IARJSET

ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 8, Issue 9, September 2021

DOI: 10.17148/IARJSET.2021.8938

Planning for Optimal location of Charging Station for EV in Distribution Network with stability condition

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Abstract: A methodology is presented here to determine the optimal location and size of charging station in distribution system by maintaining stability conditions and also investigated in what way electric vehicle charging station affects the electric distribution network by observing active & reactive loss, voltage deviation power flow through transmission line. The method carried out evaluates the maximum utilizations of primary energy resources, considering all the operating constraints and distribution network stability. The optimal location and charging stations capacity are explored in different case studies in which we analyze impact of single charging station and three charging stations with different capacities in distribution network. IEEE 33 Node distribution network is used to verify the effectiveness of the proposed method.

Keywords: Electric vehicle, voltage deviation, charging station location, size, distribution network constraints.

1. INTRODUCTION

People depend on fossil fuels, particularly petroleum, as the prime source of conventional vehicles. As the count of vehicles increases day by day, pollution issues has become more serious.it is believed that the large penetration of Electric vehicle helps to reduce the greenhouse gases emission. Electric vehicles have low pollution and sustainability. Therefore countries make Electric vehicles as one of the national strategic plans [1-5]. Several categories of Electric vehicles available in market namely Battery Electric Vehicles, Hybrid Electric Vehicles and Plug-In Hybrid Electric Vehicles. However, BEVs have huge battery storage systems, since this is the only source of power responsible for their move [6-9].

As the EVs are penetrated they get charge from power grids and sometimes to discharge their batteries. The penetration of EVs as developing electrical load for distribution network has drawn care. The peneteration of EVs may cause electrical surges in demand side at peak hours and therefore harm the stability and security of the distribution network. Best solution is to use the potential of EVs as movable energy storage devices, during off-peak hours EVs withdrawing electricity from grid and during peak hours feeding back energy to grid deposited in batteries [7-10].Several authors have been studied the effect of EVs under various charging and discharging strategies in distribution network [10-13]. For stable operation of distribution grids with EV charging station it is essential to develop EV load models.

Several papers focused on EVs bulk penetration produce adverse effects on distribution system [17-19].In [16], the transient voltage margin index of the distribution system due to EV penetration in discussed. From [17] voltage profiles and stability in weak buses have negative effects due to large load composed by EV charging stations. According to [18] power quality and losses of distribution network is greatly affected due to uncoordinated EV charging station. EVs penetration in distribution network has other issues like voltage sag, harmonics, flicker caused by AC/DC [21].

A method to plan optimal locaitonof EV charging station with maximum capacity in distributinn netwok. At the same time safety and stability of distribution network is also considered. high penertation of EVs in distribuiton netwok violated the voltage boundaries and power flow limits hece affects the power network security. to check the voltage violence sensitivity and pwer flow violence sensitivity is poposed. Various equality and inequality costriants are defined for safety and stability of distribuiton network and tested.

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2. PLANNING FOR LOCATING CHARGING STATION WITH STABILITY CONDITION

Now adays location planning of EV charging stations in any distribution network is a great challenge. Before planning of EV charging stations we need to consider many factors, like capacity of charging station, number of vehicles in distribution network, location of charging station, available power capacity of that area as well as the safety and stability of that network. In this section intially, capacity of charging station is planned next safety and stability of the network equality and inequality constraints are defined.

2.1 Distribution network capacity mode:

we have estimated total load of the 33 bus Distribution area by using first equation

$P_{D,dn,new} = P_{D,dn} + P_{dn,loss} + P_{res}$ (1)

Where,

P_{res} = 10% of load

$P_{D,dn}$ = demand of distribution network

$P_{dn,loss}$ = Active loss of distribution network

Equation 2 gives electric vehicle charging station capacity

$EV_{csc} = P_{D,dn,new} - P_{dn}$ (2)

where, P_{dn} = Total power available in distribution network

For IEEE 33 bus distribution network total power available in the network is 10MW. Total fixed load of the network is 3.7 MW. For base case active loss is 0.20MW.

Therefore $P_{D,dn,new}$ = 4.27MW and EV_{csc} = 5.73MW

On assumption it is given that 7.2KW energy is required to charge one electric vehicle then total number of vehicles to be charged is approximately 690.

2.2 Constraints

EV charging capacity and location is restricted from following grid safety constraints.

2.2.1 Equality constraints

$$\text{(i)} P_{dn,i} - P_{D,dn,i} - \sum_{i=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} + \delta_i + \delta_j) = 0 \quad (3)$$

$$\text{(ii)} Q_{dn,i} - Q_{D,dn,i} - \sum_{i=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} + \delta_i - \delta_j) = 0 \quad (4)$$

Where,

$P_{dn,i}$, - Real power available at i^{th} bus of distribution network

$Q_{dn,i}$– Reactive power available at i^{th} bus of distribution network

$P_{D,dn,i}$- Real power demand at i^{th} bus of distribution network

$Q_{D,dn,i}$-Reactive power demand at i^{th} bus of distribution network

n- Number of buses

$|V_i|$-Magnitude of voltage at i^{th} bus

$|Y_{ij}|$ - Admittance value between i^{th} and j^{th} buses

θ_{ij} - Admittance angle between i^{th} and j^{th} buses

$\delta_i \delta_j$ - voltage angle of i^{th} and j^{th} bus

2.2.2 Inequality Constraints

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A. Real power maximum and minimum limit

$P_{dn,i}^{min} \leq P_{dn,i} \leq P_{dn,i}^{max}$ (5)

Where,

$P_{dn,i}^{min}$ – minimum limit of real power at ith bus of distribution system

$P_{dn,i}^{max}$ – maximum limit of real power at ith bus of distribution system

B. Reactive power maximum and minimum limit

$Q_{dn,i}^{min} \leq Q_{dn,i} \leq Q_{dn,i}^{max}$ (6)

Where,

$Q_{dn,i}^{min}$ – minimum limit of reactive power at ith bus of distribution system

$Q_{dn,i}^{max}$ – maximum limit of reactive power at ith bus of distribution system

C.Bus voltage maximum and minimum limits

$V_i^{min} \leq V_i \leq V_i^{max}$ (7)

where,

V_i^{min}, V_i^{max} - minimum and maximum limit of Voltage at ith bus of distribution system

C. Line flow maximum limit

$S_{i,j} \geq S_{i,j}^{max}$ (8)

$S_{i,j}$ - Power flow capacity of line i-j of distribution network

$S_{i,j}^{max}$ – Maximum power flow capacity of line i-j of distribution network

Voltage, Power flow violence sensitivity for any bus is given below

$$VV_s = \left[1 - \left(\frac{S_{ij,k}}{S_{ij}}\right)\right] * 100 \quad (9)$$

$$VV_s = \left[1 - \left(\frac{V_{ij,k}}{V}\right)\right] * 100$$

Where, $V_{i,k}$is the voltage of bus i with EV charging station

The equality constraints (3) and (4) satisfy the real power with demand and reactive power with demand balance at load buses of distribution network. The inequality constraints (5) and (6) show the upper and lower limits of real and reactive power available at load buses of distribution network. The voltage limit constraint (7) presents the upper and lower boundary limit of bus voltage magnitude. Constraint (8) ensures that the line loading should not exceed its maximum line flow limit of distributionlines.

3. EV CHARGING STATION LOCATION PLANNING

One of the major issues during the installation of EV charging station is location identification in existing distribution network. Simultaneously estimating the maximum number of vehicles to be charged is also a challenge. To deal with this crucial challenge, in this paper, a novel approach is used to estimate EV charging statin capacity by calculating total number of electric vehicles that can be charged in existing distribution network. After estimating maximum number of vehicles in the distribution system, a novel four step framework has been suggested to identify the best location to install EV charging station with maximum capacity in any distribution network. In this framework in each step both equality and inequality constraints, voltage violence and power flow violence are checked.

Step 1: In step 1 maximum number of vehicles that can be charged is calculated based on Distribution network capacity mode. An IEEE 33 bus distribution network is given below in fig.1 which is considered for estimating charging station capacity and location in existing network without violating the distribution network constraints. The distribution network can be divided into four areas. 10MW is the total generation capacity of distribution network is with fixed load of 3.7MW. Table I gives the detail of area wise connected consumers with the total load of that area in KW. Extreme number of EVs that can be charged by Distribution network capacity mode is 690 for base case. But, it is not a practical approach that all customers are using EV vehicle and all EVs are charged at the same time. Here assume that only 30% of customers are using EVs. Total active and reactive losses for base case are 0.203MW and 0.14MVAr respectively.

IARJSET

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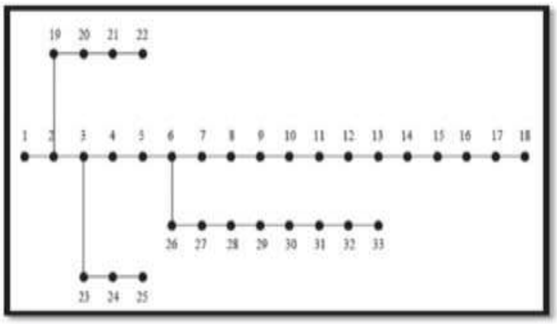

Fig.1. IEEE 33 bus system

Table.1. Area Wise Load Distribution

Connected Consumer Nodes	Area	Customers	Total Load (KW)
CN6 — CN7-C8-CN9- CN10-CN11—CN12- CN13-CN14-CN15 — CN16-CN17-CN18	Area 4	215	1075
CN6-CN26-CN27-CN28- CN29—CN30-CN31-CN32-CN33	Area 3	196	980
CN3-CN23-CN24-CN25	Area 2	204	1020
CN2-CN19-CN20-CN21- CN22	Area 1	92	460

Step 2: Distribution network is simulated with single charging station of 100EVs capacity at each consumer node to identify the location of charging station with equality and Inequality constraints does not violate. In IEEE 33 Bus distribution network the optimal location of charging station is determined by MATLAB simulation based optimal power flow solution. For each consumer node (CN) with charging station of 100 EVs capacity is simulated using OPF program. Total active and reactive loss, voltage, lines flow can be found by solving above mentioned optimization problem. Next check whether real and reactive power limits, voltage limits and all line flow limits are within the maximum limits or not. The figure given below shows the total active loss, reactive loss at each consumer node (CN). However, constraints are violated for CN 8-18 and CN 28-34 hence it is not possible to install EV charging station in these consumer nodes. From the figure given below it clear that CN2, CN3, CN19, CN20, CN21 and CN22 are the best optimal location for charging station. CN4, CN6, CN23, CN24 can also be considered for locating charging station and CN5, CN7, CN25, CN26 and CN27 are not suitable for locating charging station as active and reactive losses are high.

Step 3: IEEE 33 bus Distribution system is simulated by OPF program, initially with two charging station of capacity 100EVs. The combination of two charging station with 100EVs capacity is not possible at any combination of consumer node meanwhile constraints limits are violated. One charging station with 100EVs and two charging station with 50EVs are simulated. First combination with 100EVs capacity is at CN 6 and two charging station with 50 EVs capacity is at CN2 and CN3 respectively.

Step 4: Keeping in view that customer can also charge their vehicle at home so we are increasing 10% load of Individual customer. The best grouping of charging stations of different capacity at different location with

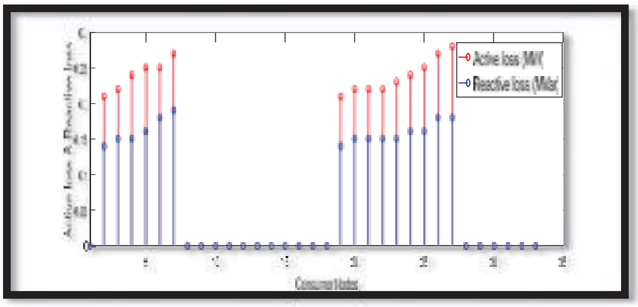

Fig.2. Impact of single chaging station

increased customer demand without violating constraints are identified. Here OPF program is simulated for IEEE 33 bus Distribution system with increased demand and two EV charging station of different capacity at location

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identifies in step 2. First Combination with charging station at CN2 with 50 EVs CN6 with 50 EVs capacity and Second combination with charging station at CN2 and CN3 with 50 EVs capacity respectively.

4. DISTRIBUTION NETWORK STABILITY ANALYSIS

This section shows the effectiveness of the proposed methodology for optimal location of EV charging station by analyzing the impact of charging station on stability of any distribution network. Four cases are considered to evaluate the impact of EV charging station on stability of distribution network below.
Case1: The base case study is carried out without any charging station
Case2: With charging station at CN2 with 50 EVs and CN3 with 50 EVs and CN6 with 100EVs
Case3: Increase in load with 10% and with charging station at CN2 (50 EVs) and CN6 (50 EVs)
Case4: With 10% increased load and with charging station at CN2 (50 EVs) and CN3 (50 EVs)

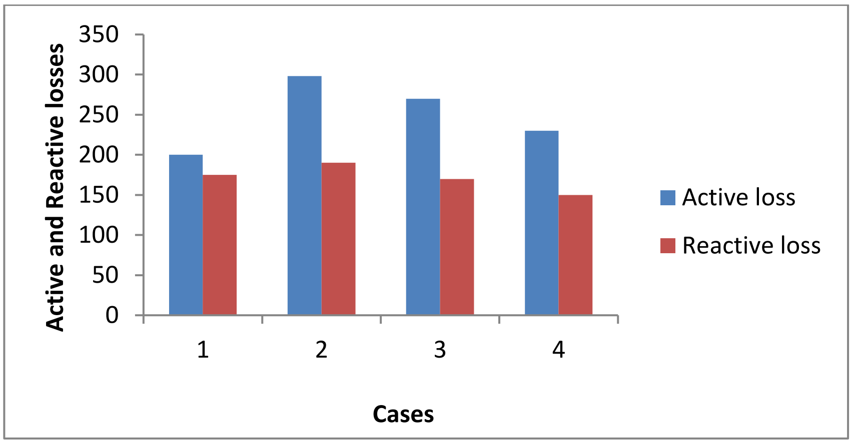

Fig.3.Active and Reactive losses of 4 cases

Table.2. Charging Station with area covered

Case	Charging Station	Charging station location	Covered Area	Maximum EVs charging capacity
Case4	1	CN2	A1	50
	2	CN3	A2	50
Case3	1	CN6	A3 and A4	50
	2	CN2	A1	50
Case2	1	CN6	A3 and A4	100
	2	CN2	A1	50
	3	CN3	A2	50

Four cases losses (active and reactive) are shown in fig.3. For case1 as it is a base case with no charging station losses are low. Losses are greater in case 2 as in this case three charging station with capacity of 200EVs are installed. However in case 3 and 4 the charging capacity is same but losses are altered. It can be easily concluded from figure shown above that case 4 has minimum losses with 100EV charging capacity. From all these four cases it is concluded that for 100EVs charging capacity case4 give the best location with minimum losses and for 200EVs charging capacity case 2 is the only solution.

Table.3. Voltage Violence Sensitivity in percentage(%)

Consumer Node	Case4	Case3	Case2
CN1	0.00	0.00	0.00
CN2	0.00	0.00	0.00
CN3	0.00	0.00	0.00
CN4	0.00	0.00	0.00

CN5	1.03	1.03	1.03
CN6	1.05	1.05	1.05
CN7	1.05	1.05	**2.11**
CN8	1.10	1.10	1.10
CN9	0.00	1.10	1.10
CN10	1.10	1.10	1.10
CN11	1.10	1.10	1.10
CN12	**2.15**	**2.15**	**2.15**
CN13	1.1	1.10	1.10
CN14	1.10	1.10	1.10
CN15	**2.17**	**2.17**	**2.17**
CN16	**2.17**	**2.17**	**2.17**
CN17	1.10	1.10	1.10
CN18	1.10	1.10	1.10
CN19	0.00	0.00	0.00
CN20	0.00	0.00	0.00
CN21	0.00	0.00	0.00
CN22	0.00	0.00	0.00
CN23	0.00	0.00	1.02
CN24	0.00	0.00	0.00
CN25	1.03	0.00	1.03
CN26	1.05	1.05	**2.11**
CN27	0.00	1.06	1.06
CN28	0.00	1.08	1.08
CN29	1.08	**2.15**	**2.15**
CN30	1.10	1.10	1.10
CN31	1.10	1.10	**2.17**
CN32	1.10	**2.17**	**2.17**
CN33	1.10	**2.17**	**2.17**

Four cases have been considered the first case is the base case study. In case study we install only one charging station of 100 EVs charging capacity at each consumer node. One charging station in some distribution network cannot link all areas. It is tried to cover all areas by assessing optimal location and size of charging station with stability condition in different case studies. From table II it can be analyzed that case 2 give the most suitable combination of charging station with 200 EVs capacity. Case 3 also covers four areas with charging capacity is only 100EVs. Case 4 covers only two areas but suitable location from losses consideration.

TABLE.4. Power Flow Violence Sensitivity in Percentage (%)

Line No.	Case 4	Case 3	Case 2
1	28.83	29.59	38.78
2	21.22	21.80	33.72

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3	10.59	26.69	32.63
4	10.36	27.48	34.23
5	10.28	27.57	35.05
6	10.00	10.00	0.00
7	10.11	10.11	0.00
8	10.14	10.14	0.00
9	11.29	11.29	0.00
10	10.71	10.71	0.00
11	9.62	9.62	0.00
12	11.11	11.11	0.00
13	10.26	10.26	0.00
14	11.11	11.11	0.00
15	9.52	9.52	0.00
16	13.33	13.33	0.00
17	11.11	11.11	0.00
18	11.11	11.11	0.00
19	11.11	11.11	0.00
20	11.11	11.11	0.00
21	11.11	11.11	0.00
22	9.57	9.57	0.00
23	9.41	9.41	1.18
24	9.52	9.52	0.00
25	10.53	10.53	0.00
26	10.11	10.11	0.00
27	10.98	10.98	1.22
28	10.67	10.67	0.00
29	9.52	9.52	0.00
30	9.52	9.52	0.00
31	11.11	11.11	0.00
32	16.67	16.67	0.00
33 to 37	0	0	0

The voltage violence sensitivity for case 2, case 3 and case 4 shown in table 3. Consumer nodes which are not affected with any charging stations are 1,2,3,4,19,20,21,22,24. The most affected nodes with charging station installation are 7, 12, 15, 16, 26, 29, 31, 32 and 33. Table 4 indicates Power flow sensitivity for all the distribution lines. Power flows are least affected in case 2 but are most affected in case3 and case 4 as load demand of each node is increased by 10%.

CONCLUSION

A robust method is presented to identify the number of electric vehicles in any distribution network by using distribution network capacity mode. For the determination of optimal location and size of EV charging station in any distribution network a novel stepwise framework is proposed. The impact of EV charging station on real and reactive power, voltage and power flow violence shown by different case studies. IEEE 33 bus Distribution systems simulation result shows that maximum 200 EVs can be charged without violating the distribution network

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constraints and the best combination of three charging station with 200EVs capacity to cover the 4 areas of distribution network. To identify the optimal location and size of charging station the distribution network is simulated with increased load demand and it is concluded that case 3 is the suitable location as it covers all area.

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