i$$

$$VD_i = V_i^{base} - V_i$$

   If after the increase of load the voltage of the buses of the distribution network dropd to less than 0.9 pu then the utility has to pay the penalty for voltage deviation.

$$AENS_{penalty} = P_{AENS} \times AENS$$

$$\frac{\sum L_i U_i}{\sum N_i}$$

$$F_2 = \min\,(C_{penalty})$$

3. Waiting Time

   Under the premise of reasonable utilization rate of the charging station, the shorter the user's waiting time, the higher the customer satisfaction.

   The waiting time in the charging station is modeled by M/M/C queuing theory

$$W_f = \frac{\sum_{i=1}^{m} \frac{\rho_f^{f_i+1}}{(f_i - 1)! \times (f_i - \rho_f)^2} \times P_0^f}{\lambda_f}$$

$$F_3 = \min\,(W_f)$$

Constraints:

$$F_{min} < F_p \leq F_{max}$$

$$f_{\min} < f_p \leq f_{\max}$$

$$Q_i^{\min} \leq Q_i \leq Q_i^{max}$$

$$P_i^{\min} \leq P_i \leq P_i^{max}$$

$$L \leq L_{max}$$

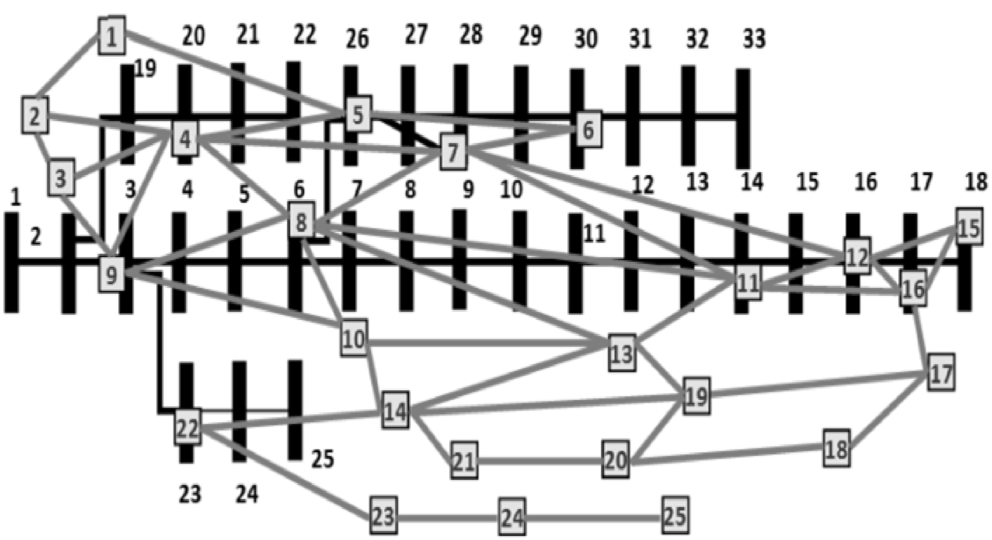
$$P_{gi} - P_{di} - V_i \sum_{j=1}^{N_D} V_j Y_{ij} \cos\left(\delta_i - \delta_j - \theta_{ij}\right) = 0$$

$$Q_{gi} - Q_{di} - V_i \sum_{j=1}^{N_D} V_j Y_{ij} \cos\left(\delta_i - \delta_j - \theta_{ij}\right) = 0$$

TEST SYSTEM

The charging station placement problem is validated on the test network consisting of superimposition of 33 bus distribution network and 25 node transport networks.

The line data, branch data of this network along with outage data can be found in the appendix.



Different types of nodes of the transport network are enlisted in the following table.

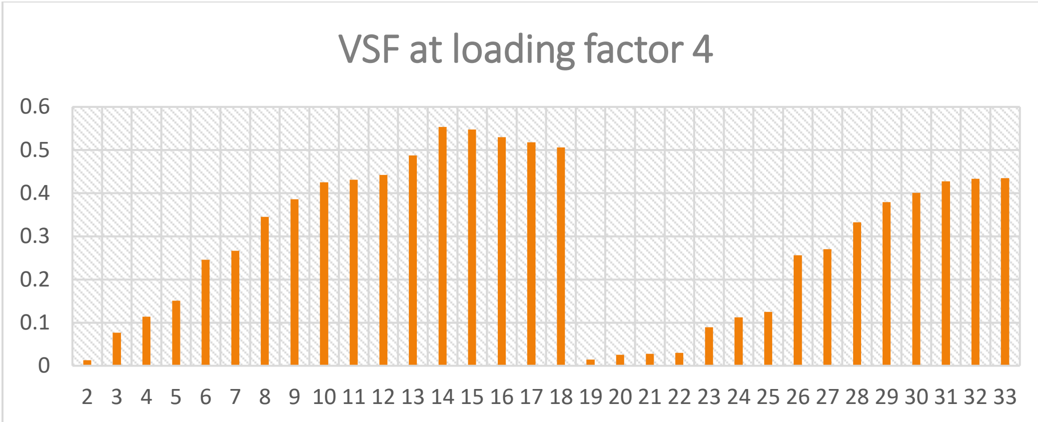
Type	Node No.
Residential	1,2,3,18,20,22,24,25,21
School	4,11,15,18,19
Market	13,14,16,17
Office	5,6,7,8,10,23

Input parameters are numerated in the following table

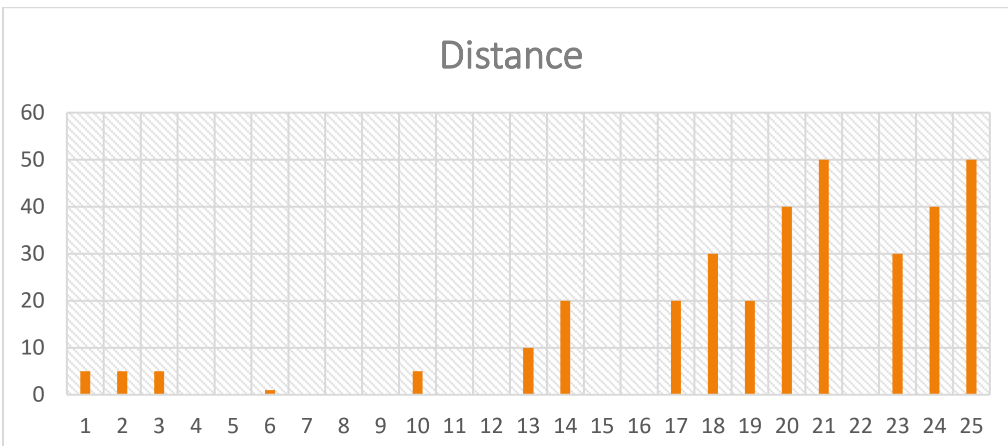
Parameter	Value
C_{fast}	3500$
CP_{fast}	50 kW
P_{elec}	70$/MWhr
λ_f	5.6/hr

Stage 1: Screening of candidate locations for charging station placement

The candidate locations for the placement of charging of charging stations are found using the Bayesian network. VSF of 33 bus distribution network is shown in the following table. Its analysis indicates that the bus 14 of the distribution network has the highest VSF, indicating that it is the most sensitive and vulnerable to voltage instability.



The following graph provides the graphical representation of the distance between road network and its nearest bus of the distribution network.



Bayesian network is used to finally get the candidate locations.

On evaluation, the candidate locations are $P_{candidate}$ = {3, 5, 6, 7, 19, 22, 24}

Stage 2: Optimization – optimal allocation of charging stations

Further, analysis of the impact of EV charging station on Distribution network is done and VRP index has been used to optimally place DGs.

CASE STUDY

Chandigarh, Delhi and Ahmedabad have been considered for case study.

CONCLUSION

Sustainable development of charging infrastructure is must to promote EVs. This work solved the charging station placement problem in the context of various urban cities. Future works in the same field might address some of the critical issues related to charging infrastructure planning like pricing strategies in the charging stations, planning of Vehicle to Grid (V2G) enabled charging stations along the intercity networks.

REFERENCES

[1] *S. Deb, K. Tammi, K. Kalita, and P. Mahanta, ''Review of recent trends in charging infrastructure planning for electric vehicles,'' Wiley Interdiscipl. Rev., Energy Environ., vol. 7, no. 6, p. e306, 2018.*

[2] *S. Deb, K. Kalita, and P. Mahanta, ''Review of impact of electric vehicle charging station on the power grid,'' in Proc. Int. Conf. Technol. Advancements Power Energy (TAP Energy), Dec. 2017, pp. 1–6.*

[3] *S. Deb, K. Tammi, K. Kalita, and P. Mahanta, ''Impact of electric vehicle charging station load on distribution network,'' Energies, vol. 11, no. 1, p. 178, 2018.*

[4] *D. Ghosh, S. Deb, and D. K. Mohanta, ''Reliability evaluation and enhancement of microgrid incorporating the effect of distributed generation,'' in Handbook of Distributed Generation. Cham, Switzerland: Springer, 2017, pp. 685–730.*

[5] *M. M. Rahman, S. Barua, S. T. Zohora, K. Hasan, and T. Aziz, ''Voltage sensitivity-based site selection for PHEV charging station in commercial distribution system,'' in Proc. IEEE PES Asia–Pacific Power Energy Eng. Conf. (APPEEC), Dec. 2013, pp. 1–6*

[6] *S. Deb, K. Kalita, and P. Mahanta, ''Impact of electric vehicle charging stations on reliability of distribution network,'' in Proc. Int. Conf. Technol. Advancements Power Energy (TAP Energy) Dec. 2017, pp. 1–6.*

[7] *M. Mohammadi, F. Jolai, and H. Rostami, ''An M/M/c queue model for hub covering location problem,'' Math. Comput. Model., vol. 54, nos. 11–12, pp. 2623–2638, 2011.*