Protection of Power Electronic Multi Converter Systems in AC and DC Applications

Prof. Norbert Grass
Technische Hochschule Nürnberg, Institute for Power Electronic Systems, Nuremberg, Germany, Norbert.Grass@th-nuernberg.de

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Protection of power electronic systems, which are connected to public power grids or telecom power supply grids, is gaining importance due to the ongoing installation of decentralized power sources. The transition of the grid control from a small number of large synchronous generators towards a high number of power electronic converters requires the development of novel concepts, regarding the properties of power electronics converters and fuses.

In telecom power supply grids the trend is moving to high voltage DC technologies, which operate in the range of 400 V DC or even above. The higher voltages comprise the advantages of higher efficiency, power rating and lower installation cost (less copper conductor cross section).

For both kinds of power electronic grids mentioned above, the protection against short circuits, arcs and further electrical hazards requires new concepts which will need to guarantee similar safety functions, while the operation modes of grids are significantly changing, as we observe reverse or bidirectional power flow.

DC link capacitors provide very high short circuit current capabilities with extremely short rise times because of very low circuit inductivity, which may result in severe DC arcs, which need to be extinguished safely and reliable.

For isolating power lines, which are affected by a short circuit, synchronous generators used to provide high short circuits currents and selective fuse concepts could be compiled by the combination of the required current ratings of the fuses. Power electronic systems are current controlled, which prevents the systems from delivering high short circuit currents. New concepts have to be found to retain the selective isolation of faulty grid parts in order to keep other lines alive, which are not affected from the fault. Therefore, the generation of sufficient short circuit currents is to be regarded in protection strategies and in the development of grid connected power converters.

Fault modes, short circuit currents and control features of fully power electronic fed grids needs to be defined in regards of protection strategies. Though, power electronic converters need to be economically designed and hence provide specified short circuit current capability.

Functional Properties of Power Electronics Converters on Renewable Sources

Power electronic converters deliver fully controllable currents or voltages up to the magnitude, as far as the connected energy sources (e.g. PV-, wind generator, battery storage) are able to deliver instantaneous electrical power. In contrast, synchronous generators can use their inertia to deliver higher power on short term. Basically, the generator inherent inertia is a kind of energy storage, which can be activated on high electrical loads or on the occurrence of a short circuit. Basically, the output current of a power electronic converter is always fully controlled, if the system is properly operating, even under short circuit or any other grid fault conditions.

Power electronic converters conduct electrical power from one terminal to the other, which means, that the electrical power is almost identical on both sides of the converter. Only the converters losses, which are in the area of one or a few percent, have to be supplied by the energy source additionally to the conducted power. Because power is the product of current and voltage, the deliverable current depends on the voltage in case of a given power, as shown in Figure 1. Therefore, in case of a short circuit, the voltage is very low and hence, the current can be increased by the converter in principle, even if the power source is e.g. a PV plant, which can deliver limited current only.

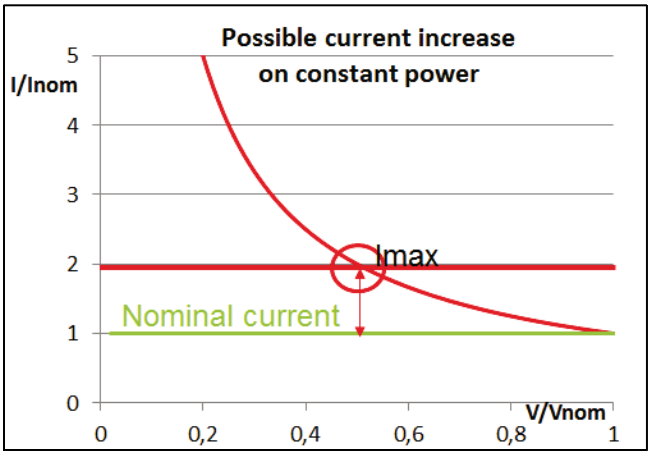
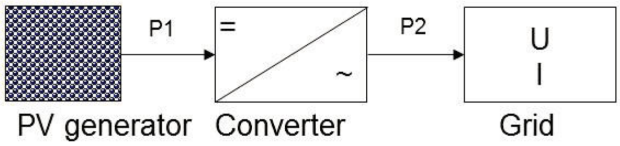


Figure 1: Current increase with converter on constant power source



$I_{Grid} = P_2 / U_{Grid}$

The real achievable grid current certainly depends on the converter design and in particular on the overload current capacity, which is always a tradeoff between cost and functionality. Converters are usually economically designed for their specified continuous nominal output current on the maximum specified ambient temperature. The technical limit of the converter current is the resulting chip temperature of the power devices, which is in the range of 150 °C to 175 °C for commercial available IGBT semiconductor devices. However, power semiconductors are mounted on heatsinks, which have substantial thermal capacities. That means, for a short period of time, higher currents can be conducted as long as the chip temperature limits are not exceeded. The question which arises is the required magnitude of the short time overcurrent capability for the short circuit protection of the grid.

Modes and Protection Scenarios for Converter Faults

In power electronic circuits, there might be a fault on an IGBT power switch, which usually results in a short circuit of the regarding power device. Figure 2 shows the fault condition in a typical converter topology. If grid voltage L1 is positive against grid voltage L2, then a short circuit path from L1 over the faulty IGBT in phase leg 1 and the diode in phase leg2 towards L2 draws a high current from the grid. The current increase is limited by the chokes shown in Figure 2. Because the scenario is a severe internal converter fault, it needs to be protected by fuses on the grid connection of the converter. Using fast switching fuses may limit converter internal damage, as the diode in the scenario explained above could be prevented from overload.

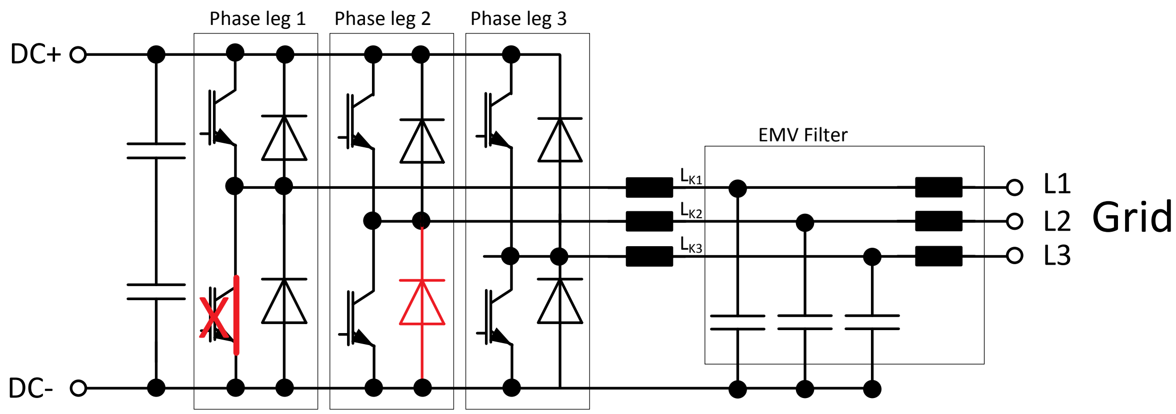


Figure 2: Possible converter fault caused by faulty IGBT power device

An IGBT fault in a power converter may probably cause a short circuit of the DC link voltage, which might result in a very high and fast rising short circuit current through both serial IGBTs. The energy, which will be transferred in heat, is limited by the stored DC capacitor energy. With today foil capacitors the energy is usually much lower than it has been with electrolytic capacitors, because the design value besides the required capacity is the current capability, which is much higher for foil capacitors. The most important protection feature is the short circuit proof and current limiting operating mode of the IGBTs. Therefore, the driver circuit can turn off the short circuit current through an IGBT, if properly designed. That means, if one IGBT fails, the second one can turn off the short circuit current safely. Using fuses in the DC link connection would require very low inductance of the fuse to avoid over voltages during IGBT switching and therefore many converters can't use fuses in the DC link.

Modes and Protection Scenarios for Grid Faults

In case of a short circuit on the grid lines, which is close to the entire converter, the fault can be detected by the converter control just by acquiring the grid voltages. Due to the current limited operation of the converter, no over currents would occur and no further protection would be required. After the occurrence of the fault, limited / controlled current would be fed from the inverter. Therefore, no damage on the grid lines would occur. After detecting the fault, the converter can be automatically turned off to isolate the faulty circuits.

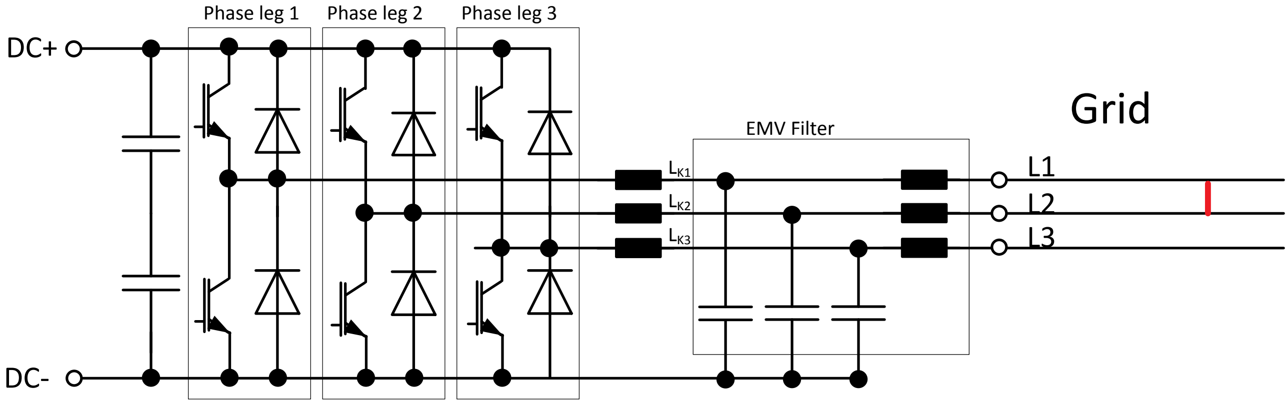


Figure 3: Grid short circuit, close to converter

For large grids selectivity of isolation is essential to avoid shut down of the whole grid after the occurrence of a short circuit. One possible solution is to synchronize converters to deliver sufficient currents to switch fuses, as shown in Figure 4.

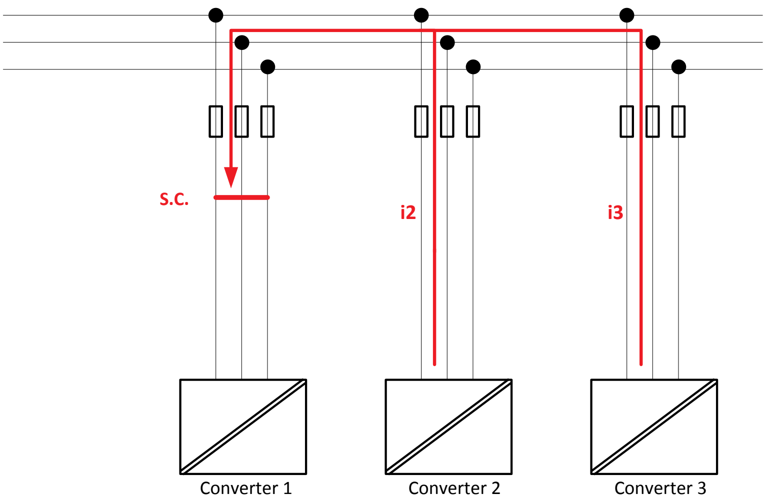


Figure 4: Short circuit treatment on a power electronic driven grid

Power converters are controlled by DSPs or FPGA and therefore algorithms can be implemented to distinguish, if the short circuit is located between the entire converter and the fuses or if the short circuit has occurred beyond the fuses. Therefore converter 1 in Figure 4 cannot help to switch the fuses and has to turn off its current. Converters 2 and 3 can add their currents and if designed for, they might inject even a higher current to switch the fuses to isolate the faulty part of the grid. Two converters, as shown in the example might be not sufficient to drive the required short circuit current, but in a real grid there would be much higher quantities of converters available to achieve the currents as high as required. The fuses should be designed to switch on lower currents compared to standard NH types.

For DC grids there is an additional problem in the possibility of the ignition of an arc, which would not extinguish as known from AC grids, because there is no zero crossing of the voltage. This problem can be solved by the power converters control, if the voltage on the grid is being monitored. Due to the current limiting control of the converter, the voltage will drop in case of an arc and therefore it can be detected in the DSP and then the converters can be switched off to extinguish the arc, even before major damage can occur.

Conclusion:

Efficient protection of converter fed grids is possible by a combination of fuses and converter control techniques. Special requirements for fuses will be derived. Technically and economically optimum parameters need to be evaluated.

The particular arc hazard treatment will be discussed for 600 VDC grids. The short circuit detection algorithms and converter operation in a distributed multi converter fed grid is possible with today available DSP controllers.

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