Design and Preliminary Testing of a V2G Smart Charging Lab for Electrical Vehicles in Bidirectional Charging Applications

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Abstract

The energy transition demands advanced solutions to manage the inherent variability of renewable sources such as solar and wind power. A key strategy to address this challenge is the integration of Electric Vehicles (EVs) as distributed storage units through bidirectional charging (V2X). This technology allows vehicles not only to draw energy from the grid but also to feed it back, enabling critical services such as demand balancing, optimization of self-consumption, and peak load reduction. This thesis focuses on the Design and Preliminary Testing of a V2G (Vehicle-to-Grid) Smart Charging Laboratory for Electric Vehicles dedicated to bidirectional charging applications.

1. Introduction and Motivation

This thesis addresses the design and preliminary testing of a V2G Smart Charging Lab, a full-scale testing facility developed within the flagship project ELECTRO (PNRR/NODES) at Politecnico di Torino. The lab is a key infrastructure created to accelerate technology transfer in electric mobility, specifically focusing on:

- V2G, V2V, and V2X integration and scenarios.
- Implementation of the ISO 15118-20 communication protocol.
- Interoperability between charging systems, including the capability to emulate electrical grid disruptions for AC charging.

Strategically located within the Piedmont automotive industrial hub, the lab enables experimental validation of bidirectional charging architectures and supports the development of sustainable mobility services.

2. System Architecture and Methodology

The system architecture is designed to replicate a complete bidirectional charging environment (Vehicle-to-Grid, V2G), focusing heavily on the communication and control layers before the final power stage.

2.1. Communication Emulation and Control Hardware

The preliminary testing setup employs a **Vector VT System** as the core testing platform. The system uses a dedicated VT7970 "Smart Charging Module" to emulate the communication and modem aspects of the Electric Vehicle (EV). This module is crucial for simulating the communication unit (SECC) on the vehicle side. On the charging infrastructure side (EVSE), the communication emulator is implemented as a Supply Equipment Communication Controller (vSECC). This vSECC is configured to use the latest ISO 15118-20 DC Bidirectional Power Transfer (BPT) standard, enabling the control of both charging and discharging power flows.

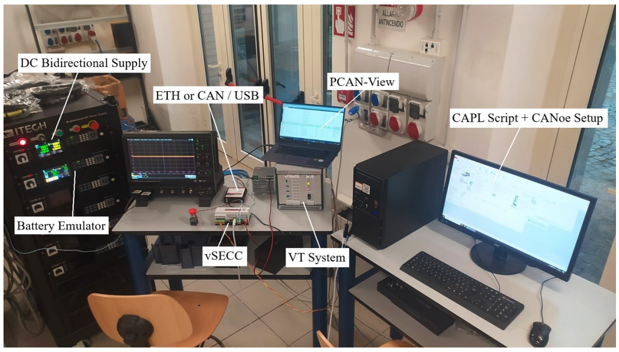

Figure 1: *Setup for preliminary testing: vehicle emulation is made using a VTSystem and ITECH battery emulator*

Low-level and high-level communication signals between the vSECC and the VT System are transmitted via the standard Control Pilot (CP) and Protective Earth (PE) cables, emulating the physical interface of the charging cable.

2.2. Power Hardware and Interfacing

The power stage of the EVSE is realized using an ITECH IT6642C-1200-200 DC power supply. This unit provides the necessary power output and is integrated into the control system via a **CAN network**.The essential link between the vSECC (communication) and the ITECH power supply (hardware) is achieved by a software-based **Power Electronics Communication Controller**. This PECC was developed using the proprietary **CAPL programming language** from Vector Informatik, translating the high-level charging instructions received by the vSECC into control commands readable by the ITECH unit over CAN.

2.3. Vehicle Emulation (Battery Model)

To accurately emulate the behavior of the electric vehicle's battery, a second ITECH IT6642C-1200-200 unit is utilized in battery emulator mode. This mode allows the precise definition of the battery's characteristics. The model is configured by setting the nominal capacity and incorporating a detailed lookup table that defines the

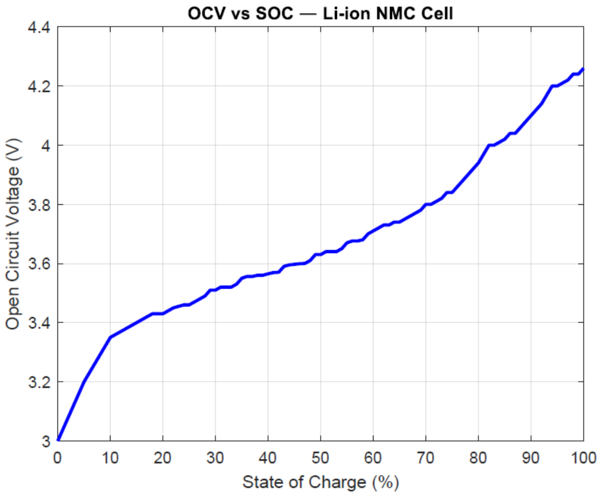

Figure 2: *Voltage characteristic of a NMC cell used for converter battery emulation*

relationships between open circuit voltage, internal resistence and state of charge. This detailed battery model is loaded into the emulator using a specific .csv file. . This setup ensures that the dynamic response of the charging process accurately reflects real-world battery physics.

3. Preliminary Experimental Results

The charging session test was carried out at low power, since the main objective was to verify the functionality of the complete system. The measurements taken are shown in Figure 3.

The first voltage variation corresponds to the *CableCheck* phase, during which the voltage is raised to the maximum value of 500 V. At time t_2, the behavior of the *Precharge* phase is emulated, where the power supply system voltage is increased to a value close to the battery voltage before closing the contactor.

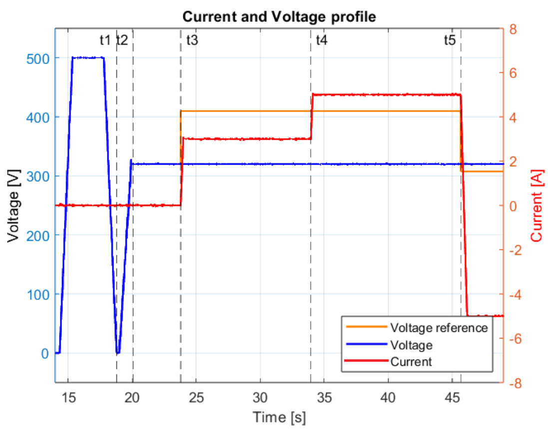

Figure 3: Voltage and current profile during charging session test.

Subsequently, starting from t_3, power transfer begins with a current of 3 A. A particular event occurs at time t_5, where the charging process reverses polarity and the battery supplies −5 A (i.e., 5 A in discharge) back to the grid.

4. Work in progress

Another test under development at the SCL concerns AC charging. In response to an industrial partner request, we are implementing a system (Vsecc + ITECH IT7915P + Matlab code) capable of emulating grid disturbances during charging, allowing EV manufacturers to validate conversion-state control and BMS operation under boundary conditions.

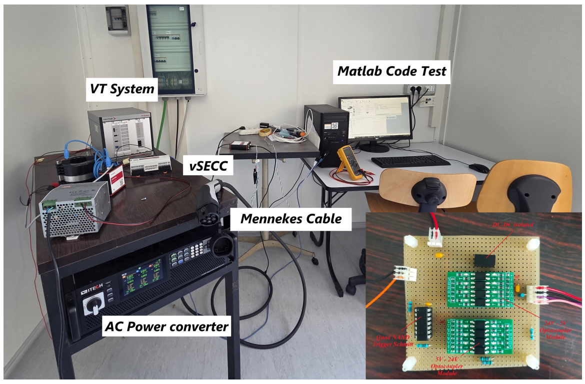

Figure 4: AC charging setup installed inside the Smart charging lab container

5. Conclusion and future works

The results demonstrate the successful integration of the Vector vSECC with a commercial ITECH converter, enabling full power-profile control and signalling without the need for custom hardware. The use of CANoe Pro and a CAPL-based PECC proved essential to system development and vehicle testing, providing high flexibility and visibility of protocol behaviour.

Future work will include implementing a CSMS module using OCPP 2.0.1 to enable full grid-level integration, as well as advancing grid-disturbance emulation for real-world validation in collaboration with an industrial partner.

6. References

1. ISO (2022). *ISO 15118-20: Road vehicles — Vehicle to grid communication interface — Part 20: 2nd generation network and application protocol requirements.* International Organization for Standardization.

2. IEC (2023). *IEC 61851-23: Electric vehicle conductive charging system — Part 23: DC electric vehicle charging station.* International Electrotechnical Commission.