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Impact of Clusters of DC Fast Charging Stations on the Electricity Distribution Grid in Ottawa, Canada

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Summary

With the introduction of longer-range Electric Vehicles (EVs), the need for DC Fast Charging (DCFC) will greatly increase. DCFCs have a high power level: currently 50 kW, in the future 100 kW or more. Clusters of DCFCs may therefore have a significant impact on the local electricity distribution grid.

In a simulation study, Natural Resources Canada and Hydro Ottawa Limited jointly investigated the need for DCFCs in Ottawa, Ontario, Canada, the locations at which they will likely be installed, and their impact on the distribution grid for different scenarios of EV penetration for the period of 2017-2037.

Keywords: fast charge, infrastructure, cost, simulation

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1 Introduction

With the introduction of longer-range Electric Vehicles (EVs), like the Chevrolet Bolt and the Tesla III, the need for DC Fast Charging (DCFC) will greatly increase to facilitate long-distance driving and to provide regular recharging for EV owners who cannot charge at home.

DCFC locations are expected to have multiple chargers to minimize wait times. Given the high power level of DCFCs (currently 50 kW, in the future 100 kW, 150 kW, or more), clusters of DCFCs may have a significant impact on the local electricity distribution grid. Etezadi-Amoli et al., for instance, present research that indicates that the dynamic load of a cluster of eight 250 kW DCFCs could cause unacceptable voltage sags on certain distribution feeders [1].

In a simulation study, Natural Resources Canada and Hydro Ottawa Limited (Hydro Ottawa) jointly investigated the need for DCFCs in Ottawa, Ontario, Canada, the locations at which they will be installed, and their impact on the distribution grid for the period 2017 - 2037. The study focused on charging stations that would be accessible to electric vehicles from all manufacturers. Tesla supercharging stations were excluded from the analysis.

The investigation of the impact of DC Fast Chargers on the grid focused on how the total load from all DCFCs would compare to the existing load for the city of Ottawa in terms of required capacity and electricity consumption. Additionally, installation costs for clusters of DCFCs with different overall load were determined for three locations in Ottawa, taking into account the potential upgrade costs that may be required to maintain acceptable operation conditions for the grid given the dynamic load of the DCFC clusters.

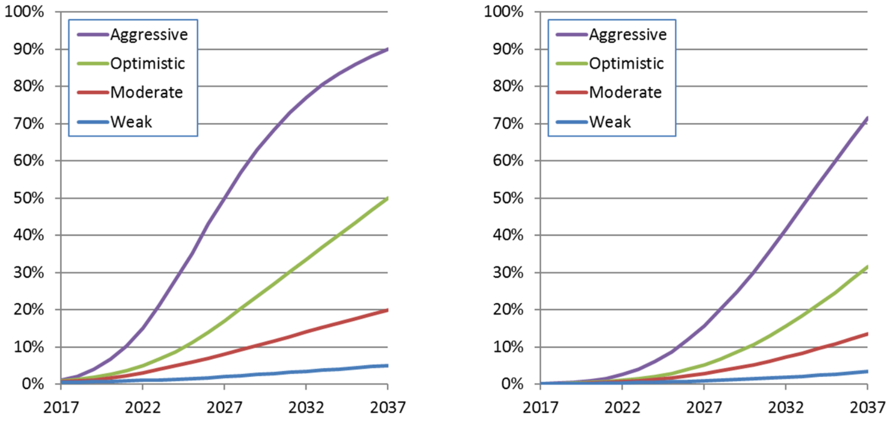
2 Need for DCFCs

The need for DCFCs strongly depends on the number of EVs on the road and on how these vehicles are driven and recharged.

2.1 Number of EVs on the road

Historical EV sales data for Canada provided the starting point for four different EV penetration scenarios (“Weak”, “Moderate”, “Optimistic”, and “Aggressive”). Together, these four scenarios cover a broad spectrum of potential EV sales scenarios, see Figure 1a.

Historical data of the light-duty vehicle fleet in Ontario from 2000 – 2015 [2] was used to develop a model to forecast the growth of this fleet until 2037. The model determines the number of vehicles on the road using the balance of new vehicle registrations (vehicle sales) and vehicle retirements, based upon a vehicle lifetime of 14 years. A similar model was made to calculate the number of EVs on the road, based upon the penetration of EVs into the provincial light-duty vehicle sales. As it takes time to replace the current fleet of light duty vehicles, the fraction of vehicles on the road that are EVs will increase more slowly (Figure 1b)than the EV sales percentage (Figure 1a).



(a) (b)

Figure 1: Penetration of EVs in (a) sales, and (b) in the fleet of light-duty vehicles in Ottawa

The market segment of EVs is generally divided in Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs). PHEVs have a fossil fuel powered drive train that can be used as a back-up when the EV battery is empty. PHEVs therefore do not need to be charged at fast chargers. The study thus only addressed the fast charging need of BEVs. BEV sales figures were extracted from overall EV sales figures, assuming a gradual shift from current sales ratios to almost exclusive BEV sales by 2037.

For each scenario, BEV sales were attributed to suburban drivers, i.e. EV owners who can charge at home, and EV owners who cannot charge at home, i.e. apartment dwellers. This is an important distinction to be made, as currently only about 60% of all dwellings in Ottawa have the possibility of home charging of EVs. Additionally, EV sales were divided over BEVs with different battery sizes. Small battery sizes dominate in the scenarios with low EV sales penetration, while the scenarios with higher EV sales penetration display higher fractions of long-range BEVs. Figure 2 displays the composition of BEV sales for the four EV penetration scenarios.

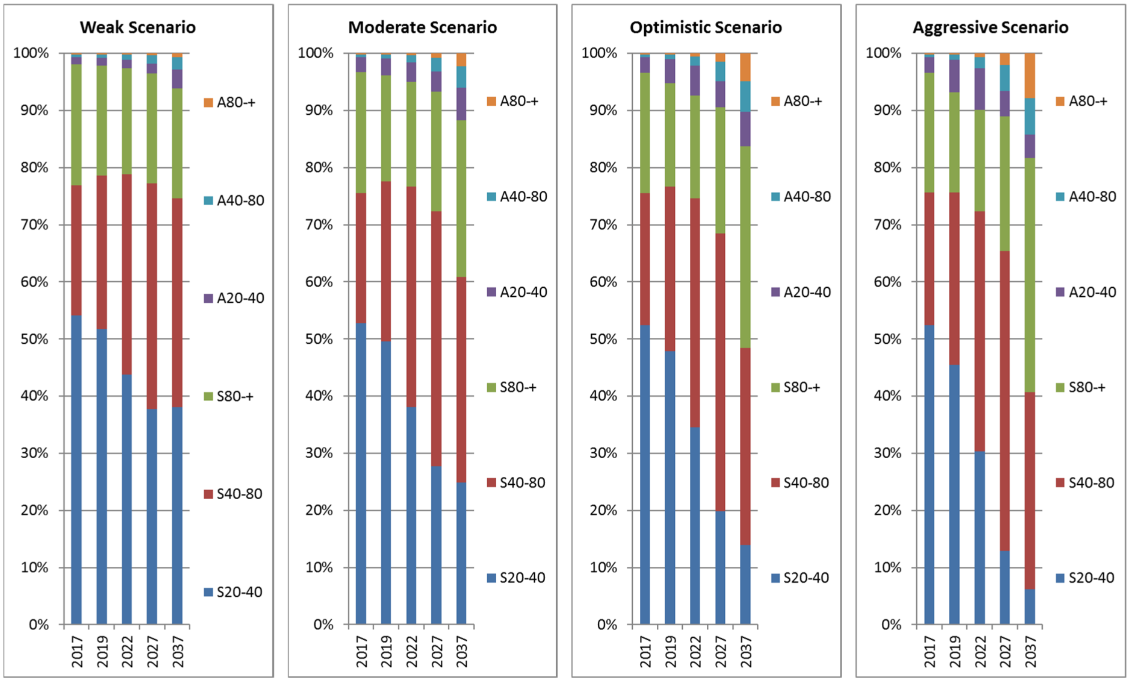


Figure 2: Composition of BEV sales under four EV penetration scenarios. BEV sales are split over suburban drivers ("S") and owners living in apartments ("A"), and over BEVs having battery capacities of 20-40, 40-80, and 80+ kWh.

The EV sales information was then used in the vehicle penetration model to calculate the number of BEVs on the road under each scenario (see Table 1).

Table 1: Number of BEVs on the road in Ottawa

Year	2017	2019	2022	2027	2037
Weak scenario	511	912	1,949	5,540	23,343
Moderate scenario	522	1,184	3,902	17,997	94,307
Optimistic scenario	577	1,572	6,091	33,214	221,786
Aggressive scenario	633	2,667	15,464	99,094	502,173
Total light-duty vehicles	*562,189*	*576,211*	*597,245*	*632,302*	*702,414*

2.2 BEV charging need

The need for fast charging for the fleet of BEVs was determined based upon their daily driving profile, their battery capacity, the availability of home charging, and the possibility of opportunity charging (at workplaces, shopping centers, entertainment locations, etc.). Suburban BEV owners predominantly need DCFC for long-distance driving. Apartment dwellers cannot charge at home and will therefore need to use fast chargers for all driving not covered by opportunity charging.

Real world driving data from the Canadian Vehicle Use Study [3] were analyzed to determine how often Canadians would use their vehicles for long-distance travelling. It was also assumed that BEVs with smaller batteries were less likely to be used for longer trips. Tables 2 – 4 display the DCFC recharging need for suburban BEV owners and apartment dwellers with and without access to workplace charging, respectively.

Table 2: DCFC recharging need for suburban BEV owners (per year)

	Local travel			Long-distance travel		
Battery capacity	frequency	km added	kWh added	frequency	km added	kWh added
20-40 kWh	6	60	12	2	100	20
40-80 kWh	3	100	20	5	165	33
80+ kWh	1	100	20	3	180	36

Table 3: DCFC recharging need for apartment BEV owners with access to workplace charging (per year)

	Local travel			Long-distance travel		
	frequency	km added	kWh added	frequency	km added	kWh added
20-40 kWh	52	50	10	4	125	25
40-80 kWh	1	100	20	10	233	47
80+ kWh	1	100	20	6	265	53

Table 4: DCFC recharging need for apartment BEV owners without access to workplace charging (per year)

	Local travel			Long-distance travel		
	frequency	km added	kWh added	frequency	km added	kWh added
20-40 kWh	151	100	20	4	125	25
40-80 kWh	66	200	40	10	233	47
80+ kWh	47	300	60	6	265	53

Canadians drive on average about 50 km per day, which corresponds to slightly more than 18,000 km per year. Suburban BEV owners need to visit DCFC stations for 560 km to 1,125 km per year, which is 3% to 6% of their annual kilometres. EVs with a 40-80 kWh battery are expected to more frequently visit the DCFC stations. The access to workplace charging has a major impact for apartment BEV owners on their need for DCFCs. Apartment BEV owners who have access to workplace charging will need DCFCs for 1,690 km to 3,100 km (9% to 17%, of their annual kilometres), while apartment BEV owners with no access to workplace charging need DCFCs for 86% of all their driving (15,600 km per year).

2.3 DCFC usage profiles

The first DCFC stations are mainly installed to provide ‘coverage’ and to ensure prospective BEV owners that they can indeed use their vehicles for long-distance travelling. These stations are therefore not expected to be used very frequently, as the number of potential clients is still low. However, DCFC usage is expected to rise over the time frame evaluated in the study as future DCFCs will need to provide a positive business case. The number of DCFC stations required to meet the charging need of BEV owners in Ottawa is determined from the total charging requirement of all BEVs on the road using a number of equivalent full-load hours for each year of the forecasting period (see Table 2).

Table 5: Equivalent daily full load hours used to determine required number of DCFC stations

Year	2017	2019	2022	2027	2037
Equivalent daily full load hours	1	2	3	4	6

2.4 Required number of DCFC stations

Using the inputs and assumptions described in the previous sections, the required number of DCFC stations in Ottawa was first determined assuming all stations would have a 50 kW power level (Table 6). These numbers of DCFCs include both city and highway stations, as it was assumed that the recharging need for the long-distance travel of visitors to Ottawa was equal to that of BEV owners from Ottawa for their long-distance trips outside the city.

The trend in the required number of charging stations for the various scenarios shows a close correlation with the number of EVs on the road (Figure 1b).

Table 6: Required number of DCFC stations in Ottawa (50 kW stations only)

Year	2017	2019	2022	2027	2037
Weak scenario	5	5	8	19	62
Moderate scenario	6	8	19	77	343
Optimistic scenario	7	11	36	168	974
Aggressive scenario	8	22	105	547	2,366

Although most current (non-Tesla) DCFCs have a power level of 50 kW, it is expected that over time more and more charging stations with higher power levels will be installed to reduce the duration of the charging events. Table 7 presents the result of a scenario in which DCFCs with 50 kW, 100 kW, and 150 kW output will be installed. In the first years of the 20 year time frame used in this study, mostly 50 kW stations will be installed, while in later years new stations will mainly have power levels of 100 kW and 150 kW.

Table 7: Required number of DCFC stations in Ottawa (stations of 50 kW, 100 kW, and 150 kW)

Year		2017	2019	2022	2027	2037
Weak scenario	50 kW	5	5	6	10	15
	100 kW	0	0	1	3	4
	150 kW	0	0	0	1	13
	Total	**5**	**5**	**7**	**13**	**32**
Moderate scenario	50 kW	6	8	14	33	68
	100 kW	0	0	3	13	21
	150 kW	0	0	0	6	77
	Total	**6**	**8**	**17**	**52**	**167**
Optimistic scenario	50 kW	7	11	25	71	180
	100 kW	0	0	5	28	55
	150 kW	0	0	0	14	228
	Total	**7**	**11**	**30**	**112**	**463**
Aggressive scenario	50 kW	8	21	70	222	466
	100 kW	0	0	17	93	153
	150 kW	0	0	0	47	531
	Total	**8**	**21**	**87**	**361**	**1,150**

To serve the growing fleet of EVs in Ottawa over the next two decades, close to 500 DCFCs will need to be installed under the Optimistic Scenario. To put this number in perspective, the current size of the infrastructure for refueling conventional vehicles was investigated. There are approximately 150 gas stations in Ottawa with in total around 1,000 pumps. The required number of DCFC stations in 2037 is thus comparable to about half of the existing number of refueling points for conventional vehicles.

Once DCFC stations with higher power levels will become available, it is expected that BEV owners, who were first ok with a 20-30 minute wait at a 50 kW DCFC station, will gradually become less patient and will prefer to use the faster charging stations, especially during long-distance trips. A group of mainly German OEMs has already announced plans to build a network of 400 fast charging stations with power levels up to 350 kW in Europe between 2017 and 2020 [4].

Table 8 presents the results for a scenario under which DCFC stations have power levels of 50 kW, 150 kW and 400 kW. Using a 400 kW DCFC station, all recharging described in Tables 2-4 can be completed in 10 minutes of less.

Table 8: Required number of DCFC stations in Ottawa (stations of 50 kW, 150 kW, and 400 kW)

Year		2017	2019	2022	2027	2037
Weak scenario	50 kW	5	5	6	10	15
	150 kW	0	0	0	2	3
	400 kW	0	0	0	0	5
	Total	**5**	**5**	**7**	**12**	**22**
Moderate scenario	50 kW	6	8	14	33	68
	150 kW	0	0	2	8	14
	400 kW	0	0	0	2	29
	Total	**6**	**8**	**16**	**44**	**112**
Optimistic scenario	50 kW	7	11	25	71	180
	150 kW	0	0	3	19	37
	400 kW	0	0	0	5	85
	Total	**7**	**11**	**28**	**95**	**302**
Aggressive scenario	50 kW	8	21	70	222	466
	150 kW	0	0	11	62	102
	400 kW	0	0	0	17	199
	Total	**8**	**21**	**81**	**301**	**767**

3 Where will DCFCs be installed?

The impact of the load of clusters of DCFC stations on the distribution grid will strongly depend on where the DCFCs will be installed. Fast charging stations along the highway are most likely to be installed at existing rest facilities or at service centres close to the highway. In the city, many locations could potentially host DCFC stations. 12 typical city locations were evaluated regarding the likelihood that publically accessible DCFCs would be installed there. The results of this activity are summarized in Table 9. Many typical locations were found to not need fast charging stations, because vehicles would be parked there for several hours and could get sufficient power from Level 2 charging stations.

Recharging at current 50 kW DCFC stations can easily take 20-30 minutes or more. DCFC stations are therefore expected to be installed at locations where people would already spend time, for instance at shopping centers, fast-food restaurants, etc. DCFC stations are also expected to be installed in clusters, as this would greatly reduce the need for BEV owners to drive around trying to find a station that is available.

Table 9: Evaluation of the likelihood of publically accessible DCFC stations being installed at 12 typical city locations

	Typical location	Likelihood	Comments
1	Residential area	-	Unfavourable location
2	Gas stations	+	Intuitive location
3	DCFC recharge facilities	+	Intuitive location
4	Shopping centres & malls	+	Conveniently shop & charge
5	(Fast food) restaurants/coffee shops	+	Conveniently eat & charge
6	Hotels	-	Parking duration too long for DCFC
7	Entertainment (cinema, stadium, ski hill)	-	Parking duration too long for DCFC
8	Community/sports centres, green spaces	0	Depends on public policy
9	Fleet owners (couriers, school buses, taxis)	-	Not publically accessible
10	Electrified public transit (buses)	-	Not publically accessible
11	Work places	-	Parking duration too long for DCFC
12	Parking lots	+	DCFCs in addition to Level 2 chargers

Figure 3 shows the results of an exercise, in which all DCFC stations required in the year 2027 under the Optimistic scenarios were assumed to be installed at shopping centres in Ottawa. The DCFCs would be installed in clusters of 2-8 stations, the cluster size depending on the size of the shopping centre. The map clearly indicates a wide spread of DCFC stations over all parts of the city, ensuring appropriate access for BEV owners from all neighbourhoods.

Figure 3: DCFC locations in Ottawa (with number of chargers per location) for the Optimistic scenario in 2027

It is uncertain which typical location(s) in 2037 will host large numbers of fast charging stations. Shopping centres, gas stations and dedicated DCFC recharge facilities seem strong candidates.

4 Impact of DCFCs on the distribution grid

4.1 Impacts on the operation of the grid

The load of the clusters of DCFC stations will impact the operation of the electrical grid in Ottawa in two ways: (1) It will increase the demand for power over the day and (2) it will add to the total amount of electricity consumed in the city. To evaluate this impact, a worst case scenario was evaluated in which all installed DCFC stations would be used at the same time and at their maximum power output.

Under the Optimistic Scenario, the total load of all DCFC stations installed in 2037 is 48.7 MW. Hydro Ottawa forecasts the peak electricity demand for the city of Ottawa in 2037 to be 2,000 MW [5]. The total load of all DCFC stations corresponds thus to 2.4% of the annual peak load of the city.

Under the same scenario, the electricity consumption of the DCFC stations would add 95.9 GWh to the total annual electricity consumption of Ottawa, which is estimated to reach 11,000 GWh in 2037 [5]. The electricity consumption of the DCFC clusters reflects an increase of 0.9% in the annual electricity consumption.

It can be concluded that the impact of clusters of DCFC stations on the *bulk power supply* in Ottawa is fairly limited. Given the long period (20 years) over which the impact slowly increases, this should not be a problem for the local electrical utility to prepare for. However, DCFCs can have a large impact at the *local interconnection spots*, which will be addressed below.

4.2 Impact on installation costs of DCFC stations

Electrical utilities pro-actively manage the potential impact of the dynamic load of clusters of DCFC stations in the *installation phase* of the stations. When installing a DCFC station, the utility will calculate the proper size of the grid connection equipment (e.g. transformer, wiring) and will require upgrades to the grid if the load to be connected exceeds what can be handled in worst case scenarios. This approach may result in additional costs when installing DCFC stations.

For three example locations in Ottawa, the installation costs of clusters of DCFC stations and the potential grid upgrade costs were determined. Table 10 displays the characteristics of the various cluster sizes, the required transformer capacity, and the types of costs that were included in calculating the overall installation costs.

Table 10: DCFC cluster characteristics, size of transformer, and considerations for connection cost evaluations

# of DCFCs in cluster	DCFC station (kW)	DCFC cluster (kW)	Transformer (kVA)	Connection costs (see notes below table)
4	50	200	150	1, 3/3', 4, perhaps 5
8	50	400	500	1, 3/3', 4, perhaps 5
4	100	400	500	1, 3/3', 4, perhaps 5
8	100	800	750	1, 3/3', 4, perhaps 5
4	150	600	500	1, 3/3', 4, perhaps 5
8	150	1,200	1,500	2, 3/3', 4, perhaps 5
4	400	1,600	1,500	2, 3/3', 4, perhaps 5
8	400	3,200	2*1,500	(2)*2, 3/3', (2)*4, perhaps 5

1 *pad*
2 *cable chamber and pad*
3 *concrete encased duct & radial feed primary and secondary cable, incl. hard surface reinstatement*
3' *concrete encased duct & looped primary feed cable, radial secondary cable, incl. hard surface reinstatement*
4 *transformer*
5 *switchgear*

The electricity distribution grid in Ottawa contains about 900 feeders, which supply the electricity to the end-users. For each feeder, the amount of spare capacity was determined, taking into account the proper operation of the grid, even if the total capacity needed to be served. More than 90% of the feeders in Ottawa were found to have at least 500 kW spare capacity, which would allow the installation of small clusters of DCFCs without grid upgrades.

Of the three example locations, two locations (Location A and Location B) were selected from feeders that had less than 500 kW spare capacity, while a third location (Location C) was chosen from the group of feeders having ample spare capacity. Location A and B were expected to have higher installation/grid upgrades costs than Location C.

For each location, the costs to connect clusters of DCFCs with different sizes and power levels were calculated (see Table 11).

Table 11: Connection costs (in Canadian dollars) for DCFC clusters at three example locations. Transformer costs are identical for all locations and are included in the total costs.

		Location A		Location B		Location C	
DCFC cluster (kW)	Trans-former ($)	Civil & electrical ($)	Total costs ($)	Civil & electrical ($)	Total costs ($)	Civil & electrical ($)	Total costs ($)
200	14,000	82,000	96,000	10,000	24,000	105,000	119,000
400	21,000	82,000	103,000	10,000	31,000	105,000	126,000
600	21,000	82,000	103,000	10,000	31,000	105,000	126,000
800	28,000	82,000	110,000	10,000	38,000	105,000	133,000
1,200	41,000	90,000	131,000	18,000	59,000	113,000	154,000
1,600	41,000	90,000	131,000	18,000	59,000	113,000	154,000
3,200	82,000	97,500	179,500	25,500	107,500	120,500	202,500

The installation costs for the DCFC stations were strongly influenced by the specific distance between the charging stations and the feeder. For Location A the chosen spot for the DCFC station was far (125 meters) from the feeder line, causing a large increase in the installation cost in comparison to Location B, where this distance was only five meters. Although the specific DCFC site was next to the feeder line at Location C, safety regulations allowing only one grid connection per customer forced the stations to be connected to the existing grid connection point 80 meters away. Alternatively, the property could be split into two properties allowing the DCFC station a much shorter connection path to its own Supply Point, but the costs for this option were not evaluated.

Table 12: Grid upgrade costs (in Canadian dollars) for DCFC clusters at three example locations.

	Location A		Location B		Location C	
DCFC cluster (kW)	Upgrade costs ($)	Comments	Upgrade costs ($)	Comments	Upgrade costs ($)	Comments
200	-	-	-	-	-	-
400	-	-	-	-	-	-
600	-	-	-	-	-	-
800	-	-	-	-	-	-
1,200	-	-	-	-	-	-
1,600	-	-	-	-	500,000	new smart switching devices
3,200	-	-	200,000	new switching devices	500,000	new smart switching devices

The specific grid configuration at Location C also added to the costs for the installation. The grid is set up in a way that nearby feeders will serve as back-up for each other. Although the feeder itself at Location C had sufficient capacity, the back-up feeder did not and additional costs were encountered to be sure the back-up function could be accommodated.

The costs for potential grid upgrades at the three example location were determined and results are given in Table 12. Location A and B were selected because they were served by a feeder with limited spare capacity. However, in both cases a different feeder with more spare capacity was also available for use, eliminating or greatly reducing the upgrade costs. Table 12 shows that grid upgrades are expensive, but only required for very large clusters of DCFCs.

The grid upgrades could generally be prevented by controlling the load of the DCFC stations. Whether or not this is practical will depend on the specific load reduction required and the number of DCFCs in the clusters. A detailed evaluation will be required for each specific application.

5 Conclusions

The growth of the electric vehicle fleet over the next 20 years will require the installation of a large number of DC Fast Charging stations to facilitate long-distance travelling and provide charging opportunities for EV owners who cannot charge at home. Under the Optimistic Scenario, EV sales will grow to 50% of total light duty sales in 2037, which will result in almost 1 out of every 3 vehicles on the road being electric. Assuming DCFC stations of 50 kW, 100 kW, and 150 kW output power will be installed, Ottawa will need more than 100 DCFCs in 2027 and close to 500 in 2037, which is about half the current number of gas pumps in Ottawa.

The DCFCs are expected to be first installed at locations where people already plan to spend some time, like shopping centers and fast-food restaurants. The installation of clusters of DCFCs at dedicated EV recharge facilities, the equivalent of the current gas stations, is also plausible in later years.

The impact of the large load of clusters of DCFCs on the operation of the electricity grid was investigated. This impact was found to be fairly limited. The simultaneous load of all DCFCs in 2037 was equal to 2.4% of the forecasted peak load in Ottawa, while all recharging at DCFCs would only add 0.9% to the estimated annual electricity consumption of the city. It should not be a problem for the local electric utility to prepare for this, given the 20-year period over which this impact will slowly increase.

The dynamic impact of the large load of clusters of DCFC on the distribution grid will need to be taken into account in the installation phase to ensure the proper operation of the grid, even under worst case conditions. Installation costs of clusters of DCFCs were determined for three example locations. DCFC installation costs strongly depended on the specific location, and especially on the distance of the DCFC to the connection point of the distribution grid. Costly upgrades to the electricity grid to accommodate the large load of DCFC clusters were only necessary for very large clusters (total load > 1.5 MW). Most feeders in Ottawa will allow the installation of DCFCs without upgrades to the distribution grid.

Acknowledgments

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