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Estimation of Radial Distribution Feeder Sections Average Failure Rate for Different Located Future Forecasted EV Charging Stations.

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Abstract - *The number of Electrical vehicles increasing day by day and this increased load results in increase in the magnitude of currents passing through different line sections of the distribution feeder circuit. Due to the increase of the magnitude of current, the resistive losses increase. As a result, the increase in temperature of the feeder section moderates its average failure rate and reliability. In this paper the average failure rate of different line sections of a feeder is calculated for future increased EV charging stations for different possible locations and the total load of Electrical vehicles assumed to be charged from equal rated two charging stations. The four possible locations of charging stations are considered based on the voltage sensitivity factor which indicates strength of load buses. The average failure rate of all sections of the feeder are evaluated and compared for all four different locations of charging stations to meet the future EV demand. This analysis is carried out on IEEE33 test bus system.*

Key Words: Electrical Vehicle, Voltage Sensitivity Factor, Future Load Forecast, Average Failure rate.

1. INTRODUCTION

The analysis of a distribution system is an important area of activity, as distribution systems provide the final link between the bulk power system and the consumers. Such a radial system needs adequate planning so that it can operate efficiently and achieve the greatest possible incremental reliability [1], [2]. The main goal of an electrical distribution network's operation is to maintain an appropriate operational state of its elements to supply reliable power to its customers. The reliability of the distribution network depends on the average failure rate and repair time of its feeder sections. The reliability of distribution systems is measured in terms of load point indices and system indices. The load point reliability indices are (i) average failure rate, (ii) average outage time, r_s *and* (iii) average annual outage time, U_s. The indices are normally used to predict or assess the reliability of a distribution system. [1] The reliability of the distribution system also depends on the loading of the buses. One of the loads on the distribution system is the transportation sector, i.e., integrating electrical vehicle (EV) charging stations.

The transportation industry is a significant contributor to CO_2 emissions, causing global warming and climate change. EVs are being introduced to reduce this emission, however the rising number of EVs has demanded the development of a sustainable charging infrastructure. The installation of charging stations increases the burden on the electrical system. The charging load of EV charging stations will decrease the distribution network's operational parameters, such as voltage stability, failure rate, power loss, etc. A large number of studies reports the adverse effects of EV charging load on various distribution network parameters. [3]-[9]. To evaluate the reliability of the future EV load, it is Forecasted using Holt's model, and the impacts of EV charging station load on the failure rate of the feeder section analysed on Fig-1 IEEE33 standard test.

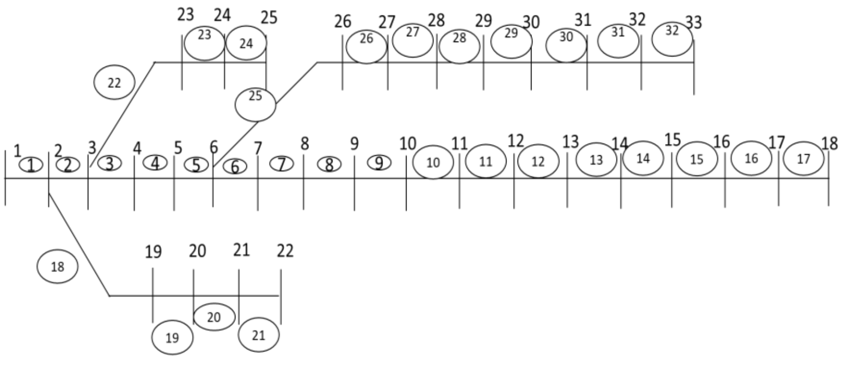

Fig -1: IEEE 33 Standard Test Bus System.

The rest of the paper is organised as follows: Section II presents a brief review of distribution network load point parameters [1]. Section III reports the numerical analysis and discusses the key findings of this work. Section IV concludes the work.

2. METHODOLOGY

To calculate the voltages and currents of radial distribution system load flow analysis is considered by using Backward/forward sweep method.

2.1 Load flow analysis.

Load flow analysis is used to study balanced and unbalanced power systems. Distribution systems are unbalanced. The backward/forward sweep [10] is a classical algorithm that determines the bus voltages, currents passing through each line. Backward sweep (BS) is the process of solving for the currents with the provided voltages, while forward sweep (FS) is the process of solving for the voltages with the provided currents [11]. Fig-2. represents the radial distribution system with N number of Nodes. Figure 2 depicts the algorithm for forward and reverse load flow.

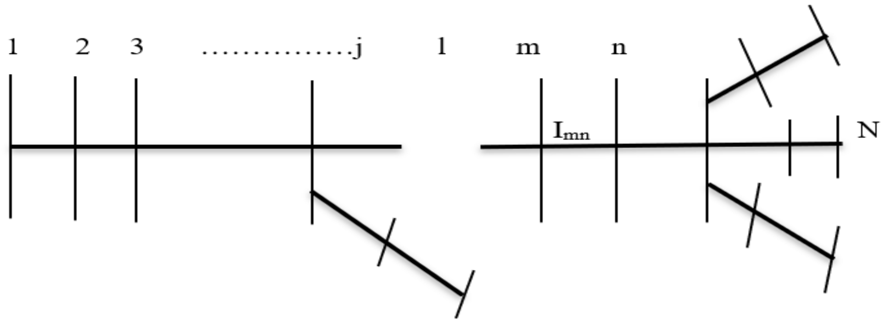

Fig -2: Radial distribution system

Algorithm

Step 1: Initialize voltages at each node.

$$V_j^0 = V_s\angle 0^0 (for\ all\ j = 1,2,3,\dots.N)\ \text{(N=Number of nodes)} \quad (1)$$

Step 2: Initialize Iteration Count, k=1

Step 3: Calculate Load current.

$$I_L^k = \left(\frac{PL_j+QL_j}{Vj^{(k-1)}}\right)^* for\ all\ j = 2,3,\dots..N,\ \text{k=Iteration} \quad (2)$$

Load currents at each Node is calculated by using Equation (5)

Step 4: Backward Sweep used to calculate Branch currents.

$$I_{mn}^{(k)} = I^{(k)}{}_n + \sum All\ the\ currents\ of\ branches\ emanated\ from\ bus\ n \quad (3)$$

Where I_n=Load current at n^{th} node calculated at k^{th} iteration. m=1,2,3…(N-1), n=2,3,4…N

Step 5: Forward sweep: Calculating Voltages at each Node so voltage at n_{th} node.

$$V_n^{(k)} = V_m^{(k)} - Z_{mn}I_{mn}^{(k)} \quad (4)$$

Where $I_{mn}^{(k)}$ calculated from step 4.

for all n =2,3,4…N, m=1,2,3…(N-1)

Step 6: Calculate the Error.

Error at any j_{th} node is given by.

$$e_j^{(k)} = \left|V_j^k - V_j^{(k-1)}\right| \quad for\ j = 2,3, \ldots N, k^{th}\ iteration \tag{5}$$

Step 7: Calculating Maximum error.

$$e_{max}^{(k)} = \max\left(e_1^k, e_2^k, \ldots\ldots e_N^k\right) \tag{6}$$

Step 8: Compare error values with Tolerance.

$$if\ e_{max}^{(k)} \leq \varepsilon(Tolerance) \tag{7}$$

Then converge and print the results; else update the iteration count k = k+1 and go to step (3).

If the voltage difference is smaller than the stated tolerance, or 0.001, convergence can be achieved. At first, it is expected that all nodes will have a flat voltage profile, or 1.0 p.u. The updated voltages at each node are used to repeatedly calculate the branch currents. The IEEE33 radial bus network uses the Backward Forward sweep method to calculate voltages in the node and currents in the branches [12]. This test network's line and branch data were taken from references [13]

This section explains the method of calculating the strength of buses using VSF, calculating the future EV load forecast using Holt's model, and applying the future forecasted EV load to different possible cases of buses obtained from VSF. Further, the new failure rate of feeder sections is calculated by considering the change in currents after applying load in different possible cases.

2.2 Voltage sensitivity factor (VSF).

The voltage sensitivity factor (VSF) is the ratio of the change in the voltage at a particular bus to the change in the real power load at the bus. Equation (1) gives the VSF for the nth bus during the kth interval.

$$VSF_n = \left|\frac{dV_n}{dP_n}\right| \tag{8}$$

Where dV_n and dP_n are the change in voltage and real power load at n^{th} bus. The node voltages are calculated using Equation (7). This index is used to determine the strength of bus. It is preferable if the VSF at a bus in each time interval is low. A high VSF value shows that the voltage drops significantly even for a slight change in loading, which suggests the bus is weak [14] The loading margin of the system is defined as the loading for which all bus voltages fall within an acceptable range [14].

2.3 Holts Model for EV load forecast

Holt's two-parameter model [15], also known as linear exponential smoothing. It is a popular smoothing model for forecasting data with a trend. Holt's model consists of three distinct equations that collaborate to provide a final forecast. The basic smoothing equation (5) adjusts the latest smoothed value directly for the trend of the previous period. Equation (6) is used to update the trend over time, where the trend is given as the difference between the two most recent smoothed values. Equation (4) is then used to get the final forecast.

The Holt model employs two parameters, one for the overall smoothing L_t and another for the trend smoothing equation b_t.

The equation for forecast

$$F_{t+1} = L_t + b_t \tag{9}$$

$$L_t = \alpha Y_t + (1-\alpha)(L_{t-1} + b_t - 1) \tag{10}$$

$$b_t = \beta(L_t - L_{t-1}) + (1-\beta)(b_t - 1) \tag{11}$$

where L_t and b_t represents estimate of the level and trend of time series respectively at time t.

$F_{t+1}$is the forecast for next year.

Assumptions

α and β are smoothing constants for level and trend respectively whose values lie on the interval between 0 to 1.

Initial estimates are needed for L_1 and b_1. Simple choices are $L_1 = Y_1$ and $b_1 = 0$.

2.4 New Average failure rate of feeder sections.

The percentage change in average failure rate (λ_{avg}) of a feeder section is assumed to be directly proportional to the percentage change in current passing through that component due to addition of EV charging stations to meet the future EV demands. The current in each branch is calculated using load flow analysis using Equation 3.

The new average failure rate is calculated as

$$\lambda_{avgnew} = \lambda_{avgold} + (\Delta\lambda_{avg}) \quad (12)$$

Where $\Delta\lambda_{avg}$ is the increase in average failure rate due to addition of EV charging stations

3. CASE STUDY

This section explains how to find the nature of the bus using VSF. After calculating VSF, the strengths of the buses are confirmed, and the EV load is forecasted and applied to the test bus by assuming different cases, for these different cases, the average failure rate is calculated and analysed.

3.1 Finding the strength of the Bus using VSF.

VSF of each bus is calculated using (1) with loading factor 2, and the buses are categorised into strongest, strong, moderate, and weak buses [16]. The VSF of bus 14 for loading factor 2 is 0.1163 and is higher in comparison with other buses. Thus, bus 14 was regarded as the weakest bus of the system. Similarly, the VSF of bus 2 was least making it the strongest bus of the system. The VSF values also signify that bus 15 and bus 19 were the second weakest and second strongest bus respectively.

Representation for Table 1: *Strongest-SG, Strong-S, Moderate-M, Weak-W

Table -1: Strength of buses according to VSF values

Bus	VSF	Nature	Bus	VSF	Nature	Bus	VSF	Nature
-		-	12	0.0986	M	23	0.0234	M
2	0.0034	SG	13	0.1064	M	24	0.0305	M
3	0.0196	S	14	0.1163	WK	25	0.0341	M
4	0.0284	S	15	0.1156	WK	26	0.0617	M
5	0.0372	S	16	0.1129	W	27	0.0647	M
6	0.0593	S	17	0.1112	W	28	0.0786	M
7	0.0636	M	18	0.1093	W	29	0.0886	M
8	0.0803	M	19	0.0039	SG	30	0.0930	M
9	0.0882	M	20	0.0076	S	31	0.0981	M
10	0.0956	M	21	0.0083	S	32	0.0993	M
11	0.0967	M	22	0.0089	S	33	0.0996	M

3.2 Forecasting EV load.

From the data about number of EVs given upto the year 2020 [17] and then the Holt's Model is used for forecasting the EV load upto 2030 by assuming alpha(α) and beta (β) as 0.2 and 0.3 respectively. The results obtained (percentage of increased in number of EV's) is used in estimating the number of EV's increased in case of IEEE33 bus test system and validated as shown in Table 2. The load for the IEEE 33-bus system is calculated for the years 2023, 2025, 2030 considering 5 kW for 2 wheeler, 30 kW for 3 wheeler, 50 kW for 4 wheeler and results are validated.

Representations for Table.2: *2 wheeler-(2-W), 3 wheeler -(3-W), 4 wheeler-(4-W)

Table -2: Forecasted 2,3 and 4-wheeler EV vehicles in Millions.

Year	2-W	3-W	4-W	Year	2-W	3-W	4-W
2011	7.892	0.132	1.953	2021	18.093	0.645	3.386
2012	9.452	0.156	2.062	2022	18.966	0.692	3.469
2013	10.568	0.205	2.485	2023	19.838	0.740	3.551
2014	11.720	0.380	2.870	2024	20.711	0.788	3.633
2015	12.447	0.394	2.871	2025	21.584	0.835	3.715
2016	13.298	0.412	2.902	2026	22.457	0.883	3.798
2017	14.150	0.423	2.935	2027	23.330	0.931	3.880
2018	15.071	0.441	3.015	2028	24.203	0.978	3.962
2019	16.186	0.490	3.158	2029	25.076	1.026	4.044
2020	17.314	0.566	3.305	2030	36.796	1.074	4.126

The EV forecasted loads from Table.2 are applied equally on 2 assumed locations of the buses on the IEEE33 test system is shown in Table 3.

Representation for Table 3: *Strongest-SG, Strong-S, Moderate-M, Weak-W

Table-3: Different locations of charging stations with forecasted EV load.

Case	Bus No	Nature	Load (kW) (2023)	Load (kW) (2025)	Load (kW) (2030)
2	2	SG	1375	1466	1943
	19	SG	1375	1466	1943
3	2	SG	1375	1466	1943
	15	WK	1375	1466	1943
4	28	M	1375	1466	1943
	8	M	1375	1466	1943
5	15	WK	1375	1466	1943
	14	WK	1375	1466	1943

Table 4 represents the results of change in average failure rate of the feeder sections for the year 2023 after applying the load on assumed cases 2 to 5. The values obtained in Table 4, Table 5, Table 6 are rounded to three decimals.

Representations for Table 4, Table 5, Table 6: *Case 1(Base case)-C1, Case 2-C2, Case 3-C3, Case 4-C4, Case 5-C5, *Section-(S)

Table-4: Average failure rate of feeder sections with increasing EV load in 2023 for different charging station locations.

2023						2023					
S	C1	C2	C3	C4	C5	S	C1	C2	C3	C4	C5
1	0.05	0.079	0.103	0.085	0.085	17	0.04	0.040	0.058	0.046	0.043
2	0.04	0.041	0.088	0.058	0.072	18	0.04	0.177	0.040	0.040	0.040
3	0.06	0.062	0.159	0.098	0.126	19	0.04	0.040	0.040	0.040	0.040
4	0.03	0.031	0.082	0.050	0.065	20	0.04	0.040	0.040	0.040	0.040
5	0.03	0.031	0.084	0.051	0.066	21	0.05	0.079	0.103	0.085	0.085
6	0.09	0.090	0.414	0.215	0.203	22	0.04	0.041	0.088	0.058	0.072
7	0.03	0.030	0.162	0.081	0.076	23	0.06	0.062	0.159	0.098	0.126
8	0.03	0.030	0.199	0.095	0.032	24	0.03	0.031	0.082	0.050	0.065
9	0.02	0.020	0.143	0.067	0.022	25	0.03	0.031	0.084	0.051	0.066
10	0.03	0.030	0.232	0.108	0.032	26	0.09	0.090	0.414	0.215	0.203
11	0.03	0.030	0.250	0.115	0.032	27	0.03	0.030	0.162	0.081	0.076
12	0.06	0.060	0.560	0.254	0.065	28	0.03	0.030	0.199	0.095	0.032
13	0.03	0.030	0.319	0.143	0.032	29	0.02	0.020	0.143	0.067	0.022
14	0.03	0.030	0.252	0.198	0.033	30	0.03	0.030	0.232	0.108	0.032
15	0.03	0.030	0.044	0.034	0.033	31	0.03	0.030	0.250	0.115	0.032
16	0.03	0.030	0.044	0.034	0.033	32	0.06	0.060	0.560	0.254	0.065

Table 5. presents the results for new average failure rates of the feeder sections for the cases 2 to 5 after applying the load for the year 2025.

Table-5: Average failure rate of feeder sections with increasing EV load in 2025 for different charging station locations.

2025						2025					
S	C1	C2	C3	C4	C5	S	C1	C2	C3	C4	C5
1	0.081	0.108	0.087	0.088	0.081	17	0.04	0.040	0.046	0.046	0.044
2	0.041	0.092	0.060	0.074	0.041	18	0.04	0.186	0.040	0.040	0.040
3	0.062	0.169	0.101	0.131	0.062	19	0.04	0.040	0.040	0.040	0.040
4	0.031	0.088	0.052	0.068	0.031	20	0.04	0.040	0.040	0.040	0.040
5	0.031	0.089	0.052	0.068	0.031	21	0.05	0.081	0.108	0.087	0.088
6	0.090	0.438	0.225	0.211	0.090	22	0.04	0.041	0.092	0.060	0.074
7	0.030	0.170	0.085	0.079	0.030	23	0.06	0.062	0.169	0.101	0.131
8	0.030	0.212	0.101	0.033	0.030	24	0.03	0.031	0.088	0.052	0.068
9	0.020	0.152	0.071	0.022	0.020	25	0.03	0.031	0.089	0.052	0.068
10	0.030	0.248	0.114	0.033	0.030	26	0.09	0.090	0.438	0.225	0.211
11	0.030	0.269	0.122	0.033	0.030	27	0.03	0.030	0.170	0.085	0.079
12	0.060	0.604	0.270	0.065	0.060	28	0.03	0.030	0.212	0.101	0.033

13	0.030	0.346	0.152	0.033	0.030	29	0.02	0.020	0.152	0.071	0.022
14	0.030	0.269	0.211	0.033	0.030	30	0.03	0.030	0.248	0.114	0.033
15	0.030	0.035	0.035	0.033	0.030	31	0.03	0.030	0.269	0.122	0.033
16	0.030	0.035	0.035	0.033	0.030	32	0.06	0.060	0.604	0.270	0.065

Table 6. gives the results for new average failure rate of feeder sections for the forecasted load of 2030 for cases 2 to 5.

Table-6: Average failure rate of feeder sections with increasing EV load in 2030 for different charging station locations.

2030						2030					
S	C1	C2	C3	C4	C5	S	C1	C2	C3	C4	C5
1	0.05	0.091	0.110	0.102	0.103	17	0.04	0.040	0.062	0.050	0.045
2	0.04	0.041	0.094	0.069	0.086	18	0.04	0.235	0.040	0.040	0.040
3	0.06	0.062	0.174	0.119	0.155	19	0.04	0.040	0.040	0.040	0.040
4	0.03	0.031	0.090	0.061	0.080	20	0.04	0.040	0.040	0.040	0.040
5	0.03	0.031	0.091	0.062	0.082	21	0.05	0.091	0.110	0.102	0.103
6	0.09	0.090	0.460	0.284	0.249	22	0.04	0.041	0.094	0.069	0.086
7	0.03	0.030	0.181	0.109	0.094	23	0.06	0.062	0.174	0.119	0.155
8	0.03	0.030	0.224	0.132	0.034	24	0.03	0.031	0.090	0.061	0.080
9	0.02	0.020	0.160	0.094	0.022	25	0.03	0.031	0.091	0.062	0.082
10	0.03	0.030	0.261	0.151	0.034	26	0.09	0.090	0.460	0.284	0.249
11	0.03	0.030	0.282	0.162	0.034	27	0.03	0.030	0.181	0.109	0.094
12	0.06	0.060	0.631	0.361	0.067	28	0.03	0.030	0.224	0.132	0.034
13	0.03	0.030	0.360	0.204	0.034	29	0.02	0.020	0.160	0.094	0.022
14	0.03	0.030	0.283	0.289	0.034	30	0.03	0.030	0.261	0.151	0.034
15	0.03	0.030	0.047	0.037	0.034	31	0.03	0.030	0.282	0.162	0.034
16	0.03	0.030	0.047	0.037	0.034	32	0.06	0.060	0.631	0.361	0.067

From Table.4, Table.5, Table.6 the percentage change of failure rate for the years 2023,2025,2030 with respect to the base case is calculated. The effected feeder sections for cases 2 to 5 after application of EV load are shown in Table.7.

Table-7: Average failure rate affected greater than 20%, greater than 50%, greater than 100% on sections.

Case	**> 20%**	**No. of sections**	**> 50%**	**No. of sections**	**100%**	**No. of sections**
2	1, 18,30,31	4	18	1	18	1
3	1 to 17, 30,31	19	1 to 14	14	1, 4 to 14	11
4	1 to 7, 25 to 27, 30,31	12	1 to 7, 25 to 27, 31	11	25,26,27	3
5	1 to 17, 25 to 31	23	1 to 17, 31	18	1 to 14	14

4. CONCLUSION

Average failure rate is the basic index used to calculate the reliability parameter SAIFI and is expressed as the average number of outages experienced by a system customer during a year (or time period under study). From table 7, the average failure rate of the sections for the year 2030 increased. It is noted that case 5 is the most affected case, where 23 feeder sections are affecting greater than 20%, 18 feeder sections are affecting greater than 20%, and 14 feeder sections are affecting greater than 100% of the average failure rate. It is mandatory that the engineers need to compensate the increase in current in the distribution feeder sections so that the increase in losses compensates and the effect on the failure rate of the components corresponding to that section is also reduces. This paper concludes that it is necessary to concentrate on weaker sections of the distribution system and observes that choosing proper locations for placing charging stations is necessary to maintain reliability.

Future work.

The current passing through the lines are reduced by placing distributed generators, reconfiguring the network, optimal placement of capacitors etc., thereby the average failure rate of the distribution system reduces.

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BIOGRAPHIES

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