Optimal Management of Electric Vehicles in a Building Environment: Real Cloud Development

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Abstract

The increased adoption of electric Vehicles (EVs) is creating new challenges for building management. The massified use of EVs will significantly increase power consumption in buildings, potentially making it unable to answer to all encompassed loads due to insufficient available power. In the proposed paper, a pilot in the scope of the EV4EU project is described considering the management of EVs that are connected to a real building in the Azores, Portugal. Herein, a management platform is responsible for the control of two Electric Vehicles Supply Equipment (EVSEs) with Vehicle-to-Everything (V2X) capability. The building also has a solar Photovoltaic (PV) system which is mainly used for self-consumption. The main results indicate that the proposed EVSE management platform successfully controls the EV charging/discharging, maximizing the state of charge of the battery through intelligent decisions based on optimization processes.

1 Introduction

Electric vehicle (EV) consumption is shortly expected to be an integral part of many buildings, especially in service buildings [1]. The consolidation of the EVs as integral part of the power system requires attention, since it can consequently introduce a high demand, and jeopardize the grid network [2]. To address this issue, multiple approaches have been proposed in the literature in the field of smart charging strategies [3], [4], considering different assumptions and levels of information to control EVs in building environments. Considering EVs and Photovoltaic (PV) integration, different works have been focused on building energy management [5], [6]. A linear optimisation approach to encourage the green energy usage for workplace EV users was proposed in [5]. The proposed methodology presents interesting results optimizing the charging process of EVs by considering the power limits of the buildings. Nevertheless, real-world data related to EV consumption and building demand were not considered.

For instance, various studies have proposed cloud-based EV charging management system [7], [8]. focusing on making optimal decisions for mobility service providers, distribution network operators and utilities focused on purpose optimal making decisions for mobility service providers, distribution network operators and utilities [7], or devoted to creating cloud-based simulations to analyse vehicle-grid integration (VGI), including the impact of EV charging on the grid [8]. Nevertheless, these proposed approaches are not appropriate for real buildings since their higher degree of user behaviour uncertainty is not considered.

In this paper, within the scope of the European Project - Electric Vehicle Management for Carbon Neutrality in Europe - EV4EU[1], a pilot considering the management of two EVs connected, in a real building in the Azores, Portugal, to a controllable Electric Vehicles Supply Equipment (EVSEs) will be described. Herein, a management platform is responsible for controlling these two EVSEs with Vehicle-to-Everything (V2X) capability. Additionally, the building is equipped with a solar PV system used for self-consumption. However, the building is also contractually authorized to sell energy to the grid, which occurs mainly during weekend days and the summer holidays.

2 Real EVSE management platform

The real EVSE management platform comprises two main systems, as shown Figure 1, which details a high-level communication and control architecture of the proposed EVSE management platform. It contains information about the protocols used for monitoring the building consumption and production, controlling and monitoring EVSE, communicating with APIs, distribution system operator (DSO), transmission system operator (TSO), and interacting with graphical user interface (GUI). In depth information

[1] https://ev4eu.eu/

about the two main systems, namely cloud-based and edge systems, are described in the following subsections.

2.1 Cloud-based system

The cloud-based system is used to host: the forecast and optimizer modules inside the EV4EU cloud, the application programming interface (APIs) for weather data and market price, a GUI for EV4EU usage, and the communication back-office of distributed system operator (DSO) and transmission system operator (TSO).

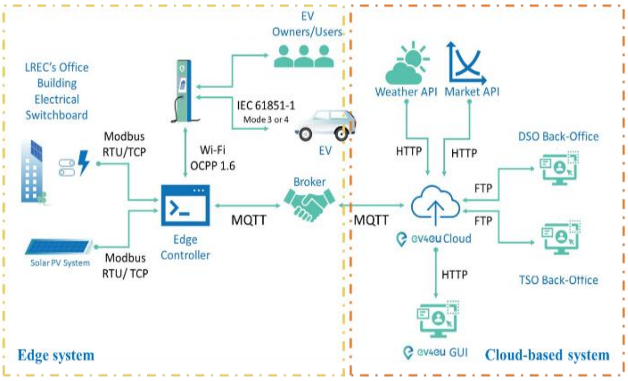

Figure 1: EVSE management platform

2.1.1 Forecast module

The forecast module predicts three variables: the EVSEs' power demand, the PV power production and the building's consumption. The number and selection of features for each target variable are determined from the lag features (target values from previous periods), the weather forecast is provided by the API [9] and from the date/time features. The forecast method used correspond to eXtreme Gradient Boosting (XGBoost), an ensemble machine learning algorithm that utilizes a high-performance implementation of gradient boosted decision trees. On the other hand, the EVSEs' power demand is forecasted based on their historical use.

2.1.2 Optimizer Module

The Optimizer Module is composed of EV management algorithms based on mathematical modelling and rule-based approach [10] to schedule the operation of the EVSEs, considering building's power demand and generation forecast. The main objective of this algorithms is to reduce the energy bills for the users, increase the self-consumption from green energy, and offer wind curtailment and congestion management services [11], [12]. Therefore, the algorithm into the optimizer module considers the electricity price (which is different depending on whether the system is consuming or supplying energy to the grid) received through the market price API [13], and specific grid services, such as wind curtailment mitigation and voltage control in low voltage grids. These services will be activated by the Azorean system operator, which is responsible for managing both the transmission and distribution local grids. The wind curtailment mitigation grid service intends to coordinate EV charging with excessive wind generation [12], to increase the global hosting capacity of the grid. In the case of the voltage control grid service, the aim is to mitigate voltage deviations in low voltage grids, therefore improving the local hosting capacity of the distribution system and, on a larger scale, the grid's global hosting capacity.

2.2. Edge system

The Edge system and is responsible for the real-time control of the EVSEs based on control logic algorithms hosted by it, considering their proposed scheduling and the building's operating conditions. The edge controller is installed and connected to the monitoring systems of the building such as smart meters that provide it with information about the real-time consumption, real-time production (related to the PV generation). Moreover, it is also connected with the EVSE via Open Charge Point Protocol (OCPP) to receive information about the successfully connection with the EV. Continuous communication between the cloud-based system and the edge system is essential to receive scheduling decisions about the charging control of the EVSE (from the cloud-based system). These decisions, based on the optimal result from the optimizer module, are executed in real time for the edge system. On the other hand, the edge system will send information related to historical data about, consumption and production, to the cloud-based system use as input for the forecasting module. For the real experimental test, a commercial Edge was used, which had the necessary protocol for the communication with the different parts of the system previously installed [14].

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Concerning the control algorithms, three distinct control logics for managing the charging and discharging of EV where developed, considering three key factors. *i) Real-time measurements* - transmitted by the Reduxi Edge through the MQTT protocol, captured, and formatted by an middleware agent, before being stored in a database in real-time. *ii)*

Charging scheduling based on planned events - Generated by an optimizer using calculations performed by a solver to determine the optimal solution. *iii) Static information* - from both the devices and the installation infrastructure was also taken into consideration. The first logic considers that state of charge (SoC) of the EVs is known. Calculations are performed to determine a power setpoint to charge/discharge the EV. The second and third logics were developed under the assumption of unknown battery SoC. The second logic handles charging only, while the third logic manages both charging and discharging operations. Both logics yield a setpoint in current for EV charging considering the minimum control order established by the EVSE.

2.3. Communication protocols within the systems

Different communication protocols are used inside the EVSE management platform: Modbus RTU/TCP for communication with both consumption and production smart meters; Wi-fi OCPP 1.6 for communication with the EVSE; Message Queuing Telemetry Transport (MQTT) for communication between the two mainly systems (Edde and Cloud-based system); Hypertext Transfer Protocol (HTTP) for communication with the APIs, and GUI, FTP (File Transfer Protocol) for the transfer data with both DSO and TSO. Moreover, a MQTT broker became necessary to uphold data exchange between the Edge system and cloud-based system. The MQTT broker executed two mainly tasks, namely: *(i)* to transmit device data from the edge system to the cloud-based system; *(ii)* to transmit the control algorithm setpoints stored within cloud-based to the edge. Data exchange will be enabled via MQTT commands and JavaScript object notation structures. The cloud-based storage platform will be responsible for continuously processing device data from the edge controller, grid service data from DSO and TSO back-offices, and as well as weather and market pricing data from the different APIs. These data were used in the forecast and optimizer modules. The cloud-based system exchanges data with the DSO's back-office and the TSO's back-office systems via FTP, and with the external APIs via HTTP. In the Azores, the TSO and DSO are the same entity, due to this location's insular nature. At last, data exchanges involving the cloud-based system is monitored by the EV4EU manager via a GUI.

2.4. Databases

Different data exchanges are executed within the EVSE management platform as described above. For successful information exchange, seven types of relational database (DB) management systems are utilized to store different types of data. These include: *(i) measurements DB*: stores real-time measurements from smart meters. *(ii) Scheduling DB*: stores planning data generated by the optimizer. *(iii) Setpoint DB*: records setpoint values sent to the edge system, along with the metric (currently either current or power) and the corresponding transmission time. *(iv) Price DB*: stores energy prices over time. *(v) Weather DB*: stores weather information retrieved from the Open weather API. *(vi) Forecast DB*: stores weather forecast predictions calculated by our algorithms. *(vii) Static DB* includes data from both devices and installation infrastructure. These databases utilize structured query language (SQL) language [15], such as MySQL and MariaDB, for robust management and querying capabilities, and SQLite for lightweight and embedded applications.

3 Experimental Tests and Results

3.1. Simulations focused on the optimizer module behaviour

To validate the EVSE management platform, several simulations were conducted, focused on the optimizer module behaviour. For this purpose, various scenarios were analysed, including with smart charging control and V2X capability. The mainly results are illustrated in Figure 2.

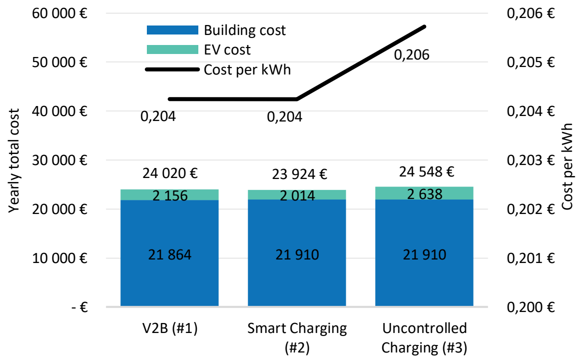

Figure 2: EVSE management platform [11]

By observing Figure 2 is possible to validate the optimisation solution, in which, when the smart control is not implemented (#3), the highest yearly total cost is incurred. Therefore, these simulations verify the usability of the optimizer module in a real-world scenario.

3.2. Real-world experiments at laboratory level

In real-world experiment test conducted at a laboratorial level, we utilized two shelly smart meters, which offer operational versatility through LAN/Wi-Fi, Ethernet, and Bluetooth networks. Additionally, these meters support integration with cloud home automation services via MQTT, HTTP, and WebSocket protocols, ensuring secure inbound connections with Transport Layer Security (TLS) support, a wallbox charger to guarantee communication with the EV, and an EV. More details about these meters as well as al devices considered in the tests are described as follows.

- *Shelly Pro 3EM:* it is used to measure the combined three-phase resistive load, simulating household consumption along with the presence of an EV. Moreover, we emulate the integration of solar photovoltaic generation by employing power supplies connected with a Sunny Boy grid inverter.
- *Shelly EM50:* it plays a crucial role in monitoring the charging process of EVs, particularly when it relates to

the Wallbox Copper SB Three-Phase AC charging station system.

- EVSE: In our tests we are utilizing a Wallbox and V2C EV chargers. Both chargers offer a cloud interface enabling connectivity to Reduxi Edge via OCPP 1.6. This interface provides real-time information, including charging power rate and the charging power limit. Moreover, it is important to highlight that the minimum charge order received for it must be 6 A. State indications including disconnected, locked, standby, and charging is also accessible on the cloud platform.
- EVs: We successfully tested the three control logics with two different car models: the Fiat 500 and the Polestar 2.

As an example, Figure 3 illustrates the GUI developed for the EVSE management platform, in which is possible to observe the energy importing by the system during the day, facilitating even visualization about the percentage of energy imported by the load and by the EV.

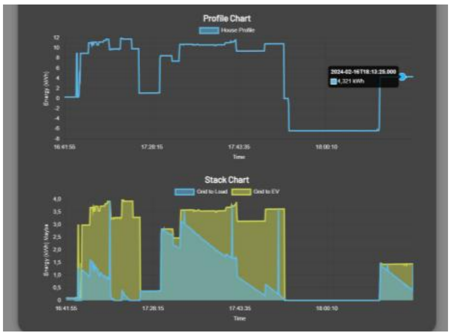

Figure 3: EV4EU platform GUI

4 Conclusion

An Electric Vehicles Supply Equipment (EVSEs) management platform is proposed as part of a pilot, within the scope of the EV4EU project, focusing on the management of electric vehicles (EVs) connected to a real building in the Azores, Portugal. This platform, comprising a cloud-based and Edge systems, is able to communicate with consumption and production smart meters; and to communicate and control an EVSE to execute manage orders, based on optimisation process, to charge an electric vehicle (EV). The results obtained in a test at laboratory environment confirm that real platform can charge the EV tested in a secure level guarantee optimal solution for the users such as minimisation of energy bills.

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