Title

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Impacts of Plug-in Electric Vehicles on a Distribution Level Microgrid

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***Abstract*— Plug-in Electric Vehicles (PEVs) have been transforming the fossil fueled transportation system into a sustainable and emission free transportation system. This paper studies the integration of electric vehicles and associated complexities involved with energy management in a distribution level microgrid. The microgrid is situated at University of California Riverside College of Engineering- Center for Environmental Research and Technology (UCR CE-CERT). Efficiency issues of electric vehicles in comparison to conventional gasoline engine vehicles have been discussed from the source of energy viewpoint. The real time charging characteristics for different types of electric vehicles have been addressed considering level II and level III chargers. The charging impacts on building load and distribution grid of the system are also shown to assess the future challenges of large scale EV integration.**

***Index Terms*— Charging impacts, Microgrid, PEV charging, PEV efficiency, sustainable transportation.**

I. INTRODUCTION

The transportation sector is one of the largest users of energy throughout the world. Population growth, advanced technology and economic growth are the leading reasons that cause the increase in transportation sector energy consumption. According to Statista, 272.48 million vehicles were registered in U.S in 2017 [1]. The total petroleum consumption in the world was 93 million barrels per day in 2015 and U.S is the largest user of petroleum. Average petroleum consumption in the U.S. was 19.96 million barrels per day. Seventy one percent of this petroleum was consumed in transportation sector [2]. Alternative fuel technologies are needed to reduce the dependency on petroleum consumption. As renewable energy resources are making inroads in recent years, electrification of transportation may be a solution towards sustainable transportation future.

Electric power sector in the U.S. uses 38% of primary energy as shown in figure 1 followed by transportation sector's energy use of 28% of the total in 2018 [3]. If transportation electrification continues with increasing number of electric vehicles (EV), then there will be rapid increase in electric power generation. Additional power transmission and distribution capacities will be needed to satisfy this increased demand.

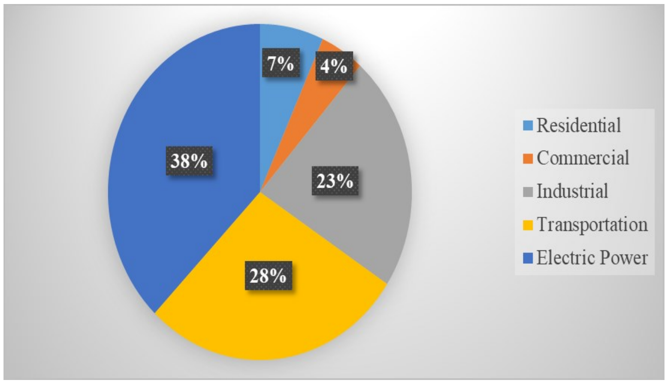

Fig 1. U.S. Primary Energy Usage in Various Sectors, 2018.

The energy consumption in both electric and transportation sectors in U.S are summarized in tables I and II [3]. About 92% of the total transportation energy use is petroleum whereas coal and natural gas are the top primary energy contributors for electricity sector. Transportation electrification energy demand will be met by mostly fossil fuel as shown in table I energy mix. However, recent rapid increase in the penetration of renewable resources like solar PV and wind, along with additional nuclear power offer carbon free electrical energy. As solar and other renewable sources are intermittent in nature, the integration to the electrical grid is more challenging and need either back up generation facilities or energy storage.

Table I. Energy Consumption (Trillion Btu) by electric sector in 2018

Annual Total	**Coal**	**Natural Gas**	**Petroleum**	**Nuclear**	**Renewables**
2018	12,037	10,949	243	8,441	6,459

Table II. Energy Consumption (Trillion Btu) by Transportation Sector in 2018

Annual Total	**Coal**	**Natural Gas**	**Petroleum**	**Biomass Energy**
2018	0	873	26,027	1,413

The rate of growth of electric vehicles compared to conventional vehicles depends on factors such as energy policy, available infrastructure and cost. In 2016, the total number of electric vehicles was 2 million worldwide and it had been increased by 55% in a year. The Battery Electric Vehicle (BEV) share of total light-duty vehicle sales has grown the most since 2012. The number of electric vehicles are 2.5% to 4.0% of total light-duty vehicle sales in 2012-2017 [4-5].

China and United States are the largest markets for electric vehicles. According to International Energy Agency (IEA), the growth rate of EVs in China is greater in comparison to Unites States [5]. Figure 2 shows the energy used in U.S. transportation sector for different types of vehicles [6]. Light duty vehicles are the largest in number and consume 62% of transportation energy followed by heavy duty vehicles use of 23%. Transportation electrification efforts are mostly focused on these two types of vehicles.

In this paper the following items are discussed and presented:

1. Presenting the overall energy consumption scenario in transportation and electric sector.
2. Showing the actual charging signature of different electric vehicles.
3. Projecting broader impact on the distribution grid and “Duck Curve” of California to address the EV integration challenges.

This paper has the following subsections. Section II provides the relationship between EV efficiency and electric power generation, Section III describes the testbed for PEV operation, Section IV shows the real time EV characteristics, Section V analyzes the impacts of EV integration and Section VI concludes the paper.

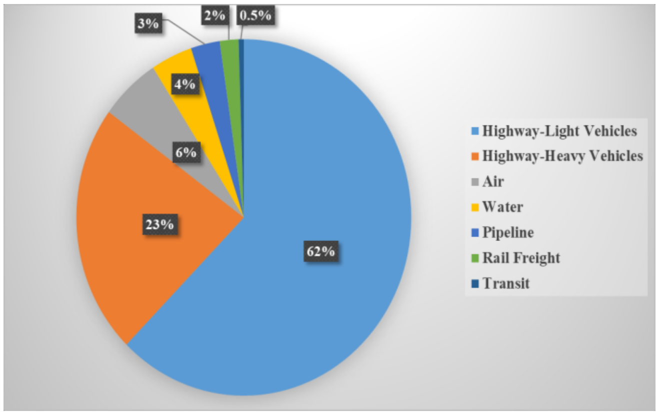

Fig 2. Energy Used in U.S. Transportation Sector by mode of Transportation, 2016.

II. RELATIONSHIP BETWEEN ELECTRICITY PRODUCTION AND EV CHARGING

Efficiency is one of the key factors for consumers to choose between gasoline and electric vehicles. Electric vehicles always have been assumed as the most efficient cars among all the cars available. Temperature, driving and charging patterns influence efficiency calculation of electric vehicles [7-8]. Battery technology is also an indicator for electric vehicle efficiency. Battery life depends on the frequency of charging and discharging. Ultra capacitor banks are being used for improving battery efficiency [9].

Motive power is the net output power of the total input power that drives any vehicle. It has been used to indicate the overall efficiency of any vehicle. Only 12-30% of the energy from the fuel input has been used to move a gasoline vehicle down the road and for an electric car 72–94% of the input energy is used to move it down the road [10-11]. This high electric motive power number does not consider the significant energy loss at the power plant where basic energy is converted to electricity.

Most of the internal combustion engine vehicles run on gasoline. On the other hand, battery electric vehicles run on electricity which comes from different sources such as coal, natural gas, petroleum, nuclear energy and hydro power. During the calculation of efficiency of different vehicles all the losses need to be considered. Both gasoline engine vehicles and electric vehicles have parasitic losses and other losses. The gasoline engine vehicles have engine losses too. In case of gasoline engine vehicles, it’s refined from crude oil. There are some refinery losses to extract petroleum from crude oil [12]. The refinery loss is 16.7%. By taking the evaporation loss (1.5%) in consideration too, the motive power for any gasoline engine vehicles is only 20.5%.

On the other hand, the sources are different for battery electric vehicles. Supplied electricity for charging the vehicle comes from different power plants. The efficiency of the power plants come into play to define the efficiency of the electric vehicles in this regard. The power plants’ efficiency depends on the source of energy that produces electricity. The power plant operating in a combined cycle (natural gas) has the largest efficiency of all power plants which is 44.6%. Taking this as a source of electricity for charging any electric vehicle, the motive power is 32.6%. Electricity transmission and distribution losses have also been considered to find out the motive power which are 0.9% and 1.8% respectively. This results on a 59.02% increment in motive power in comparison to gasoline engine vehicles. If the power plant operates with nuclear energy, the motive power will be the least (23.8%). For power plants operating in combined cycle (petroleum) mode, the motive power is 25.2%. Coal power plant is the largest source of electricity production in 18 states of U.S. Electric vehicles get 24.9% motive power for coal produced electricity. Figures 3 and 4 show the energy flow for gasoline engine vehicles and electric vehicles considering the natural gas as a source of electricity.

The scenario is different when the electricity comes from renewable energy resources. Geothermal, Conventional Hydroelectric, Solar Photovoltaic, Solar Thermal and Wind power plants are renewable energy power plants. Conventional hydroelectric power plant has the largest efficiency among these power plants. If a conventional hydroelectric power plant provides electricity, then 65.8% motive power can be extracted from an electric vehicle. There are 1451 conventional hydroelectric power plants in U.S and that is 16.9% of the total number of power plants in U.S. and 28% of the total power plants in utility scale. Hydroelectricity is the most prevalent renewable source in 19 states of US.

States such as California, Washington where renewable energy generation excels than conventional electricity production, electric vehicles may have better efficiency if the electricity can be extracted from renewable power plants like hydro-electric power plants. For 2016 total utility-scale capacity additions, more than 60% were wind (8.7 GW) and solar (7.7 GW) power plants, compared to only 33% (9 GW) from natural gas power plants. Wind power plants are also expected to surpass hydroelectricity generation by 2019 [3]. Wind power plant can provide 19% motive power to an electric vehicle which is close to gasoline engine vehicle efficiency.

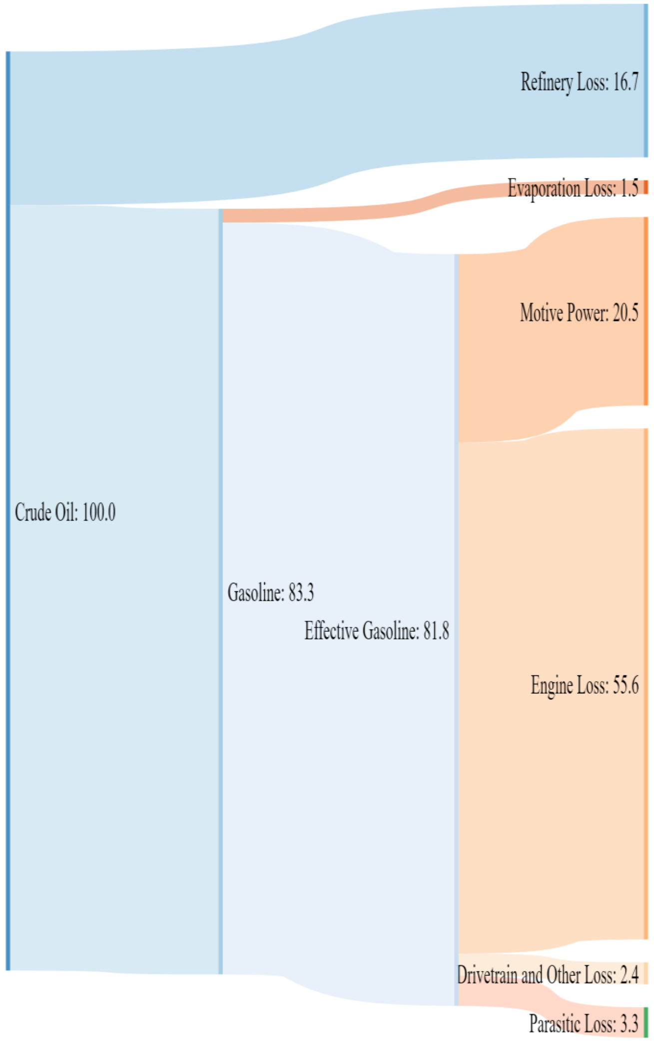

Fig 3. Energy flow for Gasoline Engine Vehicles

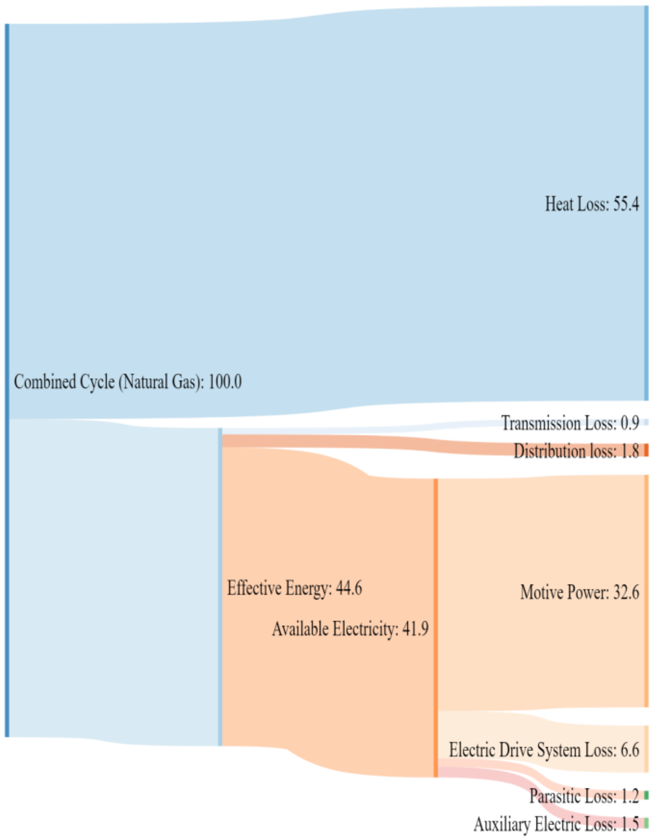

Fig 4. Energy flow for Electric Vehicles: Source of Electricity is Natural Gas.

III. TESTBED FOR PEV CHARGING

UCR's CE-CERT has four Level II EV chargers capable of supplying 240V at a rate of up to 19.2 kilowatts. It has also a Level III EV charger capable of supplying 480 V at a rate of up to 50 kW [13]. These EV chargers are available to both CE-CERT employees and the general public. It consists of three microgrids. All EV chargers are connected to the Administration building. The PV solar capacity is 180 kW and the battery energy storage capacity is 500 kWh.

This testbed was designed to incorporate actual EV chargers and evaluate the impacts of EV charging in a microgrid scale. The overall one-line electrical diagram of these chargers along with the rest of the electrical load in the Administration Building (1084 Columbia Avenue) is shown in Figure 5.

IV. EV CHARACTERISTICS

Since the charging characteristics vary depending on the vehicle type, understanding the charging patterns of each individual vehicle is essential. Based on these patterns we can eventually be able to identify, solely from the charging characteristics plots, which vehicles are charging by themselves or with other vehicles at the same time. To understand which vehicles were connected to which chargers at any given time, the vehicle make, model, license number, and charging station were logged in a spreadsheet every morning, afternoon, and late afternoon. In order to capture these charging characteristics, Fluke 435 Series II power analyzers were installed along the 3-phase 220 VAC and 480 VAC lines.

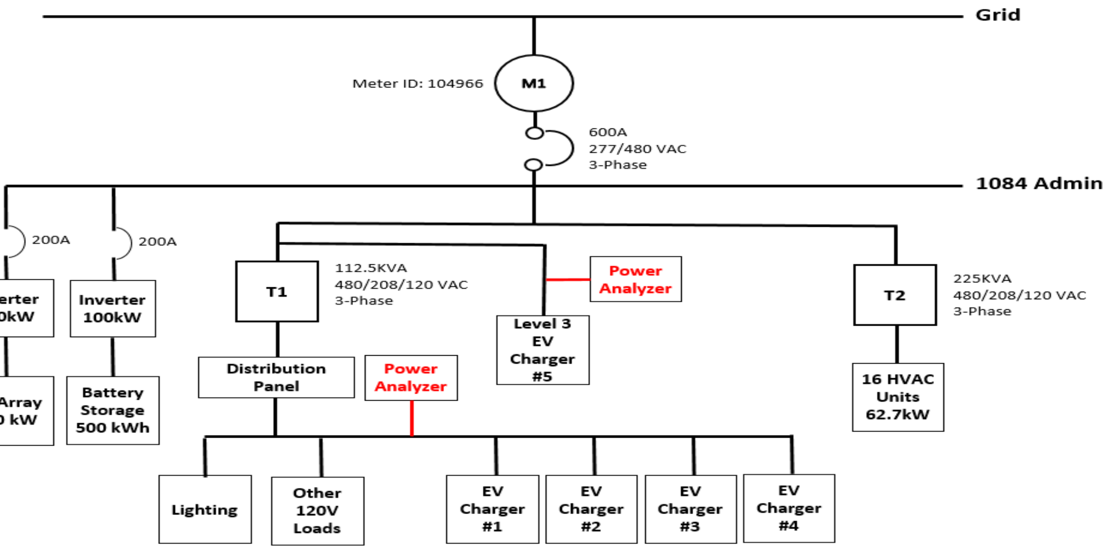

Fig 5. Electrical Layout: The System with EV Chargers

A. Level II Chargers

The main measurement variable that we were interested in was active power. The experiment was run from July 15 to July 22, 2015. The characteristic of each vehicle was recorded by reviewing the total kW use by the chargers while only one vehicle was plugged in. The charging characteristics of Chevy Volt, Nissan Leaf, Ford Fusion, and Mitsubishi Miev was observed respectively. Chevy Volt charges at a rate of 3.2 kW, Nissan Leaf charges at a maximum rate of 6 kW, Ford Fusion charges at a rate of 3.3 kW, and Mitsubishi Miev charges at a rate of 4 kW. Charging duration for these vehicles range between 210 min – 270 min depending on the state of charge of the battery systems were in when charging was started. These charging characteristics of Chevy Volt, Ford Fusion, and Mitsubishi Miev were cross checked with results from references [14-16].

Figure 6 shows the power consumption when two cars were charged at various times of the same day. The charging characteristics of Chevy Volt is shown first for 150 minutes. After that, Nissan Leaf started charging. Both continued charging for 120 minutes, then Chevy Volt stopped charging. Nissan Leaf stopped charging after an additional 90 minutes.

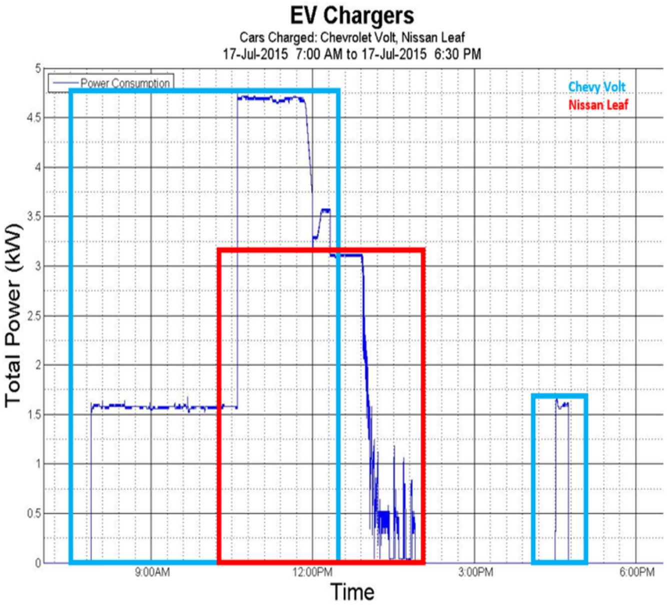

Fig 6. Level II EV Chargers Characteristics for Chevy Volt and Nissan Leaf

B. Level III Charger

This testbed has only one level III EV charging plugpoint. The experiment was run in the same way as level II chargers on different days of November and December 2018. As there is only one charger, so individual EV characteristics have been recorded separately. Nissan Leaf and Chevy Volt have been plugged in on different days. Nissan Leaf was charged at a constant 50 kW rate throughout the full charging period. Chevy Volt was charged at different rates in different time intervals with a maximum charging rate of 50 kW for about half an hour. Figures 7 and 8 show the charging characteristics for Nissan Leaf and Chevy Volt respectively.

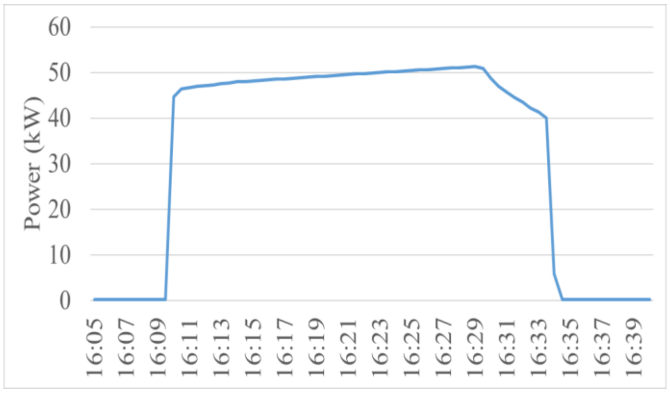

Fig 7. Level III EV Charger Characteristics for Nissan Leaf on 26th November, 2018

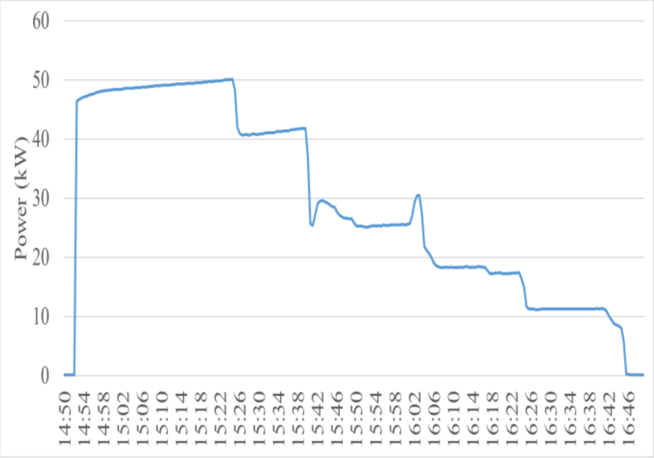

Fig 8. Level III EV Charger Characteristics for Chevy Volt on 30th November, 2018

V. CHARGING IMPACTS

A. Impacts on Administration Building

EV charging is closely associated with the overall energy management when EV shares the same meter with the building. The charging characteristics vary depending on the size of the building load to follow the cost optimization strategy [17].In case I, while the EV uses level II charger, the impact is insignificant, when only one EV is charging. But when two EVs are being charged, the average demand of the building go up. In case II, while the EV uses DC fast charging or level III charger, then it gets charged at a rate of 50 kW. It creates a huge impact on building load. Figure 9 shows the impact of DC fast charging on building load. The average building load increases to a great extent and results in a higher electricity bill for Time of Use (TOU) demand charges.

Charging characteristics of Chevy Volt, Nissan Leaf, Ford Fusion, and Mitsubishi Miev show that charging rates vary from 3.2 kW to 6 kW per vehicle. If all four vehicles charge at the same time during any 15-minute period, the total demand over a given month will be 19.2 kW. Due to implementation of optimal HVAC peak shaving controllers, peak demand for this building was 34.4 kW at the time of experiment. If all four level II chargers are used simultaneously, the additional peak demand of 19.2 kW is equivalent to an increase of 56% in the building peak demand and the associated increase in the monthly electric bill.

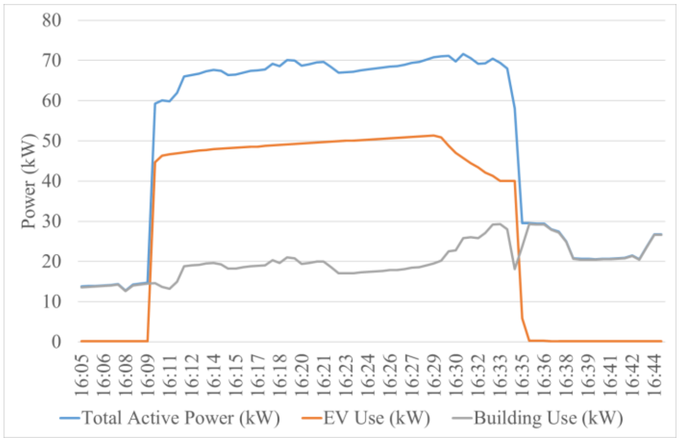

Fig 9. Level III EV Charging Impacts on Building Net Load on 26th November, 2018

B. Impacts on CE-CERT Feeder

Ce-Cert is situated at Columbia Avenue, Riverside. Along Colombia Avenue from the I-215 Freeway to Michigan Avenue, approximately 1.7 mile long industrial/commercial sector of Riverside, California, there is a total of 2,288 parking spaces. If 10% of these parking spaces are turned into EV charging spaces, there will be roughly 230 EV charging stations. In a 12-month period, all chargers will be simultaneously used for at least a duration of 10-15 minutes. The measurement results presented above shows an average kilowatt usage per car to be approximately 3.875 kW for level II EV chargers and 50 kW for level III EV chargers. By converting regular parking spaces into EV charging spaces, there will be an additional maximum demand created on the distribution feeder.

1) If 80% of these are level II chargers and 20% are level III chargers, and the vehicles have the same charging characteristics as CE-CERT charging stations, then the additional maximum demand created by the charging stations will be approximately 3,000 kW. 12.47 kV feeder may have a 4 MW capacity, so only 10% EV penetration adds an additional 75% to the peak capacity.

2) If 20% of the available parking spaces are converted into EV charging stations, then the additional maximum demand created by the charging stations will approximately be 6 MW. A 20% EV penetration will add an additional 150% to the peak demand for that feeder.

3) If 50% of the available parking spaces are converted into EV charging stations, then the additional maximum demand created by the charging stations will approximately be 15MW resulting in an additional 376% to the peak demand.

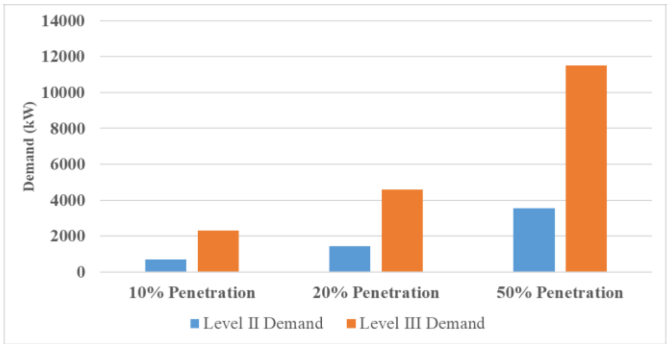

Fig 10. PEV Charging Impacts on CE-CERT Feeder

C. *Impacts on California Grid*

The availability of solar energy during daytime reduces the net demand. But it starts to decrease in the afternoon or evening. Having the same power consumption from the commercial and industrial consumers without the solar availability makes a rapid ramp up in net demand in a very short period. This gives a shape of 'duck' to the net demand profile. Hence, it is called "Duck Curve" and a very common scenario for a grid such as California, which is abundant with solar energy.

Multiple generation units are needed to provide this rapid ramp up and they are needed to be in operating mode in a very short period. If there are multiple EVs that are being charged at the same time from the grid, it will increase the net demand eventually. National Renewable Energy Laboratory (NREL) has made a projection of PEV load demand for 2025 [18]. By 2025 the lower estimate for Level II chargers are 99,333 and level III chargers are 9,064. The maximum charging load will be 981 MW for weekdays and 794 MW for weekends. This maximum PEV load demand will happen in the evening which is the ramp up period for duck curve. If 10% parking space penetration scenario is also considered for California feeder and it has been assumed that all EVs are plugged in at the same time, then it will badly affect the duck curve. This penetration scenario is so small of total potential conversion. Figure 11 is showing the net increase in ramp for PEV.

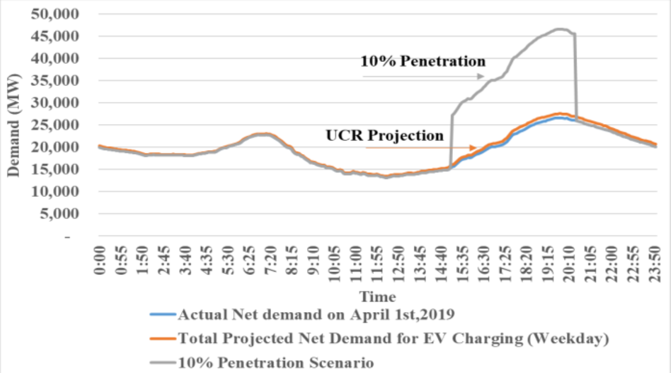

Fig 11. PEV Charging Impacts on California Net Demand

VI. CONCLUSION

The growth of electric vehicles all around the world has impacted transportation systems, building level energy management issues and electricity distribution grids. This paper discusses the interrelated effects of EV integration on various sectors and their infrastructures. Energy flow assessment shows that EVs using combined cycle power plant electricity receives 32.6% of energy for motive power compared to internal combustion engines 20.5%. Presented characteristics from level II and level III chargers connected to a microgrid show 56% peak demand increment at building level. The impacts of EV charging are more alarming at feeder and grid level. Only 10% EV penetration can result in an increase of 75% in peak demand at feeder level. The infamous "Duck Curve" can face 80% increment than it's regular demand due to same level of EV penetration in the grid. New overlapping issues of transportation and electric sectors due to high EV penetration are needed to be analyzed more to secure sustainability.

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