Poster: Smart Charging of Electric Vehicles with Cloud-based Optimization and a Lightweight User Interface

A Real-World Application in the Energy Lab 2.0

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ABSTRACT

Smart Charging (SC) of Electric Vehicles (EVs) integrates them into the power system to support grid stability by power management. Large-scale adoption of SC requires a high level of EV user acceptance. Therefore, it is imperative to make the underlying charging scheme tangible for the user. We propose a web app for the user to start, adjust and monitor the charging process via a User Interface (UI). We outline the integration of this web app into an Internet of Things (IoT) architecture to establish communication with the charging station. Two scenarios demonstrate the operation of the system. Future field studies on SC should involve the EV user due to individual preferences and responses to incentive schemes. Therefore, we propose the *Smart Charging Wizard* with a customizable UI and optimization module for future research and collaborative development.

CCS CONCEPTS

• **Information systems** → **Web applications**.

KEYWORDS

Electric Vehicles, Smart Charging, Web Applications, Battery Aging

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1 INTRODUCTION

The increasing adoption of Electric Vehicles (EVs) poses tremendous challenges to the electrical power distribution system — especially if many EVs are charged at peak load times. Smart Charging (SC) addresses this problem by shifting the power demand to times of sufficient local power grid capacities or supporting the power grid in peak load times by power refeeding, known as Vehicle-to-Grid (V2G) [1]. Large-scale deployment of SC will require a high level of user adoption. Key to SC adoption is the user's wish to reduce the personal carbon footprint. In contrast, the desire for individual mobility inhibits SC adoption [5]. Further, EV battery aging is critical, as not accounting for degradation implications of SC underestimates EV operating cost up to 30 % [3]. Therefore, transparent communication about the impact of SC is essential.
In the broad scope of research on SC, many approaches have been discussed theoretically. However, there is a lack of customizable solutions and real-world applications. The app *Jedlix* [4] shifts charging to low electricity price zones. Though, the app is only available for *Tesla*, *Jaguar I-Pace*, or *BMW i3*. Further, a modification of the charging optimization scheme by researchers or the user is not foreseen.

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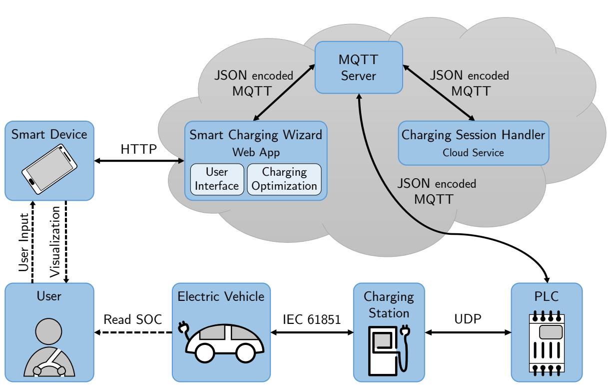
2 ARCHITECTURE

Integrating EV user interaction into SC requires adequate communication technology. Figure 1 shows an overview of the proposed IoT architecture for the *Smart Charging Wizard* web app with cloud-based optimization.

The **User Interface** (UI) assists to customize the charging process and visualizes the optimized power profile and predicted State



HTTP: HyperText Transfer Protocol, IEC: International Electrotechnical Commission, JSON: JavaScript Object Notation, MQTT: Message Queuing Telemetry Transport, PLC: Programmable Logic Controller, UDP: User Datagram Protocol

Figure 1: An overview of the proposed IoT architecture and the communication protocols used.

of Charge (SOC) progression. Integrated live monitoring provides a transparent view of the charging process.[1]

For **charging optimization**, the grid operator can use dynamic electricity pricing to create a decentralized incentive system for EV charging. The profitability of bidirectional power flow V2G services depend on the electricity price spread and battery aging costs; the latter hinders power feedback from being profitable in present electricity tariffs [3]. In the initial deployment of the *Smart Charging Wizard*, we hence apply unidirectional charging. The optimization targets to minimize the operating cost by controlling the charging power to achieve the best trade-off between electricity and battery aging costs.[2]

The **Charging Session Handler** (CSH) runs independently of the *Smart Charging Wizard* and the Programmable Logic Controller (PLC) to enable starting, updating, and stopping a charging session from different devices. After receiving the optimized profile from the *Smart Charging Wizard*, the CSH creates the charging session and persists the corresponding data. The CSH periodically publishes the latest optimal power setpoint to the PLC until the session reaches the scheduled end or a stop is initiated by the user.

PLC controlled charging stations enable the implementation of a generic communication interface. The PLC receives charging power setpoint messages from the CSH and verifies the compliance with the charging station's current limits. If the message is valid, the PLC schedules the next charging power update at the station; otherwise, the PLC raises an error message via MQTT. Live measurements and the station's state are displayed on the User Interface (UI). The PLC's MQTT client subscribes to a topic in which power setpoint requests are pooled and publishes responses to a separate topic, where other stakeholders may subscribe. Thereby, the PLC bundles the communication from multiple stakeholders to the attached charging stations via one IP address.

3 APPLICATION

We integrate the charging application into the Energy Lab 2.0 [2] and demonstrate the realization of SC in two scenarios (Table 1) based on characteristic electricity price curves.

Scenario I reflects a typical charging event on a working day. Thereby, the electricity price forms a valley between the price peaks at 8:00 and 18:00. Optimized charging occurs in the range of the low electricity price zone between 12:00 and 17:00. The consideration of battery aging results in a shift of charging to a later time, instead of symmetrically filling the price valley. The cost savings compared to default charging are given in Table 1.

Scenario II-a exemplifies charging overnight from 12:00 to a planned departure on 09:00 with a price peak between 16:30 and 20:00 due to underproduction of electricity. While default charging would ignore the shortage, SC shifts the optimized profile to the low electricity prices in the night.

In **Scenario II-b**, the EV user decides at 14:15 to use the EV earlier, already at 18:00 on the same day. The price peak displayed in the UI prompts the user to reduce the departure SOC, as 55 % is sufficient. The optimization scheme accounts for a preference of the user's desire for individual mobility. Yet, the communication of the price curve may influence the user's behavior.

[1] https://energylabsmartcharging.github.io/Smart-Charging-Wizard.
[2] For details on the formulation of the optimization problem and the constraints, as well as the battery model and its validation refer to [3].

Table 1: Optimization scenario conditions and results. Absolute cost values correspond to the optimized profile; relative cost values refer to the difference to default charging.

	Scenario I	Scenario II-a	Scenario II-b
Price curve	workday	underprod.	underprod.
t arr. – dep.	09:00 – 17:00	12:00 – 09:00	12:00 – 18:00
SOC arr. – dep.	45 % – 95 %	20 % – 95 %	20 % – 55 %
p min. – max.	0 kW – 11 kW	0 kW – 11 kW	0 kW – 11 kW
Operating cost	-5 % / 16.49 €	-11 % / 26.53 €	-13 % / 12.38 €
Battery aging costs	-12 % / 2.78 €	-22 % / 4.93 €	-52 % / 1.65 €
Electricity costs	-3 % / 13.72 €	-8 % / 21.59 €	-1 % / 10.73 €

arr.: arrival, dep.: departure, min.: minimum, max.: maximum, underprod.: underproduction

4 CONCLUSION & OUTLOOK

We propose the *Smart Charging Wizard* web app, outline its integration into an IoT architecture, and exemplify the realization in the Energy Lab 2.0 [2], a real-world environment. The proposed web app is lightweight, customizable, and provides a cloud-based optimization that considers charging-related battery aging and dynamic electricity prices as a stimulation measure from the power grid operator. The exemplary scenarios in our real-world application visualize the underlying optimization scheme and highlight the realization of the EV user's preference for individual mobility. In future work, the IoT system will be extended by solar power generation and stationary battery storage. Furthermore, the optimization scheme will consider stochastic influences.

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