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HVDC PLUS – Basics and Principle of Operation

Answers for energy.

Content

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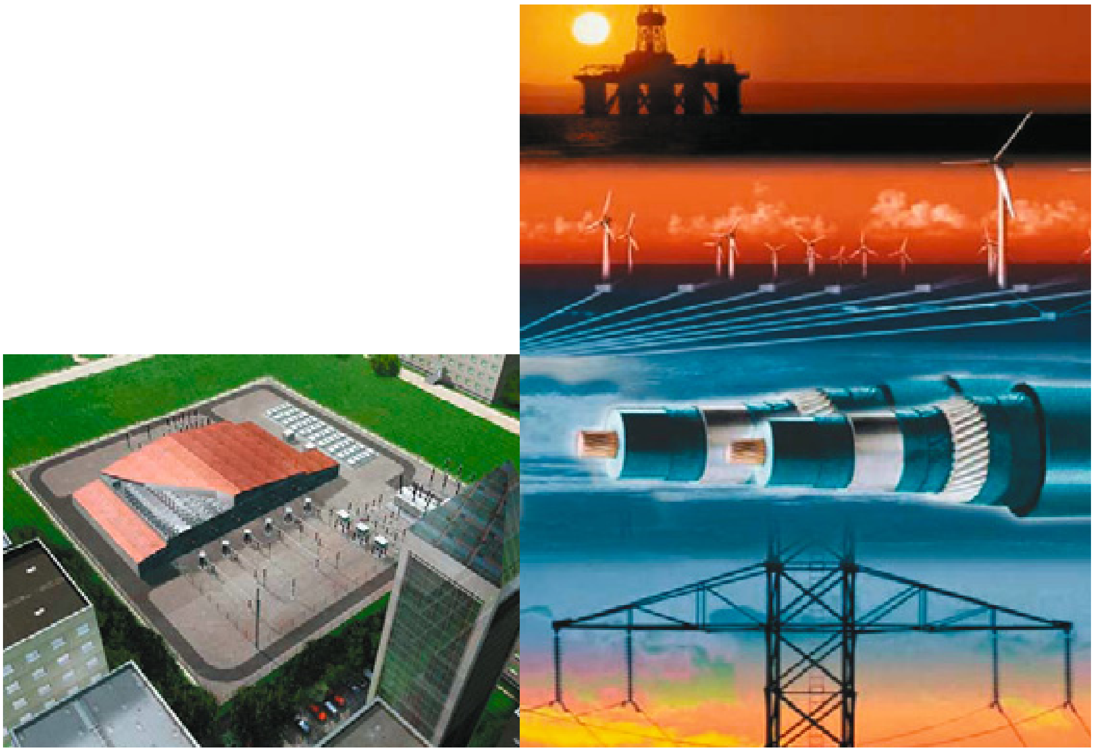
M. Davies, M. Dommaschk, J. Dorn, J. Lang, D. Retzmann, D. Soerangr



0. Preface

This special edition summarizes prospects and technology issues of the latest developments in voltage-sourced converters for Advanced High Voltage DC transmission systems in the range of medium power applications [4–10, 16–19, 21, 22, 24–27].

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1. Introduction

Environmental constraints will play an important role in the power system developments [1–2, 18]. However, regarding the system security, specific problems are expected when renewable energies, such as large wind farms, have to be integrated into the system, particularly when the connecting AC links are weak and when sufficient reserve capacity in the neighboring systems is not available [3]. In the future, an increasing part of the installed capacity will be connected to the distribution levels (dispersed generation), which poses additional challenges to the planning and safe operation of the systems. Power electronics will be required to control load flow, to reduce transmission losses and to avoid congestion, loop flows and voltage problems [4–6, 12].

HVDC (High Voltage Direct Current) systems and FACTS (Flexible AC Transmission Systems) provide essential features to avoid technical problems in the power systems; they increase the transmission capacity and system stability in a very efficient way, and assist in prevention of cascading disturbances [11–27].

HVDC systems and FACTS controllers based on line-commutated converter technology have a long and successful history. Thyristors are the key components of this converter topology and they have achieved a high degree of maturity due to their robust design and high reliability. It is, however, worth mentioning that line-commutated converters have some technical restrictions. Particularly the fact that the commutation within the converter is driven by the AC voltages requires proper conditions of the connected AC system, such as a minimum short-circuit power.

Power electronics with self-commutated converters, such as Voltage-Sourced Converters (VSC), can overcome these limitations and they provide additional technical features. In many applications, VSC have become a standard of self-commutated converters and will be used increasingly more often in transmission and distribution systems in the future. VSCs do not require any "driving" system voltage – they can build up a three-phase AC voltage via the DC voltage (Black-Start capability). So, in the case of DC transmission, HVDC PLUS with VSCs is the preferred technology for interconnection of islanded grids, such as offshore wind farms, with the power system.

So far, VSCs for HVDC and FACTS applications are mostly based on two or three-level converters. It is, however, a fact that multilevel VSCs provide advantages with respect to the dynamic performance and harmonic impact. For these reasons, a new Modular Multilevel Converter technology (MMC), referred to as HVDC PLUS and SVC PLUS, has been developed, which provides significant benefits for high voltage applications.

2. HVDC and FACTS Technologies

HVDC systems and FACTS controllers based on line-commutated converter technology (LCC) have a long and successful history. Thyristors have been the key components of this converter topology and have reached a high degree of maturity due to their robust technology and their high reliability. HVDC and FACTS with LCC use power electronic components and conventional equipment which can be combined in different configurations to switch or control reactive power, and to convert the active power. Conventional equipment (e.g. breakers, tap-changing transformers) has very low losses, but the switching speed is relatively low. Power electronics can provide high switching frequencies up to several kHz which, however, leads to an increase in losses.

Fig. 1 indicates the typical losses depending on the switching frequency [16]. It can be seen that due to the low losses, line-commuted Thyristor technology is the preferred solution for bulk power transmission, today and in the future.

It is, however, worth mentioning that line-commutated converters have some technical restrictions. Particularly the fact that the commutation within the converter is driven by the AC voltages requires proper conditions of the connected AC system, such as a minimum short-circuit power.

A comparison of the different HVDC technologies is depicted in Fig. 2.

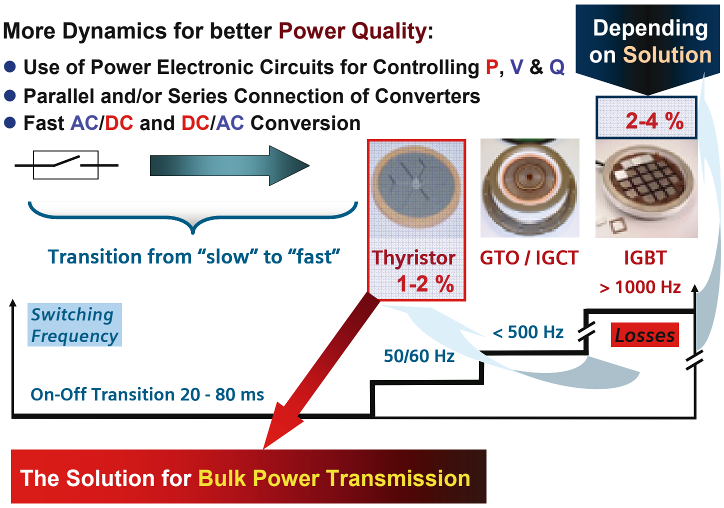
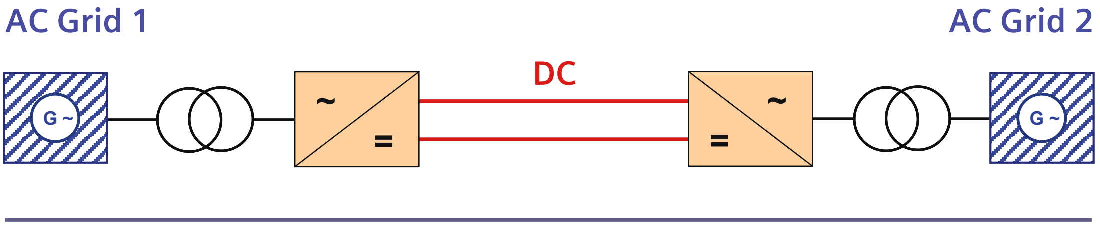


Fig. 1: Power Electronics for HVDC and FACTS – Transient Performance and Losses



HVDC "Classic"	HVDC PLUS
Line-Commutated Current-Sourced Converter (LCC / CSC)	Self-Commutated Voltage-Sourced Converter (SCC / VSC)
Thyristors with Turn-on Capability only	Semiconducting Switches with Turn-On and Turn-Off Capability, e.g. IGBTs

Fig. 2: HVDC "Classic" and HVDC PLUS – Technologies

2.1 Voltage-Sourced Converters

Power electronics with self-commutated converters can cope with the limitations mentioned above and provide additional technical features. In DC transmission, an independent control of active and reactive power, the capability to supply weak or even passive networks and lower space requirements are some of the advantages. In many applications, the VSC has become a standard of self-commutated converters and will be used more often in transmission and distribution systems in the future. Voltage-Sourced Converters do not require any "driving" system voltage; they can build up a 3-phase AC voltage using the DC voltage. This kind of converter uses power semiconductors with turn-off capability such as IGBTs (Insulated Gate Bipolar Transistors).

The benefits of VSC technology are depicted in Fig. 3. Figs. 4 and 5 show the P and Q outputs of HVDC "Classic" and HVDC PLUS.

Grid Access for weak AC Networks

Independent Control of Active and Reactive Power

Supply of passive Networks and Black-Start Capability

Multiterminal easier with 4-Quadrant Capability

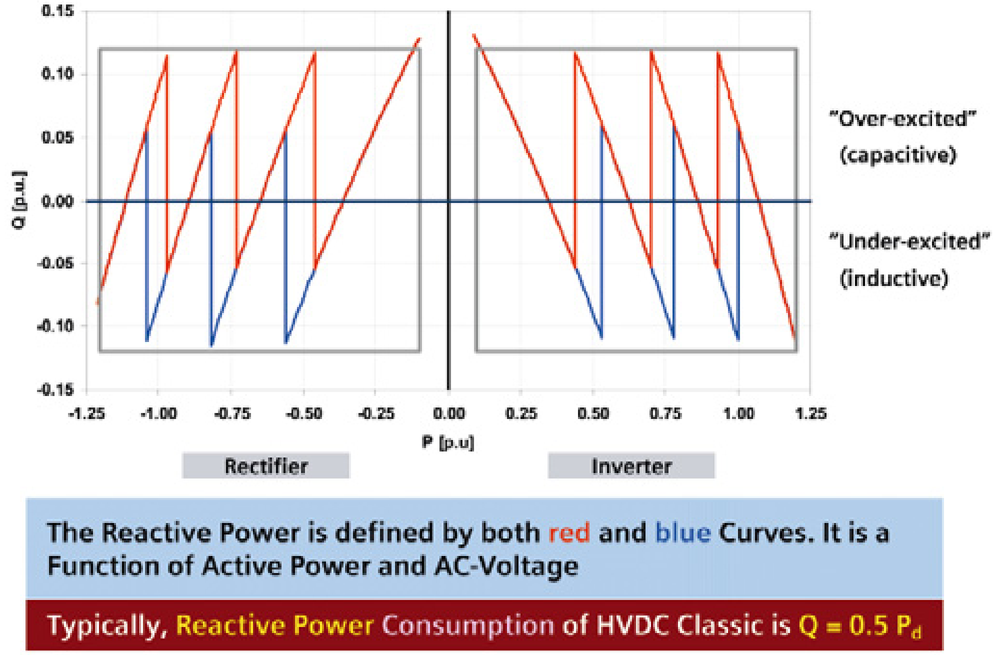
High Dynamic Performance

Low Space Requirements

VSC Technology makes it feasible

HVDC PLUS offers additional Benefits

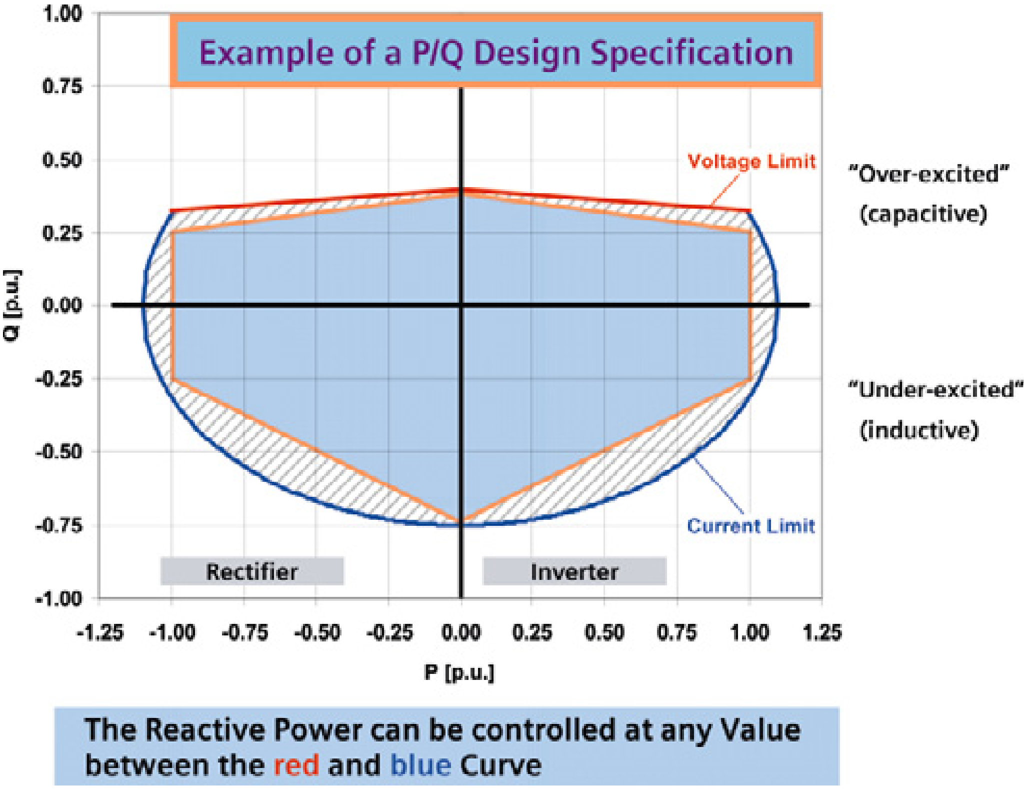
Fig. 3: General Features of VSC Technology



The Reactive Power is defined by both red and blue Curves. It is a Function of Active Power and AC-Voltage

Typically, Reactive Power Consumption of HVDC Classic is $Q = 0.5\ P_d$

Fig. 4: HVDC “Classic” – Generic P/Q Diagram



The Reactive Power can be controlled at any Value between the red and blue Curve

Fig. 5: HVDC PLUS – Typical P/Q Diagram

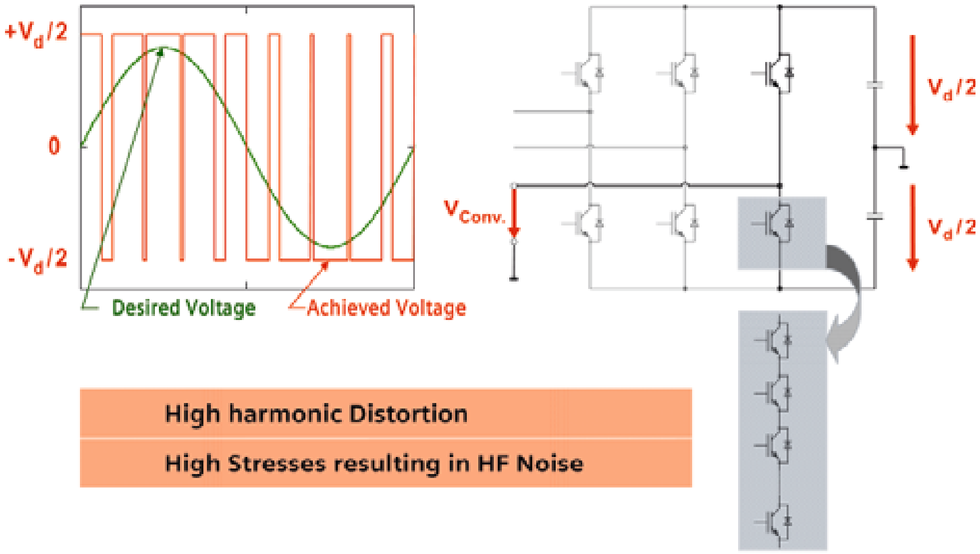


Fig. 6: VSC Technology – a look back

Up to now, the implemented VSC converters for HVDC applications have been based on two or three-level technology which enables switching two or three different voltage levels to the AC terminal of the converter. For such converter topologies a high number of semiconductor devices with blocking capability of a few kilovolts are connected in series – up to several hundreds per converter arm, depending on the DC voltage. To ensure uniform voltage distribution not only statically but also dynamically, all devices connected in series in one converter arm have to switch simultaneously. High and steep voltage steps are applied at the AC converter terminals which causes high component stresses and require extensive filtering measures.

In Fig. 6, the principle of the two-level converter technology is depicted. From the figure, it can be seen that the converter voltage, created by the PWM (Pulse-Width Modulation), is far from the desired “green” voltage. It needs AC filters to achieve an acceptable waveform.

2.2 The Modular Multilevel Converter (MMC) Approach

Both the size of voltage steps and the related voltage gradients can be reduced or minimized if the AC voltage generated by the converter can be selected in smaller increments than at two or three levels only.

The more steps that are used, the smaller is the proportion of harmonics and the lower is the high-frequency noise. Converters with high number of steps are termed multilevel converters.

With a high number of levels the switching frequency of individual semiconductors can be reduced. Since each switching event creates losses in the semiconductors, converter losses can be effectively reduced.

Different multilevel topologies [7–10], such as diode clamped converter or converters with what is termed “flying capacitors” were proposed in the past and have been discussed in many publications.

In Fig. 7, a comparison of two, three and multilevel technology is depicted. A new and different approach is the Modular Multilevel Converter (MMC) technology [9].

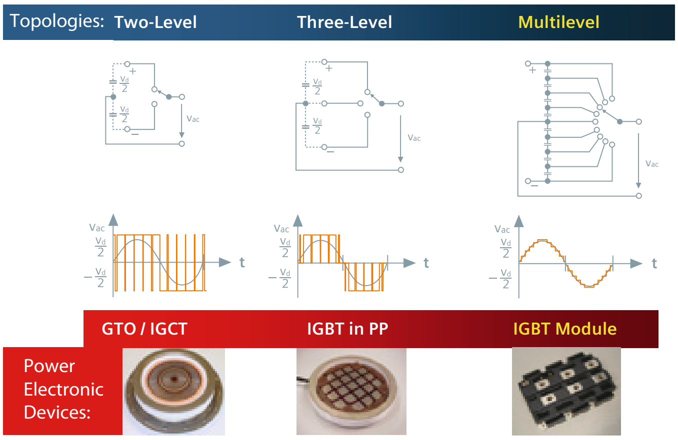
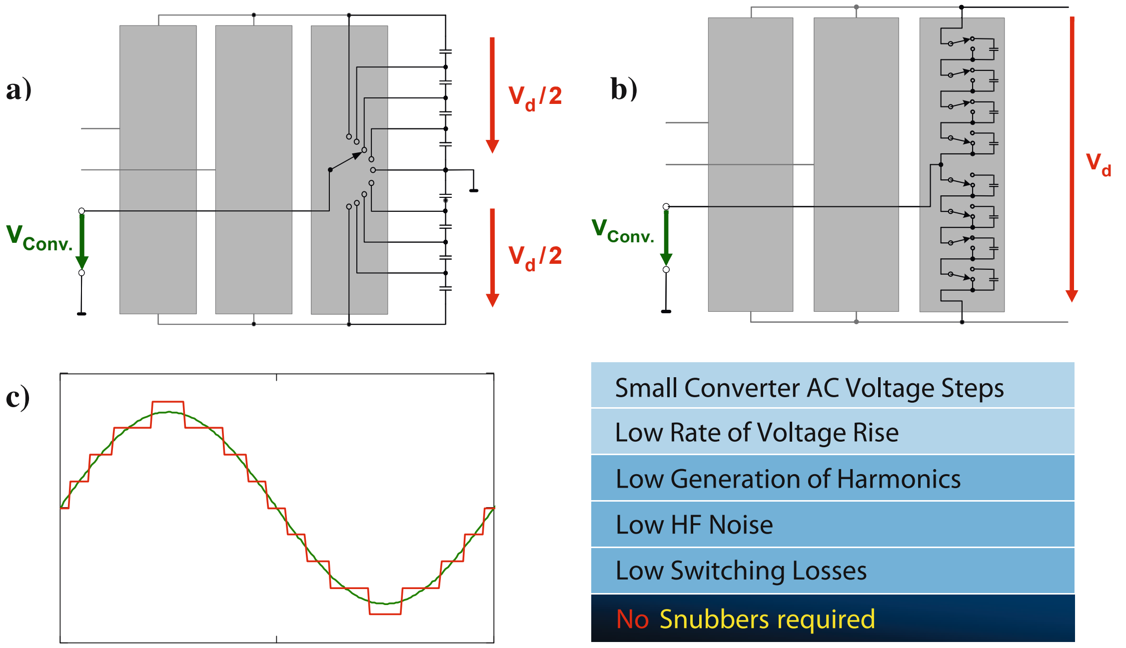


Fig. 7: The Evolution of VSC and HVDC PLUS



Small Converter AC Voltage Steps

Low Rate of Voltage Rise

Low Generation of Harmonics

Low HF Noise

Low Switching Losses

No Snubbers required

Fig. 8: The Multilevel Approach
a) “Basic Idea”
b) The MMC Solution
c) Sinus Approximation – and Benefits

The basic idea of a multilevel converter and the principle design of an MMC are shown in Fig. 8. Fig. 9 depicts the HVDC PLUS MMC solution in detail.

An MMC consists of six converter arms. Each of them comprises a high number of power modules (PM) and one converter reactor connected in series. The power modules contain [9, 16, 17]:

- an IGBT half bridge as a switching element
- a DC capacitor unit for energy storage

For the sake of simplicity, the electronics for the control of the power semiconductors, the monitoring of the capacitor voltage, and the communication with the higher-level controllers are not shown in Fig. 9.

Three different states are relevant for the proper operation of a power module, as illustrated in Table I:

1) “Energization” – Both IGBTs are switched off:

This can be compared with the blocked condition of a two-level converter. Upon charging, i.e. after closing the AC power switch, all power modules of the converter are in this condition. Moreover, in the event of a serious failure all power modules of the converter are put in this state. During normal operation, this condition does not occur. If the current flows from the positive DC pole in the direction of the AC terminal during this state, it charges the capacitor. When it flows in the opposite direction, the freewheeling diode D2 bypasses the capacitor.

2) “Capacitor-On” – IGBT1 is switched on, IGBT2 is switched off:

Irrespective of the current flow direction, the voltage of the storage capacitor is applied to the terminals of the power module. Depending on the direction of flow, the current either flows through D1 and charges the capacitor, or through IGBT1 and thereby discharges the capacitor.

3) “Capacitor-Off” – IGBT1 is switched off, IGBT2 is switched on:

In this case, the current either flows through IGBT2 or D2 depending on its direction which ensures that zero voltage is applied to the terminals of the power module (except for the conducting- state voltage of the semiconductors). The capacitor voltage remains unchanged.

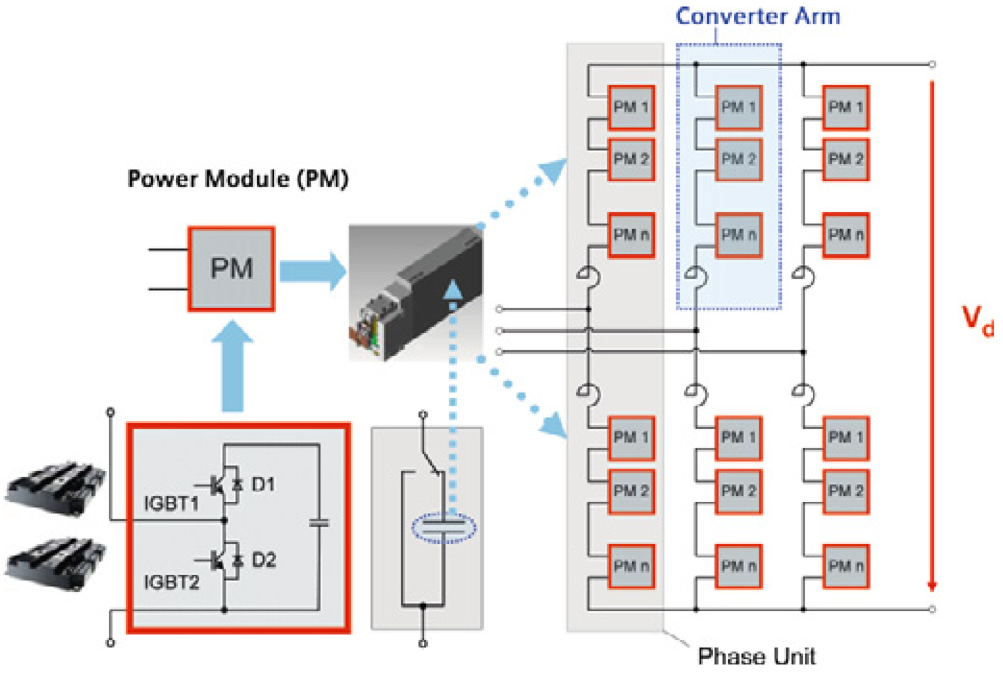
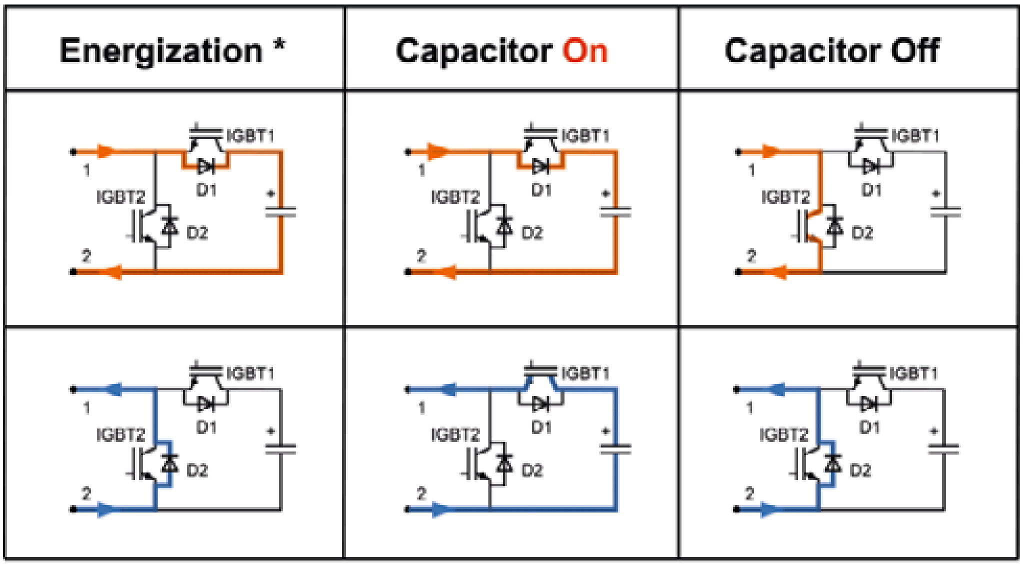


Fig. 9: HVDC PLUS – Basic Scheme



* Converter blocked

Table I: States and Current Paths of a Power Module in the MMC Technology

It is possible to separately and selectively control each of the individual power modules in all phase units. The two converter arms of each phase unit represent a controllable voltage source. The total voltage of the two converter arms in each phase unit equals the DC voltage, and by adjusting the ratio of the converter arm voltages in one phase unit, the desired sinusoidal voltage at the AC terminal is achieved.

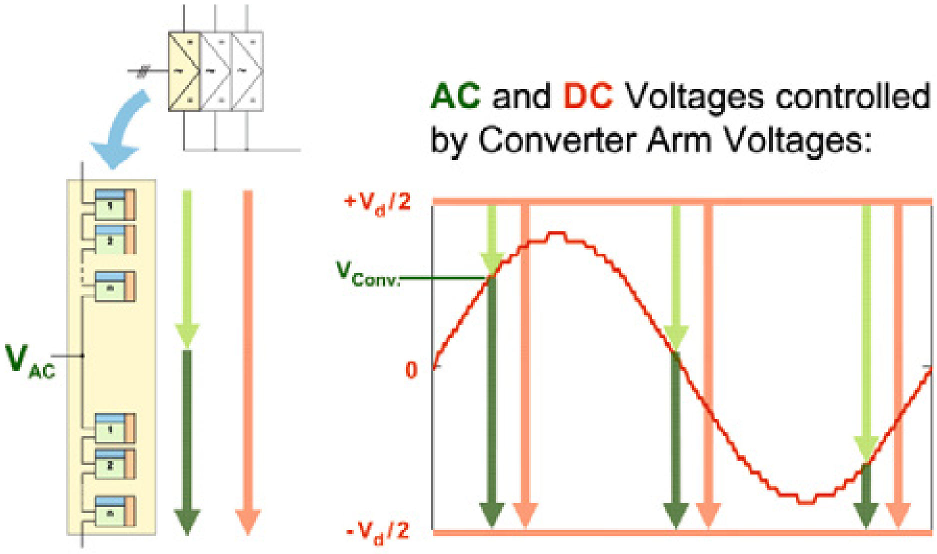


Fig. 10: The Result – MMC, a perfect Voltage Generation

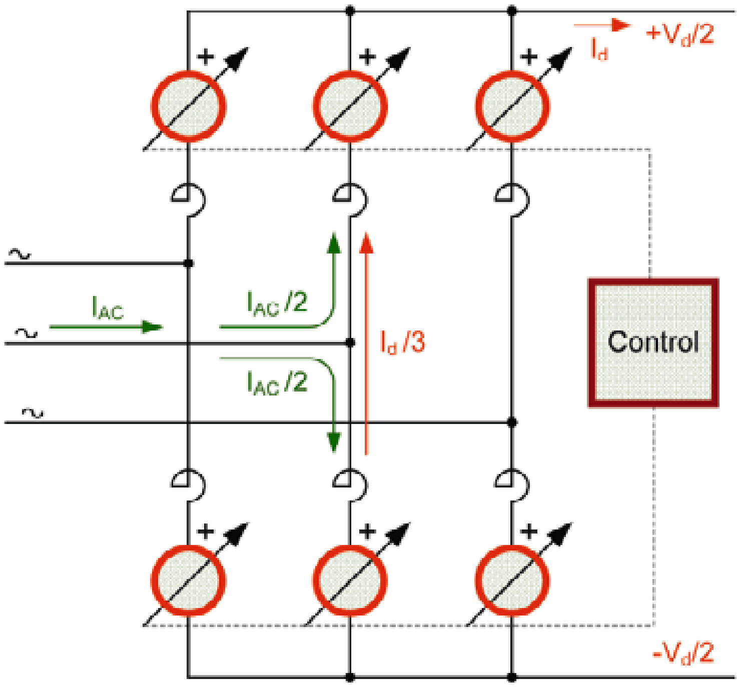


Fig. 11: AC & DC Converter Currents – controlled by MMC Voltage Sources

Figs. 9–11 depict this advanced principle of AC voltage generation with MMC. It can be seen that there is no or – in the worst case – negligible need for AC voltage filtering to achieve a clean voltage.

As is true in all technical systems, the possibility of sporadic failure of individual components cannot be excluded, even with the most meticulous engineering and 100-percent testing. However, if a single component failure occurs, the operation of the system must not be impeded as a result. In the case of an HVDC transmission system this means that there must be no interruption of the energy transfer and that the system will actually continue to operate until the next scheduled shut-down for maintenance.

Redundant power modules are therefore integrated into the converter, and, unlike in previous redundancy concepts, the unit can now be designed so that, upon failure of a power module in a converter arm, the remaining power modules are not subjected to a higher voltage. The inclusion of the redundant power modules thus merely results in an increase in the number of power modules in a converter arm that deliver zero voltage at their output during operation. In the event of a power module failure during operation this fault is detected and the defective power module is shorted out by a highly reliable high-speed bypass switch, ref. to Fig. 12. This provides full functionality, as the current of the failed module can continue to flow, and the converter operates without any interruption.

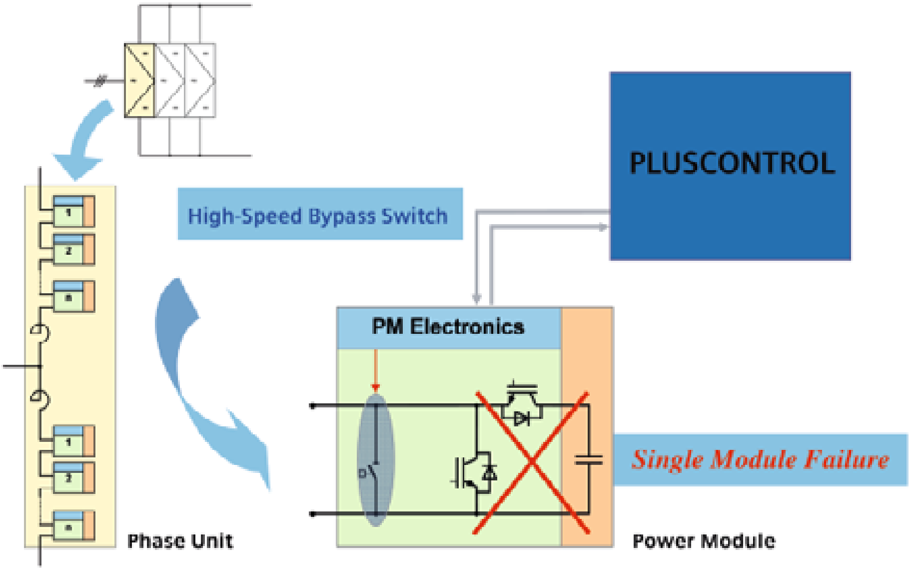


Fig. 12: MMC – Redundant Submodule Design

As in all multilevel topologies it is necessary to ensure, within certain limits, a uniform voltage distribution across the individual capacitors of the multilevel converter. When using the MMC topology for HVDC this is achieved by periodic feedback of the current capacitor voltage to a central control unit. The time intervals between these feedback events are less than 100 microseconds.

Due to the fact that in the converter arms current flows in both directions in each line cycle, and therefore charging and discharging of the individual capacitors is possible. Evaluation of the feedback and selective switching of the individual power modules can be used to balance the power module voltages. With this approach, the capacitor voltages of all power modules of a converter arm in HVDC PLUS are maintained within a defined voltage band.

From the perspective of the DC circuit, the described topology looks like a parallel connection of three voltage sources – the three phase units that generate all desired DC voltages. During steady-state operation, the voltage sources (ref. to Fig. 11) are controlled in order to achieve one third of the total DC current in each phase unit and to achieve an equal sharing of the AC current in the upper and lower part of each phase unit. Each of the 6 variable voltage sources are designed with a number of identical but individually controllable power modules, as shown in Fig. 6. In practice, however, there will be little difference between the momentary values of the three DC voltages, owing to the finite number of available voltage steps.

To reduce the resulting balancing currents between the individual phase units to a very low value by means of appropriate control methods, a converter reactor is required in the individual converter arms. These reactors are also used to substantially reduce the effects of faults arising within or outside the converter station. As a result, unlike in previous VSC topologies, current rise rates of only a few tens of amperes per microsecond are encountered for critical faults.

These faults are swiftly detected, and, due to the relatively low current rise rates, the IGBTs can be turned off at uncritical current levels. This provides effective and reliable protection of the system.

The following describes a very interesting fault occurrence:
In the event of a short-circuit between the DC terminals of the converter or along the transmission route, the current rises in excess of a certain threshold value in the converter arms, and, due to the aforementioned limitation of the speed in the current rise, the IGBTs can be switched off within a few microseconds before the current can reach a critical level, which provides an effective protective function. Thereafter – as with any VSC topology – current flows from the three-phase AC system through the free-wheeling diodes to the short-circuit, so that the only way this fault can be corrected is by opening the AC circuit breaker.

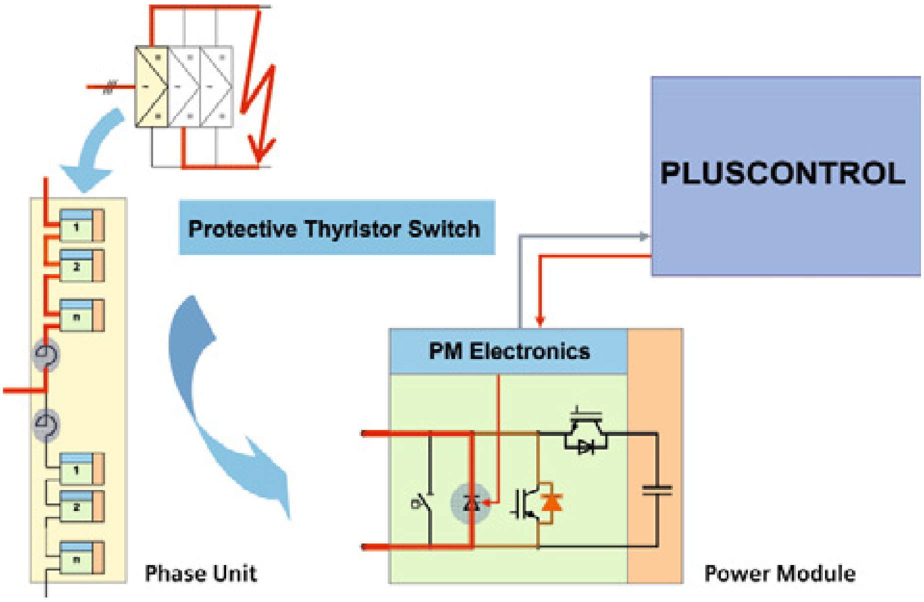


Fig. 13: Fully suitable for DC OHL Application – Example Line-to-Line Fault

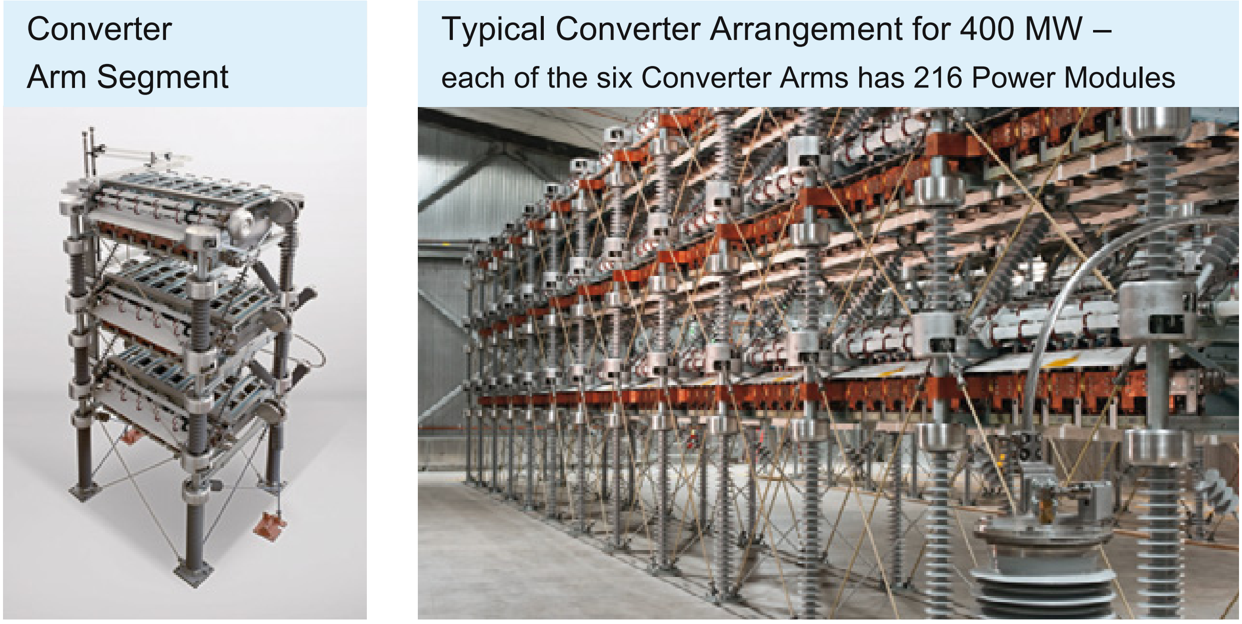
The fast recovery free-wheeling diodes used with IGBT modules have a relatively low surge current withstand capability. In an actual event, the diodes have to withstand a fault current without damage until the circuit breaker opens, i.e. in most cases for at least three line cycles. In HVDC PLUS, a protective function at the power module level effectively reduces the load of the diodes until the circuit breaker opens. This protective measure consists of a press-pack thyristor, which is connected in parallel to the endangered diode and is fired in the event of a DC line-to-line fault, ref. to Fig. 13.

As a result, most of the fault current flows through the thyristor and not through the diode it protects. Press-pack thyristors have an inherent capability to withstand high surge currents. This characteristic is also useful in conventional, line-commutated HVDC transmission technology. This fact makes HVDC PLUS suitable even for overhead transmission lines, an application previously reserved entirely for line-commutated converters with thyristors.

Thanks to its modular construction, the HVDC PLUS converter is extremely well scalable, i.e. conveniently adaptable to any required power and voltage ratings. The required number of power modules per converter arm can be realized by a horizontal array of such units and – if required – by assembling them in a vertical arrangement to meet the specific project requirements. Other arrangements are also possible.

Fig. 14 depicts a view of an MMC design. In principle, both a standing and a suspended construction can be readily achieved. However, a standing construction was chosen, since in that case the converter design imposes less special requirements to the converter building.

If required in specific projects, highly effective protective measures against severe seismic loads can also be implemented (ref. to Fig. 14). For such a situation, provisions have been made for diagonal braces at the individual units that ensure adequate stability of the construction.


Converter Arm Segment

Typical Converter Arrangement for 400 MW – each of the six Converter Arms has 216 Power Modules

Fig. 14: HVDC PLUS – The Advanced MMC Technology

Each power module is connected via two optical fibers to the PLUSCONTROL (Fig. 15), the central control unit. The PLUSCONTROL was developed specifically for HVDC PLUS and has the following functions:

- Calculation of appropriate converter arm voltages at time intervals of several microseconds
- Selective control of the power modules depending on the direction of power flow and on the relevant capacitor voltages in the power modules so as to assure reliable balancing of capacitor voltages

In addition to the current status of each power module, the momentary voltage of the capacitor is communicated via the fiber optics to the PLUSCONTROL. Control signals to the power module, such as the signals for the switching of the IGBTs, are communicated in the opposite direction from the PLUSCONTROL to the power modules.

Key features of the PLUSCONTROL are:

- Mechanical construction in standard 19-inch racks,
- High modularity and scalability through plug-in modules, and the capability of integrating different numbers of racks into the system,
- Uniform redundancy concept with an active and passive system and the ability to change over on the fly,
- Modules and fans can be replaced during operation,
- Sufficient interfaces for communication and control of well over 100 power modules per rack, and
- High performance with respect to computational power and logic functions.

The PLUSCONTROL is fully integrated into the industry-proven SIMATIC TDC environment, which provides the platform for the measuring system and the higher-level control and protection.

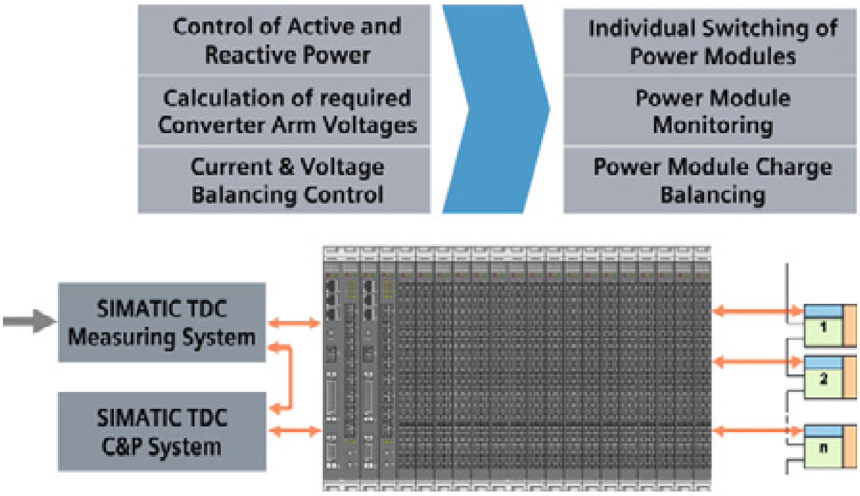


Fig. 15: Main Tasks of PLUSCONTROL

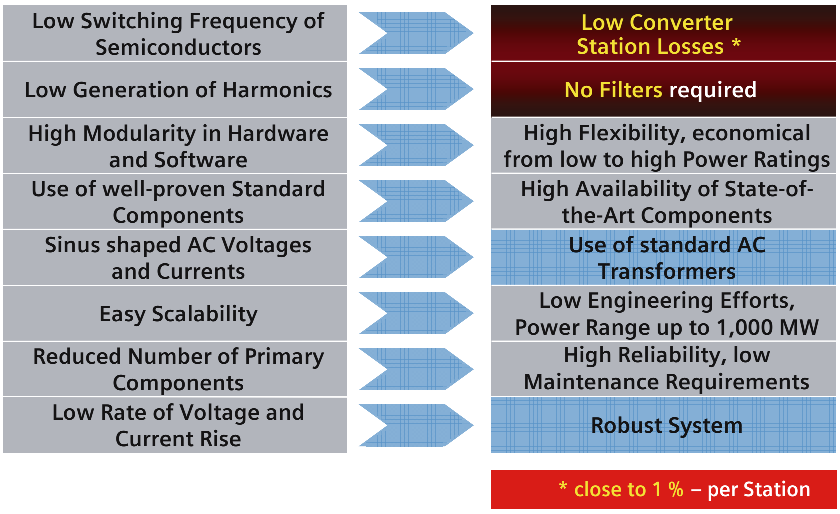
The MMC topology used in HVDC PLUS differs from other, already familiar VSC topologies in design, mode of operation, and protection capabilities. The following summarizes the essential differences and related advantages:

- A highly modular construction both in the power section and in control and protection has been chosen. As a result, the system has excellent scalability and the overall design can be engineered in a flexible way. Thus, the converter station can be perfectly adapted to the local requirements, and depending on those requirements, the design can favor either a converter hall with a small footprint or a building with a low profile.
- In normal operation, no more than one level per converter arm switches at any given time. As a result, the AC voltages can be adjusted in very fine increments and a DC voltage with very little ripple can be achieved, which minimizes the level of generated harmonics and in most cases completely eliminates the need for AC filters. What's more, the small voltage steps that do occur cause very little radiant or conducted high-frequency interference.
- The low switching frequency of the individual semiconductors results in very low switching losses. Total system losses are therefore relatively low for VSC PLUS technology, and the efficiency is consequently higher in comparison with existing two and three-level solutions.
- HVDC PLUS utilizes industrially proven standard components, such as IGBT modules, which are robust and highly reliable. These components have proven their reliability and performance under severe environmental and operating conditions in other applications, such as traction drives. This wide range of applications results in long-term availability and continuing development of these standard components.
- The encountered voltage and current loads support the use of standard AC transformers.
- The achievable power range as well as the achievable DC voltage of the converter is determined essentially only by the performance of the controls, i.e. the number of power modules that can be operated. With the current design, transmission rates of 1000 MW and above can be achieved.
- Due to the elimination of additional components such as AC filters and their switchgear, high reliability and availability can be achieved. What's more, the elimination of components and the modular design can shorten project execution times, all the way from project development to commissioning.
- With respect to later provision of spare-parts, it is easy to replace existing components by state-of-the-art ones, since the switching characteristics of each power module are determined independently of the behavior of the other power modules. This is an important difference to the direct series-connection of semiconductors as in the two-level technology where nearly identical switching characteristics of the individual semiconductors are mandatory.
- Internal and external faults, such as short-circuit between the two DC poles of the transmission line, are reliably managed by the system, due to the robust design and the fast response of the protection functions.

Figs. 16–18 summarize the advantages in a comprehensive way. Added to these are the aforementioned advantages that ensue from the use of VSC technology in general (see Fig. 3).

With these features, HVDC PLUS is ideally suitable for the following DC systems (Fig. 18):

- Cable transmission systems. Here, the use of modern extruded cables, i.e. XLPE, is possible, since the voltage polarity in the cable remains the same irrespective of the direction of current flow.
- Overhead transmission lines, due to the capability to withstand DC side short-circuits
- Back-to-Back arrangement, i.e. rectifier and inverter in one station
- The implementation of multiterminal systems is relatively simple with HVDC PLUS. In these systems, more than two converter stations are linked to a DC connection.
- The converters can to some extent be used as STATCOMs, e.g. when the transmission line or cable is out of service during maintenance or faults. STATCOM with PLUS technology is also useful in unbalanced AC networks, for instance in the presence of large single-phase loads. Symmetry of the three-phase system can be improved by using load unbalance control.



Low Switching Frequency of Semiconductors	Low Converter Station Losses *
Low Generation of Harmonics	No Filters required
High Modularity in Hardware and Software	High Flexibility, economical from low to high Power Ratings
Use of well-proven Standard Components	High Availability of State-of-the-Art Components
Sinus shaped AC Voltages and Currents	Use of standard AC Transformers
Easy Scalability	Low Engineering Efforts, Power Range up to 1,000 MW
Reduced Number of Primary Components	High Reliability, low Maintenance Requirements
Low Rate of Voltage and Current Rise	Robust System

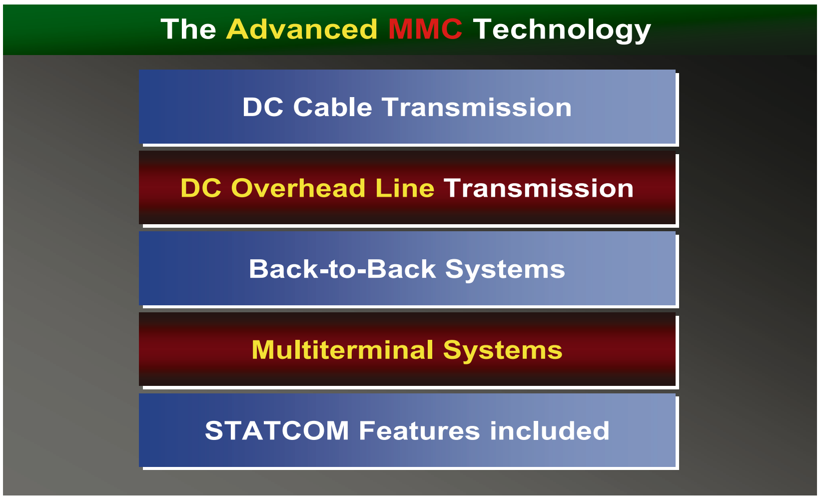
* close to 1 % – per Station

Fig. 16: Features and Benefits of MMC Topology

This multitude of possibilities in combination with the performance of HVDC PLUS opens up a wide range of applications for this technology:

- DC connections for a power range of up to 1,000 megawatt, in which presently only line-commutated converters are used,
- Grid access to very weak grids or islanded networks, and
- Grid access of renewable energy sources, such as offshore wind farms, via HVDC PLUS. This can substantially help reduce CO_2 emissions. And vice versa, oil platforms can be supplied from the coast via HVDC PLUS, so that gas turbines or other local power generation on the platform can be avoided.

Furthermore, with its technical performance (Figs. 16, 17) and its space-saving design (Fig. 18) HVDC PLUS is tomorrow’s solution for the supply of megacities.


The Advanced MMC Technology

DC Cable Transmission

DC Overhead Line Transmission

Back-to-Back Systems

Multiterminal Systems

STATCOM Features included

Fig. 17: Applications and Features of HVDC PLUS

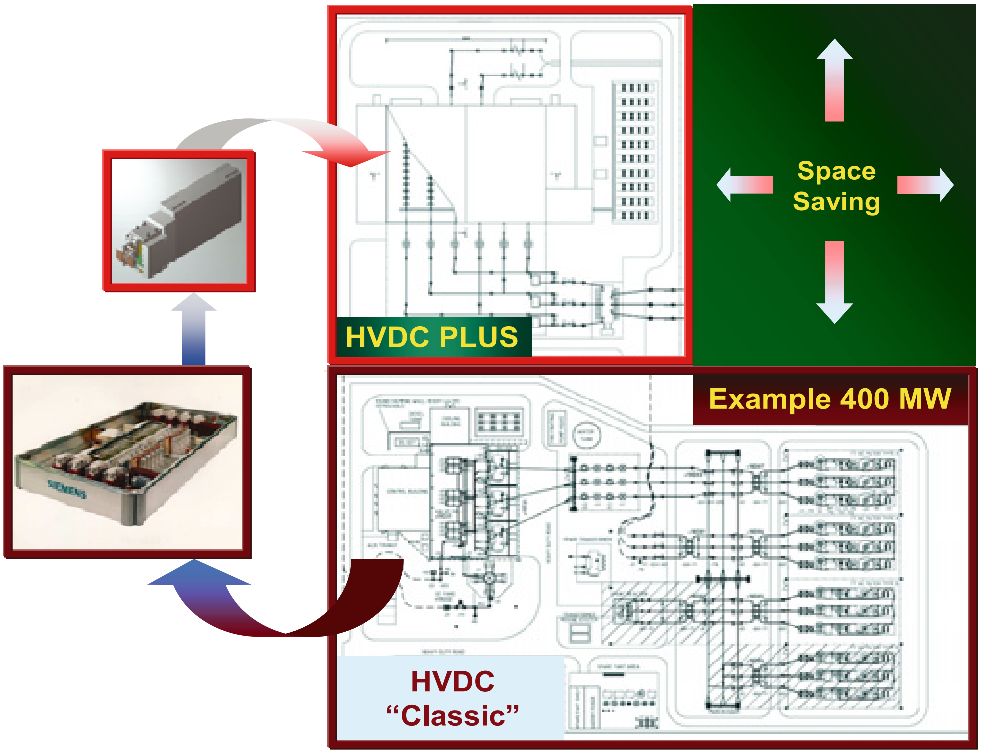


Fig. 18: Space Saving in Comparison with HVDC “Classic”

2.3 The Trans Bay Cable HVDC Project

Due to the aforementioned technical and economical benefits, in September 2007, Siemens secured an order to supply two converter stations for a new submarine HVDC transmission link in the Bay of San Francisco. The HVDC PLUS system will transmit up to 400 megawatts at a DC voltage of ± 200 kV. This is the first order for the innovative HVDC PLUS technology. A project overview is given in Fig. 19.

From March, 2010, the 55 mile (88 kilometers) long HVDC PLUS system will transmit electric power from the converter station in Pittsburg to the converter station in San Francisco, providing a dedicated connection between the East Bay and San Francisco. Main advantages of the new HVDC PLUS link are improved network security and reliability due to grid enhancement, voltage support and reduction in system losses.

Today, the major electric supply for the City of San Francisco is coming from the south side of the San Francisco peninsula. The city relies mainly on AC grids which run along the lower part of the bay. With the new HVDC PLUS interconnection link, power flows directly into the center of San Francisco and closes the loop of the already existing “Greater Bay Area” transmission. This will increase the system security. The DC cables will be buried in a safe corridor separate from any existing AC cables.

Due to the DC transmission link, the building of additional new power plants in the City of San Francisco may be postponed or even avoided.

The link will reduce grid congestion in the East Bay and it will also boost the overall security and reliability of the power system.

The order was placed by Trans Bay Cable LLC, based in San Francisco, and a wholly-owned subsidiary of the project developer Babcock & Brown.

As the consortium leader, Siemens was awarded a turnkey contract which comprises the converter stations for the HVDC PLUS system, including engineering, design, manufacturing, installation and commissioning of the HVDC transmission system. The design fulfills all requirements which have to be considered for the electrical components as well as for all buildings in a highly seismic active zone such as San Francisco.

The consortium partner Prysmian will supply and install the submarine cables.

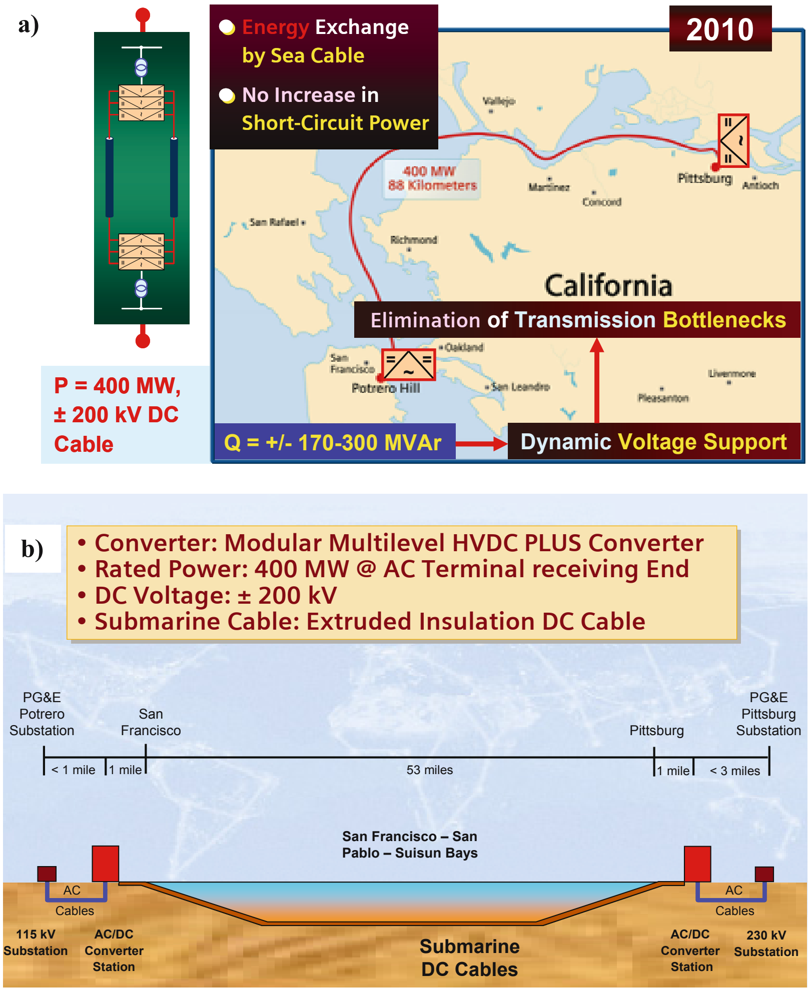


Fig. 19: Trans Bay Cable, USA – World’s 1st VSC HVDC Project with Advanced MMC-Technology and ± 200 kV XLPE DC Cable
a) Geographic Map and System Requirements
b) Siemens Converter Stations and Prysmian Cable Technologies

The new link provides tremendous benefits for power transmission. It will help increase sustainability and security of transmission systems significantly.

As an example, a significant reduction in transmission constraints by using HVDC PLUS for the Trans Bay Cable Project is depicted in Fig. 20.

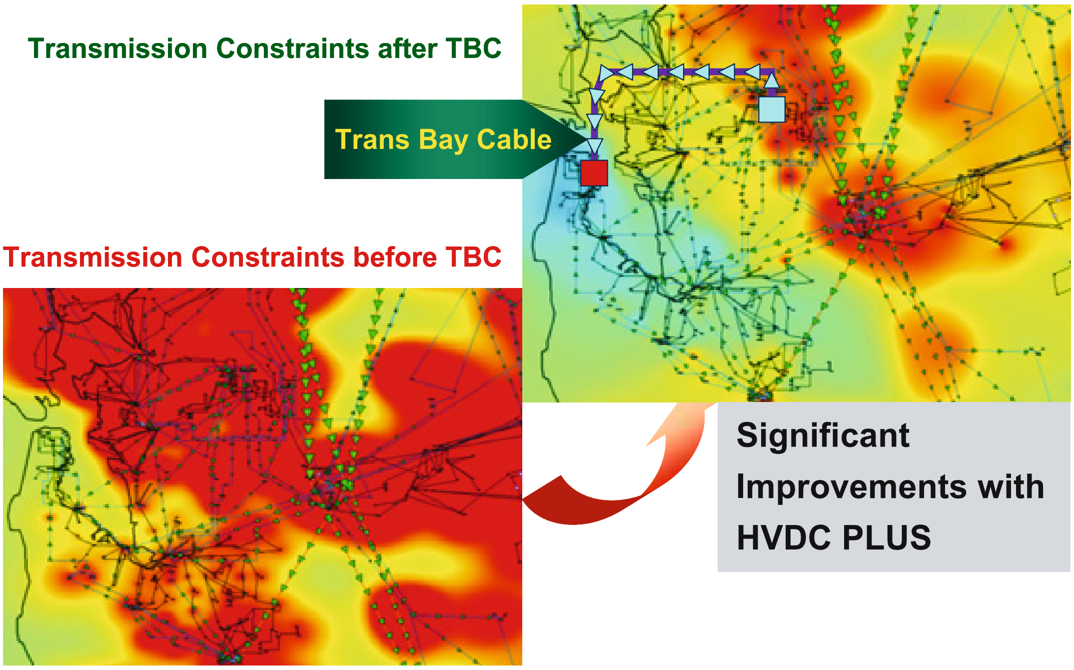


Fig. 20: Benefits of HVDC PLUS for Trans Bay Cable Project

3. Design Verification

Numerous activities are carried out to ensure that the Transbay Cable transmission system will perform as required.

3.1 Equipment Tests

The test schedule includes routine tests and type tests for all major equipment. Fig. 21 shows the dielectric type test of a section of a converter arm.

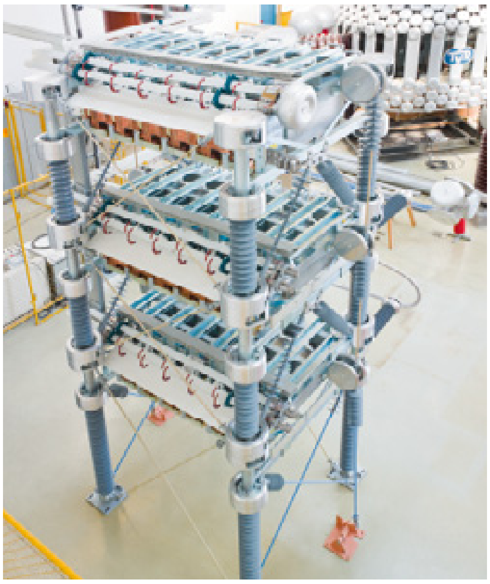


Fig. 21: Dielectric Type Test of HVDC PLUS

3.2 System Performance Verification

The verification process for the system performance of the converter and its controls includes extensive computer simulations as well as a wide range of tests with the real control and protection equipment connected to digital and analog simulator hardware.

For further verification of the performance of the controls and also the simulator models a full scale converter hardware in the form of a 30 MW Back-to-Back converter was installed.

Fig. 22 shows details of this test facility.

Fig. 22: 30 MW Hardware Functional Tests

3.3 Results of Computer Simulations

Fig. 23 depicts the results of a computer simulation for the 400 MW MMC system which will be applied in the case of the Trans Bay Cable project. The figure clearly shows that with 200 power modules per converter arm no additional AC filtering will be required.

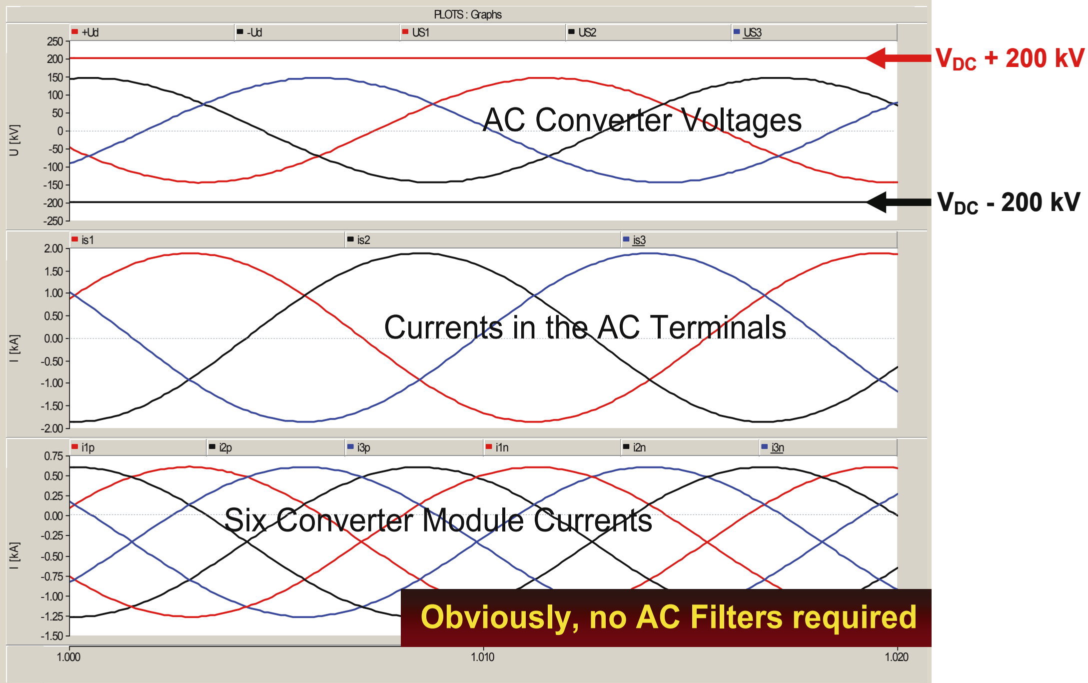


Fig. 23: 400 MW with 200 Power Modules per Converter Arm

Figs. 24–25 show the transient performance of HVDC PLUS during AC faults, incl. “fault ride-through capability”.

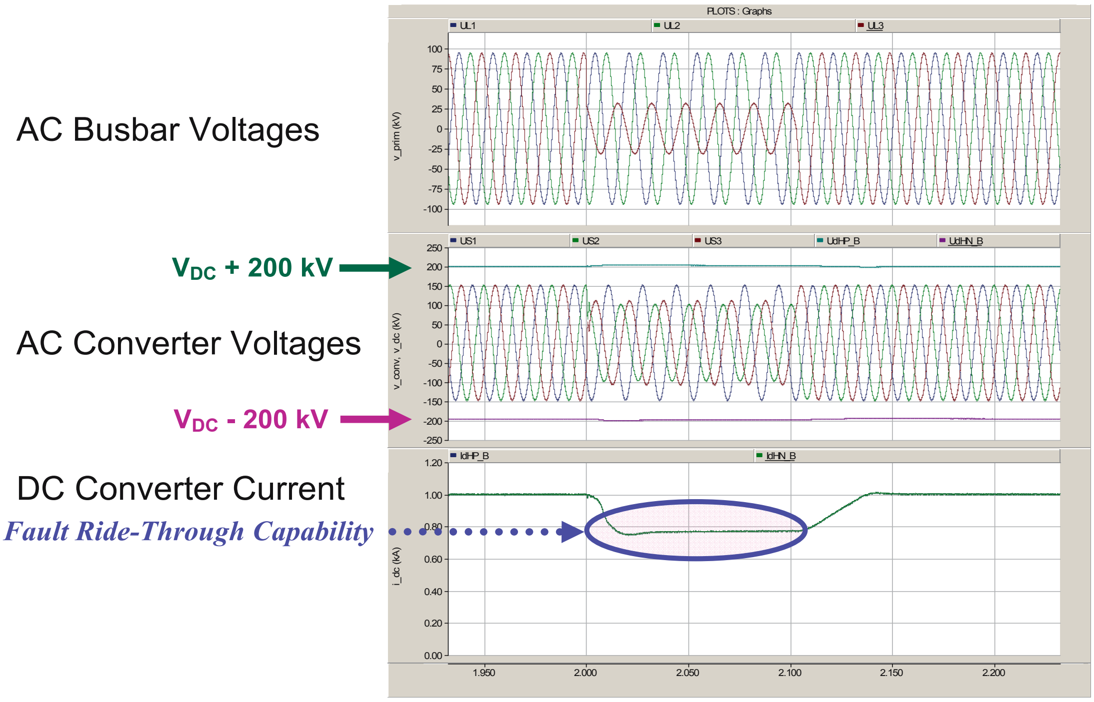


Fig. 24: Dynamic Response to an AC Line-to-Ground Remote Fault on the Inverter Side

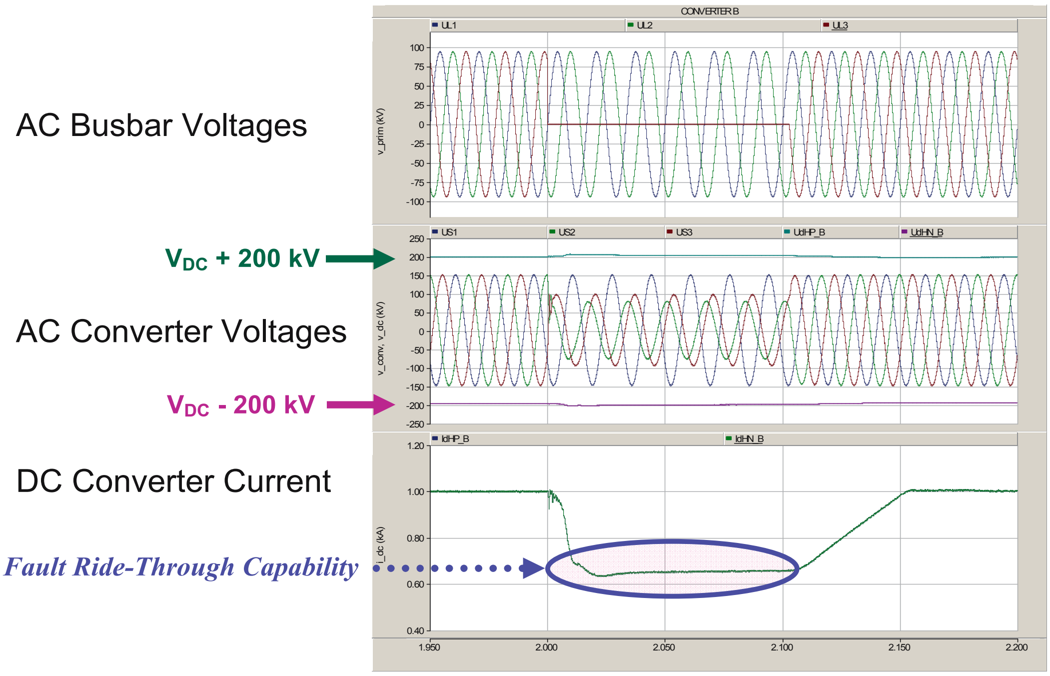


Fig. 25: Dynamic Response to an AC Line-to-Ground Busbar Fault on the Inverter Side

4. Example of Station Layouts

In Fig. 18 the space saving of HVDC PLUS in comparison with HVDC "Classic" is illustrated.

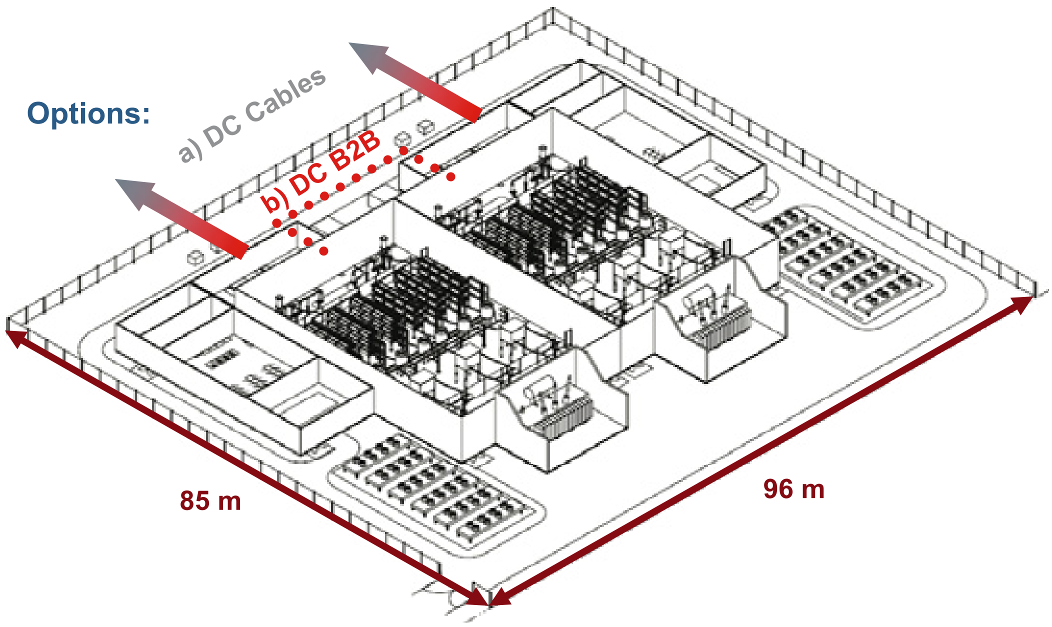
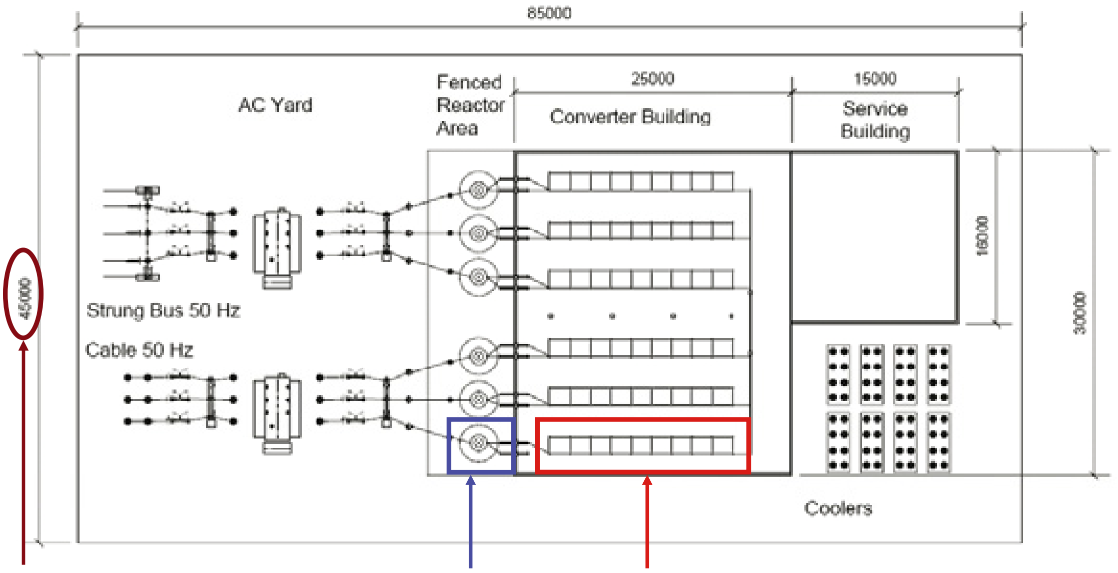


Fig. 26: Example of HVDC PLUS Station – 2 x 100 MW

In principle, there are two configuration possibilities. Fig. 26 depicts a fully horizontal arrangement which can be used either as a 200 MW converter station for long-distance transmission cable/overhead line, or as a 100 MW B2B. In Fig. 27, the 100 MW B2B option has a vertical arrangement of reactors and converters, thus saving approx. 50 per cent of space.



Half the Width by **vertical Arrangement: 2 Reactors** and **2 Converter Modules on Top of each other**

Fig. 27: HVDC PLUS Station – Option for 100 MW B2B

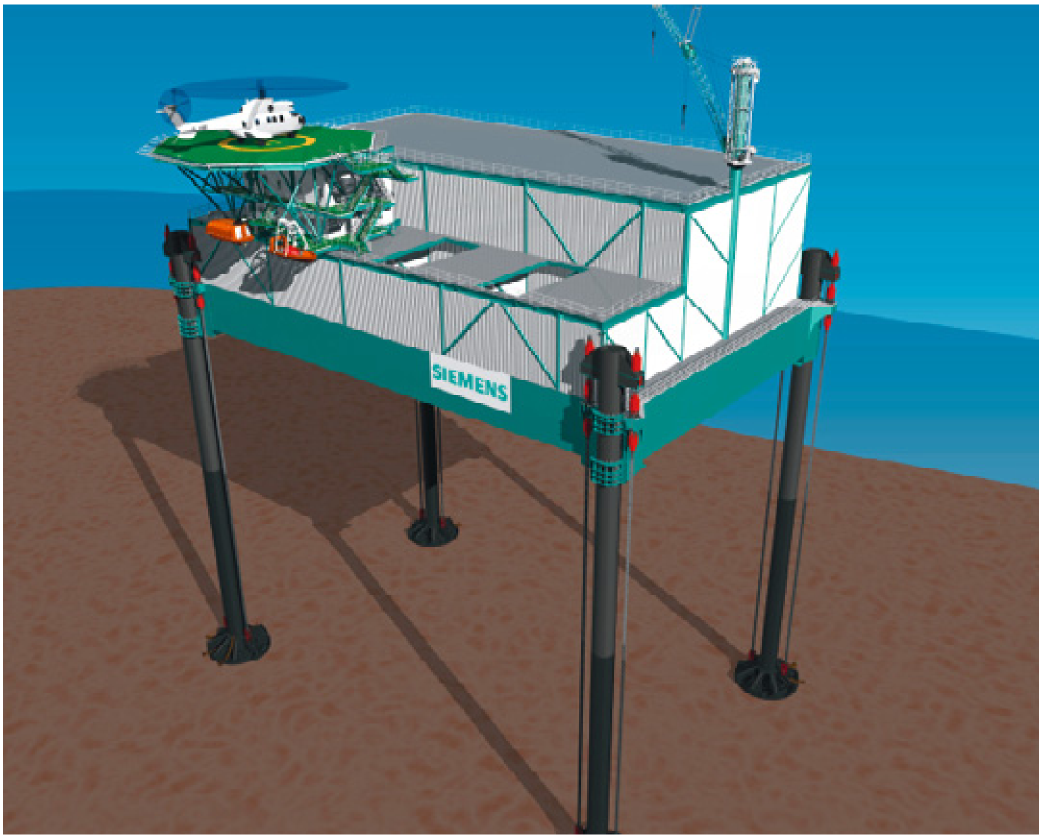


Fig. 28: Offshore HVDC PLUS Substation

Fig. 28 shows an example for an offshore HVDC PLUS Converter Station with a Submarine Cable Connection.

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