WEES-2020 Special Issue

J. Indian Chem. Soc.,
Vol. 97, No. 10b, October 2020, pp. 1941-1948

Efficient method to plan EV fast charging station in distribution system using particle swarm optimization techniques

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Manuscript received online 14 June 2020, revised and accepted 06 August 2020

Today the Electric Vehicles (EVs) market in India is growing rapidly but the efficient charging infrastructure or charging stations is for EVs still a big challenge. Due to the problem of depletion of convention fuel sources and increasing pollution by internal combustion (IC) engine based vehicles the EVs are more beneficial and cost-effective and provide social benefits. Therefore adoption of EVs is the alternate source of transportation and the replacement to a as they emit zero carbon emission, energy efficient and are economical. For the expansion of EV market, the charging station infrastructure is very important to provide efficient energy for various EVs. This paper presents the optimal planning of charging infrastructure to establish efficient charging location by considering the power losses, voltage and economic consideration in distributed system. The locations of Electric Vehicle Charging Station considering the network performance parameter are objectives in proposed multi-objective function. The minimum value of multi-objective function decides based on the system performance indices as power loss, charging cost, voltage deviation and reliability indices.

Keywords: Electric Vehicles (EVs), EV fast charging stations (EV FCS), distribution system (DG), particle swarm optimization (PSO).

Introduction

Concern of global warming, climate change, urban air pollution and credence on ambiguous and costly supplies of foreign oil have advance research and policy makers management to explore alternatives. Electric operated vehicles have the lowest or negligible greenhouse gases and urban air pollutant[7,8].

Of the major industries that have to comply and redesign to medicate the present scenario of sustainable development, vehicle assembling is one of the most important requirements[7,8]. With the availability the electric vehicle in the present scenario the overall requirement of electrical power increases with a large ratio. To overcome this problem power generation must be increased in the same ratio. Power generation dependence should also decrease from thermal to other conventional source to meet the objective of the implementation EVs that is air pollution.

Dependency on the fossil fuel must be decreased before the implementation of EV because it will not be able to meet our objective. As the pie chart represents we are completely dependent on fossil fuel this scenario should change completely before the implementation EV[18].

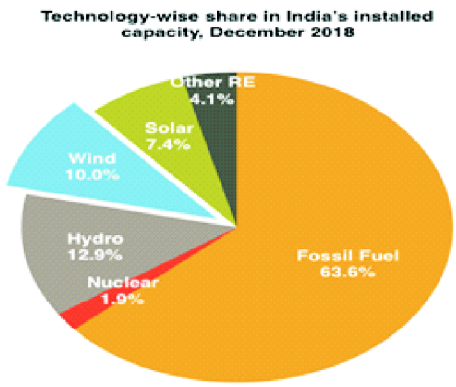

Fig. 1. Pie chart of power generation in India.

After the major change the next step milestone is the life cycle of the batteries of EVs, the cost of the EVs manufacturing and anxiety of charging station as well as the charging[12,13]. All the above mention challenges are the areas of

Table 1

Vehicle type	Fuel	Initial cost (k$)	Battery replacement cost, Life cycle 10 yrs (k$)	Specific fuel consumption (MJ/100 km)	Specific fuel cost (k$/100 km)	Range of driving (km)
Conventional	Gasoline	15.3	1×0.1	236.8	2.94	540
Electric	Electricity	42	2×15.4	67.2	0.901	164

research these days. In this paper focus is on the charging station and the charging time that is allocation of fast charging station (FCS) and also deal with present scenario of the power system configuration to handle the requirement of power by EVs[9,10].

This paper considered the IEEE-33 bus distribution system where EV load is incorporated in the system[1]. Different zones are created considering range anxiety. Each zone has EV fast charging station and each zone is considered to have uniform distribution of EV population. So, this paper allocate the optimum location depending upon the requirement of specific zone having a specific fast charging station which ultimately overcome range anxiety.

As the Table 1 represents the technical and economical characteristics for conventional and EVs[7]. The table completely expresses the advantages as well as the disadvantage in broad point of view. In spite of major disadvantage like initial cost and battery replacement cost one of major concern of motivation toward EV is the running cost that is fuel cost. Fuel cost of EV is almost one third of the conventional vehicle. Other anxiety of pursuing EV is the availability of charging station because the table represents the driving range of the EV. In this paper our major concern deals with the driving range anxiety. The driving range anxiety can be decreased by increasing the charging station in the specified range limits as we are having the conventional gasoline station.

Station development

The FCS consists of Sub-station consisting overhead line. Sub-station consists of low voltage and high voltages buses and having two parallel transformers[13].

Station development has need of equipments and land area. Variation of equipments price is considered linear which has dependence on the rating and number of the connector points to be installed. Each connector requires area at least 9′ width and 18′ length. And clearance between each connector is considered to be 3′. Area required for each connector to be assumed being 25 m^2.

or station, the installation cost (SIC_i) is then calculated as:

$$SIC_i = C_{ini} + 25 \times C_{land} \times S_i + RP \times C_{con} \times (S_i - 1) \quad (1)$$

where,

RP - connector capacity power, kW;

C_{con} - connector installation cost, \$/kW;

C_{ini} - capital cost, \$;

C_{land} - rental cost of land per annum, \$/m^2; and

S_i - connector's quantity

The Rating of station (in KW) SC_i:

$$SCi = RP \times Si \quad (2)$$

System parameters

This paper deals mainly with three parameters that is voltage profile, power losses and reliability.

Voltage profile:

Quality of power depends upon two factors that are frequency and voltage. If voltage deviation is within the limits then power is considered as good quality of power. All equipment is designed to operate smoothly on a certain voltage or with a variation of 5%.

Power losses:

Active power loss:

$$PL = \sum_{i=1}^{N_{br}} |I_i|^2 \times R_i \quad (3)$$

Reactive power loss:

$$QL = \sum_{i=1}^{N_{br}} |I_{br}|^2 \times X_{br} \quad (4)$$

where,

R = resistance of the line

X = inductance of the branch

I_i = bus current

I_{br} = branch current

As the load is increased in the system the value of current is increased in the system which leads to the increase in power losses.

Reliability:

The primary objective of the power system is to provide its customer uninterrupted power supply. System ability to satisfy consumer power demand is termed as power system reliability[2,17]. Power outage has several factors like load condition, worst weather, environment state, failed equipment and improper planning. The outage has a major impact on the economical aspect for the power sector as well as the power consumer. The importance of reliability came into existence after the large scale blackout. Now reliability is the part of the power system for designing and planning points of view. It is also considered for the operation and maintenance of the power system. For calculation point of view, there are a lot of indices to measures reliability like ENS (Energy not supplied), LOLP (Loss of load probability), EFLC (Expected frequency of load curtailment), EDLC (Expected duration of load curtailment) and LOLE (Loss of load expectation). In this work, we are using the index that is ENS. ENS mathematical formula can be given as:

$$\text{ENS} = \beta\mu\sum_{i=1}^{N_{br}}\gamma_i |I_{ik}| \times V_{rated} \tag{5}$$

where,

N_{br} = number of branch or line

β = load factor

μ = repair duration

γ_i = failure rate of k-th bus

I_{ik} = peak load branch current

V_{rated} = rated voltage

Mathematical formula for reliability can be given as:

$$\text{Reliability} = 1 - \left(\frac{\text{ENS}}{\text{PD}}\right) \tag{6}$$

where, PD = total power demand.

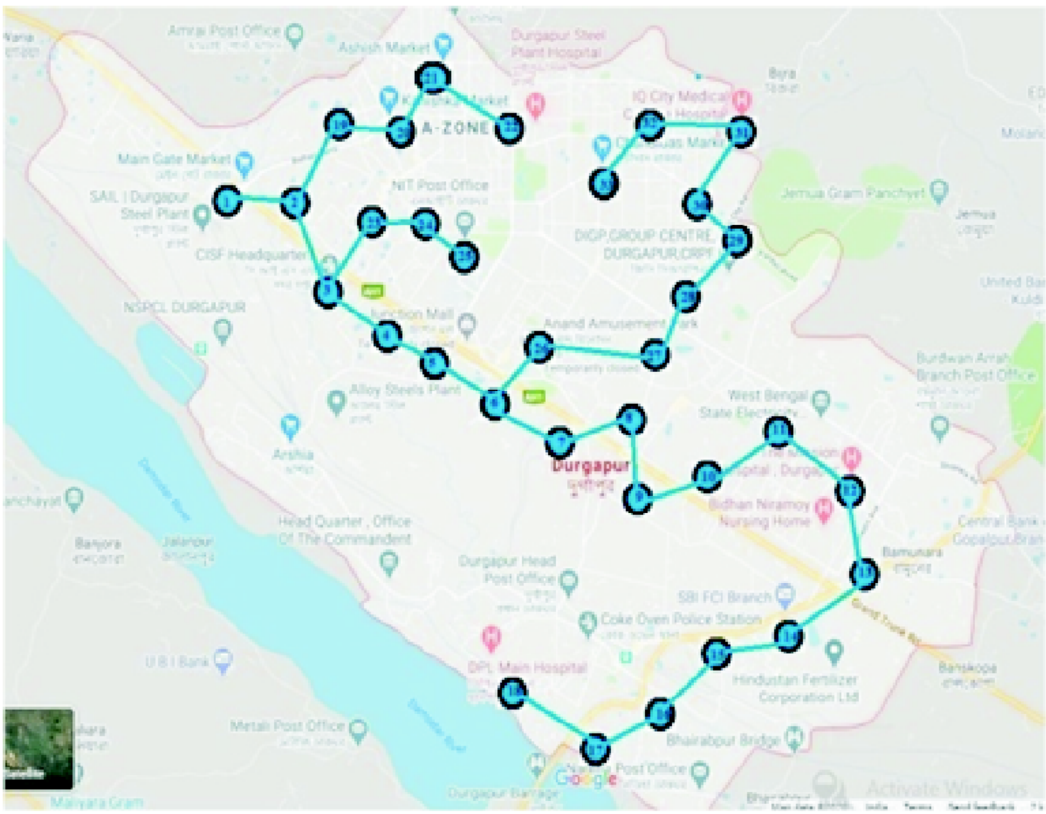

Fig. 2. Durgapur with the placement FCS.

Defining problem

Our objective is locating the EV charging station; there must be charging station of EV considering the technical and economical aspect. We tries to find fast charging station in all the four zones distribution system[13] (IEEE-33). Considered the Durgapur map having 33 bus configurations as shown in Fig. 2, where four different FCS is to be placed in different zones.

Consider the area in 4 different zones as Z_1, Z_2, Z_3 and Z_4. Each zone has uniformly distribution EV population. Each zone has different sets of buses mentioned below:

Z_1 ~ {19, 20, 21 and 22}

Z_2 ~ {23, 24 and 25}

Z_3 ~ {27, 28, 29, 30, 31, 32, 33}

Z_4 ~ {9, 10, 11, 12, 13, 14, 15, 16, 17, 18}

So, goal is place the fast charging stations (FCS) where the power loss is minimum which reduces the cost and also the voltage deviation. We have also considered the reliability parameter which is to be maximized.

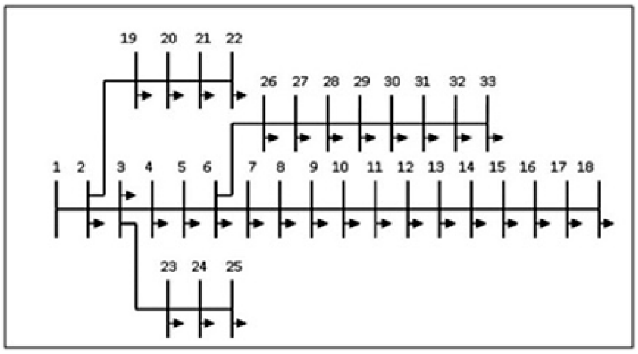

Fig. 3. IEEE-33 Bus distribution system.

Decision variable

Allocating the FCS in all the 4 zones.

Objective function

As mentioned we are optimizing the cost of charging and power loss.

$$Z_1 = \min \{(PL + S_1 + S_2 + S_3 + S_4)\times Pri\} \quad (7)$$

where,

P_{loss} = power loss of distribution system

S_1 = EV FCS No. 1

S_2 = EV FCS No. 2

S_3 = EV FCS No. 3

S_4 = EV FCS No. 4

Pri = cost of unit of electricity

Constraints

Stability of bus voltage depends upon the voltage deviation constraint[1,3]. As the load is increased there is variation in the voltage which must be in the certain range.

Constraints expressed as follows:

$$V_i^{Min} \le V_t^t \le V_i^{Max} \quad (8)$$

where,

$\forall_i \, \varepsilon \, \{1, 2, \ldots\ldots N_b\}$

Penalty voltage functions in the objective function:

$$PVC = [\max(V_{i,t}, V, Max) - V_i^{Max}] + [V_i^{Min} - \min(V_{i,t}, V_i^{Min})] \quad (9)$$

The 2nd constraint is the reliability is designed to be maximized.

$$Z_2 = 1/\text{Reliability} \quad (10)$$

Index function

$$Index_1 = Z_1/Z_{10} \quad (11)$$

$$Index_2 = \max(PVC)/\max(PVC_0) \quad (12)$$

$$Index_3 = Z_{20}/Z_2 \quad (13)$$

The overall objective function is:

$$0 = \min \{x\times(Index_1) + y\times(Index_2) + z\times(Index_3)\} \quad (14)$$

where,

x = price and power loss coefficient (0.4)

y = penalty voltage factor coefficient (0.3)

z = reliability coefficient (0.3)

0: "denotes the initial condition that is without EV (specific in second term underlined like Z_{20})".

Experimental value is considered for the coefficient mentioned above that is x, y and z.

Particle swarm optimization (PSO)

The particle swarm optimization was firstly incorporated in 1995 by experts Eberhart Russell and Kennedy James, which was dealing with fishes and birds social habits of living. This optimization model depends up on the displacement and skill of swarms. This model uses the technique of social interaction (problem-solving). Each swarm is considered as a particle in N-dimensional space which alter its speed and flying technique as per own experience and also the experience of other swarms. It uses the number of swarms (particle) moving in the search space for the best solution[14,16].

(a) Each swarm keeps the record of its solution space which helps to obtain the fitness (best solution) that has obtained till now. This is termed as personal best (p_{best})

(b) PSO keeps the track of another best value obtained till now by any swarm (particle) in the neighborhood of that swarm. This is termed as global best (g_{best})

(c) PSO basic concept lies in accelerating each particle towards its personal best (p_{best}) and global best (g_{best}) locations, with a random weighted factor in every step time.

The basic two equations for updated values of velocity and population for i^{th} iteration are given as:

$$V_i^{t+1} = V_i^t + C_1 U_1^t \left(pb_i^t - P_i^t\right) + C_2 U_2^t \left(gb_i^t - P_i^t\right) \tag{15}$$

$$P_i^{t+1} = P_i^t + V_1^t \tag{16}$$

where,

V_i = inertia of the particle

p_i = position of the particle

pb_i = personal best solution

gb_i = global best solution

c_1 and c_2 = random weighted factor

t+1 = updated value

The different PSO parameters consider for case study are such as c_1=c_2=2, inertia weight (w) range 0.95 to 0.4. Also, the total number of trials is 30 and the total number of iterations is 50 correspondingly defined here.

PSO algorithm for EV FCS allocation optimization

<u>STEP 1:</u> Read input data of IEEE-33 bus system.

<u>STEP 2</u>: Run power flow and evaluation all the system parameter without EV FCS Station.

<u>STEP 3</u>: Updating of some parameter in the test system.

<u>STEP 4</u>: Initialization of the EV FCS location of the entire four zone.

<u>STEP 5</u>: Run power flow and evaluate all the system parameters.

<u>STEP 6</u>: Evaluating initial fitness function using multi-objective function.

<u>STEP 7</u>: Compute local best and global best.

<u>STEP 8</u>: Update swarm velocity and swarm position.

<u>STEP 9</u>: Update EV FCS Station location based on the swarm and updated system data.

<u>STEP 10</u>: Calculate fitness using multi-objective function.

<u>STEP 11</u>: Compute and update local best and global best.

<u>STEP 12</u>: Check for maximum iteration limit or converging criteria if exceed move next step <u>else go to STEP 7</u>.

<u>STEP 13</u>: Print the EV FCS Station location

Case study

To meet the increased load demand of EV charging stations following implementation are to be done:

Assumption and setting

1. Requirement of fast charging station (FCS) is being considered at different location before implementation of optimization[1,3].

2. Although it doesn't makes difference any difference in the solution but, we are considering the Tesla Model S (released in 2014) having:

Efficiency - 92%

Battery capacity - 85 kWh

3. We are considering three charging station in which each charging station can at least 20 EV at a time which means overall system can charge 60 EV.

4. Considered the Durgapur map having 33-bus configurations as shown in Fig. 4, where four different FCS is to be placed in different zones.

5. For the reliability calculation, considered the energy not supplied (ENS) equation.

Table 2. Result obtained

Objective Function	4.926440795
EV Station no. 1 Location	9th bus
EV Station no. 2 Location	28th bus
EV Station no. 3 Location	25th bus
EV Station no. 4 Location	22nd bus

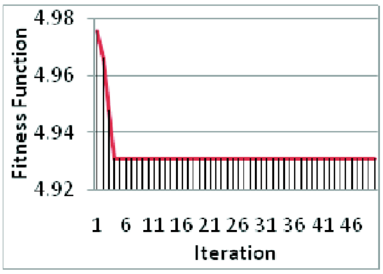

Fig. 4. Fitness function convergence with EV Station only.

Electrical distribution system

We have changed the IEEE-33 bus system. Overall load of the system is increased from 3.75 MW to 11.1 MW. So, we raised the active load as well the reactive load in the same proportion that is 11.1/3.75 and to meet the demand we have to alter different parameter like overall voltage of the system is raised from 12 kV to 20 kV. As well as the parameter like resistance and inductance of the line to be reduced with a factor that is (2/3). Maximum and minimum voltage deviation is to maintained from 1.05 p.u to 0.95 p.u. It is assumed the initially the EV charging station are consider at the bus number 18, 12, 33 and 28.

As we are using the distribution system which has high R/X ratio as well as the unbalanced load then we cannot use the Newton-Rapson or Guass-Shield method of power flow studies. For the distribution system we usually the help of forward and backward sweep method of load flow study.

Load flow – Forward and backward sweep method (Algorithm)

STEP 1: Initialization current = 0 and initialization voltage = V_0

STEP 2: Compute node current I_b using Node model

STEP 3: Backward compute branch current using link model and KCL

STEP 4: Forward update $V_{K+1} = V_k$ based I_b over link model

STEP 5: Check the convergence d(s)< error limit stop or go to step.

Results

The result is expressed in this section.

To evaluate the PSO algorithm we have used the 10 trial and 50 iterations for evaluating the accuracy of the result.

As the Fig. 2 displayed the overall bus configuration in Durgapur City which has 4 different zones as Z_1, Z_2, Z_3 and Z_4. Each zone has uniformly distributed EV population.

Results of different zones are as follow:

Z_1 FCS is 22.

Z_2 FCS is 25.

Z_3 FCS is 28.

Z_4 FCS is 9.

As the graph below represents that the fitness function coverges at 23rd iteration of the best trial.

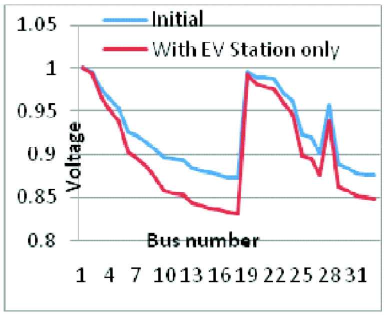

Fig. 5. Voltage graph with EV Station only.

In above Fig. 5 represents the voltage profile of all the two cases that is initial and with EV only.

Above Fig. 6 represents the reliablity of the system of the initial (case 1) and the system connected with EVs (case 2) respectively. The reliability of the system increases by 1.63 percentage after implementation of FCS in the system. As the load increases then the realibililty should decrease but

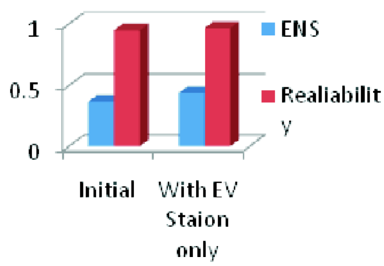

Fig. 6. Bar gragh of ENS and reliability.

the objective function is designed in such a mannner that it improves the reliability because of higher dependence on the the weightage factor of the reliability index.

P and Q losses of the system is represented below with two cases that is initial and with EV Stration.

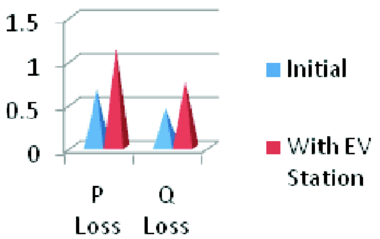

Fig. 7. Real and reactive power losses.

Table 3

Parameters	Initial	With EV Station only
ENS	0.3658	0.4396
Reliability	0.9493	0.9665
Reliability %	94.93%	96.65%

Table 4

Losses	Initial	With EV Station only
P Loss (in MW)	0.667867	1.139965624
Q Loss (in Mvar)	0.445989	0.760827628

Conclusion

This paper allocated the optimum location fast charging station (FCS) in different four zones of the Durgapur city which covers the overall requirements the EV distribution in the city. Particle swarm optimization technique is used to allocate the best location FCS in the city. Overall PSO is used for minimization of cost by minimizing the power losses, minimization of voltage deviation and maximizing the reliability of the system. Also calculated the station infrastructure cost (SIC), which is fixed as per the land area requirement as well as the electrical equipment like connector, transformer etc. The placement of FCS at different location is bus number 9, 22, 25 and 28. Each location FCS is best location as per the concern of this paper that is it dependence of cost, voltage and reliability. But, this paper has considered the FCS requirements before the implementation of optimization.

Acknowledgements

Authors want to acknowledge NIT Durgapur to provide the research platform and supporting for it.

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