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IMPACT OF ELECTRICAL VEHICLE CHARGING ON ELECTRICAL POWER DISTRIBUTION

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ABSTRACT

The introduction of electric vehicles (EVs) in the transportation system has gained significant impacts on reducing the pressure on exhaustible energy resources as well as combating climate change. People are encouraged to go for EVs owing to the positive environmental benefit they provide. Governments provide subsidies for purchasing of the EVs and the production of EV cars. Such initiatives have pushed people's attention toward EVs and the number of EVs on the road is gradually increasing. It is expected that this number will further increase exponentially in near future. To cater to the EVs, the associated EV charging system will also grow. Though there are various advantages of using EVs, it is observed that its charging system hampers the quality of power on the distribution system. This paper elucidates various effects of EV charging on the power system through intensive paper research such as total harmonics distortion, low voltage profile, and transformer aging.

Keywords: Electrical Vehicle, Charging System, Total Harmonic Distortion, Voltage Profile, Distribution System.

I. INTRODUCTION

At present, global heating and changes in climatic conditions are one of the greatest threats the earth is facing. Concerns over air pollution and the dependency on unstable and costly supplies of fossil fuels have compelled policymakers and researchers to explore other possibilities for conventional internal combustion engine vehicles which depend on fossil fuels [1]. One of the prominent step towards such initiative is the introduction of electric vehicles (EV) in the transportation system. EVs may bring about numerous benefits, such as lower emissions of various harmful air and noise pollution, increasing energy efficiency compared to internal combustion engines, and the substitution of oil as the main primary energy source for road transport [2]. The numbers of EVs users are expected to increase around the world as it is drawing increased public recognition. However, EVs has their own challenges and impact on the power distribution system. There are numerous studies carried out on the impact of transportation system on greenhouse gas, but it's only recently that the researchers begun to understand the impacts of EVs on power structures [3]. The massive increase in the number of EVs in the transportation system may have a significant impact on the power grid. The impact such as poor voltage profile, transformer aging, total harmonic distortion, and power losses are associated with the charging of EV. The study of charging EVs and its impact on the power grid will help stakeholders to adopt the mitigation techniques and use the required technologies to minimize its negative impact on the power distribution system. Through different literature review, this works highlights various impacts that are there on power distribution system as a result of EV charging.

II. EV TECHNOLOGY

Most EVs nowadays are plug-in electric vehicles (PEV). It is necessary to know the classification of PEV before studying their impacts on the power systems. There are many architectures such as drivetrain architecture and powertrain architecture which describes the different classification of plug-in charging. The drivetrain architecture of PEV has included components such as; an electric motor, a battery, and a device to charge the battery by connecting to the electricity grid [4]. Depending on which of those components exist, the PEV is divided into Battery electric vehicles (BEVs), Plug-in Hybrid electric vehicles (PHEVs), and Extended range electric vehicles (EREVs).

Battery Electric Vehicles (BEVs)

BEVs are vehicles that run purely by electric batteries and hence do not have any internal combustion and they need to be recharged at the end of their designed driving range [5]. BEVs are also referred to as Full Electric

Vehicles (FEVs) in [23] but they will be referred to as BEVs throughout this writing. BEVs generally have the highest all-electric range of 100 to 160km and the largest battery capacity of 25-35 kWh [6]. BEVs electric range varies between different production companies it varies roughly 80 km (for Mahindra) and 400 km (for Tesla Model S) [7].

The average energy in kilowatt-hours (kWh) required for each kilometer for BEVs is about 0.2, but this depends on the vehicle and manufacturer [7]. Battery recharging time varies with the type and capacity of EV battery and the output capacity of the charger. Examples of BEVs include Nissan Leaf and Tesla Roadster.

Plug-in hybrid Electric vehicles (PHEV)

PHEV is commonly equipped with a drivetrain that contains an internal combustion engine (ICE), an electrical motor, a battery storage system, and means of recharging the battery system from an external source of electricity [8]. The all-electric range is around 40–60 km [7]. Its battery capacity is usually several kWh or more to power the vehicle in all-electric drive mode [9] and its internal combustion engine can be engaged to extend its drive range when the battery's charge is not sufficient [10].

Compared to BEVs, PHEVs have an extended range because they contain a small internal combustion engine for longer distances. PHEVs also have a lower purchase price as the battery pack is smaller compared to BEVs. A larger battery pack of BEV is expensive and demands a longer time to charge [11]. The modified Toyota Prius with plug-in capability is an example of a PHEV. Other models like Ford Fusion, C-Max Energi, and the Porsche Panamera E-Hybrid are several models which are on market today.

Extended-Range Electric Vehicles

An EREV is like a PHEV in terms of drivetrain architecture, i.e., it has combustion engine, motor, and a battery. However, it offers more pure electric driving capability in the initial driving range, known as the all-electric range (AER). While PHEVs derive most of its power from a gas engine and directly propel the wheels. EREVs are pure electric vehicles that utilize a small combustion generator to generate more electricity just to charge its battery in order to increase the range of vehicle beyond its battery capacity. To realize pure electric driving in all driving conditions, EREVs are provided with a full-sized traction motor which is being powered by battery pack. The large battery capacity allows all-electric driving ranges of about 100-160 km. However, EREVs have increased system cost due to the full-sized traction motor and power requirements for the battery [7]. Chevrolet Volt, built by General Motors is an example of EREV.

III. EV CHARGER

The power needed to charge PEVs vary based on the specific battery pack and charging equipment and thus it is desirable for the vehicle to control battery charging; currently charging systems are set to provide the maximum available current by default. Yet the functionality details in standards was developed for the U.S. According to the Society of Automotive Engineers (SAE), the charging methods for EVs are classified into three types as; AC Level 1, AC Level 2, and AC Level 3 [12].

AC Level 1 Charger

AC Level 1 charger uses a standard electrical outlet dedicated at 120/16A which has capacity of up to 2kW and it is the most found outlet in a household [5]. Depending on the initial State of Charge (SOC) and battery capacity, charging takes about 5-8 hours to fully charge the vehicle's battery [12]. This charger are used for overnight charging due to its longer charging duration and thus it is not suitable to use for commercial or public charging purposes.

Figure 1: Level 1 charger type

AC Level 2 Charger

It uses the electric outlet of 240 V with the power demand up to 15 kW and a current level not greater than 80A [12]. It has half the charging time comparing to that of level 1 and they are mostly found in homes and commercials areas. It must be permanently hard-wired cord set into a special box with safety electronics in the premises which requires charging purposes only. Vehicle owners seem likely to prefer Level 2 charging technology because of its fast charging time and the availability of vehicle to charger connection.

Figure 2: Level 2 charger

AC Level 3 Charger

Level 3 is a 3-phase charger and rated at 208-600 VAC, maximum current up to 400A and power demand greater than 15-96 kW. Level 3 is commercial fast charging and offers the possibility of charging time about 10-15 minute to fully charge a vehicle battery, depending on the capacity and the charging state of the battery. [13]. Naturally these chargers use higher power in comparison with residential charging. A lower power demand of charger is an advantage for utilities, especially at the distribution level seeking to minimize on-peak impact. High power penetration of charging can increase demand load and has the potential to quickly overload local distribution system and its equipment at peak times [14]. Table 1 shows standard charging ratings for different charging levels.

Figure 3: Level three type

Table 1: PEV Charging limits for various levels

Type	Nominal Voltage	Max Current	Power Level
AC Level 1	120V, 1 phase	16A	2 kW
AC Level 2	208-240V, 1 phase	32A	8kW
AC Level 3	208-600A AC, 3 phase	400A	15-96kW

IV. IMPACT OF EV CHARGING ON DISTRIBUTION SYSTEM

Total Harmonic Distortion

Power quality (PQ) is a measurement of the fitness of electrical power from the utility to the electrical customer. Low PQ causes variation in the magnitude voltage. It also disrupts the continuity of power supply to utility with transient voltages and currents. Harmonic distortion is main cause of reduced power quality.

The research [15] is mainly focused on investigating three hypotheses. One, they speculated that, because nonlinear nature of EV charge controllers and because EVs demand a huge amount of power, the PQ issues caused by EV charging could have an impact on distribution system.

Two, they also made hypothesis that the total harmonic distortion (THD) of the current drawn by an EV charge controller would vary as a function of time as the charge controller go through various phases of the charging cycle. And third, hypothesis was made that the multiple charge controller on the same feeder would have greater distortion than that of one charging controller in the same feeder. As specification under IEEE 519.1992, that impact of total harmonic distortion depends on the size of given distribution feeder and it is measured by the ratio of the short circuit current available at the point of common connection to the maximum fundamental load current. It is quantified by the quantity of total demand distortion (TDD).

They used Electric Avenue to collect data characterizing real-world EV charge controller PQ, measured as THD, for those individual chargers. The THD information was used to project the consequences in distribution feeders as a function of feeder size and its design as a function of total number and type of charge controller used in the feeders. The core concepts harmonic distortion within power distribution systems are as discussed below.

The current or voltage waveform distorted from its sinusoidal shape are harmonic distortion. Due to the need of nonlinear nature of load such as EV charge controller, which is power electronic switches used to convert AC to DC form, the current distortion is very common. Thus there will be distorted supply voltage and it would also overload the electrical distribution equipment. The IEEE standard 519-1992 was established to do recommendation on practices and the need of harmonic control in electrical power system. This standard mainly describes impacts of harmonic current distortion in electrical system if it is not mitigated. The standard points out that it is electrical user’s responsibility not to distort current and voltage by using heavy nonlinear loads. EVs uses power electronics within the charge controllers that links the vehicle's electric power system with the grid. Vehicle charging Level I and Level II are done by onboard AC-DC controlled rectifier that links to electric service through single-phase connector. Charging in Level III charger is controlled by electronic in charge controller. In both the cases harmonic distortion is measured in THD. The THD of a charger changes throughout the charging cycle with change in firing angles of the power electronics switches in response to the various phases of the charging cycle. The THD on a utility feeder is cumulated when multiple EVs are charged in same system. The THD for each charger is calculated as in equation 1. Nearby loads such as electronics devices and motors are affected by harmonic distortion.

$$I_{THD}=\frac{\sqrt{\sum_{n=2}^{k} I^2}}{I1}\times 100\% \qquad \text{Equation 1}$$

Transformer loading and aging

Current harmonics adversely affects the power transformer. I2 R losses is one of the losses caused by high harmonic content in the system. These are mainly due to high current in transformer winding. I2 R losses increase with the increase in root mean square value of load current which is increased with harmonic component. Thus the efficiency of transformer to transform power to consumer decreases as it consumes more real power than it should. It also increases the eddy current loses in the core of transformer due to increased harmonics. This currents abnormally increases temperature in winding of devices. The increased in temperature escalates the insulation losses in transformer and thus results in shortening life expectancy of transformer. Eddy current and core losses are frequency-dependent thus the harmonics of higher-order are detrimental for transformer. Stray flux losses are also the types of losses as a result of increased harmonic content. These can exist in the iron component, tank, clamps, and in core of the transformer. Such stray losses increases oil temperature and results in heating within transformers. This will be one of the contributor of premature degradation of the transformer insulation and oil resulting to the eventual catastrophic failure of the equipment.

Power cables

The main effect of harmonics on power cables is supplemental heating due to an increase in the I^2 R losses. This are as a result of phenomenon called skin effect and proximity effect. Both of the effects changes as a function of frequency and also the size on conductor and its spacing. Cables involved in such system are also undergo voltage stress and corona, resulting to insulation failure (IEEE std. 519-1992).

Relays, Switch Gear and Metering Equipment

Presence of harmonic current also negatively impact its protective relay equipment, metering equipment and switch gear. Higher pick-up values than setting would dictate results in slow operation of relaying equipment and result in unexpected operation. I2R heating by harmonics makes fuses to operate fuses prematurely. The CTs and VTs will be heated due to I2R, eddy currents and saturation in core, leading to shorter lifespan of asset. The presence of harmonics in switch gears results to I2R heating, reduces steady-state capacity, and shortens the lifespan of insulating components.

Capacitors

If the harmonic frequency is in resonance with LC time constant, the harmonic induced by a nonlinear load may interact with nearby capacitors. The inherent positive reactance of distribution cabling, loads and transformer can couple with the negative reactance of capacitor banks. This will result in very high current and voltage at resonant frequencies. Thus it results in reduced lifetime of asset and sometime to catastrophic failure.

System imbalance

Nonlinear loads create imbalance in three-phase systems. The current and voltage in one phase differs from that in another during system imbalance. This produces what is referred to as zero-sequence components. The zero-sequence components add up in the neutral line of wye configured system or circulate in the case of delta wired system and causes trouble to the system. Zero-sequence currents superpose in the neutral line and causes excessive currents which lead to conductor heating [15].

Power loss and voltage profile

[16] introduces a simple model for electric vehicles suitable for load flow studies of electric bus charging. The electric bus demand system is analyzed from the Li-ion charging characteristics.

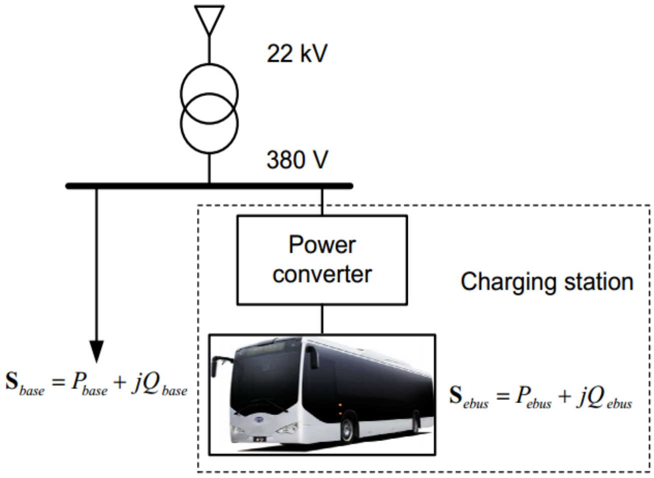

Figure 4: Schematic model of EV charging station

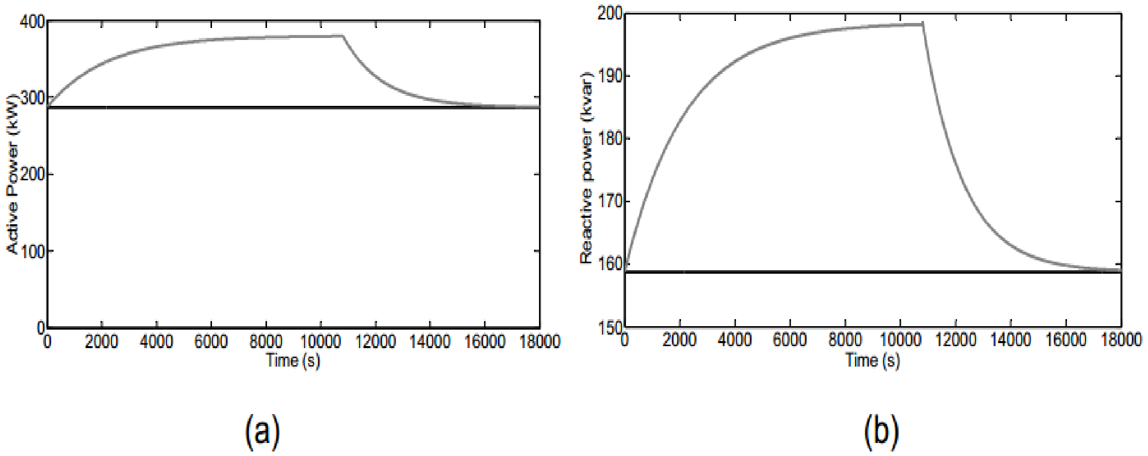

Figure 5: (a) the active power demand (b) The reactive power demand

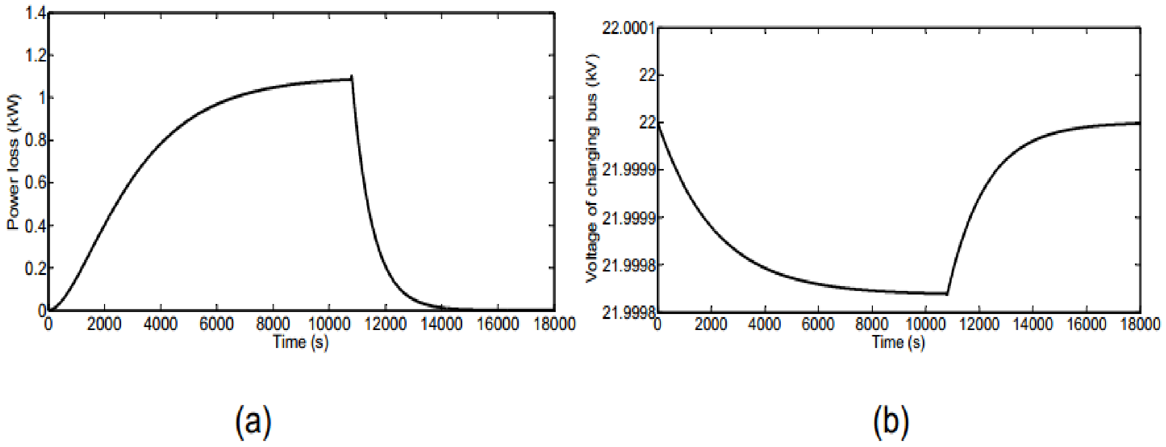

Figure 6: (a) The power loss (b) The voltage profile

According to Figure 5. the active power increase about 100 kW during the period of charging while the reactive power increase about 40 kVAR. The increasing of total load demand resulting of electric bus charging effect both of power loss and voltage profile of charging bus as shown in Figure 6. The increasing of power loss is the function as same as charging power of electric bus. Thus, the control of charging power is the control of power loss too. The voltage profile as shown in Fig. 6 (b) fall by the decay exponential function. The high number of electric bus is the more effect to the voltage profile and voltage regulation of power distribution system. Therefore, to design optimal schedule and a penetration level of electric bus charging is required. This paper proposes the electric bus charging modelling and simulation impact results of electric bus charging in power distribution systems. The simulation results have shown that charging with a high energy level increases the total load demand of the electrical distribution system. The consequence effects are the increasing of power loss and degrade the voltage regulation of the overall system. According to this work, it is clear that the optimal schedule of charging system is the most important for the future operation of the electric vehicles.

V. CONCLUSION

There are tremendous benefits of using electric vehicles to combat the phenomena of climate change. In addition, EV can use clean electricity generated using renewable sources apart from fossils. The number of different models of EVs are introduced in the market every now and then and people going for EV is growing. Increased in the number of EVs are associated to increased impacts on the power system. These impacts by different EVs charging were presented and it is noted that total harmonic distortion is one prominent impacts which lead to several destruction to the power system component. Thus, all impacts are highlighted in this works by referring several research papers. This paper concludes that the impacts of plug-in Electric Vehicles on the electrical power system should be carefully addressed as the irregular charging could have detrimental effects on the power system and electricity market operation in addition to power quality at the power distribution level.

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