SMART PEAK SHAVING
CHARGE MANAGER FOR AN
ELECTRIC SCHOOL BUS
FLEET

Guillaume Fournier, P.Eng.
Program manager (EV)
ABOUT IVI

We develop electric, autonomous and connected vehicle prototypes
PROJECT PARTICIPANTS

Sponsors

Québec
Consortium Inno-Vé
Hydro Québec

Partners

Autobus Laval
Lion
Peaks occurred when block heaters were manually activated while electric buses were charging. These excessive peaks resulted in a significant cost increase.

- **Context**
  - **1.** Autobus Laval had multiple instances of excessive power peaks.
  - **2.** Peaks occurred when block heaters were manually activated while electric buses were charging.
  - **3.** These excessive peaks resulted in a significant cost increase.
PROBLEM

Loads – Block Heaters
PROBLEM

Loads – EVSE
Empirical data shows that building power demand can be roughly estimated by:

For $T > 7^\circ C$, $W_{\text{building}} = 50$ kW

For $T \leq 7^\circ C$, $W_{\text{building}} = (-2.67 \cdot T + 70)$ kW

For example, at $-10^\circ C$, building power demand is around 97 kW
PROBLEM

Loads – Sum of loads
PROBLEM

Loads – Sum of loads
PROJECT GOALS

Prevent power peaks, smooth power as much as possible
PROJECT GOALS

Decrease electricity cost by reducing maximum power demand (MPD)
PROJECT GOALS

Maintain bus availability

Start SOC 85% Trip 15%
End SOC 65%
PROJECT GOALS

VERSATILITY

Besides schedule, everything else should be automatic

MONITORING

Realtime monitoring of charge plan administration
+ It should be possible to look back and learn from our errors

SAFE

Possibility to disable at all time by the end user
+ SMS sent when problem occurs
PROJECT LOCATION
PROJECT LOCATION

Electric buses

Diesel buses

Building
TARGET CUSTOMERS

1. Small fleet operators that cannot afford large-scale custom solutions
2. Having little knowledge on charging challenges
3. Heavily impacted on power peak increase (no masking loads)
4. Newcomers in the electric fleet management that want to gradually increase their EV count
### SOLUTION

#### Overview – Information gathered

<table>
<thead>
<tr>
<th>Information</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start and end time of all bus routes</td>
<td>Google calendar</td>
</tr>
<tr>
<td>Distance for each trip planned</td>
<td>Google calendar</td>
</tr>
<tr>
<td>State of charge of each bus</td>
<td>Fleet management interface</td>
</tr>
<tr>
<td>Presence or absence of a bus at each EVSE</td>
<td>EVSE Bridge</td>
</tr>
<tr>
<td>Temperature-compensated 24-hour power profile prediction of the building without the electric buses including the profile from the diesel buses' block heaters</td>
<td>Electric utility interface</td>
</tr>
<tr>
<td>The instantaneous power reported by the meter</td>
<td>Electric utility interface</td>
</tr>
<tr>
<td>Demand Response Event list</td>
<td>Electric utility interface</td>
</tr>
<tr>
<td>Battery capacity of each bus</td>
<td>Web administration interface</td>
</tr>
<tr>
<td>Dedicated EVSE for each bus</td>
<td>Web administration interface</td>
</tr>
<tr>
<td>Estimation of power lost while charging*</td>
<td>Web administration interface</td>
</tr>
<tr>
<td>Maximum power target to aim for*</td>
<td>Web administration interface</td>
</tr>
<tr>
<td>Energy consumption per km traveled*</td>
<td>Web administration interface</td>
</tr>
<tr>
<td>Phone numbers of emergency contacts</td>
<td>Web administration interface</td>
</tr>
<tr>
<td>Operating mode: safe or normal</td>
<td>Web administration interface</td>
</tr>
</tbody>
</table>

*These values are entered for each month of the year, based on experimental data, since they are highly correlated to external temperature.*
SOLUTION

Overview

Cloud / Google
  - Calendar (bus schedule)

Cloud / Charge Manager
  - Multi-stage linear optimizer
  - Charge plan administration
  - MQTT broker

Cloud / Utility
  - 24-hour power profile prediction & line contactor drivers

On-site
  - Line contactors for block heater circuits
  - Diesel buses

Cloud / EVSE
  - EVSE local bridge
  - EVSE bridge
  - EVSE backend

Cloud / Fleet management
  - Interface to buses

Cloud / EVSE
  - EVSE local bridge

4G

Cloud / Google
  - Calendar (bus schedule)

Cloud / Charge Manager
  - Multi-stage linear optimizer
  - Charge plan administration
  - MQTT broker

Cloud / Utility
  - 24-hour power profile prediction & line contactor drivers

On-site
  - Line contactors for block heater circuits
  - Diesel buses

Cloud / EVSE
  - EVSE local bridge
  - EVSE bridge
  - EVSE backend

Cloud / Fleet management
  - Interface to buses

4G

Innovative Vehicle Institute
SOLUTION

Trip calendar
SOLUTION

Trip calendar

Unplugged

Distance (m)

Description

Units: 201702 - Circuit 054
06:50 - 09:17
2139
**SOLUTION**

*Data from Hydro-Quebec*

1. Energy accumulator (kWh) every 5 min
2. Average power is calculated
3. Control loop on EVSE

### Demand Response Event list

- Block heaters (between 2 and 4 AM)
- Building
SOLUTION
Data from fleet management

From school bus

- State of charge
SOLUTION
Data to/from EVSE

To EVSEs
- Current to propose to bus

From EVSEs
- Instantaneous supplied current
- Voltage and energy meter
- Plugged status
The output of each stage is a charge plan. More specifically, it is represented by 7 arrays (one per bus) of 96 power values to propose to each bus. Each square represents a 15-minute interval and its value (in kW) is the amount of power that is going to be offered for that bus for this interval. The charge plan covers the next 24h.
SOLUTION

Stage 1: Minimize the “Maximum Power Demand” for the next 24 hours

Constraints

- Charge power must be between 0 and 16.64 kW
- Charge allowed only when bus is plugged in
- Energy in a bus must be between 0 kWh and its max capacity
- Energy in buses must be sufficient to perform all trips
The objective is to compute, for each interval, the maximum power available that can be drawn without increasing the maximum power demand already registered for this billing cycle.
SOLUTION

Stage 2: Minimize power demand on Demand Response Events

Contraints

- All constraints from stage 1
- Never go above the maximum power available (stage 1.5)
SOLUTION

Stage 3: Maximize the time when the buses are ready for their next trip

1. For each trip, for each bus, for the next 24h, calculate how long before the trip the bus is ready

2. Maximize the smallest time

Bus #1 trip #1: ready 30 min before trip
Bus #2 trip #1: ready 15 min before trip
Bus #3 trip #1: ready 58 min before trip
.....
Bus #7 trip #4: ready 35 min before trip

Constraints

- All constraints from stage 2
- The energy consumed on each Demand Response Event does not exceed what was calculated on stage 2
SOLUTION

Stage 4: Maximize the amount of energy in the buses before each trip – Step 1

1. For every trip (all buses) for the next 24h, calculate how much exceeding energy is available before the trip

2. Maximize the smallest energy

   Bus #1 trip #1: 17 kWh more than needed before trip
   Bus #2 trip #1: 15 kWh more than needed before trip
   Bus #3 trip #1: 10 kWh more than needed before trip
   ....
   Bus #7 trip #4: 5 kWh more than needed before trip

Constraints
- All constraints from stage 3
- For each trip, the amount of time before the bus is ready must be greater or equal than the result of stage 3
**SOLUTION**

Stage 5: Maximize the amount of energy in the buses before each trip – Step 2

1. For every trip (all buses) for the next 24h, sum the amount of remaining expected energy after each trip

2. Maximize this value

   Bus #1 trip #1: 14 kWh remaining after trip
   Bus #2 trip #1: 27 kWh remaining after trip
   Bus #3 trip #1: 36 kWh remaining after trip
   ..... 
   Bus #7 trip #4: 34 kWh remaining after trip

   \[14 + 27 + 36 + ... + 34 = 168 \text{kWh}\]

**Constraints**
- All constraints from stage 4
- For each trip, the amount of excess energy must be greater or equal than the result of stage 4
SOLUTION

Stage 6: Minimize power variations

1. For the next 24 hours, minimize the variations of power offered to the vehicles between two adjacent intervals

2. Probably unnecessary

Constraints
- All constraints from stage 5
- The sum of excess energy before trips in the next 24 hours must be greater than or equal to the result of stage 5
RESULT

Overview
RESULT
Energy in batteries
RESULT

Energy in batteries
UNIQUENESS OF OUR SOLUTION VS OTHERS

A lot more than your typical load sharing solution

- Predicts other loads and plans the charging profiles accordingly
- Considers past MPD to increase power without increasing cost
- Retrieves state of charge from vehicles
- Integrates a vehicle calendar (distance, charge time)
- Solution is EVSE agnostic
- Realtime feedback on the meter to compensate for estimation
- Reduces energy drawn on Hydro-Quebec’s Demand Response Events
- Uses linear optimization techniques for optimal solutions
IMPLEMENTATION CHALLENGES

What went wrong

- Selecting and controlling EVSEs
- Getting the information from the buses
- Getting the information from the smart meter
LESSONS LEARNED SO FAR

What we uncovered

- Although the technology is available, it is not completely mature
- Getting all stars aligned is almost impossible
- Aggregating information from multiple sources is complicated
- Make sure partners have incentives (could be result, financial, etc.) to work toward a common goal
WHAT’S NEXT
Activation and data gathering

- Activation should be possible by the end of the summer
- Grafana dashboards will give real-time insights
- Adjustments to the algorithm will be performed

- Monitoring data will be saved in the Cloud in a database
- PowerBI can also be linked to the Cloud monitoring database
WHAT’S NEXT
Possible future improvements

- Make everything more robust, more mature
- Auto match a vehicle to any EVSE
- Improve feedback to end user (in web UI or even an app)
- Allow priority charging on a per vehicle basis
- Transfer charge plan administration to the EVSE
- Getting rid of fleet management dependency (OBD2 Wi-Fi dongle)
- Account for local power production such as solar
WHAT’S NEXT
More possible improvements

- Charging algorithm (AI?)
- Use upcoming ISO15118-20 to recover SOC from vehicle
- Better integration with Hydro-Quebec (MPD, billing, Demand Response Events)
- Integration of schedule in business process management (ERP)
- Building power consumption prediction (AI?)
- Bloc heaters load management (including FEA sims or empirical data)
- Interface to Building Management Systems
FOLLOW IVI
on social networks

Subscribe to our newsletter

https://www.ivisolutions.ca
Guillaume Fournier, P.Eng.
Program manager – Electric Vehicles

+1(855) 731-5744 #225

gfournier@ivisolutions.ca