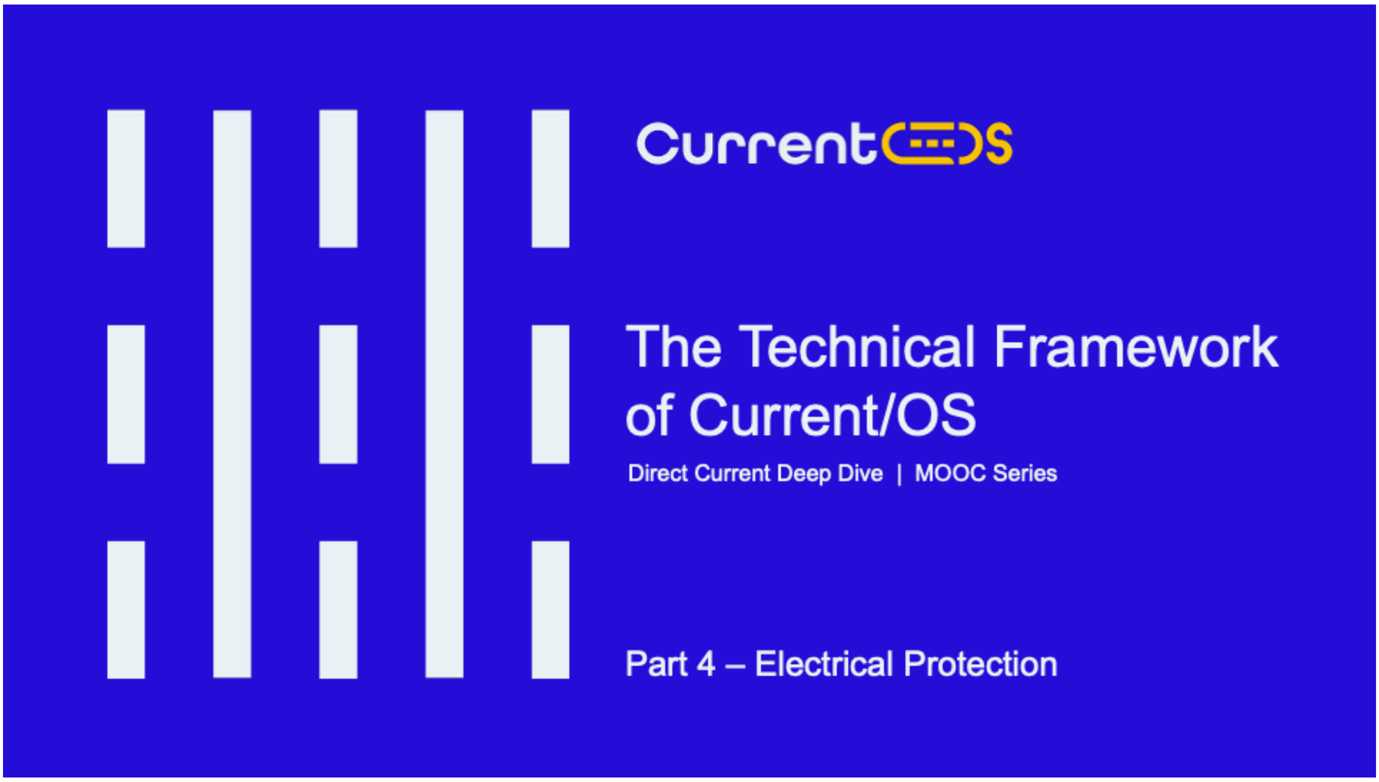


Welcome to the Direct Current Deep Dive Series: the Technical Framework of Current OS” , a MOOC designed to dive into the principles behind Current OS technical decisions and their role in defining the standard for Direct Current electrical systems, also commonly referred to as DC-coupled systems, or DC microgrids

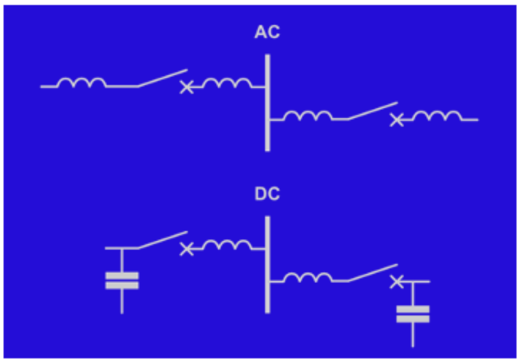
This video is part 4 of a six-part series. Explore the remaining videos on the Current OS YouTube Channel to continue learning about the world of Direct Current.

In this video, we’ll explain the underlying principles that drive Current OS's technical choices on electrical protection and the definition of risk categories. The aim is to deliver an arc-free solution that simplifies system design, while reducing the need for cables and electrical equipment.

Defining Standards for Direct Current Electrical Systems CurrentOS

AC and DC Networks Do Not Behave The Same

AC	DC
Sources induction is much higher than cables induction.	Sources induction can be very low.
High impedance in the fast time domain.	Very low impedance in the fast time domain.
Large reduction effect in the fault currents.	Lead to very high fault currents.
Electromechanical protection devices are effective.	Protection devices must be very fast to limit the current and to prevent semiconductor breakdown: SSCB are effective



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Protection in DC systems marks a significant shift from AC practices. Why is this necessary? The primary reason lies in the fundamental differences between the electrical characteristics of AC and DC installations.

On this slide, a basic installation with a bus and cables is represented, highlighting their inductance.

In AC systems, the source is typically inductive—whether it's a medium-to-low voltage transformer or the alternator of a diesel generator. Similarly, many loads, such as motors or fluorescent tubes, are also inductive. In the event of a fault, such as a short circuit, these inductances result in current increases that are relatively slow—on the scale of tens of milliseconds. Electromechanical circuit breakers are well-suited for this, reacting effectively within 10 to 50 milliseconds.

In direct current, however, each source is capacitive, meaning that in the event of a fault, capacitors discharge rapidly. This includes the capacitors from sources and, potentially, from loads, depending on their characteristics. All these capacitors discharging simultaneously produce extremely high inrush currents within just a few microseconds.

This rapid rise in current occurs too quickly for electromechanical circuit breakers to react. By the time they attempt to open, much of the capacitor energy has transferred into the inductance of the cables, and the breakers must then dissipate the stored energy in the cables.

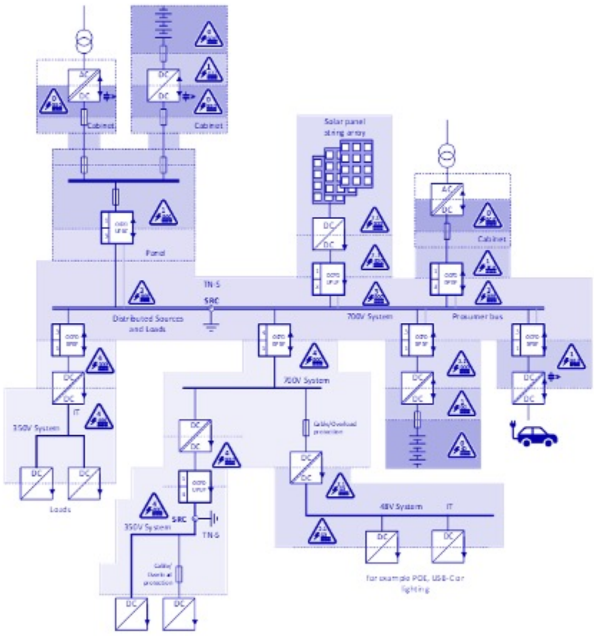
For a multi-source system like a building, this presents a major challenge. Calculating fault energy becomes highly complex, requiring detailed knowledge of every capacitor in the system. However, manufacturers rarely provide this information in their datasheets.

Moreover, accurately determining cable lengths in a building is almost impossible. You would need precise layouts, and as buildings evolve, maintaining this information over time becomes impractical.

To make things even more complicated, certain devices like batteries are sometimes loads and sometimes sources. The behavior during faults can vary significantly, especially with bidirectional systems such as vehicles that supply energy back to the building (vehicle-to-building systems). As the number of sources and bidirectional systems increases, the complexity of calculating a protection plan for electromechanical circuit breakers in a DC microgrid grows exponentially.

This is why a simplified approach is essential. Current OS addresses this challenge by categorizing circuits using the concept of zones. Zoning reduces complexity while ensuring effective protection for DC microgrids.

The Concept of DC Zones

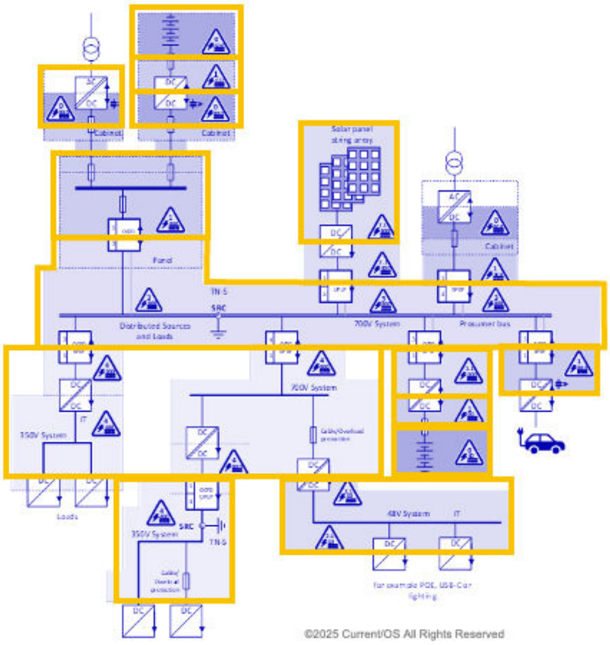


What is the concept of zones? It is a method for mapping out an electrical schematic.

Defining Standards for Direct Current Electrical Systems

The Concept of DC Zones

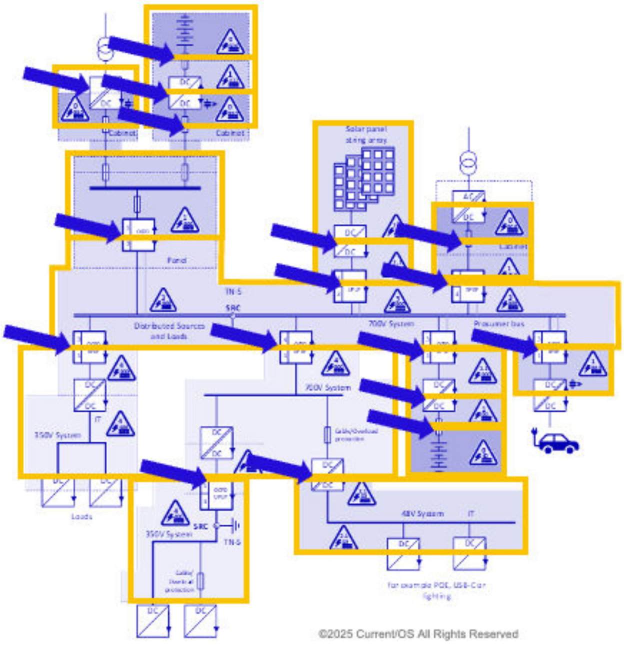
- Classify areas



to classify areas

The Concept of DC Zones

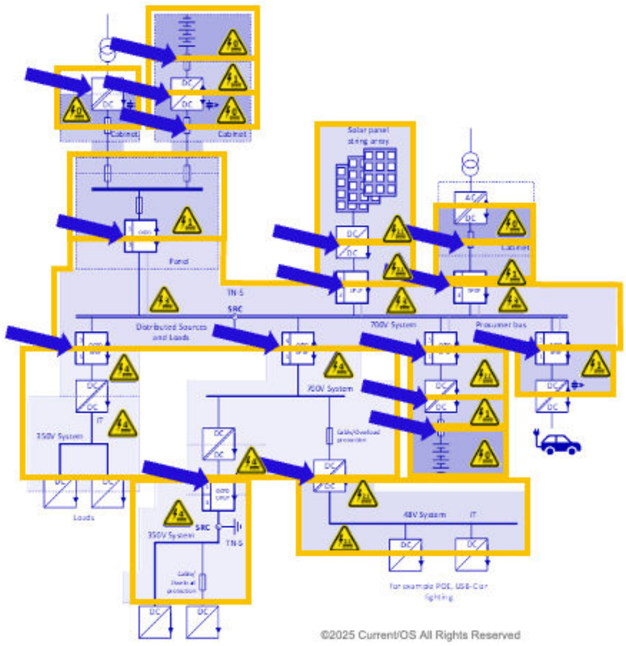
- Classify areas based on their level of protection and associated risk



based on their level of protection and associated risk.

The Concept of DC Zones

- Classify areas based on their level of protection and associated risk
- Installations can be divided into zones ranking from 0 to 4



Installations can be divided into zones ranking from 0 to 4.

The concept of DC zones ismajor part of the Current OS set of rules.

We will now explain in detail the characteristics of each zone.

Defining Standards
for Direct Current Electrical Systems

Electrical Conductor

A conductor may lead to different zones depending on the protection device.

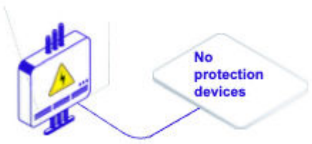
A conductor may lead to different zones depending on the protection device.

Electrical Conductor

A conductor may lead to different zones depending on the protection device

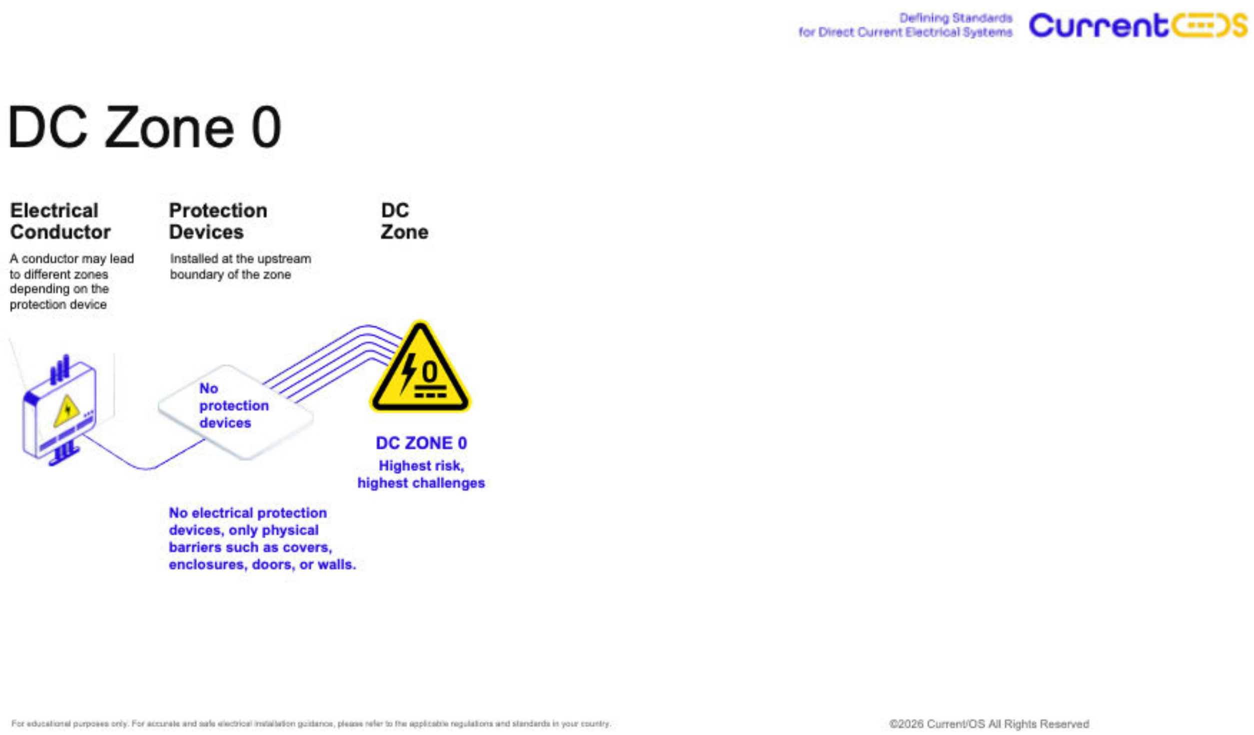
Protection Devices

Installed at the upstream boundary of the zone

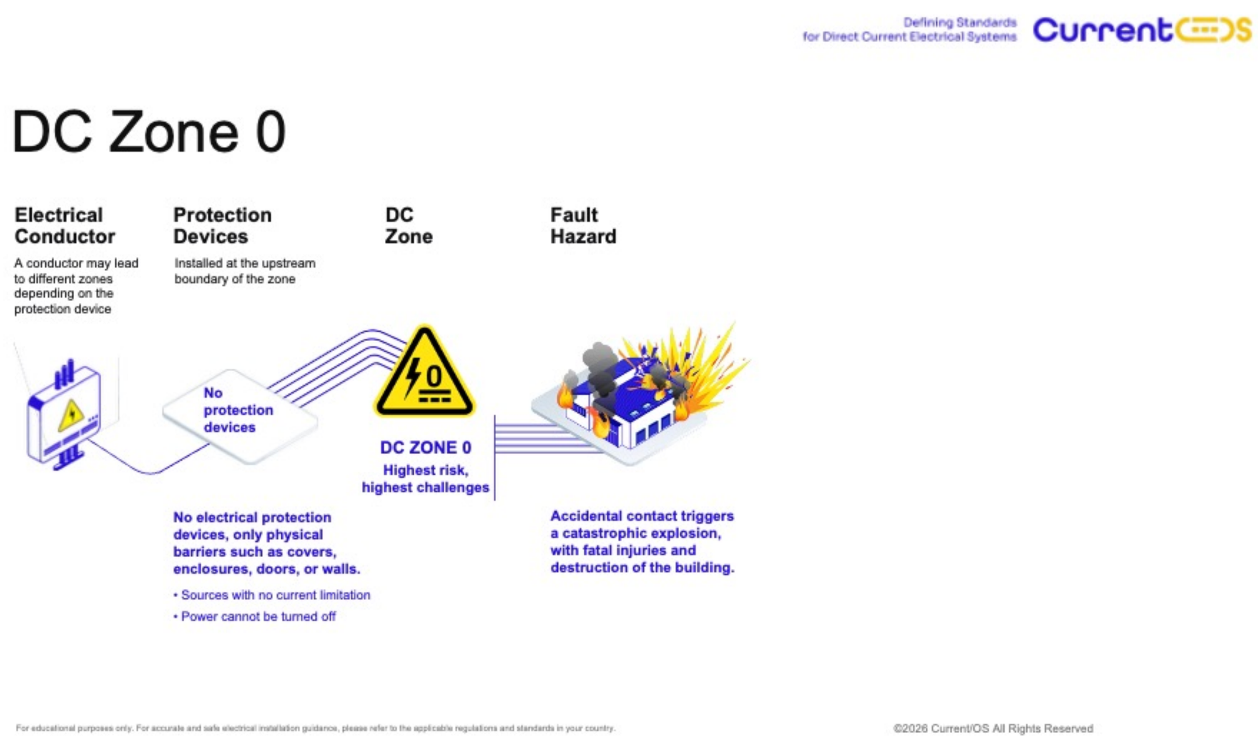


No electrical protection devices, only physical barriers such as covers, enclosures, doors, or walls.

Let’s start with a voltage source with no electrical protection devices, a battery for example. At the battery terminals, the risk is extremely high. The only protection consists of physical barriers such as covers, enclosures, doors, or walls.

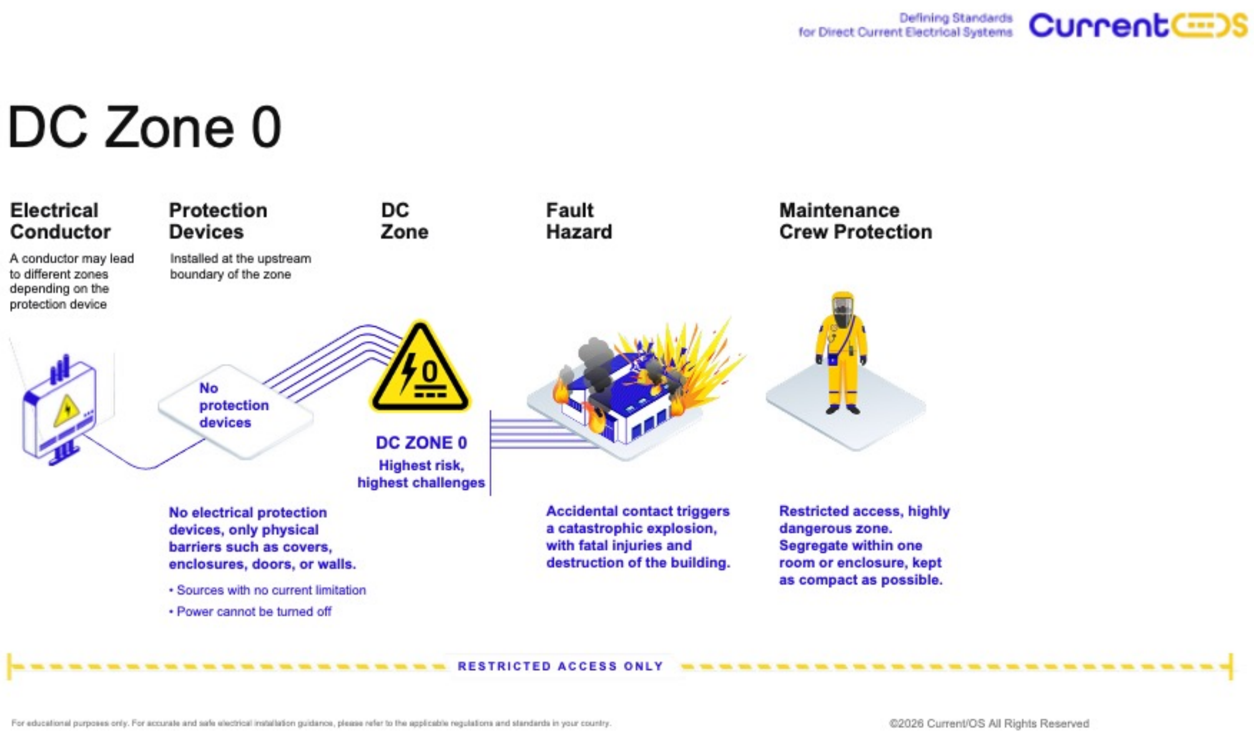


This is classified as DC Zone 0. It has the highest level of risk and challenges.



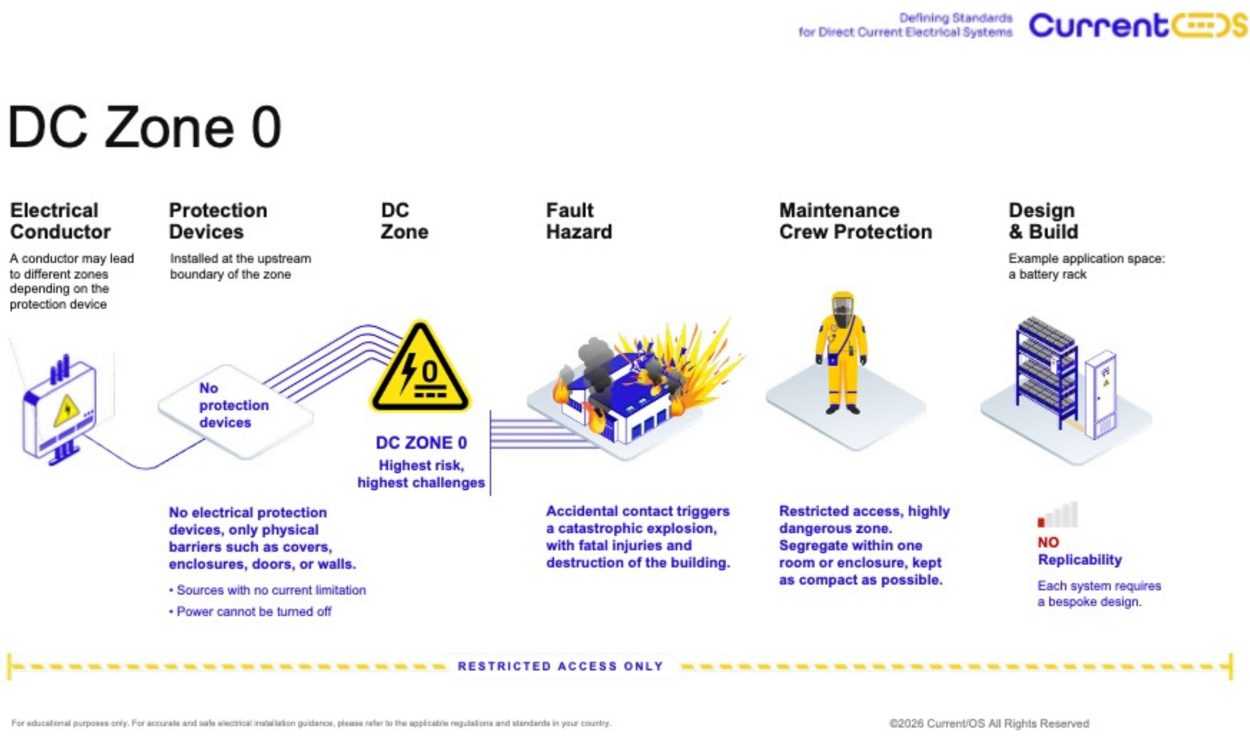
In case of arc flash, there is a high incident energy risk.

Any short circuit in this zone could result in catastrophic damage or even fire, eventually resulting in the destruction of the building.



When maintenance is needed, maintenance crew needs to wear highly protective clothing.

This zone is segregated within one room or enclosure, it is not distributed, it is kept as compact as possible, and access is restricted.



A battery rack is a typical example of DC zone zero.

From a design and build perspective, the system design is not readily replicable, in the sense that each system requires a bespoke design.

To reduce the risk, a protection is introduced through a fuse or circuit breaker, with a response time of less than 50 microseconds.

Defining Standards
for Direct Current Electrical Systems CurrentOS

DC Zone 1

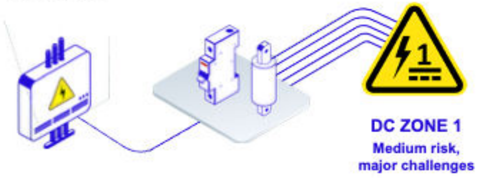
Electrical Conductor

A conductor may lead to different zones depending on the protection device

Protection Devices

Installed at the upstream boundary of the zone

DC Zone

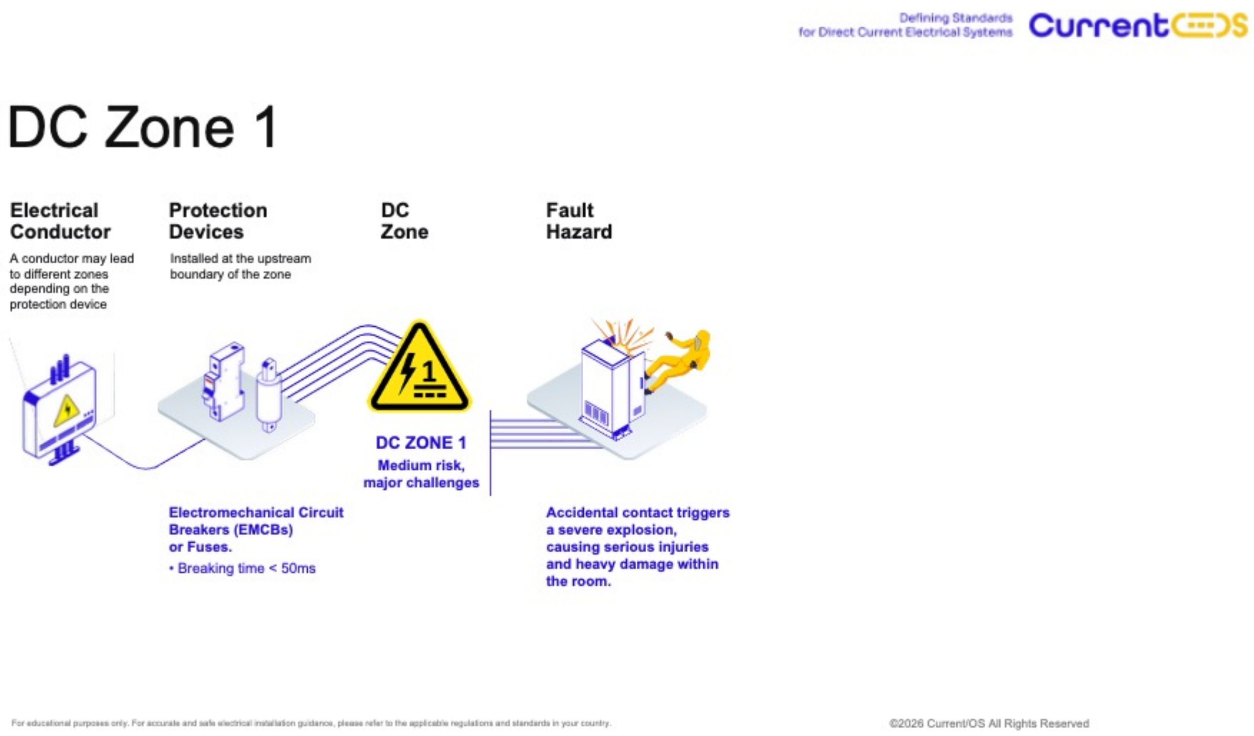


Electromechanical Circuit Breakers (EMCBs) or Fuses.

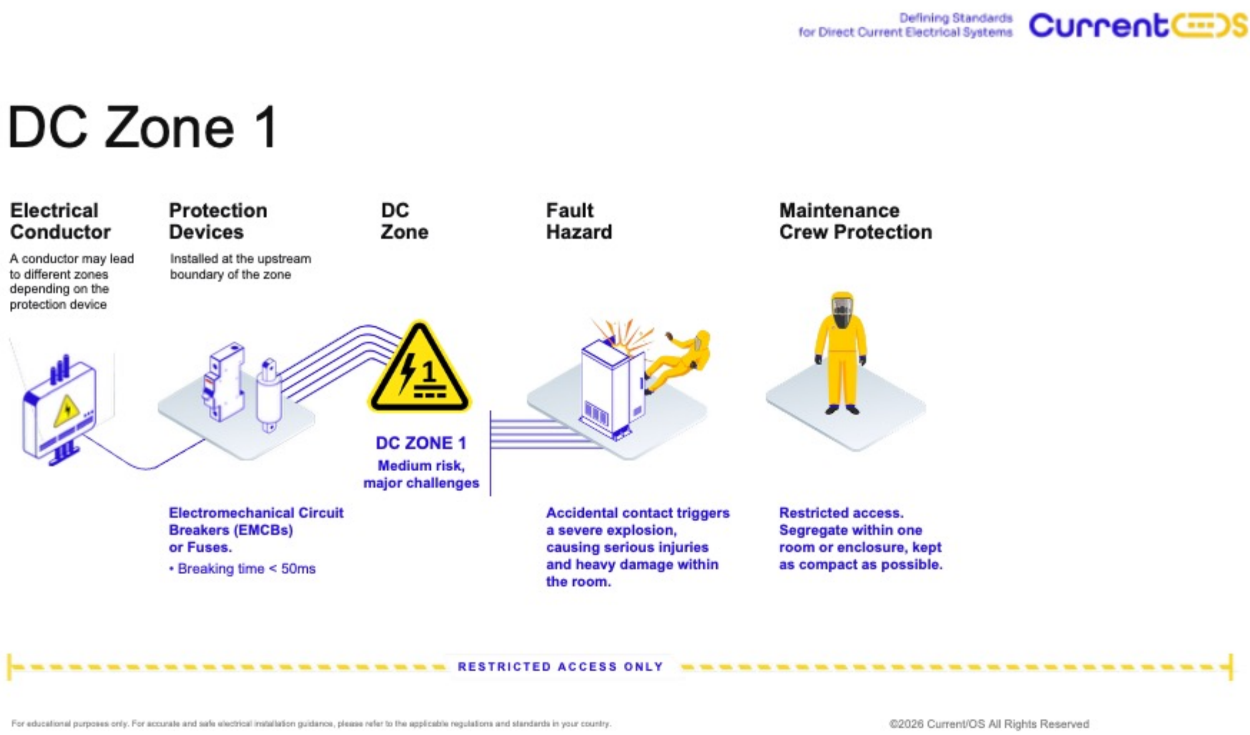
- Breaking time < 50ms

For educational purposes only. For accurate and safe electrical installation guidance, please refer to the applicable regulations and standards in your country.

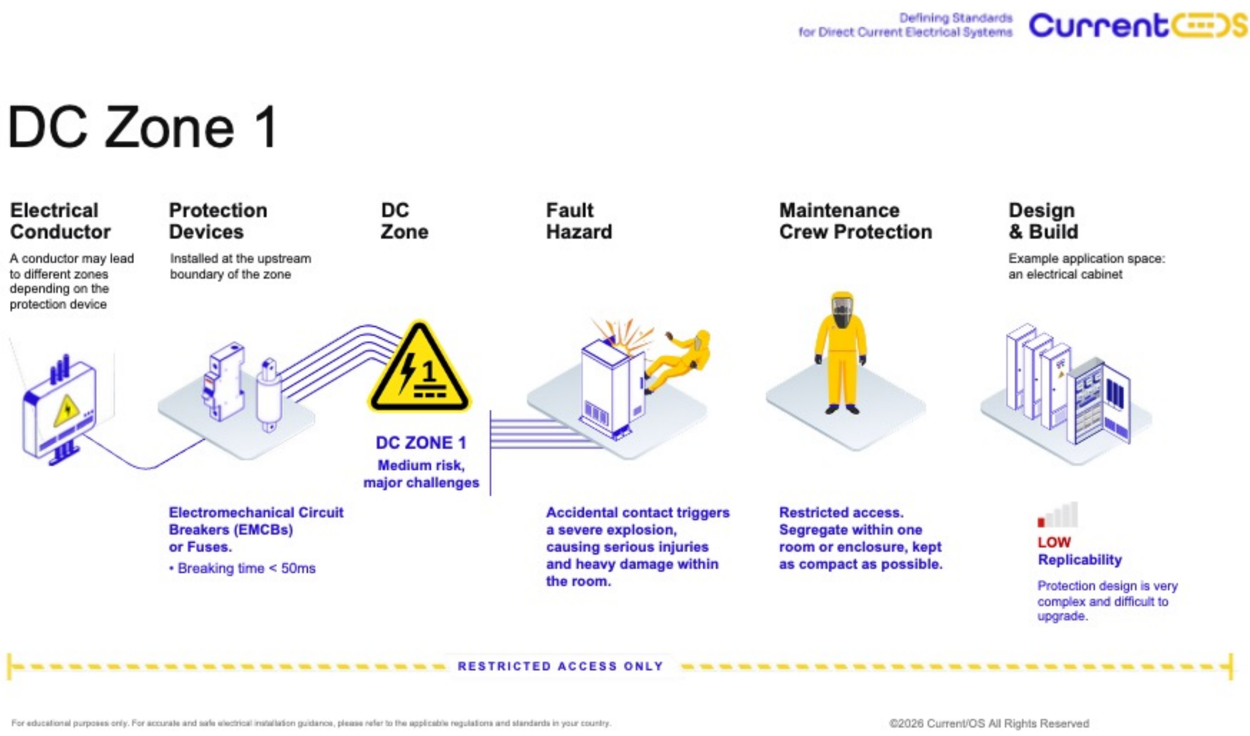
Beyond this fuse, the area becomes Zone 1. The fault hazard level becomes much lower already. However significant arc flash risk remains and system design is challenging.



Accidental contact triggers a severe explosion, causing serious injuries and heavy damage within the room.



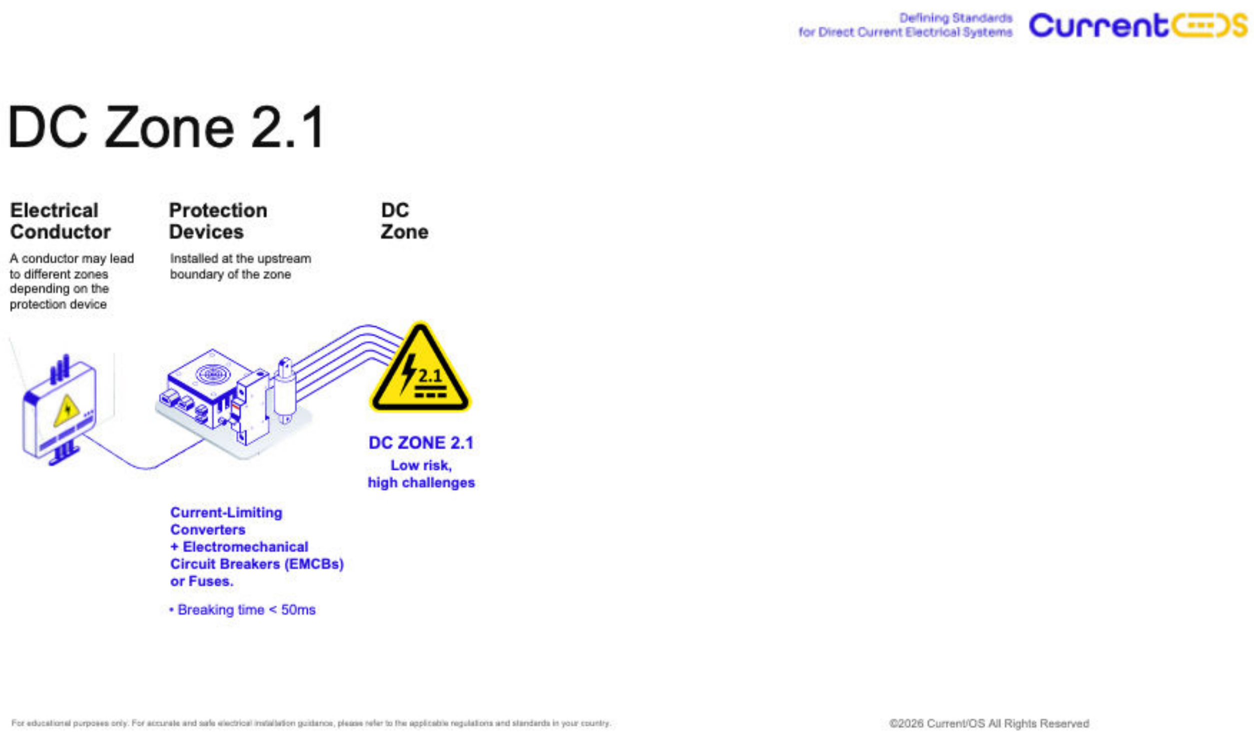
Maintenance crew needs to wear protective clothing, this is a skilled environment where only maintenance crew can attend, it shall be segregated within one room or enclosure, kept as compact as possible.



A typical example of Zone 1 is an electrical cabinet in a distribution system.

Protection design is complex and difficult to upgrade, it requires a fresh design for each project to calculate the capacitor specifications and variable cable lengths. Additionally, topology presents issues, as all sources must connect to the main panel, adding more cables and complexity. It is impractical for replication across projects.

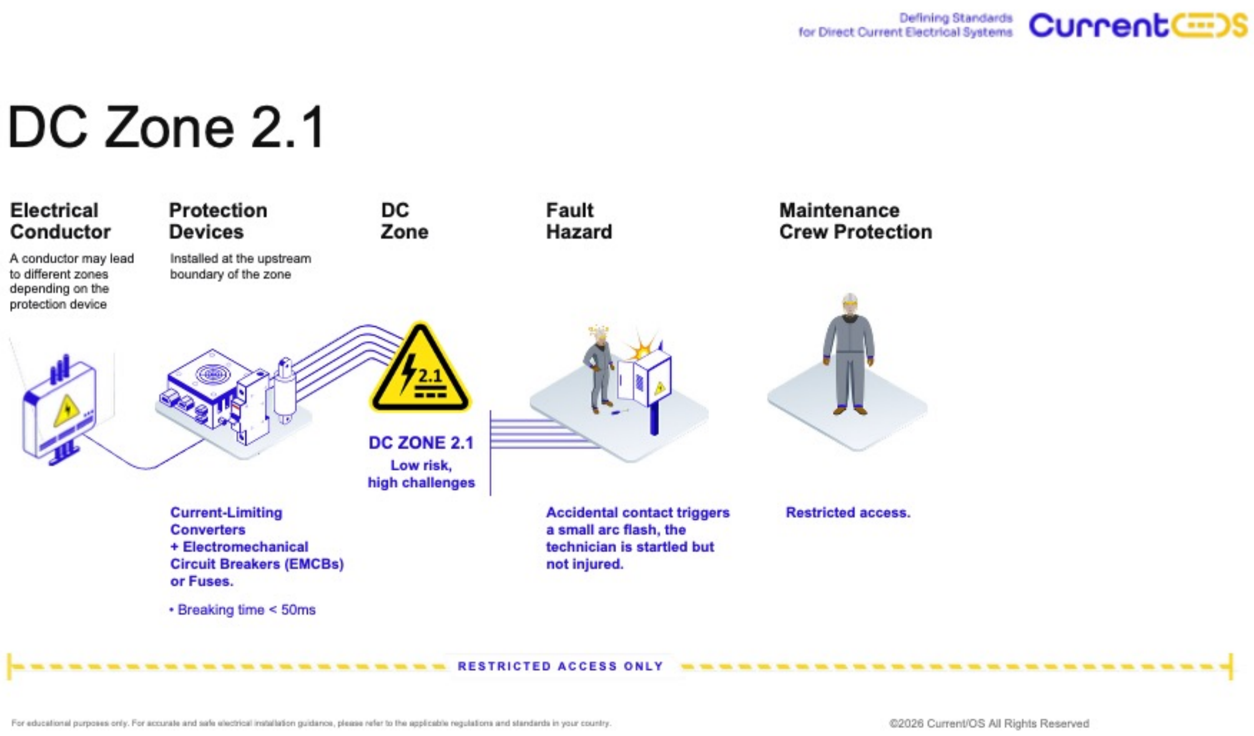
To reduce the risk further, a classical protection is installed, using current-limiting converters and electromechanical circuit breakers or fuses, with a response time of less than 50 microseconds.



Beyond this protection, the area becomes Zone 2.1, with reduced risks of arc flash, a significant step forward, but still high protection challenges.

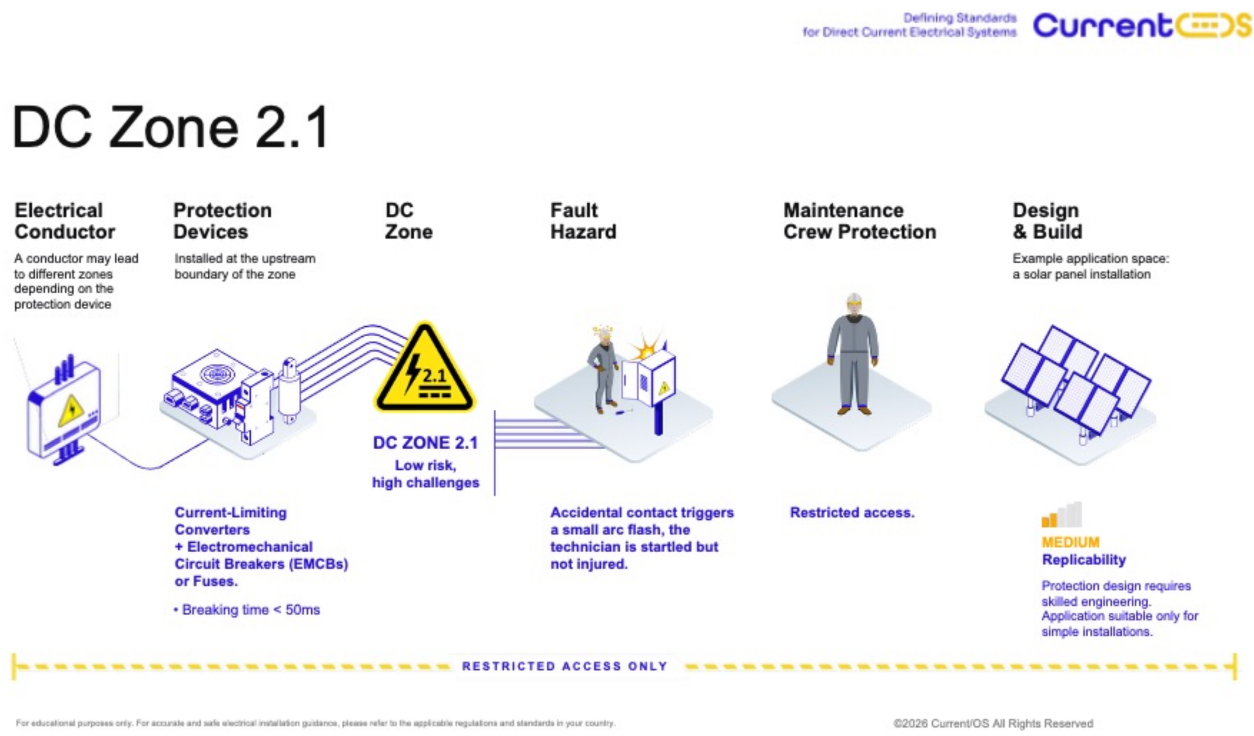
Operating behind converters limits fault currents. Still, the system must limit the energy stored in capacitors, with a maximum set at 600 Joules. More details on this limitation can be found in the Current OS System Reference Document. This approach is supported by existing IEC standards and was previously used by ETSI in telecommunications.

Significant challenges remain. Sometimes, fault currents are insufficient to trigger circuit breakers. Solutions include adding extra capacitors, which can revert the system to Zone 1 characteristics, or using external relays to activate breakers.



Again, the risk is already lower. There is a small arc flash risk, which may startle the technician, but cause no serious injury.

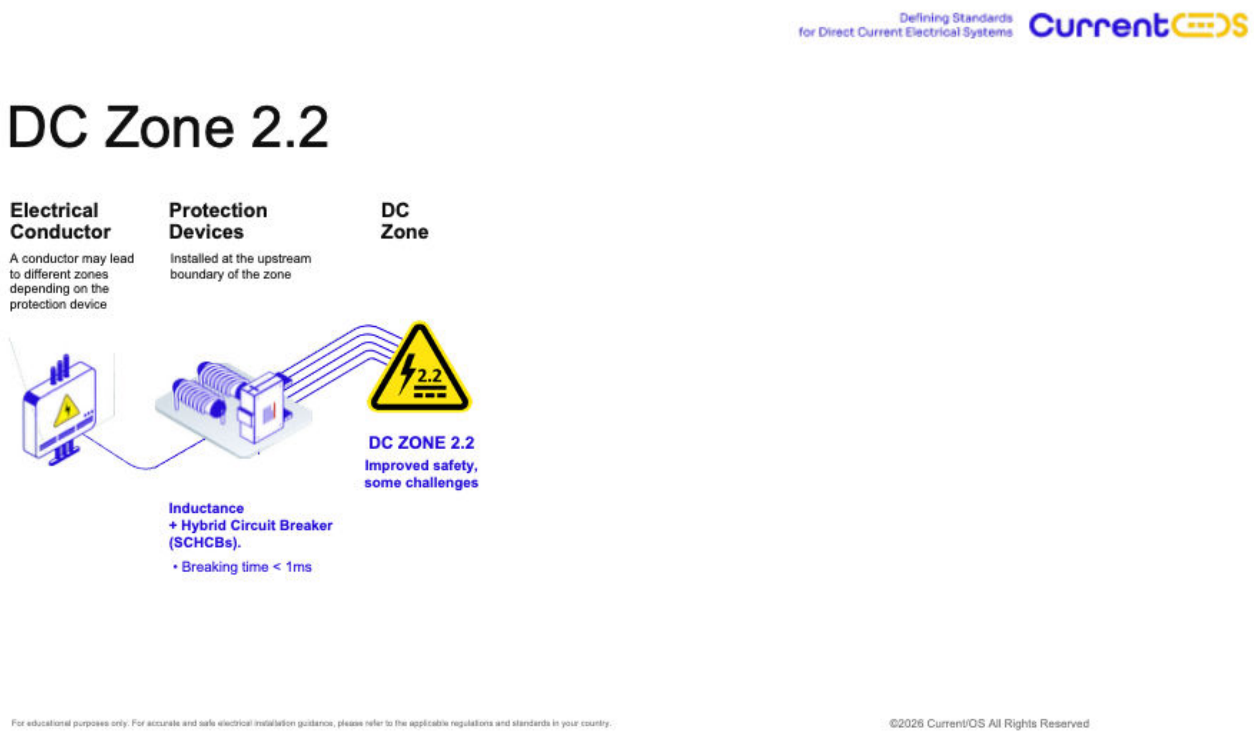
Special clothing is needed, but not as heavy as in the previous zones.



A typical application for zone 2.1 is a solar installation.

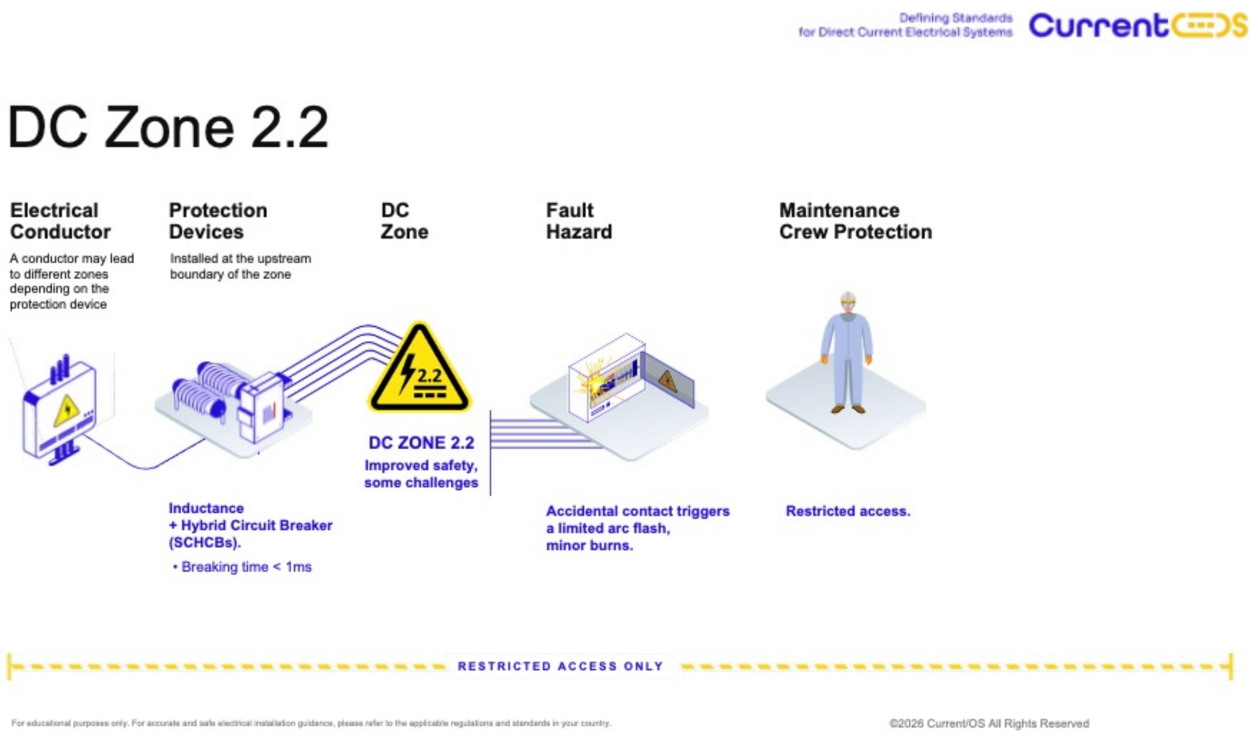
However, the complexity of calculating protection plans still limits the scalability and replicability of Zone 2.1 systems, and selectivity is not possible, making them suitable only for installations with limited complexity.

To further improve protection, inductance and hybrid circuit breakers are introduced. Hybrid circuit breakers have a typical break time of less than one millisecond. These breakers aim to reduce energy release during faults significantly, offering better safety than Zones 1 or 2.1.



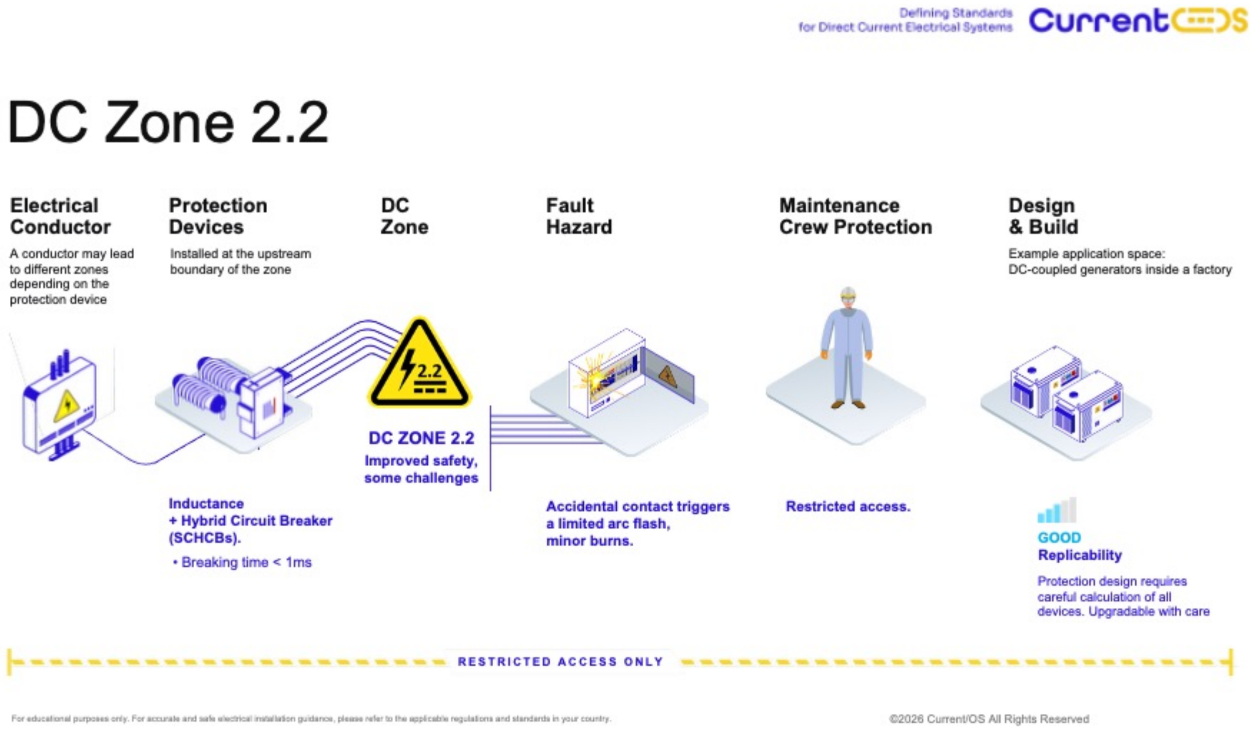
The area beyond is classified as Zone 2.2

It offers improved safety, so this is quite an attractive solution. The current doesn't flow through semi-conductors all the time. So, intuitively, losses are reduced. This isn't necessarily true all the time, however, because inductances have to be added to protect these semi-conductors, and there are often significant losses in the inductances.



Compared with Zone 2.1, we’ve significantly limited capacitor discharge. Incident energy during faults is further reduced. If there is a fault, there is a small arc, but it's very limited.

The risk for maintenance crew is lower, and protective clothing is significantly lighter.



A typical application for Zone 2.2 is the coupling of DC generators within a factory distribution system.

However, designing and implementing these systems still requires highly skilled engineers. Fault conditions must account for all sources, bidirectional devices, and converters, complicating calculations further. While Zone 2.2 allows for some degree of system replication and extensions, mastering transient phenomena and overvoltage issues remains critical. IEC standards groups are actively addressing these challenges, but full guidelines are not yet in place.

Now, let’s bring the protection further by utilizing fully electronic circuit breakers, as defined by IEC 60947-10.

Semi conductor circuit breakers operate in just a few microseconds—typically under 10 microseconds, often closer to 1, 2 or 3 microseconds, compared to traditional electromechanical breakers, which take tens of milliseconds.

Defining Standards for Direct Current Electrical Systems

DC Zones 3 & 4

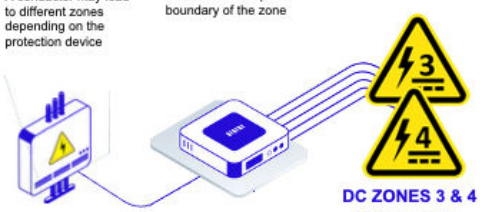
Electrical Conductor

A conductor may lead to different zones depending on the protection device

Protection Devices

Installed at the upstream boundary of the zone

DC Zone



DC ZONES 3 & 4

Highest saferty, simple design

Semi Conductor Circuit Breaker (SCCBs)

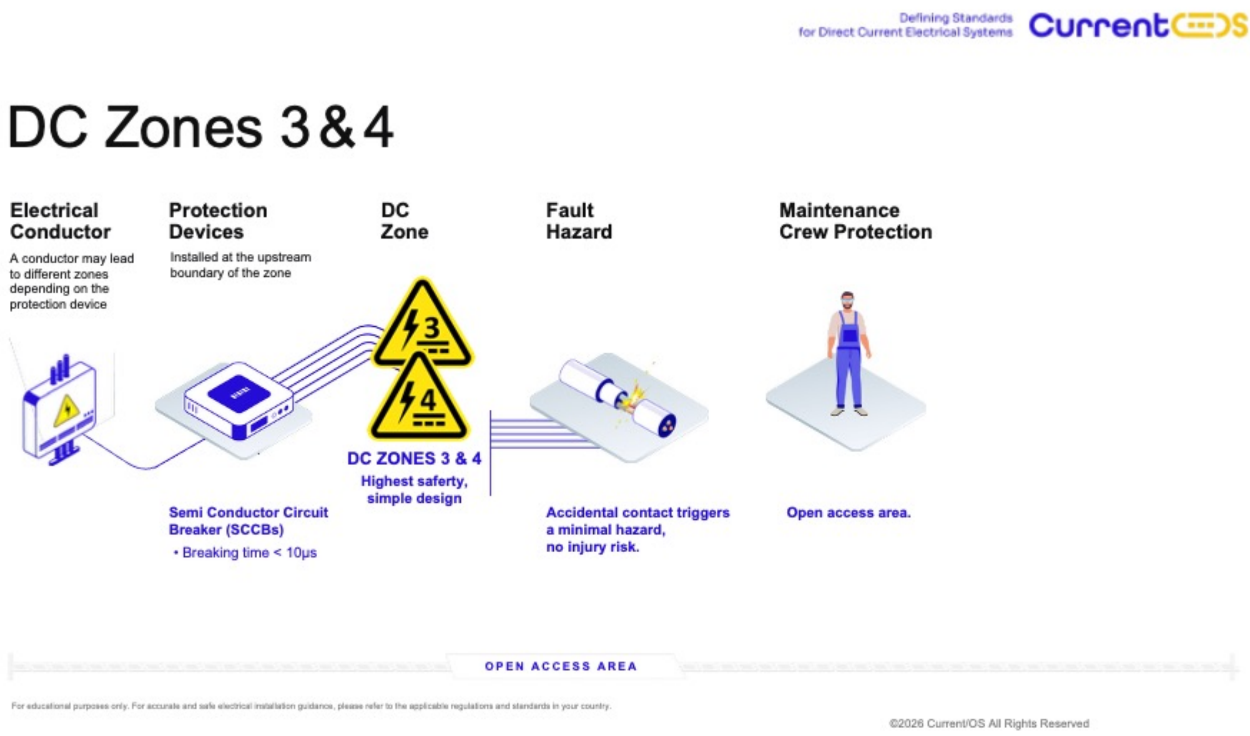
- Breaking time < 10µs

For educational purposes only. For accurate and safe electrical installation guidance, please refer to the applicable regulations and standards in your country.

The areas beyond are classified as Zones 3 and 4.

Zone 3 and 4 are similar. Zone 3 has multiple energy sources. Zone 4 has a single source.

Zone 3 is the zone championed by Current OS, with the benefit of highest safety and simple design altogether.

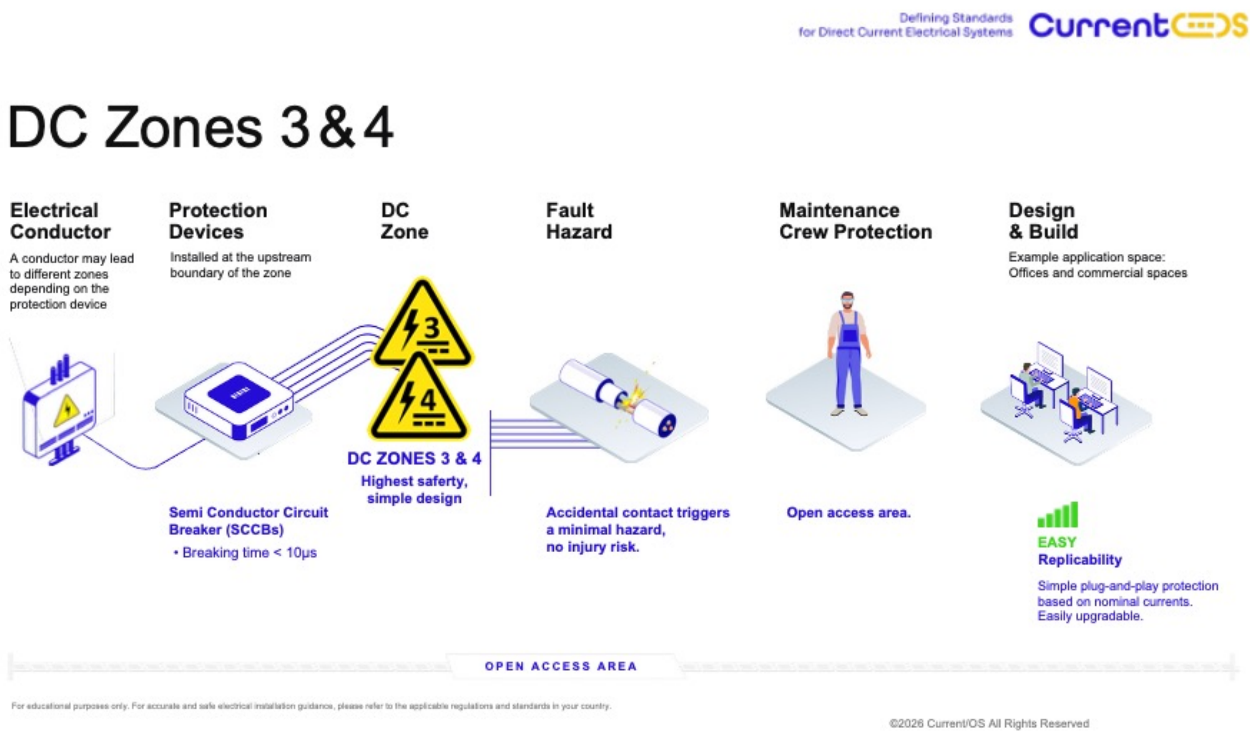


Accidental contact triggers a minimal hazard, with no injury risk. The ultra-fast protections limit the contribution of different sources to a short circuit. Even the inductance of the cables ensures that only the closest source contributes significantly. This electronic protection effectively isolates the system from fault-related phenomena. Incident energy is below 1,2 Cal/cm². This is thanks to the ultra-fast response of SCCBs, addressing safety concerns that have traditionally made electricians wary of DC systems.

The safest zone is Zone 4. While both have ultra-fast electronic protections, Zone 3 is multi-source, meaning all sources must be deactivated to secure the circuit. In

Zone 4, there is only one source, making it much simpler to identify and control the current source.

Mid-point earthing makes maintenance simpler. The maintenance crew does not need to wear special clothing because it's actually an unskilled environment. It is an open access area.



Typical applications for Zones 3 and 4 include offices, commercial spaces, residential areas as well, so actually everywhere where there is a need for DC.

System design is simple, and can easily be replicated and upgraded.

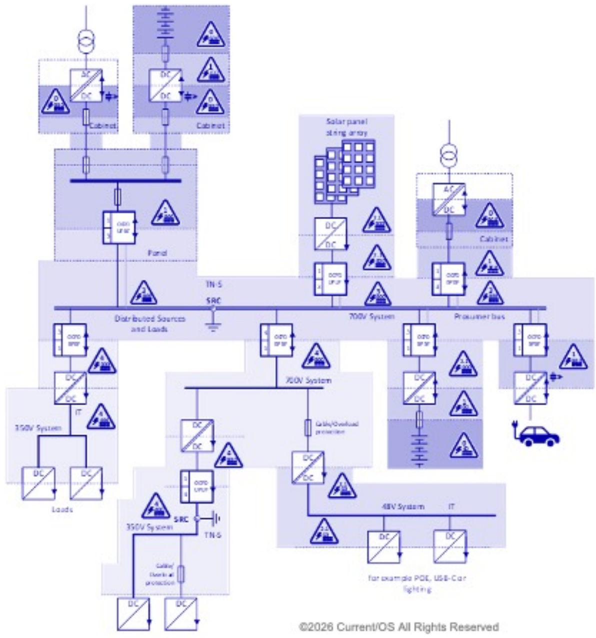
Unlike traditional radial systems where all sources connect to the main panel, Zone 3 allows loop, mesh, or bus architectures. There's no longer any need to bring all the sources back to the main panel and start again with radial distribution. You can connect as close as possible to the bus. For example, photovoltaic converters on a parking lot are connected to the same point as the electric recharging stations underneath. Photovoltaic converters don’t need to route through the main panel and then back to EV chargers.

This architectural innovation is paired with simplified calculations. DC Zones 3 & 4 are design free, or rather, are designed at nominal. Fault-related calculations become unnecessary because faults are cleared so quickly that issues like cable overheating, electrodynamic forces, or contributions from distant sources are eliminated. They don’t even have time to contribute. Fault energy no longer depends on the number of sources. Only the closest source contributes. It simplifies protection design and ensures natural selectivity—the nearest breaker always trips first.

Additionally, this new architecture reduces copper usage significantly, cutting conductor requirements by three on a complete installation. There is no need to transfer energy from one point to another in a cable. DC can save conductors by changing the topology and organizing the cables differently in the building. We will explore this topic in more detail later.

Zones 3 and 4 are championed by Current OS. Together with enhanced safety, simplfied design at nominal and flexible topologies make Zone 3 & 4 uniquely suited for complex installations, offering groundbreaking benefits for commercial buildings—benefits that are distinctly different and entirely new compared to traditional AC systems.

DC Zones and Protection Rules



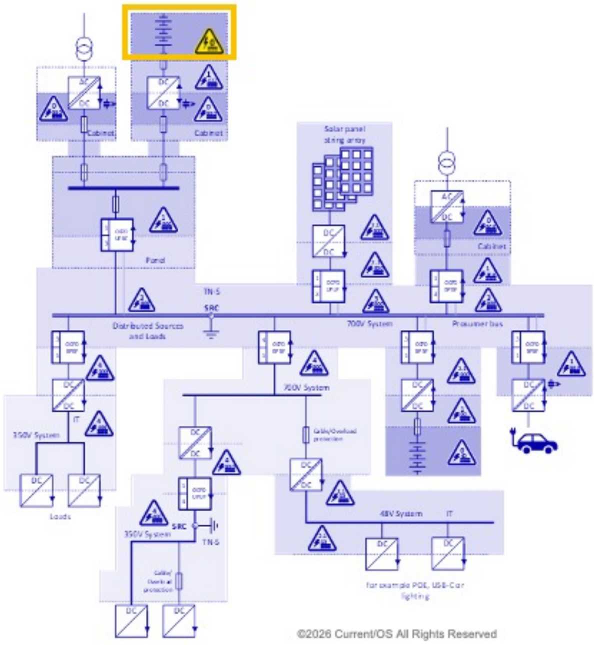
To summarize, let’s look back at this electrical schematic example. As the DC Zone number increases, the level of safety also increases.

Defining Standards for Direct Current Electrical Systems

CurrentOS

DC Zones and Protection Rules

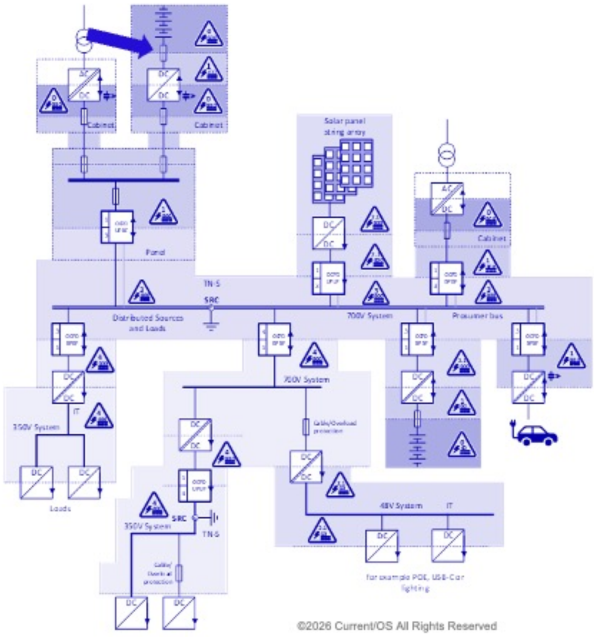
- **DC Zone 0** voltage source without protection device



Let’s start with a battery. This is classified as Zone 0, the most dangerous zone, without protection devices.

DC Zones and Protection Rules

- **DC Zone 0** voltage source without protection device

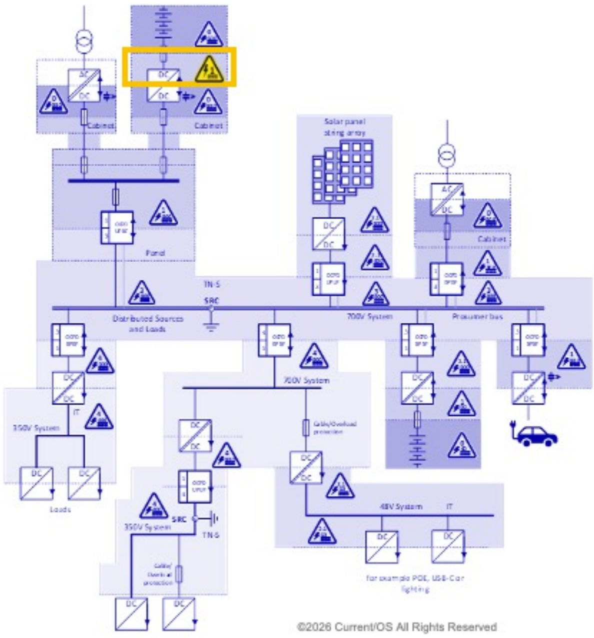


A fuse or breaker is installed.

Defining Standards for Direct Current Electrical Systems

DC Zones and Protection Rules

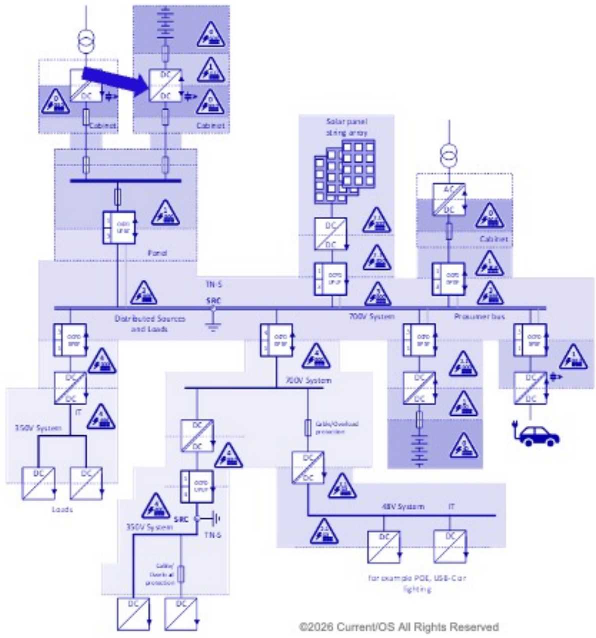
- **DC Zone 0** voltage source without protection device
- **DC Zone 1** voltage source protected by breakers or fuses, high fault currents and flash risk



Beyond, the area becomes Zone 1. The danger is significantly lower, but as mentioned earlier, currents can still be very high, and the risk of arc flash remains high.

DC Zones and Protection Rules

- **DC Zone 0** voltage source without protection device
- **DC Zone 1** voltage source protected by breakers or fuses, high fault currents and flash risk

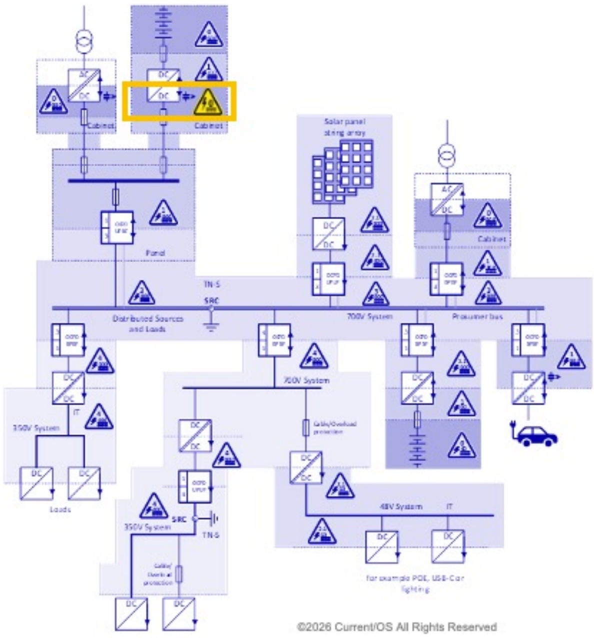


Next, let’s add a large converter.

Defining Standards for Direct Current Electrical Systems CurrentOS

DC Zones and Protection Rules

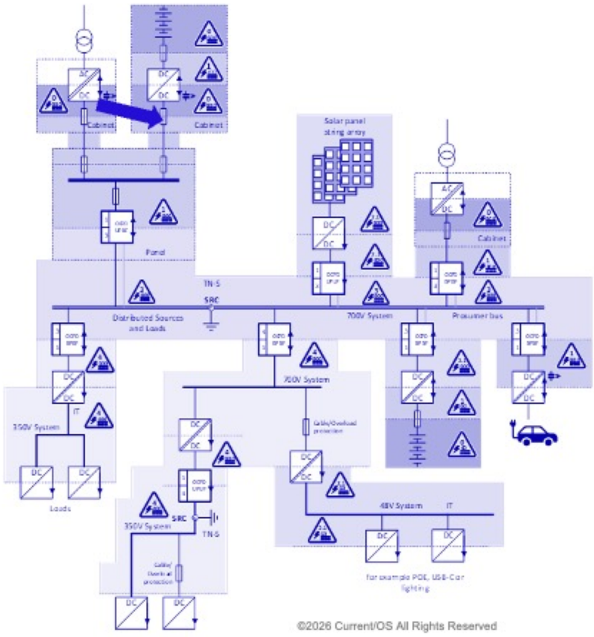
- **DC Zone 0** voltage source without protection device
- **DC Zone 1** voltage source protected by breakers or fuses, high fault currents and flash risk



At its output, the converter has substantial capacitors that store a lot of energy, similar to a battery. As a result, the output of this converter is also classified as Zone 0.

DC Zones and Protection Rules

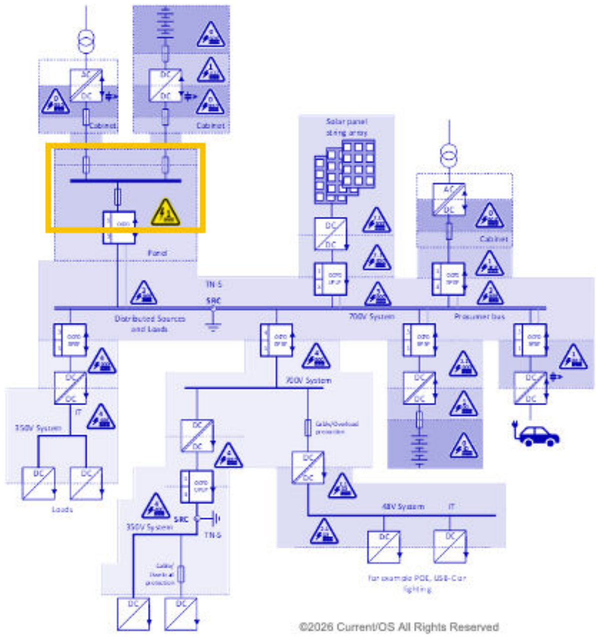
- **DC Zone 0** voltage source without protection device
- **DC Zone 1** voltage source protected by breakers or fuses, high fault currents and flash risk



Adding another fuse reduces the risk again, Defining Standards for Direct Current Electrical Systems Current/OS

DC Zones and Protection Rules

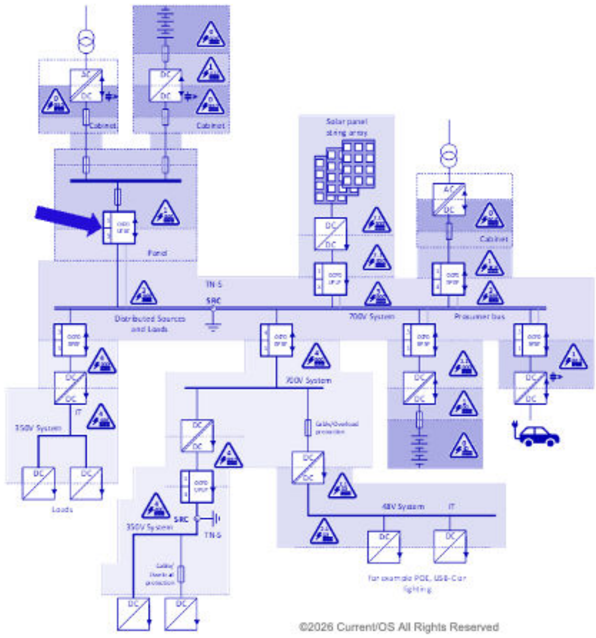
- **DC Zone 0** voltage source without protection device
- **DC Zone 1** voltage source protected by breakers or fuses, high fault currents and flash risk



returning this part of the circuit to Zone 1. On the same busbar where the battery is connected, a converter linked to the public grid is also connected, which remains part of Zone 1.

DC Zones and Protection Rules

- **DC Zone 0** voltage source without protection device
- **DC Zone 1** voltage source protected by breakers or fuses, high fault currents and flash risk

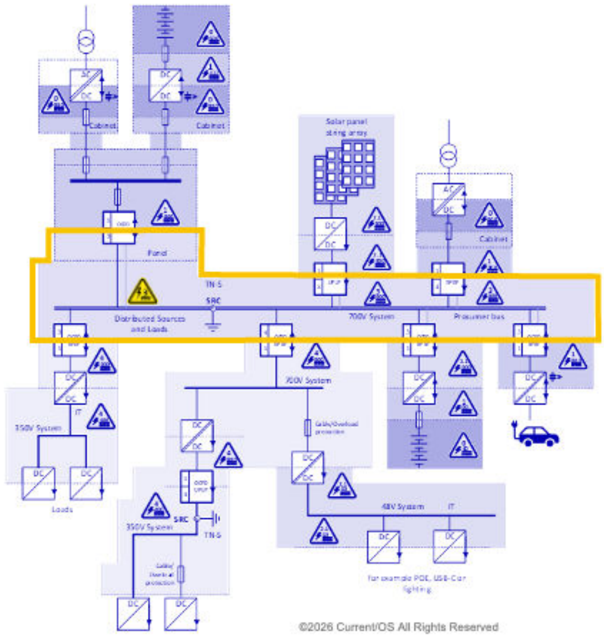


Now, an electronic circuit breaker can be installed. IEC 60947dash 10 defines these electronic breakers.

Defining Standards for Direct Current Electrical Systems

DC Zones and Protection Rules

- **DC Zone 0** voltage source without protection device
- **DC Zone 1** voltage source protected by breakers or fuses, high fault currents and flash risk
-
- **DC Zone 3 and 4** ultrafast semiconductor protection simplifies a lot the design and increase safety with very low fault energy



The area transitions to Zone 3.

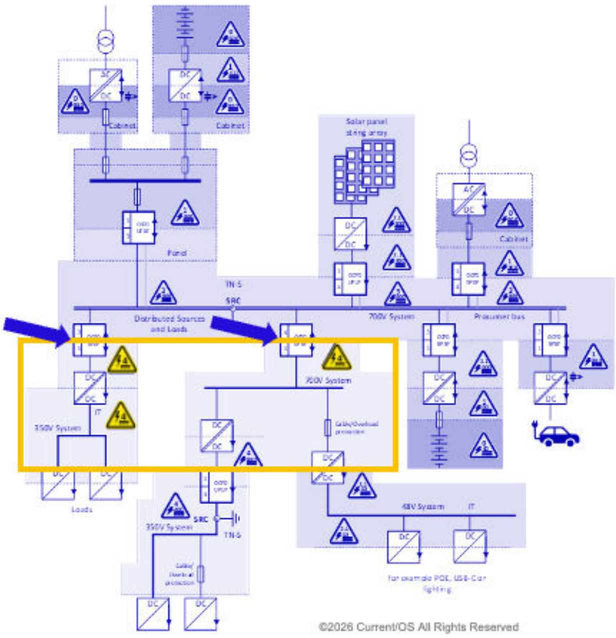
In Zone 3, ultra-fast protections effectively isolate the system from fault-related phenomena.

Designing a protection plan is much simpler as the installation can be calculated based on nominal conditions. Cables are sized for their nominal current, and protection planning is straightforward.

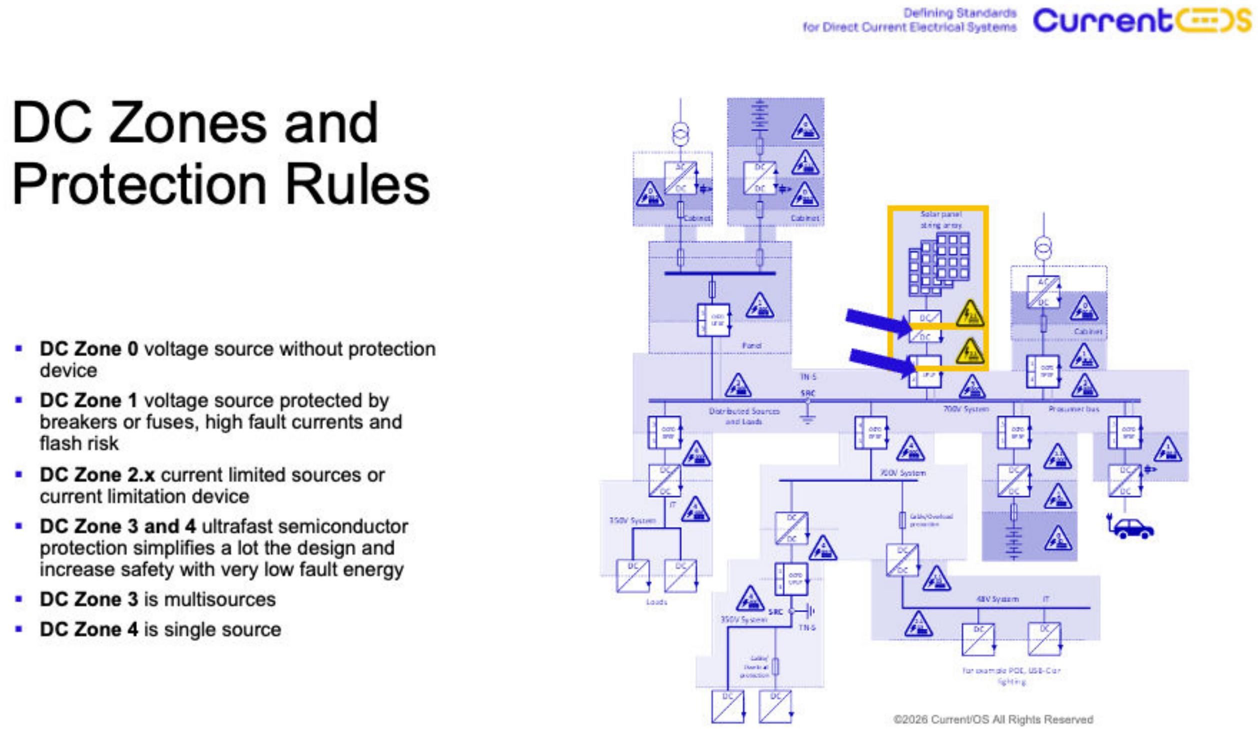
Defining Standards for Direct Current Electrical Systems CurrentOS

DC Zones and Protection Rules

- **DC Zone 0** voltage source without protection device
- **DC Zone 1** voltage source protected by breakers or fuses, high fault currents and flash risk
-
- **DC Zone 3 and 4** ultrafast semiconductor protection simplifies a lot the design and increase safety with very low fault energy
- **DC Zone 3** is multisources
- **DC Zone 4** is single source



If there is only a single energy source, the area is classified as Zone 4.



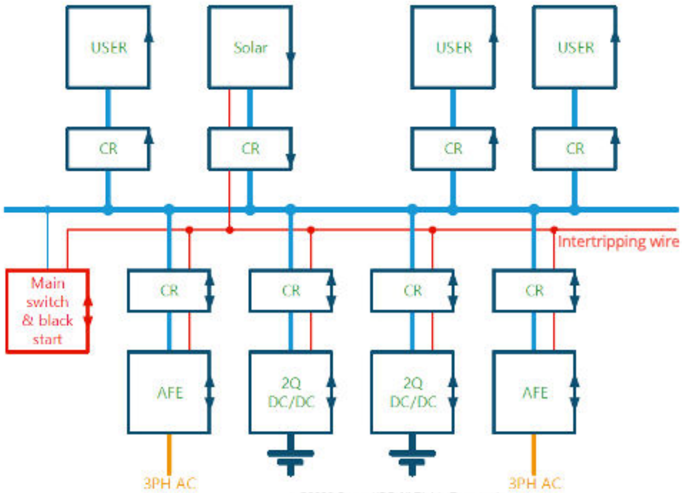
Zone 2.1 is typical of photovoltaic installations, with current-limiting converters and electromechanical circuit breakers or fuses. There are high fault currents and flash risk. Complex calculations are required which limit the scalability and replicability. Selectivity is not possible, making it suitable only for simple installations.

In Zone 2.2, hybrid circuit breakers are introduced to further reduce capacitor discharge and incident energy during faults. However, designing and implementing these systems still requires highly skilled engineers. Mastering transient phenomena and overvoltage issues remains critical. Standards groups are actively addressing these challenges, but guidelines are not yet in place.

Defining Standards for Direct Current Electrical Systems CurrentOS

Intertripping Wire: A Simple Solution

- The safety intertripping wire provides a general fault protection solution
- It can also shut down all surrounding power sources during maintenance
- A 48 V high-impedance signal trips the connected source when shorted to 0 V. It also disconnects the power feed to the grid



For personal safety in a multi-source system, several protective measures are implemented, including differential protections. However, in a system that is both extremely fast and multi-sourced, coordination becomes essential. This requires a mechanism to trip all differential protections simultaneously or to cut off power sources collectively.

To address this, Current OS promotes a solution called the Intertripping Wire. This is a simple yet highly effective method. Alongside the power cable, a small 48-volt wire runs in parallel within the same cable. This wire serves as a high-impedance signal. If it is short-circuited, the signal drops to zero without causing significant sparks.

This high-impedance signal enables power conversion in the converters. When the signal drops to zero, the converters stop operating with a predefined response time.

The Intertripping Wire is remarkably straightforward to implement and highly efficient, making it an essential feature in systems with multiple sources.

Currently, in traditional setups, there is often only a single source—the public grid. Cutting all power simply involves tripping the main breaker. However, in tomorrow’s multi-source buildings, power sources could be scattered throughout the structure. To intervene safely, it will be crucial to ensure that all power within a specific area is disconnected.

The Intertripping Wire provides this assurance. Short-circuiting the wire to zero volts in any location shuts down all sources in the surrounding zone. Importantly, this doesn’t mean the entire building goes dark—only the specified zone is isolated. This ensures that maintenance personnel can work safely, knowing the area is fully powered down.

Additionally, the Intertripping Wire facilitates coordination among differential protections, ensuring seamless personal safety measures across the system.

The Intertripping Wire not only enhances safety for workers but also reinforces the overall reliability and efficiency of multi-source DC systems.

Defining Standards for Direct Current Electrical Systems Current/OS

Protection against electric shock

- Breaking times much faster
- Fault energy much lower
- Low arc flash risk (Incident Energy < 1.2 cal/cm^2)
- RCD possible for long cables as fault protection and additional protection against direct contacts
- Certified equipment for interoperability and safety via the Current/OS Certification Scheme

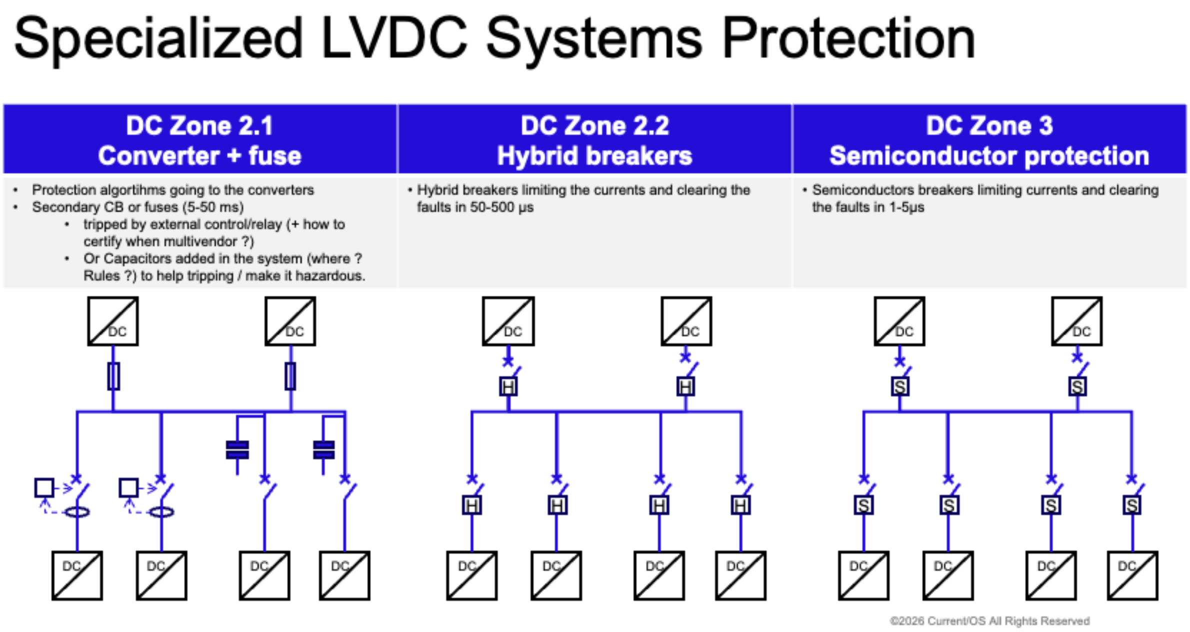
Current/OS DC Zones 3 & 4 are safer than traditional AC installations

With all this being said, we now understand that Zone 3 and 4 are safer than traditional AC installations, for several reasons.

First of all, because in Zone 3 and 4, we use ultra fast circuit breakers, with very, very fast breaking time. We are talking about tens of microseconds. The related fault energy is extremely low. And if we have a very low fault energy, also in the case of an arc flash, the incident energy is lower than 1.2 calories per square centimeter as we mentioned earlier, which means that maintenance crew doesn't need personal protection equipment inside Zone 3 and 4.

Nevertheless, Residual Current protection Devices, or RCDs, can still be used on long distribution cables. They may be used for fault protection and as an additional protection against direct contact.

Current OS has developed a certification scheme to guarantee that certified equipment are available for interoperability and safety.



As you have seen, Current/OS recommends keeping the extent of Zones 0, 1 and 2 as small as possible. Whenever possible, power distribution should take place in Zones 3 and 4.

This is the principle behind General Purpose LVDC Systems: use multiple sources and minimise the distribution of power in areas other than Zones 3 and 4. This approach requires the use of protection devices based on solid-state technologies.

However, in certain use cases, the use of these devices may be challenging, either because the operating currents are very high or because such products do not yet exist or are not readily available.

In these situations, it may be appropriate to distribute power instead within Zone 2.1 or Zone 2.2.

Current/OS has therfore defined Specialized LVDC Systems. These systems are intended for applications where Zones 1 to 2.2 cannot be fully contained, and where power distribution within these zones is essential.

In these cases, the system should remain as confined as possible, ideally within a dedicated electrical room, and should be designed with the support of qualified experts.

The use of hybrid protection devices offers certain advantages, but it also requires a more detailed system design, particularly regarding the calculation of cumulative fault currents. These calculations can become extremely complex in systems with multiple sources, especially when some sources, such as batteries, can also behave as loads at other times.

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DC Zone 3 can bring up to 2/3 copper saving

Let's now review the benefits and copper savings associated with Zone 3 we've mentioned. Current OS states that copper usage can be reduced by up to two-thirds in Zone 3 configurations. Understandably, this raises the question: how is that possible?

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DC Zone 3 can bring up to 2/3 copper saving

- In addition to the inherent DC ~20% copper savings at equivalent rms (refer to numerous academic studies)

First, let’s start with a foundational concept. When transferring power through a DC cable, approximately 20% of copper can be saved compared to AC. This efficiency is due to the absence of the skin effect in DC, which allows better utilization of the cable's cross-section. This is why high-voltage DC (HVDC) is used by utilities to transport energy over long distances.

While this 20% savings is valuable, it alone isn’t transformative enough for standard building applications. But Zone 3 allows us to achieve even more.

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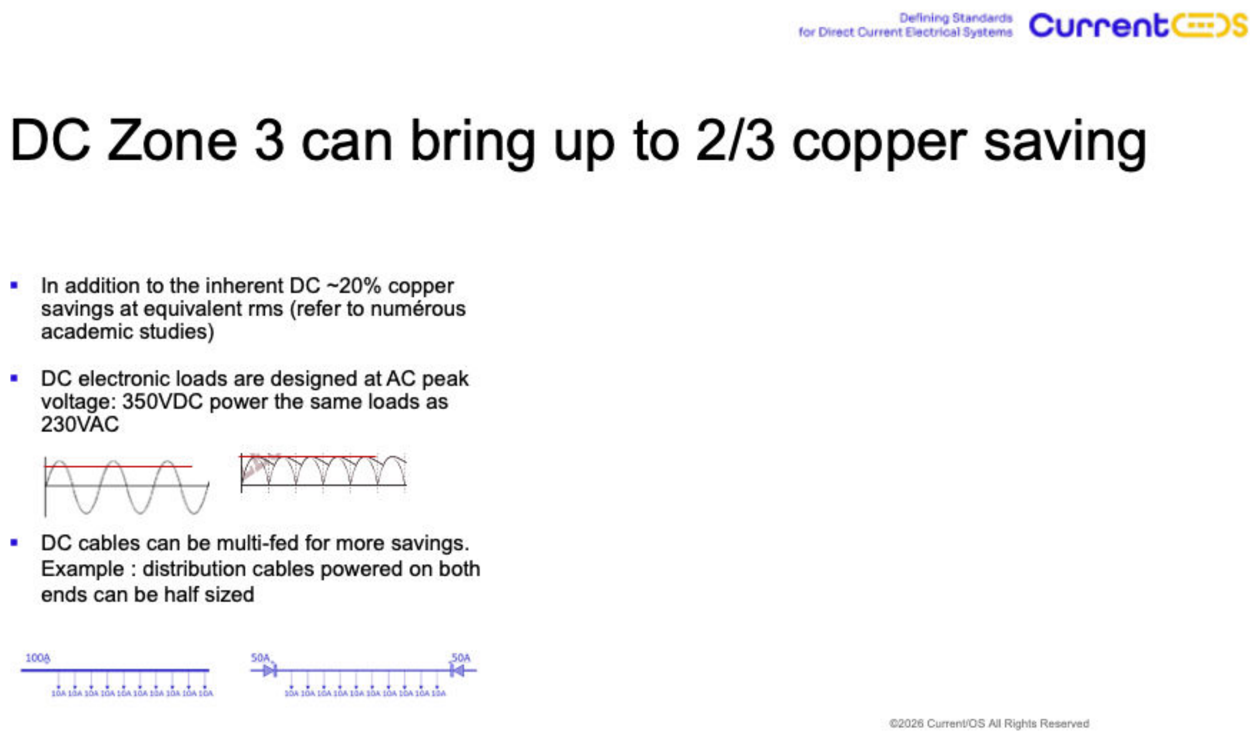
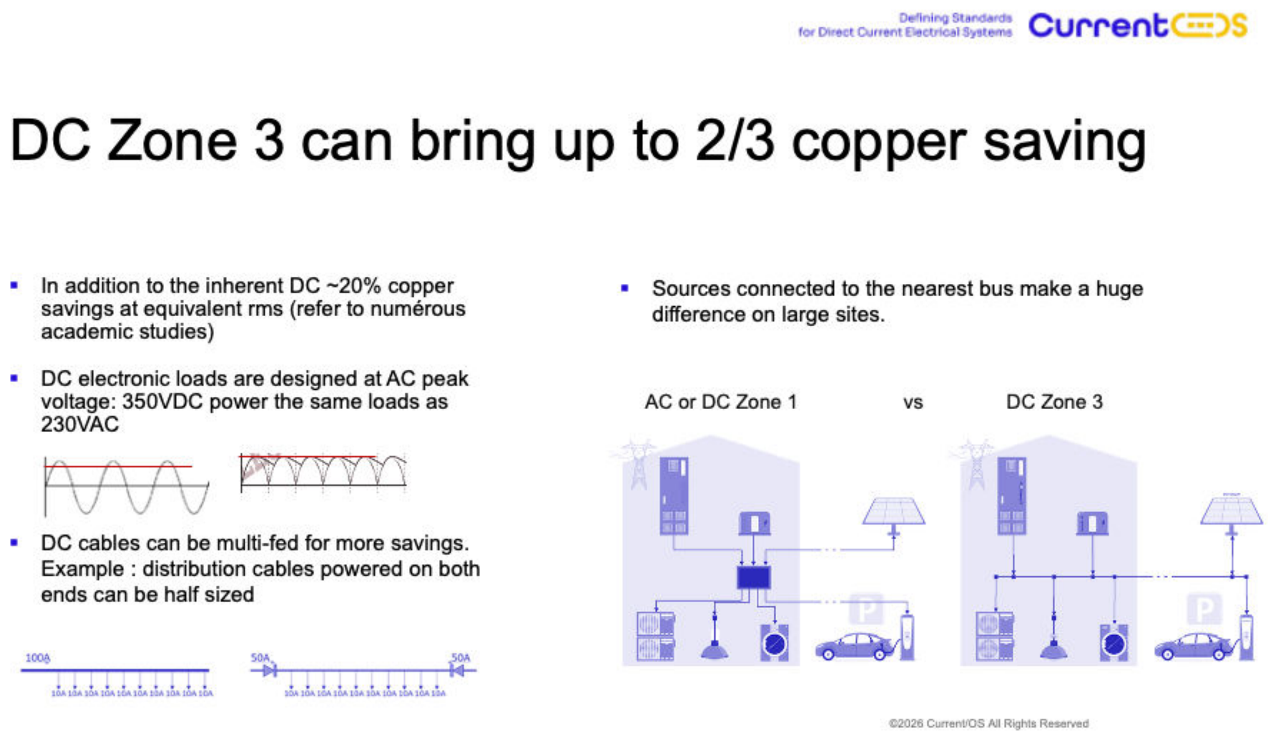
DC Zone 3 can bring up to 2/3 copper saving

- In addition to the inherent DC ~20% copper savings at equivalent rms (refer to numérous academic studies)
- DC electronic loads are designed at AC peak voltage: 350VDC power the same loads as 230VAC

The next point involves load voltage. Many modern loads designed for 230 volts AC internally convert that voltage to DC. For example, EV chargers, LED lights, televisions and computers, all rectify AC to DC internally, typically operating around 350 volts DC. By increasing the operating voltage, copper requirements are further reduced.



The third factor is distribution topology. Consider this example: in a radial AC distribution system, if you have 10 loads, each requiring 10 amps, you need a 100-amp cable to supply them. However, in DC, thanks to components like diodes that prevent reverse energy flow, you can inject energy at both ends of the cable. This means that to support the same 10 loads, only a 50-amp cable is required.



Finally, unlike AC or Zone 1 setups, where all sources must route energy to a main panel before being distributed to loads, Zone 3's ultra-fast electronic protections allow energy to be injected or drawn from the bus at distributed points.

So this distributed energy approach drastically reduces cable length. When comparing diagrams of AC and Zone 3 topologies, the reduction in cabling on the Zone 3 side is immediately apparent.

You can see on the right hand side of this slide, 2 diagrams: AC or Zone 1 and Zone 3. Zone 3 has fewer cables than AC, it is obvious.

By combining all these factors—improved copper utilization, higher load operating voltages, distributed bus energy injection, and advanced topologies enabled by ultra-fast protections—Zone 3 achieves significant copper savings. In many cases, these savings reach up to two-thirds. It’s important to note that this is not a universal rule; the actual savings will vary depending on the specific building and project design. In some cases, the reduction may be less, while in others, it could exceed two-thirds.

However, across multiple projects, these observations consistently demonstrate the potential for substantial copper savings, making Zone 3 not only efficient but a game-changer for modern electrical installations.

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Recommended Use of DC Zones

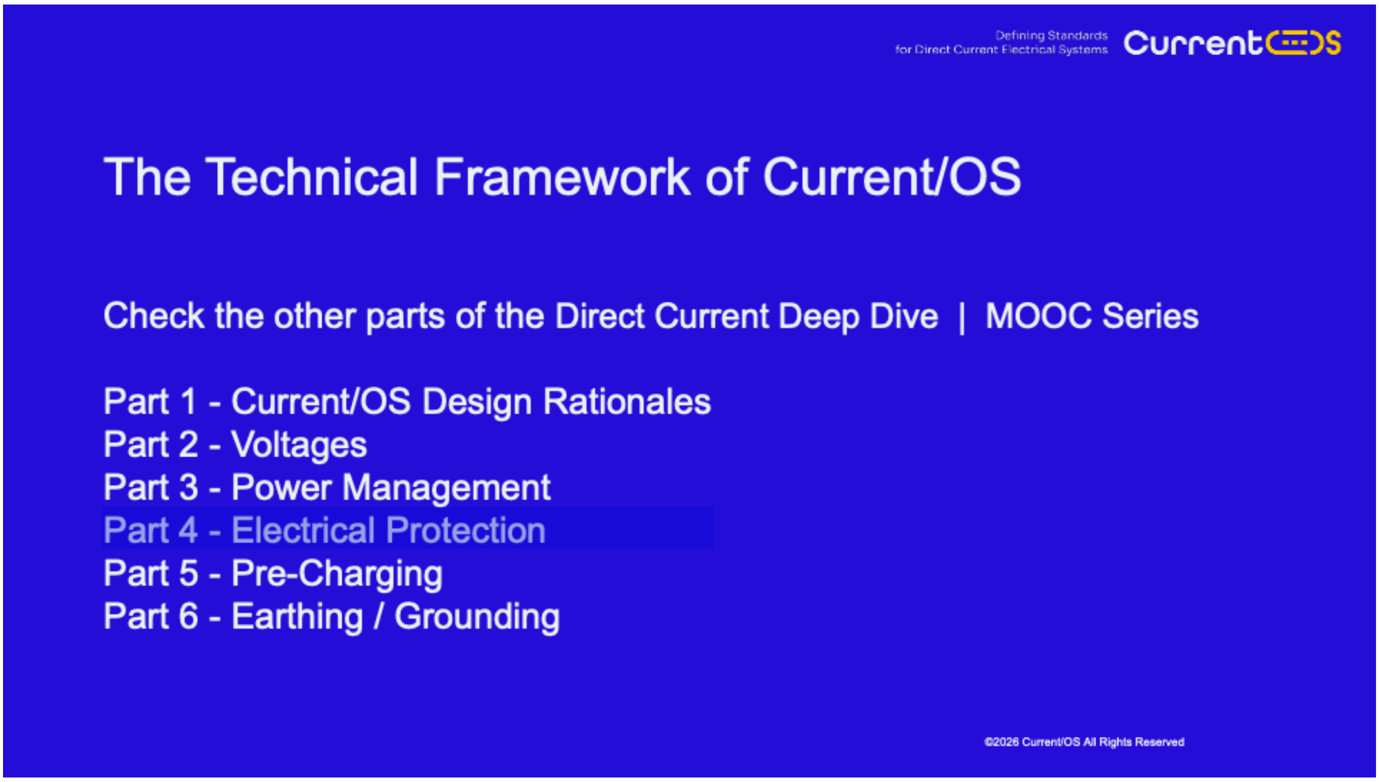
DC Zone 0 DC Zone 1	DC Zone 2.1 DC Zone 2.2	DC Zone 3 DC Zone 4
Never extend beyond an equipment or the electrical room	Only for protected places with a qualified 24/7 maintenance team	Can be distributed in a commercial building

To summarise the intended use of the DC zones:

Zones 0 and 1 should never extend beyond a piece of equipment or the electrical room.

Zones 2.1 and 2.2 are intended only for protected areas with a qualified 24/7 maintenance team.

Zones 3 and 4 can be distributed throughout a commercial building with open access.



This concludes the electrical proof Current OS.

Want to learn more? Check out the other five Current/OS MOOC videos covering an introduction to Current OS, voltages, power management, precharging and earthing or grounding

Thank you for watching, see you in the next video!

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