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EV Fast Charging Stations and Power Quality

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SUMMARY

"The Electric Circuit", an initiative of Hydro-Quebec, is the most important network of public charging stations for electric vehicles (EV) in Quebec. It establishes a major initiative in the deployment of the charging infrastructure to support the arrival of the electric vehicles in Quebec. Since his inauguration in March 2012, more than 425 private and institutional partners joined "The Electric Circuit", and the network now has over 68,000 members.

At the present time, the network counts more than 2400 charging stations (approximately 90% of them are level 2 EV chargers at 240 V and 10% of them are 50 kW EV fast chargers at 400 V), essentially situated in the province of Quebec.

The state-of-the-art superstation offers four 50 kW fast-charging stations that can simultaneously recharge up to 80% of an EV battery in about twenty minutes. It has an adaptable configuration that renders its installation optimizable making possible both the addition of charging stations and the integration of new, more powerful technologies.

Currently, four vendors provide fast and ultra-fast-charging stations to "The Electric Circuit". First one has started supplying stations to the network in the fall of 2017, the second in 2019, the third in 2020 and the fourth in 2021.

The fast-charging models DCFC (50kW/400V), from first two vendors, went through rigorous climate and PQ testing at Hydro-Québec's research institute (IREQ). The power quality impact was evaluated during idle periods (no EV charging) and over three-stage activity of a charging station including:

1) Start-up,
2) Full charge,
3) End of charging process.

Equipped with power electronic (PE) interfaces, these charging stations are causing voltage waveform distortions. The evaluation of the impact on power quality is a three-phase process including laboratory and field tests:

- Phase 1 (2018): Laboratory tests on DCFC (50kW/400V)
- Phase 2 (2019/2020): Field tests on DCFC (50kW/400V)
- Phase 3 (2021 and +): Field tests on DCUFC (125, 160 and 350kW/400V or 800V)

These tests are part of the project to set up the afore mentioned public network of charging stations for electric vehicles in Quebec.

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The field tests were performed in phase 2 and will be continued in phase 3. The phase 2 tests, started in 2019, and evaluated two superstations. One of them includes 4 fast-charging stations from vendor A and the second one is equipped with 4 fast-charging stations from vendor B. Each superstation is supplied by a dedicated 3-phase autotransformer (600/480V). For each superstation, a PQ monitoring system PQube3 was connected between the primary side of the autotransformer and the secondary of a 3-phase delta connected (25kV/600V) MV power transformer. The PQ analyzers measure and record PQ disturbances related to the fast-charging stations, including harmonic emissions (<2kHz) and also high frequency or supraharmonic emissions (2 to 150kHz). Permanently installed, the PQube3 communicates wireless (cellular) with the PQ server located at IREQ's facility. It sends by email graphical and numerical information about trends statistics and charts using different types of files such as: .pqd, .gif, .csv, .htm and .xml.

This paper addresses "The Electric Circuit" project implemented in Quebec and discusses the results of the Phase 2 field tests, including trends of THD, TDD, harmonics, etc.

KEYWORDS
Electric vehicle, charging station, Power Quality, disturbances, harmonics, high frequency harmonics.

INTRODUCTION

Hydro-Quebec, a well-known Canadian utility, committed a decade ago to significantly contribute to transportation electrification in Quebec and elsewhere. Its sustainable development goals include:

- Generating 98.8% of electricity from a clean, renewable source and through initiatives such as *"The Electric Circuit"* for reducing GHG emissions in Quebec.
- Supporting energy transition, by implementing transportation electrification and gradually abandoning fossil fuels globally as part of the fight against climate changes.

Hydro-Quebec, using its expertise, is revolutionizing the transportation industry by developing advanced technologies for electric batteries and as well a network of charging stations for electric vehicles known as ***"The Electric Circuit".***

Among feasibility studies and pilot projects, the company focused its attention on the impact of electric vehicle charging stations on its distribution network.

This paper addresses ***"The Electric Circuit"*** project implemented in Quebec and discusses the results of the tests performed at IREQ's facility and on the field to determine the impact on power quality of two different models/vendors of fast charging stations (DCFC) (50kW/400V).

THE ELECTRIC CIRCUIT

"The Electric Circuit", an initiative of Hydro-Quebec, is the most important network of public charging stations for electric vehicles (EV) in Quebec. He establishes a major initiative in the deployment of the charging infrastructure to support the arrival of the electric vehicles in Quebec. Since his inauguration in March 2012, more than 425 private and institutional partners joined ***"The Electric Circuit"***, and the network now has over 68,000 members.

At the present time, the network counts more than 2400 charging stations (approximately 90% of them are level 2 EV chargers at 240 V and 10% of them are 50 kW EV fast chargers at 400 V), essentially situated in the province of Quebec. A significant number of double stations, with two fast-charging stations, and superstations offering up to 4 fast-charging stations (see Figure 1) are functional. The fast-charging station allows recharging 80 % of the battery of an electric vehicle in about twenty minutes.

Figure 1. The superstation (source HQ web site)

The four 50kW fast-charging stations of a state-of-the-art superstation can simultaneously charge one vehicle each. Designed by a Quebec firm, the superstation has an adaptable configuration that renders its installation optimizable, making possible both the addition of charging stations and the integration of new, more powerful technologies.

Lately ***"The Electric Circuit"*** has deployed ultra-fast-charging stations (DCUFC) with capacities from 125kW to 350kW.

CHARGING STATIONS

According to [1], there are three EV charging setups:

1. Level 1 Charging: Charging from a 120V outlet which provides between 2 and 5 miles of range per hour of charging.
2. Level 2 Charging: Using an EV service equipment to provide power at 220/240V and up to 30 amps for 10 to 25 miles of range in an hour of charging at home or at a public station.
3. DC Fast Charging (DCFC) (Level 3 charging): Using a charging station with standards such as: Supercharger (Tesla), CHAdeMO and CCS (Combined Charging Systems) for about 50 miles of range per 20 minutes.

A fourth charging setup might be based on:

4. DC Ultra-Fast Charging (DCUFC) (Level 4 charging): Using a charging station with standards such as: CHAdeMO and CCS (Combined Charging Systems).

CHARGING STATIONS UNDER PQ TEST

So far four vendors have supplied charging stations to "The Electric Circuit". The first one has started adding DCFC (50kW/400V) stations to the network in the fall of 2017, and the second one on spring 2019. Two more added DCUFC (125kW/400V or 800V up to 350kW/400V or 800V) stations in the fall of 2020 and at the beginning of 2021.

The charging stations/devices under test (DUT) at IREQ, Hydro-Québec's Research Institute, were DCFC stations (50 kW/400V). They required a 3-phase 480V a.c. power supply. The main component of the DUTs is a power convertor (or several) providing power at a voltage between 200 to 500V d.c. to the EV. The DUTs were equipped with CHAdeMO and CCS handles. The EVs available for the tests were:

1. SPARK from GM,
2. LEAF from Nissan.

EVALUATION OF CHARGING STATIONS

The evaluation of the charging stations impact on power quality is a three-phase process scheduled over several years, which includes laboratory and field tests:

- Phase 1 (2018): Laboratory tests on DCFC (50kW/400V):
  - Environmental
  - PQ impact
- Phase 2 (2019 and 2020): Field tests on DCFC (50kW/400V)
  - PQ impact
- Phase 3 (2021 and +): Field tests on DCUFC (125, 160 and 350kW/400V or 800V)
  - PQ impact

Charging stations face an unfriendly climate in Quebec, mostly in the winter season when they must withstand very cold weather and icing conditions. For this reason, the DUT were submitted to a rigorous testing in a climate chamber.

Equipped with power electronic (PE) interfaces, these equipments cause voltage waveform distortions, whose levels were measured during the PQ tests to assess if they exceed or not the thresholds suggested by the international standards [2] [3] [4] [5].

These tests are part of the project to set up the afore mentioned public network of charging stations for electric vehicles in Quebec.

Laboratory tests

The laboratory tests have been conducted in 2018 and included environmental and power quality tests.

Environmental tests

The environmental tests were conducted in the "Mechanical and environmental Tests Laboratory" at IREQ [6].

Power Quality tests

The PQ impact evaluation laboratory tests included the monitoring of the power supply of charging stations from vendors A and B during idle periods (no EV charge) and during EV charging periods based on a three-stage process:

- Start-up,
- Full load,
- End of charging process.

The results are analyzed and presented in [7], [8].

Field tests

The phase 2 field tests were performed in 2019. Two super stations, each equipped with four DCFC stations (50kW), deployed in the field, were continuously monitored. They are supplied by a dedicated 3-phase autotransformer (600/480V). A PQ monitoring system PQube3 has been connected between the primary side of the autotransformer and the secondary of a 3-phase (25kV/600V) MV power transformer. It measures and record PQ disturbances related to charging stations, including harmonic emissions (<2kHz) and also high frequency harmonics also known as supraharmonic emissions (2 to 150kHz). Permanently installed, the PQube3 communicates wireless (cellular) with the PQ server located at IREQ's facility.

The phase 3 test started in 2021. The DUTs are ultra-fast charging stations DCUFC of 125kW, 160kW, 350kW.

MONITORING SYSTEM

The PQ monitoring system (see la Figure 2) used in the survey includes:

1. PQ Analyser PQube3,
2. Power Manager Module PM1,
3. Currant clamps 300 A (SCN4-300A:333mV, 600V, accuracy ±0.2 %, ±0.5°),
4. Microhard IPn4Gii Cellular modem.

Figure 2. PQ Monitoring system

The PQube3 analyser was configured to send by email files such as .gif, .csv, .pqd (PQDiff), .htm, .txt et .xml, with:

1. Worst cases such as:
   - Load current > 50A,
   - RVC,
2. Voltage sags

3. Frequency. variations
4. Daily trends,
5. Weekly trends
6. Monthly trends.

PQube3 power quality analyzer was selected and used for PQ monitoring and waveform analyzing because of its ability to measure:

- Traditional harmonics (<2kHz),
- High-frequency harmonics also known as supraharmonics in the 2-150kHz range.

ANALYSIS OF FIELD TESTS RESULTS

The analysis of the results has been done according to the active power recorded at the POC of the two EV charging superstations, which was discriminated as [9][10]:

1. Zero DCFC station active/operating
2. One DCFC station active/operating
3. Two DCFC stations simultaneously active/operating
4. Three DCFC stations simultaneously active/operating
5. Four DCFC stations simultaneously active/operating.

In the next section, results corresponding to four DCFC stations simultaneously operating at superstation A are exemplified, discussed, and presented.

Four DCFC stations simultaneously operating

On 02/16/2020, the three-phase active power measured by PQube3 at the superstation POC varied between 0.526kW (min value) corresponding to four idle charging stations and 214.082kW corresponding to a switching operation of a converter of one of the four DCFC stations simultaneously operating.

Three-phase active, reactive, apparent power and power factor daily trends are shown in Figure 3.

These charging stations are configured to operate at a power factor close to unity and the reactive power value is near to zero.

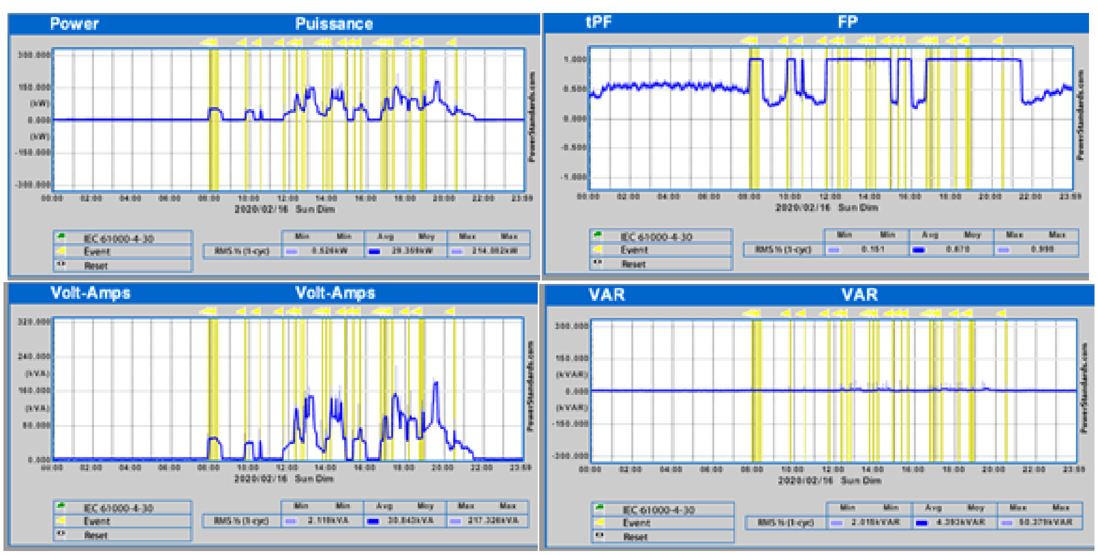

Figure 3 : Three-phase active, reactive, apparent power and power factor daily trends measured by PQube3 on 02/16/2020

At the same time, the maximum single-phase active powers were 70,945kW on phase A, 69,523kW on phase B and 73,614kW on phase C (see Figure 4).

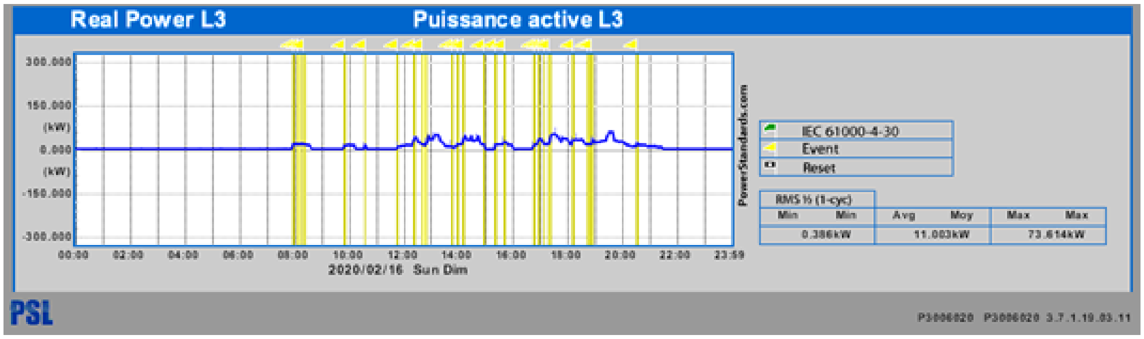

Figure 4 : Phase C active power daily trend measured by PQube3 on 02/16/2020

Recharging events experienced one, two, three and even four charging stations operating simultaneously. At 13:04, 14:12 and 17:28, three DCFC stations were active simultaneously and around 19:30 hour, four DCFC stations were feeding EVs.

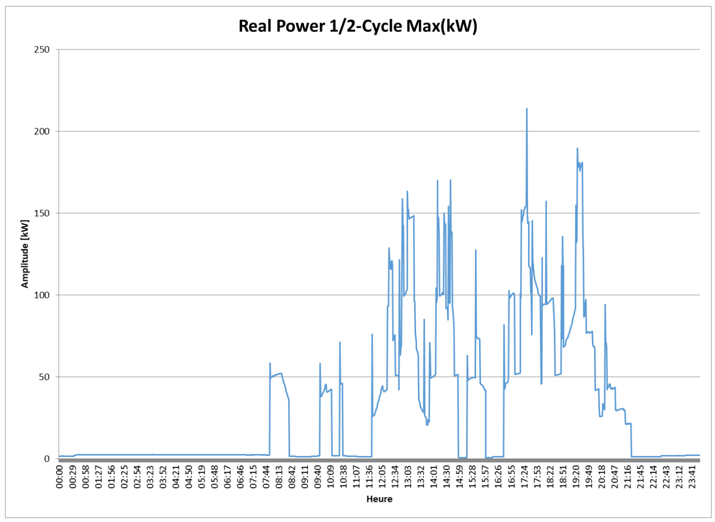

Figure 5. Three-phase active power daily trends measured by PQube3 on 02/16/2020 (max values)

The active power is well balanced among the three phases and the daily trend is shown in Figure 5.

The THD 95% value calculated for 2020/02/16 is lower than 2% and the TDD 95% value calculated for the same day is lower than 1.27% (see Figure 6).

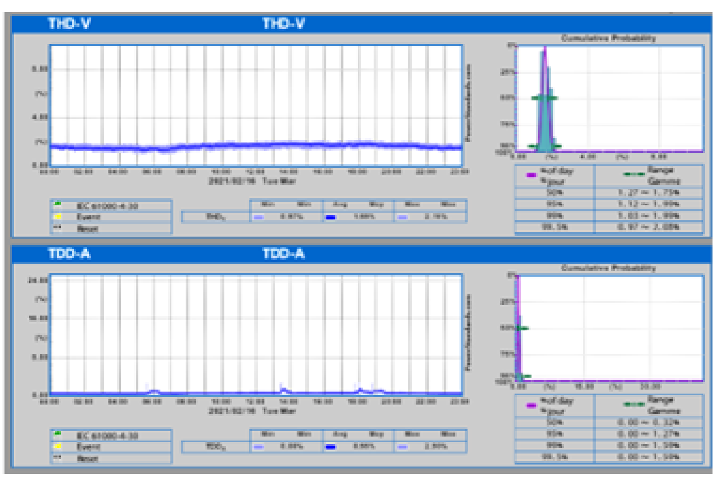

Figure 6. THD and TDD daily trends measured by PQube3 on 02/16/2020

The highest amplitudes measured by the PQube3 correspond to supraharmonics in the range 10 to 50kHz, and the graphical representation in Figure 7, illustrating high frequency emissions levels on phase C, is limited to that range.

It should be noted that elevations of amplitudes of high frequencies harmonics follow the elevations of active power and their peaks correspond to peaks of active power due to switching operations either at the start or at the end of the charging process.

Peak values of high-frequency emissions at the start of the EV charging cycle were mostly of 16kHz. During the full load recharging stages of two, three or four DCFC stations, the levels of max values of 32kHz supraharmonic (green colour) reached 2V on phase A, 2.75V on phase B and 4.5V on phase C. When only one charging station was active, the 10 kHz supraharmonic (blue colour), with amplitudes of 1.6V, 1.5V and 2V on phase A, B and C, respectively, was predominant.

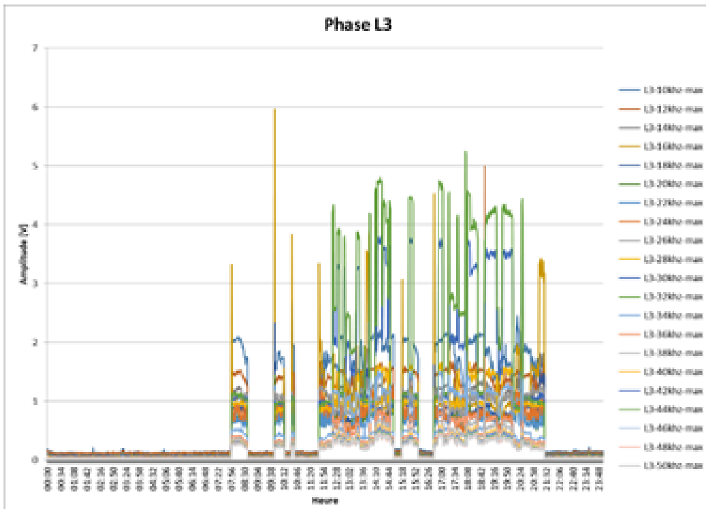

Figure 7 : High frequency harmonics levels in the range 10 to 50 kHz (phase C) measured by PQube3 on 16/02/2020 (max values)

In the range 2 to 9kHz, the peaks of the 2.2kHz voltage harmonic reached 3.13V and in the range 9 to 150kHz, the peaks of the 16kHz and 32kHz supraharmonics, reached 5.96V and 5.25V, respectively (see Figure 8).

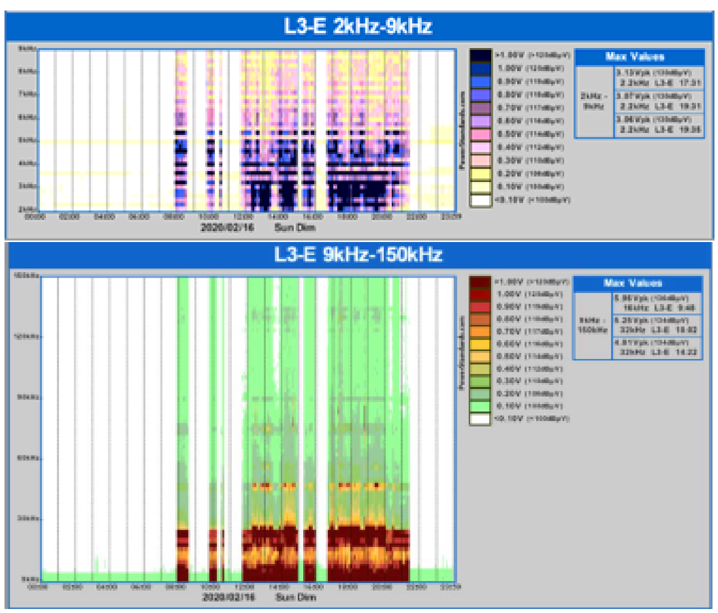

Figure 8 : High frequency (2 to 9kHz and 9 to 150kHz) harmonic levels (phase C) measured by PQube3 on 02/16/2020 (max values)

Comparison between results from monitoring superstations A and B

During periods of inactivity, the levels of high-frequency emissions measured at superstations A and B are lower than 0.18V and 0.15V, respectively.

The startup of charging cycle is similar for both superstations with peaks corresponding to 10, 14 and 16kHz supraharmonics. During the full load stage of charging cycles, the predominant supraharmonics at superstation A are of 10, 16 and 32kHz with amplitudes (max values) lower than 2V (0.57% of the nominal voltage of 347 V) most of the time. At superstation B, the PQube3 measured emission levels (max values) below 0.6V (0.17% of the nominal voltage of 347 V) for 10 and 12kHz supraharmonics.

On a few occasions the analyzers recorded peak supraharmonics of 16kHz at the end of charging process.

It should be noted that next to the superstation A there is a Tesla charging station. It may be interesting to monitor both to observe if, depending on their POCs, primary and secondary supraharmonic emissions might occur.

CONCLUSIONS

Studies in Europe and elsewhere have found high-frequency harmonics, also known as supraharmonics, in EV charging station emissions. Mainly, these emissions (2 to 150 kHz) are generated by the power electronics of the power converters components of EV charging stations.

This paper focuses on supraharmonics, which have been measured and recorded at the connection points of two fast charging stations. The levels of these emissions are discussed, compared, and interpreted according to the three-stage charging cycle:

1. Start up,
2. Full load,
3. End of recharge process.

Some graphics, provided by PQube3 in .gif, show daily trends/statistics of active powers and spectral distributions of 2 to 9 kHz and 9 to 150 kHz.

Analysis of the active power plots allowed to approximate the number of EVs operating simultaneously. Together, active power and supraharmonic max values plots, facilitated the association of power peaks created by switching operations of the charging station converter with supraharmonic peaks. They also helped to identify supraharmonic emissions and their levels during idle periods (zero active charging stations) or full-load stages of one at a time or two, three or four simultaneously active/operating charging stations. These four situations correspond to active power measurements up to 50, 100, 150 and 200 kW, respectively.

The subject of the supraharmonics being relatively new, knowledge and control of the phenomenon is limited, although several studies are finalized or in progress and associated standards are still in production.

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