WHITE PAPER

MONITORING EV CHARGING CYCLES

THE WORLD OF DC AND AC CHARGING OF ELECTRIC VEHICLES AND DEWETRON‘S ALL-IN-ONE MONITORING SOLUTION

DEWETRON

ABSTRACT

The global transition to sustainable energy is accelerating, with electric vehicles (EVs) at the forefront. As EV adoption surges, robust and efficient charging infrastructure becomes crucial. This white paper reviews the current state of EV charging, its challenges, and future innovations.

EVs help reduce greenhouse gas emissions, cut fossil fuel reliance, and improve air quality. However, their widespread adoption depends on accessible charging infrastructure, requiring both public and private solutions.

Effective EV charging infrastructure is essential for a sustainable future. In this white paper the complexities of EV charging will be examined, focusing on the differences between AC and DC systems, their advantages, challenges, and roles in the EV ecosystem.

DEWETRON, a leader in high-precision test and measurement systems, provides solutions for various industries. This white paper includes a test with DEWETRON hardware, verifying that the measured current matches the control pilot's duty cycle.

INTRODUCTION

The global transition towards sustainable energy is accelerating, with electric vehicles (EVs) at the forefront of this movement. As the adoption of EVs continues to surge, the need for robust and efficient EV charging infrastructure becomes increasingly critical. This whitepaper aims to provide a comprehensive overview of the current state of EV charging, the challenges faced, and the innovations driving the future of this essential component of the electric mobility ecosystem.

Electric vehicles offer a promising solution to reduce greenhouse gas emissions, decrease reliance on fossil fuels, and promote cleaner air quality. However, the widespread adoption of EVs hinges significantly on the availability and accessibility of charging infrastructure. Unlike traditional internal combustion engine vehicles, which rely on an extensive network of fueling stations, EVs require a different approach to refueling that involves both public and private charging solutions.

The electrification of transportation is a pivotal step toward achieving a sustainable and environmentally friendly future. As electric vehicles (EVs) gain popularity, the development of effective and efficient EV charging infrastructure becomes paramount.

This whitepaper aims to elucidate the complexities of EV charging, with a particular focus on the differences between alternating current (AC) and direct current (DC) charging systems, their respective advantages, challenges, and roles in the EV ecosystem.

CHARGING PILE TYPES

Electric vehicle (EV) charging piles, also known as charging stations or chargers, can vary significantly based on several key factors. These differences can affect the charging speed, user experience, installation requirements, and overall cost. Here's an overview of the general differences in EV charging piles:

Charging Levels

Level 1 Charging

- Voltage: 120V AC (typically used in North America).
- Power Output: Around 1.4 kW.
- Charging Speed: Slow (adds about 3-5 miles of range per hour).
- Use Case: Home charging using a standard household outlet.
- Installation: No special installation required, just plug into an existing outlet.

Level 2 Charging

- Voltage: 240V AC (used in North America) or 230V AC (used in Europe and other regions).
- Power Output: 3.7 kW to 22 kW.
- Charging Speed: Moderate to fast (adds about 10-60 miles of range per hour).
- Use Case: Home, workplace, and public charging stations.
- Installation: Requires dedicated charging equipment and potentially an upgrade to the electrical system.

Level 3 Charging (DC Fast Charging)

- Voltage: 400V to 800V DC.
- Power Output: 50 kW to 350 kW or more.
- Charging Speed: Very fast (adds about 100-200 miles of range in 30 minutes).
- Use Case: Public charging stations, particularly along highways and in urban areas.
- Installation: Requires specialized, high-power equipment and significant electrical infrastructure.

Installation Environment

Residential Charging Piles

- Typically Level 1 or Level 2 chargers.
- Focus on convenience and integration with home electrical systems.
- Often include smart features like scheduling and energy monitoring.

Commercial and Workplace Charging Piles

- Primarily Level 2 chargers.
- Designed for multiple users with access control and billing features.
- Often networked for remote monitoring and maintenance.

Public Charging Piles

- Can include Level 2 and Level 3 chargers.
- High visibility and ease of access are critical.
- Equipped with multiple connectors to support different EV models.
- Integrated payment systems for user convenience.

Features and Capabilities

Connectivity and Smart Features

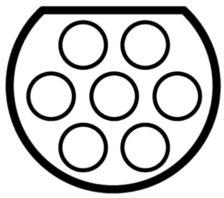
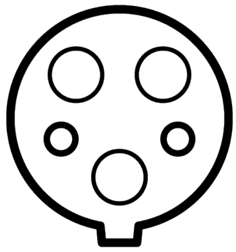
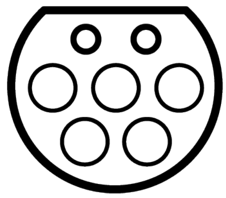
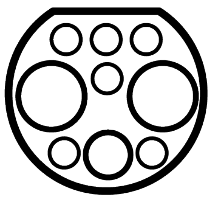
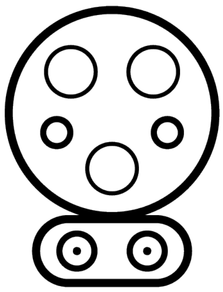
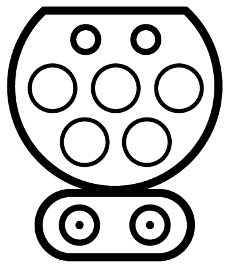
- Wi-Fi, Bluetooth, or cellular connectivity for remote management.

- Integration with mobile apps for locating, reserving, and paying for charging.
- Smart charging features like load balancing and demand response participation.

Durability and Safety

- Weatherproof and vandal-resistant designs for outdoor installations.
- Compliance with safety standards (e.g., UL, CE) and certifications.
- Features like ground fault protection, overcurrent protection, and surge protection.

Connector types

Current type and plug	**Region**		
	China	**US**	**Europe**
AC			
	GB/T	Type 1 – J1772	Type 2
DC			
	GB/T	CSS – Type 1	CSS – Type 2

Tab. 1: Connector types

GB/T plugs

GB/T plugs are the standard for electric vehicle charging in China, set by the Chinese government. There are two main types of GB/T connectors:

- GB/T AC (GB/T 20234.2): This is used for AC charging. The connector is similar to the Type 2 plug but has a different pin configuration. It is designed for single-phase and three-phase charging.
- GB/T DC (GB/T 20234.3): This is used for DC fast charging. The connector resembles the CHAdeMO plug but is unique to China. It supports high-power charging, making it suitable for rapid charging stations.

Type 1 (J1772) plugs

Type 1 plugs, also known as SAE J1772, are predominantly used in North America and Japan for AC charging.

The Type 1 connector supports single-phase AC charging and is common in residential and public charging stations. It has five pins: two for AC power, one for ground, and two for communication between the vehicle and the charging station.

Type 2 plugs

Type 2 plugs, also known as Mennekes connectors, are the standard in Europe for AC charging and are gaining popularity in other regions.

Features: The Type 2 connector can support both single-phase and three-phase AC charging. It has seven pins: three for AC power, one for ground, and three for communication. This makes it versatile and suitable for both home and public charging stations. Additionally, it is capable of handling higher power levels compared to Type 1.

Combined Charging System (CCS) plugs

The Combined Charging System (CCS) is a standard that combines AC and DC charging capabilities in a single connector. There are two types of CCS plugs:

- CCS Type 1 (Combo 1)

  Description: CCS Type 1 is based on the Type 1 (J1772) connector and is used in North America and some parts of Asia.

  Features: The top part of the connector is identical to the Type 1 plug, enabling AC charging. Below it, two additional pins are used for DC fast charging. This combination allows the same inlet on the car to support both slow (AC) and fast (DC) charging.

- CCS Type 2 (Combo 2)

  Description: CCS Type 2 is based on the Type 2 (Mennekes) connector and is used in Europe and other regions adopting the Type 2 standard.

  Features: Similar to CCS Type 1, the top part of the connector is a Type 2 plug, and below it, there are two additional pins for DC fast charging. This setup allows for both AC and DC charging through the same vehicle inlet, providing high flexibility and convenience.

Summary

Each type of plug has its own regional preferences and specific use cases:

- GB/T plugs: Standard in China, with separate versions for AC and DC charging.
- Type 1 (J1772) plugs: Common in North America and Japan for AC charging.
- Type 2 plugs: Standard in Europe, supporting both single-phase and three-phase AC charging.
- CCS plugs (Type 1 and Type 2): Combined connectors that support both AC and DC charging, providing a comprehensive solution for various charging needs.

Taking the SAE J1772 or Type 1 connector as an example, all the connected Pins to charge an electric vehicle is explained in detail below.

Fig. 1: SAE J1772 Type 1 connector pins

Pin	Description	Level
L1-L2-L3	Three phase AC voltage	Typ. 230V
N	Neutral	Ground potential 0 V
PE	Protective earth	Ground potential 0 V
PP	Proximity pilot	±12 V
CP	Control pilot	±12 V

Fig. 2: Type 1 connector pins

The control pilot is a crucial component in the communication system between an electric vehicle (EV) and the EV charging station (EVSE - Electric Vehicle Supply Equipment). It plays a significant role in ensuring safe and efficient charging. Different conditions of the control pilot voltage waveform indicate different charging process stages and fault conditions. The duty cycle of the Puls Width Modulated voltage on the control pilot also depicts the supplied current.

Condition	Control pilot voltage	Description
A	+12 V	Vehicle disconnected
B1	+9 V	Connected
B2	PWM +9–12 V	Charging pile discloses current
C	PWM +6–12 V	Charging
D	PWM +3–12 V	Ventilation requested
E	0 V	Connection error
F	-12 V	Error

Fig. 3: Control pilot

The supplied current by the charging pile can be calculated from the duty cycle (0% - 100%). On a Type 1 connector the provided current is calculated by, with an example of 10% duty cycle, which is translated into 6A charging current:

$$I_{\text{charge}} = dutycycle[\%] \cdot 0.6A$$
$$I_{\text{charge}} = 10\% \cdot 0.6A = 6A$$

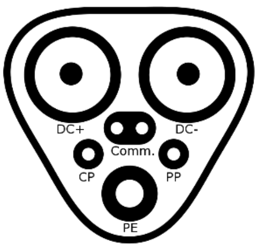


Fig. 4: MCS connector

New developments in connector types are increasing the energy transfer capability and thus decreasing charging times.

The Megawatt Charging System (MCS) is a charging connector under development, allowing charging at a maximum rate of 3.75 MW (3,000 A at 1,250 V_{DC}).

DC LOADING VS AC LOADING

The difference between DC (Direct Current) charging and AC (Alternating Current) charging for electric vehicles (EVs) lies in the way electrical power is delivered to the vehicle's battery, the speed of charging, and the infrastructure requirements. Here are the key differences:

1. Charging speed

AC charging

- Speed: Generally slower compared to DC charging.
- Typical power levels: Level 1 (up to 1.4 kW) and Level 2 (up to 22 kW, typ. around 7.2 kW).
- Charging time: It can take several hours to fully charge an EV battery. For instance, a level 2 charger might add about 16–100 km (10–60 mi) of range per hour.

DC charging

- Speed: Much faster than AC charging.
- Typical power levels: Ranges from 50 kW to 350 kW or more.
- Charging time: DC fast chargers can significantly reduce charging times, adding about 160–320 km (100–200 mi) of range in 30 minutes or even less for higher power levels.

2. Conversion of power

AC charging

- Conversion Process: The EV's onboard charger converts AC power from the grid to DC power to charge the battery.
- Onboard Charger Limitation: The charging speed is limited by the capacity of the onboard charger, which is usually designed for lower power conversion to keep costs and weight down.

DC charging

- Conversion process: The conversion from AC to DC happens outside the vehicle, within the charging station itself.
- Direct battery charging: DC power is fed directly to the EV's battery, bypassing the onboard charger, which allows for much higher power levels and faster charging.

Neither AC nor DC charging is universally „better" — the choice depends on specific needs and circumstances. AC charging is generally more cost-effective and sufficient for daily use, making it ideal for residential and workplace settings. DC charging is essential for quick charging and long-distance travel, despite its higher costs and potential impact on battery life. A well-rounded EV infrastructure will incorporate both types of charging to cater to the diverse needs of EV users.

FUNCTIONAL UNDERSTANDING – INVERTER IN CAR OR IN CHARGING PILE

With the mains network being usually a 3 Phase AC network and the EV energy storage being a DC battery one important component in charging electric vehicles is the conversion from AC to DC. This component is a rectifier. In general the converter from one electric supply (AC or DC) to another supply (AC or DC) with or without level shifting is known as an inverter.

The choice between having an inverter in the charging pile versus in the EV depends on the desired balance between charging speed, infrastructure cost, and flexibility:

Inverter in the EV (AC charging):

- Pros: More flexible, lower cost, suitable for residential and workplace settings.
- Cons: Slower charging speeds due to the limitations of the onboard charger.

Inverter in the charging pile (DC charging):

- Pros: Much faster charging, ideal for quick top-ups and long-distance travel.
- Cons: Higher cost, requires more complex infrastructure, less suitable for widespread residential use.

A well-rounded EV charging ecosystem typically includes a mix of both AC and DC charging options, allowing users to benefit from the flexibility of AC charging for daily use and the speed of DC charging for long trips and quick refueling stops.

IN FIELD TESTING WITH DEWETRON

Having all the insight into a charging cycle of an EV can be handled by DEWETRON Hardware and software.

Fig. 5: Charging Pile Connection

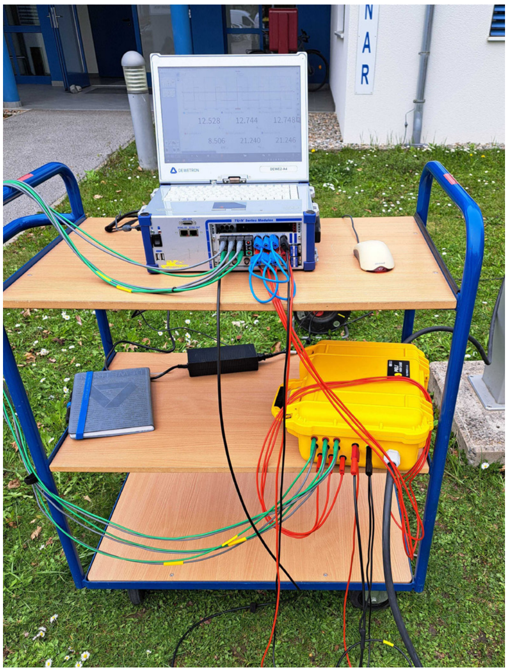


Fig. 6: Break Out Box and DEWETRON Measurement

With DEWETRON's power measurement board it is possible to handle 4 phases (4x voltage up to 1000 V_{RMS} and 4x current direct up to 20 A_{RMS}). For higher currents up to 2000 A_{RMS} transducers are utilized.

For this application the direct inputs of the power measurement board 1000 V_{RMS} input and 20 A_{RMS} input is sufficient.

The breakout box allows for measuring the 3 AC voltages, the 3 AC currents and the control pilot.

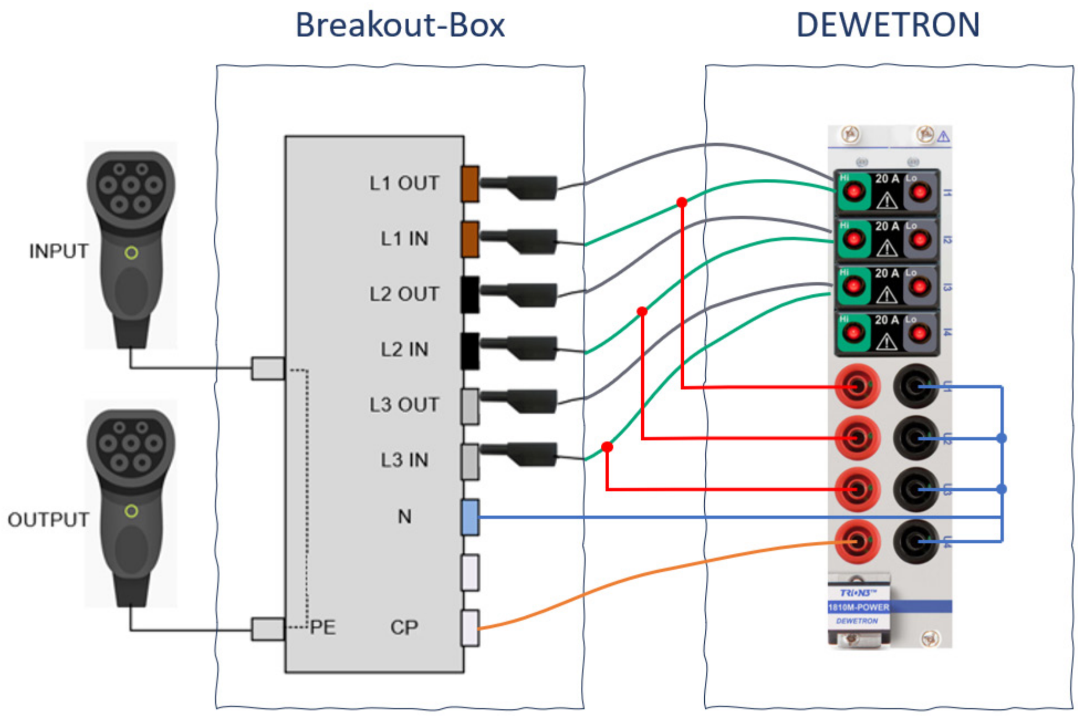


Fig. 7: Breakout box AC charging

The 3 Phase AC charging cycle start-up is depicted in the diagram below.

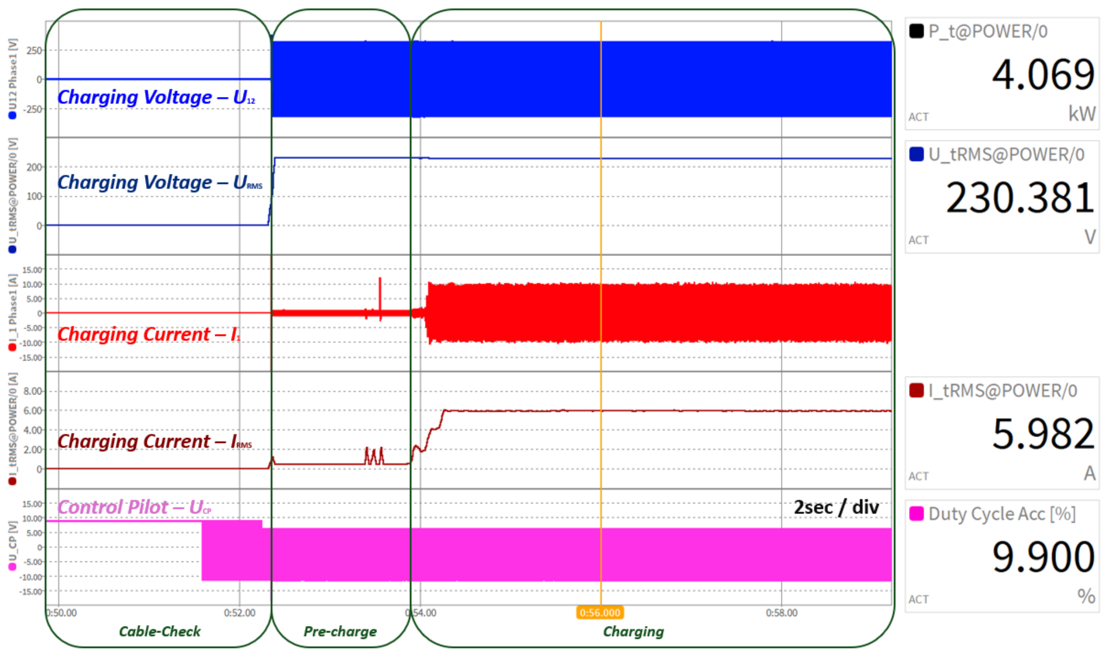


Fig. 8: AC charging procedure big time scale

The different levels of control pilot voltage and the pulse width modulation can be clearly seen in the charging procedure above. After a short cable check the voltage is released and after approximately 1.5 seconds the current is ramped up to 6 A which is equivalent to about 4 kW of active power transfer.

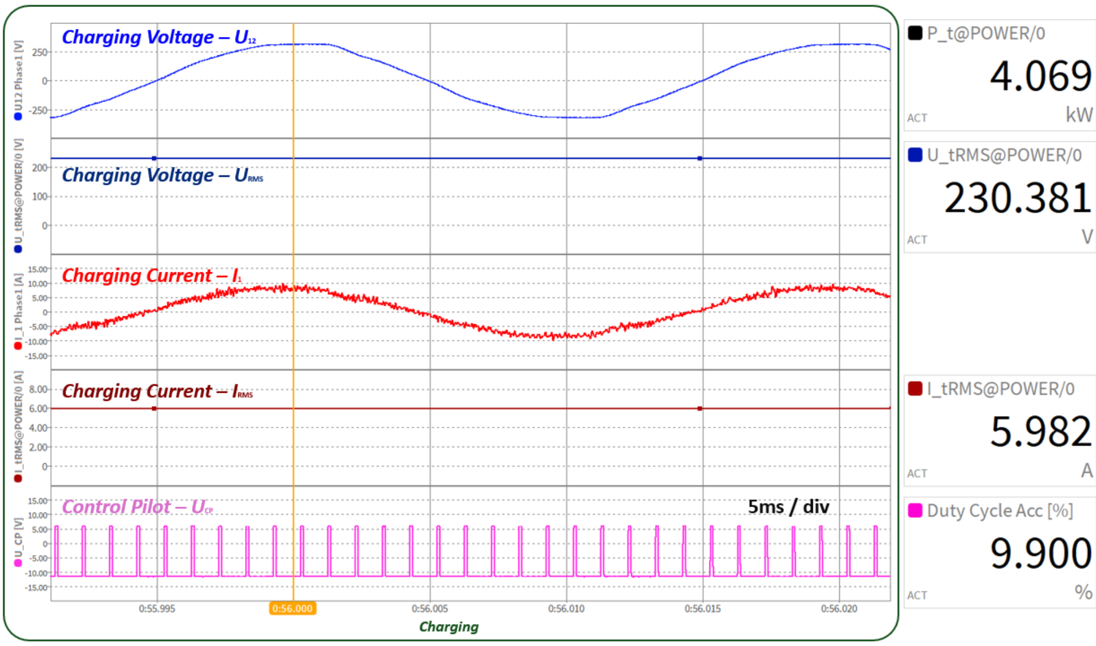


Fig. 9: AC charging procedure small time scale

In the diagram above in the smaller time scale of about one full period of 50 Hz voltage (20 ms) the pulse width modulation of the control pilot can be easily observed. About 10 % duty cycle is equivalent to about 6 A current that is being transferred from the charging pile to the vehicle.

As comparison, an DC charging cycle would like very similar to an AC charging cycle.

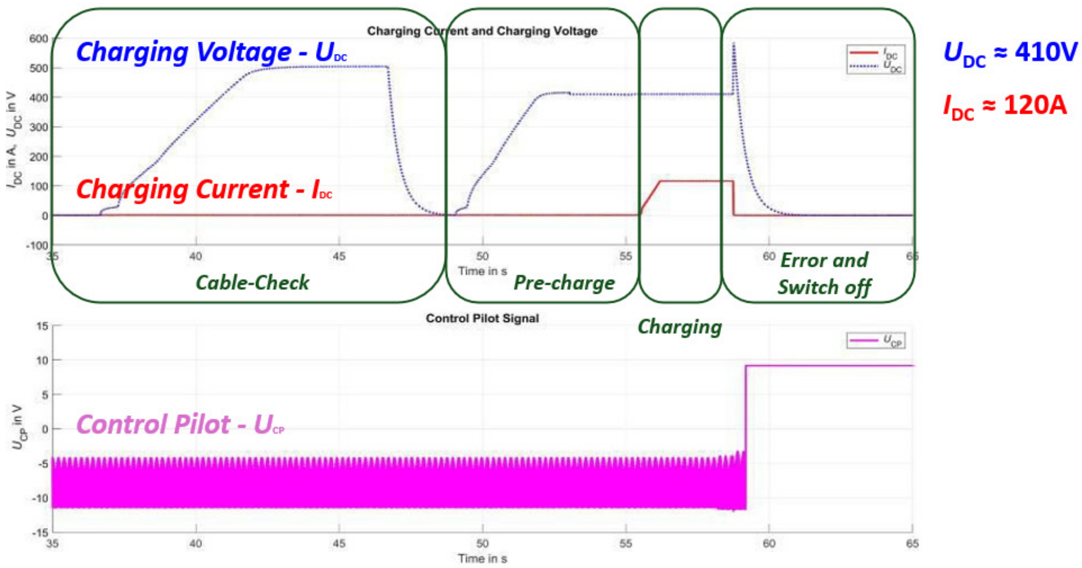


Fig. 10: DC charging procedure

At about 58 seconds in the diagram above an error condition is forced by a disconnected PE (protective earth) line. Since a disconnected PE line is a safety risk, the charging procedure is interrupted and energy transfer is shut down by the charging pile.

Modern EV charging cycles follow in general the same sequence. This sequence includes:

1. Cable check

When an EV is connected to a charging station, the process begins with a series of safety checks to ensure a secure and safe connection.

- Physical connection check: The EV and the charging station check if the charging cable is properly connected.
- Control pilot signal: The control pilot signal initiates communication between the EV and the charging station, confirming the cable connection and readiness to start charging.
- Ground check: The charging station verifies that the vehicle is properly grounded to prevent electrical faults.

2. Pre-charge

Before full power is delivered to the battery, a pre-charge phase ensures the system is ready and any potential issues are addressed.

- Voltage matching: The charging station and the EV synchronize their voltage levels to ensure compatibility.
- Handshake protocol: The EV and the charging station exchange information regarding battery status, desired charge level, and maximum current capacity.
- Initial power dupply: A small amount of current is supplied to ensure the connection is stable and to prepare the battery for full charging.

3. Charging

Once the pre-charge phase is complete, the main charging process begins.

- Current ramp-up: The charging station gradually increases the current to the agreed-upon level, preventing sudden surges that could damage the battery.
- Continuous monitoring: Throughout the charging process, both the EV and the charging station continuously monitor parameters such as current, voltage, temperature, and state of charge (SoC).
- Dynamic adjustment: If necessary, the charging station adjusts the power delivery to maintain optimal charging conditions and to protect the battery's health.

4. End of charge

The charging process ends when the battery reaches its desired charge level or when the user manually stops the charging session.

- Tapering: As the battery approaches full charge, the charging station gradually reduces the current to prevent overcharging and to balance the cells within the battery pack.
- Final checks: Both the EV and the charging station perform final safety checks to ensure the charging process has been completed correctly.
- Disconnection: The control pilot signal confirms that it is safe to disconnect the charging cable. The EV and the charging station may also lock and unlock the charging connector to prevent premature disconnection.

Summary of the EV charging cycle

1. Cable check: Verifying physical connection, ground, and initial communication.

2. Pre-charge: Voltage matching, protocol handshake, and initial power supply.

3. Charging: Gradual current increase, continuous monitoring, and dynamic adjustment.

4. End of charge: Tapering off the current, final safety checks, and safe disconnection.

This cycle ensures a safe, efficient, and reliable charging process, protecting both the vehicle's battery and the charging infrastructure. Each step is designed to maximize the efficiency of the charging session while maintaining the safety of the EV and its components.

SUMMARY – WE CAN MEASURE IT ALL

The hardware used in the in field testing:

DEWETRON

- Chassis: DEWE3-A4
- Measurement board: TRION3-1810M-POWER-4
- Sub-modules: TRION-POWER-SUB-CUR-20A-1B

Charging pile

- GARO Wallbox GLB (400V/32A)

Car

- VW ID4

With the DEWETRON hardware it is very easy to verify that the measured current is equivalent to the one depicted by the duty cycle of the control pilot.

DEWETRON stands out as a leading provider of high-precision test and measurement systems tailored to meet the diverse needs of industries such as automotive, aerospace, energy, and transportation. Their comprehensive portfolio includes modular and portable data acquisition systems, advanced power analyzers, versatile mixed-signal DAQ systems, intuitive software solutions, and a wide range of sensors and accessories.

Key advantages of DEWETRON systems include:

1. High precision and accuracy: Ensuring reliable data for critical applications.

2. Modular and scalable design: Facilitating easy customization and expansion.

3. Versatility: Supporting a wide range of measurements and signal types.

4. User-friendly software: OXYGEN software offers powerful data visualization and analysis tools.

5. Rugged and portable solutions: Suitable for field testing and harsh environments.

6. Synchronized measurements: Capturing perfectly aligned data for accurate analysis.

7. Comprehensive support: Providing excellent customer service and integration capabilities.

These strengths make DEWETRON an ideal choice for organizations seeking robust, accurate, and flexible solutions for their test and measurement needs.

AUTHORS

Maximilian KAISS

Maximilian Kaiß, M. Eng. studied Electrical Engineering and Information Technology at the Technical University of Regensburg. During his master's degree, he specialized in electrical machines and power electronics. Before joining DEWETRON in 2022, he worked as design engineer of technical building equipment in an engineering office. At DEWETRON, he is an application engineer for automotive, e-mobility, power applications and general test and measurement solutions.

Thomas KLUG

Thomas Klug has a background in natural sciences, and materials science at the Technical University Graz. During his bachelor studies he specialized in semiconductors and solar cells, whereas he focused on biobased materials in the master studies. Before graduation he worked at AVL List GmbH and Virtual Vehicle Research Center. After graduation he started his career at DEWETRON in 2023 as application engineer for industrial manufacturing, and software interfaces as well as general test and measurement solutions.

About DEWETRON

DEWETRON is a manufacturer of precision test & measurement systems designed to help our customers make the world more predictable, efficient and safe. Our strengths lie in customized solutions that are immediately ready for use while also being quickly adaptable to the changing needs of the test environment and sophisticated technology of the energy, automotive, transportation and aerospace industries.

More than 30 years of experience and innovation have awarded DEWETRON the trust and respect of the global market. There are more than 25,000 DEWETRON measurement systems and over 400,000 measurement channels in use in well-known companies worldwide.

DEWETRON employs over 120 people in 25 countries and is part of the TKH Group, a global corporation, that specializes in the development and supply of innovative solutions worldwide.

DEWETRON's quality is certified in compliance with ISO9001 and ISO14001. The high integrity of the measurement data is guaranteed by our own accredited calibration lab according to ISO17025.

Get to know our
GLOBAL OFFICES

THE MEASURABLE DIFFERENCE.

DEWETRON

HEADQUARTERS
DEWETRON GmbH
Parkring 4, 8074 Grambach
AUSTRIA

+43 (0) 316 3070-0
info@dewetron.com
www.dewetron.com