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V2B Vehicle to Building Charging Manager

- Concept and Implementation -

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ABSTRACT: Due to a fast rise in the share of renewable energy with a corresponding destabilizing impact on the energy grid and a rapidly growing share of electric vehicles (EVs), the smart integration of electric mobility and facility energy management promises substantial social, ecologic, and economical benefits for drivers, facility and grid operators, and society in general. Vehicle-to-grid (V2G) technologies, which allow a bi-directional energy flow to and from the car, show an even greater potential. To investigate this potential in a company environment we have developed a smart charging manager that considers various objectives like peak load costs and users' charging requests to optimally control a number of uni-directional and bi-directional charging stations. Based on a prediction of the building's energy demand and Photo Voltaic (PV) production, an optimal charging plan is derived from a Mixed Integer Linear Programing approach. This work describes the main technical and algorithmic concepts and solution. We also present first results of some real-world tests in our facility.

KEY WORDS: smart charging, V2G, scheduling, prediction

1. INTRODUCTION

Renewable energy systems like PV or wind power are key components in the fight against GHG emissions, but due to their uncontrollable nature they pose a severe challenge for electric grid operators, who need to maintain the delicate balance between demand and supply. A mass adoption of electric vehicles in combination with simple charging controllers (charge with maximum power as soon as the car is plugged in) is likely to worsen the situation even more.[(1)]

Fortunately, it has been shown[(2)] that a smarter charging control can not only reduce the negative impact, but actually help to stabilize the grid by using the substantial energy storage capacity of EV batteries. The standard approach is a so-called controlled charging where the charging power is modulated depending on the state of the electricity grid (or related incentives like flexible energy prices). A larger benefit can be gained if EVs are equipped with V2G technology which allows to transfer energy back from the EV to the grid. This would allow a fleet of EVs to temporally act as a virtual power plant.[(3)]

As already announced, Honda is proposing the eMaaS [(4)] concept. The term "eMaaS" refers to a synergy between "Energy as a Service" and "Mobility as a Service".

Due to the leading position of Europe in the use of renewable energies and electric mobility [(5)], Honda has decided to develop and test a smart charging manager that connects electric vehicles to the company energy management. We call this concept V2C (Vehicle to Company). This concept is in an important position to first build in-house energy management and accumulate technology and know-how toward the realization of Honda's eMaaS concept.

In the following we will first explain the basic approach and main system modules, then elaborate more on the smart charging algorithm, present some initial results, before concluding this work and giving an outlook to future challenges.

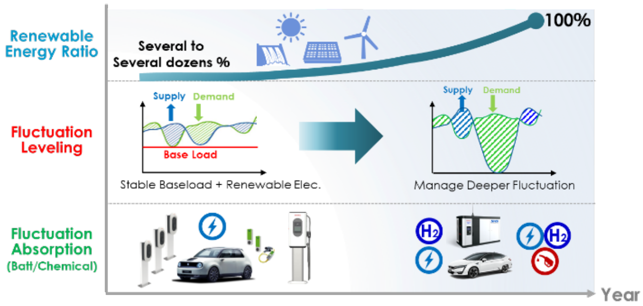


Fig. 1 Fluctuation of renewable energy and storage

2. PROJECT SETUP

To realize the overall functionality of smart charging at Honda R&D Europe, various hardware and software components have to interact with each other. They are as described in the following: charging stations, user input terminal, renewable energy productions systems, smart charging system and the operator graphical user interface.

Fig.2: Honda R&D Europe (Germany) facility equipped with a solar roof and a solar carport

Fig.3: Honda R&D Europe (Germany) 150kW fast charger which generates high power demand peaks.

2.1. Charging Stations

Three types of charging stations were used in our test setup: uni-directional AC chargers, AC chargers equipped with a mobile metering system(6) and bi-directional DC chargers(7).

2.1.1 Uni-directional AC Charging Stations

The AC charging stations are using the communication protocols IEC 61851 for station to vehicle communication. This allows a charging control to start and stop charging sessions. The charging power is also controllable in a range from approx. 1.4 - 22kW.

Fig.4: Uni-directional Honda Power Charger

2.1.2 AC Charger with Mobile Metering

For correct accounting of e.g. business cars, a calibrated billing system is necessary. Therefore, we are using a mobile metering cable to have a dedicated energy meter for every vehicle. The charging control is handled over the air via the cable. The charging behavior is the same as of the AC charging stations.

2.1.3 Bi-directional Charging Stations

The Honda Power Manager was used for bi-directional charging sessions. This allows to discharge the vehicles for reducing high power peaks further.

Fig.5: Honda Power Manager connected to a Honda e for a bi-directional charging session

2.2 Second-life Battery

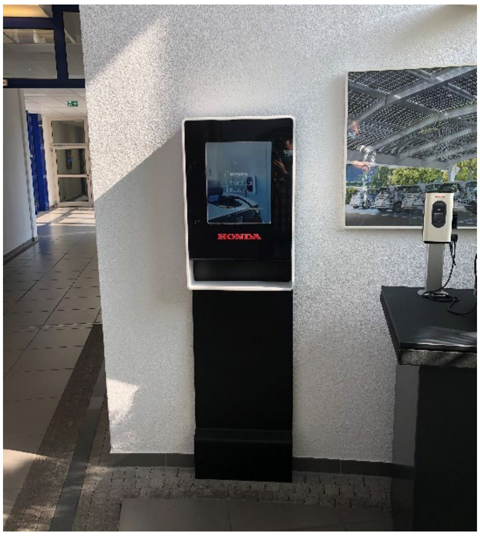
To reduce high power peaks further a stationary second life battery was added to the test setup. The overall battery size is about 50kWh. The system can be charged and discharged with up to 40kW.

Fig.6: Second-life battery installed in a container

2.3 User Terminal

When the user arrives, he or she needs to provide charging preferences; these are the current State Of Charge (SOC), the departure time and the departure SOC. These input values are used by the Charging Manager, our own developed Energy Management System (EMS), to calculate the charging plans for each charging session.

Fig.7: User input terminal located the facility entrance



2.4 Renewable Energy Production System

The integration of the installed solar system enables us to provide CO_2 free energy to each electric vehicle. This is done by adjusting the charging schedules calculated by the Charging Manager to charge the EVs preferentially in times when surplus green energy is available from the solar system.

2.5 Smart Charging system

The main component of the system interacts with each asset to collect all necessary information of the live system. This information will be processed to generate operation schedules for all charging stations and the stationary battery.

2.6 Operator Graphical User Interface

A Graphical User Interface (GUI) visualizes all necessary information to an operator to keep the system running. In this GUI the system operator can monitor all connected EVs, the current load curve as well as error states, thereby simplifying system maintenance.

2.7 Smart Meters

To create detailed schedules for each charging sessions the systems need to know how much energy is consumed by the building and how much will be produced by the solar system. Therefore, we installed smart meters at every main consumer and producer at the facility. The most important one is the main energy meter of the facility. Based on this data, power peaks will be charged by the grid operator.

3. SMART CHARGING SYSTEM

The core of the smart charging approach is a predictive scheduler that combines a linear programming-based scheduling approach with a prediction of the PV production on site and the company's energy usage.

3.1. Scheduling approach

The charging power is determined with help of a scheduler. Based on the current situation (e.g., the SOCs of the connected EVs), the charging requests of the EVs, and a prediction of the future energy balance of the building, the scheduler constructs a plan for charging the connected EVs within a certain planning horizon (per default, eight hours). The plan is constructed by formulating and solving a resource allocation problem analogous to that described in a previous work [(8)]. The optimization problem is solved through linear programming with help of the commercial solver software SCIP[(9)]. The scheduler is employed in a rolling horizon strategy, meaning that the charging plan is periodically updated in order to react to changing conditions.

3.2. Considered objectives

One of the main challenges of smart control is the integration of a larger number of objectives. Among others we consider the following goals and constraints for the scheduler:

- Minimizing the 15 min average of the load peak of the total facility considering both controllable (charging stations) and uncontrollable loads and the PV system. Note that for our facility only the average consumption in a fixed 15 min interval is considered by the grid operator.
- Maximizing the self-consumption of our company's PV system to reduce costs and CO_2 emissions.
- Satisfying users' charging requests (i.e. reach a certain SOC level at a specified departure time).
- Minimizing charging and discharging of EV and stationary battery systems to reduce battery degradation.
- Ensuring that no EV is ever discharged below its arrival SOC level. To avoid inconvenience to the drivers.

The system can optionally also consider some (VIP) users with priority, so that these EVs are charged preferentially.

3.3. Prediction System

In order to compute an optimal charging plan, we need a reliable and accurate prediction of future power consumption and production. The prediction is split into two parts, the total load of the building and the on-site energy production. Analyzing past load time-series, we see a regular weekly pattern subject to seasonal influences. We extract simple models by grouping all historical data by day-of-week and averaging for every day and point-in-time. The resulting day-models are stored and fitted into the measurements of the load for the past 7 days. The load prediction is updated every minute.

The second part of the prediction deals with forecasting on-site energy production. As photovoltaic power output strongly depends on weather conditions, we use a commercial PV-prediction package to update the PV-prediction twice a day.

4. RESULTS

The first prototype of the smart charging system was tested in various artificial and real-world scenarios as described in the following sections.

4.1. Prediction performance for building load and PV production

First experiments show that the resulting predicted load as well as the PV-production match the lower-frequency parts of the actual measurements. That is, the day trend as well as the peak load/production are nicely approximated while the high-frequency changes cannot be predicted well. However, as the over- and under-prediction cancel out on short timescales (usually less than on hour) the present prediction is a robust and suited basis for later scheduling and the application in general (see Fig.8 for the example of building load prediction).

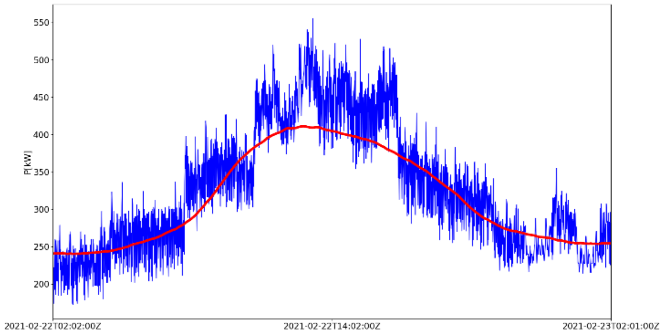


Fig.8: Real (blue) vs predicted (red) building load for one day in February 2021.

4.2. Scheduler output

The charging scheduler was first tested on some artificial input data (energy balance and user requests were provided). The data showed that the scheduler managed to satisfy all objectives when physically possible and put the desired priorities in case not enough energy (or time) was given.

An example of a real charging session with 6 EVs is shown in Fig.9. All user requests (target SOCs of 100% at the stated departure times (deadlines)) were fulfilled.

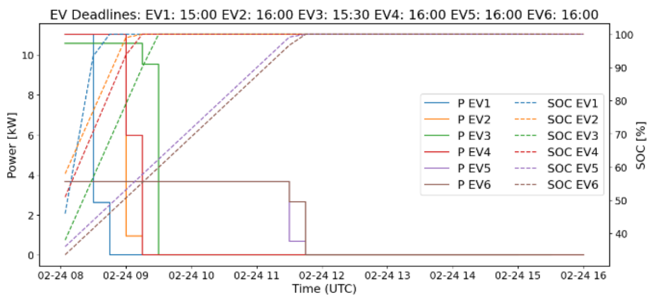


Fig.9: Example charging schedule (power and SOC over time) for 6 EVs with varying departure deadlines for an exemplary day in February 2021.

4.3. Tests of system in simulation

In order to avoid costly mistakes due to software bugs and to compute the building's saving potential in advance the smart charging manager was tested in a simulation environment, a so called digital twin [10] Therefore, we used both random input scenarios and detailed simulation of the building with measured sensor data from past years for assessing the controller performance under various conditions. Fig.10 presents a snapshot of the actual physical simulation tool.

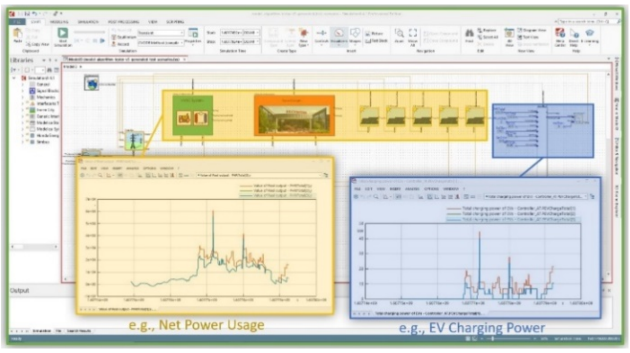


Fig.10: Modelica-based physics simulation tool used for controller development and validation. External controllers implemented in Python can be connected to the simulation.

4.4. Real-world tests

Real world tests are mandatory to analyze the behavior of connected EVs and charging stations. The effects of the setup can also be analyzed to adjust system settings to detect unexpected behavior. We started a test with 6 test participants who use the system regularly. During the day, the system calculates the best possible charging plans to fulfill user preferences and to not exceed the maximum peak power in an interval of 15 minutes. In this setup an overall peak limit of 250kW has been set (see Fig.11).

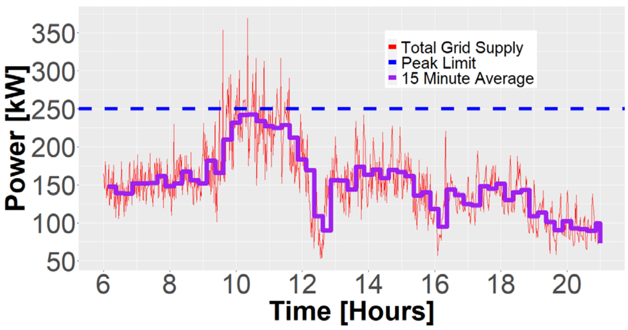


Fig.11: Facility grid supply

Between 9:30 and 11:30 o'clock the system measured the highest building load. However, due to the operation of the Smart Charging System the 15-min average building consumption (solid purple line) did not exceed the 250kW limit (dotted blue line).

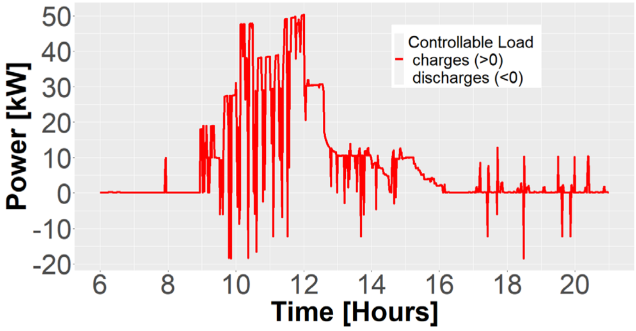


Fig.12 Controllable EV and Battery Load

The vehicles were charged as usual in the morning. When the power comes close to the peak limit, some charging sessions were stopped. When the system then detected that the power needs to be reduced further, the second life batteries were discharged. The control of the assets made it possible to keep the peak limit.

After the power peak the electric vehicles were able to continue their charging session and the batteries were also fully charged again, to be prepared for the next power peak.

4.5. Analysis of financial and ecologic benefits

To analyze the financial and ecologic benefits a lot of boundary conditions like the number of connected EVs, type of charging stations and the amount of renewable energy production need to be considered. The peak cost in 2020 at Honda R&D in Germany is around 100 €/kWp. This represents about 20% of the yearly electricity cost. We were able to reduce the peak power costs of our facility by installing a large PV system and the charging manager. The specific savings are difficult to measure due to various effects like the extension of our charging infrastructure and lock-down effects.

Due to the Covid-19 pandemic, extensive real world tests with regular users were not possible so far. We therefore increased the number of simulation-based tests, which allows us controlled studies with well-defined usage statistics and weather conditions. However, simulation studies will be complemented by extensive tests with the actual users of our building once lock-down measures have been lifted.

Besides the use case of peak shaving, the use case PV-self consumption increases the financial and ecologic benefits of a smart charging system further.

5. CONCLUSION

From our experiments we conclude that EV fleets could provide new economic value to a company, limit GHG emissions, and reduce the grid impact, if a smart charging strategy is employed.

When the COVID-19 pandemic is under control, we will increase tests under normal, real-world conditions. We will also continue to further improve the energy management, load and production prediction algorithms of the building in this research.

In the future we will investigate how to integrate different revenue streams and how to choose the most profitable service at each instance of time.

In addition, by integrating with the results of related activities being promoted by Honda around the world, Honda will move toward the realization of the eMaaS concept, and will propose the new value of EV fleets, contribute to the expansion of renewable energy and the reduction of CO_2.

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