Forecasting Grid Capacity Impacts of Electric Vehicles

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SUMMARY

Electric vehicles ("EVs") are rapidly gaining popularity, creating new challenges for utilities to consider when formulating their asset management strategies. EVs represent a significant increase to transportation-related electricity demand on the grid but also present an opportunity for advanced energy management and energy storage through vehicle-to-grid ("V2G") applications. The depth of these challenges is dependent on the capabilities that EVs can deploy as well as the quantity of EVs in the market. Probabilistic forecasting techniques can be used to predict the development of these variables to support utility planning in both short-term and long-term scenarios.

There are four main steps to forecast the demand of EVs for any given region. The first is to create an EV adoption model to predict the distribution of new EVs entering the fleet and total number of EVs throughout the forecast period. Key factors include government policy, consumer behavior, customer characteristics, and market forces (EV pricing and gasoline/diesel prices). Using the EV adoption model, alternative scenarios of EV adoption are defined to provide insights into the range of potential EV adoption levels throughout the forecast period. It is then necessary to identify and assess EV charging profiles and demand contributions for EV charging given the current and potential future mix of EV types, charging locations, and charging levels.

Pairing the EV adoption model with the EV charging demand profiles, an outlook on the load demand of EVs can be established. The macro factors such as market forces and government policy determine the load growth at the system level whereas as micro factors such as income, residential and usage characteristics of customers in different neighborhoods helps predict where the load growth will materialize. Different scenarios of EV adoption between urban, suburban, and rural areas and different types of vehicles can be systematically analyzed as part of the probabilistic approach.

An EV forecast can provide utilities insights on how future load demand will change based on EVs to make better asset management decisions. This will lead to a more efficient and reliable utility that is ready for the global energy transition.

A probabilistic forecast can provide a utility with insights to forecast future peak demand based on weather and economic trends. This is an effective tool to help utilities predict load growth on their system and prepare long-term capacity plans. This paper demonstrates various approaches to long-term load forecasting.

Forecasting future load on a system can be accomplished through a two-pronged approach. The top-down approach uses a multi-variate regression to predict load for the entire region based on macro-economic trends. The bottom-up approach predicts localized growth due to changing consumer behavior and new developments. Combining the macro- and micro-analysis yields a full picture of system growth expectations.

EVs related demand are an example of new challenges for utilities to consider during long-term planning. Transportation electrification is a significant change to traditional electricity demand of the grid but also presents an opportunity for advanced energy management and energy storage in V2G applications. The future landscape will depend on technological development from manufacturers, consumer inclination toward EVs and V2G, public policy and perhaps most importantly the advancement in capabilities of utilities to integrated and monetize V2G services. An EV forecast for an electric utility in Ontario will show how forecasts for EV uptake and the required charging infrastructure can inform the future demand profile.

KEYWORDS

Electrification of Transportation, V2G-V2H, Load Forecasting, Probabilistic Forecasting, Energy Transition

INTRODUCTION

Electric utilities engaged in capacity planning try to forecast future load on the system to ensure adequate supply and equipment ratings. The more dramatically the change in electricity consumption behaviors, the greater the necessity to develop more sophisticated forecasting methods. Key drivers of this change facing utilities in 2022 include:

- The prevalence of work-from-home practices following the COVID-19 pandemic;
- New types of large, concentrated loads such as cryptocurrency mining and large data centres;
- Decarbonization of heating loads from natural gas to electricity;
- Distributed energy resources and microgrids; and
- Electric vehicle (“EV”) charging infrastructure.

This paper focuses on forecasting the impacts of EV charging on peak demand of the electrical grid. The impacts of EVs are complex for many reasons, including government policies and incentives, consumer behaviors for purchasing and charging, the effects of managed vs. unmanaged charging, and the potential for bidirectional power flow, also known as vehicle-to-grid (“V2G”) and vehicle-to-home (“V2H”) applications.

A report by Meticulous Research estimates that the growth in North American EV market volume will grow between 30% and 50% annually (cumulative average growth rate - “CAGR”) over the next seven years, the highest projected market volume being 10.2 million passenger vehicles by 2029 and the highest CAGR being 48.7% for light commercial vehicles [1]. The related forecast for EV charging infrastrcture in North America is 2.7 million Level 2 chargers, 260,000 Level 1 chargers, and 12,000 dc fast charging (“DCFC”) stations [2]. With current technologies, Level 1 chargers are widely understood to be low-power chargers operating at 120 V ac, Level 2 chargers operate between 208 and 240 V ac at a higher power than a Level 1 charger, and DCFC stations provide high power between 200 to 1000 V dc at up to 300 kW dc.

The California Energy Commission (“CEC”) has forecast that the State of California will require close to 1.2 million public and private EV chargers – excluding at-home charging – to support 8 million light-duty EVs by 2030 [3]. The CEC models the resultant charging peak in California to be 5.5 GW overnight and 4.6 GW daytime peak occuring at 10 am [3]. Another study by McKinsey estimates that EVs represent a 30% impact to coincident peak for residential customers [4].

In Canada, the federal government is targeting 100% of new vehicle sales to be zero-emission vehicles by 2035 [5]. It is broadly expected that EVs will make up the vast majority of these vehicles. In July 2021, the CD Howe Institute published their review of the Canadian governments climate plan and targets titled *Driving Ambitions: The Implications of Decarbonizing the Transportation Sector by 2030* [6]. The report estimates that to achieve the Government of Canada’s 2035 targets, zero-emission vehicles would need to make up 70-75% of new vehicle sales in 2030 and approximately 30% of all vehicles on the road. While the plan appears to be very aggressive, the Canadian Government is allocating significant investment dollars to support achievement of the policy’s goals. As a result, many municipal and provincial governments, system operators, and utilities are attempting to evaluate the impacts of this energy transition. This paper demonstrates a probabilistic planning approach to forecast EVs and their impacts on peak demand and how it relates to probabilistic load forecasting in general.

METHODOLOGY

For the purpose of this study, the EV market was segmented into the same categories used by Statistics Canada: Light-Duty Electric Vehicles (“LDEVs”) with a gross weight less than 4500 kg, Medium Duty Electric Vehicles (“MDEVs”) with a gross weight between 4,500 kg and 14,999 kg, and Heavy-Duty Electric Vehicles (“HDEVs”) 15,000 kg and above. The main steps of the analysis are:

1. **EV Adoption Model** – develop a range of scenarios for EVs sales and total number of EVs for a ten-year forecast period by vehicle type.

2. **EV Charging Demand Profiles** – estimate aggregated system demand profiles by vehicle type given the projected mix of EVs, charging locations, and charging levels.

3. **EV Load Forecast** – combine the adoption model and charging demand profiles to estimate the weekday system load profile for each forecast year.

4. **Geographic Distribution of Peak Demand** – the system-wide EV charging peak demand forecast is distributed into different neighborhoods based on its characteristics.

EV ADOPTION MODEL

The number of new light-duty, medium-duty, and heavy-duty vehicle registrations in Ontario were obtained from StatsCan and are shown in Table 1 [7]. The historical average growth rate between 2015-2019 (prior to COVID-19) was assumed to be more representative than subsequent years.

Table 1 : Ontario vehicle registrations by year

	2015	2016	2017	2018	2019
Light-duty	7,866,332	8,037,343	8,199,865	8,357,600	8,514,952
Medium-duty	122,686	125,157	128,564	131,755	134,789
Heavy-duty	122,462	125,594	129,084	131,952	134,202
Total	**8,358,366**	**8,538,070**	**8,707,286**	**8,870,625**	**9,031,832**

The average rate of increase for light-duty vehicle registrations over this time frame is 162,000 per year. Whereas all three datasets resemble a linear trend, the extrapolated vehicle population count for medium-duty and heavy-duty vehicles from this trend would be unrealistically high. Rather than trending linearly, drawing a relationship between economic predictors and annual vehicle registrations is a more comprehensive approach to forecasting vehicle population. For Toronto, Canada, business license renewals ("BLR") and gross domestic product ("GDP") proved to be good indicators of vehicle population growth. The annual rate of change of GDP and BLR were averaged and compared against the annual rate of change for different vehicle types. In other words, BLR is a leading indicator and GDP is a lagging indicator of fleet growth. Figure 1 shows the historical trend.

Figure 1 : Historical correlation of GDP and BLR compared to vehicle registrations

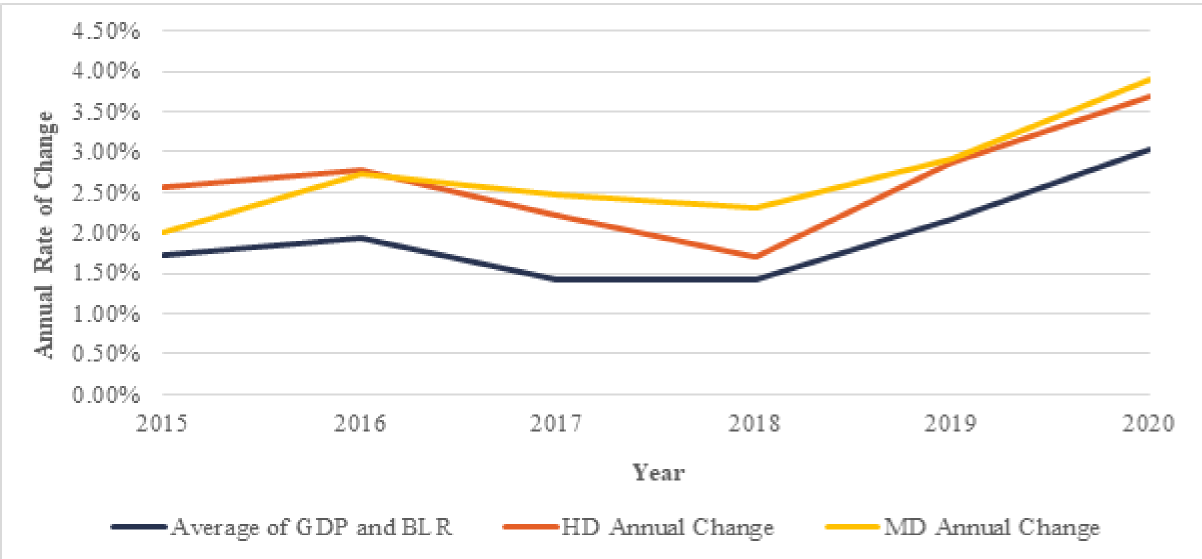
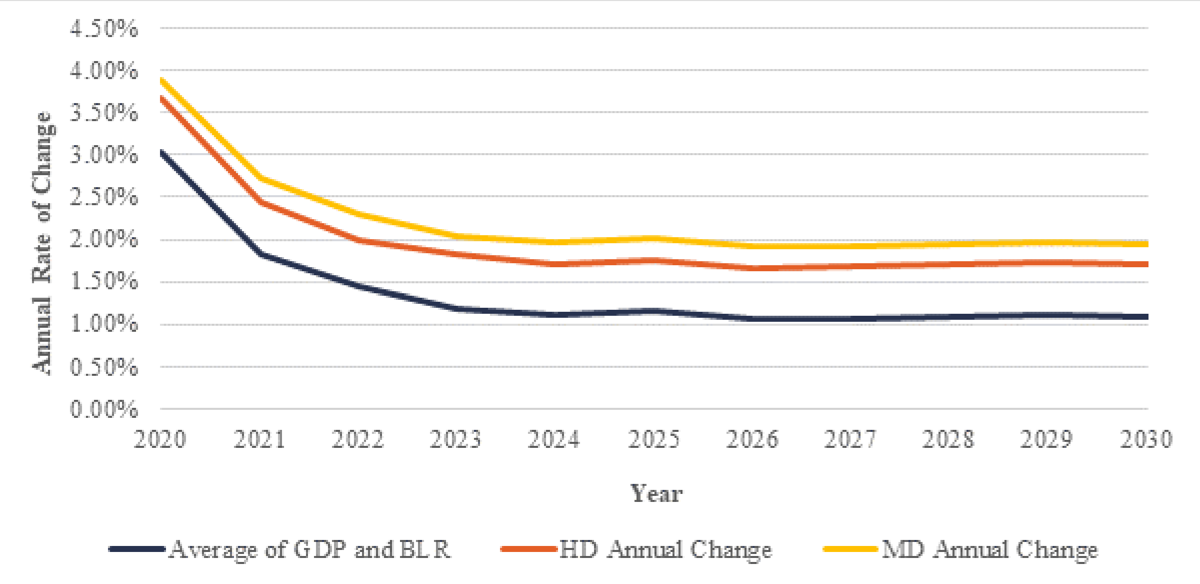


Figure 2 shows the forecast for GDP and BLR and the corresponding vehicle registration forecasts for MD and HD vehicles. Steady growth between 1.5% and 2% per annum is expected after some near-term transient behavior.

Figure 2 : Forecast of GDP and BLR and the corresponding vehicle registration forecasts



The City of Toronto was selected as the study area to forecast EV adoption. In 2019, the City of Toronto published its *Electric Vehicle Strategy – Supporting the City in Achieving its TransformTO Transportation Goals* [8]. The report targets the proportion of EV to be 15% of new sales and 5% of total vehicles by 2025, and 40% of new vehicle sales and 20% total vehicles by 2030. A forecast of new vehicle registrations and total vehicle counts was built for each forecast year to achieve the target of 220,000 LDEVs in Toronto by 2030. For both the light-duty vehicle and LDEV forecasts, a percentage of vehicle retirements is modelled for each year. Due to the low average age of LDEVs in Toronto, their retirement rate is expected to increase over time. Table 2 shows the resultant forecast for light-duty ("LD") vehicles by year.

Table 2: City of Toronto EV forecast

Year	New EV Registrations	Total EVs	EV % of New Registrations	EV % of LD Vehicles in Toronto
2017	1,032	2,577	1.0%	0.25%
2018	3,656	6,215	3.6%	0.59%
2019	1,289	7,442	1.3%	0.70%
2020	2,570	9,915	3.4%	0.96%
2021	3,406	13,143	4.2%	1.28%
2022	5,000	17,854	5.4%	1.7%
2023	9,000	26,408	8.9%	2.6%
2024	13,000	38,615	12.7%	3.7%
2025	15,500	52,764	15.0%	5.0%
2026	25,000	75,653	23.9%	7.2%
2027	33,000	105,249	31.3%	9.9%
2028	43,000	142,460	40.3%	13.2%
2029	46,000	179,770	42.7%	16.5%
2030	52,000	220,085	47.8%	20.1%
2031	60,000	265,339	54.6%	24.0%

EV CHARGING DEMAND PROFILES

The electrical demand impact of EVs depends on numerous factors including the rated output of the charger, the rated charging power of the EV, its current state of charge, the capacity of the battery, the charging duration, and temperature. Like electrical demand in general, the diversity of load drives the overall impact when modeling EV chargers in aggregate. There are limited data available for aggregate EV charging profiles. There are two summary reports by USDRIVE [9] and the U.S. Department of Energy [10] which focus on the impacts of LDEVs. The U.S. Department of Energy report identified an aggregated peak of 1.05 kW/LDEV for a home-dominant charging model under a mix of scenarios, whereas the USDRIVE report determined that the peak would be 1.50 kW/LDEV for the uncontrolled charging scenario, with an evening peak between 17h and 20h. Thus, the time of charging and EV control scheme are crucial factors to consider.

The bihourly demand profile based on the USDRIVE report is shown in Table 3. Both the USDRIVE and U.S. Department of Energy reports note that the actual profiles vary by geography. Drivers in Toronto commute an average of 40.3 km per day, which translates to 5.8 kWh per day using an efficiency factor of 0.233 kWh/km. The resultant profile for Toronto is shown below.

Table 3: Bihourly kW/LDEV from USDRIVE and scaled to Toronto

Hour of Day	0	2	4	6	8	10	12	14	16	18	20	22	kWh/ Day	Km/ Day
USDRIVE	0.42	0.20	0.05	0.01	0.10	0.15	0.20	0.30	0.80	1.50	1.30	1.00	12.1	83.9
Scaled USDRIVE	0.20	0.10	0.02	0.00	0.05	0.07	0.10	0.14	0.38	0.72	0.62	0.48	5.8	40.3

Reference data for MDEV and HDEV charging profiles include those collected by the Lawrence Berkeley National Laboratory [11] specific to California and demand profiles for food and beverage trucks aggregated by the National Renewable Energy Laboratory ("NREL") [12]. Similar to the demand profiles for LDEVs, these demand profiles were transformed to fit the City of Toronto. Table 4 shows the resultant hourly profile.

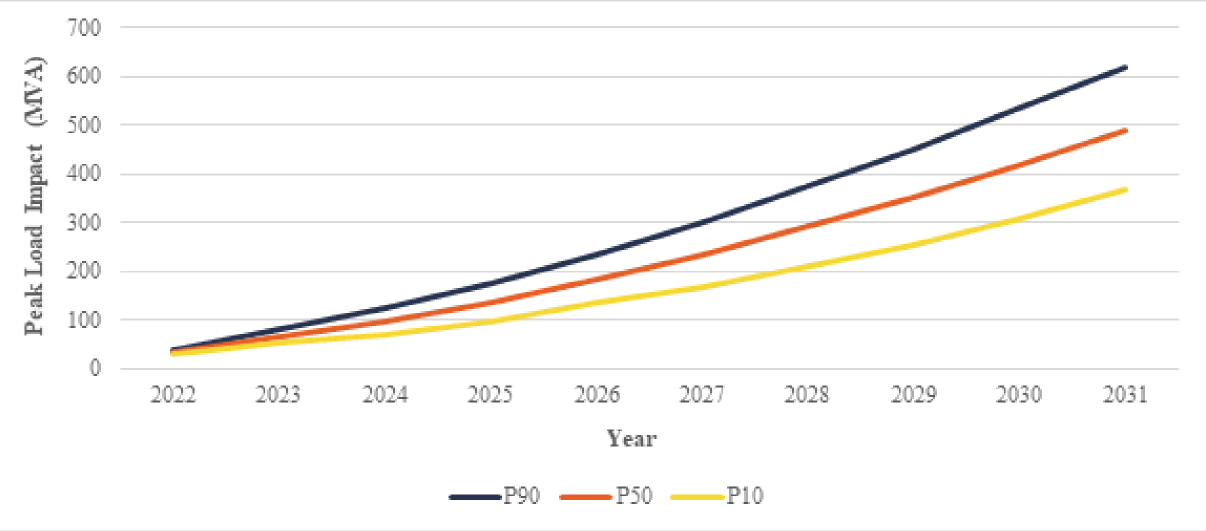
Table 4: Hourly charging demand profile for MDEVs and HDEVs

Hour	MDEV	HDEV	Hour	MDEV	HDEV
0	4.47	32.20	**12**	4.54	12.97
1	4.57	28.04	**13**	4.07	11.48
2	4.07	21.50	**14**	3.96	12.16
3	4.84	16.40	**15**	5.29	10.51
4	4.56	15.74	**16**	6.33	10.19
5	4.00	13.49	**17**	5.74	9.76
6	3.53	14.22	**18**	5.48	7.13
7	3.18	13.23	**19**	5.57	6.47
8	0.95	2.69	**20**	6.42	4.91
9	1.12	9.66	**21**	6.45	4.48
10	2.00	11.63	**22**	5.70	3.65
11	2.28	15.17	**23**	4.47	32.20
Daily Per EV Charge Load (kWh)				103.56	319.87
Daily Per EV Peak Demand (kW)				6.45	32.20

RESULTS – EV LOAD FORECAST

The EV load forecasts for LDEVs, MDEVs, and HDEVs were modelled individually. For each vehicle type, the annual vehicle adoption rate and peak kW demand were treated as random variables to be selected from a normal distribution via a Monte-Carlo simulation of 1,000 trials per year of the ten-year forecast. The results are displayed as the 90th percentile or “P90”, 50th percentile (“P50”), and 10th percentile (“P10”) in Figure 3. It is predicted that much of this load will be caused by HDEVs due to their high impact per vehicle despite their relatively low numbers compared to LDEVs; however, the impact of LDEVs is still predicted to be substantial.

Figure 3: Predicted aggregate EV demand in Toronto



CONCLUSIONS AND NEXT STEPS

This paper presents an estimate of the impact on EVs on peak demand of the electricity system in the City of Toronto based on populations forecasts and operating patterns of vehicles. This analysis can be applied to other cities or neighborhoods if scaled appropriately to representative EV adoption and charging profiles.

As consumers and businesses become more attuned to EVs their use patterns may continue to change and should be monitored in the future. Changes to EV charging policies through price signals or controlled charging will also have a significant impact on the peak demand and can help with peak shifting. Types of control options include:

a) Timers and load sensors for passive control
b) Active control from the utility control room
c) Smart controls using automated schemes; and
d) Bidirectional V2G control schemes.

Utilities implementing any of these strategies and programs should be cognizant of whether they may introduce a new peak (i.e., overnight when timers switch on) and whether the grid is able to handle such a peak. Utilities should also be cognizant of the last-mile impacts along distribution lines. A Level 2 charger can draw more load than the entire house is rated for, which can cause concern for voltage drop at the service entrance, depending on the length of the cable run. The available load at the distribution transformer is also likely to be a concern as neighborhoods become more electrified. These issues will be exacerbated by building electrification trends and may require utilities to enforce balancing schedules on EV chargers to avoid customer transformer overloads.

Beyond the ten years forecast in this paper, electrification trends are expected to continue. The City of Toronto may be home to more than 1 million EVs by 2040. Efforts spent on forecasting and planning now will help prepare all stakeholders for this energy transition and avoid costly pitfalls along the way.

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