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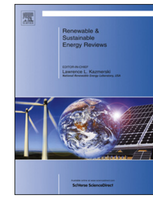

Power quality of actual grids with plug-in electric vehicles in presence of renewables and micro-grids

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ABSTRACT

The penetration of plug-in electric and hybrid-electric vehicles (PEVs and PHEVs) will increase significantly in the next 20 years. The insertion of PEVs in households will facilitate the use of renewable sources and possibly create economic benefits to users, as shown in a Mexican example here presented, but also will introduce some challenges such as how the penetration of PEVs affect the quality of existing power grids. The contribution of this work is to review the literature in reference to the power quality problems and to test them in a real distribution system based on the Mueller community in Austin, Texas that has PEVs and photovoltaic panels (PVs). The results show that a coordinated delay charge mode reduces the loading on transformers at peak hours and improves voltage regulation. Additionally, it is shown that photovoltaic panels introduce a power factor reduction during daytime in the main feeder. Corrective measures should be considered for high levels of PV penetration, such as reactive power support, VAr compensators or community energy storage, which can be presented as one potential solution to most of the problems listed in current literature. However, more research needs to be done in a much broader scale because power systems differ from each other and between countries, but there is a consensus that high power demand by PEVs leads to voltage statutory violations at some points in the grid and smart charging is required to operate the system efficiently.

Contents

1. Introduction

In future years, the growth of the market of plug-in electric vehicles will trigger the rise in electric energy demand that can

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lead to undesirable effects on the power system. The complexity of current grids will also grow because PEVs charging characteristics will vary from manufacturers, and also users have different needs.

PEVs may bring relevant benefits to the power systems, because they will facilitate the integration of renewable energy sources (RES), and will reduce contaminant emissions to the atmosphere, specially in large cities, as inefficient combustion engine cars are replaced with electric cars that are supplied by efficient generation stations or clean energy sources [1].

There are many difficulties that need to be taken into account with the addition of this technology such as transformer and line overloading if a fleet of PEVs is suddenly connected to the grid. If no corrective actions are done the transformers life could be significantly reduced and possibly the current capacity of the conductors could be dangerously exceeded. Harmonic distortion is another problem that power electronics, included in PEV's chargers and photovoltaic panel inverters may create in the grid. Some studies state that distortion is more relevant at low penetration because little to none harmonic cancelation takes place [2]. The impact PEVs have on the demand supply is significant at high penetration levels because the peak demand created by them could surpass the transformer capacity, and voltage deviations might even violate voltage constraints [3]. Transient stability is relevant in order to determine the systems behavior under faults and sudden load change. This is fundamental to be taken into account mainly when vehicle to grid operations occur. If a fleet of PEVs is charging and suddenly they start discharging to aid the system in covering the power demand, a transient state will appear that may affect the grid's voltage and frequency [4]. On long term, with a larger PEV population, smart metering, charge control, communication interfaces between user and operator will be necessary to maximize system's power quality without compromising users needs. Some of the stated problems have been previously addressed in a publication of this journal [5]. After three years of thorough research, some areas have considerably advanced, such as the vehicle to grid technology (V2G), the interaction of renewable sources with PEVs and micro-grids to balance demand, even with the high uncertainty related to the power output of distributed generation [6].

The contribution of this work is to review the literature in reference to the power quality problems mentioned above, and to study, in light of the above mentioned work, a real distribution system based on the Mueller community in Austin, Texas. The charge delay mode presented for the PEVs reduces considerably the transformer load during peak time, as this method defers the charging to later time, typically after midnight. The photovoltaic panels at homes bring an economic benefit to users in countries with sliding scale pricing but introduce a challenge as there is a reduction in the power factor of the main feeder because during the day, the PVs are producing an important part of the active energy consumed in the community.

The paper is structured with the following sequence. Section 2 reviews the most important topics related with PEVs and their impact on current power grids, including their interaction with renewable energy sources and micro-grids. Section 3 describes an economic analysis of photovoltaic generation implemented in Mexico that reduces the cost of electricity related to the PEVs. Section 4 defines the distribution system under study and presents the results shown in the simulations. Finally, Section 5 presents the main conclusions of this research work.

2. Literature review

2.1. PEVs charging and storage characteristics

Each electric vehicle has unique charging characteristics as manufacturers aim their presence to varying markets with different production costs. Up to date, some of the most known electric vehicles (EVs) are the Chevrolet Volt [7], the Ford Fusion Hybrid [8], and the Toyota Prius [9], which are hybrid-electric vehicles and the Nissan Leaf [10], the BMW i3 [11], and the Tesla Model S [12], which are fully electric. Table 1 presents the batteries storage capacity for these vehicles, but it has to be noted that none of these EVs can use the full extent of the capacity as batteries have a state of charge (SoC) limit, in order to extend their lives. For example, the Chevy Volt only uses 10.8 kWh of the 16.5 kWh available [13], about 65% of the SoC. Fig. 1 shows a generic Lithium-ion (Li-ion) battery curve modeled in Matlab Simulink [14]. The charge–discharge battery quasi-linear voltage region defines the SoC limits and most manufacturers establish an optimal working range with an upper limit of 85% and a lower limit of 20% of state of charge. The exponential regions should be avoided in order to increase the battery's life.

Table 1
PEVs and PHEVs storage capacity.

PEV and PHEV	Battery storage capacity (kWh)
Tesla Model S	85.0
Nissan Leaf	24.0
BMW i3	18.8
Chevrolet Volt	16.5
Ford Fusion Hybrid	7.6
Toyota Prius	4.4

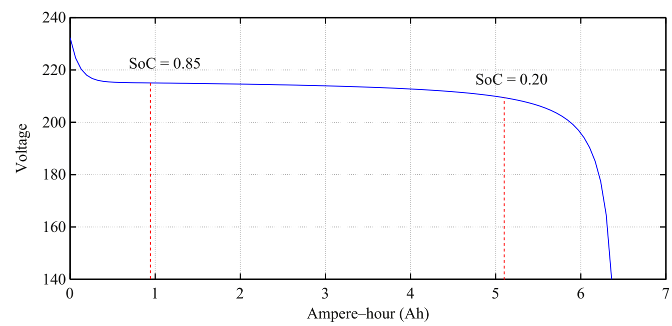

Fig. 1. Li-ion battery charge–discharge characteristic [14].

There is not a consensus on how many miles are driven everyday; it depends on the location where the measurement is done. According to the 2001 National Household Travel Survey (NHTS) the most common travelling range was 25–30 miles in the United States [15]. The Australian Bureau of Statistics car vehicle usage survey showed that a passenger vehicle travelled 23.4 miles per day [16]. Some other authors use a 60-mile range to establish the SoC [17,18]. A study done by ECOtality and the Idaho National Laboratory [19] collected information from "The EV Project" vehicles and charging units. The data analyzed belonged to 2903 PEVs, which travelled over 10 million driving miles in 2011. On average the vehicles drove 30.3 miles per day with a median of 26.8 miles, and the average and median number of times the vehicles were charged per day driven were 1.05, and 0.99, respectively. It is clear that countries have varying driving ranges, but even in cities users have diverse driving patterns, where some will require to charge their PEVs twice a day and some others every other day.

According to the previous study, [19], 82% of the PEV owners charged them at home. Fig. 2 shows that the range of SoC is wide during the start of the charging event. It could be implied that the data follows a normal distribution, with a mean value around 50% of SoC. At the end of the charging event, the distribution has a negative skewness, meaning that it is asymmetrical and owners