Impact of Distribution Feeders that do not have Voltage Regulators on the number of Charged Electric Vehicles using IEEE 34 Bus Test Feeder

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Abstract - Voltage regulators help maintain an acceptable voltage profile for the system. This paper discusses the effect of installing voltage regulators to the system to fix the voltage drop resulting from the electrical vehicles loading increase when they are being charged. The effect will be studied in the afternoon, when the peak load occurs, using the IEEE 34 bus test feeder. First, only one spot node is used to charge the electric vehicles while a voltage regulator is present. Second, five spot nodes are loaded at the same time to charge the electric vehicles while voltage regulators are installed at each node. After that, the impact of electric vehicles on distribution feeders that do not have voltage regulators will be discussed.

***Index Terms*—Electric Vehicles, Voltage Regulators, Voltage Violation, Power Distribution.**

I. INTRODUCTION

Since the industrial revolution started, the acceleration of technology development never stopped. However, with the development of new technologies, environment is suffering the consequences. The rate of carbon dioxide and other emissions have been increasing rapidly ever since. To mitigate these pollutions, there is global push to increase the use of electric vehicles (EV) and substantially reduce the use ofgasoline power vehicles [1]. To meet this goal, EVs must be integrated to the electric grid. EVs are effectively electric power loads. Therefore, when electric vehicles are charged, they will cause voltage drop on the distribution feeders. Hence, the presence of voltage regulators might change the voltage response of the system.

II. VOLTAGE REGULATION OVERVIEW.

In electric power distributions system voltage regulation is an important concept. It deals with ways to maintain a good voltage profile delivered to the customers. The voltage level at the customer node has to be maintained within a specified range. There are many standards that determine customer's voltage range. Some standards assume a variation of ±10%. However, it is determined by the utility based on their circumstances.

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III. VOLTAGE REGULATION METHODS

The concept of voltage regulation associated with the electrical distribution system is caused by the radial distance between the power source and the loads. There will be a voltage drop across the feeders powering the customers load. However, the voltage delivered to the customers must be within a minimum and a maximum value specified by the utility company as well. Otherwise, it will violate the voltage profile of the customers load.

The voltage drop occurs in the distribution system is due to the current flowing to customer's load and the impedance of the electrical elements. Since the conductors of the feeders have impedances, the flow of current through the feeder causes voltage drop across the feeder which reduces the voltage at the customer bus. The common ways to regulate the voltage are changing the turns ratio of the on load tap-changing transformers and installing capacitor banks that supplies reactive power to the network. The capacitor bank is used because most eclectic loads are inductive which consume reactive power. Therefore, capacitors are needed to supply the consumed reactive power to achieve a power factor that is close to unity.

A) Voltage regulators or on-load tap-changing transformer

The voltage regulator, or the on-load tap-changing transformer, is one of the most important elements in the network of the power distribution. The on-load tap-changing transformer is adjusted automatically to maintain the voltage level at the distribution feeder to be near constant. The voltage level is adjusted with respect to the load changes at the customer terminal. Controlling the voltage level with the load change is called " Line Drop Compensation [2]." The allowed voltage increases is restricted. Therefore, adding more voltage regulators along the distribution feeder is essential.

B) Capacitor Bank

Capacitors are installed to supply the reactive power consumed by the inductive loads. The capacitor bank could be switched on when the system needs reactive power supply or connected to the electrical network permanently. The consumer's demand changes with time. Therefore, It is impossible for the capacitor bank to meet the consumed reactive power exactly. Additionally, the reactive power generated by the capacitors is directly proportional with the square of the voltage. As a result of that, connecting more capacitor than needed to the grid results in overcompensation which results in an increase in the system voltage. Therefore, capacitors should be removed to lower the voltage level, or a voltage regulator must be installed to accommodate the voltage increase in the system.

IV. CHARGING LEVELS

A) Level 1

Level 1 charging uses 120 Ac-volts and 15 AC-Amperes[4]. It charges using a household socket directly without a charging unit. Additionally, the battery used determines the amount of time needed to be fully charged. Typically, the time range is between four to eleven hours[4]. Since level 1 requires many hours to charge, it is recommended for customers to charge their vehicles overnight.

B) Level 2

Level 2 charging uses 240 Ac-volts and 32 AC-Amperes[4]. Separate charging unit is mandated to charge through level 2. Typically, charging unit is installed in public or inside the house. Most electric vehicles are charged through level 2 because it is economic and does not require a lot of time to charge. The average charging time is between two to six hours[4].

C) Level 3

Level 3 charging uses 480 DC-volts. Therefore, a rectifier is required to rectify the voltage from AC to DC. Level 3 charges electric vehicles faster than level 2 and level 1. The average charging time is between forty minutes up to an hour[4]. The main disadvantage of level 3 is the high cost of the charging unit.

V. MODELING

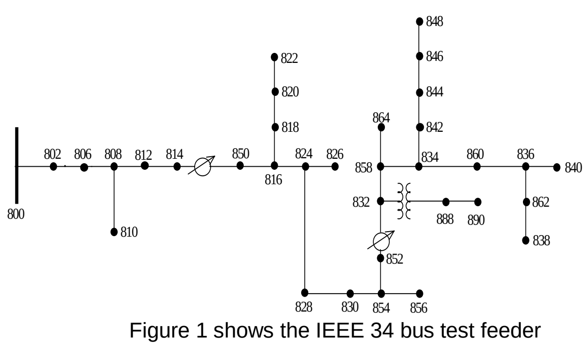

Figure 1 shows the IEEE 34 bus test feeder

The test is done using IEEE 34 node test feeder which is a real distribution system located in Arizona. The nominal voltage in the system is 24.9 KV. However, the transformer between nodes 832 and 888 steps down the voltage to 4.16 kV. To regulate the voltage profile of the system, two voltage regulators are connected at buses 814 and 852.The entire system is overhead. It consists of four wires three phase and single phase loads connected in different phase sequences and different overhead distribution line types. Nodes 830, 844, 860, 840,890 and 830 are spots loads. The rest of the nodes are unbalanced distributed loads. The shunt capacitors in the system are considered as fixed. The distribution system is modeled using EDD software. Reference [3] provides detailed information about the IEEE 34 bus test feeder.

V. ASSUMPTIONS

1) LOAD CURVE

Customer demands vary continently throughout the day. It could be classified into peak demand and off-peak demand. The peak demand describes the period when the electrical demand reaches the highest point, or the period in which the customers are consuming the highest rate of power. Peak demand varies with respect to many factors such as the season of the year and whether the day is a holiday or not. On the other hand, the off-peak demand is the period thatis not included in the peak period.

The impact of electric vehicles in the existence of voltage regulators at distribution substations is tested in the peak period. The peak period is the afternoon with 100% of the capacity. On the other hand, the morning and evening are about 55% and 35% respectively.

2) TESTS

Vehicles that are charged using level 1 charging are assumed to be 2 kW because the voltage and current rating are 120V and 15A respectively[4]. On the other hand level 2 charging vehicles are assumed to be 8 kW because the voltage and current rating are 240V and 32A respectively[4]. Voltage violation at bus 890 is ignored because it is connected to a transformer. Therefore, when a voltage violation occurs, transformer ratio could be modified to accommodate the voltage violation. Also, electric vehicles are not connected to bus 890.

A) TESTING EACH NODE SEPARATELY

The same loading in the IEEE 34 node test feeder is used. Also, the spot loads are used to connect the electric vehicles. In each step the power consumed is increased per phase. After that, a voltage regulator is connected to the same node to examine the voltage profile of the system in case of connecting the voltage regulator at the substation. The power consumed is increased in each step per phase. A voltage regulation of +8.2% or -8.2% will be accepted. Also, voltage regulator current is allowed up to 20% of the rated value. The process is repeated at each of nodes that are spot loads. Also a regulator is connected to node 816 to determine the effect on the system.

A.1) Test at bus 840

A.1.1) No voltage regulators

Table1 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2458.53	no
240	2940.10	no
330	3297.59	no
360	3414.56	At node890
580	4346.86	At nodes 830&890

A.1.2) Regulators connected to node 840

Table2 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2457.34	no
240	2939.22	no
330	3299.44	no
360	3416.78	At node 890
580	4349.39	At nodes 830&890

A.1.3) Regulators connected to node 816

Table 3 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2455.52 kW	no
240	2936.32 kW	no
360	3440.52 kW	no
580	4436.15 kW	At node 890
630	4670.31 kW	At node 890
635	4692.33 kW	At node 890 and 808-812 line voltage

A.2) Test at bus 860

A.2.1) No voltage regulators

Table 4 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2458.25	no
240	2934.96	no
330	3295.73	no
360	3412.30	At node 890
580	4339.75	At node 890
590	4383.17	At nodes 890&830

A.2.2) Regulators connected to node 860

Table5 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2457.87	no
240	2931.56	no
330	3296.22	no
360	3410.40	At node 890
580	4345.58	At nodes 890 & 830 !!!!!
590	4390.28	At nodes 890 & 830

A.2.3) Regulators connected to node 816

Table6 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2459.19	no
240	3096.56	no
360	3438.33	no
580	4425.30	At node 890
630	4657.71	At node 890
640	4684.26	At node 890 and line 808-812 voltage

A.3) Test at bus 848

A.3.1) No voltage regulators

Table7 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2458.45	no
240	2939.98	no
330	3297.46	no
360	3414.44	At node 890
540	4171.42	At node 890
580	4346.99	At nodes 890 & 830

A.3.2) Regulators connected to node 848

Table8 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2451.34	no
240	2937.24	no
330	3293.64	no
360	3417.72	no
540	4175.22	no
580	4350.56	At node 890
590	4395.33	At node 890
600	4435.69	At nodes 890 & 830

A.3.3) Regulators connected to node 816

Table9 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2455.44	no
240	2935.83	no
360	3444.18	no
580	4436.19	At node 890
620	4621.78	At node 890
640	4670.30	At nodes 890 and 808-812 voltage

A.4) Test at bus 844

A.4.1) No voltage regulators

Table10 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2450.84	no
240	2935.01	no
330	3295.32	no
360	3411.83	At node 890
580	4338.54	At node 890
600	4425.69	At nodes 890 & 830

A.4.2) Regulators connected to node 844

Table11 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2471.70	no
240	2948.34	no
330	3319.33	no
360	3443.07	At node 890
580	4417.21	At nodes 890 &830
600	4509.27	At nodes 890 &830

A.4.3) Regulators connected to node 816

Table12 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2471.22	no
240	2947.59	no
360	3437.87	no
580	4424.24	At node 890
630	4656.45	At node 890
640	4705.07	At nodes 890 and 808-812

A.5) Test at bus 830

A.5.1) No voltage regulators

Table13 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2423.14	no
240	2860.76	no
360	3316.13	no
580	4172.50	At node 890
630	4370.85	At node 890
640	4417.71	At node 890
650	4456.17	At nodes 890 & 830

A.5.2) Regulators connected to node 830

Table14 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2425.28	no
240	2857.47	no
360	3313.95	no
580	4219.42	no
630	4433.53	At line 828-830 voltage
640	4477.08	At line 828-830 voltage

A.5.3) Regulators connected to node 816

Table15 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
120	2429.31	no
240	2864.16	no
360	3315.31	no
580	4202.10	no
630	4413.88	no
660	4529.82	no
690	4673.74	no
700	4716.86	At line 808-812

B) INCREASING LOAD AT ALL BUSES AT THE SAME TIME

B.1) No voltage regulators

Table16 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
20	2371.43	no
40	2757.17	no
60	3160.92	no
80	3549.13	At node 890
100	3954.78	At node 890
110	4166.82	At node 890
120	4376.19	890 & 830

B.2) Voltage regulator at each bus

Table17 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
20	2385.55	no
40	2770.69	no
60	3168.89	no
80	3593.42	no
100	4040.37	no
110	4271.48	no
120	4510.83	At line 828-830

B.3) Voltage regulator at 816

Table18 shows total power in the system and any voltage violation occurs after the increase

Power Increase (kW)	Active power (kW)	Voltage Violation
20	2368.42	no
40	2758.22	no
60	3154.83	no
80	3572.87	no
100	4007.97	no
120	4460.73	no
130	4695.61	At node 890
140	4923.76	At line 808-812

VI. RESULT AND ANALYSIS:

At bus 840, the system was able to withstand up to 580 kW of electric vehicle load. This is equivalent to 290 electric vehicles using level 1 charging. Moreover, it is equivalent to 72 electric vehicles using level 2 charging station. Connecting a voltage regulator at the bus could not increase the number of electric vehicles charged from the distribution system. On the other hand, installing a voltage regulator at bus 816 increases the electric vehicles connected to 317 electric vehicles using level 1 charging and 79 electric vehicles using level 2 charging.

At bus 860, the system was able to withstand up to 590 kW of electric vehicles. This is equivalent to 295 electric vehicles using level 1 charging. Moreover, it is equivalent to 73 electric vehicles using level 2 charging station. Connecting a voltage regulator at the bus could not increase the number of electric vehicles charged from the distribution system. On the other hand, installing a voltage regulator at bus 816 increases the electric vehicles connected to 320 electric vehicles using level 1 charging and 80 electric vehicles using level 2 charging.

At bus 848, the system was able to withstand up 580 kW of electric vehicles. This is equivalent to 290 electric vehicles using level 1 charging. Moreover, it is equivalent to 72 electric vehicles using level 2 charging station. Connecting a voltage regulator at the bus increases the number of electric vehicles charged from the distribution system to 300 and 75 using charging level 1 and 2 respectively. On the other hand, installing a voltage regulator at bus 816 increases the electric vehicles connected to 320 electric vehicles using level 1 charging and 80 electric vehicles using level 2 charging.

At bus 844, the system was able to withstand up to 600 kW of electric vehicles. This is equivalent to 300 electric vehicles using level 1 charging. Moreover, it is equivalent to 75 electric vehicles using level 2 charging station. Connecting a voltage regulator at the bus could not increase the number of electric vehicles charged from the distribution system. On the other hand, installing a voltage regulator at bus 816 increases the electric vehicles connected to 320 electric vehicles using level 1 charging and 80 electric vehicles using level 2 charging.

At bus 830, the system was able to withstand up to 650 kW of electric vehicles. This is equivalent to 325 electric vehicles using level 1 charging. Moreover, it is equivalent to 81 electric vehicles using level 2 charging station. Connecting a voltage regulator at the bus decreased the number of electric vehicles charged from the distribution system to 315 using level 1 charging station and 78 using level 2. On the other hand, installing a voltage regulator at bus 816 increases the electric vehicles connected to 330 electric vehicles using level 1 charging and 82 electric vehicles using level 2 charging.

VII. SUMMARY AND CONCLUSION

As shown in table 17 and 18 connecting a voltage regulator at the distribution substation does not have an impact on how many electric vehicles can the system withstand without any voltage violation for most of the cases. However, installing a voltage regulator at bus 816 increases the number of electric vehicles in all cases. Therefore, regulating the voltage in a distribution system when electric vehicles are charged is not only related to the buses loaded. It is a matter of the entire system. The system must be tested to find the best location to install voltage regulators. On the other hand, when a voltage regulator is connected at bus 848, the number of electric vehicles increases. This does not mean that the optimum place to install a voltage regulator is at loaded bus. As seen in table 17, the number of electric vehicles connected to the bus when a voltage regulator is installed at bus 816 exceeds when a regulator is connected at but 848.Thus, a study must be conducted to find the optimum place to install regulators and the place is not necessarily be at the loaded bust.

Table17 shows the number of EV's (Electric Vehicles) each bus can withstand at three different cases when each bus is loaded separately.

Bus number	# of EV's without regulator at the bus		# of EV's with regulator at the loaded bus		# of EV's with regulator at bus 816	
	Level 1	Level 2	Level 1	Level 2	Level 1	Level 2
840	290	72	290	72	317	79
860	295	73	295	73	320	80
848	290	72	300	75	320	80
844	300	75	300	75	320	80
830	325	81	315	78	350	87

Table18 shows the number of EV's (Electric Vehicles) can each bus withstand at three different cases when five spot nodes are loaded at the same time.

Scenario	# of Electric vehicles	
	Level1	Level2
No regulator at each bus	60	15
A regulator at the loaded buses	60	15
Regulator at bus 816	70	17

VIII. REFERNCES

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BIOGRAPHY

Ahmed Allehyani was born in Jeddah, Saudi Arabia in April first 1990. He earned his bachelor's degree from King Abdulaziz University in Jeddah, Saudi Arabia. He graduated from King Abdulaziz University in 2012 with a bachelor of science in Electrical Engineering.

He did a summer training at the Saudi Electricity Company in the distribution department for two months. After graduation, he worked also for the Saudi Electricity Company but in the transmission department. He was hired as a project manager for the electricity transmission projects. He quit his job after six months to get a Master Of Science from the University Of Southern California located in Los Angeles, CA, United States. He is currently studying MS in Electrical Engineering at the University of Southern California.

Dr. Mohammed Beshir is Associate Professor of Electrical Engineering at the University of Southern California (USC), USA. He has a Ph.D. in Electrical Engineering from USC and Masters in Business Administration (MBA) from Pepperdine University in Malibu, California, USA. He is registered professional engineer in the state of California and is a Senior Member of IEEE.

Formerly, he was an Assistant Director of Power System Planning and Development Division at the Los Angeles Department of Water and Power (LADWP). He worked for LADWP for over 30 years in various responsibilities including integrated resource planning, transmission planning, renewable project development, HVDC design, power contracts, distribution planning, power reliability, and energy storage systems.