Evaluating the Impact of Electric Vehicles on the Smart Grid

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***Abstract*— With the 23% of total global GreenHouse Gas (GHG) emissions coming from the transport sector, many initiatives have been suggested to address this emissions sector, including reducing the number of vehicles on the roads using ridesharing programs, and switching from Internal Combustion Engine Vehicles (ICEV) to battery powered Electrical Vehicles (EV). While many governments around the world have started various programs to help increase the adoption of EVs, including incentive to purchase, introducing new policies, increasing public awareness, and installing charging infrastructures, the impact of EVs on the electric grid (load, harmonic, line and transformer lifespan) is still not completely understood. In this paper, we present a literature review about the impact of EV on the electric grid, and the evaluation results carried on the grid on a small community in the Greater Toronto Area (GTA). The results of the evaluation show a 12.5% increase in overloaded transformers within the simulated city.**

Keywords-Electrical vehicle; Energy management; Smart grid.

I. INTRODUCTION

Over the last few decades, there has been an increase in GHG emission from various sectors, because of fossil fuel use. This increase in GHG has resulted in an increase of some 0.8ºC and likely over 2ºC this century, and the amount of GHG emission is expected to double by 2050 if fossil burning continues at the current rate. Much of the emission is attributed to vehicles that use fossil fuel in their internal combustion engines. In Canada, GHG emission from the transport sector accounts for around 23% of the total GHG emissions in Canada in 2013, second only to the oil and gas sector.

To help reduce greenhouse emissions from the transport sector, several new technologies (e.g., Plug-in Electrical Vehicles (PEVs) and buses, natural gas fueled buses) and community services (e.g., ridesharing) are currently proposed and being tested. Each of these alternatives has social, economic, technical, and environmental impacts, as well as business opportunities. Of interest to this paper is the PEVs. These vehicles can use electricity stored in battery packs instead of fuel, and can be recharged from the electrical grid. These vehicles have potential for lower cost for operation, with minimal or no air pollution and GHG emissions [1]. In addition, using EV can also improve the efficiency, stability, and reliability of the grid [2].

While EV's can help reducing GHG, their effect on the electric grid is still not yet completely understood. The main objective of this paper is to present literature review about the impact of EV on the electric grid, and the evaluation results carried on the grid on a small community in the GTA. The rest of the paper is organized as follow: Section 2 presents a literature review on the effect of EV on smart grid. The results of a simulation exercise on a small community smart grid is provided in Section 3, and a conclusion is presented in Section 4.

II. LITERATURE REVIEW

Electrical Vehicles have been recognized as an alternative that can diminish toxin and gas emissions. Because of their high-energy capacity and potential mass production, electrical vehicles will have critical impact on power networks, electricity cost, power transmission and distribution. Since this kind of vehicles are not popular yet, it is important to study their energy consumption and their impact on the electricity infrastructure, which can help in to plan for development of the infrastructure. Studies show that increasing number of EVs have significant impact on transformer life specially in residential area and may require more investment on electricity infrastructure [3].

There has been some research work on the impact of EVs on smart grid in the literature. General effects of EVs on grid surveyed by [4] upon their characteristics. These characteristics are divided into two different categories: vehicle characteristic and charging characteristics. Most of the research is geared toward considering three main factors when they estimate the impact of EVs on grid. These three factors are charging location, charging demand and charging moment [5]. Charging location indicates the site where the EV connect for charging. It can be residential area, working place, urban area or even rural area. Charging demand reflects the model that is used by EVs to consume electricity, which was stored on their batteries. Charging moment represents the model that is used to charge the vehicle. There are also additional factors that can have indirect effects on the grid, such as driving habits, mobility pattern, etc.

Early research work used simple methods to model vehicle behavior, mobility pattern and charging demand [6][7][8][9]. For instance, the Shao et al. [9] reviewed the impact of EVs on distribution network at Blacksburg residential area. They considered five houses and two electrical vehicles and applied different charging strategies to see the effect of charging on transformer. The study showed that in the worst-case scenario, charging the EVs can increase transformer load by 68 percent. They also show that if quick charging is used, it can easily overload the transformer.

Recent research studies use complex methods and more factors to model the effect of EVs on the grid [10][11][12][2]. For example, Razeghi et al. [2] modeled the residential electricity demand based on household and EVs data. Household factors which used are average daily miles travel, arrival and departure time, number of available vehicle per household and number of trips per day. EVs data is also categorized based on the type of charging and consumption model. Razeghi et al. [2] then developed a thermal model to find the grid hot spots and calculate the loss of life of all transformers. Based on the simulation on southern California residential neighborhood, they claimed that uncontrolled level 1 charging has a little effect on transformers life but uncontrolled level 2 charging will result high transformer aging rate and probably transformers failure.

Hilshey, et al., [13] have similar findings to [2] with some little differences. The authors used Monte Carlo model to predict transformers life and aging when EVs charged with level 1 and level 2 charging in Phoenix and Burlington residential area. In addition to prediction model, Hilsey et al. [13] presented a new strategy for decentralized autonomous charging. This autonomous charging model can keep the transformers power to nominal or acceptable limit value.

Clement-Nyns, et al., [14] used driving pattern and road traffic to find the impact of vehicles on Belgium distribution network. They considered two different scenarios for charging. In the first scenario vehicles are charged between 6:00 to 8:00 pm and in the second scenario they are charged at the midnight (2:00am). The paper concluded that charging pattern and charging characteristic can significantly effect on transformers load and consequently effect on distribution network.

The impact of EVs on the smart grid was also studied in different areas worldwide such as the work presented in [15][16][17]. In Canada, Maitra et al., [18] evaluated the impacts of EVs on Hydro- Quebec power network. They considered multiple factors in their evaluation such as battery type, charging scenario, demands, etc.

Some research work proposed the use of statistical information to model household characteristic such as the work in [19], which considered area population, people per house, number of vehicle each household has and EVs penetration rate as a simulation factor. Other research used historical data as load profile and quadratic programming to forecast transformer failure and overloading [14].

III. SIMULATION RESULTS

In this section, we will present the design of a simulation tool that was used by Veridian Connections, a local distribution company, to evaluate how their electric grid performs under various degrees of EV adoption rates. Based on mobility models of residents, the work investigated the EV specific requirements, and local grid system capabilities, in one community in the GTA communities as personal transportation is electrified. The work focused on assessing the grid performance, as personal vehicles move to electric vehicles, EVs, by 5%, 15% and 50% of total fleet over 20 years. A simulation tool was developed and used to inform projections for a GTA-wide roll-out of EVs in terms of grid capacities, life-cycle impacts, and specific household impacts under a province-wide carbon tax or Emissions Trading System (ETS) [20].

To identify the effect of various percentage of EV penetration on the electric grid (load, harmonic, line and transformer lifespan), data about how people commute in the designated community, as well as information about the electric grid needed to be modeled and used to run different simulations using various simulations tools (ns-2 and CYME). The details of the work included the following ordered steps:

- Step 1: Analysis of current traffic and driving patterns from the Transportation Tomorrow Survey (TTS) database and building mobility models of drivers, which include the number and mode of trips (use standard engineering practice, and modeling tools to enable replication across jurisdictions).
- Step 2: Gathering information on different various charging/discharging models for various electric vehicles. Vet (and possibly obtain) data through Local Distribution Companies (LDC), Veridian Connections and Toronto Hydro.
- Step 3: Running various simulations using the *ns-2* simulation tool to incorporate the mobility and charging/discharging models, and various EV penetration rates to compute the load that electric vehicles can add to the grid.

Running the simulation, we have performed the following tasks:

A. *Loading Traffic and Transformers Profile*

The simulated area was divided into four wards; each ward has its own traffic behavior. Based on the traffic data, electrical vehicles were loaded into the map and given a destination for their route that relates to the data (Fig. 1). For this simulation, the highest load period in December was selected and the hourly transformer data was loaded into the simulation as the base load. The simulation covered a 24-hour period. Maps are constructed based on OSM files, for the purposes.

B. *Electrical vehicle specifications*

The simulation was set so that each electrical vehicle begins with a full charge. The simulation had a range of battery capacities depending on the type of vehicle. The batteries range from 18 kWh to 80 kWh. The vehicles supported are: Tesla, Volt, Leaf, Kia Soul.

TRIPS MADE BY RESIDENTS OF TOWN OF AJAX																	
Time Period	Trips	% 24 hr	Trip Purpose				Mode of Travel						Median Trip Length (km)			
			HB-W	HB-S	HB-D	N-HB	Driver	Pass.	Transit	GO Train	Wlk & Cy	Other	Driver	Pass.	Transit	GO Train
6-9 AM	59,700	25.4%	41%	22%	23%	14%	62%	13%	5%	9%	7%	3%	9.0	2.7	14.5	36.8
24 Hours	235,000		31%	13%	39%	17%	67%	16%	4%	5%	5%	2%	5.3	3.7	14.2	36.7

Figure 1. Traffic Profile for Simulated Area.

C. Assumptions

Most people will charge their vehicles after work or before they go to bed. Therefore, it is a reasonable assumption that most cars will be plugged in from 6:00 pm to 5:00 am. Due to technical restraints, this simulation will have no electrical vehicles from other cities commuting to the simulated city to charge. All the electrical vehicles will be residents of the town of Ajax.

D. Charging

Vehicles are assumed to connect to a transformer that is within 250 meters away or less to the charge. If no transformers are near, that vehicle is disregarded from the simulation. All vehicles are under the assumption that they use stage 2 charging. There are 118 potential transformers used in our simulation. The rate of charging specific to a car is added to the base load depending on the battery level.

E. Simulation Scenario

Vehicles are loaded into the simulation beginning at hour 24:01. The simulation covers a 24-hour period. Simulated vehicles have normal behaviors and routes, waiting at red lights, obeying traffic speed limits, traffic congestion. The collected traffic data is confined to four wards; the simulation was built with wards to emulate the data. Vehicles are brought into the simulation based on the data from that ward. For this simulation, 10% of vehicles are electric (penetration rate). Electrical vehicles behaved the same as combustion vehicles, however at the end of their route, electric vehicles check to see if a transformer is nearby to charge.

F. Experimental Results

Out of the 118 transformers in the simulated area, the largest amount with EV connected to was 48 (Fig. 2), among those 48 there was an average load increase of 27.222 kW. Out of the 48 transformers, 12.5% were overloaded (Fig. 3). The results represent the highest peak of transformer loads within the 24-hour simulation.

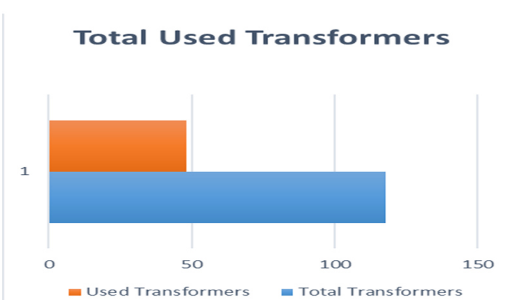

Figure 2. Total used transformer.

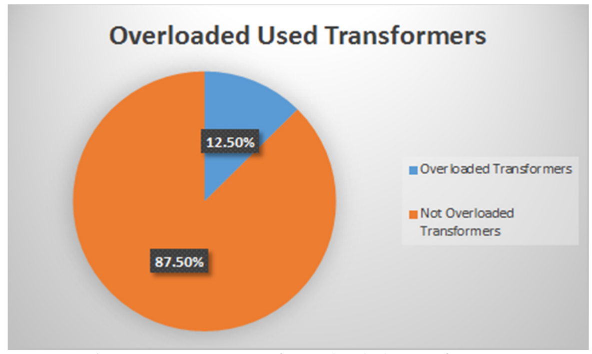

Figure 3. Percentage of Overloaded Transformers.

IV. CONCLUSION

To help curb GHG emissions, governments around the world started considering various ways to reduce the number of ICEV on the roads, including improving public transport, introducing High Occupancy Vehicle (HOV) lanes, and tolls on vehicles. However, the results of these approaches are not well documented. This paper presented a literature review on the impact of EV on the electric grid and the preliminary experimental results of varying degree of penetration rate on the electric grid of a local community in the GTA.

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