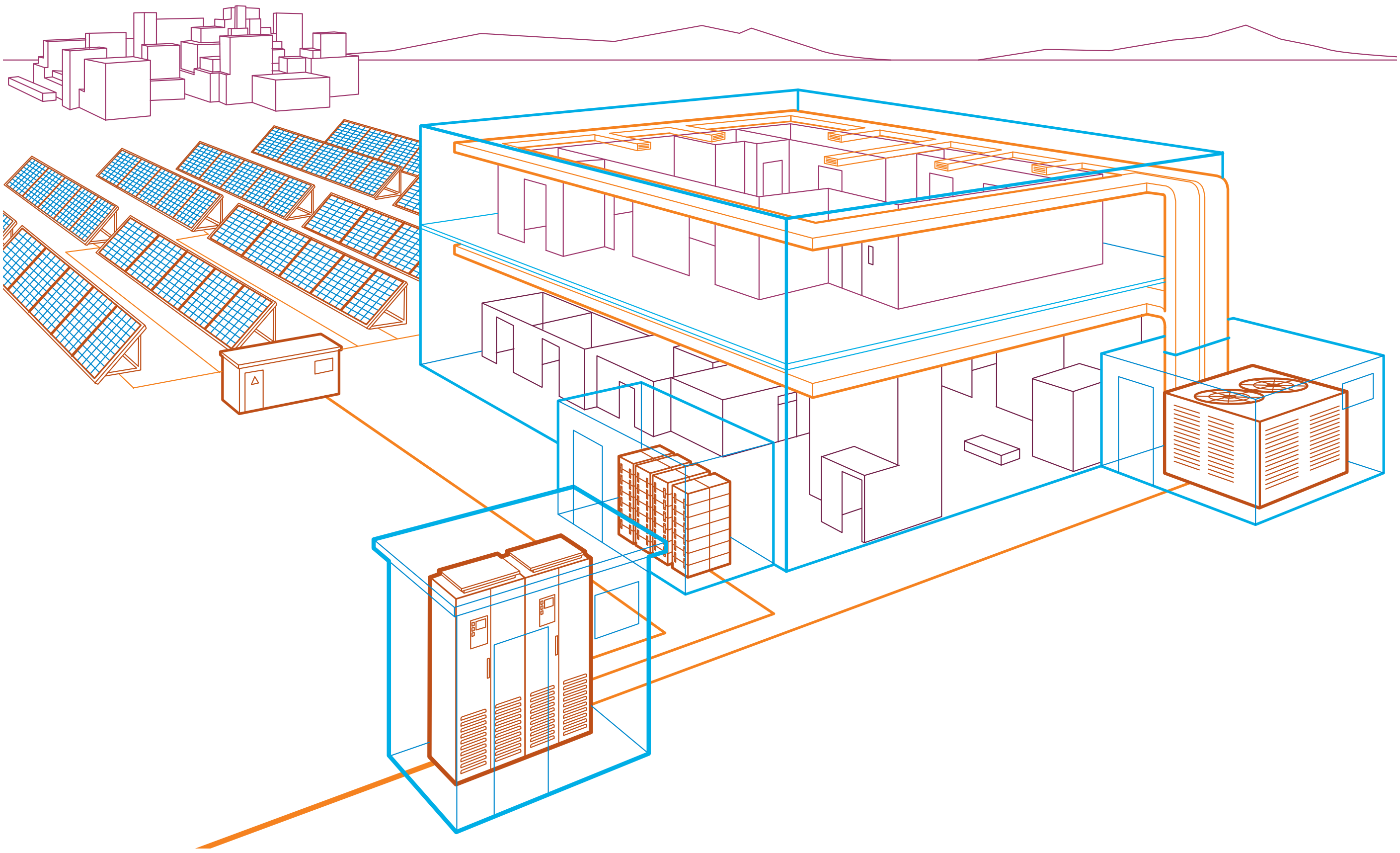
Product note
Fault protection of LVDC microgrids



New scenarios in electrical distribution networks, with increasing presence of distributed generation and loads with strict power quality requirements, include DC microgrids with energy storage systems as a replacement for traditional AC systems.

A number of realistic cases exit in which converters can't limit ground or short circuit fault current.

DC electrical distribution offers several advantages compared to AC in many applications, such as data centers, marine installations and in particular in low voltage distribution in the presence of distributed generation and storage.
Battery energy storage systems and distributed generation such as PV plants or wind microturbines, and their related electronic converters, affect system behavior both during normal operation and in the presence of faults, in different ways depending on different possible grounding schemes.

Most converter systems are actually based on double conversion: a DC bus is interposed between power electronic-based subsystems.

A thorough analysis of fault conditions must therefore be carried out and dedicated protection devices must be employed.

In such an arrangement, the DC section is typically of limited extension and totally enclosed in a single switchgear. As a result, probability of DC fault is quite low, and used to be neglected in many designs.
Nevertheless, in the new scenarios described above, extension of the DC section becomes more and more significant. In some application, DC distribution even covers the majority of plant extension. (e.g. this happens in marine applications, in DC microgrids, and in DC data centers).
In these cases, probability of a fault in the DC section is no longer negligible, and such faults need to be dealt with by proper analysis and protection design.

Fault protection of LVDC microgrids

Conventional wisdom is that converters limit currents in any situation, hence the fault current level is no longer a concern in circuit design. While this might indeed be the case for some specific situations, there are others in which converters are not able to limit fault currents.
This depends on type and connection of converters, as will be shown.

If fault is on the DC side, current flows in the freewheeling diodes with no possibility for the IGBTs to limit it.

Some most common types of power converters are shown in Figure 1.
Each has defined features and applications:

– three phase thyristor rectifier, which converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. thyristors are commonly used in place of diodes to create a circuit that can regulate the output voltage (application examples: feed and control of DC motors – Figure 1a);

– AC/DC IGBT converter, which is a forced commutated three-phase converter that can be used as a rectifier or as an inverter. Electronic component commutation (from ON to OFF position) occurs hundred times per period, so it guarantees performances that otherwise could not be reached with thyristors, such as current or voltage may be modulated (PWM – Pulse Width Modulation) producing a low harmonic contribution, the power factor may be controlled and it may follow an established profile; the power reversal occurs by means of the voltage reversal in thyristor rectifiers, while forced commutated rectifiers may be used for current reversal (application examples: HVDC light transmission, DC/AC converter in drives, front-end converter in LVDC microgrids – Figure 1b);

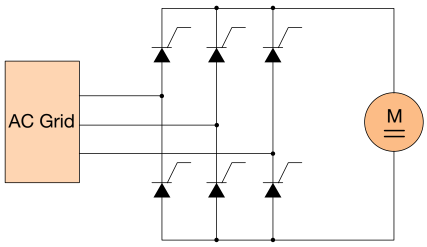
– step up converter (boost converter), which is a DC/DC converter with an output voltage higher than its input voltage (application example: PV plants connected to DC systems – Figure 1c);

– step down converter (buck converter), which is a DC/DC converter with an output voltage lower than its input voltage (application example: DC loads connected to DC systems – Figure 1d);

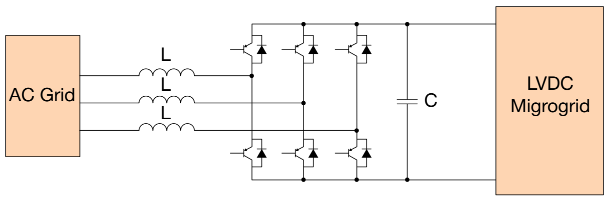
– DC/DC bidirectional converter (buck boost converter), which is obtained by the combination of the previous two converters. This configuration allows the bidirectional power flow (application example: charging and discharging of energy storage systems con connected to DC systems – Figure 1e).

Figure 1 – Most common types of power converters

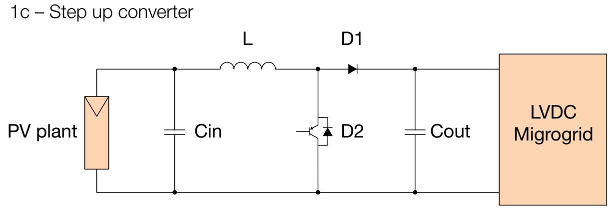
1a – Thyristor rectifier



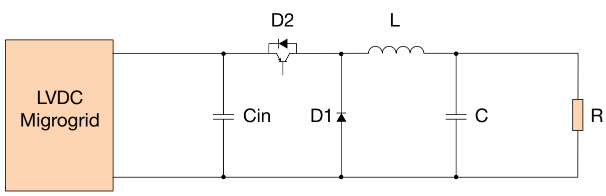
1b – AC/DC IGBT converter



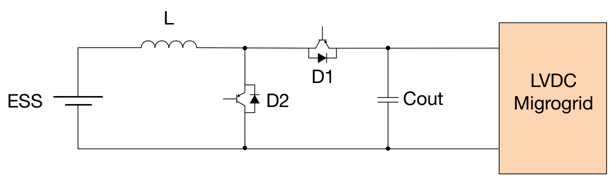
1c – Step up converter



1d – Step down converter



1e – Bidirectional converter



As shown in pictures, semiconductors with freewheeling diodes are widely employed. Purpose of such diodes is to prevent overvoltages and countervoltages when semiconductor is swiched off. Depending on type of converter and type and location of the fault, different effects may occur. A common situation frequently described is the connection of a DC active microgrid (e.g. with PV plant or energy storage system) to the AC grid by means of a IGBT converter. If a short circuit occurs on AC side, the converter is able to limit the fault current. If, on the other hand, the fault is on the DC side, fault current flows in the freewheeling diodes without any possibility for the IGBTs to limit it, even if an IGBT block signal is sent by the control system (Figure 2).

Similar situations occur in all cases in which short circuit current path can include freewheeling diodes, hence all AC/DC IGBT converter, step-up and DC/DC bidirectional converters may suffer from this effect.
Moreover, a similar effect may take place in the case of a DC ground fault in a microgrid with the neutral point of the MV/LV transformer grounded (Figure 3) or DC negative pole grounded. Both grounding configurations are widely used as they guarantee operation safety from overvoltages. However, when a ground fault occurs, the front-end converter may not be able to limit the AC grid contribution to the fault current, even if the DC generators contribution may be switched off by IGBT block. It must be pointed out that ground faults are far more frequent than short circuits in electrical installations, hence DC ground fault are expected to become more frequent as DC section of installations extend. Similar cases can be made for several other configurations of converters.

Thyristor rectifiers, which are immune from this issue, can't be applied as front-end converters in DC distribution with distributed generation, because in case of reversal of power flow, they require voltage polarity to be switched, with obviously serious problems to devices connected to the DC-Bus.
It is thus apparent that the naive statement that fault currents are of no concern, and that protection can be fully implemented by converters, is not generally true. A number of realistic cases exit in which converters can't limit ground or short circuit fault current. A thorough analysis of fault conditions must therefore be carried out, and dedicated protection devices must be employed in order to safeguard installation and operator safety.

Full details can be found in Technical Application Paper No. 14 "Faults in LVDC microgrids with front-end converters"- 1SDC007113G0201

Figure 2 – DC short circuit current components in an active LVDC microgrid

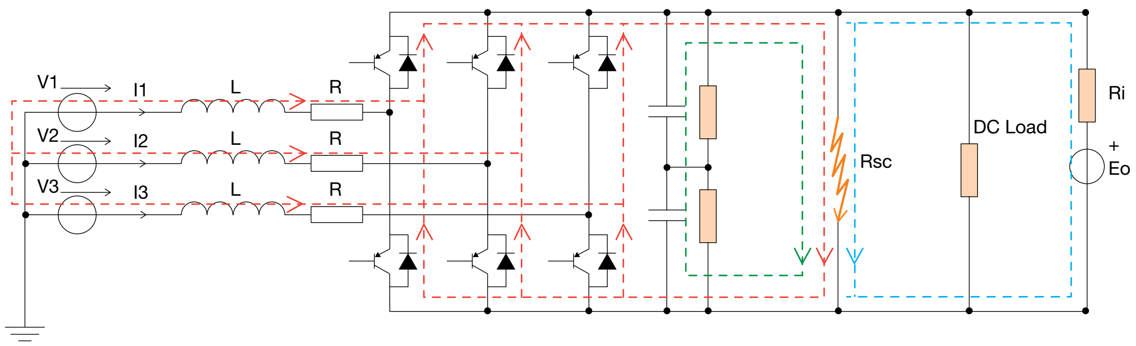
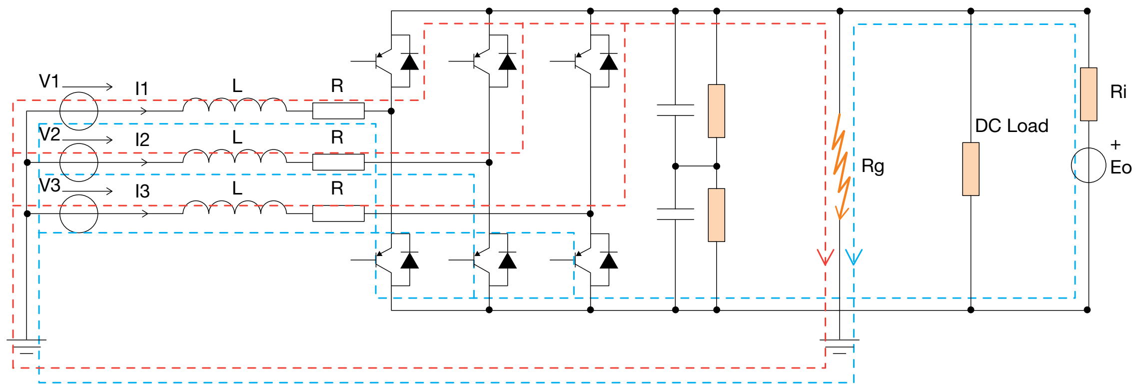


Figure 3 – DC positive pole ground fault current path in an active LVDC microgrid with the neutral point of the MV/LV transformer grounded



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1SDC007113L0201 - 08/2015 - 4.000