DIVERGENT

Decision-making and data-processing methods for Vehicle-to-Home power flow management

Programm / Ausschreibung	Leuchttürme eMobilität, Zero Emission Mobility, Zero Emission Mobility 2022/01	**Status**	laufend
Projektstart	01.10.2023	**Projektende**	30.09.2025
Zeitraum	2023 - 2025	**Projektlaufzeit**	24 Monate
Keywords	vehicle-to-home; smart bidirectional charging; multi-criteria decision making; ac-charging; battery lifetime estimation		

Projektbeschreibung

Geparkte Elektrofahrzeuge stellen eine vielversprechende Möglichkeit zur Speicherung von variabler erneuerbarer Energie dar. Smart Bidirectional Charging (SBC) - also der Austausch von Informationen über Datenverbindungen zwischen Fahrzeug, Ladestation und Ladestationsbetreiber - eröffnet die Möglichkeit, das gesamte Energiesystem so zu beeinflussen, dass Leistungsspitzen vermieden und "überschüssige" erneuerbare Energie genutzt werden kann.

Im Rahmen von DIVERGENT werden dezentrale Entscheidungsfindungsmethoden (DM- Methoden) und -algorithmen zur Unterstützung des intelligenten bidirektionalen Ladens von Elektrofahrzeugen untersucht und die vorgeschlagenen Methoden in Form eines Labor Demonstrators, der u.a. einen OBC (OnBoard Charger) und eine automatisierte AC-Ladetechnologie umfasst, implementiert und bewertet.

Für die Entwicklung von DM-Methoden werden sowohl klassische Entscheidungsalgorithmen als auch Algorithmen auf der Grundlage von (Multi-Agenten) Reinforcement Learning (MARL) und/oder anderen maschinellen Lernmethoden in Betracht gezogen. DIVERGENT ermöglicht eine Knowhow Erweiterung in den Bereichen der Fahrzeugnutzungssimulation, der Modellierung des EV-Nutzerverhaltens sowie im Bereich des Energiemanagements.

Auf der Grundlage der Ergebnisse wird ein AC SBC Labor Demonstrator entwickelt, aufgebaut und evaluiert, der den bidirektionalen Energie- und Datenfluss zwischen der EV-Batterie, dem OBC, der automatisierten AC-Ladetechnologie und dem lokalen (Haushalts-) netz simuliert.

Im Zuge von DIVERGENT werden folgende Ergebnisse erreicht:
1. DM-Methoden, die eine bidirektionale Aushandlung des EV-Ladeprofils unterstützen und in weiterer Folge
- eine Optimierung der Energieverbrauchsmuster von Haushalten/Gebäuden, die mit bidirektionalen Ladegeräten ausgestattet sind und
- eine Glättung der Lastspitzen im Netz, die durch das gleichzeitige Laden und Entladen von Elektrofahrzeugen verursacht werden,

ermöglichen.
2. Methoden zur Abschätzung des Batteriezustands und zur Prognose der verbleibenden Batterie Nutzungsdauer, die die Bewertung und Vorhersage der Auswirkungen des bidirektionalen Ladens auf den Batteriezustand möglich machen.
3. Einen Labor Demonstrator der Softwareprototypen für den Electric Vehicle Communication Controller (EVCC) und den Supply Equipment Communication Controller (SECC) umfasst. Der EVCC und SECC werden über eine drahtlose Schnittstelle zwischen dem Elektrofahrzeug und der Ladeinfrastruktur kommunizieren und den gesamten Strom- und Datenfluss innerhalb des SBC-Prozesses simulieren.

Abstract

Currently, the use of parked electric vehicles represents a promising option for the storage of variable renewable energy. Smart bidirectional charging (SBC) (i.e., the exchange of information via data connections between the vehicle, charging station, and operator) opens a way of influencing the entire energy system in such a way that power peaks can be avoided and "excess" renewable energy can be used.

In DIVERGENT, we will investigate the decentralized decision-making (DM) methods and algorithms to support smart bidirectional charging of EVs; implement and evaluate the proposed methods in the form of an integrated demonstrator of the onboard charger and automated AC power supply equipment.

We will consider both classical decision-making algorithms and algorithms based on reinforcement learning and/or machine learning for the development of DM methods. We will expand the knowledge in vehicle usage simulation, including modeling the user behavior of EV owners, as well as in the field of energy management. Based on our results, we will design, implement, and evaluate an AC SBC laboratory demonstrator, simulating bidirectional energy and data flow from EV battery and on-board-charger through automated AC power-supply equipment to a local/household grid.

Successful implementation of DIVERGENT would yield the following results:

1. DM methods supporting a bidirectional EV power profile negotiation will support:

- optimization of energy consumption patterns for households/buildings equipped with bidirectional charging equipment;

- smoothing out the peak loads on the grid, influenced by simultaneous EV charging/discharging patterns.

2. Battery State of Health estimation and Remaining Useful Life prognosis methods will enable assessment and prediction of the impact of bidirectional charging on the battery condition.

3. Laboratory demonstrator will incorporate software prototypes for Electric Vehicle Communication Controller (EVCC) and Supply Equipment Communication Controller (SECC), providing wireless communication between the EV and power supply equipment, and simulate the entire power and data flow within the SBC process.

Endberichtkurzfassung

Within the DIVERGENT project we sucsessfully developed and validated decentralized decision-making methods and algorithms to support smart bidirectional charging (SBC) of electric vehicles, enabling "batteries on wheels" to serve as flexible energy storage assets. All primary objectives were achieved, including

Development of decision-making methods supporting bidirectional EV power profile negotiation,
Investigation of bidirectional charging's influence on battery state of health (SoH) and lifetime,
Implementation of a smart bidirectional automated AC charging system demonstrator.

A key technical achievement was the development of a Deep Reinforcement Learning (DRL) framework for optimizing bidirectional charging decisions. The Soft Actor-Critic (SAC) algorithm demonstrated superior performance compared to both alternative DRL methods and rule-based approaches, achieving significantly better energy cost optimization while maintaining vehicle readiness for planned trips. The project also delivered an ISO 15118-20 compliant bidirectional charging software system supporting Vehicle-to-Home (V2H) functionality in both scheduled and dynamic charging modes. Simulative investigations confirmed that V2H combined with excess photovoltaic charging can be profitable, though benefits strongly depend on user profiles and the consideration of charging/discharging efficiency losses.

The project produced substantial open-source contributions to advance the field. The complete DIVERGENT Core implementation, including Supply Equipment Communication Controller (SECC), Electric Vehicle Communication Controller (EVCC), and decision-making modules, is publicly available at https://opensource.silicon-austria.com/divergent/core . The DRL-based home energy management system for bidirectional EV charging control is available at https://opensource.silicon-austria.com/schererj/drl-hems . These releases enable researchers and industry practitioners to build upon the project's findings.

The DIVERGENT consortium, comprising Silicon Austria Labs, Easelink GmbH, Virtual Vehicle Research GmbH, CISC Semiconductor GmbH, and Energie Steiermark, successfully disseminated results through multiple peer-reviewed publications and international conferences, including IEEE ICDCM 2025 and ICECET 2025. User acceptance research conducted through workshops revealed that smart charging and V2X technologies are generally well-received when monetary benefits, intelligent functions, and ease of use are provided, with control and transparency emerging as decisive factors for adoption.

Projektkoordinator

- Silicon Austria Labs GmbH

Projektpartner

- Energie Steiermark AG
- Easelink GmbH
- Virtual Vehicle Research GmbH
- CISC Semiconductor GmbH