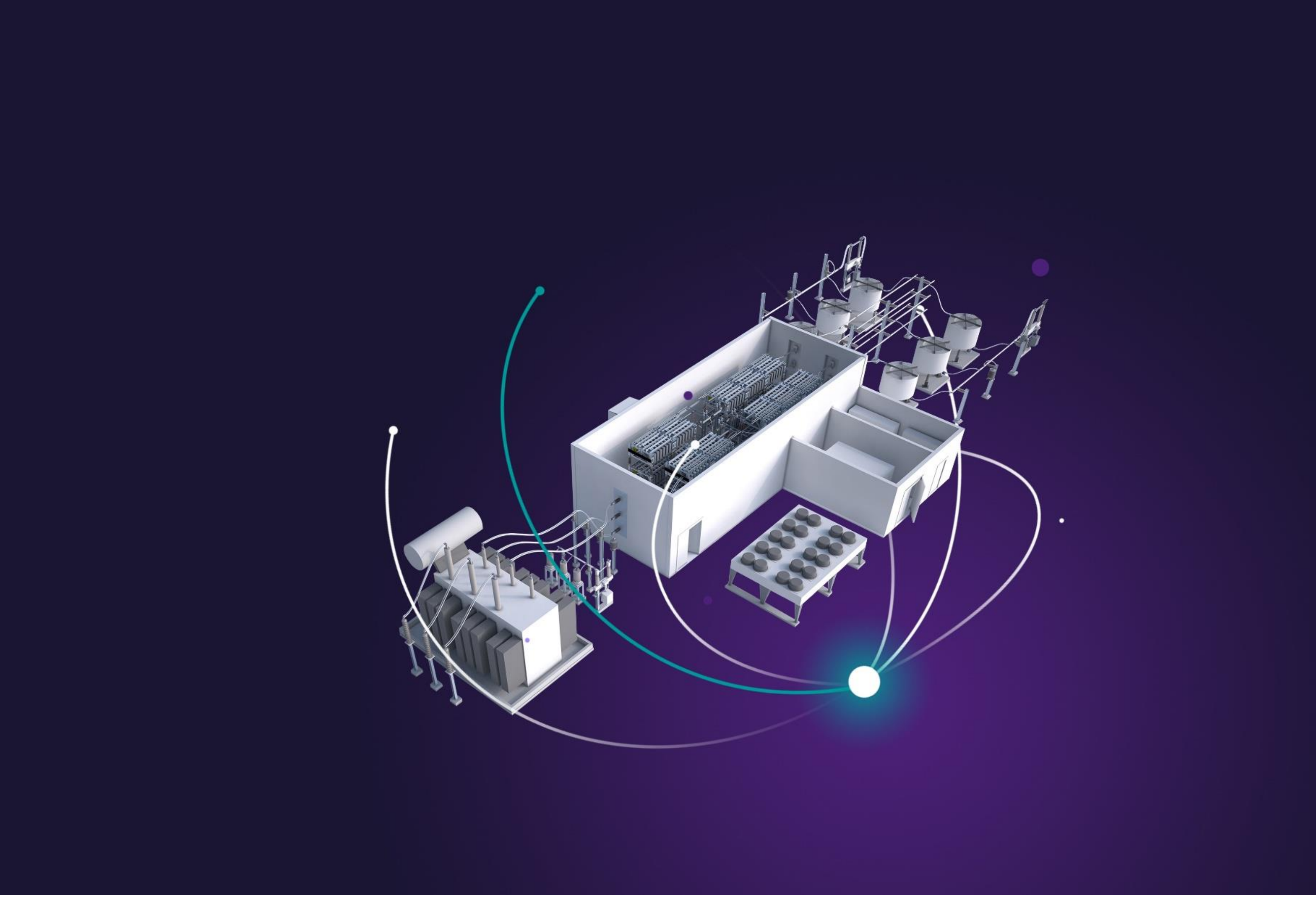

MVDC PLUS

Medium Voltage Direct Current

Managing the future grid

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Abstract

Germany and many countries in the world are facing a transition in transmission and distribution systems, due to the change from centralized energy produced in power plants to decentralized and local energy produced by renewables.
This leads to several new requirements for modern energy supply systems and thus the design and operation of the network becomes more complicated. The future electricity infrastructure has to fulfill new tasks like bidirectional power transfer, active management of power quality and ensuring grid stability as well as bridging longer distances.
The innovative Medium Voltage Direct Current (MVDC) technology based on Siemens Energy PLUS technology helps to tackle these challenges.
The new transmission solution is based on HVDC PLUS technology and combines the advantages of an MMC such as fast control of active and reactive power, low converter losses with a compact footprint for reduced costs.

CONTENTS

MVDC PLUS – Managing the future grid

Introduction

The concept of HVDC (high voltage direct current) technology is well-established within the electricity supply industry. Compared to AC overhead lines, DC links require no reactive power compensation and have no skin and proximity effect.

Today HVDC VSC technology is an appropriate solution for grid interconnections, power transmission and offshore grid access.

Low and lower medium voltage direct current is established in renewable generators (photovoltaic and wind) but also in industrial environment as well as public transport and sees a boost due to e-mobility. Higher medium voltage direct current (MVDC) becomes attractive for future network applications.

Various studies that address network reinforcement and integration of renewables show results with potential benefits regarding MVDC technology in comparison to conventional AC connections. The reasons are among others, less losses and therefore a higher power transfer capability at a similar voltage level and the ability to control the power flow [1], [2].

The potential applications are:

- Enhancement of existing infrastructure
- Need for load flow control preventing re-dispatching and congestion in the grid
- Connection of islands, autonomous systems and regional medium-voltage grids
- Integration of remote generators or consumers, like onshore windfarms, utility scale photovoltaic, mining sites or as backup solution for existing local supply

To overcome public concerns and objections regarding new installations of high voltage overhead lines and substations and to avoid complicated planning and approval procedures, the industry develops new strategies [3], [4]. The reconversion of AC lines into MVDC lines is a solution to increase the utilization of existing connections at limited costs and without the risk of a stranded investment.

Losses in DC energy transmission are lower compare to AC. The main benefit is to cover greater distances, but also to control the power flow. This is becoming increasingly important as energy is now generated at all levels, which leads to undirected energy flows and thereby jeopardizes the stability of our grids or rather causes “grid congestions”.

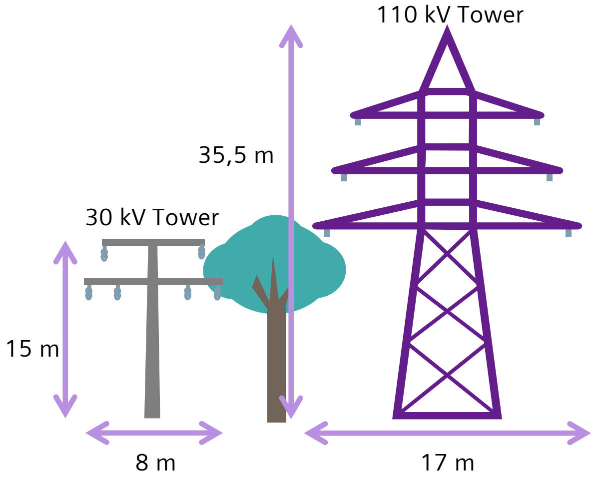

Figure 1 Power Towers for 30 and 110kV AC overhead line

In case of a new connection, MVDC can reduce the needed space and the visual impact in comparison to an AC connection due to the same power capability with reduced voltage.

A new solution

Siemens Energy MVDC PLUS is based on proven HVDC PLUS technology by means of modular multi-level (MMC) voltage sourced converters (VSC). The number of sub-modules and the DC voltage are adapted to the applicable voltage level, the principles are nevertheless preserved. In order to optimize the MVDC PLUS costs, the following strategies are applied: simplification of the installation compared to HVDC, standardized design with predefined type rating, use of MVAC components qualified for DC voltage.

The reactive power control of the converter aims to stabilize the grid voltage. It means that during AC overvoltage, the converter shall consume reactive power in order to decrease the AC voltage. Conversely, during undervoltage, the converter shall supply reactive power to the grid. A different behavior would endanger the voltage stability and is not suitable. MVDC PLUS, in accordance with German standards [5], offers only the possibility to operate with reasonable operating points. As a benefit, the converter transformer needs no tap changer. During AC undervoltages, priority is given to the reactive power over active power supply, in order to efficiently support the grid without overloading the converter. Figure 2 shows the operating area for an MVDC PLUS with a nominal active power of 150 MW for a converter connected to a 110 kV grid.

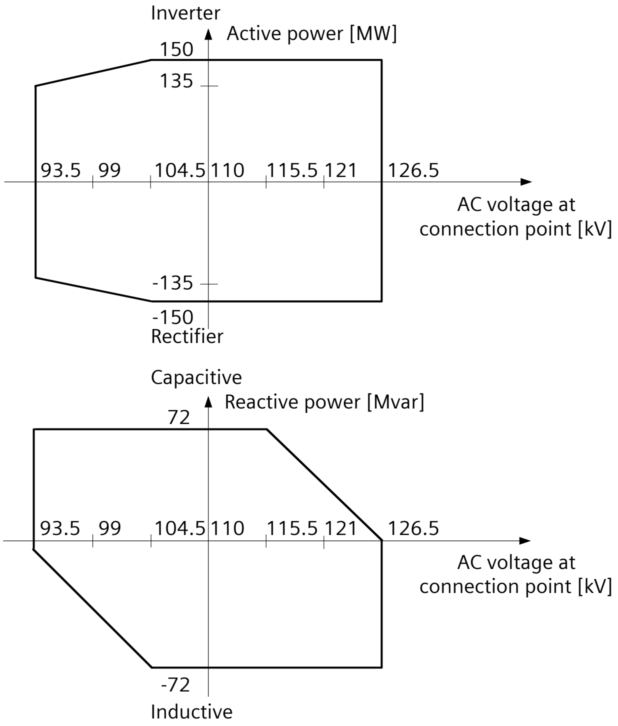

Figure 2 Operating areas depending on the grid voltage at connection point

Because of the low sub-module number, the converter of MVDC PLUS is compacter than a HVDC converter. Combined with medium voltage components, the space requirement is considerably reduced. As the sub-modules used are the same for MVDC PLUS and HVDC, the nominal current in the converter is comparable. It allows a relatively high power transfer related to the size of the installation.

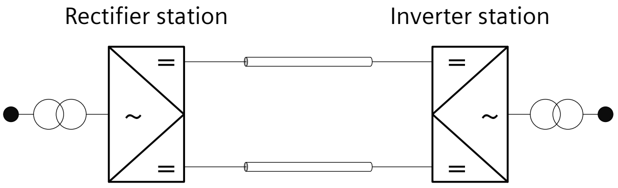

Figure 3 MVDC PLUS symmetrical monopole configuration

MVDC PLUS uses standard medium voltage AC components. It saves type tests and specific developments costs. It also leads to reduced storage costs, as spare parts are quickly deliverable. To this extent, the symmetrical monopole configuration selected is advantageous compared to a bipole configuration, as no DC offset is present (see Figure 3).

	Variant 1	Variant 2	Variant 3
DC voltage at rectifier station	±24 kV	±30 kV	±50 kV
Active power, inverter station	30 up to 70 MW	up to 90 MW	up to150 MW
Power factor	0.9	0.9	0.9

Table 1 MVDC PLUS design variants

Line losses

From an economic point of view, it is a commonplace to say that DC lines are advantageous for long distances over AC lines. The power losses on a DC line are lower because of the absence of skin-effect, proximity effect and reactive power exchange than for an AC line of the same voltage. However, the losses in the stations are higher for a DC link than for an AC link because of the presence of converters. The acquisition costs of the station are also higher for converter station than for conventional station. In terms of operational cost, AC lines are therefore the optimal option for short distances, whereas DC lines are optimal for long distance. The break-even distance depends on various aspects: right of way, transmission medium (cable or overhead lines) and environmental aspects.

HVDC line lengths above 1000 km are therefore quite common. For HVDC, the voltage drop between rectifier and inverter station is usually small (<°10%) compared to the nominal DC voltage.

For DC lines, the resistive voltage drop is the main limitation to the line length, as in contrast to AC lines, DC lines don’t consume reactive power. The Ferranti effect, which limits AC line length, is not present.

For MVDC, these conceptions have to be adapted. The ratio voltage drop between rectifier and inverter to nominal DC voltage is higher than for HVDC. To get a better understanding of the topic, some fundamental calculations based on Ohm's law are presented below.

The DC currents for MVDC and HVDC are comparable. As a consequence, the voltage drops are similar in amplitude for the same DC line resistance. This voltage drop impacts directly the ratio losses to transferred power of the DC link.

The ratio losses to transferred power is

$$losses_{DC} = \frac{P_{DC,rectifier} - P_{DC,inverter}}{P_{DC,rectifier}} \qquad (1)$$

$P_{DC,\ rectifier}$ is the DC power at rectifier station and $P_{DC,\ inverter}$ is the DC power at inverter station.

For a symmetrical monopole configuration, the expression can be reformulated as:

$$losses_{DC} = \frac{2 \cdot R_{DC} \cdot I_{DC}^2}{P_{DC,rectifier}} \qquad (2)$$

where R_{DC} is the resistance of one DC line and I_{DC} the DC current. It can be reformulated in:

$$losses_{DC} = \frac{R'_{DC} \cdot l \cdot P_{DC,rectifier}}{2 \cdot U_{dc,rectifier}{}^2} \qquad (3)$$

R'_{DC} is the specific resistance of the DC line, l the DC line length and $U_{DC,\ rectifier}$ the DC voltage pole to ground at the rectifier station. The losses are therefore inversely proportional to the square of the DC voltage pole to ground. A reduction of the losses can be achieved by, for example, lowering the specific resistance. This can be realized by increasing the total conductor cross-section. Another possibility is to increase the nominal DC voltage level according to equation 3.

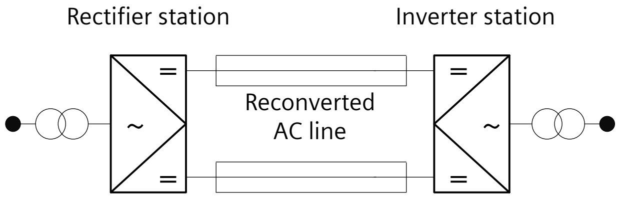

Figure 4 Reconversion of a 3-phase AC system into a symmetrical monopole MVDC

In Figure 5 the case of two three-phase AC systems reconverted in a symmetrical monopole is used (see Figure 4). The conductors are assumed to be aluminum conductor steel-reinforced cable with an aluminum cross-section of 265 mm², which are very common in Germany and have a sufficient current capacity for the application. The calculations are performed with a conductor temperature of 70°C. For comparison a XLPE cable of cross-section 2000 mm² copper at a core temperature of 70°C is used.

A variation of the DC line length is realized as illustration for a DC power at the rectifier station of 90 MW. Figure 4 illustrates that for a DC voltage of ±30 kV and overhead lines, the losses become already higher than 10% for a length of about 50 km. For a DC voltage of ±50 kV, this distance is about 125 km. Even though the MVDC PLUS variant with a DC voltage of ±30 kV is able to transfer 90 MW at rectifier station, with overhead lines, it is advisable to invest in the ±50 kV variant for long distances in order to reduce the losses. Cables cause fewer losses than overhead lines.

The power production of renewable power plants, photovoltaic or wind farms, has a high volatility. Moreover, network load is also far from being constant. Depending on the hour and the day, the electricity transfer can differ radically. If a MVDC link is used to evacuate power from renewable power plants, it means that it won't operate continuously at its maximum capacity.

The average generation duration curve for onshore wind farms in Germany, simplified, is used as input for an illustrating calculation [6].

A wind farm of maximum capacity 90 MW and a DC link length of 100 km with ±30 kV as DC voltage are assumed. Figure 6 shows that the average losses reach 7%, which is significantly lower than the 22% calculated at the peak power. The link has however the capacity to transfer this power. A converter with a DC voltage of ±30 kV can therefore be an economical solution to connect an onshore wind farm.

To sum up, the DC line losses are inversely proportional to the square of the DC voltage. For long distances, the use of a MVDC PLUS variant with a higher nominal voltage than needed can therefore be justified in order to improve the efficiency. Nevertheless, MVDC PLUS variants with fewer submodules are a suitable and economical solution to connect renewable power plants, as they are able both to evacuate their peak power generation and to ensure acceptable average losses.

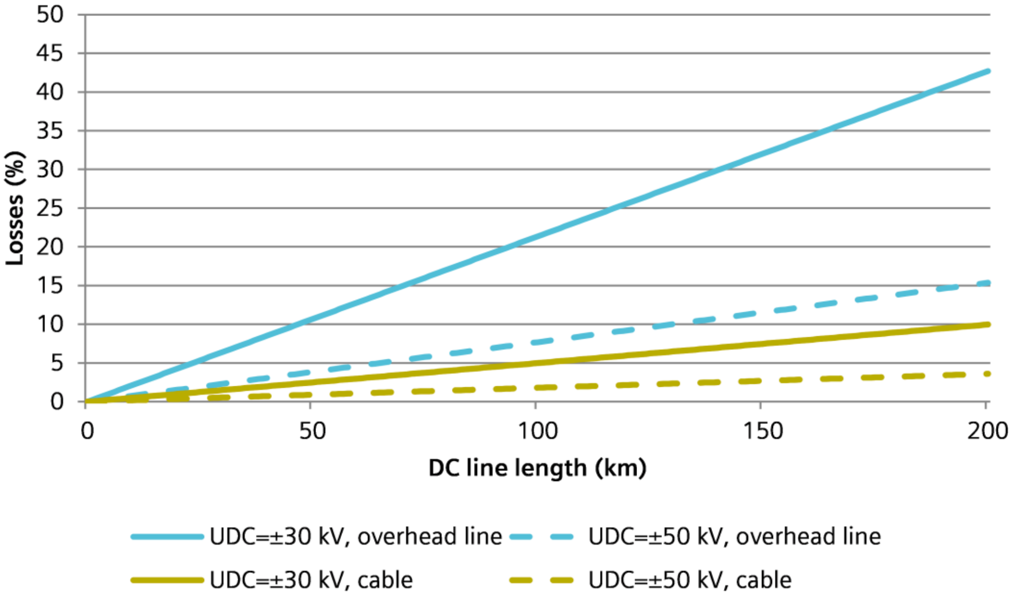

Figure 5 DC line losses for an active power of 90 MW at rectifier station

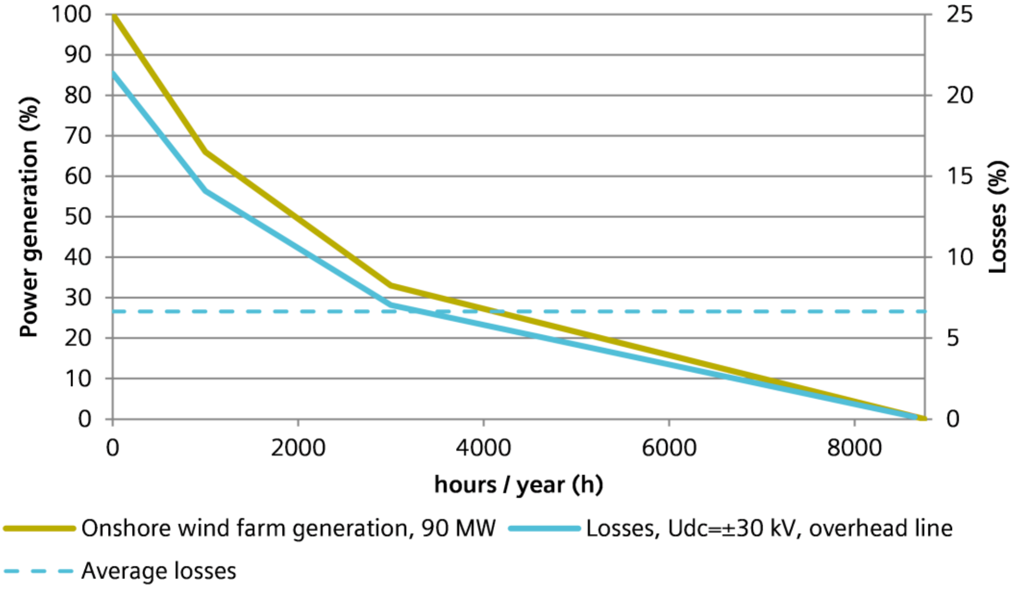

Figure 6 Yearly average losses for onshore wind farm grid access

AC Fault Ride Through capability

Networks experience short-circuits regularly, for instance in the case of lightning. Until clearance of the fault by the grid protection, the voltage is reduced to a low level. For the grid stability, the power plants shall:

- Support the grid voltage level by reactive current injection at the point of connection. It implies that they have to stay connected to the network during the fault.
- Come back to the pre-fault state immediately after fault clearance.

This capability is named AC Fault Ride Through and is required in grid codes [5], [7]. For MVDC PLUS, it means that the converter shall not block during fault in the grid.

MMC converters consist of sub-modules that can themselves be divided in a power electronic part and a capacitor. This last component is used to store energy. It buffers energy between the DC and the AC side. The converter control has the task to balance the incoming and outgoing energy.

For a short circuit directly in the vicinity of the inverter station, the voltage is reduced close to zero and therefore the active power evacuated from the station as well (Figure 7, a)).

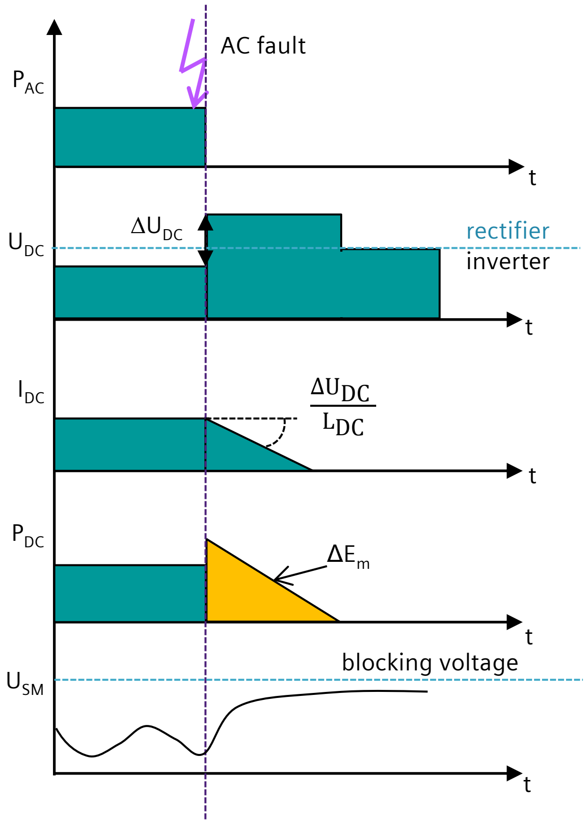

Figure 6 AC Fault Ride Through process

To recover the energy balance, the converter control has to reduce the DC power (P_{DC}) received from the DC line. The strategy used is to increase as fast as possible the DC voltage at the inverter station (Figure 7, b)). As a consequence, the DC current (I_{DC}) drops to zero (c). The inductance of the DC line limits however the gradient to:

$$\frac{dI_{DC}}{dt} = \frac{\Delta U_{DC}}{L_{DC}}$$

In this equation, ΔU_{DC} is the difference between the DC voltage at the rectifier and the inverter, pole to ground. L_{DC} is the inductance of the DC line, given for one polarity.

As the DC current can't be reduced immediately to zero, energy is accumulated in the converter capacitors (d). Their voltages increase accordingly (e). In order to avoid damaging the converter, if the capacitor voltages exceed a certain threshold, the converter blocks. The AC Fault Ride Through capability of the MVDC PLUS converter is therefore directly linked with the capability of the DC current to be reduced to zero. The insulation coordination limits the DC voltage at the inverter station. The inductance of the DC line has therefore to be kept low.

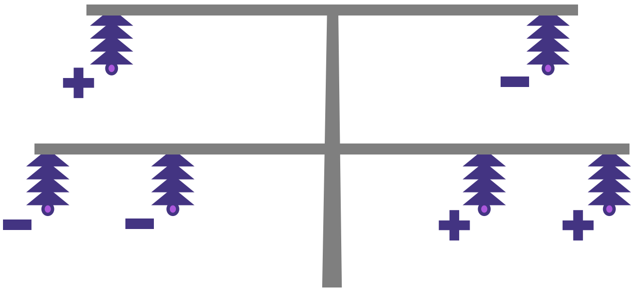

Figure 7 Alternation of conductor polarity to reduce the DC line inductance

The standard design for a HVDC line is to place the positive conductors on one side of the tower and the negative on the other side. The distance between positive and negative conductors is therefore high, which leads to a high specific inductance. For MVDC PLUS, an alternative conductor configuration is proposed (Figure 7). The positive and negative conductors are alternated on each side of the tower. Hence, the specific inductance is significantly lower. With this configuration, simulations show that length up to approximately 150 km can be reached without converter block during fault close to the inverter station.

Conclusion

The MVDC PLUS combines the features and advantages of MMC technology like advanced control, low converter losses and a reduced footprint with reduced costs due to systematic standardization, utilization of existing MVAC components and simplification in comparison to HVDC MMC.

MVDC PLUS is Siemens Energy' answer to the questions how to

- connect islands, platforms and remote areas
- integrate and stabilize weak grids
- enhance existing infrastructure
- fulfill the new tasks as a DSO
- minimize the visual impact.

MVDC links are adapted to variable power transmission and part load scenarios; therefore the expected histogram of the connected load or generation profile has to be taken into account for the decision on the voltage level in order to achieve a high overall efficiency of the MVDC system. The average efficiency can be significantly better than in case of peak power transmission.

Siemens Energy MVDC PLUS technology is one innovative solution to overcome the new requirements and challenges of the future network development, increase the quality of distribution networks, despite increasing decentral infeed, use existing infrastructure, connect micro grids and control load flow as well as provide backup solutions for continuous production and optimize CO_2 footprint.

MVDC offers a great advantage to independent energy producers. It will be easier to transmit electricity via DC links, achieve bundling, and so sell energy, because DC offers power flow control, unlike Ohm's law, where the alternating current flows where the least resistance is.

Abbreviations

AC	Alternating current
DC	Direct current
Em	Converter module energy
HVDC	High voltage direct current
IDC	DC current
LDC	Inductance of the dc line given for one polarity
MMC	Modular Multilevel Converter
MVDC	Medium voltage direct current
TSO	Transmission system operator
UDC	DC voltage
XLPE	Cross-linked polyethylene

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Siemens Energy Global GmbH & Co. KG

Transmission

Freyeslebenstraße 1

91058 Erlangen

Germany

Siemens Energy, Inc

Transmission

4601 Six Forks Road

Raleigh, NC 27609

USA

siemens-energy.com