DC Microgrids Principles and Benefits

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dc.systems

SYSTEMS

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1 Introduction

1.1 The Company

DC Systems is a company based in Amsterdam that manufactures products for DC microgrids, acquired in December 2020 by Schneider Electric.
https://www.dc.systems/ (the site is currently being renovated).

The size of the company is approximately 20 people who have very strong experience in R&D for electrical distribution in Direct Current. It is not just a manufacturer of power converters, as there are many. DC Systems has a real competence in electrical distribution (in DC) such as grounding schemes, protection of goods and persons, selectivity, connection to public networks, wiring problems etc.

The founder of DC Systems, Harry Stokman is now a prominent employee of Schneider Electric. Harry has been a DC entrepreneur since 1988. He has been the owner and CEO of Hellas Rectifiers since 1998. He has been the founder, owner and CEO of Direct Current BV and DC Systems BV since 2009. He founded and has been chairman of the DC foundation since 2010. He is a globally recognized specialist in DC on the following topics: Control, Distribution, System Grounding, Corrosion, Protection, power electronics and High Current systems. He is the inventor of Current/OS protocol based on 350V DC and 700V DC. He received multiple awards for his work in the LVDC: Nennovation Award from the NEN (2019), 1906 IEC Award from the IEC (2018), Runner-up The Process Award from the European Commission (2016), Greendeal Award from the Dutch government (2016). He is very active in standardization bodies. He is the Convener of Dutch TC64 NEN1010 WG DC. He is the convener or member of SyC LVDC multiple TG and WG, member of some TC 8 working groups and member of multiple TC 64 working groups.

1.2 DC Systems by Schneider Electric

DC Systems is owned and managed by Schneider Electric. The brand is managed as an endorsed brand. This means it is operated with a large autonomy from Schneider Electric: independent sales team and supply chain, independent website, etc.

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1.3 The Business References

Nowadays, many works of DC distribution remain academic papers. DC Systems went one step beyond with real field experience in DC electrical distribution. Its range of converters and protection products is a unique catalogue of DC devices. This enabled to carry out numerous successful, real-life achievements.

The Circl office building in Amsterdam has a DC power distribution and has been in operation since 2017. https://circl.nl/ From a visitor's point of view, the DC distribution is not visible except for the fact that USB sockets have replaced 230VAC sockets!

DC Systems also has its technology in place on more than 300km of public lighting. These installations were carried out by local installers like Citytec or Dynniq.

Recently, a 5km stretch of the N470 provincial road in Delft was commissioned with a microgrid (solar panels, 1MWh of batteries) that powers lighting, traffic lights and 5G antennas almost autonomously.

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2 Vision of DC Systems

All starts from 3 major facts:

- The electricity needs are increasing due to rapid growth of electrical vehicles (EV), digital and communications (IT) and heating with heat pumps; at the same time, more affordable local electrical resources such as photovoltaic (PV) and battery storage systems (BESS), combined here and there with public grids limitations, leads to more and more **microgrid** applications in buildings, infrastructure, and industry. We are in a transition period moving from one single electrical source (the public grid), to some electrical sources (PV, batteries, grid), to an unlimited number of sources (1000 EV on a parking lot can become 1000 electrical sources !).

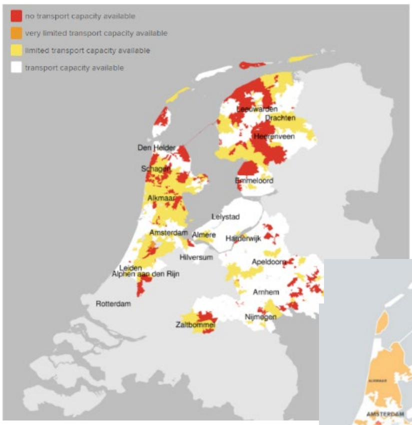
- The **Direct Current** (DC) electrical distribution seems more and more accurate to link DC sources (PV, BESS) with DC loads (EV, IT, etc.). DC also brings intrinsic benefits in long distance applications or in motor breaking energy harvesting.

- The **power electronics** components are more and more affordable, opening the door to solid state protection devices.

In an electrical world, in the years to come people are expected to make more use of electrical power, and we will see an increased dependency on power availability. At the same time, the public electrical grid gets more congested and is facing an increase in decentralized power generation with more intermittent sources.

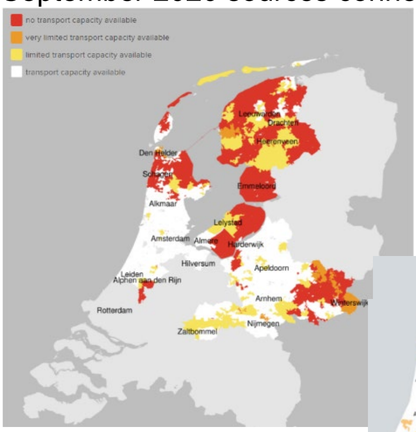
In mature economies, electrical grids are already reaching their limits. Maps below show an example of the grid situation in the **Netherlands**, where the maximum grid capacity has been already reached. On these maps, areas with either limited or no electrical power availability are depicted. Please consider that only 2% of the vehicles in the Netherlands are fully electric.
We can also witness the very rapid change if we compare to July 2019.

September 2020 consumption headroom

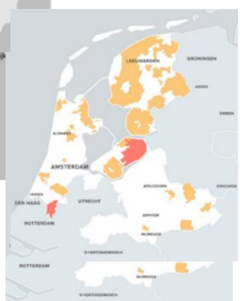


July 2019 à

September 2020 sources connection headroom



July 2019 à



This triggers not only the need for local generation and microgrids, but also a change of mindset. People nowadays take electricity as granted. We must deploy more and more electrical installations with an opportunistic behavior: permanently adapting energy demand to energy availability with the least visible effects for business and life activities.

3 The Current OS foundation

In order to support the above-mentioned challenges, we have developed a protocol allowing to design scalable DC grid architectures: a protocol that defines all systems aspects for loads and sources such as voltage levels, protection, grounding, corrosion mitigation etc.

To assure the availability of this protocol to any product manufacturer, the Current/OS Foundation is being set up. As the foundation aims to come to a unified standard for grid control purposes, it provides to its partners an open protocol and clear guidelines on how to manufacture products that work in a Current/OS based DC environment. Major electrical corporations such as Schneider Electric and Eaton are supporting us to make this protocol a global standard for DC infrastructures.

The Foundation focuses on speeding up market ramp-up and increased potential sales volumes, supported by the following drivers:

- The foundation: Management board
  - Eaton & Schneider Electric as initial board members
  - New board members from unanimity vote
  - Decisions from 2/3 vote

- The foundation: Working groups are created on the basis of needs such as
  - Partners relationship: ensures management of adopters' contracts
  - Protocol marketing: ensures promotion of the foundation and protocol benefits
  - Technical committee: ensures protocol technical documentation edition, products test reports checking and protocol amendments
  - Standardization relationship: manages relationship with standardization bodies to help this technology into global standards such as IEC

- Foundation: Membership structure
  - Partners
  - Supporters

Fees for small business (below 250 employees)

	Launch period	Normal fee
Gold	20 000 €	20 000 €
Silver	0 €	5 000 €
Bronze	0 €	1 500 €
Supporter	2 500 €	2 500 €

Fees for other business (above 250 employees)

	Launch period	Normal fee
Gold	40 000 €	40 000 €
Silver	5 000 €	10 000 €
Bronze	1 500 €	3 000 €
Supporter	5 000 €	5 000 €

*Launch period includes the 2 first years of subscription.

4 The Current OS Protocol

The Current OS protocol is the system approach of DC Systems' offer.

The Current OS protocol is a new system approach of DC electrical distribution that makes the most of **Direct Current** and **power electronics** to build **microgrids simpler, safer, cheaper**:

- The Current OS protocol solves the usual objections raised against Direct Current electrical distribution and makes the best use of DC intrinsic features while offering very **high safety to people and assets**.
- The Current OS protocol defines **energy management** rules to make microgrids easy to control. It also enables a very opportunistic behavior of the microgrid to **make the most of available electrical resources** and power the loads according to their priority.
- The Current OS defines the **communication** model to open the door to **software interaction** with the electrical system. However, the intrinsic structure of Current OS microgrids makes fully resilient to communication losses and cyber-attacks.

Safety reaches unseen levels with Current OS protocol.

- Current OS relies on the protection zones.
- It specifies the current profiles at circuit connection, pre-charge, and disconnection to allow black start and avoid nuisance tripping.
- It specifies the tripping criteria for detection of short circuit fault, earth leakage faults, serial arc fault, while ensuring bi-directional selectivity.
- It specifies the safety wire function that safely de-energizes microgrid sections for maintenance purposes.
- Current OS protocol defines EMC requirements for all connected devices.

Energy Management is distributed at the circuit level to reach the highest resiliency and the most opportunistic behavior.

- Current OS protocol defines operating voltages and limits.
- It specifies the circuits voltage response and voltage dependent prioritization service with either on/off thresholds or linear adjustment of the power use/supply of the circuit.
- It specifies how to calibrate the devices, how to compensate line losses and voltage drops.
- It explains how to influence the loads and sources behavior beyond initial settings.

Communication with different software is enabled with a description of data model in use over Modbus communication.

As multiple aspects of the protocol are patented, partnership with the Current OS foundation offers license rights to manufacture compatible products.

In addition, supporters such as designers (consultants, design offices, design institutes, etc.) will be delivered with installation rules and guidelines.

The Current OS foundation aims to develop the protocol in the future to offer more and more services.

4.1 SAFETY FIRST!

Direct Current is generally feared by electricians.

Electricians who deal with mixed AC/DC applications encounter DC in the most hazardous parts: battery rooms, solar panels arrays. These zones are under permanent voltage, very difficult to switch off (because battery is loaded, or the sun is shining) and short circuit very difficult to break.

When the DC distribution system is protected with classical electromechanical breakers or fuses, many issues are encountered:

- Short circuit currents are difficult to break
- Arc can develop during disconnection or on the busbars with dramatic consequences.
- Selectivity is very difficult to ensure. Capacitances on sources and loads will probably make all protections blow simultaneously.
- Fuses and general breakers can only manage a limited line length, otherwise can explode.

Note: In railway traction, DC has been in use for decades in long lines network. Yet these networks have a large inductance that limit the fault current. The breakers in use in these applications usually have very large breaking chambers. Way bigger than general purposes breakers like Schneider Electric CompacT or MasterpacT.

In other words, with high short circuit currents and electromechanical technologies, DC raises so many issues that AC is the only option. This is the reason why DC did not emerge until recently. High short circuit current DC sections with electromechanical protections should be limited to short distances such as one electrical cabinet.

Solid state technology, ultra-limited short circuit currents and ultra-fast breaking, is the only combination possible to handle this emerging context and allow a new generation of optimized architectures.

A deeper look and definition of electrical zones can help. And we will show that not only DC is not more dangerous than AC, but the most part of DC installations will benefit of higher safety than traditional AC installations because of very low short circuit current thanks to converters and ultrafast breaking times thanks to solid state switching.

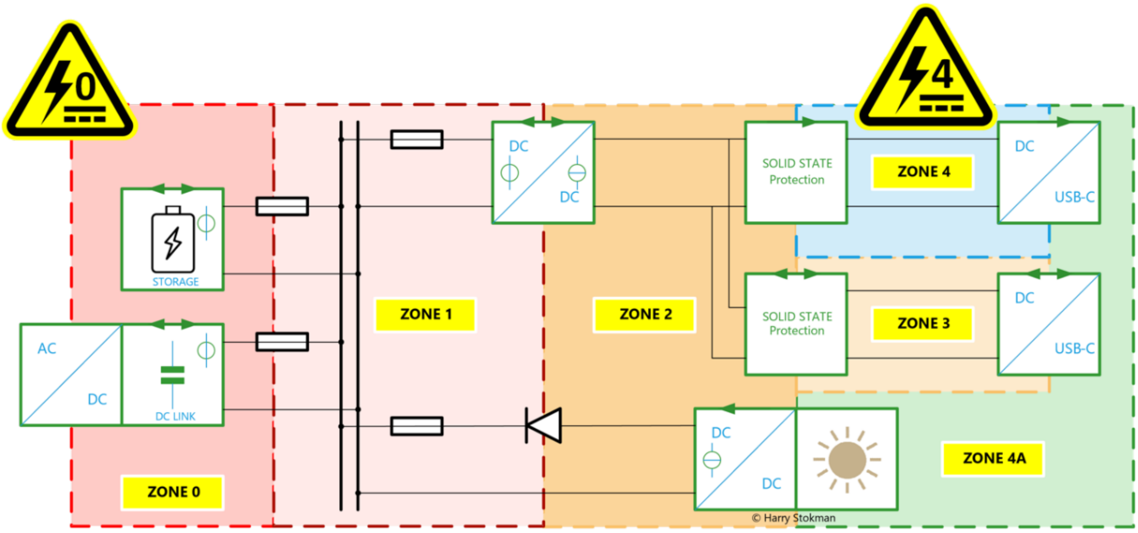
Depending on the type of security, the voltage level and the maximum current in a segment, it has been shown to be important to provide clarity on the risks of DC and to define these protection zones.

The learnings of the Current/OS founders led to the conclusion that the only way to secure DC microgrids and scale up DC microgrid business is solid state technology, ultra-limited short circuit currents and ultra-fast breaking. (Zones 2, 3 and 4 as described in next page).

4.2 Protection zones

The risk of an electrical installation always depends on the type of security, the voltage level and the maximum current in a segment

A DC installation can be assigned to a certain risk. Based on the stored energy in batteries and the power that can be supplied by the installation at a certain point, a classification can be made between dangerous and less dangerous installation parts. For DC installations, five different risk classes are identified from Zone 0 (highest risk) to Zone 4 (lowest risk). These zones are described below:



Zone 0 - Unprotected source In this zone, there are autonomous sources with a high power. This zone includes batteries (multiple linked batteries or batteries with large energy content), the public electricity grid and large PV installations.	Very high overcurrent possible Multiple sources possible
Zone 1 – Protected source with high short-circuit power In this zone, there are distribution lines (possibly combined in assembly rails) of the power sources from Zone 0 on the secondary side of a passive flood protection from the source. This has a passive protection for short circuits.	High overcurrent possible Multiple sources possible
Zone 2 – Protected source with low (bounded) short-circuit power In this zone, current-bound ELV sources (< 120 VDC or 60V or 30 V may be in humid or wet conditions).	Overcurrent too small, preventing safety devices mechanical breakers to perform its security function Multiple sources possible Bi-directional power flow
Zone 3 – Multiple electronic source(s) In this zone, there may be "prosumers" (generators or users of power or a combination of both).	Very limited overcurrent Absence of short-circuit power. Multiple sources possible Bi-directional power flow
Zone 4 – Single electronic source In this zone, there are only users of electrical energy.	No significant overcurrent Multiple sources not allowed Uni-directional power flow

5 Grid Stability and Energy Management Principles

5.1 Operating voltages and limits.

With a traditional approach, Voltage is defined by a nominal value and a tolerance. With DC Systems' microgrids, nominal voltage value is just a label. The key values are the voltage band limits inside which the system operates. Inside these limits, the voltage is a meaningful signal for all circuits to inform them about the power availability within the system and to make them react accordingly.

For instance, the so-called 350VDC "nominal" system will in fact operate normally between 320VDC and 380VDC. 250VDC to 320VDC will be an emergency range. 380VDC to 540VDC will be an overvoltage area.

DC Systems' microgrids are available in 350VDC or 700VDC. They can also be delivered in 3 poles + and – 350VDC or + and – 700VDC. (1400VDC is feasible but not available for now).

As a core principle of DC Systems' solutions, the voltage level triggers the operating modes of loads and sources. Therefore, no communication system and central control is required to keep the application stable.

Current/OS values										
	U_{DC}	B6	AC Line	U_{DC}	B6	AC Line	U_{DC}	U_{DC}	Dead band	Transients
U6	540			1080			270	2160	OVP Protection band	
U5	420			840			210	1680		
	410			820			205	1640	Over voltage	Blead
U4	400			800			200	1600		
	390			780			195	1560	Overshoot	
U3	380			760			190	1520		
	375			750			187.5	1500	Over supplied	Normal operation
	370			740			185	1480		
	365			730			182.5	1460		
	360			720			180	1440		
	355			710			177.5	1420		
Nom.	350			700			175	1400		
	345			690			172.5	1380	Under supplied	
	340			680			170	1360		
	335			670			167.5	1340		
	330			660			165	1320		
	325			650			162.5	1300		
U2	320			640			160	1280		
	310	308	220	620	616	440	155	1240	Emergency	Emergency operation
	300	294	210	600	488	420	150	1200		
	290			580			145	1160		
	280	280	200	560	560	400	140	1120		
	270	266	190	540	532	380	135	1080		
	260			520			130	1040		
U1	250	252	180	500	504	360	125	1000		
	0			0			0	0	Black out	Off

5.2 Voltage driven grid balance

Usually, voltage is understood as a nominal value with some tolerance. In the DC Systems solutions, we prefer to consider a voltage band where voltage value reflects the energy availability in the application.

When voltage exceeds the middle or "nominal" value (350VDC or 700VDC), we are in an "oversupplied" situation. This voltage level will indicate loads to run as active as possible and to store as much energy as possible, be it electrical storage (batteries) or thermal storage (hot water, fridges and cold rooms, HVAC storage…). It can also trigger hydrogen generation.

When voltage is below the middle or "nominal" value (350VDC or 700VDC), we are in an "undersupplied" situation. This voltage level will indicate:

- for loads to de-activate according to priority settings,
- for thermal storage to be inactive,
- for electrical storage to feed the electrical loads

5.3 Load management with droops

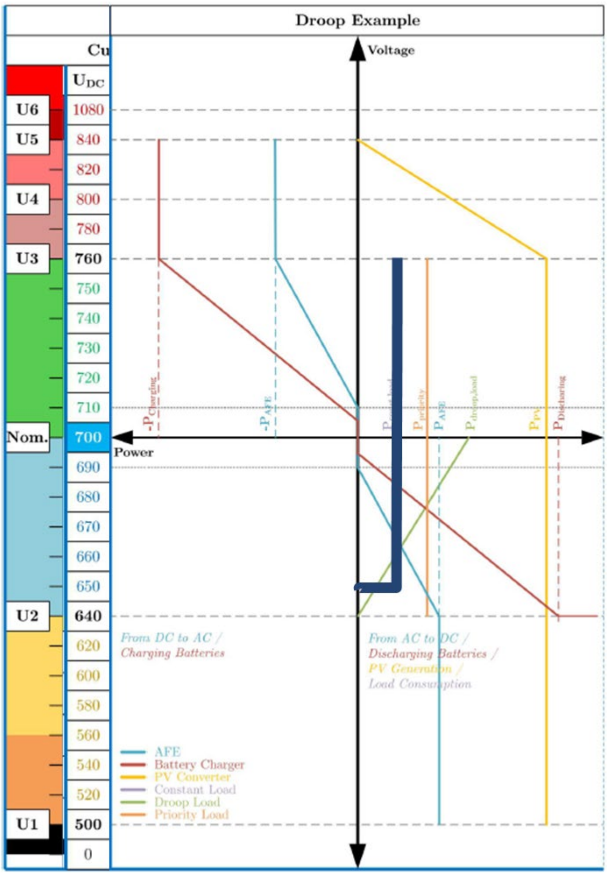
Circuits have different behaviors according to the voltage. These behaviors are defined as droop curves.

These droop curves describe the Power response (vertical axis) to the Voltage (horizontal axis).

The simplest reaction type is in use for small and simple loads. The activation and deactivation of these small loads does not threaten the stability of the microgrid. Their reaction is very simple:

- Above a voltage setting, they run full power.
- Below this voltage setting, they simply stop consuming power.

This case is detailed in the figure here →



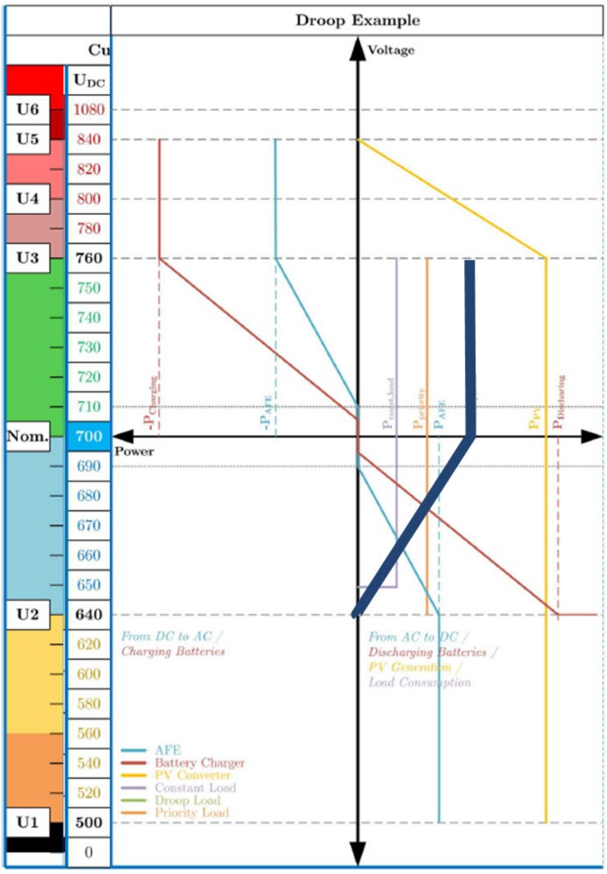
In some cases, this "threshold" mode is not suitable, and a smoother reaction is necessary:

- When the load power has significant impact on the grid stability
- When the load can provide higher value to the power consumption adjustment

For instance, a water heater in an individual house has significant impact on the microgrid stability (typically a 2kW water heater connected to a 9kW microgrid).

In such cases, we can obtain a smooth transition between over and under supplied mode. Thanks to the droop's response of each circuit, we have a more linear transition: loads will move from full power use to zero and back in a linear way. The two voltage values at both ends of the slope are settings that can be adapted to each microgrid case.

This case is detailed in the figure here →



In the case of the water heater, the power would be 2kW above 700VDC, 0kW below 640VDC and reduced in between the two values. In such cases, water heating will just take longer.

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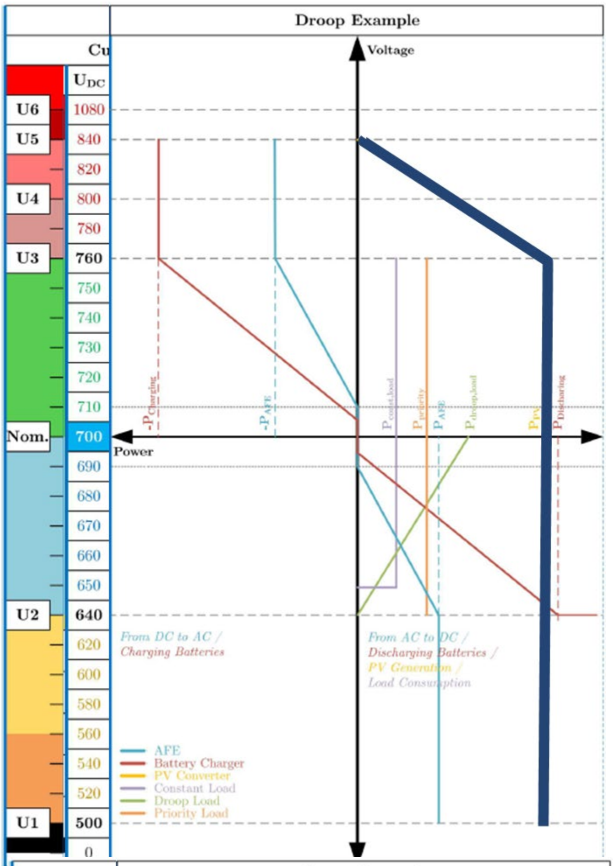
5.4 Source management with droops

When it comes to simple sources such as Photovoltaic (PV), systems can behave with a similar response to voltage: the source will provide full power until a certain defined maximum voltage. Above such voltage, power generated will reduce in a linear way to zero. The two voltage values at both ends of the slope are settings that can be adapted to each microgrid case

This case is detailed in the figure here →



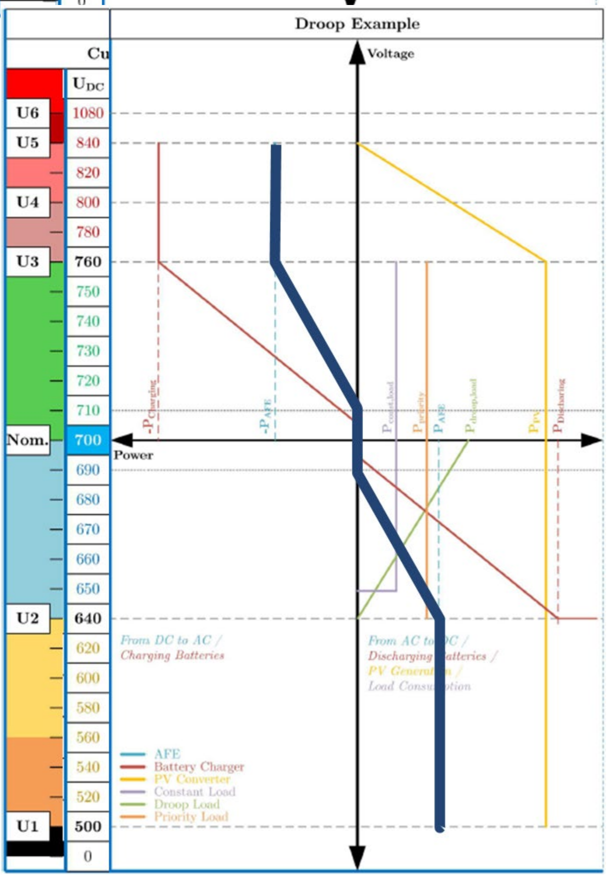
In the case of the individual house, the power would be 5kW max up to 760VDC, 0kW above 840VDC and reduced in between the two values.

5.5 Managed bidirectional circuits with droops

Managed bidirectional circuits can be battery storage, or bi-directional electrical vehicle (EV) chargers with vehicle to grid (V2G) capability, or bi-directional AC/DC converters.

Bidirectional circuits such as electrical storage will have a configured voltage band where the system will be inactive. Above this "dead band", the power used to charge the batteries or feedback the AC system will increase linearly up to the nominal charge power. Below this "dead band", the power delivered to the DC grid from the batteries' discharge, or the AC system will increase linearly up to the nominal supply power.

This case is detailed in the figure here →



Note 1: Managed bi-directional circuit does not include motor variable speed drive with reverse power capability.

Note 2: Active Front End are more than just bi-directional AC/DC converters. DC Systems' Active Front End embed additional grid stability features as well.

All these slopes and threshold can be configured through communication system.

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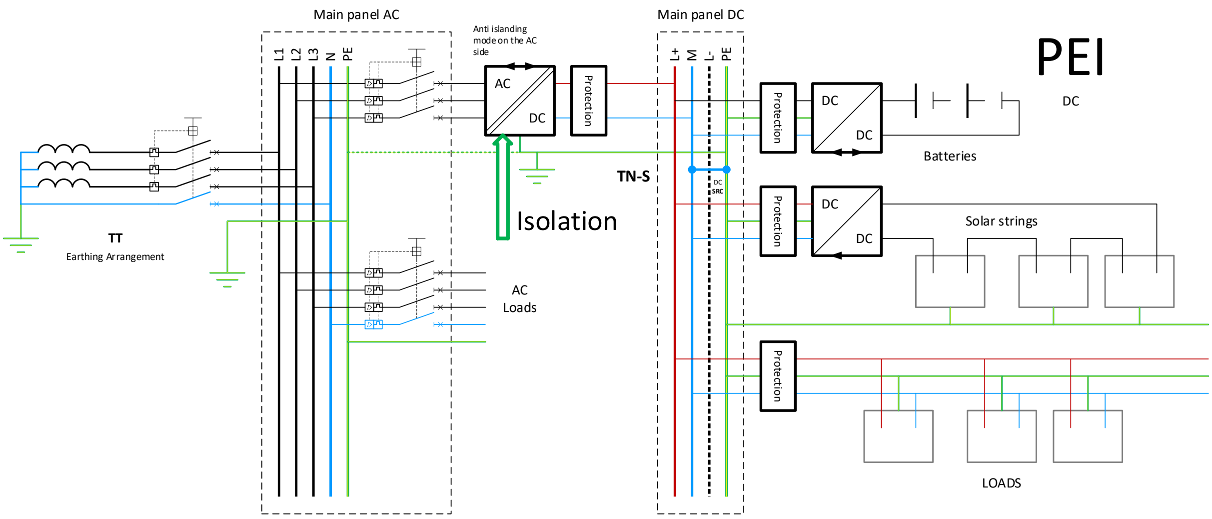
6 Safety Principles of DC Systems Microgrid

6.1 Earthing system

AC or DC leakage currents are hazardous. Residual Current Devices help to detect and isolate faulty circuits. Earthing systems need to be carefully designed to ensure people's safety.

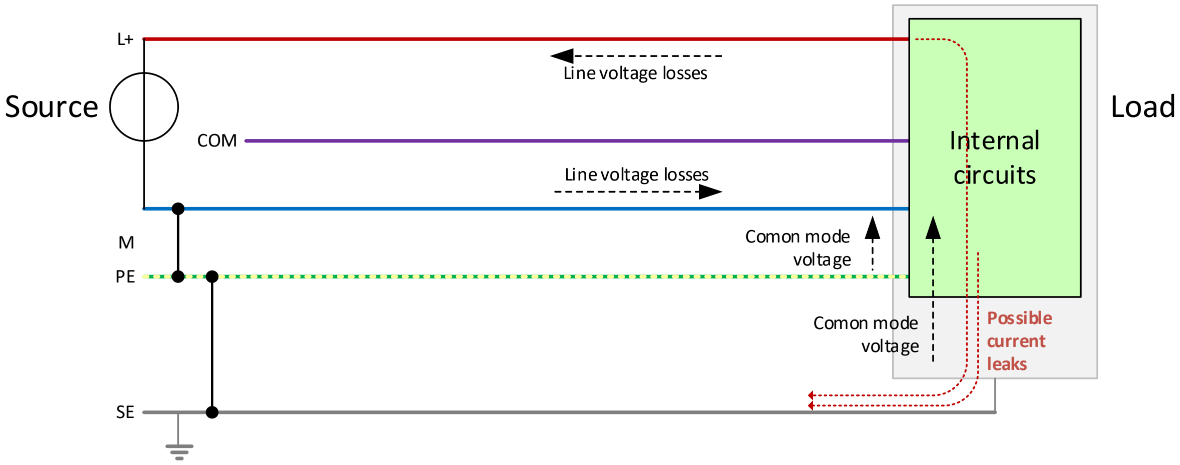
DC Systems electrical architecture is based on an AC/DC bi-directional converter named Active Front End. As seen in Energy management chapter, these AFE are active voltage sources on the DC side. A simple diode bridge + capacitor rectifier can NOT fit with a DC Systems offer. Earthing wise, AFE also provide isolation between AC application and DC microgrid.



This isolation of AC and DC applications allow TNS type earthing systems with a strong link between M and PE. This solution has many advantages compared to IT earthing systems that are commonly seen on many DC applications. It is a great improvement in asset and people safety.

- It simplifies electronic protection. Common-Mode voltages are much reduced as well as hazardous voltage live areas.
- It helps the EMC a lot to have electronic devices in the same potential as enclosure. This prevents overvoltage at devices in case of fault particular in bipolar systems in case of EMC disturbing.
- RCD is more reliable and faster
- This structure makes it more clear for installers and reduces errors.

It is also key to avoid stray currents. DC leakage currents can be harmful in another way, including leakage currents of less than 6 mA per charging point. They can have a harmful effect on the reinforcing steel in the concrete of the buildings. This metal can corrode or suffer from so-called hydrogen embrittlement. In both cases, this is accompanied by a loss of strength of the concrete construction. The leakage currents can reach the 'reinforcing bar' because both the housing of the load point and the reinforcement are part of the same earthing system. These currents leaks are generated by the common mode voltage created by the line voltage losses.



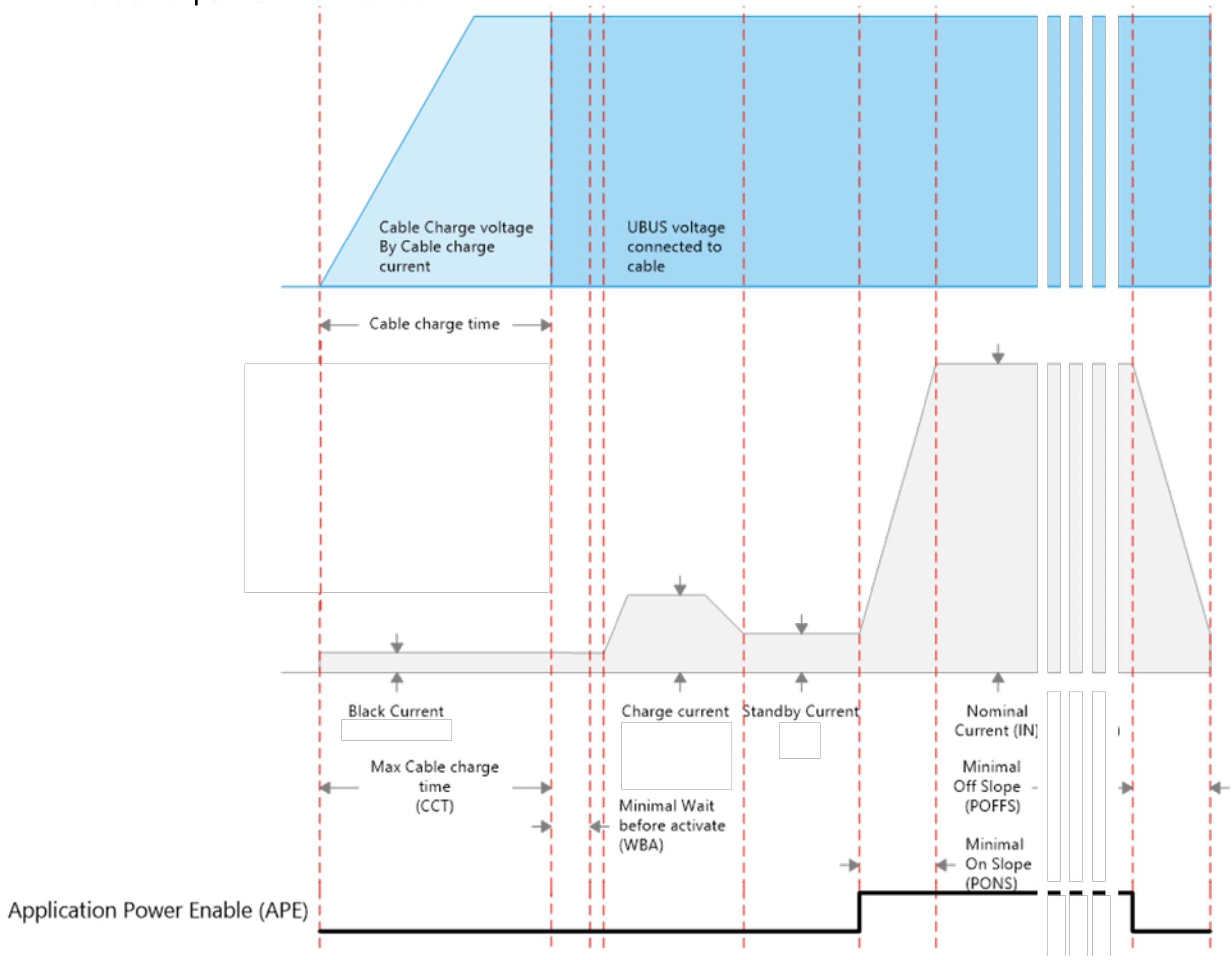
DC Systems offers different solutions to mitigate the stray currents that can damage the building.

Note: DC leakage currents are also a serious problem in an AC application. For instance, parking lots with multiple fast charging points will make extensive use of DC even if the electrical distribution backbone remains traditional AC. DC leakage current can exist in such applications. Same for data center or Telecom applications. If not properly managed, these stray currents can damage the concrete steel structure and put at risk people and assets.

6.2 Pre-charge and Disconnection

All loads connected must have a connection interface to allow black start, avoid nuisance tripping at connection and avoid arcing at disconnection. This interface provides the following features

- Current profiles at circuit connection
- Quick disconnect at voltage drop
- Voltage driven priority management and shedding (as seen in previous chapter) can also be part of the interface.



The specification and typical design of this interface will be delivered to Current/OS foundation partners. The connection sequence principle is as follows:

1. the device has no or very limited current call. Just the minimum to power a microcontroller.
2. the device is allowed to use a fraction of nominal current to charge the downstream capacitors.
3. the current is allowed to rise until load nominal with a limited rise rate.
4. Load uses the power from the system
5. At disconnect or at voltage drop, the current must be shut down in microseconds.

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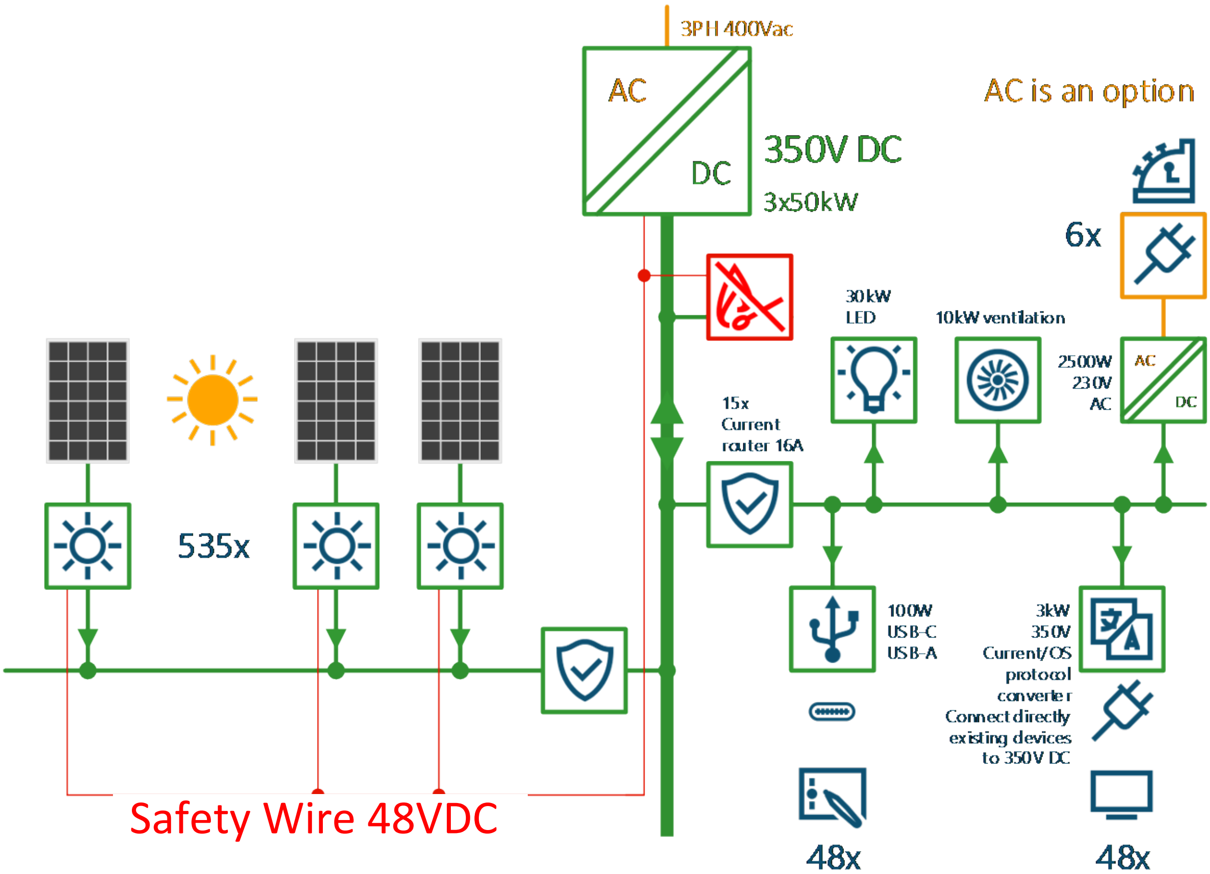
6.3 Safety wire

Unlike traditional top-down electrical distribution applications, multi-source applications require adapted safety maintenance procedures and would benefit of latest enhanced technical solutions. Simply put, energy could come from both ends of the cable, and there could always be one last source that has not been turned off that keeps the cable live!

The safety wire is a patented function that safely de-energizes microgrid sections for maintenance purposes.

Safety wires are present in a separate cable delivering a 48Volt high impedance signal. This signal is used by the auxiliary power supply of all converters, sources, or Current Routers. As soon as the system is released, the safety wire becomes active, and the sources can turn on. In the absence of the 48V, all Current Routers and sources are turned off (in segment or whole installation).

The example below is an existing installation example where the safety wire enables photovoltaic and Active Front End sources.



When the safety wire is down, all connected converters turn off. No energy flows through them. Upstream and downstream circuits are isolated with the built-in isolation of the converter. That part of the installation is then safe to work on.

Since the safety wire is a high impedance 48VDC signal, it is very safe to short it down to zero anywhere and get the area de-energized for maintenance.

7 DC Systems Microgrid Essential Products

7.1 Current Routers

Protection devices of DC Systems are named Current Routers. These devices operate in Zones 2 to 4. They ensure ultra-fast breaking of faults thanks to solid state switching.

- Detection of short circuit faults.
- Detection of overloads.
- Detection of earth leakage faults.

These devices exist in 16A and 200A versions. They operate in 700V and 350VDC networks.

The breaking time is less than 8µs:

They ensure short circuit full selectivity without rating constraints between devices.
Bidirectional protection is available in 16A Current outer and will soon be available with 200A current router.

Note: these devices are only compatible with the Current OS system in Zones 2 to 4; traditional distribution system is usually Zone 0 and 1.

7.2 Active Front Ends

Interlink converter bridging AC and DC networks are named Active Front End.

These Active Front Ends combine

- AC to DC bi-directional converters
- Galvanic isolation of AC and DC networks
- Current OS DC Grid forming (active voltage source)
- DC grid stability
- AC grid following (current source)

Active Front Ends exist in the following versions:

- 6kW 350VDC (pilots only)
- 50kW 350VDC
- 100kW 700VDC
- 500kW 700VDC (end 2022)

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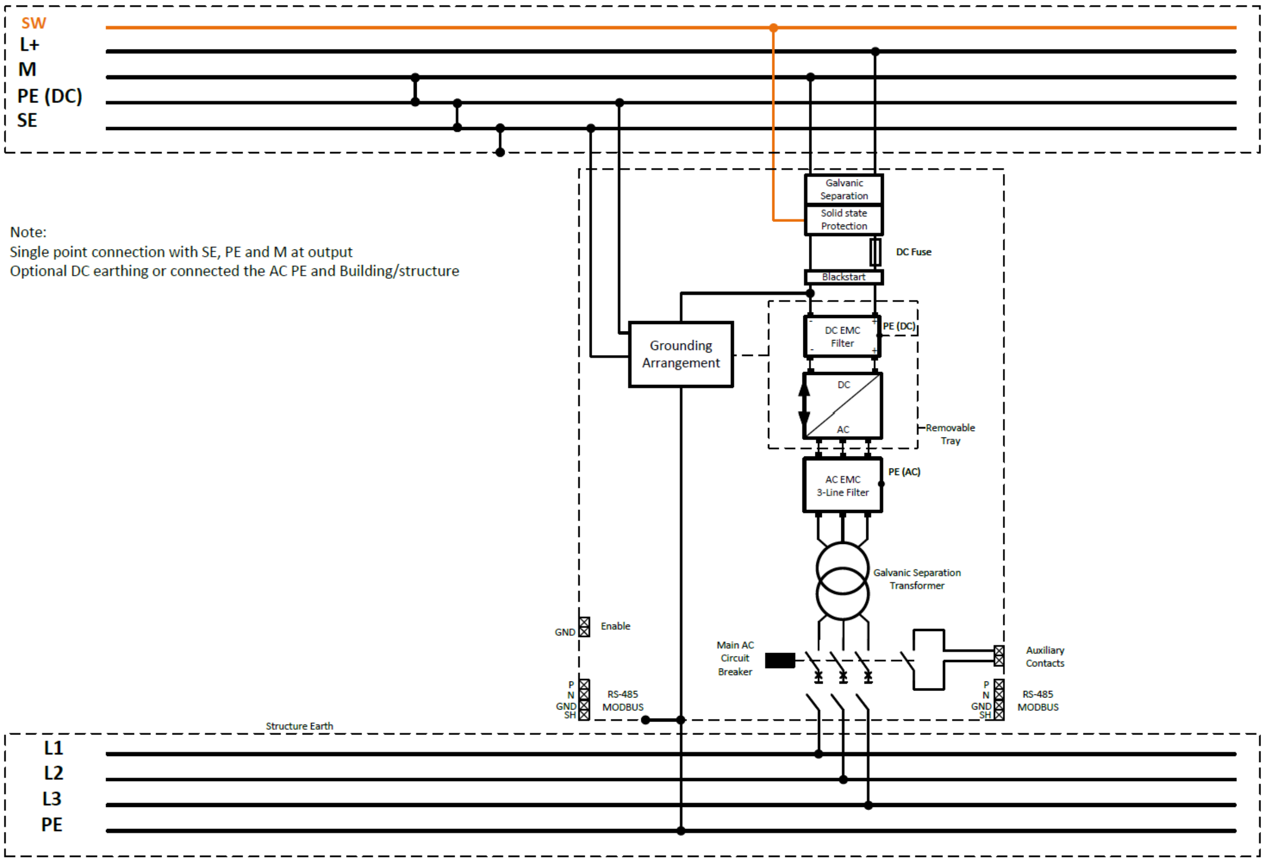
Active Front End is much more than a converter. It is a complete equipment as the synopsis here shows:



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8 Benefits of DC Systems Microgrid

8.1 General market trends leading change in electrical distribution

Some important trends lead to changes in the electrical distribution as summed up below:

Trends	**Consequences**
• Inverter based /DC sources growing faster than rotating/AC sources • DC loads rapid growth with e-mobility and digital	• Public grids are more and more overloaded, and consumers invest more and more in local electrical resources
• Resilience and Cybersecurity is a growing concern	• Microgrids are more and more considered but central microgrid controller and associated communication are exposed to cyber attacks
• Solid state power devices getting more and more affordable	• There are opportunities to do things differently as Current OS proposes

8.2 DC Systems offer relies on 3 pillars

DC Systems offer relies on 3 pillars independent from DC Systems technology:

Benefits from microgrid: most AC or DC microgrids brings the following benefits

- Microgrids reduces electricity bill. Thanks to local sources, the power demand on the public grid can be managed and peaks can be reduced. This helps to avoid peak hour prices and to reduce power subscription.
- Microgrids increases power availability and resilience in buildings. The local sources can provide power when the public grid is down.
- Microgrids provides additional source when grid capacity is limited and the site requires more power. This can happen at construction but also during site expansion or electrification of the parking lot.
- Microgrids are an economical alternative to reinforcing the MV lines and MV LV substations. In some cases, the line construction or upgrade is expensive compared to investment in local resources. Same for the delivery substation.

Benefits from DC: Direct Current brings intrinsic advantages

- DC is very beneficial in long distance applications as there are no capacitive losses due to the frequency. This can help to detect currents leaks and ensure higher safety. This is particularly beneficial for public lighting applications.
- Point to point power transfer does not show a massive difference in conductive cable cross section between DC and AC 3 phases. But when a complete electrical distribution application is considered as per the example of a commercial building installation, DC power can be easily injected in multiple points of a cable, at least on both ends. This results in cable size reduction in the overall application.
- DC is very helpful to harvest braking energy of machine motors such as robots and CNC. Reverse power is reused thanks to bidirectional converters instead of being dissipated in resistors, with side

effect of reducing workplace cooling needs. This is a huge energy saving opportunity for mechanical industries such as the automotive industry.

- Traditional AC distribution leads to an incredible number of AC/DC converters (PCs, mobile devices chargers, IT, etc.). All these small, inefficient devices generate a lot of heat in green buildings or data centers, increasing the cooling energy consumption. With a DC distribution, AC/DC conversion relocated in grey spaces. White spaces or occupant spaces then have lower cooling needs.

Benefits from solid state breaker: DC is difficult to break with traditional electromechanical technology.

- Solid state technology makes DC protection much easier and faster
- People safety with ultra-fast tripping that bring lower incident energy during faults.
- Unlike electromechanical technology, there is no gas exhaust during tripping
- Solid state technology has native capability for metering, communication, and local computing power. This reduces a lot the cost gap versus electromechanical technology. An electromechanical protection device with metering, communication, and local computing power will cost four to five times more than the core protection function.

8.3 Current OS solves major issues

On top of these intrinsic benefits of Microgrids, DC and Solid State technology, The Current/OS system approach brings **unique advantages** and **solves most of the intrinsic cons of Microgrids, DC and Solid State** technologies considered separately:

Microgrid issues in traditional approach	**DC Systems solution**
Traditional microgrids are a complex setup with an automation and communication system on top of electrical distribution system.	DC Systems' solution proposes a simple system (voltage is the main information readable from everywhere) and encapsulates the complexity in devices (solid state devices have all built in features for safety and energy management.
Upgrades and extensions on traditional microgrids require a simultaneous change on electrical installation, on the communication installation, and on the automation system.	DC Systems solution is scalable by addition of a new device and circuit with appropriate priority settings.
DC issues in traditional approach	**DC Systems solution**
Traditional electrical designs would propose a complete DC distribution in Zone 1. In this area, the breaking of DC is difficult, arc mitigation is a big threat, and selectivity is very complex especially with multiple sources.	DC Systems microgrids maximize "Zone digits". The most vital part of the microgrid is Zone 3 and 4. This provides the highest safety and solves the major objections against direct current.
Solid State issues in traditional approach	**DC Systems solution**

Solid state devices can hardly cope with high overcurrent transients. Oversizing is required, leading to higher costs. Solid state devices are more expensive than electromechanical devices.	In Zones 2 and 3, overcurrent never exceeds twice the nominal. Design is optimized. Communication, metering, and processing capabilities are native with solid state technology.

8.4 Current OS brings unique benefits

On top of **Microgrids, DC and Solid State** technologies, when considered separately, Current OS brings several unique benefits:

- Opportunistic behavior of the microgrid
  - permanently adjusting the demand to the power available.
  - bidirectional by default to import or export energy.
- Distributed control of stability
  - no critical point in central control or communication to sensors.
  - Moving complexity to components and adding simplicity to the system.
  - Autonomous systems without central real time control: Voltage fluctuation simply communicates state of microgrid (energy availability) to match demand with supply according to priority settings.
  - Intrinsically cybersafe.
- The highest safety
  - Power electronics provides faster protection and much higher safety.
  - No intermediate protection layer: protection devices in sources can power all loads directly.
  - RCD possible on long lines.
- Massive copper reduction
  - Installation downsizing (with same service): device ratings and cables size.
  - Dimensioning at the nominal and not at the peak.
  - Cable multi-feed reduces cross section.
  - Ultrafast breaking allows cable sizing at nominal current and is sufficient to withstand short circuit.

8.5 Benefit for Society

This could be seen as a side benefit nowadays but will become more and more to consider in the future.

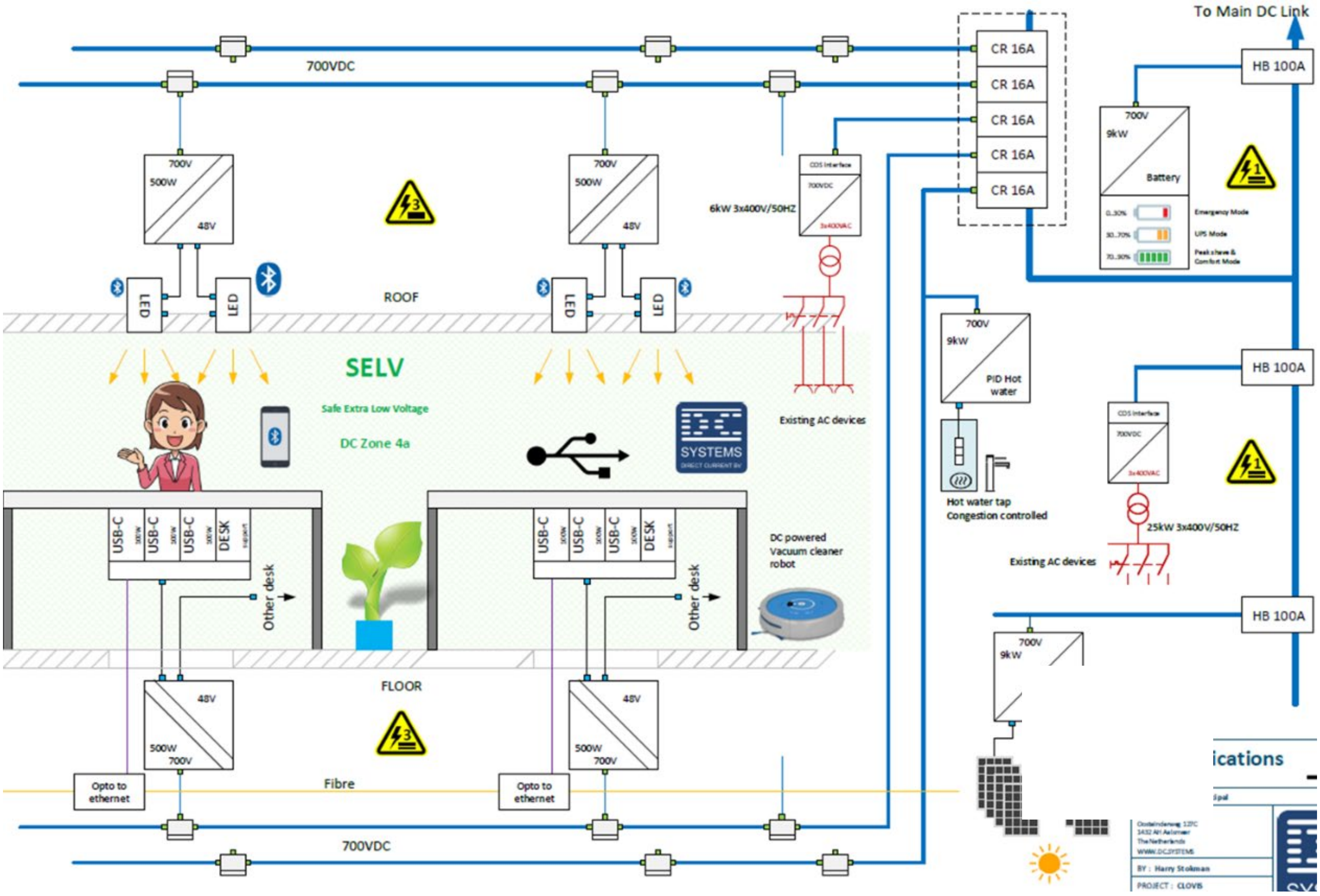
Electrification of the human activities (away from fossil fuels) will grow electrical energy demand. Current systems are dimensioned at peak and energy demand growth will require a system power upgrade.

DC Systems' solution can help to reduce the investment needed on the grid, even in very dense area like city cores. In highly dense areas and high-rise building zones, PV production covers a very small share of the power consumption. However, by implementing opportunistic microgrids with just battery storage as local electrical resources can make power demand to the grid more constant. Additionally, batteries will store energy during the low consumption periods. This will help to maintain the grid operational for the full area including the neighborhood, and thereby avoid big works in the streets to upgrade cables and delivery stations. Buildings will help to reduce consumption peaks or even to feed the peaks from the microgrids. In the end, this will reduce the bill for all citizens.

9 DC Systems Electrical Architectures

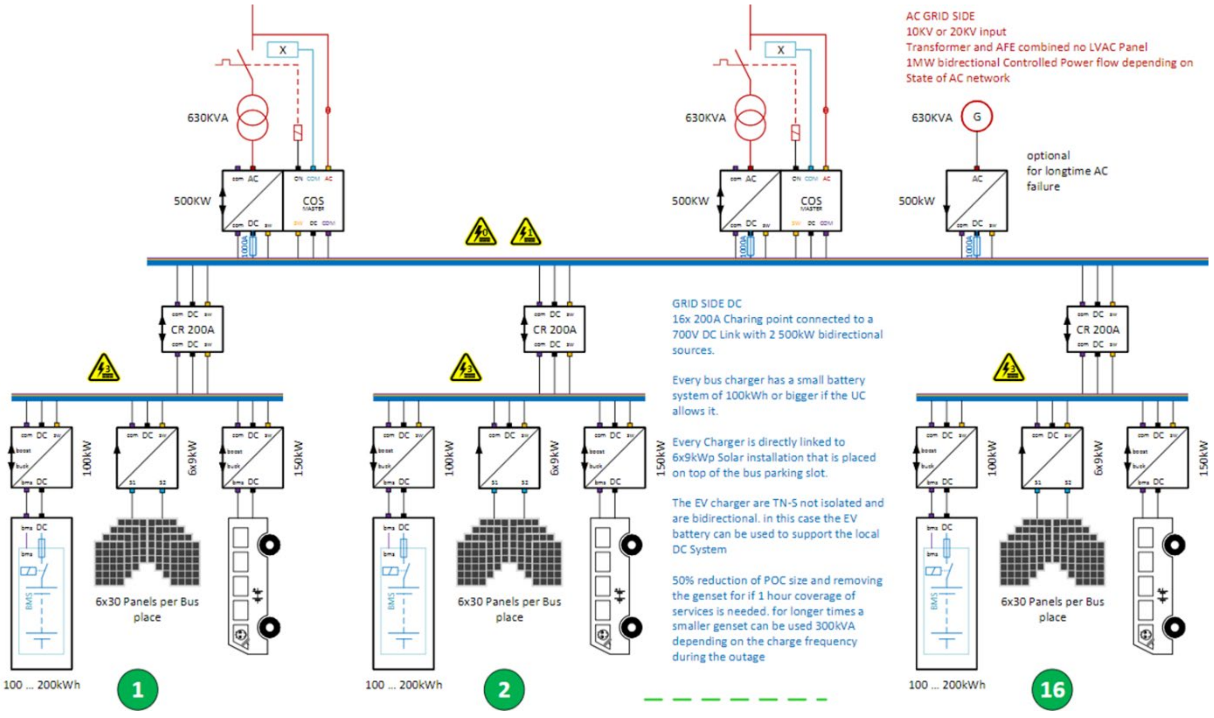
9.1 Office building architecture

Office buildings' preferred architecture has a 700VDC backbone. This backbone is distributed with only 2 cables in the ceiling and 2 cables on the floor level.
In the occupant space, only a safety voltage will be distributed such as 48VDC. 700VDC will be converted to 48VDC just before entering the occupant space. 48VDC will be used to power the lighting system in the ceiling. USB-C, now available up to 240W, is to become a global standard to power a very wide variety of loads. 48VDC will be used to power the USB-C plugs on desks.

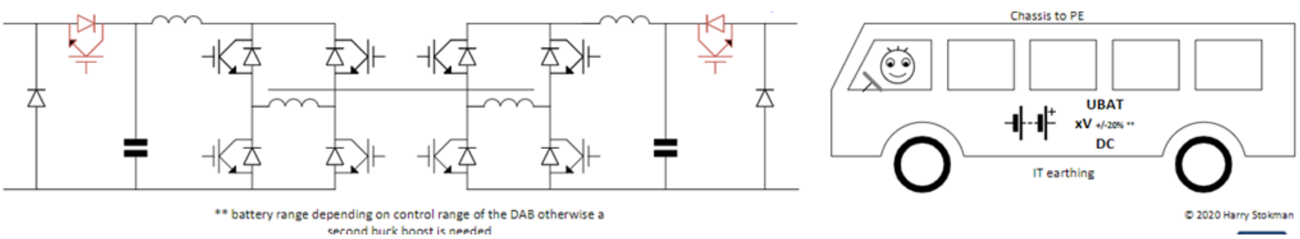


9.2 Bus charging stations architecture

Charging stations will preferably have distributed electrical resources to avoid huge peak demand that the public grid may not be able to support.

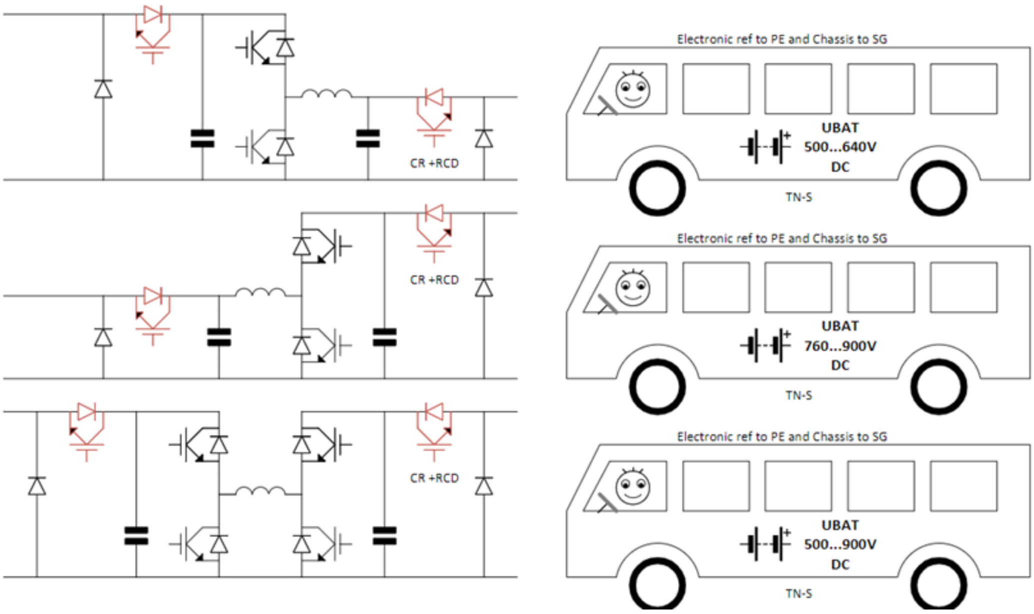


IT earthing system is popular in EV charging but brings several issues. IT looks safer BUT IS NOT! EMC filters capacitances are not small and can be very dangerous during maintenance. IT also requires an isolated converter (bigger, cost). A second buck boost could be needed upon battery range and control range required.



TNS should be preferred in DC fast charging. TN-S Electronic ref to PE and chassis to SG. TNS brings massive advantages:

- Cheaper, smaller non-isolated converters
- Chassis to SG mitigate DC corrosion effects
- Simple buck or boost converters may bring an additional optimization vs. buck-boost type (upon EV battery voltage range)
- No risks with EMC filter capacitances


CR +RCD
CR +RCD
CR +RCD
Electronic ref to PE and Chassis to SG
UBAT
500…640V
DC
TN-S
Electronic ref to PE and Chassis to SG
UBAT
760…900V
DC
TN-S
Electronic ref to PE and Chassis to SG
UBAT
500…900V
DC
TN-S

9.3 DC street lighting

The installation of a DC street lighting system brings many advantages:

- Greatly reduced total installation cost. DC lines can be much longer (up to 5km) and reduce the number of MV/LV substations (-80%).
- Simplification of the implementation. Existing cables can be reused and their capacity increased because DC allows power injections at multiple points. Cables with high leakage currents due to humidity can be "regenerated" by DC.
- Simplified maintenance: LED drivers can be installed at the foot of the pole. This limits the need for aerial work.
- The DC distribution network can be used for new urban uses such as electric bicycle charging stations or 5G antennas.
- Increased safety of the installation because the DC allows a fine detection of the ground leakage currents and thus a real protection against indirect contacts.

The N470 project is an example of street lighting architecture powered by a microgird;

The provincial road N470 was a one-of-a-kind project for the region, involving multiple partners. South Holland aspires to manage and maintain its roads, waterways, bridges, and locks in a carbon-neutral manner. These spectacular goals have been realized in the N470 project by creating the most sustainable road in the Netherlands, and by demonstrating to the market that this is a normal tender, not a demonstration project within the existing ecosystem.

It is the first road in the region to have been renovated entirely in a CO_2-negative manner and to generate its own energy for lighting and traffic signals. Additionally, traffic can continue to flow more freely, and the road has been made safer through the use of new DC technologies. The distances are short, which prevents electricity from being lost during transmission via high-voltage cables and conversion to AC. This minimizes energy consumption and CO_2 emissions. The green battery stores the energy generated during the day so that it can be used later in the evening when the sun is not shining.

The N470 is the first to be equipped with a self-sufficient energy system. The Energy Wall is a noise barrier that also produces energy via solar panels embedded in the screen's glass plates. The generated energy can be used directly to power 332 lights and 225 traffic lights further down the road. The noise barrier is made up of 100kW solar and generates 75 megawatt hours of electricity per year. This is approximately the same as providing green electricity to approximately 26 households for one year.

The following are some of the potential benefits of this project:

- The system is powered by a single cable that runs for 4.7 kilometers.

- The cable is powered by DC to avoid the difficulties associated with passing AC power through a water channel.
- The system is capable of operating in islanded mode if the main grid is lost.
- The system is a autonomous microgrid with distributed sources with managed power flow without digital communication. (Current/OS system)
- The system includes energy management features but does not require data or an internet connection for security reasons.
- The system is integrated with renewable energy sources such as photovoltaic (PV) and energy storage.
- It is a commercial project, not a demonstration project within the established ecosystem.
- The first DC project was developed in accordance with the Dutch technical guide for DC installations (NPR9090)

The project's technical specifications include the following components:

- The power distribution cable is 4.7 kilometers long contains a four-core cable of +\-700 Vdc with a +/-60Vdc droop control, and a TN-S earthing arrangement.
- The network is earthed using a TN-S with multiple earthing arrangement with additional stray-current protection provided by the use of diodes to separate the metallic and electric earthing.
- The solar panels are connected to the main power distribution system via DC/DC converters.
- Two active front ends of 100kW each interface with the AC grid (it is worth noting that AC grid support is disabled in this project) and operate on 50kW with limited line currents.
- Ambient requirements include a temperature range of -20 to 50 degrees Fahrenheit and a relative humidity of 95% at sea level.
- The AC station is rated at 150kVA.
- The DC system is electrically isolated from the AC system.
- 1MWh LiFePo4 battery system based on 12 strings connected via DC/DC converters and protected by solid state circuit breakers
- Distributed batteries equipped with autonomous system capable of communicating with the BMS and reacting to the state of the grid (SOG) in conjunction with the state of health (SOH) and state of charge (SOC).
- Streetlights connected to a network of 23 strings x ±350V with a +/-30Vdc droop control equipped with DC/DC led drivers and power line control
- The streetlights are equipped with RCDs to protect the public against direct contact.
- The network incorporates hybrid circuit breakers and solid-state protection.
- Overvoltage protection is incorporated into the network, as well as Arc fault detection
- Power flow and protection, for example, are determined by the Current/OS protocol and requirements.

Reference:

https://www.zuid-holland.nl/onderwerpen/energie/energiewegen-0/n470-geeft-energie/

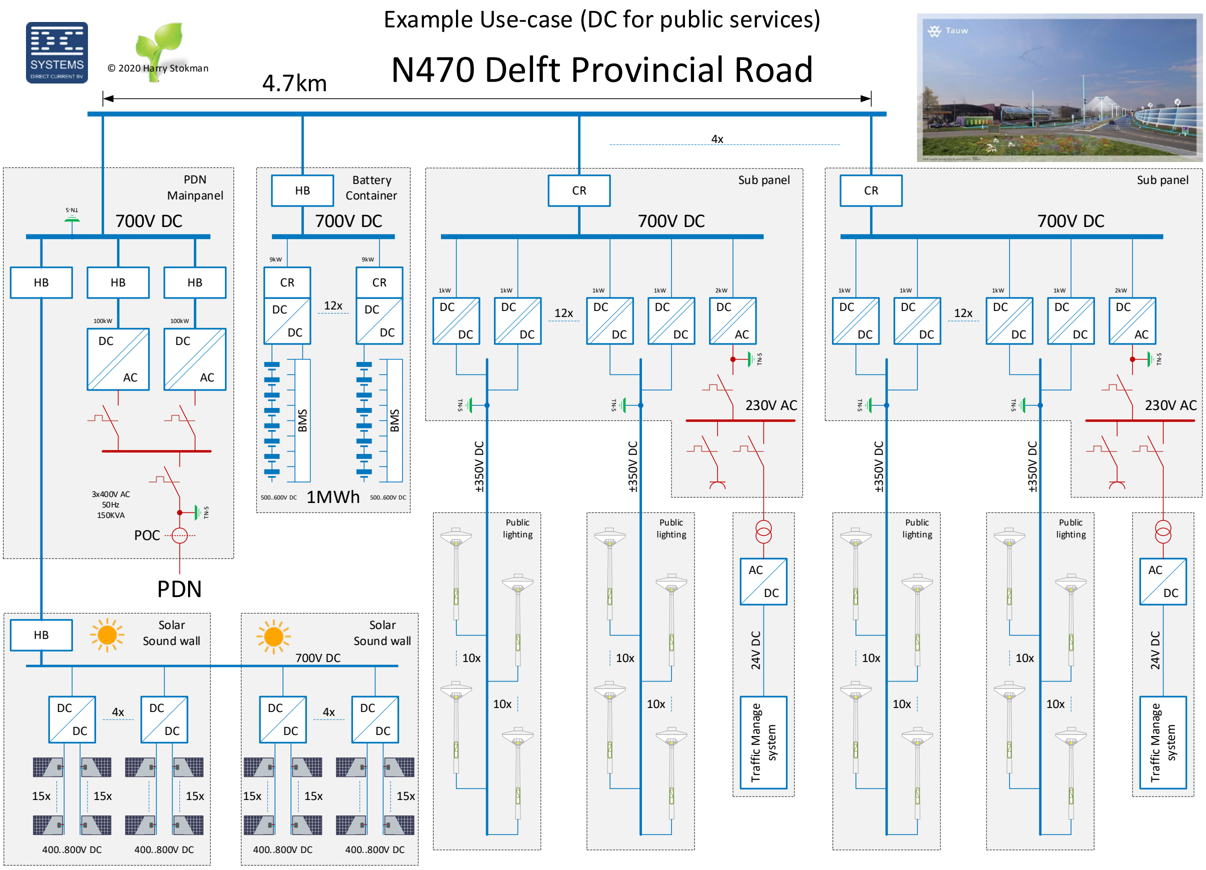


Figure: Single-line diagram of N40 site system.

SYSTEMS by Schneider Electric

 **Distributed batteries system**	 **Outdoor substation**
 **An illustration of why RCDs and protection are necessary. A minor accident occurred during testing when one of the cars collided with the project's light pole. (safety comes first).**	 **Outdoor substation for public lighting**

SYSTEMS

by Schneider Electric

Figure: The layout of the N470 project

In accordance with the Dutch standard for DC:

Agency	Number	Year	Name	Abstract	Short description	Voltage level
NPR	9090	2018	DC installations for low voltage	NPR 9090 is applicable to the design and installation of DC installations for low voltage (up to 1500 V DC) related to the scope of NEN 1010. Combined AC and DC installations are also included in the scope of this NPR as long as galvanic isolation is applied between the AC and DC parts.	This standard serves as the legal foundation for installation requirements, as the law refers to the wiring standards. As a result, this was an important standard to have when constructing DC installations for N470 project.	350-1500 V

https://www.nen.nl/en/npr-9090-2018-nl-250370