

R-E-FLEX

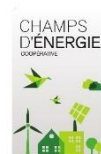
Renewable energy and E-mobility as a FLEXibility service

D2.1. Report on concept design

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(DRAFT)

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FPS Economy, S.M.E.s, Self-employed and Energy

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1. Introduction

As part of this investigation in the REFLEX project, the present deliverable (D2.1) focuses on the charging concept.

Section 2 of this deliverable presents the charging station concepts including AC and DC power distribution based concepts. Two sites considered in this project including Zuidtrant charging and Ecoob charging stations are described.

Section 3 provides the smart charging control method that can be used to further improve the energy management of power systems including EV and other systems. The description and the key innovative parts of the control method are discussed

Section 4 focuses on providing some recommendations for further efficient charging based on the KU Leuven's previous research in EV charging and project experience [1-7]. These recommendations, if considered in charging strategies could increase the operating efficiency of different charger and EV models.

Section 5 summarises conclusions.

2. Charging station concept

KU Leuven already did some studies on comparing charging concepts in previous research project and published works in [1-2]. There are two charging station concepts based on the type of the power distribution (AC or DC). The DC power distribution system based concept as illustrated in figure 2.1. is still not popular because of, for instance the availability and cost of the protection devices. However, there are several benefits for using DC distribution systems such as higher power transfer capability, possibility of two voltage levels, reduced conversion losses and increased reliability. This DC concept can be unipolar (two-wire) or bipolar (three-wire) configuration allowing the connection of different components using two voltage levels.

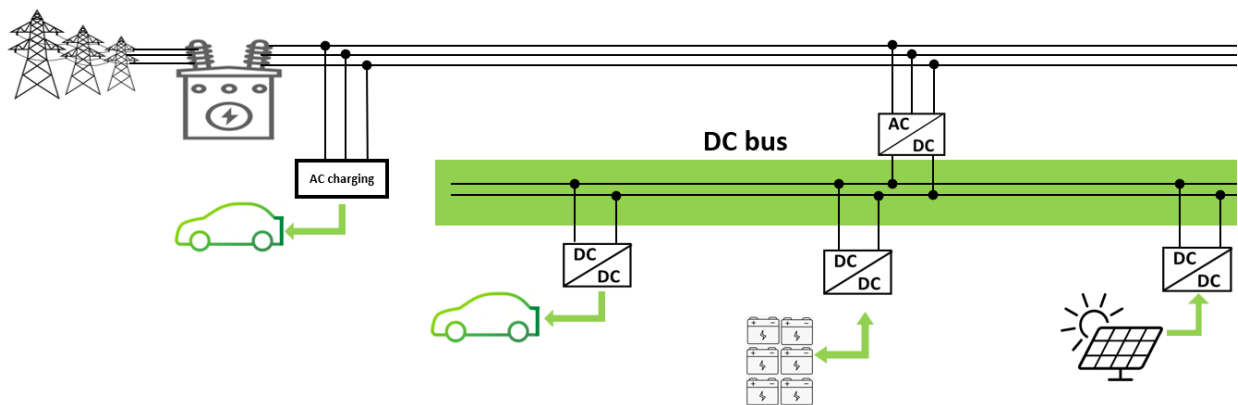


Fig. 2.1: DC power distribution system based concept

Typical EV commercial charging systems, as illustrated in figure 2.2, consists of AC distribution systems which is the conventional architecture because of some advantages such as availability of mature AC protection devices, standardized techniques of AC metering, etc. The AC power generated from different sources is collected via an AC bus before being distributed to EV. This conversion to AC has an impact on the efficiency, complexity, cost and size of the whole architecture.

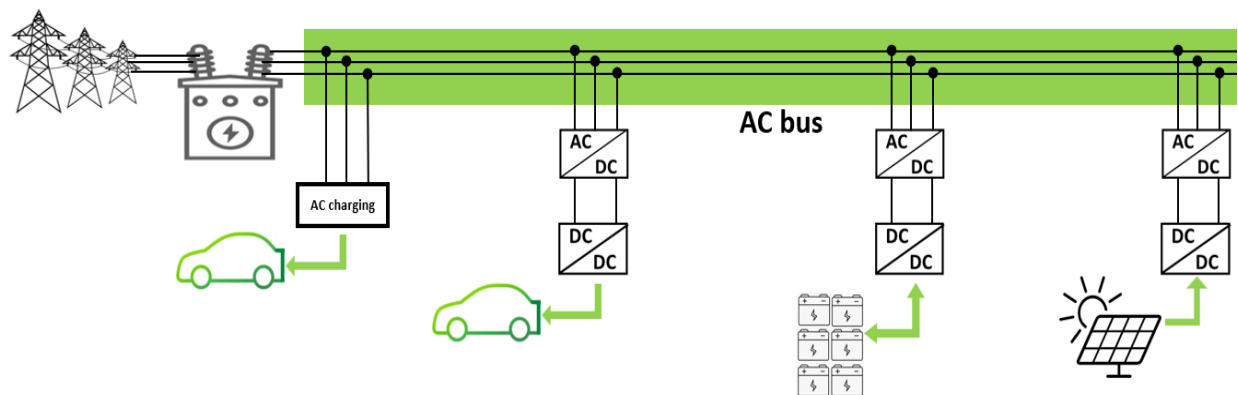


Fig. 2.2: AC power distribution system based concept

2.1. Zuidtrant charging station

Zuidtrant charging station is the first running site described in the previous report (D1.3). Figure 3.3 shows a site level power distribution. A 400 kW grid connection feeds a low-voltage bus that ties together an AC EV charger (1x22 kW), a battery energy storage system of 111 kWh, interfaced through a bidirectional power conversion stage (50 kVA) shown as AC/DC–DC/DC blocks and a PV plant rated 286 kW (connected via PV inverters). It also denotes energy flow to/from each energy systems, indicating that both the BESS and PV can supply the site and export to the grid, while the EV charger draws from the bus. The local load is not included in this figure.

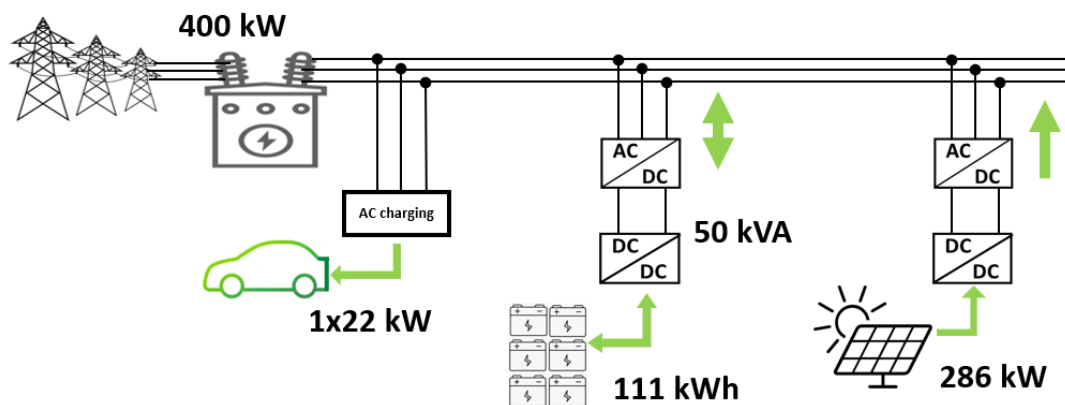


Fig. 3.3: Zuidtrant power distribution

2.2. Ecoob charging station

Ecoob charging station is one the site's described in the previous report (D1.1). Real datasets from a charging station operating AC and DC fast chargers were in that previous report. Figure 3.3 shows a site level power distribution which is a simple grid-supplied EV charging site including a transformer feeds a common bus that branches to two charger types (an AC charging block powering **two 22 kW** posts for regular charging, and a **150 kW** DC fast charger). The green arrow along the bus indicates power flowing from the grid toward the chargers; no on-site generation or battery storage is included, so all charging demand is met directly from the grid connection. The local load is not included in this figure.

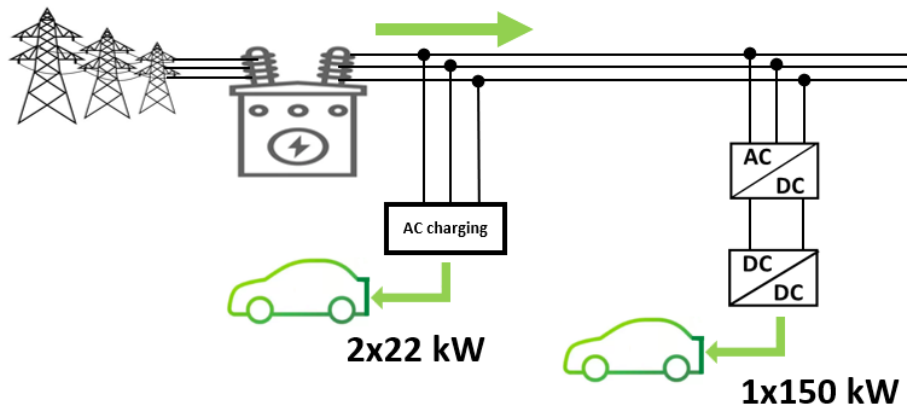


Fig. 3.3: Ecoob power distribution

3. Smart charging control

One of the best ways to manage energy in charging concept using different energy systems is by using smart charging control method. In this context, KU Leuven developed a smart charging control method using advanced machine learning models built from actual charging datasets [3-5]. Part of the work is published in [6] and submitted to a top journal in the research area [7].

Prior smart charging work typically optimizes for cost, peak shaving, or grid constraints without explicit charger efficiency modeling and battery thermal prediction. Efficiency and thermal control delivered in a deployable, closed-loop CMS is the step that turns smart charging into smart, efficient, and battery-aware charging at scale. That is what is achieved with the proposed method.

3.1. Control method description

As illustrated in figure 3.1, the proposed method delivers a smart charging controller for large scale stations that explicitly accounts for both the on-board charger's efficiency and the battery's temperature evolution, two metrics that matter to every stakeholder in the charging ecosystem. However, most EV manufacturers still restrict access to detailed battery and on-board-charger data, limiting the ability of external controllers to retrieve the signals needed for optimal operation. To overcome this, we conducted a new data-collection method, as proposed in our earlier work [4], producing a high-resolution dataset on an 11 kW on-board charger and two distinct battery packs; the dataset is publicly available in [5].

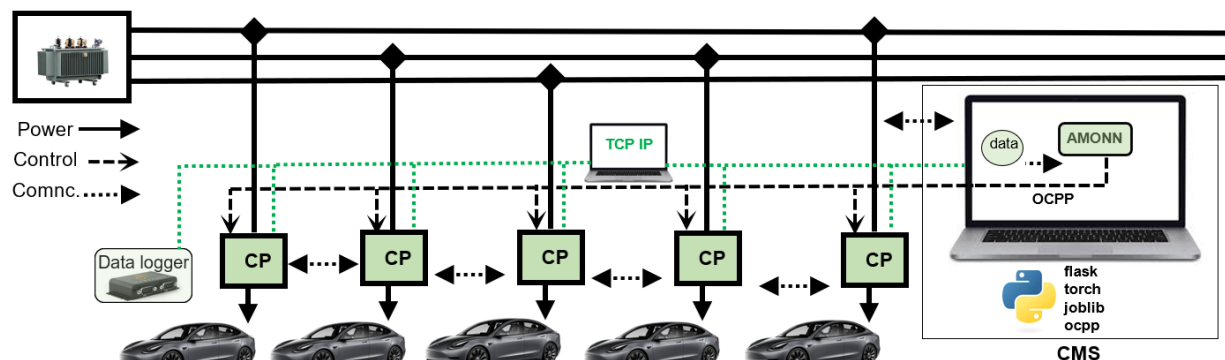


Fig. Smart charging control for large scale charging stations

These constraints have accelerated interest in data-driven charging strategies. Machine learning models trained on large-scale, high-resolution real-world datasets can predict charger efficiency and battery temperature without requiring proprietary hardware knowledge (e.g., topology, conversion stages, switching devices, or battery chemistry). In doing so, the proposed method enables optimal smart charging that remains effective across diverse EV models improving energy efficiency, safeguarding battery health, and lowering operating costs.

3.2. Innovative approaches

Despite the growing interest in smart-charging, most data-driven approaches still ignore two coupled realities:

- the efficiency map of the on-board charger (OBC) and its dependence on power/SoC/temperature, and
- the battery's thermal dynamics during a charging session.

As a result, today's controllers may meet energy or cost targets while quietly wasting energy and overheating cells. The proposed method closes this gap with a hardware-agnostic, data-driven controller for large-scale stations that co-optimizes charging efficiency and battery temperature using advanced machine learning.

We develop a smart-charging control for large depots and public sites that learns from high-resolution, real-world data and does not require OEM-proprietary signals or charger topology details. The controller predicts both OBC efficiency and battery temperature in real time and adjusts the charging power profile over the entire session, leveraging vehicles' natural time flexibility to reduce losses, safeguard battery health, and cut operating costs.

Key innovative elements:

- 1) **Attention-Augmented Multi-Output Neural Network model:** It predicts charger efficiency and battery temperature jointly from accessible features (charging power, ambient temperature, SoC), trained on high-resolution datasets from real EVs to reflect true operating conditions and to generalize across models.
- 2) **Session-level optimization** with SoC & time flexibility. It couples the trained AMONN with a greedy optimization (GO) routine that updates the entire power trajectory as SoC evolves, honoring user dwell times, thermal limits, grid constraints, and price signals, thereby maximizing efficiency while keeping the battery in a safe thermal band.
- 3) **Closed-loop deployment** on real infrastructure. It implements the controller in a Charge Management System (CMS), exchanging setpoints via OCPP and ingesting measurements through a CAN-bus data logger. This demonstrates practical, OEM-agnostic telemetry (high-resolution charger/battery data) and **verifies end-to-end closed-loop control on existing charging infrastructure.**

4. Recommendations for optimal charging

Based on the KUL Leuven's previous research in EV charging and project experience [1-7], some recommendations for further efficient charging are indicated below. Charging efficiency is important as it affects the charging duration and the charging costs. These two parameters are important for both EV users and CPOs. These recommendations, if considered in charging strategies could increase the operating efficiency of different charger and EV models. These recommendations include (but not limited to):

- **Energy prices-based control:** to obtain better financial gain, the charging strategy should consider planning the day-ahead prices. Charging station with BESS can take advantage of its flexibility to further integrate FCR and imbalance prices.
- **Charger characteristics:** the charging strategy should consider the charger efficiency for both AC and DC charging scenarios so that the overall energy efficiency is good enough to reduce higher operating costs.
- **Battery characteristics:** as the internal battery efficiency cannot be easily measured and depends on many factors (SoH, SoC, temperature, historical operation etc..) delaying charging session might cool down the battery which will probably require extra energy for heating, compared to a session started as soon as the EV arrives to the charging point. Therefore, the charging strategy should consider this kind of battery temperature and efficiency dynamics.
- **PV optimization:** Using PV prediction models might improve the charging strategy and the overall energy management system.
- **Advanced optimization strategy:** further strategy should include round-trip efficiency of BESS, cycle cost/degradation of BESS, and charger/battery limits (power, C-rate, phases) in the optimization to realistically and economically improve the overall energy management system.
- **Advanced real time monitoring:** Self-learning algorithms can be used. if an online monitoring is not possible, including more specific behavior of the charger/EV model in the algorithms could help in reaching some optimization goals.

5. Conclusions

The present deliverable (D2.1) summarised the charging station concepts including AC and DC power distribution based concepts. Two sites considered in this project including Zuidtrant charging and Ecoob charging stations are described. These sites use the commercially AC system. Because of simple control, less conversions, and the DC nature of local generation and storage, the distribution system is moving to a DC bus concept. This concept can not only lower the installation cost and size but also improve the DC charging efficiency and the use of PV-BESS systems. A combination of both AC and DC distribution systems can be used in certain use cases. DC charging station using BESS, for instance, can have a DC bus for the battery and DC charging.

Whether the concept is AC or DC bus based, its energy management control needs to be designed in an innovative approach in order to fully take advantages of the flexibility provided by different energy systems (EV, BESS, energy prices). In this context, KU Leuven developed a new smart charging control method that can be used to further improve the energy management by considering the efficiency and temperature dynamics. The description and the key innovative parts of the proposed control method are discussed. Some recommendations for further efficient charging based on the KU Leuven's previous research in EV charging and project experience [1-7] are provided in the report.

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