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Grid Impact Study of a Distribution System Due to the Connection of Fast/Slow Charging Station Load

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Abstract
Growing concerns over environmental pollution and reduction of carbon emissions have forced us to look for an alternative to the current mobility. The urban transportation sector is rapidly being electrified and electric vehicles (EV) are being promoted aggressively all over the world. The rise in EV must be complemented by a rise in the number of flexible and easily accessible charging Stations (CS) infrastructures at multiple locations. Home, workplace, and public charging stations of different capacity, charging speed are being prioritized and extensively installed. The Fast Charging Stations (FCS) needs to be installed at optimal locations to mitigate the possible risk to the distribution network and power system. The EV charging loads have an adverse impact on the operating parameters of the power system. The high charging loads of the fast charging stations and numerous slow charging stations at homes results in increased peak load demand, reduced reserve margins, voltage instability, and reliability problems. In our study, we have mostly focused on the calculation, comparison, and analysis of customer and energy-oriented reliability indices due to the connection of FCS and Slow Charging Stations (SCS) separately on extended Roy Billinton Test System (RBTS) Bus 2 Distribution Network. It has been observed that the placement of FCS at stronger buses is imperative for the smooth operation of the power system. Moreover, the study presents the importance of index based on VRP (Voltage stability, Reliability, and Power Loss) for finding out the optimal location of the placement of FCSs. Also, a sample study has been performed with coordinated Vehicle to Grid (V2G) discharging using EVs with an average of 30 kWh batteries and its role in smoothening the load profile of the distribution network has been evaluated. It has been found that the reliability indices and Energy Not Served (ENS) gets improved with V2G discharging phenomenon.

Keywords
Fast Charging Station, Home Charging, V2G,EV, Distribution Network, Reliability Indices

1. Introduction

Electric Vehicles are taking over the automotive industry with its improved technology, positive attitude of customers towards minimizing carbon footprints and flexible government incentives. There is a huge drive in investment towards the charging stations infrastructure to support the long-range battery vehicles from the leading automakers. Majority of the countries are focusing on developing EV charging networks to reduce the consumer fear of running out of charge which is a potential barrier for consumers converting to plug-in-electric vehicle (PEV). The paradigm shift from conventional vehicles to EV and electric charging plan sounds great but there are many technical and non-technical challenges behind the plan. EV chargers typically fall under one of three main categories: Level 1 charging stations, Level 2 charging stations, and DC Fast Chargers (also referred to as Level 3 charging stations). U.S.A now has over 20,000 electric car charging stations with more than 68,800 connectors out of which 10,860 units were DC fast chargers that make long-distance travel more practical for EVs [1].Even developing countries with tremendous hydropower potential like Nepal has rolled out various plans for the installation of charging stations.

The establishment of charging stations imposes an additional burden on the power grid, as the high charging loads of fast EV charging stations will degrade the operating parameters of the distribution network. The degradation of voltage profile, increase in peak load, harmonic distortions are some of the consequences of the uncoordinated charging of EVs. All the utilities aim to strike a balance between the competing goals of maximizing their profits and minimizing the disturbance to the electric power network due to installation of FCSs and slow charging stations. There are numerous literatures addressing the voltage, reliability and power loss issues relevant to EV charging station placement. [2], [3] formulated charging station placement as an optimization problem. However, they did not take into account the overall consumer satisfaction and the impact of EV charging on the electric power network in their works. The overall study of this work can be summarized as follows:

- Analysis of the impact of the EV charging station loads on the customer-oriented (SAIFI, SAIDI, CAIDI) and energy-oriented (ENS, AENS) reliability indices
- Comparative analysis of the EV charging load on different parameters of the distribution network such as the voltage stability, reliability and power losses
- Placement of the charging stations in the distribution network based on VRP index
- Case Study of V2G discharging in a Distribution Network

1.1 RBTS Bus 2 Test System

The RBTS is a six-bus composite system developed at the University of Saskatchewan for educational purpose. It is sufficiently small to permit the conduct of a large number of reliability studies with reasonable solution time but sufficiently detailed to reflect the actual complexities involved in practical reliability analysis and can be used to examine a newly developed technique or method. The details of the RBTS are given in Billinton et al. [4]. RBTS is a six-bus test system, within RBTS distribution system has been defined on Bus 2 and Bus 4.

The distribution system for Bus 2 is supplied by two 33/11 kV, 16 MVA transformers. Further distribution of the supply is done from the 11 kV switchgear. The distribution system has both high voltage and low voltage customers. The 415 V low voltage customers are supplied via 11/415 V transformers and the 11 kV customers are supplied directly. For the reliability analysis the 33 kV supply has been considered 100 percent reliable. Figure 1 shows the single line diagram for the distribution system. Bus 2 consists of 4 feeders and 22 load points with the voltage level of 11kV. The load points of the bus have been classified into residential and non-residential (commercial and small user) loads. The loads are supplied by distribution transformers of either 1200 kVA or 1000 kVA ratings. The sum of total connected distribution transformers at load points is of 22.2 MVA and the peak load of the system is 20 MW. There are total 1908 customers connected across the distribution network and residential and non-residential customers are geographically separated in the system.

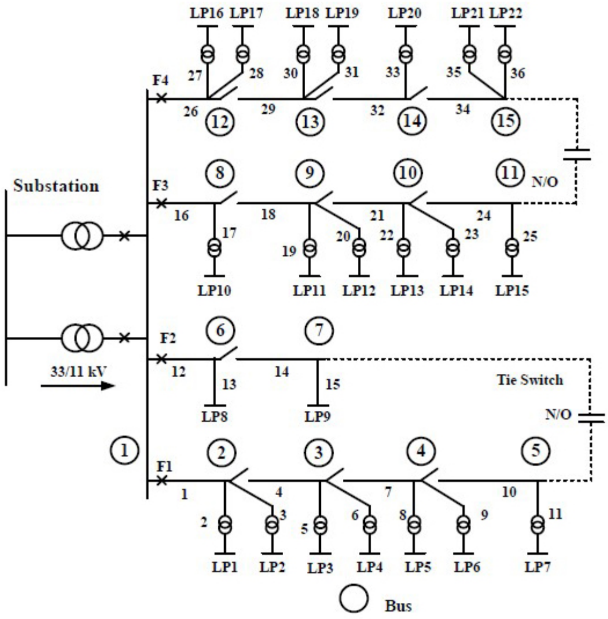

Figure 1: RBTS Bus 2 Test System [5]

2. Methodology

To evaluate the impact of connection of FCS and slow charging station load in RBTS Bus 2 system, firstly we have sorted the load buses from strongest to the weakest buses on the basis of Voltage Stability Index (VSI). Then we have calculated the reliability indices by connecting the FCS (every station has eight nodes of 50 kW charger each) at three strongest buses, three weakest buses, three mixed buses separately. After that we formulated the VRP index and carried out Genetic Algorithm with the objective of minimum VRP to deduce the optimal location for the placement of FCSs, giving highest priority to parameter related to customer satisfaction which are SAIFI, SAIDI and CAIDI. Further, we also analyzed the impact of 30 percent penetration of EV which are charged via home charging station in RBTS bus 2 test system.

Finally, for the evaluation of G2V discharging phenomenon with 30 percent penetration level of EVs, we calculated the hourly load from peak load data on the basis of multiplication factor presented in reference paper [7]. The hourly load curve was drawn and spare capacity in each transformer of 1200 kVA and 1000 kVA was calculated to check the number of EVs that can be charged to in each residential complexes and time of charging the vehicles. Based on the results obtained, the EVs could be charged between 22:00 hrs. to 8:00 hrs. through their respective 3kW home chargers connected to their respective transformers. It has been assumed that all the vehicles move to commercial complexes and they discharge the excess energy at respective commercial or non-residential complexes between 11:00 hrs. to 16:00 hrs. We then analyzed the effect of charging and discharging the energy in the RBTS Bus 2 Distribution Network.

Table 1: Cases for Analysis

Case	Case Description	Load Increase (MW)	Number of Charging Points
1	Base Case	0.000	
2	FCS placed at top three weakest buses	1.200	8*50 kW per FCS
3	FCS placed at mixed bus	1.200	8*50 kW per FCS
4	FCS placed at top three strongest buses	1.200	8*50 kW per FCS
5	Optimal placement of FCS based on VRP index	1.200	8*50 kW per FCS
6	Slow Charging stations at residences (30% penetration)	1.665	Bus16,17,18,25, 26 has 63 *3kW each.Bus27,32,33, 34 has 60 *3kWcharger
7	Analysis of Coordinated Charging and Discharging (V2G) of Evs with 30% penetration level		

2.1 Bus Voltage Stability Index (VSI) and Ranking of Load Buses

The voltage stability index developed by Eminoglu et al. [6] is utilized in this work in which following inequality in equation 1 defines the stability criterion of the two bus system (shown in figure 2) where m and n are the two buses or nodes of the system. $V_m\angle\delta_m$ & $V_n\angle\delta_n$ are the voltage at bus m and bus n respectively. I is the current flowing through the branch having resistance R and impedance X.

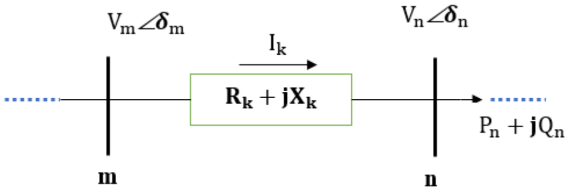

Figure 2: Two Bus System

$$2V_m^2V_n^2 - V_n^4 - 2V_n^2(P_nR_k + Q_nX_k) - (R_k^2 + X_k^2)(P_n^2 + Q_n^2) \geq 0 \quad (1)$$

Table 2: Sorting load buses from strongest to weakest bus on the basis of VSI

Rank	Bus No.	VSI	Rank	Bus No.	VSI
1	16	0.98691	12	34	0.97512
2	17	0.98691	13	21	0.97480
3	25	0.98635	14	20	0.97444
4	32	0.98445	15	22	0.97358
5	31	0.98441	16	28	0.97106
6	18	0.97905	17	29	0.97106
7	19	0.97894	18	24	0.97021
8	23	0.97877	19	30	0.96970
9	27	0.97617	20	35	0.96878
10	26	0.97587	21	37	0.96612
11	33	0.97512	22	36	0.96576

The value of Equation (1) has been defined as VSI. This is a criterion for determination of voltage stability. VSI will decrease with increase of active power. Increasing the active power beyond a certain limit will cause the system to become unstable. The VSI of all the buses are calculated based on equation 1 and the forward backward load flow by increasing the load in steps and finding out the critical loading margin of the system.

2.2 Reliability Indices

Reliability is the probability of a device or system performing its purpose adequately for the period of time intended under the operating conditions encountered [9]. As per the definitions from the book (Reliability Evaluation of Power Systems: Second Edition) by Roy Billinton and Ronal N Allan, below are the definitions of customer and energy oriented reliability indices:

$$SAIFI = \frac{\sum \lambda_i N_i}{\sum N_i} \tag{2}$$

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i} \tag{3}$$

$$CAIDI = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \tag{4}$$

$$ENS = \sum L_{a(i)} U_i \tag{5}$$

$$AENS = \frac{\sum L_{a(i)} U_i}{\sum N_i} \tag{6}$$

where λ_i is the failure rate, U_i is the annual outage time and N_i is the number of customers of load point i and $L_{a(i)}$ is the average load connected to load point i. SAIFI is System Average Interruption Frequency Index which illustrates the condition of the system in terms of interruption, SAIDI is System Average Interruption Duration Index which illustrates the condition of the system in terms of duration of interruption, CAIDI is Customer Average Interruption Duration Index which gives the average outage duration that any given customer would experience, ENS is Energy Not Supplied Index which is an indicator of energy deficiency of the system and AENS is Average Energy Not Supplied which gives an idea of how much energy is not served during a particular time period.

2.3 Power Loss

Power losses of a distribution network refer to typical I^2R losses of the network with 'n' number of branchers (nbr). For the two bus system represented in figure 2 the mathematical expression for computing the line losses is as given in Equation (7):

$$Ploss_k = I_k^2 R_k \tag{7}$$

Total Power Loss of System is given as :-

$$TP_{loss} = \sum_{k=1}^{nbr} Ploss_k \tag{8}$$

From Equation (7) and Equation (8) it is clear that increase in load demand of even a single bus will contribute to net increase in power losses of the distribution network.

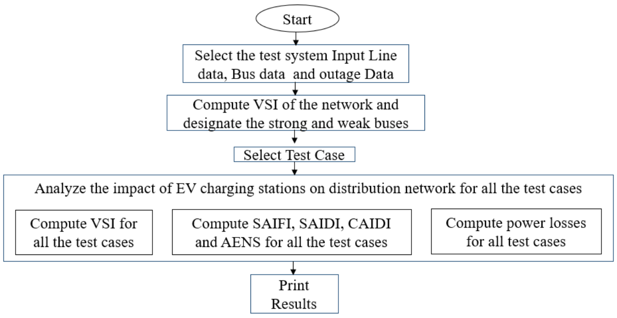

Figure 3: Flowchart of computational methodology for analyzing impact of Charging Station load on Distribution Network.

2.4 Formulation of VRP index for the optimal placement of FCS for Case 5

The mathematical formulation of VRP index in exemplified in this section from equation (9) to equation (12):

$$VRP = w_1 A + w_2 B + w_3 C \tag{9}$$

$$A = \frac{VSI_{base}}{VSI_l} \tag{10}$$

$$\begin{aligned} B = w_{21}\frac{SAIFI_l}{SAIFI_{base}} + w_{21}\frac{SAIFI_l}{SAIFI_{base}} \\ + w_{21}\frac{SAIFI_l}{SAIFI_{base}} + w_{21}\frac{SAIFI_l}{SAIFI_{base}} \end{aligned} \tag{11}$$

$$C = \frac{P_{loss}^l}{P_{lossbase}} \tag{12}$$

The values of input parameters w_x can be used as per the requirement of the system engineer and the need of the utility. In our study we have used the values of w_1, w_2, w_3, w_{21}, w_{22}, w_{23}, w_{24} as 0.1, 0.7, 0.2, 0.2, 0.4, 0.1, 0.3 respectively. Hence, it can be seen that the highest priority has been setup for reliability indices and moreover the highest priority is given to SAIDI among them.

VRP index is selected as the objective function for charging station placement problem because of its capability of taking into account voltage stability, reliability and power losses under a single umbrella. The decision variables, objective functions, and constraints for the optimal placement of charging stations in the distribution network based on VRP index are as follows. The decision variables are:

Buses of network in which CS will be placed,d
Number of FCS placed at the buses, f
Number of SCS placed at the buses, s
The optimization is aimed at minimization of VRP index. Mathematically:
min(VRP) where VRP = f (d,f , s)
Subject to the following constraints:

$$n_i \leq 0 \leq n_{FCS}$$

$$n_i \leq 0 \leq n_{SCS}$$

$$L \leq 0 \leq L_{max}$$

$$0 \leq VSF \leq 0.06$$

2.5 Formulation for the study of Coordinated V2G Discharging on Distribution Network

Below Table 3 presents the tabulated data of types of customers in our distribution network under study and their peak loads. We have classified Small Users, Government Institutions and Commercial customers under non-residential groups for ease. The peak load of the system is 20 MW and the residential load accounts for 36.25 percent of total load during the peak hour.

Table 3: Customer Type and Peak Load Data of RBTS Bus 2

Customer Type	**Peak Load (MW)**
Residential	7.25
Small Users	3.50
Government / Institution	5.55
Commercial	3.70
TOTAL	**20.00**

There are total of 4 feeders which supplies power to all the load points inn RBTS Bus 2 System. The residential customers have been placed at the starting end of the feeder and non-residential customers after that. The feeder wise loading data has been classified in Table 4.

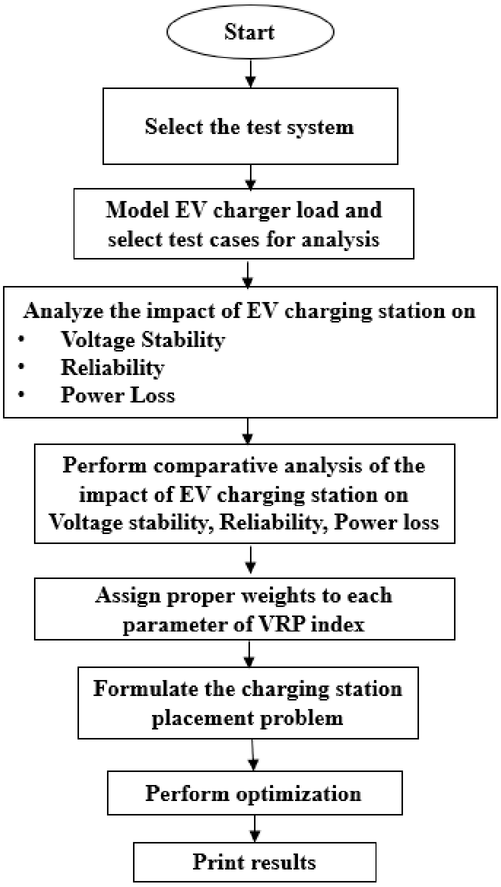

Figure 4: Flowchart for Fast Charging Stations Placement based on VRP Index

We have assumed that the EVs will travel to their desired commercial complexes for daily work during the day time and will return to their residences during the evening hours where they have the slow charging points available in the house for charging. Each vehicle has an assumed battery size of 30 kWh and battery usage during the travelling is 0.19 kWh/km. The maximum travelling capacity of the each EV per charge is 150 kms.

Figure 5 shows the travelling distance between the residential customers R1,R2,R3 to commercial complexes C1,C2,C3.

The residential loads are supplied by either 1200 kVA transformer or 1000 kVA transformer. Hence, we have calculated the number of EVs that can be charged per hour when we have a 30 percent penetration of EVs in the system. We have also kept in mind that the system

Table 4: Classification of Load Points

Load Point	Area Designation	Trf. Rating (KVA)	Peak Load (MW)	Average Load (MW)	Number of Customers
LP1	R1	1200	0.866	0.535	210
LP2		1200	0.866	0.535	210
LP3		1200	0.866	0.535	210
LP4	C1	1200	0.917	0.566	1
LP5		1200	0.917	0.566	1
LP6		1000	0.750	0.454	10
LP7		1000	0.750	0.454	10
LP8		–	1.682	1.000	1
LP9		–	1.872	1.150	1
LP10	R2	1200	0.866	0.535	210
LP11		1200	0.866	0.535	210
LP12		1000	0.729	0.450	200
LP13	C2	1200	0.916	0.566	1
LP14		1200	0.916	0.566	1
LP15		1000	0.750	0.454	10
LP16		1000	0.750	0.454	10
LP17	R3	1000	0.729	0.450	200
LP18		1000	0.729	0.450	200
LP19		1000	0.729	0.450	200
LP20	C3	1200	0.916	0.566	1
LP21		1200	0.916	0.566	1
LP22		1000	0.750	0.454	10

Table 5: Loading Data of Feeders

Feeder Number	Load Points	Feeder Load, MW		Number of Customers
		Average	Peak	
F1	1 to 7	3.645	5.934	652.0
F2	8 to 9	2.150	3.500	2.0
F3	10 to 15	3.106	5.057	632.0
F4	16 to 22	3.390	5.509	622.0
Bus 2 total		**12.29**	**20.00**	**1908**

Table 6: Travelling distances of residential customers

Route	Distance (Km.)	Number of vehicles travelling	Total Number of Vehicles
R1 to C1	19	63	189
R1 to C2	20	63	
R1 to C3	38	63	
R2 to C1	10	63	186
R2 to C2	17	63	
R2 to C3	17	60	
R3 to C1	19	60	180
R3 to C2	38	60	
R3 to C3	20	60	

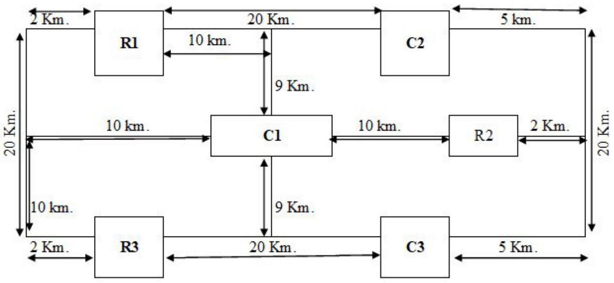

Figure 5: Modelling of Distribution System as per location of customers in RBTS Bus 2

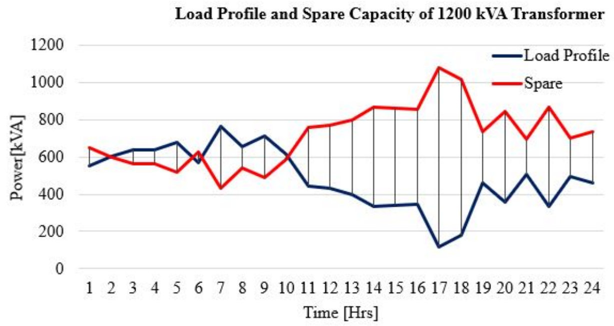

Figure 6: Load Profile and Spare capacity in 1200 kVA Transformer

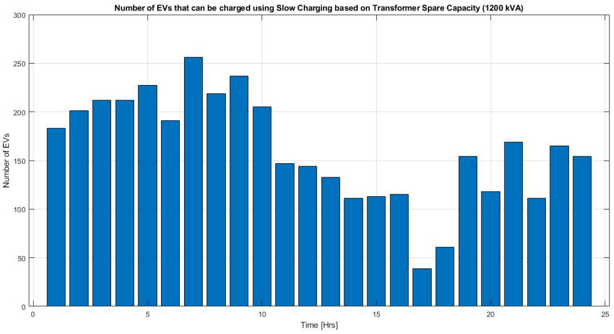

Figure 7: Number of vehicles that can be charged hourly using 1200 kVA Transformer

should not get overloaded due the integration of EVs. It can be seen form Figure 6 and 7 that each transformer has enough spare capacity to charge respective EVs between 22:00 hours to 8:00 hours. In the very time period, the EVs under study can be fully charged and will be ready to move. In the similar manner we have calculated the spare capacity of 1000 kVA transformers and number of vehicles than can be charged for our analysis.

The energy that would be availabe in the battery of EVs once they reach the commercial complexes has been calculated as follows:

Energy Available in EV before travel = Maximum

Distance that can be travelled (Dm)* Energy required to travel 1 km(E1)
Energy Available in EV after travel = Ebt(Energy Available in EV before travel) – Eut(Energy used by EV for travelling)
Energy Used in Travelling = Distance Travelled (D) * E1
Spare Energy Required = 25 percent of maximum capacity + Energy required to travel back (Enb)
Capacity Available = Energy Available in EV after travel (Eat) – Spare Capacity required (SpCap)

Table 7: Energy Available from EVs to be discharged in Commercial complexes

Commercial Complex	Total Energy Available (kWh)
C1	2848.29
C2	2223.57
C3	2158.305

3. Results and Discussions

3.1 Results from Case 1 to Case 6

In this section, we have analyzed six cases and reliability indices named SAIFI, SAIDI, CAIDI, AENS, ENS and Power Loss of the distribution network are calculated for all the cases. To calculate all these parameters we need some basic load point indices and these are failure rate (λ_i), repair hours (r) and annual outage data in hours per year (U_i), number of customers connected in each load points (N_i) and average load connected to each load points($L_{a(i)}$). All these required data of each load points have been taken from reference [8] for calculations. It is also to be noted here that the load point indices have been used in this study such that the values change linearly with the change in addition of load to the distribution network.

For the base case, no load has been added to the RBTS Bus 2 Test System and all the parameters has been calculated. Case 2 to Case 4 has been examined by introducing 3 FCSs where each FCS has eight charging points with connected charger of 50 kW each. That means each FCS has a load of 400 kW and hence while analyzing each case, there is an addition of 1200 kW in the distribution network. Case 2 has been analyzed by placing a single FCS at each bus number 35, 36 and 37 which are the three weakest buses in the system based on VSI. Case 3 has been analyzed by integration FCSs to the mixed buses that is bus number 16,27 and 37 where bus 16 is among the strongest bus and bus 37 is the weakest bus in the system, based on VSI. Similarly, Case 4 has been analyzed by introducing one FCS each at bus number 16,17 and 25 which are the strongest buses in the system based on VSI.

Case 5 is the most important case in this study as we have found out the optimal buses in the system. It is to be noted that while analyzing case 2 to case 4, we had simply added the FCSs to the locations which were ranked according to VSI only. But in case 5 we are considering the effect on voltage, reliability indices and power loss together. The optimal locations are those which would produce the least impact on the VRP of the system. Moreover, while evaluating the optimal location based on VRP, we have given 70 percent preference to the deviation of reliability indices as we are focusing more on customers satisfaction in this study. Genetic Algorithm has been used to find the optimal locations which were bus number 19,23 and 31.
In RBTS Bus 2 System, the residential buses are bus number 16,17,18,25,26,27,32,33, and 34. Thus, for the analysis of Case 6, we have removed all the FCSs and introduced Slow Charging Stations (SCS) to each bus. The study has been performed with 30 percent penetration that is it has been assumed that 30 percent of the customers have EVS with them which they charge during the off-peak hours with the 3 kW level 1 chargers installed at their homes. Based on our assumption of 30 percent penetration, there are 555 customers in our system with EVs which add the total load of 1.665 MW when connected together.

Table 8: Results from Case 1 to Case 6

Cases	SAIFI (intr/yr)	SAIDI (hr/yr)	CAIDI (hr/intr)	AENS (kWhr/cust)	ENS (MW hr)	Ploss (kW)
1	0.249	0.691	2.7779	6.946	13.253	112.284
2	0.250	0.694	2.7780	8.033	15.327	132.909
3	0.276	0.768	2.7763	8.047	15.353	126.211
4	0.286	0.794	2.7738	7.988	15.241	119.826
5	0.250	0.693	2.7781	7.912	15.096	123.286
6	0.304	0.846	2.7778	8.291	15.820	127.229

Before, we begin the graphical comparison of the reliability indices and the parameters, it should be noted that the buses have been ranked from the strongest and weakest on the basis of VSI. The distribution system under consideration is already robust enough to handle the addition of load and the voltages of the buses are between 0.97 p.u. to 1.03

p.u.. One of the most important information that we should not miss while analyzing the results is that the calculation of customer-oriented reliability indices depends upon the number of customers N_i hence the results obtained will largely be influenced by N_i. The information of N_i at each load points i can be seen in Table 4. And it can be seen in Table 4 that the bus number 35,36,37 are the weakest ones on the basis of VSI, have only 1,1 and 10 customers connected to them. However, the strongest bus 16,17,18 have 210 customers each attached to them.

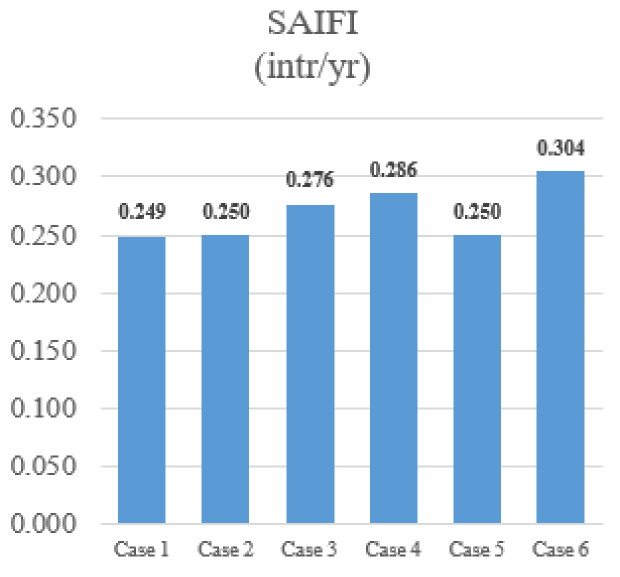

Figure 8: Comparison of SAIFI

Figure 8 shows the comparison of SAIFI of all cases and it shows that Case 5 in which we have connected FCSs at the optimum location determined by GA has the least deviation in SAIFI in comparison with base case. The optimum location determined using VRP index will affect the distribution system and the customers the least in comparison with the integration of FCSs at weakest, mixed or strongest buses. The effect on SAIFI for case 6 is more as the increase in load in this case is 1.665 MW and due to that the faliure rate of the system is increased linerarly which affects the value of it.

The results of Figure 9 remain consistent with our assumption of VRP index producing the best result in terms of SAIDI. From section 2.4, we can see that highest weightage has been given to SAIDI while considering VRP index and hence, it has produced the result considering the least deviation in customer interruption duration in comparison with the base case.

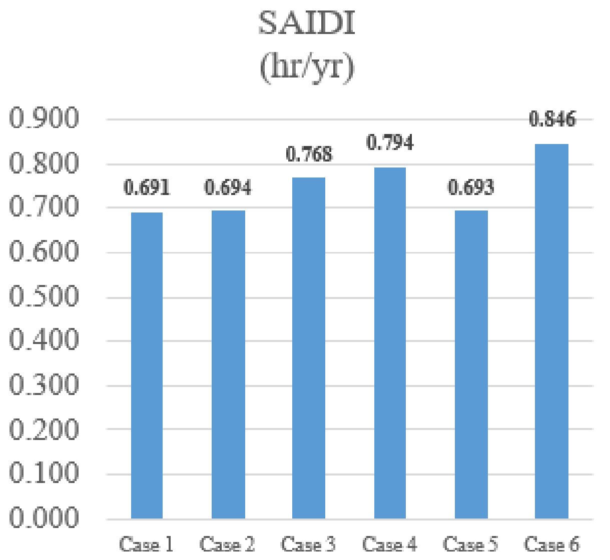

Figure 9: Comparison of SAIDI

CAIDI can also be viewed as the ratio of SAIDI:SAIFI and it gives us the average outage duration experienced by a customer in a particular unit of time. As the mean time to correct the faults and disturbances in the RBTS Bus 2 is 2 hours for all the buses; the results seen in figure 10 shows least variation with base case data for all the cases.

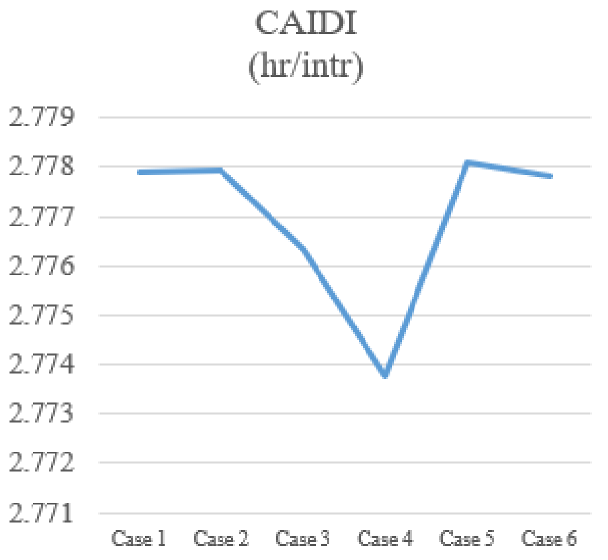

Figure 10: Comparison of CAIDI

Figure 11 and Figure 12 shows the comparative analysis of the Average Energy Not Supplied and Energy Not Served after the integration of FCSs/SCSs to the existing system. There is a minor deviation in AENS for all the cases in comparison with the base case. As we know the system under consideration is

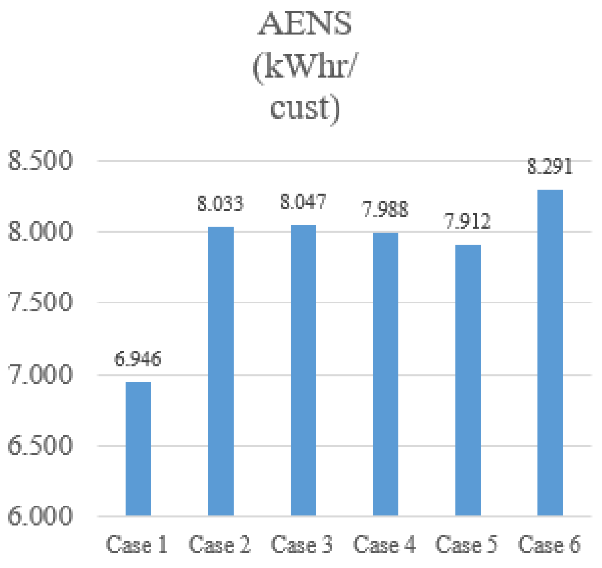

Figure 11: Comparison of AENS

already robust and the addition of load is also that not significant. We have only added 1.2 MW load for case 2 to case 5 and 1.665 MW load for case 6. The peak load of the system is 20 MW and average load is 12.291 MW whereas the system is being operated with transformers of 1200 kVA and 1000 kVA at each load points. Compared to case 2 and case 3 addition of FCS at the strongest buses and buses defined by optimal location produces less deviation in ENS of the system.

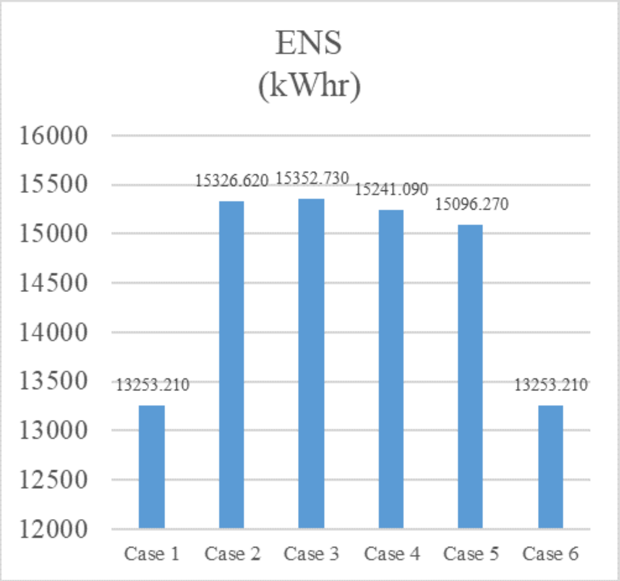

Figure 12: Comparison of ENS

As we can see from Figure 13, placing the fast charging stations at the weakest bus results in more power loss compared to their placement at mixed buses or strongest buses. Similarly, placement of FCSs at the optimum location is also less loss making compared to placement at weakest or even mixed buses. Talking about the addition of SCSs to the residential loads, the loss is more because the total addition of load is 1.665 MW in case 6 compared to 1.2 MW for cases 2 to 5. It is obvious that the losses will increase with the increase in load and hence, it is beneficial to do the analysis for finding out the optimal location for the placement of charging Station loads.

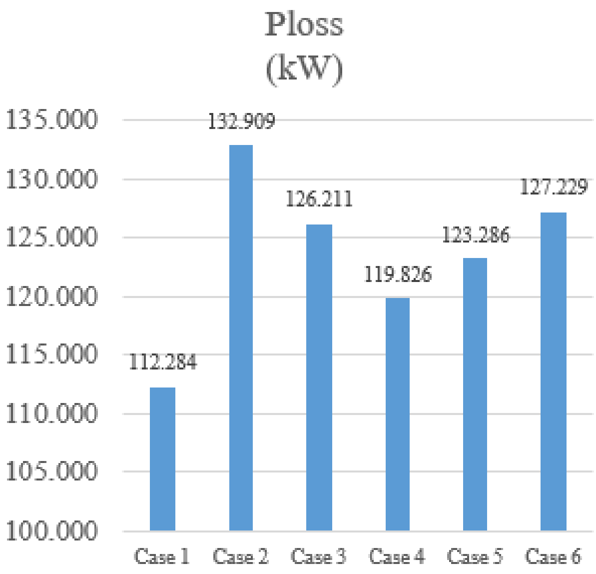

Figure 13: Comparison of Power loss

3.2 Results of Case 7: V2G

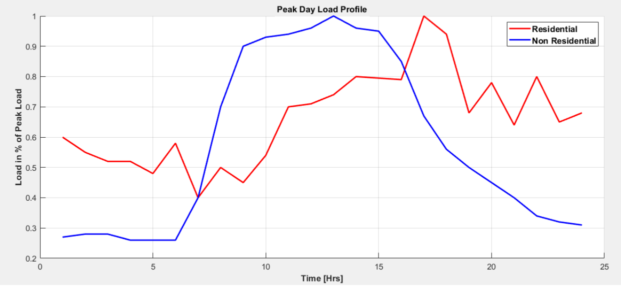

Figure 14: Load Profile of Residential and Non-Residetial Customers

In Figure 14, we have obtained the load profile of the residential and non-residential loads of our system. The curves have been drawn based on the peak load and average load data provided in Table 4. The data from [7] has also been utilized to draw these load profiles. The commercial load is high during the office hours in RBTS Bus 2 system and hence, the excess energy of the EVs has been discharged when the EVs reach their respective commercial complexes in the section below.

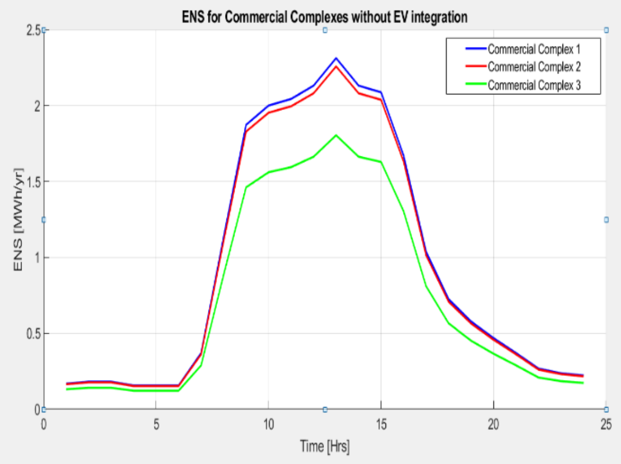

Figure 15: ENS of Commercial Complexes wihtout EV integration

Figure 15 shows the ENS for commercial complexes C1, C2 and C3 separately without the integration of EVs. Figure 16 shows the ENS of the commercial complexes with EVs discharging their excess energy (as mentioned in Table 7) from 11:00 hours to 16:00 hours. As we can see, the ENS has been reduced with EV discharging. The commercial complex C1 is supplied by total transformer capacity of 3200 kVA and has 21 commercial customers connected to it.C2 is supplied by total transformer capacity of 2000 kVA and has 20 customers connected to it. Similarly C3 is supplied by 1000 kVA transformer and has only 10 customers connected. The total peak load of C1, C2, C3 is 2416 kVA, 1500 kVA and 750 kVA respectively. This addition of EVs in the commercial complexes would increase the peak loads and hence produce the changes in ENS as represented in Figure 16.

Table 9: ENS with EVs in V2G and G2V modes

Scenarios	ENS (kWhr /yr)
Base Load-RBTS	5661.87
Base Load + G2V	6297.96
Base Load+ G2V + V2G	5930.49

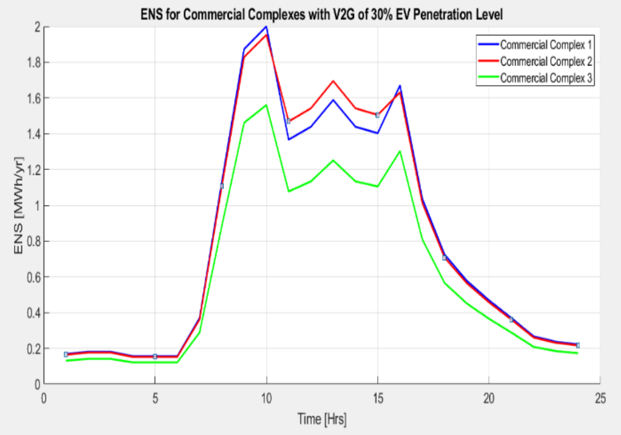

Figure 16: ENS of Commercial Complexes with EV integration and V2G discharging

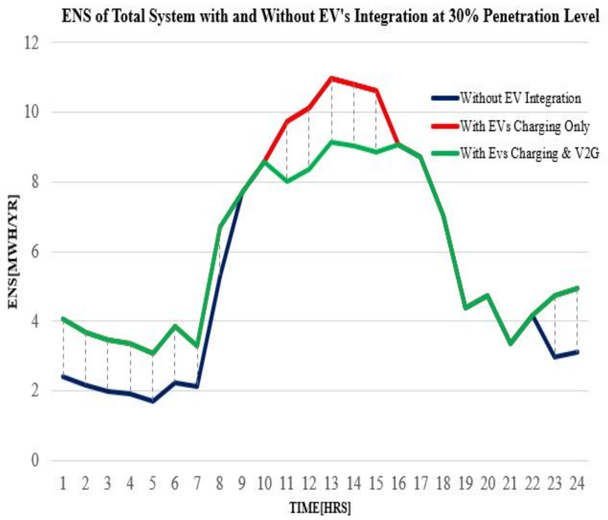

Figure 17: ENS of Total System with and without V2G discharging

The ENS of the system without EV integration is shown by blue curve, system with EV integrated to the system but not discharging to the system is shown by red curve and system with EV charging as well as discharging is shown by green curve. When the EV has been integrated and charging only then the ENS of the system increases. When EV is charging during 22:00 hours to 8:00 hours then the ENS increases and then when the EVs discharge at the commercial complexes from 11:00 hours to 16:00 hours then the ENS decreases. It also means that the coordinated charging and discharging of EVs in the system can be beneficial to the utility and the customers as well and would not hamper the stability of the system. As we can see from the data of Table 9, the ENS of the system increases by 11.23 percent in comparison with base case when the EVs are integrated to the system but not discharging but if the vehicles are discharging(G2V) as well then then ENS increases by 4.74 percent only. If the EVs have batteries of larger size and the penetration level is higher then ENS can be altered significantly.

4. Conclusion

This paper has proposed the methodology based on Voltage, Reliability and Power loss together for spotting the optimal location for the connection of Fast Charging Station loads in any distribution network. GA was used to spot the best locations with minimum VRP index as the objective function. It has been verified that the use of VRP index would help the system engineers in planning the future network with EVs integrated to the system.

Additionally, the case study of V2G discharging in the system was analyzed with 30 percent penetration level of EVs. It was seen that coordinated charging and discharging during off peak and peak hours respectively would produce benefit to the utilities while addressing the increased load of EVs. It can also be concluded from the study that the optimum use of available resources and power will create a win-win situation for all the concerned parties in the market.

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