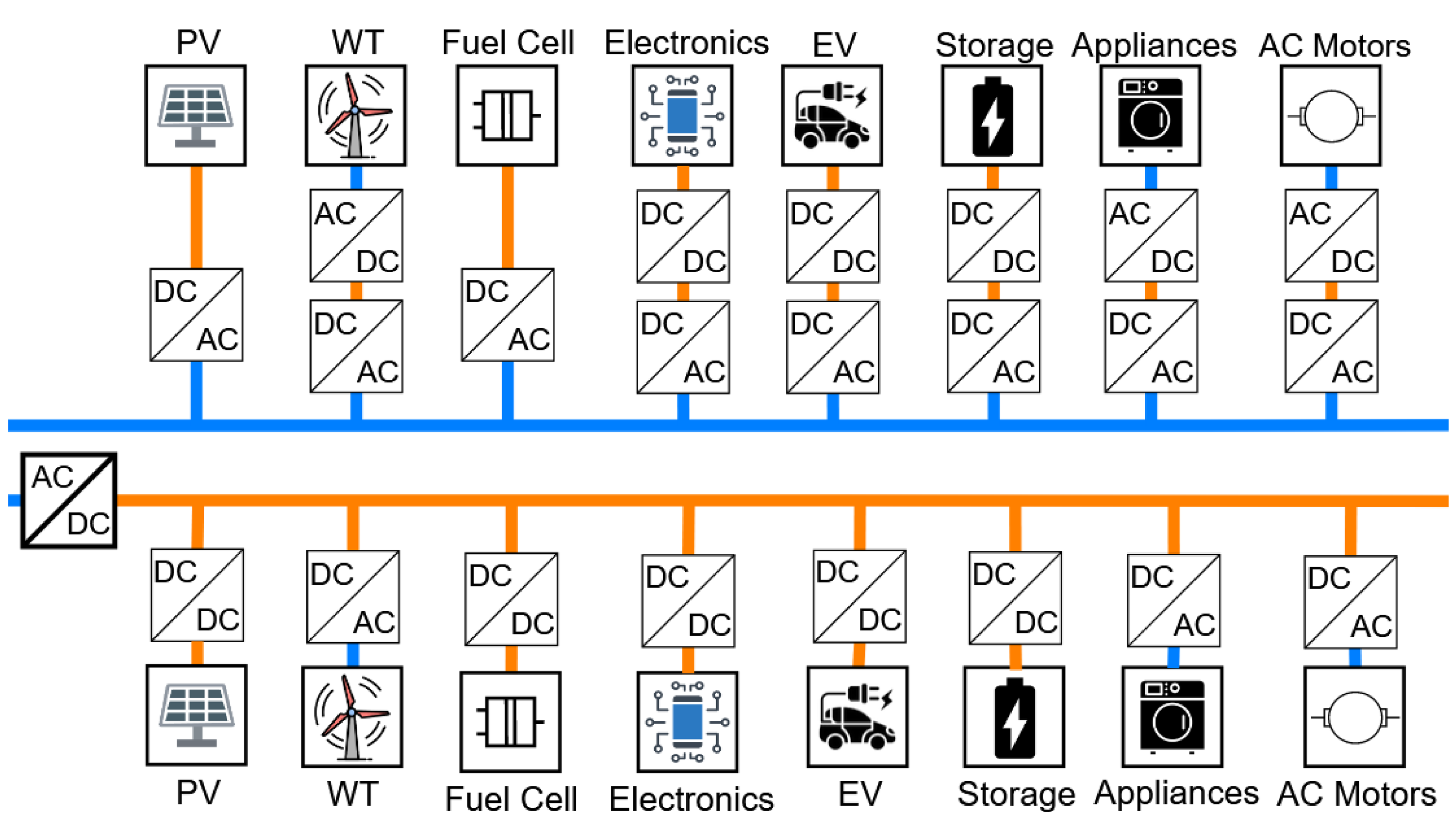
ELECTRICAL SYSTEMS

Hybrid AC/DC distribution grids

Analysis of power quality and protection aspects

CONTEXT

During the last years, distribution power systems working with Direct Current (DC) are gaining visibility and becoming more competitive. The growth in the number of theoretical and experimental studies using low-voltage DC grids can be justified as the result of three facts: the improvements in power electronics, the increase in the use of DC-based loads (electric vehicles, electronic devices, etc.) and a growing presence of DC energy generation among Renewable Energy Sources (notably photovoltaic panels). Exploring these new context, recent research appear in the literature pointing out some scenarios where DC can bring a real gain in terms of efficiency by mutualizing the conversion steps, as shown in the figure below. However, the deployment of DC distribution still faces some technical challenges, mostly related to standardization, protection capability, and ensuring power quality.

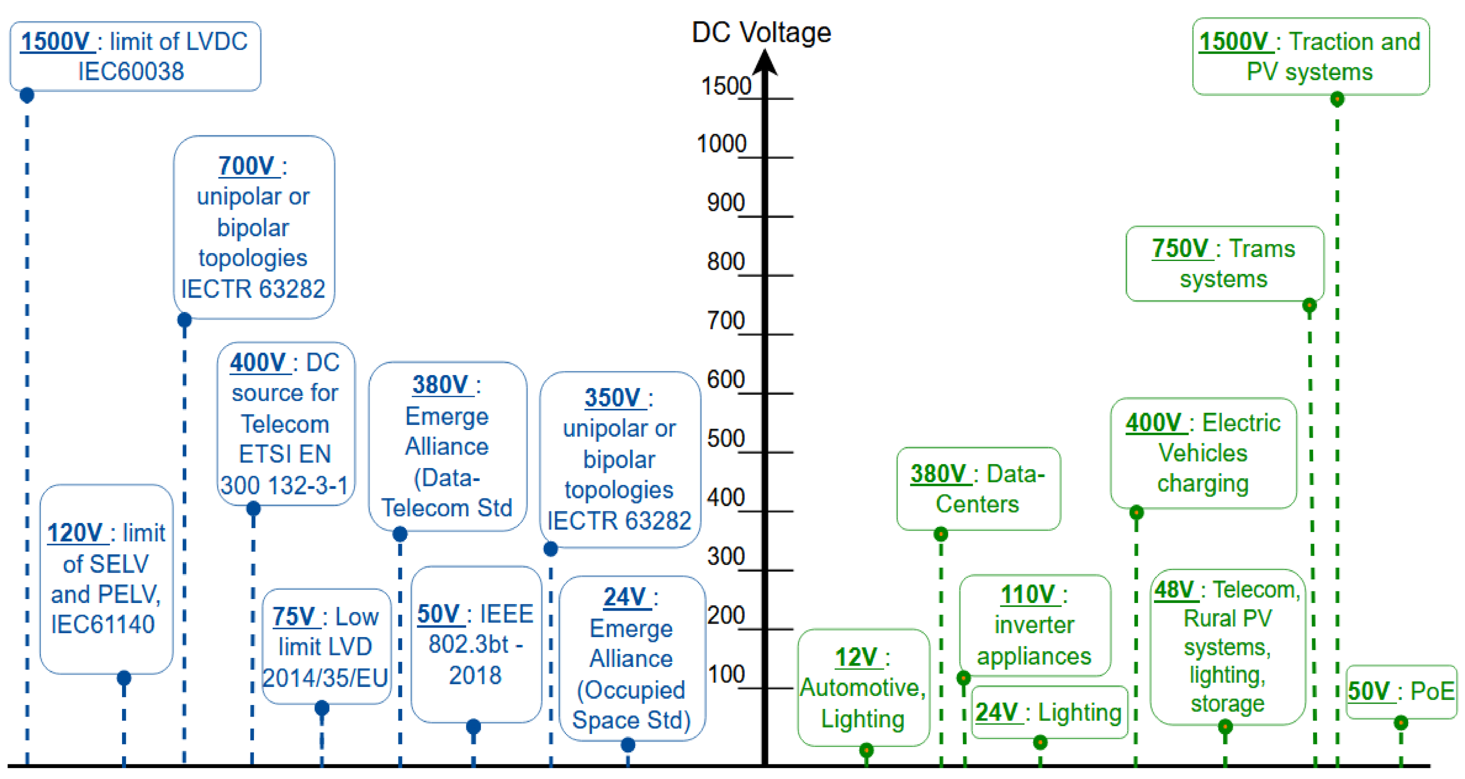


AC vs. DC distribution grid: mutualisation of conversion steps.

STANDARDIZATION OF VOLTAGE LEVELS

A literature review shows that the environment around LVDC distribution lacks standards and regulations. A complete set of rules regarding DC systems, DC distribution voltage levels, protection devices and power quality aspects in DC, is still missing. One of the most important subjects for the generalization of LVDC systems is the standardization of the distribution voltage level. Presently, most standards recommending the adoption of a certain voltage level relate to specific applications.

However, there are also some advances in the conception of a wider and global standard, resulting from the efforts of entities like the IEC and the IEEE. Even if many possibilities exist (figure below), voltage levels for LVDC distribution that are most often chosen in recent studies and real applications are within the 350-400 VDC range. This is because it represents a good compromise between protection and efficiency, and because there already are standards for this voltage level range as well as equipment available on the market.

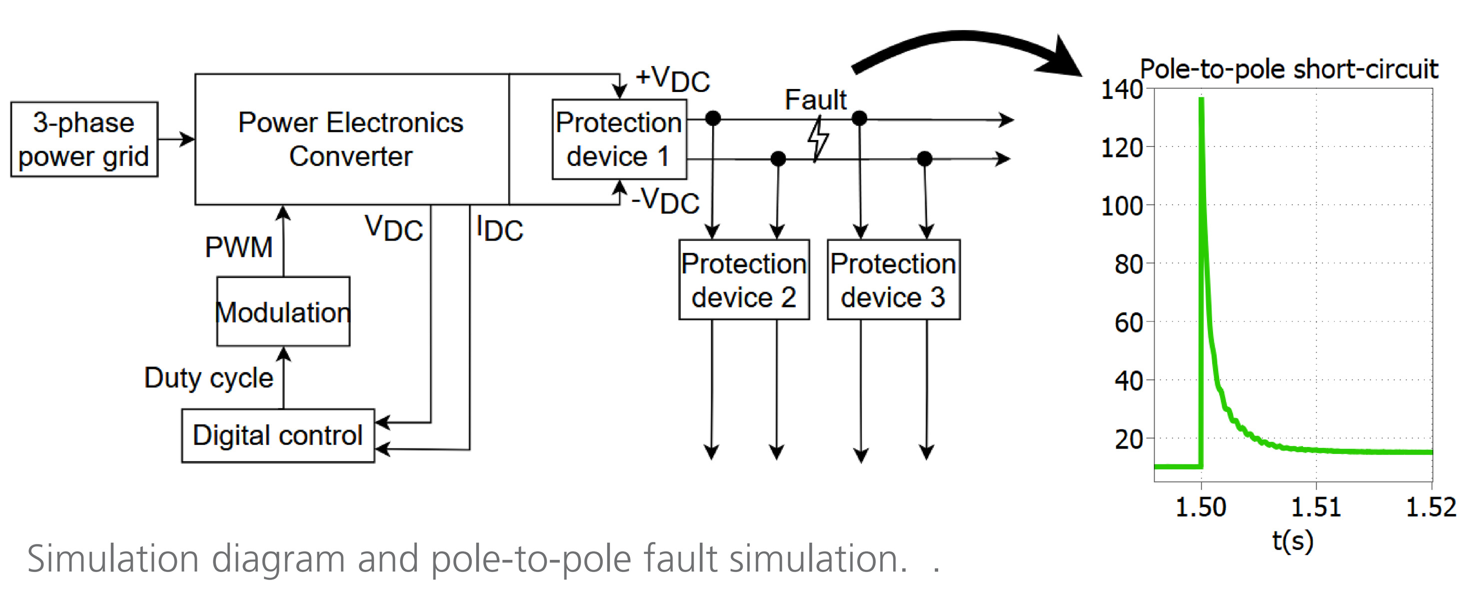


Standards (blue) and appliances (green) in the DC domain.

CHALLENGES IN PROTECTION SCHEMES

In contrast to the high maturity level found in AC protection schemes, equivalent protection architectures in DC are a developing domain since they must answer to new requirements. This study identifies two main difficulties: the application of selectivity in the elimination of short-circuit faults (1) and the protection against electric shock (2).

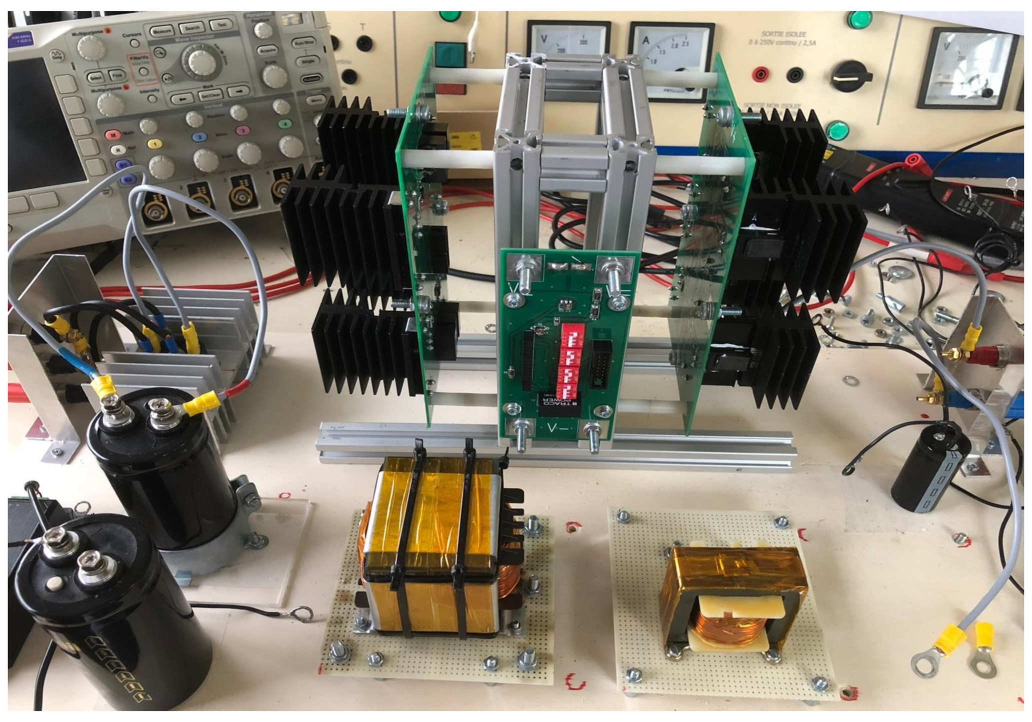
- (1) In DC, power is supplied through power electronics converters, which have a limited short-circuit power, making it difficult to ensure selectivity (for protection devices 1,2 and 3, as shown in figure below). A high short-circuit current level allows protection devices to function correctly, however, it may put the converters semi-conductors in danger. Some of the possible solutions investigated involve the use of Solid-State Circuit Breakers (SSCB), fuses with a high capacitance output filter, voltage-restrained protection devices (ANSI51V) and current limitation strategies.
- (2) Without a DC Residual Current Device, the use of a separated earth and neutral earthing (TNS) system with fuses or circuit breakers seems to be the only technical solution to prevent equipment from reaching the security voltage threshold (120V DC). However, the influence of earthing connections and the calculation of short-circuit currents must still be investigated to ensure the correct triggering of protection devices.



Simulation diagram and pole-to-pole fault simulation. .

ENSURING POWER QUALITY IN DC

Another crucial aspect to be analyzed regarding LVDC distributions is the power quality domain. It represents the boundaries in terms of voltage characteristics that must be respected to maintain the entire system operating correctly. Harmonic disturbances, voltage imbalance, low-frequency voltage variations (flicker) and surges are power quality indexes for power systems. So, as to avoid dangerous variations in voltage levels, it is important to establish ranges for voltage levels, thresholds, and maximum duration of fluctuations. Standards already exists in AC and having the equivalent in DC is crucial for the future of distribution grids. With the goal of studying the power quality domain in DC, this research identified the need of establishing a dynamic impedance model of the front-end converter through the method of disturbance injection (current source). This approach will allow the study of disturbance propagation, resonance phenomena and harmonic distortion (ripple). Simulation and experimental results (obtained with the prototype shown below) will be compared at the end.



Prototype of AC/DC converter (3.5 kW, 0-400 VDC).

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