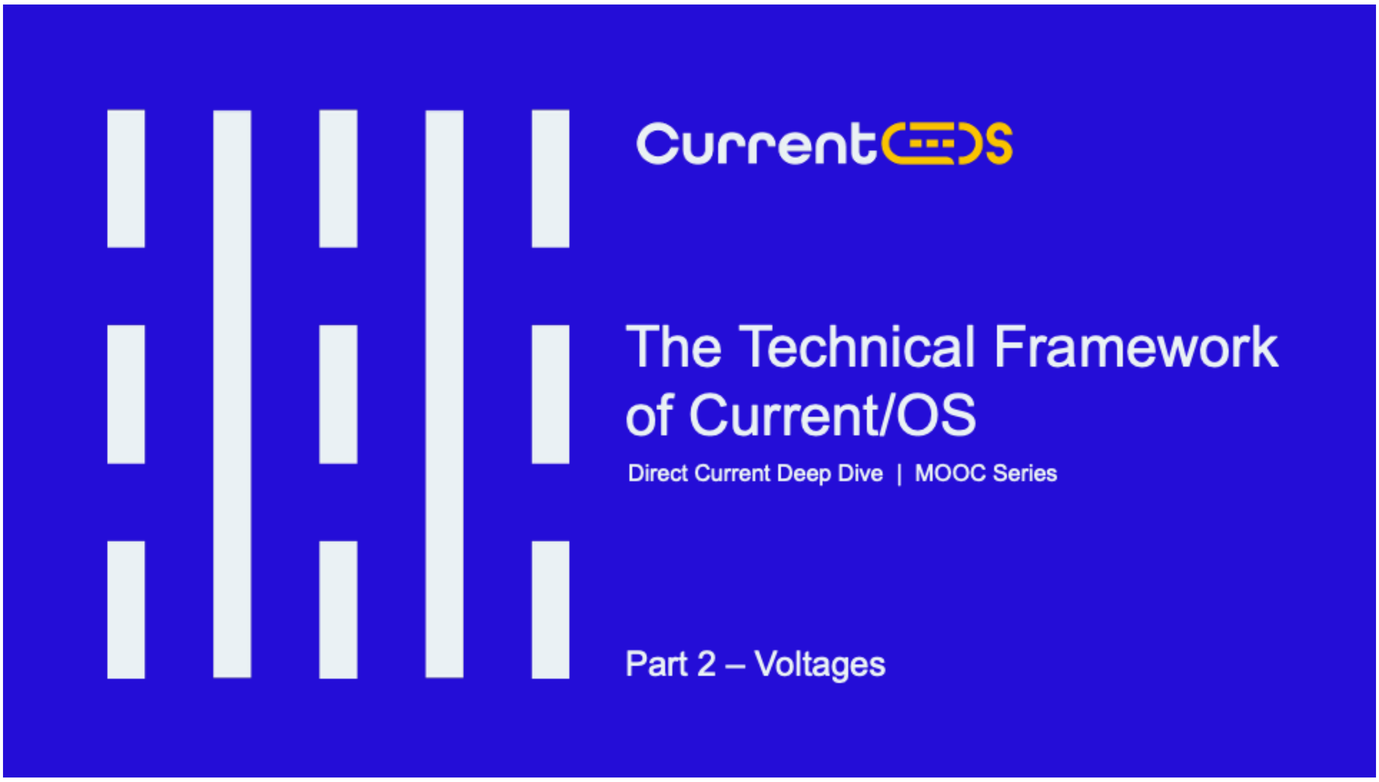
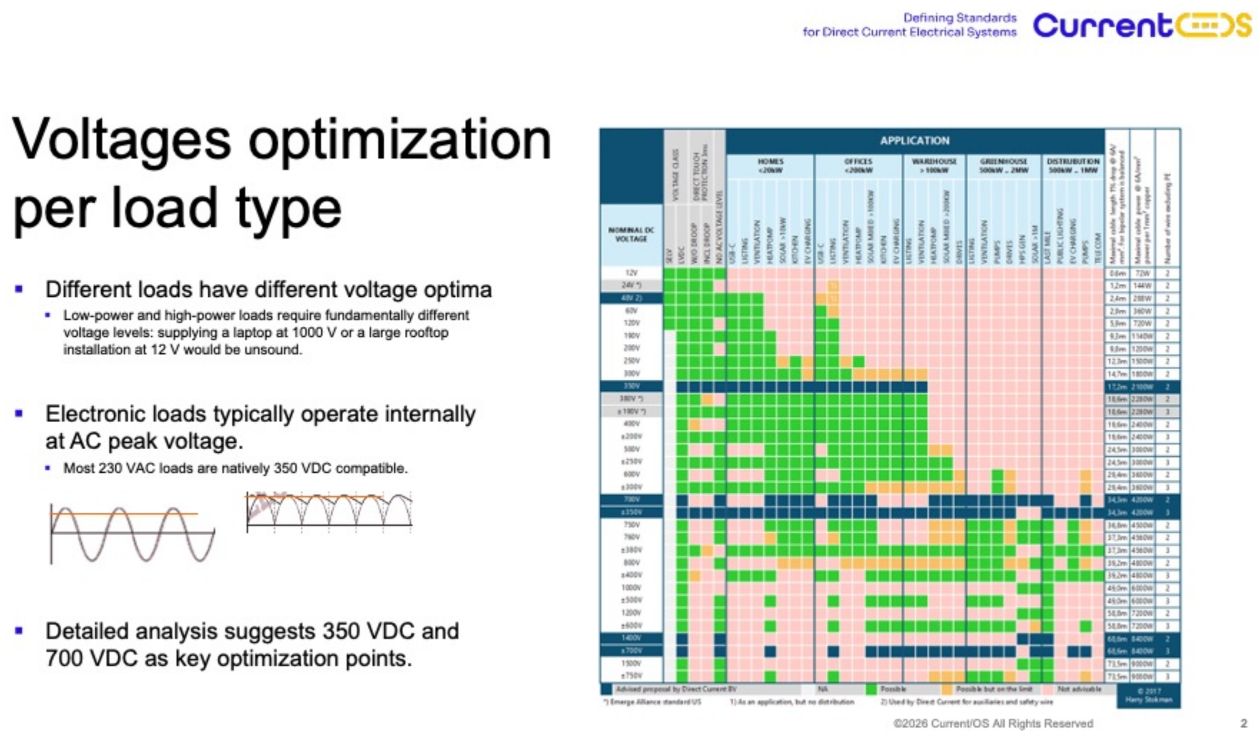


Welcome to the Direct Current Deep Dive Series: the Technical Framework of Current OS" , a MOOC designed to dive into the principles behind Current OS technical decisions and their role in defining the standard for Direct Current electrical systems, also commonly referred to as DC-coupled systems, or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

This video is part 1 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 establish the context and reasoning behind Current OS work, explain the underlying principles that drive Current OS's technical choices, highlighting why so many companies have joined forces in this collaboration within Current OS.

Quick note: from now on, we’ll refer to Direct Current as DC and Alternating Current as AC for simplicity.



Studies were conducted on different types of loads and voltage bands.

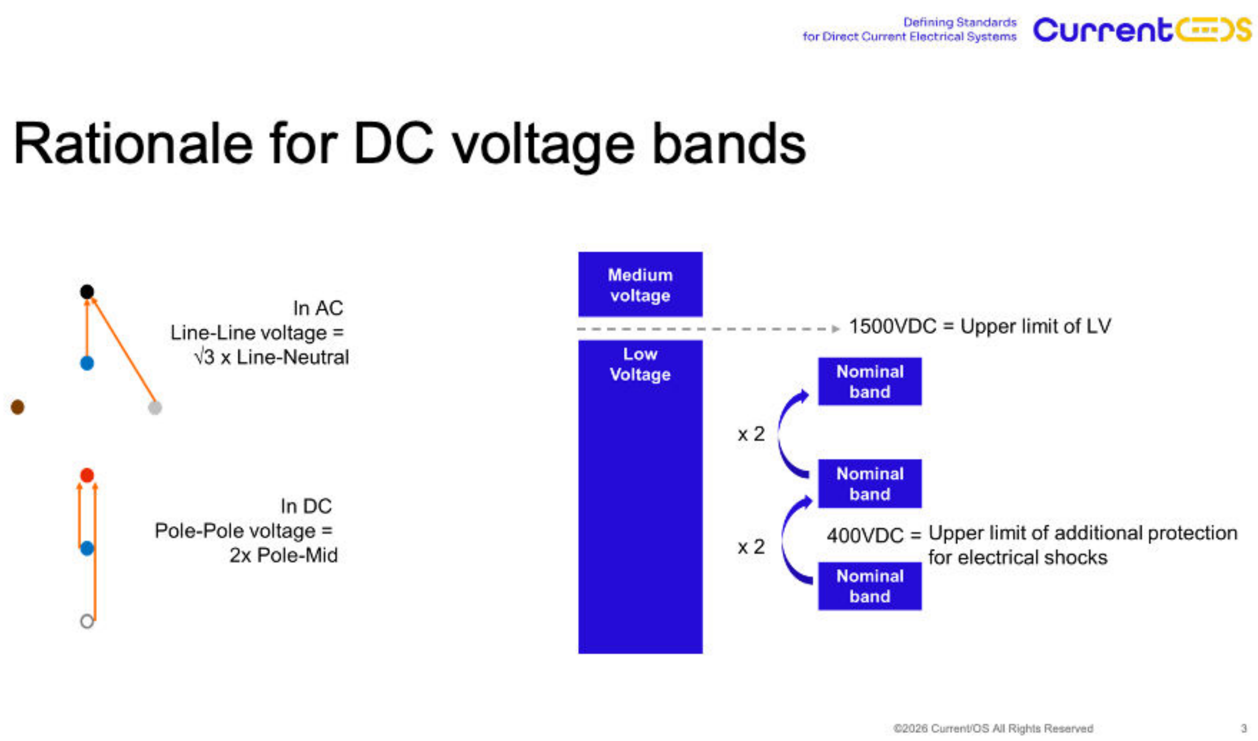
Different loads demand different voltages. There’s an optimum for each application. You wouldn’t power your laptop with 1,000 volts, nor would you run a rooftop heat pump on 12 volts. It’s about finding the right voltage for each use case, and patterns are starting to emerge.

One key finding stands out: most current loads designed for 230V AC are actually internally built to handle a maximum constant voltage of 400V. As a result, they perform very well around 350V DC.

Why is that? Many of today's AC loads include internal electronics, and the first thing those electronics do is convert AC to DC. This means their internal nominal voltage is often closer to 350V DC than to 230V AC. With DC, the loads naturally allow for higher voltage bands. It's not just about optimizing cables—it's the way many existing products are designed.

We also see a clear need for higher voltages for more powerful loads, such as EV chargers or heat pumps. These loads require something equivalent to 400V three-phase AC but in a DC system.

For even more demanding applications, such as high-power EV charging—think semi-trucks on highways—we observe the need for much higher voltage bands. For example, charging a truck in 45 minutes so the driver can resume their journey for another four hours requires megawatts of power. This might call for 1,400V or ±700V DC installations.



A key point to highlight is the difference in voltage scaling between AC and DC.

In AC systems, voltage transitions follow a multiplier of the square root of 3. For example, 230 volts phase to neutral will transition to 400 volts phase to phase, and 400 volts will transition to 690 volts in certain applications.

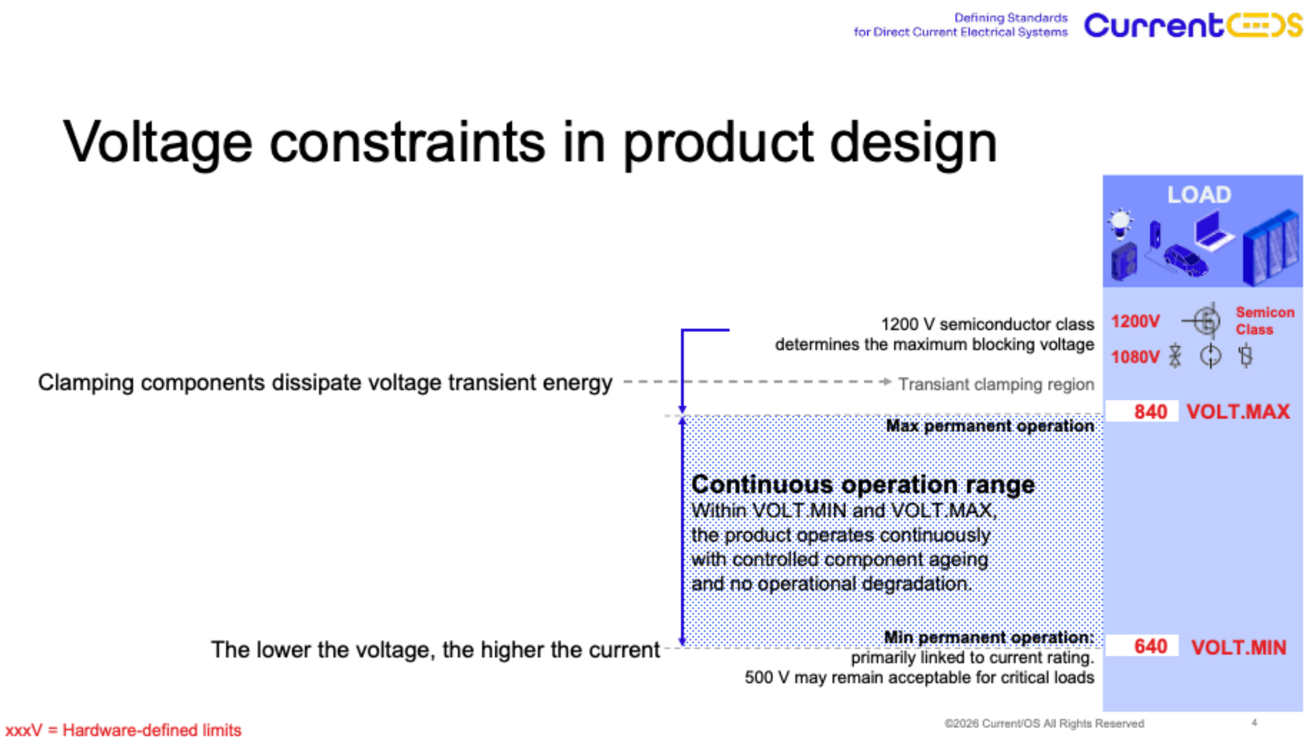
In DC systems, however, voltage jumps are based on a factor of 2. This means transitioning from the pole-to-midpoint voltage to the pole-to-pole voltage is achieved by doubling the value.

Combining these considerations, a band of voltages below 400 volts is typically used. This band aligns with the design of many loads and also represents the upper safety limit for protecting people. In environments with non-electrical professionals—such as commercial buildings—voltages below 400 volts are utilized.

For higher-powered applications, the voltage typically doubles.

For specific cases requiring significant power, such as specialized industrial or transport applications, the voltage doubles again.

However, it is crucial to stay below 1,500 volts, as exceeding this threshold shifts into the medium-voltage range.



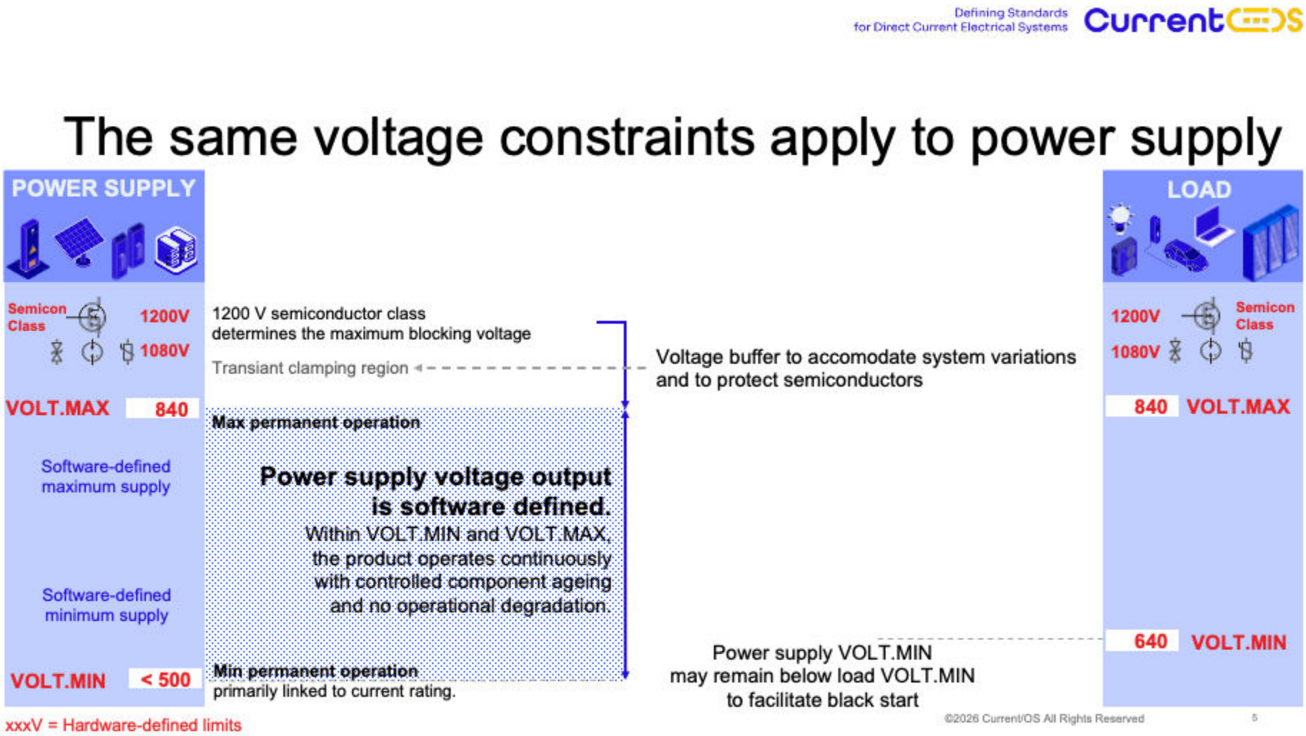
The growing use of electronic components brings new design considerations.

Take equipment designed for operation around 700 V or 800 V. To ensure optimal service life, 1200 V-class semiconductors are typically used.

To protect these semiconductors, clamping devices are implemented. These components limit overvoltages and transient events. Their threshold voltage must therefore lie between the continuous operating voltage and the semiconductor breakdown voltage (1200 V). In practice, clamping devices rated at around 1080 V are selected.

This allows the continuous operating voltage to reach approximately 840 V. A minimum continuous operating voltage must also be defined. This lower bound is determined by the maximum current the equipment can handle, which in turn drives the current rating of the semiconductors.

Certain critical loads may be designed to operate at voltages as low as 500 V. However, this results in significantly higher current levels.



These considerations regarding loads also apply in the same way to power supplies and energy sources. Here again, there will be a permanent operating voltage band.

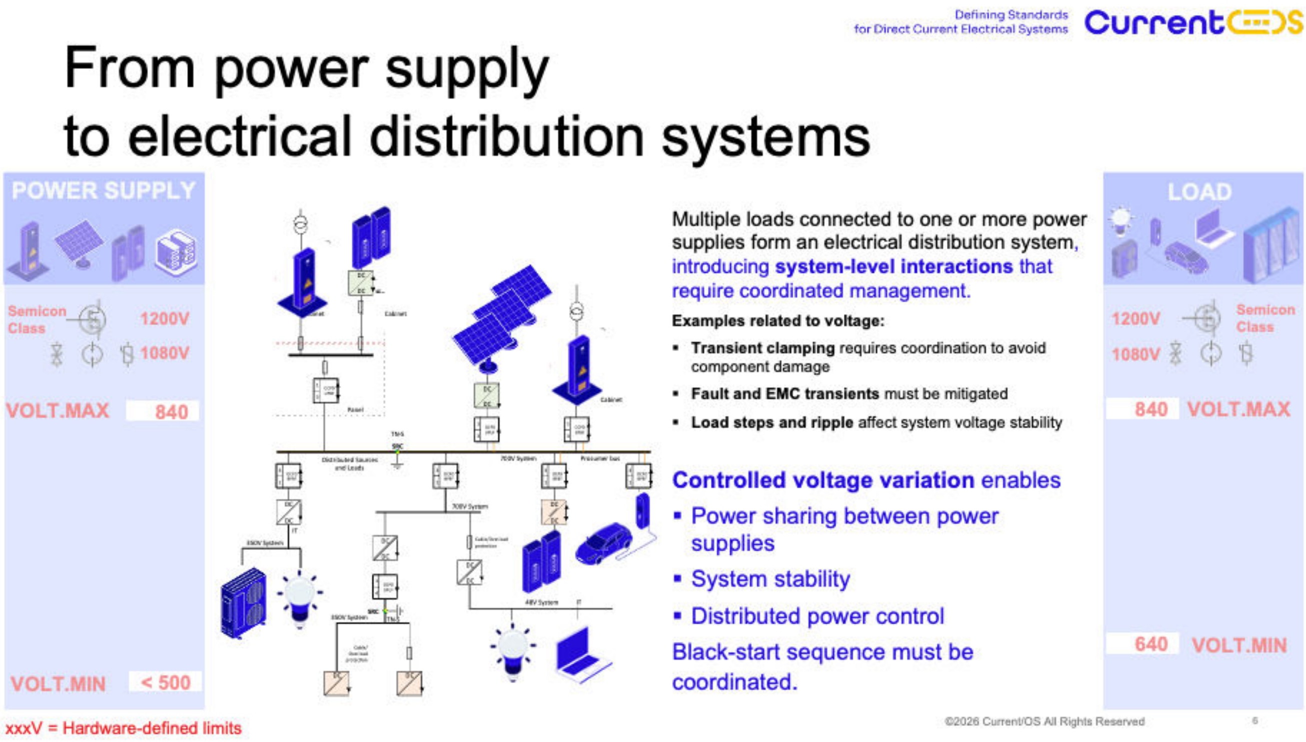
This operating voltage will naturally remain below both the semiconductor operating class voltage and the threshold voltage of the protection and clamping systems. In this example, the 1200 V semiconductor class and the 1080 V transient clamping region define the upper hardware protection boundary.

Within this VOLT.MIN to VOLT.MAX operating window, the product operates continuously with controlled component ageing and without operational degradation.

It should be noted that these voltage values are software-defined in most products and can therefore be adapted to different operating conditions and system architectures.

Unlike the load operating window shown here — with a load VOLT.MIN at 640 V — the power supply VOLT.MIN may intentionally remain below the load VOLT.MIN in order to facilitate black start capability.

This relationship between source and load applies in the simplest case of one source connected to one load.



We move beyond the simple case of one source supplying one load and enter the domain of electrical distribution systems when multiple loads are connected within the same electrical installation, potentially supplied by multiple sources.

Such an electrical distribution system introduces system-level interactions that must be managed.

First, the clamping threshold voltages of the different products must be coordinated. Because an electrical distribution system is more extensive and more complex than a simple source-to-load architecture, it is more exposed to transients and electromagnetic disturbances that must be absorbed by the clamping systems.

However, if one product in the system has a lower clamping threshold voltage than the others, its protection components will activate first and absorb the full transient energy. This may damage that product, while the other products do not participate in transient suppression. Therefore, in a system heavily based on power electronics — such as a DC electrical system — coordination of clamping voltages is required.

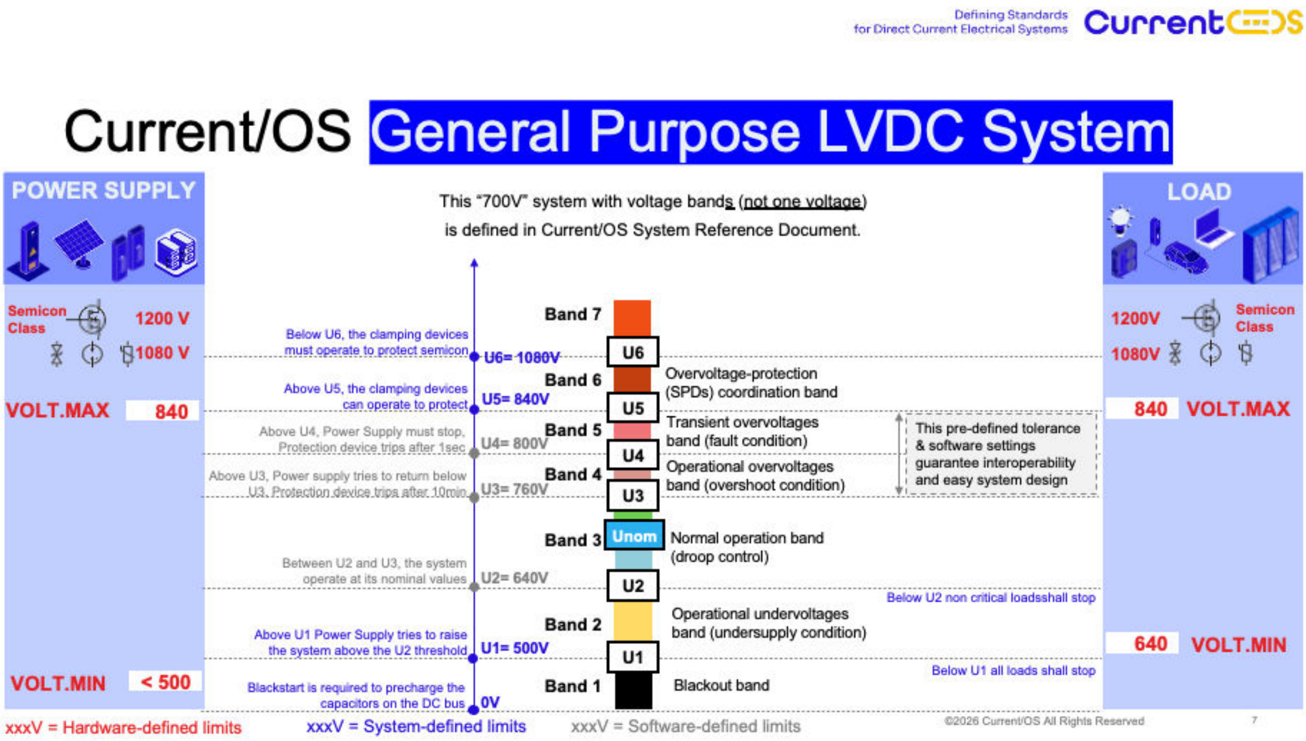
It is then necessary to consider the dynamic behaviour of the system. Loads may start or stop, while some sources — such as photovoltaic generation — may contribute more power at certain moments than at others. These events create sudden load demands or power injections that inevitably produce temporary voltage variations within the system.

As a result, the permanent operating voltage range must account for these possible overshoots in order to avoid entering the protection region associated with the clamping systems. In practice, the continuous operating voltage range of an electrical distribution system is therefore narrower than the absolute maximum and minimum voltage limits supported by the hardware, ensuring that the system remains outside the transient protection region during normal operation.

Voltage variations must also be tolerated in order to enable proper load sharing between different power sources and prevent one source from carrying the full contribution while others remain inactive. These voltage variations also provide valuable system-level indicators for maintaining installation stability and even for controlling distributed power demand.

Finally, a so-called black-start sequence must be defined. This is necessary because a DC system does not benefit from the inertia of the public AC distribution grid.

A controlled voltage ramp-up procedure allows the different power sources to start progressively, followed by a coordinated load-start sequence enabling loads to draw current gradually. This ensures a smooth system startup without unintentionally triggering protection devices such as circuit breakers or other current-limiting systems.



To address this, Current/OS has defined a number of voltage bands necessary to ensure proper coordination between the different products connected to the system and to guarantee their correct operation.

This is why defining the voltage of a system cannot be reduced to a single value, but instead requires an entire set of distinct voltage bands.

This is why defining the voltage of a system cannot be reduced to a single value, but instead requires an entire set of distinct voltage bands.

Defining a voltage isn't about agreeing on a single number—it’s about defining ranges, or bands as we say.

Why talk about voltage bands?

First, it’s necessary to define a nominal band—the band within which the system operates indefinitely. For example, when we refer to 350 volts, the nominal band might actually be between 320 and 380 volts. This band, often referred to as U2 to U3, defines the standard operating conditions.

We also talk about bands because, with DC, we enter the world of electronics and converters. This introduces the concept of voltage "swell." In AC systems, it’s well understood that nominal bands can sometimes be exceeded temporarily (between U3 and U4), often for a few minutes. These temporary conditions might occur due to events like disconnecting several loads simultaneously or a sudden influx of power.

Such conditions are not faults—they’re temporary deviations that the system will eventually self-correct. During this time, products need to continue functioning without damage, even as voltage rises up to U4, until the system returns to the nominal band.

However, beyond U4, it becomes a fault. At this point, protection devices must activate to prevent damage.

Now, because DC systems rely heavily on electronics, there’s also a need to define a band where internal clamping systems within devices activate. This band, between U5 and U6, must also be standardized across manufacturers.

Coordination is critical here. If one large device clamps at 2000 volts while a nearby LED driver clamps at 1000 volts, the smaller device, with its limited surge absorbers (like MOVs or TVS), will absorb all the transients and fail prematurely. Proper coordination is essential to manage these transients effectively and protect all components.

These bands—U3 to U4, U5 to U6—represent voltages above nominal. Now let’s address what happens when voltages drop below nominal.

In a DC microgrid, which is naturally isolated from the public grid by an AC DC converter, startup poses unique challenges.

In AC systems, powering up a building involves carefully managed steps: magnetizing the transformer, progressively energizing circuits, and bringing loads online gradually to avoid tripping protections due to high inrush currents.

DC systems require a similar approach, albeit on a smaller scale due to limitations in the nominal power of the AC DC converter and the available sources.

It's necessary to define an initial voltage, U1, to exit a blackout state and allow power sources to begin contributing. From there, the system can work toward reaching the nominal band, U2.

Between U1 and U2, certain loads might operate in emergency mode—for instance, safety lighting or fire protection systems.

To summarize, defining a voltage is not about agreeing on a single number. It's a spectrum of values that must be carefully defined, particularly when dealing with electronic protection systems. The six key voltage bands to consider are

U1 represents the blackout state and the voltage required for a Black Start to energize the microgrid

U2 marks the lower limit of the nominal voltage band

U3 defines the upper limit of the nominal voltage band

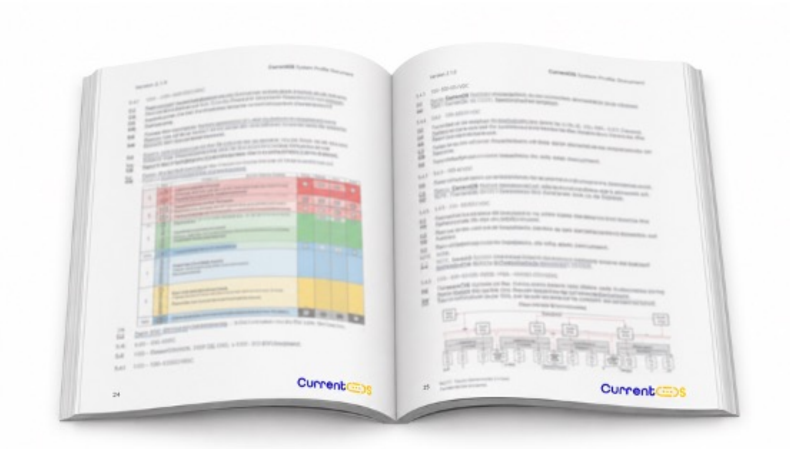
U4 accounts for the swell, a temporary voltage increase above nominal bands

U5 and U6 outline the range where clamping systems come into play to protect against transient overvoltages

Each of these values plays a critical role in ensuring the stability, safety, and efficiency of a DC microgrid, forming a framework for effective power management and protection.

Defining Standards for Direct Current Electrical Systems CurrentOS

Current/OS General Purpose LVDC System



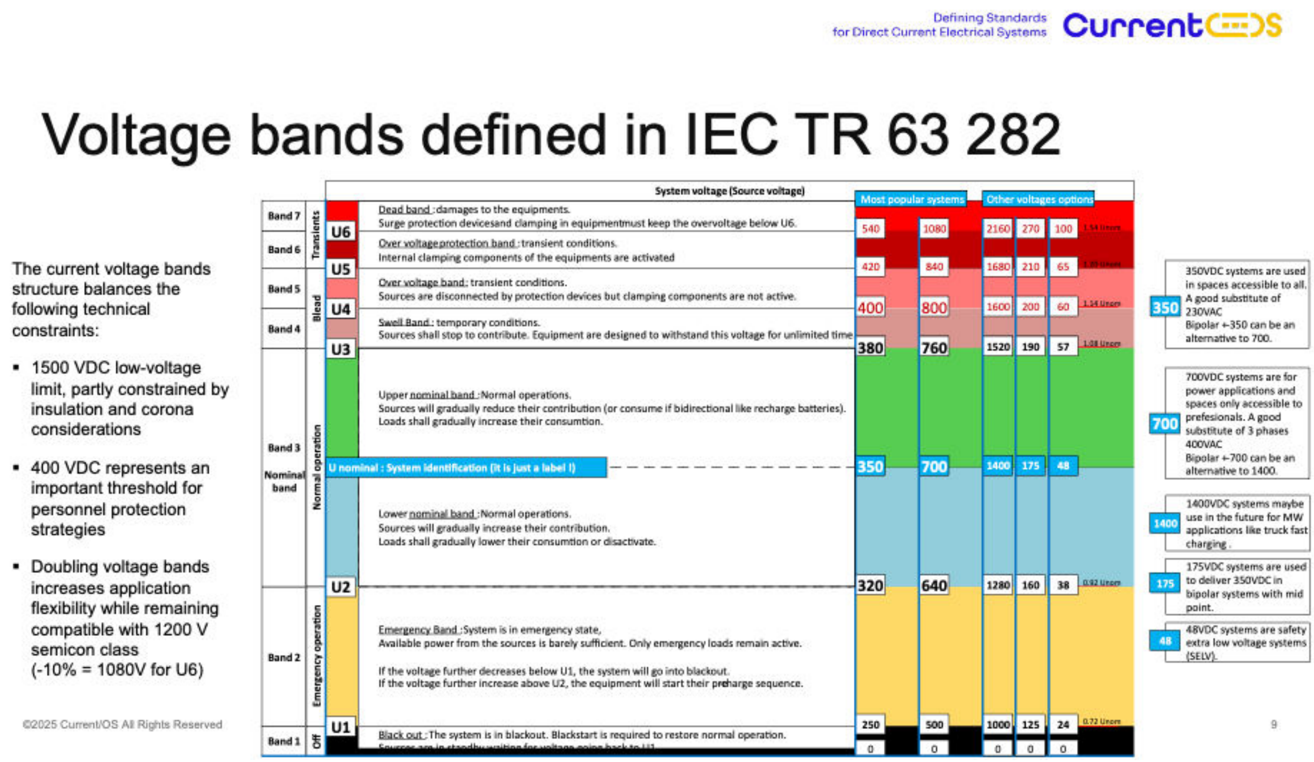
- Detailed technical rules and implementation guidance are provided in the System Reference Document (SRD)

 8

The voltage principles are formally defined within the Current/OS System Reference Document (SRD).

The term “General Purpose” refers to a system architecture designed to support a broad range of applications and interoperable products through a common set of technical rules as seen in video 1 of this MOOC.

The SRD therefore provides the detailed implementation guidance required to ensure coordinated operation, system stability, and interoperability across multi-vendor LVDC installations.



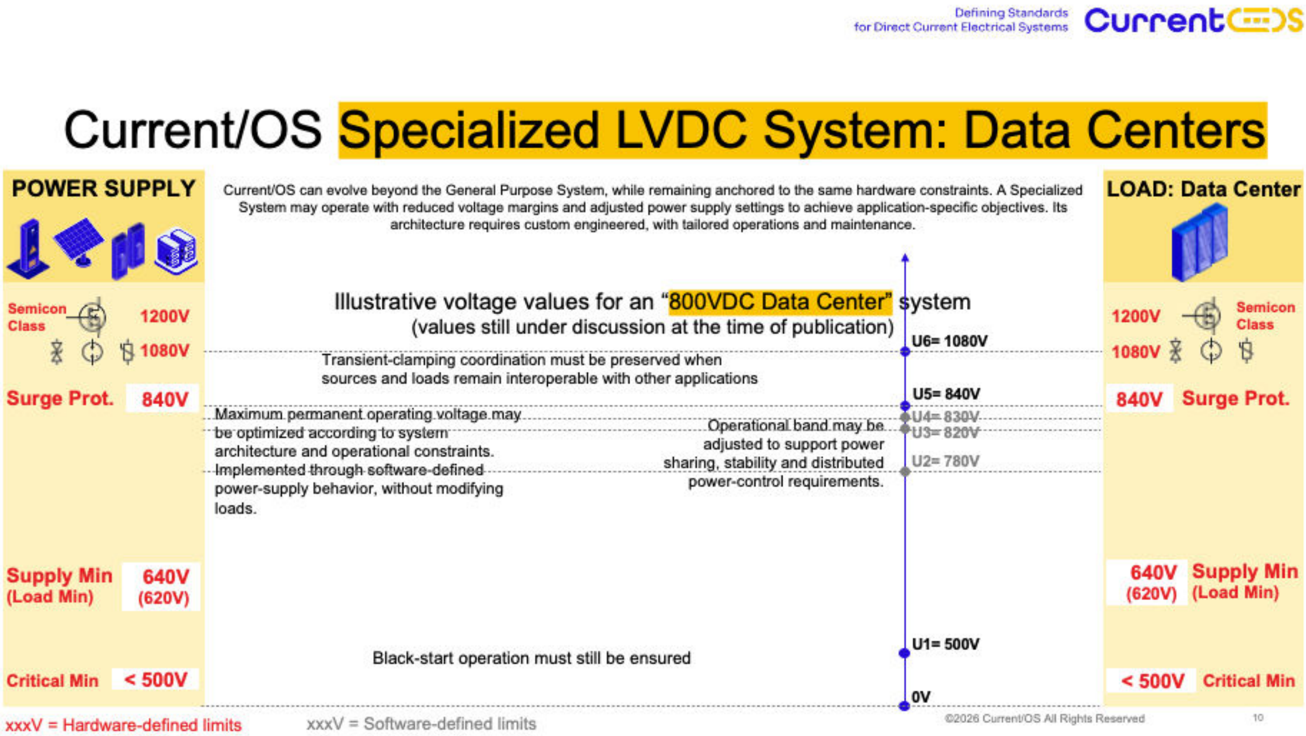
Current OS has specific voltage bands have been formalized in an IEC Technical Report, 63 282.

When we refer to 700 volts, it corresponds to a nominal band between 640 and 760 volts, with a maximum continuous voltage of 800 volts. Beyond this, there is a band where clamping systems are expected to operate.

Another defined system is referred to as 350 volts, with a nominal band between 320 and 380 volts, and a maximum continuous voltage of 400 volts. While the specification states that the system should not operate between 380 and 400 volts for more than 10 minutes, it essentially means that the equipment is designed to handle 400 volts continuously. It is built with this capability in mind. Beyond this, same logic, there is a band where clamping systems are expected to operate.

There is a growing convergence among various consortia regarding voltage bands. These bands are gradually reaching a consensus in the electrical community through collaborations beyond Current/OS.

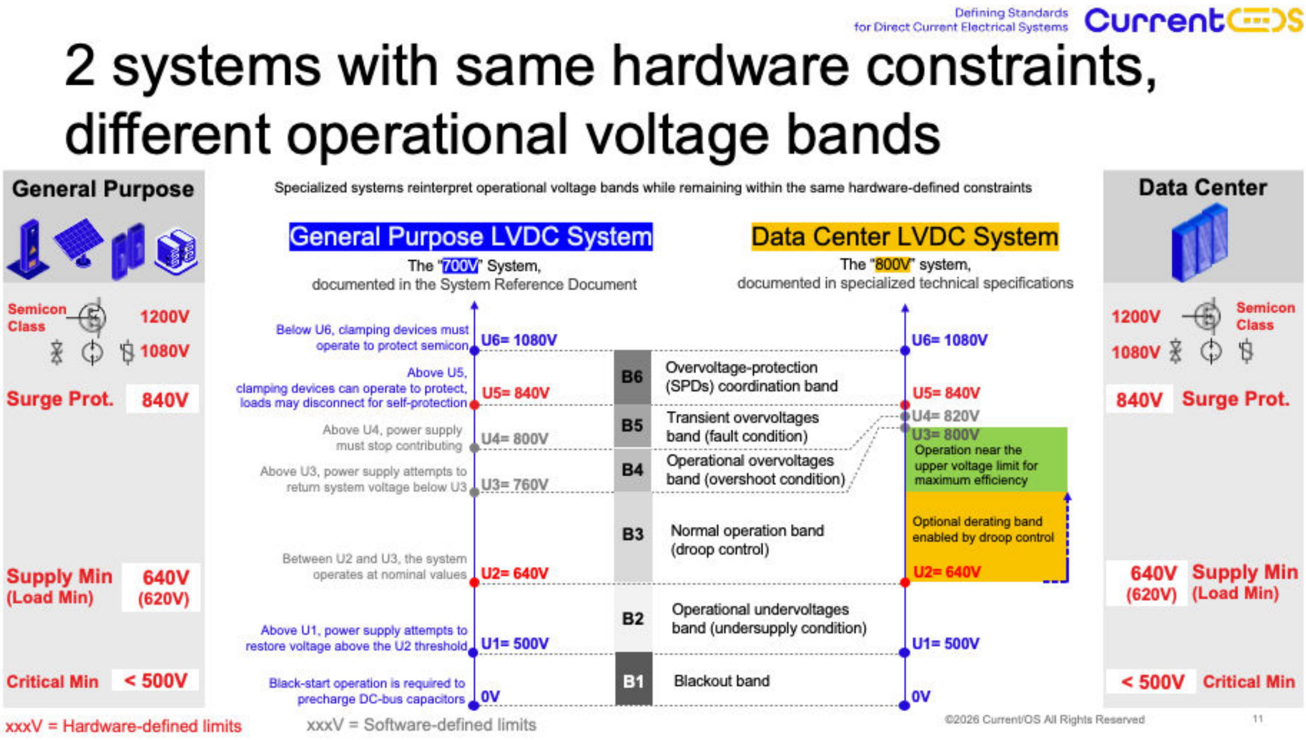
These voltage bands make it possible to design direct current installations using a simplest design approach, while ensuring safety and an optimal service life for the installation. However, in certain applications, it may be necessary to develop project-specific architectures.



For these applications, Current/OS has developed a specialized LVDC system. Current/OS technical rules are then tailored to meet the precise technical objectives of each project. They are operated and maintained by dedicated and specifically trained teams.

For example, in the case of data centers, users aim for the highest possible voltage in order to minimize currents as much as possible and thus maximize the energy efficiency of their systems. In a data center, the power levels involved are such that every gain in efficiency translates into significant savings.

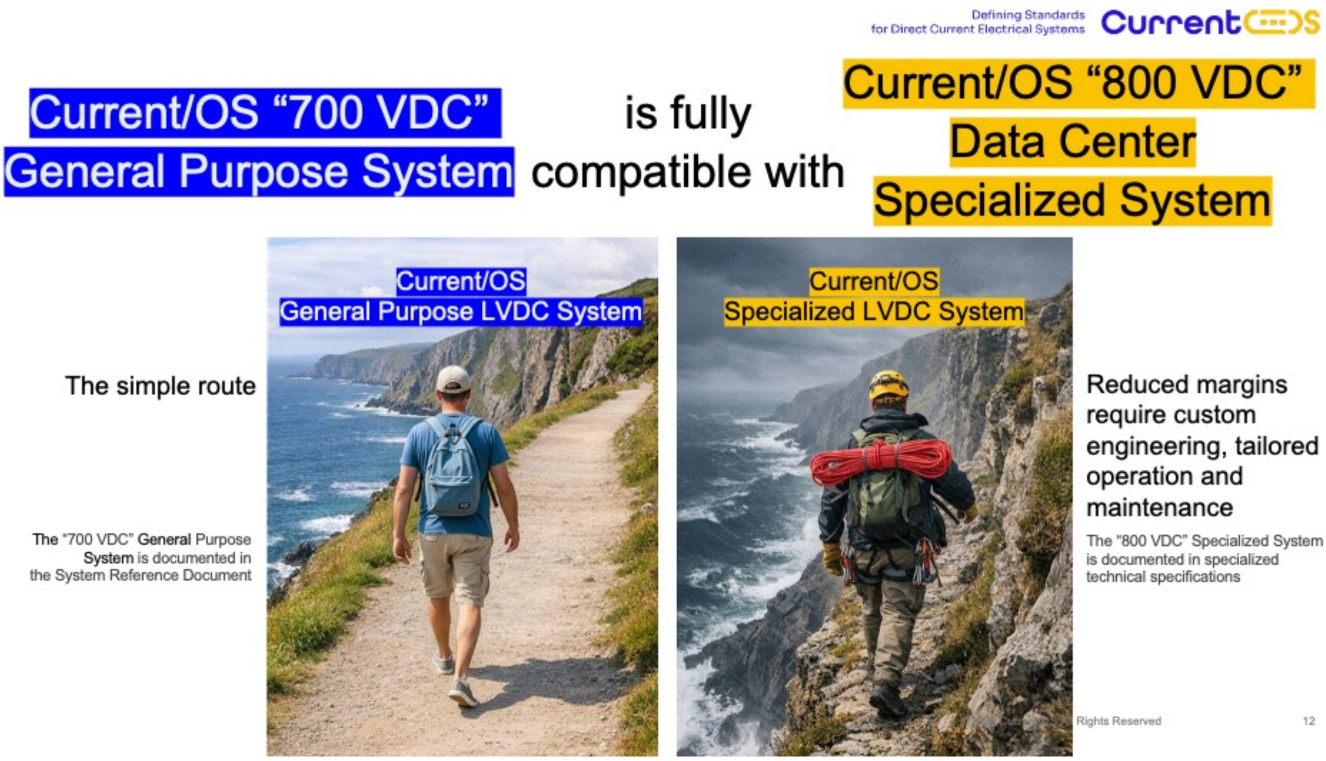
The design of a data center requires specialists and experts with a very detailed understanding of electrical distribution phenomena, who are willing to reduce certain operating margins in order to achieve these extreme efficiency targets. In this context, Current/OS is involved in collaborative work with various teams responsible for designing data centers, and together they have defined narrower voltage bands at the upper end, around 800 volts, in order to meet the requirements of these applications.



The electronic equipment used is not fundamentally different from what is required in installations operating within the 700 V and 800 V bands. The same 1200 V-class semiconductors will be used, and the same clamping devices will be required at an intermediate voltage between these 1200 V and the nominal operating voltage.

These higher operating voltages will most likely be achieved by adjusting the source settings (via software). The loads used can be deployed interchangeably in both 800 V and 700 V systems.

Therefore, the 700 V system defined by Current/OS SRD and the 800 V system sought for data centers are compatible. The differences lie simply in the settings, the safety margins, and the fact that these risks are deliberately accepted by experts with a detailed understanding of their specific application.



In a nuthsell, Current/OS 700VDC General Purpose System is fully compatible with the 800VDC Data Center Specialzed System.

We could illustrate these considerations by saying that Current/OS 700 VDC General Purpose System enables a peaceful hike along a wide cliffside path.

In contrast, certain Specialized Systems, such as the one defined for data centers, aim to operate closer to the limits and under more demanding conditions. In such cases, custom engineering is required, along with dedicated, experienced experts and operators to ensure safe and reliable operation and maintenance.

Defining Standards for Direct Current Electrical Systems Current/OS

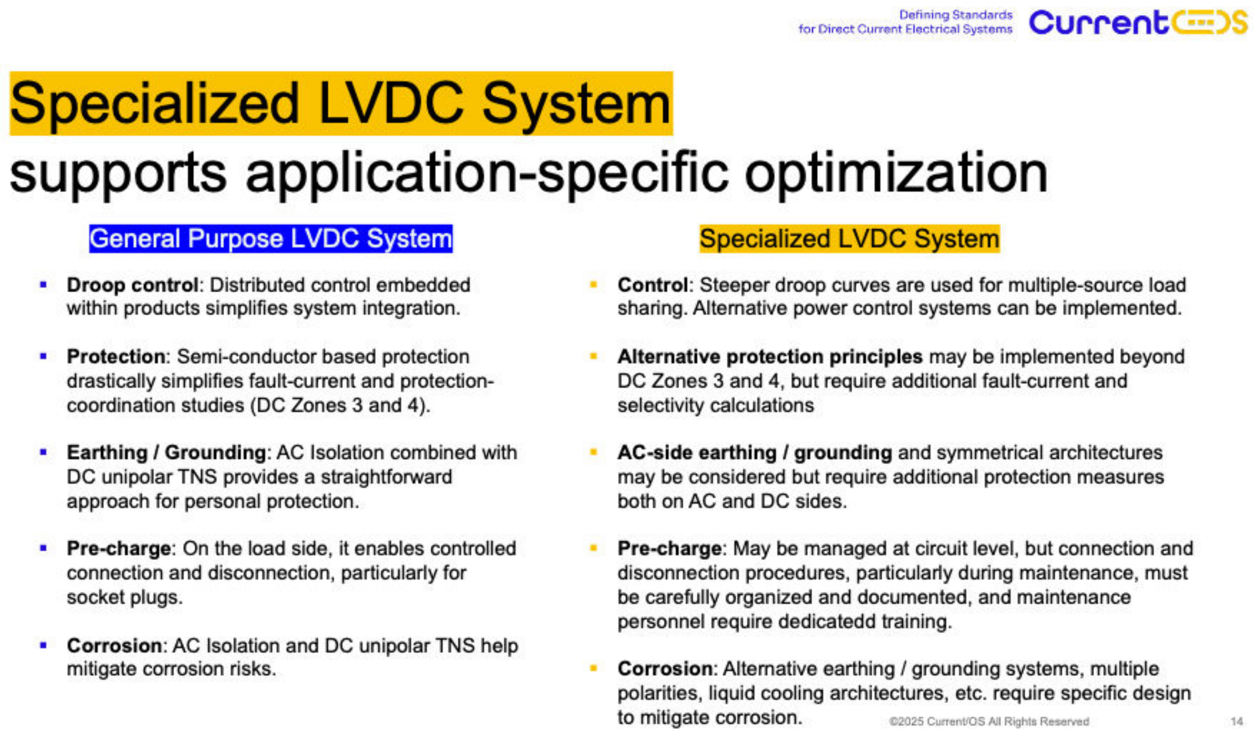
General Purpose LVDC System also defines additional operational rules

- **Droop control**: Distributed control embedded within products simplifies system integration.
- **Protection**: Semi-conductor based protection drastically simplifies fault-current and protection-coordination studies (DC Zones 3 and 4).
- **Earthing / Grounding**: AC Isolation combined with DC unipolar TNS provides a straightforward approach for personal protection.
- **Pre-charge**: On the load side, it enables controlled connection and disconnection, particularly for socket plugs.
- **Corrosion**: AC Isolation and DC unipolar TNS help mitigate corrosion risks.

General Purpose LVDC System also defines additional operational rules

In the other videos of this MOOC series, we will show that the General Purpose System goes far beyond the definition of voltage bands.

It also defines a broader set of operational rules covering areas such as distributed control, protection, earthing (or grounding), pre-charge management, and corrosion mitigation.



The Specialized LVDC System supports application-specific optimization.

In the same way as for voltage coordination, Current/OS experts may, depending on the requirements of a given use case, design solutions that intentionally depart from the standard framework in order to achieve specific performance objectives.

For example, voltage variations may be reduced and replaced by more centralized or digital control approaches.

Alternative fault-protection principles may also be implemented using different protection devices. However, this requires additional engineering work to calculate and manage fault-current propagation, accumulation effects, and selectivity coordination.

Alternative earthing and grounding architectures may also be considered, including AC-side grounding approaches. In such cases, more advanced system design expertise is required to implement the additional protection measures necessary to address DC current injection on the AC side or the presence of AC components on the DC side.

Pre-charge management may also be organized differently and centralized at circuit level when simple plug-and-play disconnection is not required.

Finally, corrosion aspects specific to DC systems must not be overlooked. Any grounding architecture differing from the recommended approach requires particular attention to corrosion mitigation.

Defining Standards for Direct Current Electrical Systems Current/OS

The Technical Framework of Current/OS

Check the other parts of the Direct Current Deep Dive | MOOC Series

Part 1 - Current/OS Design Rationales
Part 2 - Voltages
Part 3 - Power Management
Part 4 - Electrical Protection
Part 5 - Pre-Charging
Part 6 - Earthing / Grounding

This concludes the introduction of Current OS.

Want to learn more? Check out the other five Current/OS MOOC videos covering voltages, power management, electrical protections, precharging and earthing

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

Connect with the Current/OS team

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