Reliability Evaluation of Radial Distribution Feeder for Different Configurations and Considering the Effect of Forecasted EV Charging Stations

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Abstract

Electrical vehicles are becoming more prevalent,and the associated load is rising daily, this increased load results in increase in the magnitude of currents, resistive losses, and temperature of the distribution feeder. As a result, the increase in temperature of the feeder section moderates its average failure rate, reliability, and power quality. Toprovide the betterpower quality it is necessary to evaluate the reliability well in advance. In this paper the Electrical Vehicle (EV) load is forecasted using Holt's model for the years 2025 and 2030; further, the corresponding EV charging points are assumed to be locatedwith equal capacity at all load buses for four different configurations. The new average failure rate of all the feedersections considering the effect of addition of EV charging stations, the correspondingreliability indices are evaluated for four different configurations of radial feeder using FMEA technique. These results are compared with the reliability indices of the feeder for the four configurations without adding EV charging station loads. This work is validated on a standard IEEE33 test bus system.

Keywords: Electrical Vehicle, New average Failure rate, Load Forecast, Reliability.

1. Introduction

In India, gasoline, diesel, petrol, and natural gas are the most common fuels for motorized vehicles used for transportation. Due to their significant carbon emissions, these vehicles are the primary source of air pollution. The availability of fossil fuels is also constrained due to the fast depletion of petroleum products utilised in automobiles. Petroleum resources can only be used by us for the ensuing few years. The motorised vehicles must therefore be powered by a different method. The National Electric Mobility Mission Plan 2020 [1] was unveiled by the Department of Heavy Industry, Ministry of Heavy Industries and Public Enterprises, Government of India, to address the environmental issues brought on by conventional motor vehicles and boost the production of reliable, affordable, and effective electric vehicles (EVs).

The FAME (Faster Adoption and Manufacturing of Hybrid & Electric Vehicles) India Plan [2] is one of many initiatives the Indian government has launched to encourage the growth of the hybrid/electric vehicle sector and manufacturing eco-system. Yet, no thorough study has been carried out to determine the impacts of substantial EV adoption on the future Indian electric power distribution system (EPDS).The key issues that specialists are currently concerned about are the rising energy demands, the diminishing fossil fuel supply, as well as global warming and climate change. One of the biggest contributors to climate change and global warming is the transportation sector's CO2 emissions. Researchers have emphasized the advantages of converting from internal combustion engines (ICE) to electric motors (EVs) to reduce greenhouse gas emissions from the transportation sector.

Due to the additional load of fast-charging stations, the distribution network's performance characteristics, such as voltage stability, reliability, power loss degrades. Installing charging stations increases the demand on the power grid since the high charging loads of EV charging stations would cause the distribution network's operating characteristics to degrade. Harmonic distortions, a deterioration of the voltage profile, reliability are all effects of uncoordinated EV charging.Increase in EV charging loads affects 33 bus test distribution system.

These key contributions of the work are outlined below:

- Investigation of the EV charging load on distribution network and its effect on voltage, power loss and reliability.

The remaining sections are organised as follows:
The forecasting of EV load, Load flow analysis, reliability [3]are illustrated in Section 2. Section 3 presents the case studies of the EV load forecasting, impact of the charging station load as well as performance of IEEE 33 bus test network, The work is finally concluded in Section 4, which provides an overview of the research findings.

2. Methodology

This section explains the method of calculating EV the load forecast, calculation of load flow analysis, power loss, new average failure rate, reliability indices.

2.1 Loadforecastingtechniques

An electric utility can use load forecasting to help with important choices including those regarding the production and purchase of electricity, load shedding, and infrastructure development. This allows for the precise forecasting of the magnitudes and geographic distribution of the period's electric load. Forecasting the demand for electricity is regarded as one of the key elements in determining the distribution system's performance.

2.1.1 Holt's model for forecasting

Holts [4] gave a method to deal with data pertaining trend which is known as Holts linear trend model. It comprises two smoothing constants, two smoothing equations and one forecast equation. It has three equations.

$$F_{t+1}=a_t+b_t \quad (1)$$

Where,
$a_t$isthelevelwhichrepresentsthesmoothenedvalueup toandincludingthe last data.
$b_t$gives theslopeofthe linerepresenting the data.
Thevalues of$a_t$and $b_t$areupdatedusing:

$$a_t=\alpha D_t+(1-\alpha)\ (a_{t-1}+b_{t-1}) \quad (2)$$

$$b_t=\beta\ (a_t-a_{t-1})+(1-\beta)\ b_{t-1} \quad (3)$$

α and β are smoothing constants for level and trend respectively whose values lie on the interval between 0 to 1. The integration of EV charging load into the power distribution network occurs quickly and significantly in the coming years, and with the application of the suitable load forecasting method, load is forecasted as mentioned in section 2.1.1. Accordingly, the impact of EV charging station load on power loss and various operating parameters, such as the voltage profile of the distribution network, were examined for various scenarios of installing EV charging stations with an assumption of load. An overview of the method for calculating load flow analysis in the distribution network is presented in this section.

2.2 Load flow analysis

Load flow analysis is used to study balanced and unbalanced power systems. Distribution systems are unbalanced. The backward/forward sweep [5] 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. Figure 1. represents the radial distribution system with N number of Nodes.

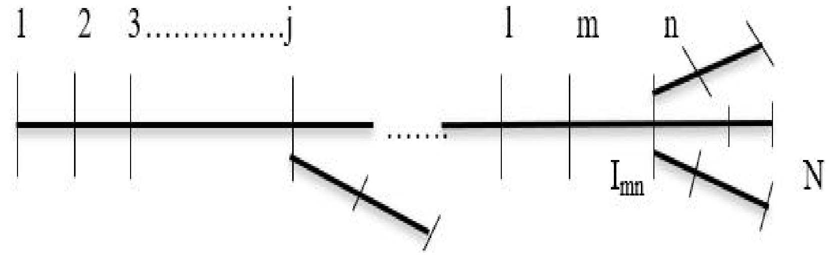

Figure1.Radialdistributionsystem

2.3 Power loss

Distribution network power losses are I^2R losses of the line.

$$_j = {}_j^2 {}_j \quad (4)$$

The determine total power losses of the radial distribution system are Equation (5) is used.

$$P_t = \sum_{j=1}^{n} {}_j \quad (5)$$

Where j is the section of radial distribution system.

The further section shows the future load forecast of EV's and applied on all possible case studies of IEEE33 distribution system and the performance is validated.

2.4 Evaluating the new average failure rate.

The percentage change in average failure rate ($_g$) 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 Equation6.

The new average failure rate is calculated as

$$_{g\ w} = {}_g + {}_g (6)$$

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

2.5 Reliability indices

The following Reliabilityindices [3] are used for the determination ofreliability of a distribution system. A distribution systemconsists of 'j' nodes or load points which supply power to 'N_j'number of customers. The customers are interrupted onaccount of various causes, and 'λ_j' being the yearly frequencyofinterruptionfor durationof'U_j'hours/year.

- System Average Interruption Frequency Index (SAIFI):

$$SAIFI = \frac{\Sigma(\ _j\ _j)}{\Sigma\ _j} \quad (7)$$

- System Average Interruption Duration Index (SAIDI):

$$SAIDI = \frac{\Sigma(U_j N_j)}{\Sigma(N_j)} \quad (8)$$

where U_j is the annual outage time and N_j is the number of customers of load point j

- The Average Service Availability Index {Unavailability} (ASAI) {ASUI}

$$ASAI = \frac{\Sigma N_j \times 8760 - \Sigma(U_j N_j)}{\Sigma N_j * 8760} \quad (9)$$

Where 8760 is the number of hours in a calendar year

- Energy not supplied (ENS)

$$ENS = \sum L_j U_j \quad (10)$$

where L_j is the average load connected to load point j.

3. Case studies

EV forecast is calculated by using Holt's model and the forecasted load is applied on IEEE33 Distribution system using Equations (1) to (3).The distribution network working parameters deteriorate because of the widespread adoption of EVs, which raises load demand. The impact of voltage stability, power loss due to EV charging station load examined on Figure 2. It shows the network is a radial network, it has 33 buses, 32 sections with load points 32. Loads are regarded as the same number displayed for sections, while sections are represented by a number with a rounded circle.

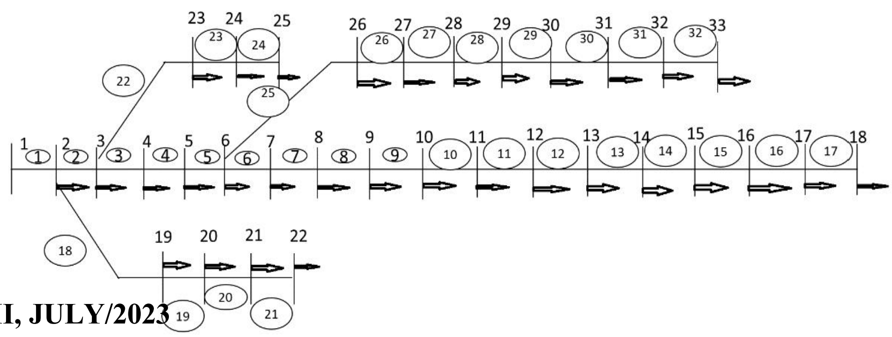

Figure 2. IEEE 33 bus system test Network

To evaluate the performance of the distribution system after applying EV load, it is necessary to forecast EV load. The information about category wise sales of electric vehicles in India is derived from a study entitled "Status quo analysis of various segments of electric mobility and low carbon passenger road transport in India" up to the year" 2020 [1], which was carried out by the German Society for International Cooperation (GIZ) GmbH, the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety, and NITI Ayog, India [2]. This data is used to forecast the future EV [6]-[7] load upto the year 2030, and the percentage of electric station load on the IEEE 33 bus system is calculated and applied. After applying the forecasted load, the voltage profile, power losses and reliability [8]-[9] are calculated.

3.1 Forecasting EV load

The Holt's Model [4] is used for forecasting the loads from the data obtained by 1. Assuming Alpha(α)=0.2 and Beta (β)=0.3[4]. The Table 3.1 gives the results of EV forecast up to the year 2030 using Holts model.The EV charging station load for the IEEE 33-bus system is calculated for the years2025,2030 considering 3kW for 2-Wheeler, 25kW for 3-Wheeler and 40kW for 4-Wheeler.

Representations for Table.3.1: *2-Wheeler-(2-W), 3-Wheeler -(3-W), 4-Wheeler-(4-W)

Table 3.1Forecasted 2,3 and 4-wheeler EV vehicles in Millions.

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

The forecasted EV for the years 2025 and 2030 is applied on the distribution system uniformly on all the buses assuming all the customers are adopting EV's is shown in Table 3.2.

Table 3.2Forecasted EV charging station load and locations for uniform distribution case.

Case (C)	Type	Load (kW) (2025)	Load (kW) (2030)
1	Base case	-	-
2	UniformlyDistributed (For Buses 2-33)	62 (At each bus)	81 (At each bus)

From section 2.2 load flow analysis is done on distribution system then the voltage profile of the buses is obtained. The voltages at the buses for the case 2 (Uniform distribution) for the years 2025 and 2030 are shown in Figure 3.

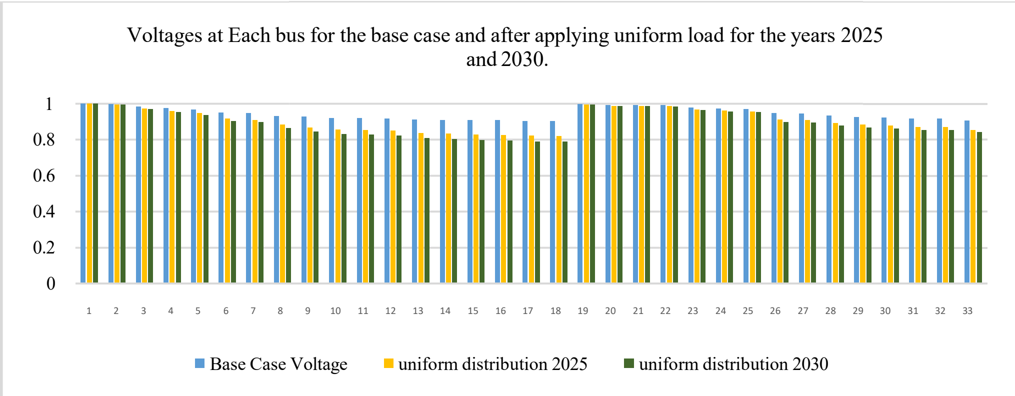

Figure 3. voltages at each bus after for base case and after applying load for case 2 for the years 2025 and 2030.

3.2 Power losses

Using Backward/Forward load flow analysis, currents in various sections of the system weredetermined using section 2.2 power losses werecomputedfor the years 2025,2030. Figure4 shows the total losses of IEEE33 bus system for the years 2025,2030. It is shown that the power losses are increasing as the forecasted load is applied in the system.

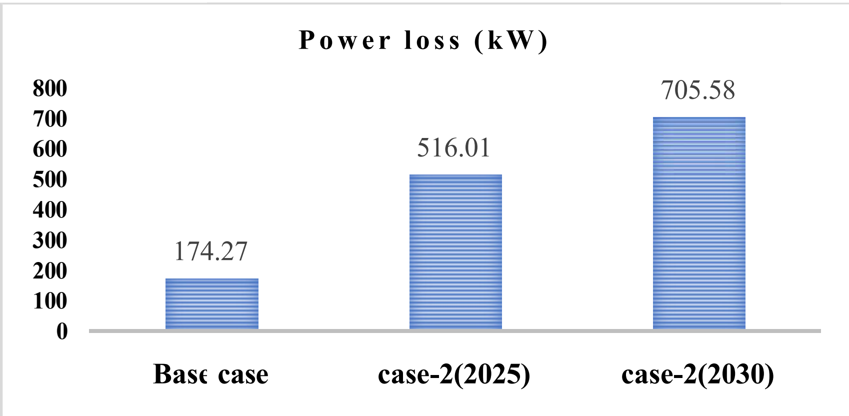

Figure4. Power loss after applying EV station load for the years 2025 and 2030.

3.3 NewAverage failure rate of feeder sections.

The current in each branch is calculated using load flow analysis [5]. The new average failure rate is calculated using Equation (6)

Table 3.3 Average failure rate of feeder sections for the base case and with increasing EV load for the year2025 and 2030 for uniform distribution of Load.

Section	C-1 Base case	C-2 (2025)	C-2 (2030)
1	0.05	0.0831	0.0958
2	0.3	0.4910	0.5654
3	0.22	0.3863	0.4528
4	0.23	0.4058	0.4764
5	0.51	0.8924	1.0468
6	0.11	0.2237	0.2672
7	0.44	0.9543	1.1518
8	0.64	1.5231	1.8628
9	0.65	1.5342	1.8759
10	0.12	0.2801	0.3422
11	0.23	0.5263	0.6415
12	0.91	2.0637	2.5134
13	0.33	0.7381	0.8973
14	0.36	0.8955	1.1026
15	0.46	1.1090	1.3615
16	0.8	1.8503	2.2607
17	0.45	0.9379	1.1298
18	0.1	0.1925	0.2228
19	0.93	1.7688	2.0513
20	0.25	0.4756	0.5516
21	0.44	0.8372	0.9711
22	0.28	0.3532	0.3782
23	0.56	0.6704	0.7080
24	0.55	0.6587	0.6956
25	0.12	0.1731	0.1965
26	0.17	0.2372	0.2675
27	0.66	0.8873	0.9930
28	0.5	0.6440	0.7133
29	0.31	0.3843	0.4221
30	0.6	0.8497	0.9852
31	0.19	0.2503	0.2935
32	0.21	0.4819	0.5835

3.4 Reliability indices evaluation

Then the EV charging station load is placeduniformly on the system for the year 2025 and 2030, then the failure rate is calculated using Equation 6.

Table 3.4 Configuration of IEEE 33 bus for different cases.

Con.	No.of Fuses	No. of Disconnecting Switches	Alternate supply
A	0	0	0
B	3	0	0
C	3	3	0
D	3	3	3

Representations for Table 3.4: Configuration-Con

In theCon.A the test distribution system is taken without protection, Con.B3 laterals are protected with 3 Fuses, in Con.C disconnecting switches are connected at sections 2,6,12 and in Con.D alternate supply is connected at bus 18 then and the load lambda, restoration time, and unavailability are calculated for all the all the configurations and also for case1, case 2 further the reliability is evaluated.

Table-3.5: Reliability indices of IEEE33 test bus system with four different configurations for base case, after applying EV load for the year 2025, applying EV load for the year 2030.

Representation for Table 3.5: Configuration-Con, Case-C, Year-Yr, Base-BS

Reliability Indices						
Con.	C	Year	SAIFI Interruption/customer-year	SAIDI Hrs./customeryear	ASAI	ENS kWh/year
A	1	BS	12.68	9.745	0.9989	36201.11
	2	2025	39.14	31.98	0.9963	118806.5
		2030	50.18	41.65	0.9952	154728.7
B	1	BS	7.929	7.370	0.9992	27524.70
	2	2025	27.38	26.86	0.9969	100673.8
		2030	36.11	34.61	0.9960	129051.4
C	1	BS	7.929	3.754	0.9996	13858.84
	2	2025	27.38	10.71	0.9988	40260.70
		2030	36.17	13.98	0.9984	52473.40
D	1	BS	7.929	2.268	0.9997	8570.963
	2	2025	27.38	9.899	0.9989	36774.03
		2030	36.17	13.00	0.9985	48196.57

Conclusion

A system without EV charging station considered as a base caseand its reliability indices are calculated. Upon the analysisperformed it can be inferred that with the increase in additional load of the EV Charging station the reliability of the system alters.The percentage change in SAIDI in comparison with base case for Configuration A,B, C,D for the year 2025 are 390.21, 298.01, 100.08, 43.40 respectively, similarly for the year 2030609.68, 450.55, 225.58, 121.26respectively. From the observation it is concluded that the percentage change for the Con.D is less when compared to other configurations. Hence this study can be implemented for real time power grids orcan be used as a reference when there is an expansion in the Electric Vehicle sectoralso helpto determine important parameters like the system average interruption duration, or new average failure rate of the system after application of EV charging station load.

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