Modular back-to-back HVDC, with capacitor commutated converters (CCC)

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1. SUMMARY

A back-to-back HVDC arrangement is used when two asynchronous AC systems need to be interconnected for bulk power transmission or for AC system stabilization reasons. In an HVDC back-to-back station there are no overhead lines or cables separating the rectifier and the inverter, hence the transmission electrical losses on the DC side can be neglected. In a back-to-back HVDC, the DC current can be kept high and the DC voltage low. The low DC voltage means that the air clearance requirement is low, which is in favor of a compact design of the valve housings. This enabled the modular back-to-back HVDC concept to be developed.

The modular back-to-back converter station can be made very compact, thus requiring a minimum of open space. It can even be designed to fit into an existing right-of-way of a typical 400 kV AC line. In environmentally sensitive areas this is also considered a great advantage from a permitting point of view. Our ISO 14001 certification states that the design of the equipment and the construction at the site are performed in an environmentally acceptable way.

The Argentinean and Brazilian networks have been interconnected via back-to-back HVDC with a rating of 1100 MW. A second interconnection of another 1100 MW is under construction. The back-to-back HVDC converter stations are of the modular type with capacitor commutated converters.

Fig.1 Overview of the 1100 MW modular back-to-back HVDC station in Garabi, Brazil.

1. HVDC BACK-TO-BACK -ARRANGEMENT

A back-to-back HVDC arrangement is used when two asynchronous AC systems need to be interconnected for bulk power transmission or for AC system stabilization reasons. In an HVDC back-to-back station there are no overhead lines or cables separating the rectifier and the inverter, hence the transmission electrical losses on the DC side can be neglected. In a back-to-back HVDC, the DC current can be kept high and the DC voltage low. In order to optimize the costs of the thyristor valves as well as the DC side equipment, the DC current is kept as high as the standard thyristor rating and valve cooling system can handle safely. This means that the DC voltage can be kept fairly low, and is thus chosen in relation to the rated DC power.

1.1 Applications

- Asynchronous connection between AC networks

To stabilize a weak AC system, it might be desired to do this by importing power from an AC system, isolated from the receiving system. These two AC systems could even have different frequencies. In such situations, a DC transmission system is the only possibility for power transmission.

- Frequency control of AC systems.

The frequency of an AC system that becomes too heavily loaded might drop, and when large loads are suddenly disconnected, the frequency of the system will rise. By interconnecting such an AC system to a stronger system by means of a DC transmission, the frequency deviation can be limited or controlled through automatically imposed DC power modulations, counteracting the frequency deviations.

- Reduction of short circuit current in strong AC systems.

The short circuit power of a strong AC system with several infeeds can cause a very high short circuit current upon ground faults. At a certain point, the number of infeeds added would cause the short circuit current to exceed the level that the existing circuit breakers are capable of handling, and the breakers in the AC system might have to be uprated or replaced. A less costly way is to split the system up by means of one or several back-to-back converters, thereby enabling isolation of certain parts of the AC system at ground faults, thus avoiding the cost of replacing all the circuit breakers of the AC system.

2. THE CCC CONCEPT

The converter used in the CCC concept is characterized by the use of commutation capacitors inserted in series between the converter transformers and the converter valves. See Figure 2. Single line diagram. It makes it possible to operate HVDC in very weak networks and eliminates the need for synchronous compensators.

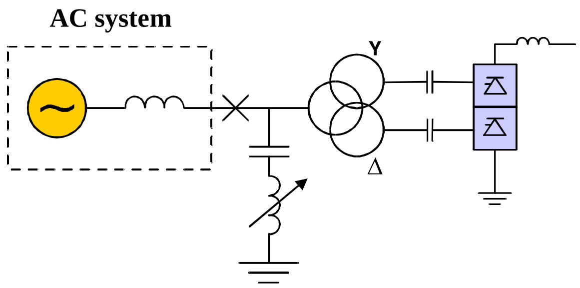

Figure 2 Single line diagram of a monopolar station with CCC and ConTune™ AC filter.

The ABB approach does not aim at achieving a self-commutated converter, instead, it provides reactive power compensation proportional to the load of the converter. The need of switchable shunt capacitor banks for reactive power compensation is thereby eliminated. Since the AC filters are necessary only from the point of view of filtering harmonics, the shunt connected reactive power generation can be minimized. In the ABB solution, the size of the commutation capacitor is chosen so that the full load reactive power consumption of the converter is compensated by the reactive generation of the small high performance AC filter. See Figure 3. Reactive power conditions.

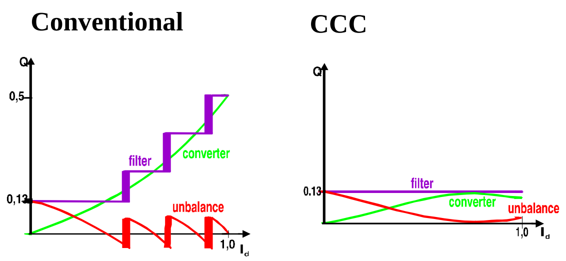

Figure 3 Reactive power conditions for a typical conventional converter and for a CCC.

2.1 The capacitor in the CCC concept

The commutation capacitors create the AC voltage to which the converter is commutating, hence these capacitors are called Commutation Capacitors, and the converter becomes a Capacitor Commutated Converter, a CCC. The steady state operating voltage of the commutation capacitor is defined by the direct current. The capacitors are protected against over voltages by parallel ZnO varistors. The voltage stresses on the capacitors are relatively low compared to the installed capacity, and consequently the commutation capacitors can be of compact design.

Fig. 4 Commutation capacitors at Garabi

The commutation capacitors improve the commutation failure performance of the converter. Typically, a CCC can tolerate a sudden 15-20% voltage drop on the network voltage.

The contribution to the commutation voltage from the commutation capacitors results in positive inverter impedance characteristics for an inverter operating at minimum commutation margin control. An increase in direct current therefore results in a DC voltage increase rather than the opposite, which is the case for conventional inverters with commutation margin control. The dynamic stability of an inverter will thus be dramatically improved with a CCC.

Figure 5 shows the MAP (Maximum Available Power) curves for a conventional converter and a CCC for SCR = 2. As can be seen, the CCC is in a very stable situation while the conventional converter is close to the stability limit. The diagrams also show that the load rejection over voltage is reduced from 1.5 to 1.2 p.u. as a result of the small size of the shunt connected filters for the CCC.

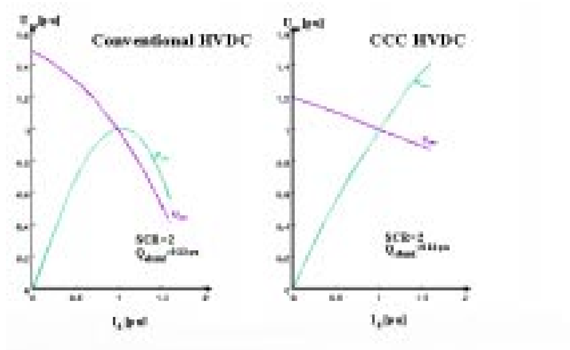

Figure 5 Maximum power curve for conventional and Capacitor Commutated Converters (CCC), SCR=2g=17°.

2.2 Impact on equipment and station design

The introduction of commutation capacitors results in different stresses on the other equipment compared to a conventional HVDC converter. The main influence from the capacitors is a considerable reduction of valve short-circuit currents. This is due to the voltage drop across the commutation capacitor varistors. On the other hand, a somewhat higher peak voltage across the valve, as well as higher extinction voltage steps, will be obtained compared to conventional HVDC. The voltage contribution from the commutation capacitors will support the commutation of the direct current from one valve to another; i.e., the overlap angle will be reduced compared to a conventional HVDC converter. The commutation capacitors reduce the rating of the converter transformer as the reactive power flow through the transformer is minimized.

The elimination of switched reactive power compensation equipment will simplify the AC switch-yard and minimize the number of circuit-breakers needed, which will reduce the area required for an HVDC station built with CCC.

ConTune AC filters:
The task for the AC filters is to filter out the harmonics, for which purpose quite small capacitor banks are needed, provided they can be tuned sharply enough. This is made possible by electronically controlled filter reactors included in the filter for the 11th and the 13th harmonics, which are the two dominant harmonics created by the twelve-pulse converter. The inductance of these reactors are continuously controlled or tuned, and hence such an AC filter branch is called ConTune. The adjustable reactors of the ConTune branches are continuously controlled by a DC current fed into a control winding mounted perpendicular to the main winding, enabling continuous adjustment of the inductance and thus continuous tuning of the filter branch.

The combination of the CCC and the ConTune offers several technical advantages. Firstly, operation is possible at very low short circuit power levels of the AC systems. A short circuit ratio of 1.0 is achievable without the need of synchronous machines added to the AC networks. Secondly, the immunity to AC system disturbances is improved, thereby maintaining constant DC power flow during severe disturbances in the AC systems. Thirdly, the reactive power balance between the HVDC converter and the AC networks can be kept within very narrow limits, since the commutation capacitors generate reactive power in accordance with the transmitted DC power, i.e. in accordance with the actual reactive power consumption of the converter.

Thyristor Valve Modules:
In order to optimize the costs of the thyristor valves, as well as the DC side equipment, the DC current is kept as high as the standard thyristor rating and the valve cooling system can handle safely. This means that the DC voltage can be kept fairly low, and is thus chosen in relation to the rated DC power. The low DC voltage means that the air clearance requirement is low which is in favor for a compact design of the valve housings. These facts enabled the modular back-to-back HVDC concept to be developed.

The thyristor valves are air insulated at atmospheric pressure and installed in modular valve housings. Each valve module contains two or more single valves, which means up to six valve modules per twelve-pulse converter. The thyristor valves are suspended from the ceiling and are easily accessible for the maintenance crew. The housings also contain the surge arresters connected across the valves, and the valve control.

Fig.6 Outdoor HVDC Valves

Each modular housing is equipped with an independent fire protection system with detectors and inert gas injectors that are automatically initiated upon detection of overheated material. For a better and more reliable supervision of the thyristors, electrically triggered thyristors are used.

Valve Cooling module:
The valve cooling system for a modular back-to-back is located in a separate module, except for the cooling towers that are located outdoors. The thyristor valves are water cooled and preferably by means of a single closed loop system.

Auxiliary Power modules:
The low voltage part of the auxiliary system is installed in two separate modular housings, one for the distribution switchgear and one for the battery system. The auxiliary power can be provided either from a separate low voltage infeed, from a dedicated auxiliary transformer, or from tertiary windings of solidly connected AC line shunt reactors.

Control & Protection Module:
The MACH 2 Control & Protection System consists of a fully duplicated system, with commercially available computers including the control functions as well as the protection functions. The AC side protections are also included in MACH 2, in the same kind of hardware as the DC side protections. Operation can take place locally or remotely through serial protocols. The Control and Protection system is located in a dedicated module.

The whole back-to-back converter station can be operated from an Operator Workstation in the control and protection module, from the station control building in the converter station, or from remote dispatch centers.

HPL Compact breaker:
The HPL Compact switching module includes all functions performed by a traditional circuit breaker bay; HPL circuit breaker, pantograph disconnectors, earthing switches, digital optical current transducer, common base frame, prewired control cubicle. All these results in a substantial reduction of required space and facilitate ease and fast maintenance of the breaker bay.

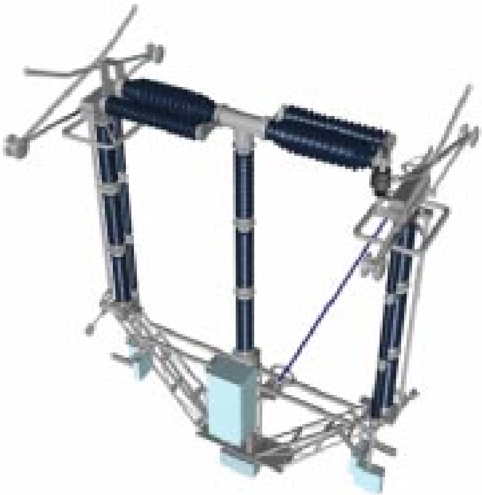

Fig.7 HPL Compact switching module

3. BENEFITS

3.1 Operation, maintenance, and availability benefits

The MACH 2 Station Control and Monitoring system, SCM, is a user friendly fully computerized operator tool. It has built-in facilities, such as operator language selector, self instructed operation flow charts, voice enunciator, sequence of events recorder, transient fault recorder, digital hierarchical documentation, etc.

The rest of the equipment, which is continuously supervised by the SCM systems, can be completely maintained from the fully duplicated MACH 2 Control and Protection systems. The system also includes the AC protections, integrated in the system in the same way as the DC protections are. Any HV, or LV equipment or measuring defect, as well as any internal MACH 2 malfunction will automatically be detected and recorded, thus eliminating the need for traditional maintenance by visual inspection and manual measurements.

Traditional maintenance like visual inspection, adjustments, lubrication, etc., is only needed for the moving parts, which are motors, pumps and fans used for the cooling equipment, and the converter transformer tap changer.

No AC breakers or disconnects, apart from the ones used for energizing purposes, are needed.

Since the number of moving parts are kept to a minimum, and the number of HV equipment is reduced, the availability of the facility is increased.

3.2 Economical benefits

The modular back-to back concept is time and cost saving with respect to permitting processes, as it can be designed to fit into an existing right-of-way.

As there is no need for a valve hall and a traditional control and service building, the civil design is reduced and consists primarily of design of the foundations for the different modules. The cost and time needed for the civil design is thus kept to a minimum.
The time and cost for construction is substantially reduced, as the construction of foundations for the different modules is easier than the construction of a valve hall and a control and service building.
The installation work can be reduced in time, because much of the installation work is factory-made in a more efficient way, and very little assembly work is needed at the site. The factory pre-assembly also detects any fitting problem at an early stage, which limits times and cost for trouble-shooting at the site. The factory pre-assembly of the modules can be done as a parallel activity to the construction at site and thus reduces the total project time.
Testing at site can be reduced as the modules are tested at the factory before shipping. As the different kinds of components included in the modular designed converter are limited substantially, the number of spare parts needed is also limited. This facilitates storage and handling of spares.

The CCC concept allows the location of stations at the edges of existing networks, avoiding costly transmission reinforcements. The modular concept also facilitates future changes in sub-station layout due to planned expansion. If the operating or the economic conditions change, relocation of the equipment might be desired. In a modular back-to-back the civil work is reduced to a minimum and therefor it allows for relatively easy relocation of the equipment.

3.3 Environmental benefits

The modular back-to-back converter station can be made very compact, thus requiring a minimum of open space. It can even be designed to fit into an existing right-of-way of a typical 400 kV AC line.

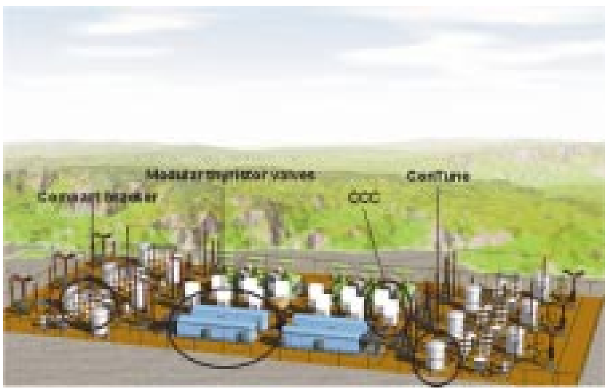

Fig.8 Modular back-to-back, side view.

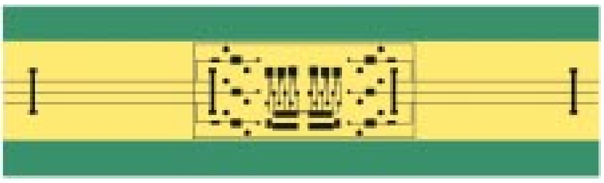

Figure 9 Modular back-to-back, overview. Fits in the right –of-way width of most AC lines.

In environmentally sensitive areas this is also considered as a great advantage from a permitting point of view.

REFERENCES

Hagman I, Jonsson T, "Verification of the CCC concept in a high power test plant", Cigré colloquium on HVDC and FACTS, South Africa, 1997.

Persson A, Carlsson L, Åberg M, "New technologies in HVDC converter design", SEPOPE, Recife, Brasil, 1996.

Jonsson T, Holmberg P, Tulkiewicz T, "Evaluation of classical, CCC and TCSC converter schemes for long cable projects", EPE99, Lausanne, Switzerland, 1999.