# ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE)

EVSE is the hardware that delivers electrical energy from the power grid to an electric vehicle for charging. In the most basic sense, it is the 'charger' or 'charging station' that you plug your Electric Vehicle(EV) into. It includes power input, wiring, protective devices, and cables.
An EVSE is the bridge between the electric grid and the electric vehicle.

An EVSE can deliver either AC or DC voltage to an electric vehicle, depending on its design. Typically, we have :

**AC charging (level 1 and level 2**)-> The EVSE provides AC power to the vehicle, and the The onboard charger in the vehicle converts AC into DC for charging the battery

**DC fast charging** -> EVSE converts grid AC into DC before supplying power to the vehicle.

More information on these has been given below :

| Charging Level | Region | Standard Voltage | Power Range | Typical Use Case | Common Connector |
|---|---|---|---|---|---|
| **Level 1** (AC) | **North America** | 120 V @ 12–16 A | ~1.4–1.9 kW | Home charging (overnight) | SAE J1772 (Type 1) |
| | Europe / Asia | Not used (min 230 V) | N/A | – | – |
| **Level 2** (AC) | North America | 208–240 V @ 16–80 A | ~3.3 – 19.2 kW | Home/public fast AC charging | SAE J1772 (Type 1), Tesla |
| | Europe | 230 V 1Φ / 400 V 3Φ | ~3.7 – 22 kW | Home / public AC charging | Type 2 (IEC 62196-2) |
| | Asia | 230 V / 400 V 3Φ | ~3.3 – 22 kW | Home / public AC charging | Type 1 (Japan), Type 2, GB/T |
| **DC Fast Charging (DCFC)** | North America | 200–920 V DC | 50 – 350+ kW | Long-distance fast charging | CCS1, Tesla, CHAdeMO |

| | | | | | |
|---|---|---|---|---|---|
| | Europe | 200–920 V DC | 50 – 350+ kW | Long-distanc e fast charging | CCS2, CHAdeMO (older), Type 2 DC |
| | Asia | 200–1000 V DC | 50 – 500+ kW | Long-distanc e fast charging | CHAdeMO (Japan), GB/T |

## Control Electronics

Inside the EVSE, control electronics manage the charging session; these circuits measure current and voltage, communicating with the vehicle and regulating the power flow.

The two most essential pins in these control electronics are the Control Pilot(CP) pin and the Proximity Pilot( PP) pin; these are part of the low-level DC communication between the EVSE and the EV.

### IEC61851 Standard

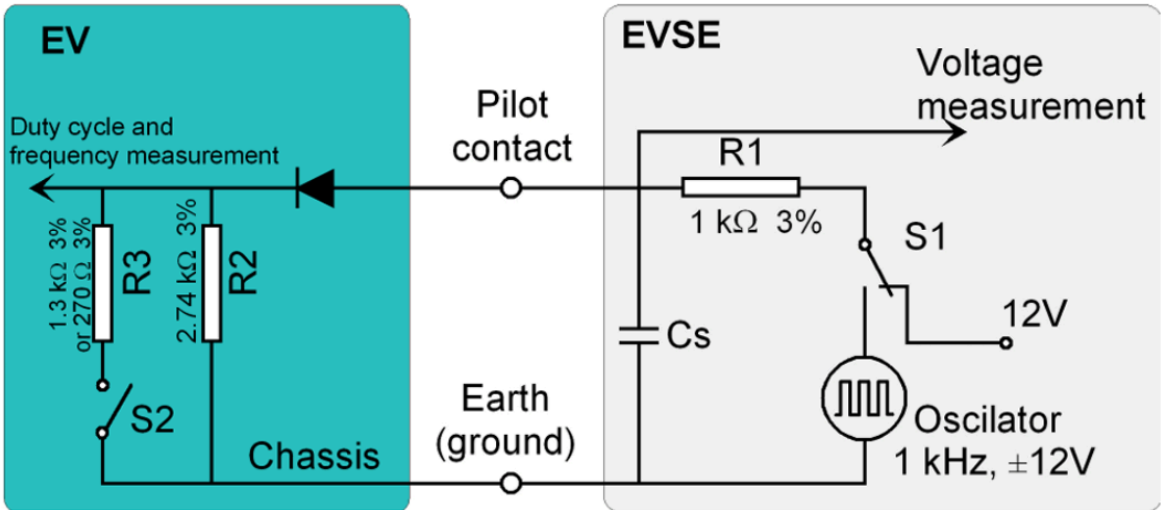
The **IEC 61851** standard not only defines the general requirements for conductive charging of electric vehicles but also specifies the **low-level signaling protocol** using the **Control Pilot (CP)** and **Proximity Pilot (PP)** lines. These signals manage key functions like vehicle presence detection, charging mode selection, current availability, and safety interlocks. Thus, IEC 61851 governs both the **electrical characteristics** of the charging system and the **basic communication interface** between the EV and EVSE through CP and PP, making it essential for safe and standardized AC and DC charging.

### Control Pilot Pin

The control pilot is a single-wire communication pin used to communicate the various charging states between the EVSE and the OBC of the EV. It allows the EV to inform the EVSE of its current state, such as idle, ready to charge, fault, etc.

This communication is done by changing the voltage available on the CP pin. This is done by using a voltage divider, one of whose resistances is controlled by the onboard charger of the EV. By changing this resistance, the voltage at the center of the voltage divider can be changed to the desired level by the EV.

A diagram of the connection as per the IEC 61851  standard has been given below :




This diagram shows that the switch S2 can be switched on or off to connect or disconnect the resistor R3 from the circuit.
Also, the S1 switch can either be connected to a stable 12V or to the oscillator, which supplies a PWM signal with a variable duty cycle.

The different states are defined based on the voltage measured :->

| | | |
|---|---|---|
| +12 V | State A | No EV connected to the EVSE |
| +9 V | State B | EV connected to the EVSE, but not ready for charging |
| +6 V | State C | Connected and ready for charging, ventilation is not required |
| +3 V | State D | Connected, ready for charging and ventilation is required |
| +0 V | State E | Electrical short to earth on the controller of the EVSE, no power supply |
| -12 V | State F | EVSE is unavailable |

### Proximity Pilot Pin

The **Proximity Pilot (PP) pin** is a crucial safety and signaling line in electric vehicle (EV) charging systems, especially in **Type 1 (SAE J1772)** and **Type 2 (IEC 62196-2 or Mennekes)** connectors. Its primary role is to indicate the presence of the charging cable, provide information about the cable's current-carrying capacity, and ensure safe disconnection.

**In Type 1 connectors**, the PP function is typically tied to a **mechanical switch** in the plug handle. When the user presses the release button to unplug the cable, this switch opens, signaling the EV to stop drawing current immediately and thus preventing dangerous arcing. However, **Type 1 does not use PP for cable current capacity identification**.

In a **Type 2 (IEC 62196-2)** EV connector—commonly used across Europe and many parts of the world—the **Proximity Pilot (PP) pin** serves two primary purposes: it helps detect whether a charging cable is connected and indicates the **maximum current** the cable is rated to handle. The PP line uses a simple hardware-based method: a **resistor** is placed inside the charging plug (the end that goes into the EVSE, not the EV) between the PP pin and **Protective Earth (PE)**. The **EVSE supplies 5 V** to the PP pin through a pull-up resistor, and it then reads the **voltage drop across the plug's resistor** to determine the cable's capacity.

Different resistor values correspond to different maximum current ratings. For example, a **13 kΩ resistor** typically signals a **13 A** cable, while a **6.6 kΩ resistor** indicates a **32 A** cable. This allows the EVSE to **limit the charging current** appropriately, preventing overheating or damaging it.

### Relation Between Duty Cycle and Maximum Current Draw :

The EVSE specifies the maximum charging current for the EV via the duty cycle. The PWM signal is applied to the control pilot circuit. The standard IEC 61851-1 defines the meaning of the applicable duty cycle values.

| | |
|---|---|
| Duty cycle < 3 % | No charging allowed |
| 3 % ≤ duty cycle ≤ 7 % | Force high-level communication protocol according to ISO 15118 or DIN 70121 |
| 7 % < duty cycle< 8 % | No charging allowed |
| 8 % ≤ duty cycle< 10 % | Max. current consumption for AC charging is 6 A |
| 10 % ≤ duty cycle ≤ 85 % | Available current = duty cycle * 0.6 A |
| 85 % < duty cycle ≤ 96 % | Available current = (duty cycle - 64) * 2.5 A |
| 96 % < duty cycle ≤ 97 % | Max. current consumption for AC charging is 80 A |
| Duty cycle > 97 % | No charging allowed |

Apart from this low-level communication, High-level communication between the EV and EVSE goes beyond the basic Control Pilot (CP) and Proximity Pilot (PP) signaling and uses digital data exchange to enable intelligent and secure charging. This communication is mainly standardized by **ISO 15118**, which operates over Power Line Communication (PLC) on the same CP line. Through ISO 15118, the EV and EVSE can authenticate each other (enabling Plug & Charge), negotiate charging parameters like power and duration, and support features such as smart charging, billing, and even vehicle-to-grid energy transfer. This digital communication ensures efficient, secure, and user-friendly charging experiences, especially for DC fast charging stations and modern smart chargers.

### EVSE Relay

The **EVSE relay** (also called the **contactor or output relay in the EVSE**) is a crucial safety component on the charging station side. Its primary function is to **physically connect or disconnect the power supply (AC or DC) from the EV's charging connector**, but **only after a successful handshake** and verification process between the EV and the EVSE.

## Interaction with Vehicle Systems :

Once power is supplied, the EVSE interacts with the vehicle's charging and battery-management systems.

In AC charging (Levels 1–2), the vehicle's onboard charger (AC-DC converter) takes the incoming AC and converts it to DC under the control of the vehicle's Battery Management System (BMS). The BMS monitors the battery's voltage, temperature, and state-of-charge and directs the charger to follow a suitable profile (typically constant-current followed by constant-voltage). During the initial plug-in handshake, the EVSE's CP/PP signals inform the onboard charger that power is available; for example, the Proximity Pilot alerts the vehicle that a plug is connected and ready. The EV may then enable its charging interface and allow current to flow. The EVSE and vehicle exchange handshaking signals to prepare the vehicle before any high-power charging begins.

When DC fast-charging (Level 3) is used, the EVSE delivers high-voltage DC directly to the battery. In this mode, the vehicle's onboard charger is bypassed; however, the vehicle's BMS still governs the charge current and voltage. The EVSE and BMS communicate over the control pilot (and often over higher-level digital links) to negotiate the correct DC output.

For example, Combined Charging System (CCS) DC chargers use the same CP/PP pins for introductory handshake and power-line communication (PLC) to manage higher-level charging parameters and safety checks. Throughout charging, the EV's BMS continuously monitors the cells and can signal the EVSE (via the vehicle control unit) to reduce or stop current if limits are reached. In all cases, the EVSE simply provides power under the constraints negotiated with the vehicle; the vehicle's electronics ultimately ensure the battery charges safely.

## Type 1 and Type 2 Connector Standards :

Type 1 and Type 2 charging refer to two different standards for AC charging connectors used in electric vehicles.

Type 1 charging, based on the SAE J1772 standard, is mainly used in North America and Japan. It supports **single-phase AC charging**. The Type 1 connector has five pins and is designed for simpler, lower-power charging applications. The pins are Line (L), Neutral (N), Earth (PE), Control Pilot (CP), and Proximity Pilot (PP)

In contrast, Type 2 charging, known as the Mennekes connector and standardized under IEC 62196-2, is widely used in Europe, India, and other regions. It supports **both single-phase and three-phase AC charging**. The seven pins are 3 phases (L1, L2, L3), Neutral (N), Earth (PE), Control Pilot (CP), and Proximity Pilot (PP).

Another point of difference between type 1 and type 2 connectors is the locking mechanism implemented in them :

The Type 1 connector uses a mechanical latch or hook that locks the plug into the vehicle's charging port. This latch is typically released by pressing a button on the plug, which physically disengages the hook and allows the plug to be removed. This means that anyone can press the release button to unlock and remove the connector from the vehicle. This means the cable is not safe against unauthorized removal or theft during charging unless the vehicle adds its own locking feature

The Type 2 connector features an automatic locking system. When the plug is inserted into the vehicle, an electromechanical locking pin engages, securing the plug in place.The locking mechanism is typically controlled by the vehicle or, in some cases, the charging station. The system automatically locks the connector during charging and can only be released by the vehicle owner (for example, via the car's remote or dashboard controls)

## Combined Charging System And Handling of DC Charging :

The Combined Charging System (CCS) is a widely adopted standard for DC fast charging electric vehicles that integrates both AC and DC charging capabilities into a single connector design. It builds upon the existing Type 1 or Type 2 AC connectors by adding two additional power pins below the standard connector, enabling high-power DC charging alongside regular AC charging using the same physical plug.

This design allows CCS to offer flexibility, supporting slower AC Level 1 or Level 2 charging as well as rapid DC charging at public stations.

CCS is popular in North America (using a Type 1 base) and Europe (using a Type 2 base), making it a global standard for many EV manufacturers. Communication between the vehicle and the charger uses the Control Pilot (CP) and Proximity Pilot (PP) lines for safety and basic signaling, while advanced digital communication protocols like ISO 15118 enable smart charging features such as authentication and power negotiation.

Overall, CCS provides a versatile and efficient charging solution that simplifies infrastructure and enhances the user experience by combining multiple charging options into a single standardized system.

## Connector Standard By Region :

EVSE connector types vary by region, largely driven by local standards bodies. Key examples include: - North America (USA/Canada): For AC charging, the standard connector is the SAE J1772 (also called Type 1). This is a five-pin plug (two AC power pins, protective earth, Control Pilot, and Proximity Pilot). For DC fast charging, the Combined Charging System (CCS) Combo 1 connector is used. CCS1 combines the J1772 AC plug with two additional DC power pins below it (so the same vehicle inlet handles both AC and DC). (Tesla vehicles in North America use the proprietary NACS connector, but many third-party chargers support NACS via adapters.)

NACS: North American Charging Standard.

**Europe**: The standard AC connector is the IEC 62196-2 Type 2 (Mennekes) plug, which has seven pins (three line phases, neutral, earth, plus Control Pilot and Proximity Pilot). It supports single- and three-phase AC up to 500 V, and can deliver up to 43 kW (400 V, 63 A) in its base form. The Type 2 design includes a flat side for automatic latching.

For DC fast charging, CCS Combo 2 extends the Type 2 by adding two DC pins at the bottom. A single CCS2 inlet thus handles both AC (using the top 7 pins) and DC (with all pins).

Type 2/CCS2 is mandated by EU law as the standard plug for public charging

An image of the type 2 Mennekes plug has been given below :

**Japan**: The AC connector for early Japanese EVs was the JEVS G-110 (similar to J1772 Type 1), but most modern Japan-market EVs use the North American J1772 plug for Level 1/2 AC.

For DC fast charging, Japan developed CHAdeMO, a proprietary round connector (characterized by a blue housing). First-generation CHAdeMO delivers up to ~62.5 kW (500 V, 125 A) DC. It uses eight contacts for power and signaling. (A new “CHAdeMO 3.0/ChaoJi” spec is emerging to support much higher power.) CHAdeMO was popular on early Nissan and Mitsubishi EVs

**China:** China’s national standard GB/T covers EV charging. For AC charging, GB/T 20234.2 uses a connector that is very similar in form to the European Type 2 but with a different signal name: it uses a CC (charging confirmation) signal instead of the international Proximity Pilot.

The physical interface is a male plug (vehicle side) and female outlet (EVSE side), opposite to Europe’s Type 2.

For DC fast charging, GB/T 20234.3 uses a larger, proprietary connector. Chinese DC fast chargers can deliver extremely high power: up to 1200 kW (≤1500 V, 800 A) per the latest standards.

In practice, Chinese EVs have separate AC and DC inlets (unlike CCS) and rapidly adopted GB/T chargers nationwide.

**India:** India has developed its Bharat EV standards for entry-level EVs. For AC charging, Bharat AC-001 mandates using a standard industrial IEC 60309 “blue” connector at 230 VAC/50 Hz, typically at 15 A (≈3.3 kW). This is the same robust plug often used for machinery, adapted for EVs. For higher-power AC, global cars use Type 2. For DC charging, Bharat DC-001 (based on China’s GB/T) was specified for low-voltage (48 V) two-/three-wheelers, with ratings around 15 kW (200 A). (However, India’s latest charging plans are shifting toward global standards like CCS.)

## Phase Reversal Fault

A phase reversal fault in an EV charging system occurs when the three-phase AC power supply's phase sequence is incorrect — that is, the order of phases L1 → L2 → L3 is swapped to something like L1 → L3 → L2. This is majorly important for type 2 or CCS 2-based systems, which consist of three-phase AC charging.

**How is it detected?**
The EVSE contains a circuit known as the phase sequence detector, which compares the phase timings of the attached L1, L2, and L3 connections. If the order is not L1->L2->L3, it raises a phase reversal fault.

## Handling Of Faults :

In an Electric Vehicle Supply Equipment (EVSE), several types of electrical faults can occur, and each must be detected and handled appropriately to ensure safety for both the user and the vehicle. The most common faults include **overvoltage**, **undervoltage**, **overcurrent**, **ground fault**, **relay welding**, and **temperature-related faults**.

**Overvoltage** happens when the input voltage from the grid exceeds the safe limit. This can damage the EV's onboard charger or other electronics. To handle this, the EVSE includes voltage monitoring circuits. If an overvoltage is detected, the EVSE disconnects the main relay to stop power flow and may alert the user via indicators or a display. Similarly, **undervoltage** occurs when the input voltage drops too low, which could lead to improper charging. The system detects this and pauses charging until the voltage returns to the safe range.

**Overcurrent** is another critical fault, which occurs when the current drawn exceeds the rated value for the connector or cable. This could lead to overheating or even fire. The EVSE uses current sensors to monitor the actual load and immediately opens the main relay if the current exceeds the limit, effectively stopping the charging process.

A **ground fault** or **earth leakage** refers to current leaking from the live conductor to the ground, which can be hazardous. EVSEs are typically equipped with a Ground Fault Circuit Interrupter (GFCI) or Residual Current Device (RCD). These devices detect leakage currents (usually above 20–30 mA) and quickly cut off the power by opening the relay.

**What is leakage current?**
Leakage current is the unintended flow of electrical current through a path that is normally considered insulating or non-conductive, rather than through the intended circuit path. This current can flow through insulation, across device surfaces, or to ground, and is generally unwanted in electrical and electronic systems

**How does a GFCI work?**
In simple terms a Ground Fault Circuit Interuptter has both the Live and Neutral wires connected to it, it continuously monitors the current flow in both these wires ensuring that they are equal, if they are not equal, meaning that some part of the current is flowing to ground as leakage current the GFCI detects it and disconnects power.GFCI outlets disconnect power typically at a current difference of 5mA.
*Source:https://www.ehs.harvard.edu/sites/default/files/ground_fault_circuit_interrupter_gfci_fact_sheet.pdf#:~:text=Whenever%20the%20difference%20is%20greater,interrupts%20the%20flow%20of%20electricity.*

**Relay welding** is a situation where the main relay contacts get stuck in the closed position due to overheating or arcing, even after the control signal is removed. This is dangerous because the EV might still receive power when it's not supposed to. To detect this, the EVSE performs a post-disconnection check by measuring voltage at the output side. If voltage is still present despite the relay being "open," the system detects a weld fault and may disable the unit or alert the user.

Lastly, **thermal faults** can occur if the components inside the EVSE or the connector itself get too hot. EVSEs often include temperature sensors inside the plug and within the electronics. If excessive heat is detected, the system will reduce the current or stop charging until the temperature returns to normal.

These faults are detected through a combination of sensors and protective circuitry, with the main relay acting as the final control point to isolate power when necessary immediately. These safety mechanisms are defined in standards such as IEC 61851 and are critical for safe and reliable EV charging.

### Split Phase Systems

**The explanation provided below is in terms of North American Values, the concept stays the same even for other regions**

A split-phase system is a type of single-phase alternating current (AC) power distribution commonly used in North America for residential applications. It provides two AC voltages from a single-phase source by "splitting" the phase into two equal and opposite voltages, which allows for both 120V and 240V power delivery using three wires.

At the transformer, a single-phase 240V winding is center-tapped: The two ends of the winding are connected to Line 1 (L1) and Line 2 (L2). The center tap is connected to Neutral (N) and is grounded (Earth). This produces:

1. 120V between L1 and Neutral (L1–N)
2. 120V between L2 and Neutral (L2–N)
3. 240V between L1 and L2

The key feature is that L1 and L2 are 180° out of phase with each other. So when you measure between them, their voltages add up, giving 240V. But from either line to neutral, the voltage is only 120V.

# Lithium-Ion Battery Charging Methodology

Lithium-ion batteries are commonly used as energy storage devices in modern electronics and electrical devices. This section focuses on the various facets of the charging of such batteries, and also on the fundamental parameters of such batteries and what they really mean.

# Common Battery Parameters

## A.Milliampere-Hour (mAh) Capacity Measurements

The capacity of a battery is often quantified by a milliampere-hour (mAh) rating, the rating represents the amount of electrical charge a battery can store and deliver over time. This indicated how much current the battery can provide for a specified duration.

So, a battery with a higher mAh rating can supply more electrical current for 1 hour than a battery with a lower mAh rating. Thereby requiring charging less regularly.

For example, a 1000mAh battery can theoretically provide 1000 mA of current for 1 hour, 500 mA for two hours, and 2000 mA for 30 minutes.

However, the relationship between mAh and actual battery performance involves many additional variables such as discharge rate, temperature, and device power consumption patterns.

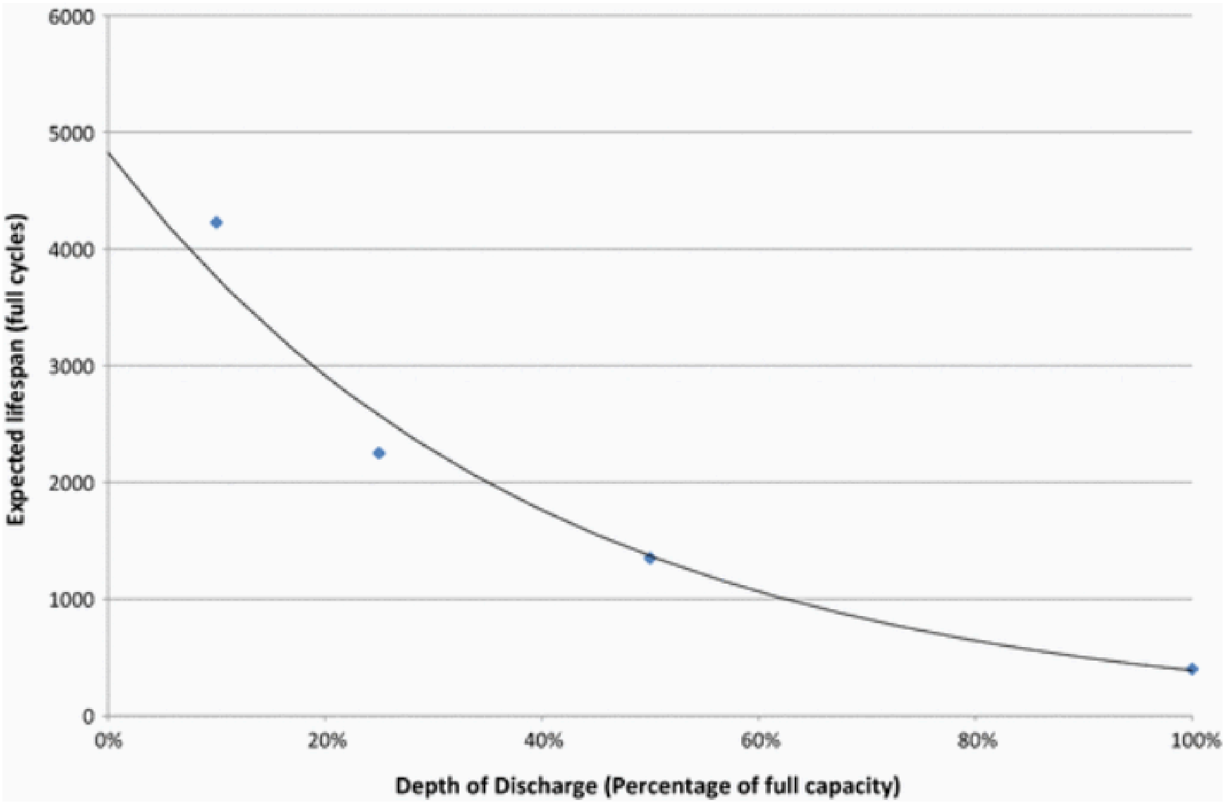
**Why don't we use voltage for capacity measurement?**
It is not favourable to use voltage for capacity measurement as Lithium-Ion batteries exhibit a nearly constant voltage across their discharge range ( 20 to 80% of charge).
This makes voltage-based capacity estimation unreliable except for the extreme charge levels ( empty and full).

## B. Depth of Discharge (DoD)

The Depth of Discharge parameter represents the percentage of battery capacity that has been used with respect to the total battery capacity. This is also one of the parameters that directly affects the longevity of a battery.

Deeper discharge cycles cause more stress and accelerated degradation compared to shallower discharge cycles. Thus, optimal longevity is achieved through more controlled discharge practices.

Given below is a plot of the relation between the Depth of Discharge and Battery Lifespan.

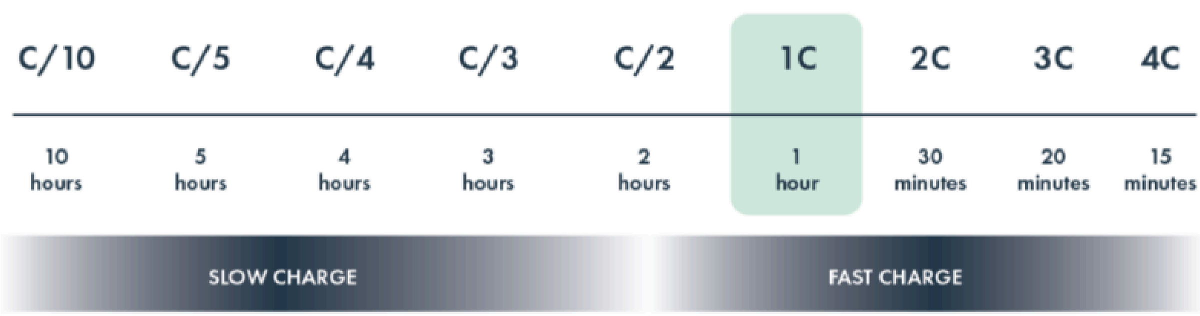



## C.C-Rate

The C-rate is a unit used to measure the charge and discharge currents with respect to the battery capacity, providing a standardized method for comparing performance across different battery sizes.

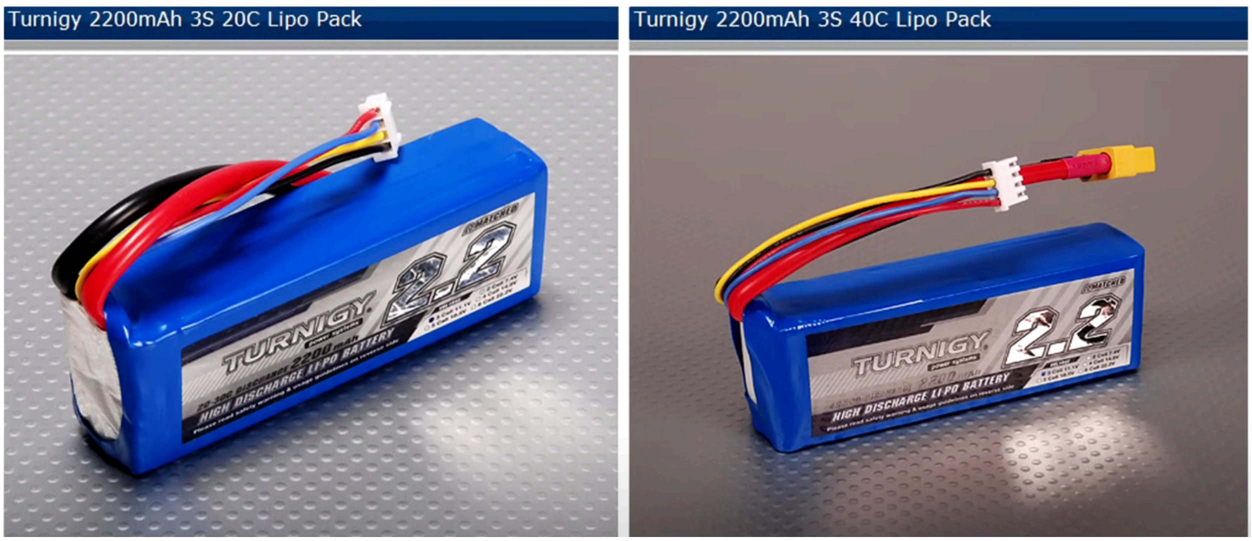
For example, charging the battery at a C-rate of 1C means hat the battery is charged completely from 0% to 100% in 1 hour, and a charging rate of 2C would mean that the battery is completely charged in 30 min.

The image given below gives us a better idea of this:



In an ideal scenario, a battery would perform well at high C-rates all the time, but this is not true as a higher C-rate leads to an increase in degradation rate of the battery, reducing the range and lifespan of the vehicle it is used in. Faster charging can also cause dangerous dendrites to form. These hurt the battery's lifespan, can lead to cell failure, and in some extreme cases have been known to cause fires. Due to this, EV battery chargers do not sustain charging rates higher than 2C for longer than a few minutes before the charging rate is reduced to avoid causing damage to the battery.

Now let's see an example of the application of C-rating: ->




Both batteries shown in the above picture have the same mAh rating, but have a different C ratings:
For the battery on the left, the maximum current that it can safely supply is 20 x 2.2 = 44 Amperes, and for the battery on the right, the maximum current that it can safely supply is 40x2.2 = 88 Amperes.

The 3S in the above image means that the battery consists of 3 cells in series.

## D.Nominal Voltage

Nominal voltage is a term that is designed to simplify the understanding of a battery for a consumer. It represents the average voltage that a battery can maintain throughout its discharge cycle, it helps by providing a useful reference point for the battery's operational range. It enables consumers and engineers to easily compare and select batteries for their devices without needing to understand the entire **discharge curve**.

Nominal voltage is used because it's simply a lot easier to grasp a single voltage rather than a range of voltages. The actual voltage of a battery can fluctuate due to various factors such as its current state of charge, the amount of current being drawn from it, the ambient temperature, and the battery’s age.

A battery's voltage will have a voltage that is higher than its nominal voltage when it’s fully charged, and then as it discharges, the voltage will drop, eventually dipping well below the nominal value before the battery is considered dead.

The value of this Nominal Voltage parameter for a Li-Ion cell is 3.7V.

Nominal voltages for some common battery chemistries are given below.
*Source: https://cellsaviors.com/blog/nominal-voltage*

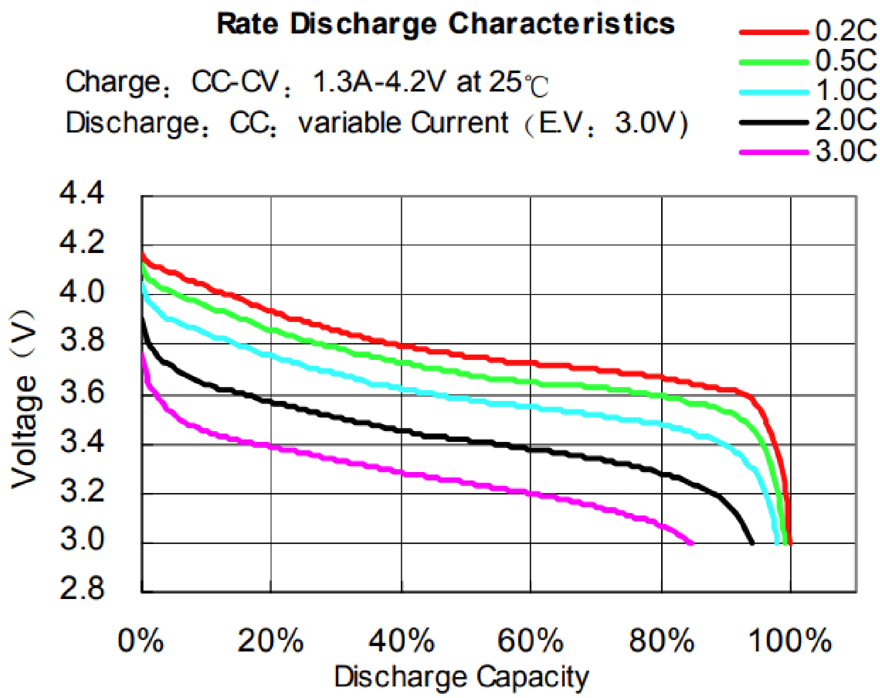
- NMC (Lithium Nickel Manganese Cobalt Oxide): 3.6 volts
- LFP (Lithium Iron Phosphate): 3.2 volts
- Lead Acid: 2.1 volts
- LTO (Lithium Titanate Oxide): 2.4 volts
- Sodium Ion: 2.1 volts
- LiCoO2 (Lithium Cobalt Oxide): 3.7 volts
- NiMH (Nickel-Metal Hydride): 1.2 volts
- NiCd (Nickel-Cadmium): 1.2 volts
- LiMn2O4 (Lithium Manganese Oxide): 4.0 volts
- Li-S (Lithium-Sulfur): 2.15 volts

## E.Discharge Curves

A discharge curve of a battery represents how the voltage of a battery changes over time as the battery is discharged.

In batteries with a flatter discharge curve, like the ones observed for Li-Ion batteries, the voltage drops out gradually and more evenly, resulting in a more constant and consistent voltage supply to any device.

Given below is an example of such a discharge curve for commonly used 18650 Li-ion batteries Of a 2600 mAh rating.




Here we can observe that there is a different discharge curve for a different current draw.

This raises the question, what actually limits the current that a battery can provide, because theoretically, just looking at the nominal voltage, **if we connect a very low resistance across the battery terminals, we should get a very high current?**

One of the factors for this is the internal resistance that every battery has. For example, the previously mentioned 18650 Li-ion battery has an internal resistance of less than 70 mΩ according to its datasheet.

Now that we have obtained a basic understanding of various battery parameters, we will go more in-depth into the process of charging a Li-Ion Battery.

## Charging A Lithium-Ion Battery

The charging of a lithium-ion battery uses a two-stage approach known as Constant Current - Constant Voltage (CC-CV) charging, which is commonly used as an industry standard for charging such batteries.

The process starts with a constant current phase where the charger supplies a fixed current to the battery while the battery voltage slowly increases up to a threshold. This charging current is pre-determined.

The change to the constant voltage phase occurs when the battery reaches its designated voltage threshold. At this point, the charger maintains this maximum voltage while allowing the current to gradually decrease. The phase continues until the current drops to approximately 3-5% of the ampere hour rating, signalling completion of the charging cycle.

The charging stages have been explained in more detail below :

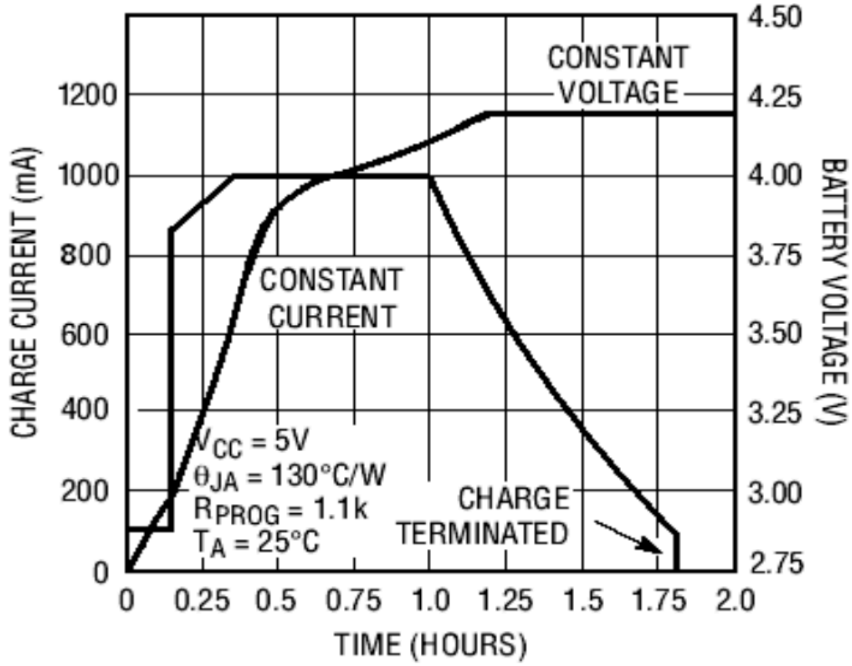
**Stage 1 – Constant Current (CC):**
The charger supplies a fixed high current (typically 0.5–1C) regardless of voltage. The cell pack voltage rises steadily from its initial (often ~3V) toward the cutoff. If a cell is deeply discharged (<2.8V), some chargers use a low “pre-charge” (≈0.1C) until ~3V, then move into full CC. During CC, the BMS continuously checks temperature and cell voltages to ensure safe limits are not exceeded.

**Stage 2 – Transition to Constant Voltage (CV)**:
As soon as the pack voltage reaches the prescribed maximum (e.g., 4.2 V per cell), the charger stops raising voltage. The voltage is held constant, so any further charging must come from adjusting the current. At the switch-over, there may be a brief transient, but essentially the regulator clamps voltage, and the pack current naturally begins to fall.

**Stage 3 – Constant Voltage (CV) – Tapering**:
In this phase, the charger enforces the maximum cell voltage, and the battery current decays as the cells fill. The pack continues to charge slowly; full charge is only reached when the current falls below a small threshold. Industry practice is to terminate charging when the current drops to about C/10 or even C/20 (roughly 5–10% of the initial current). At that point, the battery is ~100% SOC, and the charger disconnects. Waiting any longer would just “trickle” current into the cell, which is not permitted in lithium-ion chemistry

Shown below is a diagram of a charge cycle of the TP4056 charging module ( a commonly used CC-CV charger) for a Li-ion battery of 1000mAh being charged at 1C.

## Complete Charge Cycle (1000mAh Battery)




# Some More Terms

## Pre-Charging

**Pre-charging** is the initial stage for the charging process of Li-Ion batteries that are deeply discharged state and for newly manufactured batteries. It consists of applying a low current to slowly raise the battery voltage to a safe minimum level before beginning the standard charging process. The main purpose of pre-charging a battery is to extend battery life and improve battery performance.

**Why do we need pre-charging?**
Precharging helps in reducing the inrush current. When charging is started for a battery that is deeply discharged, the charging current may increase sharply, causing damage to the battery. Pre-charging can slowly increase the voltage by applying a smaller current, thus reducing the inrush current.

*Source: [https://www.powerlongbattery.com/why-do-lithium-batteries-need-to-be-pre-charged](https://www.powerlongbattery.com/why-do-lithium-batteries-need-to-be-pre-charged)*

## Trickle Charging

Trickle charging involves continuously supplying a very low current( about C/20) to a battery after it has been fully charged to compensate for any self-discharge that may take place. The goal is to keep the battery at 100% SoC.

However, this method is not used in lithium-ion batteries as it can lead to safety and degradation risks., Li-ion batteries are sensitive to overcharging and do not tolerate being held at full charge for long periods. Doing so stresses the battery, shortens its lifespan, and in extreme cases can cause overheating, swelling, or even fires.

## Topping Charge

A topping charge is a brief, controlled recharge given to a battery after it has been partially discharged, often due to self-discharge during storage or periods of inactivity. Unlike trickle charging, which continuously supplies current, a topping charge is applied only when the battery's voltage or state of charge drops below a certain threshold.

This helps bring the battery back to full capacity without the risks of constant overcharging. In lithium-ion batteries, topping charges are managed carefully by the battery management system (BMS), which ensures that the voltage and current remain within safe limits.

# State of Charge Measurement and Monitoring of A Battery

## Open Circuit Voltage Method

The open circuit voltage method is one of the simplest methods for state of charge(SoC) measurement, The method uses the relationship between terminal voltage and charge level to determine the SoC.

But the Lithium-Ion batteries pose a challenge to this method, unlike lead-acid batteries that exhibit relatively linear voltage-to-SoC relationships, the discharge curves for this kind of battery are characteristically flat, meaning it maintains a relatively constant voltage output throughout the discharge cycle.

This limitation makes it necessary to have an alternative technique for the accurate SoC determination during normal operation.

## Coulomb Counting Technique

Coulomb counting is another method that is used for SoC determination. It tracks the SoC by integrating current flow over time during the operation of the battery. This allows for the direct measurement of charge drawn or injected into the battery, allowing for precise SoC quantification throughout the discharge cycle without needing the battery to be in an open-circuit condition, making this method ideal for real-time applications.

However, the use of Coulomb counting requires precise measurement and high-frequency sampling, as the use of integration means that small measurement inaccuracies can accumulate over time, causing the need for periodic recalibration after each cycle to maintain long-term accuracy.

# Revision History

25/05/2025
Topics added :
1. Lithium-Ion Battery Charging
2. State of Charge Measurement
3. Common Battery Parameters
4. Precharging, Trickle charging, and topping charge
5. Split Phase Systems
6. Working principle of GFCI
7. Leakage Current
8. Additional difference between type 1 and type 2 connectors based on locking parameters
9. Phase Reversal Faults
10. Lithium-Ion Battery Charging Phases