Potential Drop Analysis of a Radial Distribution System with Various Loads

Priyanka Patil, Usha Surendra

Abstract: *At present the green environment plays a crucial part in fighting against the global warming. The Electric Vehicles which are eco-friendly provides the solution for these environmental issues which promotes low carbon emission. In the present scenario variation of the power flow and voltage profile at specific nodal junctions in a radial distribution system, when Electric Vehicle has been connected as a load is essential This paper shows the potential drop analysis on a distribution system with Electric Vehicle as a load. The results provide the total real power loss, total reactive power loss occurs in the radial test bus system and the voltage magnitude at nodes for an IEEE standard bus system. The Backward/Forward sweep method has been implemented on IEEE test bus radial distribution system. Various types of loads such as residential, commercial, and industrial with Electric Vehicles are considered for testing. The results indicate that a drop in voltage when Electric Vehicles has been integrated into the grid along with other consumers. The programming results has been compared with standard values and found to be satisfactory. Suggestions' for improving the voltage profile had also included in this paper.*

Keywords: Electric Vehicle, Power loss, Radial distribution system, Voltage drop

I.   INTRODUCTION

The rapid consumption of fossil fuel has led to depletion of energy sources. The increase in the usage of these fuels has affected the environment in any ways such as increase in green house gas emissions, increase in carbon foot print level, emission of CO_2 (Carbon Dioxide), Nitrogen Oxides(NO_x), Sulfur Oxides(SO_x), and other fine particulate matter(PM_{25}). The transport sector is one of the leading contributors to the climate change computing almost 51% of pollution in India [1].With these growing environmental concerns have triggered with the manufacturing of Electric Vehicles (EVs). There exits particularly two type of architecture: pure Battery Electric Vehicle (BEV) and Plug in Hybrid Electric Vehicle (PHEV) which typically works with a combination of combustion engine and batteries [2]. The electrification of

transport has not gained a wide acceptance across various parts of the world, but according to the statistics of "National Electric Mobility Mission Plan (NEMMP) 2020 ", the mission targeted for setting up about 6-7 million EVs in India by the year 2020[3]. In the recent years, the EVs have gained tremendous attention from both the governments and the public in their evolution and popularization. Due to large penetration of EVs in the transportation sector, the power and energy division will experience drastic revolution which affects the power system stability, reliability and power quality issues. The impact of EVs on power systems primarily occurs on the distribution system [4]-[5].

The total population of EVs will directly affect the distribution grid. It has been identified that a huge integration of EVs will gain energy consumption during the charging of EVs, which could lead to considerable change in the different losses such as power flows, grid losses, and voltage magnitude in the grid. Later it was discovered that uncontrolled and uncoordinated charging leads to peak demand, so it is crucial to control the requirement of charging to maintain the variation of the maximum demand [6] –[7]. Later smart charging was designed, which aimed at optimization of the charging process of the EVs [8]-[11]. The impact of EV charging on the radial system can be evaluated by considering thermal loading, voltage regulation, etc [12]. It has been verified that minimizing the power losses is equivalent to maximizing the load factor while less load variation. The standard charging power levels of the IEC6185-1 standards are used in the private sectors, domestic environments, or public areas shown in the table below [13].

Table- I: The standard charging power levels of IEC 6185-1

Mode of Connection	Grid Connection	Voltage (V)	Current (A)	Type of Charge
Mode 1 (AC)	1 phase 3 phase	230 400	16 16	Slow Slow
Mode2 (AC)	1 phase 3 phase	230 400	16 32	Slow Slow
Mode 3 (AC)	1 phase 3 phase	230 400	32 250	Slow Medium
Mode 4 (DC)	--	600	400	Fast

The purpose of this research paper is to analyze the voltage dependency by power flow method for distribution systems with improved convergence characteristics. It is based on polynomial equation on the forward and backward ladder equation for   each branch of the radial distribution system. The load flow is carried on IEEE 85 test bus system.

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There are other methods to calculate the power flow studies like as Guass Seidal, Newton Raphson, Fast Decoupled, DC load flow. But among this Backward-Forward Sweep method is suitable since the above mentioned methods are not appropriate because of non divergence ratio characteristics and also has high R/X ratio in the various branches of radial distribution systems. The loads in the radial systems are basically categorized as domestic, commercial and industrial with their proportion in the total load for power flow and dynamic studies [14]. The research showed that the voltage dependent loads would be efficient particularly for dynamic or static stability studies of power systems.

II. RADIAL DISTRIBUTION SYSTEM

The existing power system contains different kinds of loads such as residential, industrial, commercial loads. The characteristic of such loads is such that their active and reactive powers are dependent on the voltage and frequency of the grid. The load flow methods have great impact depending on the characteristics of the loads and the convergence speed [15]. To understand the complexity of the installed distribution network, Load flow studies are carried on Power Systems. The distribution networks has the following features

- Radial/weakly meshed networks
- High R/X ratios
- Unbalanced load
- Distributed generation
- Multi phase, unbalance operation.

Newton Raphson and other different load flow algorithms do not satisfy the conditions with the distribution networks and also due to the above mentioned drawbacks. Hence Backward/Forward sweep algorithm is implemented to evaluate the radial system. This method do not need Jacobian matrix like NR methods. In [16] proposed an improved method of Backward/Forward sweep method for radial distribution systems which combine the backward sweep and decomposed forward sweep, where backward sweep uses KVL and KCL to obtain the calculated voltage at each upstream bus. The divergent X/R ratios and the convergence properties of the backward/forward analysis are explained in [17].

A. CASE 1. STANDARD IEEE 85 BUS RADIAL LINES

Fig 1 show the radial line diagram of IEEE 85 radial networks with 85 nodes and 84 branches, where node 1 is considered as the reference node or substation node. The system operates at 11 KV voltages. The base case of a system has 2.5703MW real and 2.6222MVAr reactive loads. The base MVA is considered as 100 MVA. By performing the load flow algorithm, the P (Active Power) loss is 316.0698KW Q(reactive power) loss is 198.5720KVAr.
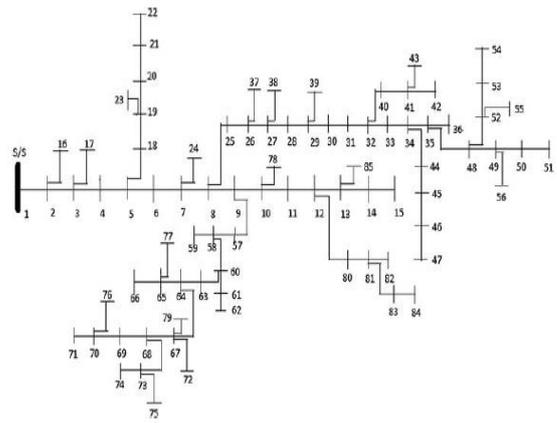

Fig 1Single line diagram IEEE 85 bus system.

B. CASE 2. STANDARD IEEE 85 BUS RADIAL LINES

Fig 2 show the single line diagram of IEEE 12 radial network with 12 nodes and 11 branches, where node 1 is considered as the reference node or substation node. The system operates at 11 KV voltages. The base case of a system has 435 kW real and 405 KVAr reactive loads. The base MVA is considered as 100 MVA. By performing the load flow algorithm, the active power loss is 20.7117KW and the reactive power loss is 8.0393KVAr.
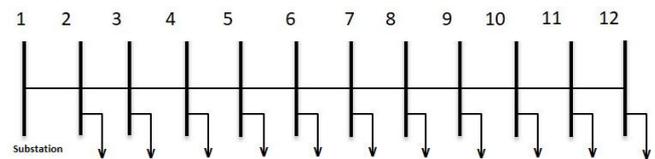

Fig 2 Line diagram IEEE 12 bus system

III. METHODOLOGY

To analyze the potential dip and power loss of the entire test system, Backward/Forward (BW/FW) load flow techniques and programming is done in MATLAB R2015a.The line flow studies in a distribution system are computed by the following iterative equations. The power flow analysis is used to achieve the voltage magnitude profile, the active power loss, the reactive power loss at all the branches of the IEEE 85 and IEEE 12 bus system. The main function is to identify the line flow for domestic and commercial and industrial type of loads in IEEE 85 and IEEE 12 bus radial system.
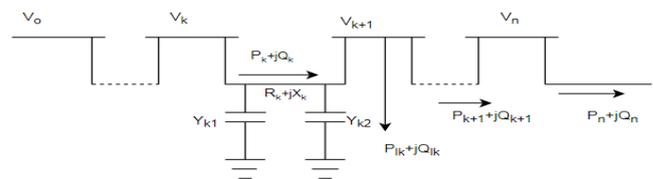

Fig 3 Single line diagram

The line flows in a radial network is estimated by the following sets of successive equations derived from the above single line diagram. The basic objective function is to find the power flow.

$$P_{loss}(k, k+1) = R_k \frac{P_k^2 + Q_k^2}{V_k^2} \quad (1)$$

$$Q_{loss}(k, k+1) = X_k \frac{P_k^2 + Q_k^2}{V_k^2} \quad (2)$$

$$P_{k+1} = P_k - P_{Loss,k} - P_{Lk+1} \quad (3)$$

$$Q_{k+1} = Q_{k-} Q_{Loss,k} - Q_{Lk+1} \quad (4)$$

Where P_k Real power which flows out of bus,

Q_k Reactive power which flows out of bus,

P_{Lk+1} real load power which flows at bus k+1,

Q_{Lk+1} reactive power which flows out of bus k+1,

$P_{loss}(k,k+1)$ is the real power loss in the line section connecting bus k and k+1

$Q_{loss}(k,k+1)$ is the reactive power loss in the line section connecting bus k and k+1.

The total power loss, $P_{T,loss}$ is then calculated by adding up the losses of all the sections which is mentioned below.

$$P_{T,loss}(k, k+1) = \sum_{k=1}^{n} P_{T,loss}(k, k+1) \quad (5)$$

$$Q_{T,loss}(k, k+1) = \sum_{k=1}^{n} Q_{T,loss}(k, k+1) \quad (6)$$

Where $P_{T,loss}$ (k,k+1) represents the total real power in the line section.

$Q_{T,loss}(k,k+1)$ represents the total reactive power loss in the line section [18].

The load flow is determined iteratively by two consecutive sets of successive equations. The first set of equations measures the power flow through the branches starting from the last branch and proceeding in the backward direction towards the root /reference node. The another set of equation measures the voltage magnitude profile and voltage angle of each node starting right from the reference /root node and proceeding forward towards the last node. The two recursive equations consist of backward sweep and a forward sweep.

A. Forward Sweep

The forward sweep is used to calculate the voltage drop while updating the current and power flows in the branches. For the forward sweep, node voltages are updated starting from the first layer to those in the last. The main objective is to determine the voltage at all nodes starting from feeder source to last node.

B. Backward Sweep

The backward sweep is used to calculate the current or the power flow solution while updating the voltage values. For the backward sweep equations the current or the power flow is determined initiating from the last node and moving towards the branches connected to the root/reference node. This implies that the backward propagation starts from the extreme end node and proceeding towards the source node. The calculated voltage values in the preceding and the present iterations are correlated and the consecutive iteration is obtained. The program is terminated until the convergence is attained if the voltage imbalance is less than the specified tolerance i.e., 0.0001. The voltage magnitude and real and reactive power losses of 85 bus system is realized by using

the backward forward sweep method. The minimum voltage of proposed system is 0.9041p.u at 85th bus for base case.
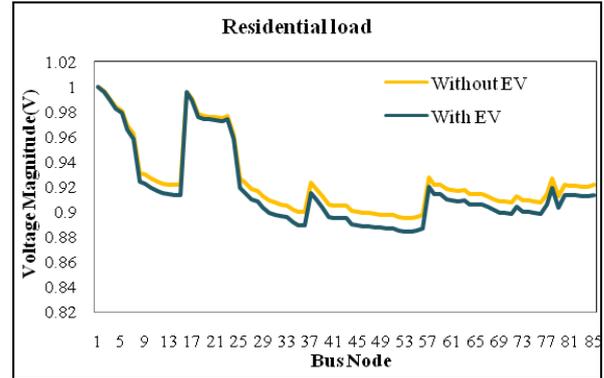

Fig 4 Residential load with EVand without EV for 85 bus system
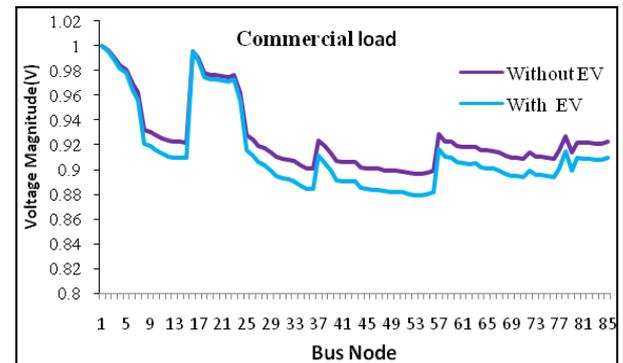

Fig 4 Commercial load with EVand without EV for 85 bus system
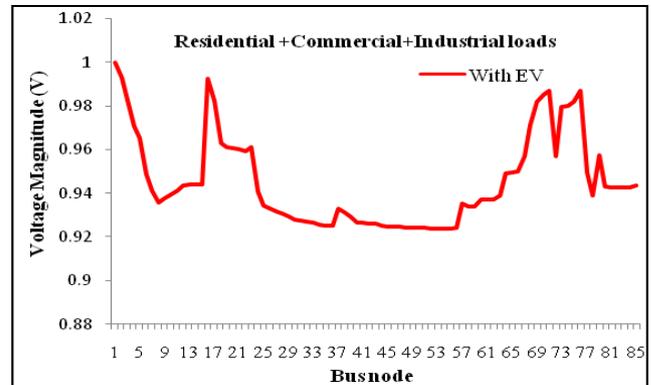

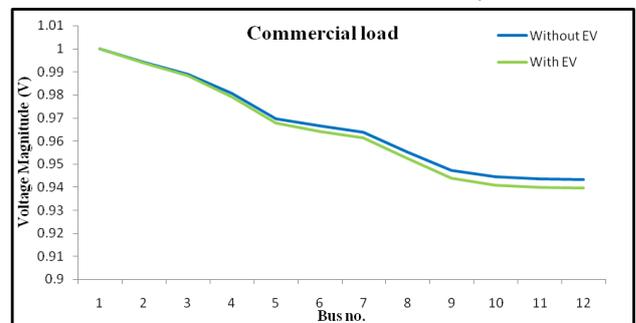**Fig 5 Residential+ Industrial+ Commercial load with EVand without EV for 85 bus system**

Fig 6 Commercial load with EV and without EV for 12 bus system.

IV. RESUTS

The static load flow analysis is solved for a Nominal load, residential load, commercial load and EVs. The simulation result indicates the minimum voltage drop at the nodes, the real power loss and reactive power loss for different types of loads and shown in the table 2. For Case 1, taken as base case for 12 bus test system, Case 2, when all the nodes are considered as commercial with 16 charging slots for 12 bus system, Case 3, when all the nodes are considered as the commercial test load for 12 bus test system, Case 4,when all the nodes are considered as base load for 85 bus test system, Case 5, when all the nodes are considered as residential for 85 bus, Case 6, when all the nodes are considered as residential with 16 charging slots for 85 bus, Case 7, when all the nodes are considered as commercial for 85 bus, Case 8, when all the nodes are considered as commercial with 16 charging slots for 85 bus, Case 9 , where 1-40 nodes are considered as residential, 41-65 are considered as commercial loads, 66-85 are considered as industrial loads with 16 EV charging for 85 bus. All the programs are run in MATLAB R2015 a. Negative reactive power generated means that reactive power is flowing from the utility grid (source) to the generator. This occurs whenever the generator field is under-excited or if an induction generator is being used.

Table- II: Results

Cases	Load type	Ploss (KVA)	Qloss (KVAr)	Vmin(p.u) (#bus no.)
Case 1	Nominal/base case (12 bus test system)	20.7138	8.0411	0.943354 (12th)
Case 2	Commercial load (12 bus test system)	19.5925	7.3685	0.937081 (12th)
Case 3	Commercial + EV(12 bus test system ,16 charging slots)	16.6273	2.5533	0.939482 (12th)
Case 4	Nominal/base case (85 bus test system)	316.59	198.48	0.9041 (85th)
Case 5	Residential (All nodes, 85 bus test system)	201.9544	127.2795	0.8954 (54th)
Case 6	Residential+ EV(85 bus test system ,16 charging slots)	241.1596	150.5683	0.88457 (55th)
Case 7	Commercial (85 bus test system)	199.0891	125.5083	0.8971 (54th)
Case 8	Commercial + EV(85 bus test system ,16 charging slots)	267.0609	165.8969	0.87889 (55th)
Case 9	Residential + Commercial + Industrial+ EV (85 bus test system,16charging slots)	2.81e+03	-1.85e+04	0.9236 (54th)

V. CONCLUSION

The paper analyzed the introduction of EVs on the radial distribution system using voltage dependent load flow analysis. The load flow has been carried on IEEE 85 bus system. The simulation results showed the electrical parameters have been changed when EVs are connected along with residential and commercial loads. The voltage drop at 55th bus, will be is 0.884572 pu when EVs are connected with the residential load and 0.878899 pu when EVs are connected along with commercial load and 0.9236 p.u when EVs are connected along with residential, commercial, and industrial load at 54th bus. Negative reactive power generated means that reactive power is flowing from the utility grid (source) to the generator. This occurs whenever the generator field is under-excited or if an induction generator/EV is being used.The mitigation of drop in voltage and reactive compensation can be solved by appropriate placing of solar PV panels or capacitor, or DVR (Dynamic Voltage Restoration). Further the proper management of integrating EVs can reduce the burden on the grid.

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APPENDIX

A system data for 12 bus radial distribution system

Branch number	Sending Bus	Receiving Bus	Resistance (ohm)	Reactance (ohm)	P (KW)	Q (KVAr)
1	1	2	1.093	0.455	60	60
2	2	3	1.184	0.494	40	30
3	3	4	2.095	0.873	55	55
4	4	5	3.188	1.329	30	30
5	5	6	1.093	0.455	20	15
6	6	7	1.002	0.417	55	55
7	7	8	4.403	1.215	45	45
8	8	9	5.642	1.597	40	40
9	9	10	2.89	0.818	35	30
10	10	11	1.514	0.428	40	30
11	11	12	1.238	0.351	15	15

A system data for 85 bus radial distribution system

Branch number	Sending Bus	Receiving Bus	Resistance (ohm)	Reactance (ohm)	P (KW)	Q (KVAr)
1	1	2	0.108	0.075	0	0
2	2	3	0.163	0.112	0	0
3	3	4	0.217	0.149	56	57.13
4	4	5	0.108	0.074	0	0
5	5	6	0.435	0.298	35.28	35.99
6	6	7	0.272	0.186	0	0
7	7	8	1.197	0.82	35.28	35.99
8	8	9	0.108	0.074	0	0
9	9	10	0.598	0.41	0	0
10	10	11	0.544	0.373	56	57.13
11	11	12	0.544	0.373	0	0
12	12	13	0.598	0.41	0	0
13	13	14	0.272	0.186	35.28	35.99
14	14	15	0.326	0.223	35.28	35.99
15	2	16	0.728	0.302	35.28	35.99
16	3	17	0.455	0.189	112	114.26
17	5	18	0.82	0.34	56	57.13
18	18	19	0.637	0.264	56	57.13
19	19	20	0.455	0.189	35.28	35.99
20	20	21	0.819	0.34	35.28	35.99
21	21	22	1.548	0.642	35.28	35.99
22	19	23	0.182	0.075	56	57.13
23	7	24	0.91	0.378	35.28	35.99
24	8	25	0.455	0.189	35.28	35.99
25	25	26	0.364	0.151	56	57.13
26	26	27	0.546	0.226	0	0
27	27	28	0.273	0.113	56	57.13
28	28	29	0.546	0.226	0	0
29	29	30	0.546	0.226	35.28	35.99
30	30	31	0.273	0.113	35.28	35.99
31	31	32	0.182	0.075	0	0
32	32	33	0.182	0.075	14	14.28
33	33	34	0.819	0.34	0	0
34	34	35	0.637	0.264	0	0
35	35	36	0.182	0.075	35.28	35.99
36	26	37	0.364	0.151	56	57.13
37	27	38	1.002	0.416	56	57.13
38	29	39	0.546	0.226	56	57.13
39	32	40	0.455	0.189	35.28	35.99
40	40	41	1.002	0.416	0	0
41	41	42	0.273	0.113	35.28	35.99
42	41	43	0.455	0.189	35.28	35.99
43	34	44	1.002	0.416	35.28	35.99
44	44	45	0.911	0.378	35.28	35.99
45	45	46	0.911	0.378	35.28	35.99
46	46	47	0.546	0.226	14	14.28
47	35	48	0.637	0.264	0	0
48	48	49	0.182	0.075	0	0
49	49	50	0.364	0.151	36.28	37.01
50	50	51	0.455	0.189	56	57.13
51	48	52	1.366	0.567	0	0
52	52	53	0.455	0.189	35.28	35.99
53	53	54	0.546	0.226	56	57.13
54	52	55	0.546	0.226	56	57.13
55	49	56	0.546	0.226	14	14.28
56	9	57	0.273	0.113	56	57.13
57	57	58	0.819	0.34	0	0
58	58	59	0.182	0.075	56	57.13
59	58	60	0.546	0.226	56	57.13
60	60	61	0.728	0.302	56	57.13
61	61	62	1.002	0.415	56	57.13
62	60	63	0.182	0.075	14	14.28
63	63	64	0.728	0.302	0	0
64	64	65	0.182	0.075	0	0
65	65	66	0.182	0.075	56	57.13
66	64	67	0.455	0.189	0	0
67	67	68	0.91	0.378	0	0
68	68	69	1.092	0.453	56	57.13
69	69	70	0.455	0.189	0	0
70	70	71	0.546	0.226	35.28	35.99
71	67	72	0.182	0.075	56	57.13
72	68	73	1.184	0.491	0	0
73	73	74	0.273	0.113	56	57.13
74	73	75	1.002	0.416	35.28	35.99
75	70	76	0.546	0.226	56	57.13
76	65	77	0.091	0.037	14	14.28
77	10	78	0.637	0.264	56	57.13
78	67	79	0.546	0.226	35.28	35.99
79	12	80	0.728	0.302	56	57.13
80	80	81	0.364	0.151	0	0
81	81	82	0.091	0.037	56	57.13
82	81	83	1.092	0.453	35.28	35.99
83	83	84	1.002	0.416	14	14.28
84	13	85	0.819	0.34	35.28	35.99