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The development of a Power Electronic Building Block for use in Voltage Source Converters for HVDC transmission applications

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Summary

This paper presents a report on the development by AREVA of a new Power Electronic Building Block (PEBB) device, which can be used to create a VSC converter for HVDC applications. Building upon its wide experience in FACTS devices, such as STATCOM for utility applications and D-STATCOM for distribution and industrial applications, AREVA has developed a new modular PEBB unit which is designed to be used for HVDC applications. The paper describes the topology of the PEBB unit and the choice of switching device used. A wide range of simulation studies have been performed to demonstrate the control principles required to provide four-quadrant real and reactive power control. The results of these studies will be presented in the paper. Studies have also been performed to demonstrate the stability of the control system to external perturbations and some results from these studies will also be presented.

In parallel with the electrical design concepts, the mechanical design concepts of the PEBB have also been developed. The paper provides details of the physical arrangement of the PEBB units and their first application to create a 25MVA demonstrator unit. The building and testing of such a demonstrator unit, at AREVA's HVDC test facility, will be an essential step in the electrical and thermal proving of this new technology.

Introduction

The widespread availability of high power semiconductor devices which can be turned on and turned off by external control action, such as Gate Turn-Off thyristors (GTO) and Insulated Gate Bipolar Transistors (IGBT), has given rise to the possibility creating an AC voltage waveform from a source of DC voltage, such as a charged capacitor. By control of the magnitude and phase angle of this voltage source, with respect to the AC system voltage, allows the possibility to independently control real and reactive power flow into the AC system. A key feature of the creation of a voltage waveform is the inherent harmonic content arising from the chosen switching technique used to control the semiconductor devices. For an ideal power converter the voltage waveform is sufficiently sinusoidal that no, or minimal, harmonic filtering is required on the AC side of the converter.

The realisation of such a Voltage Source Converter (VSC) for use in HVDC applications will bring the following benefits to the system operator,

- the use of conventional grid transformers instead of converter transformers
- operator control of reactive power exchange with the AC system
- the absence of switched reactive power/harmonic filter banks on the AC system
- the ability to operate into very weak AC systems or passive AC systems
- the ability to “black start” an AC system
- more compact site area and lower equipment weight
- rapid power reversal, without polarity reversal, allowing the use of polymeric insulated cables instead of oil impregnated cables
- the opportunity for multi-terminal without the need for the full scheme to be designed from the outset

However, the implementation of VSC technology for HVDC applications will also involve some challenges,

- the capital cost of the stations needs to match that of the mature classic HVDC designs
- the operating losses of VSC schemes to date are significantly higher than classic HVDC
- the rapid switching of the IGBT devices can create a more severe electromagnetic compatibility problem than classic HVDC
- to date the DC power levels and voltages are lower than classic HVDC, limiting the application range for VSC
- market acceptance of a “new” technology

As the use of VSC technology for HVDC already has a 10 year history, many of these issues are being resolved as technical developments proceed and many customers now actively embrace this “new” technology.

Initial VSC developments

AREVA’s first development of a VSC converter was for a STATCOM application. This used the concept of a chain-link circuit, as shown in Figure 1 to generate a controlled voltage waveform from a segmented DC capacitor [Ref 1]. In this case the switching device was a GTO, with a parallel connected diode. By controlling the magnitude of the converter voltage in relation to the measured AC system voltage, reactive power could be generated or absorbed by the converter, without the need for capacitor/inductor equipment. Figure 1 shows a simple circuit of 3 levels to illustrate the concept, with the resultant theoretical output voltage waveform.

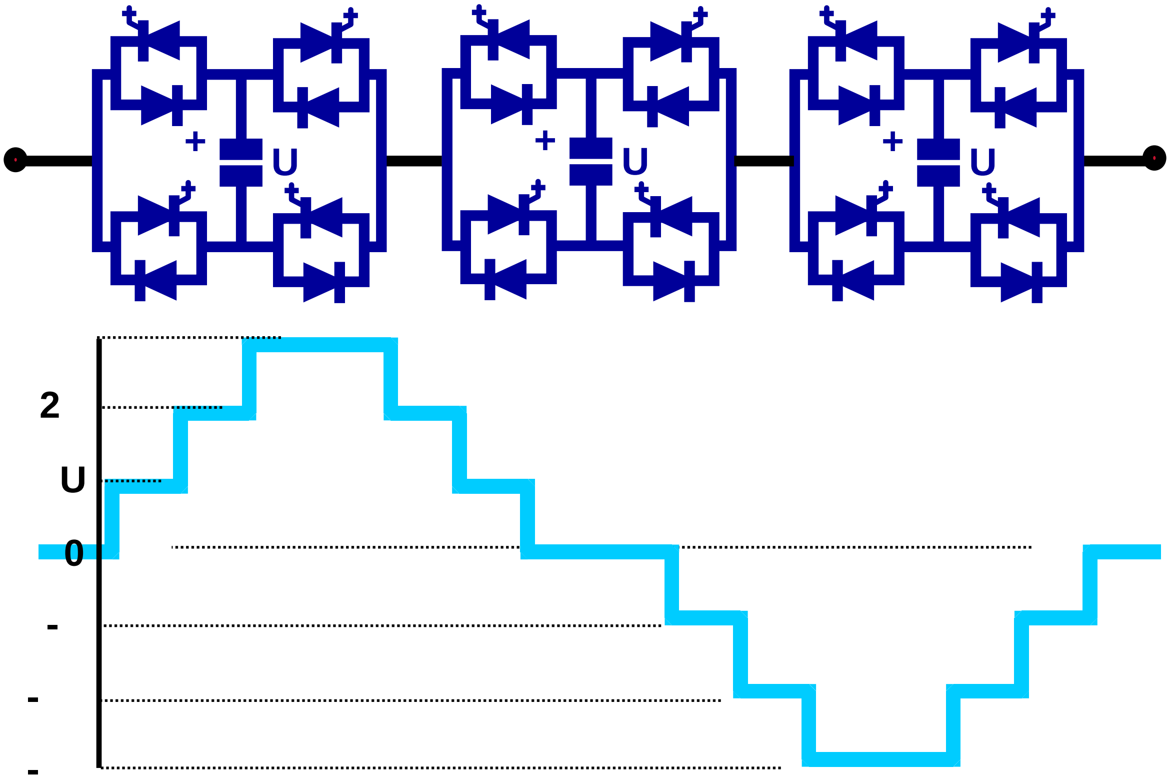

Figure 1 Chain link circuit concept and output voltage waveform

For a practical application at 75Mvar at 16kV [Ref 2], 16 links were used in each phase to ensure that the output voltage waveform, was sufficiently sinusoidal that no AC side harmonic filters were required to maintain compliance with the customers harmonic limits. An example of such a waveform is shown in Figure 2 for both generation and absorption modes of operation.

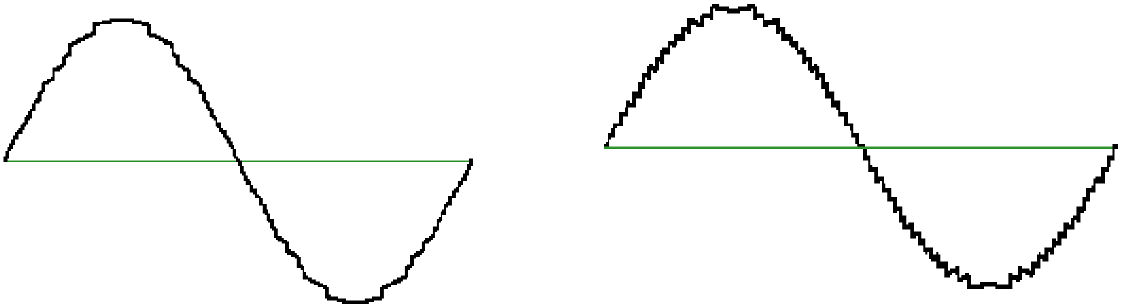

Figure 2 Output waveforms for generation (left) and absorption (right)

The same chain-link concept was used for the development of a D-STATCOM for distribution applications [Ref 3]. This unit is rated at 10MW, with 100% overload capability, and connected at 10kV. As this solution requires only 7 links per phase, the output waveform would have been unacceptable, unless additional harmonic filtering were included, which was not desirable. To overcome this, the switching device (IGBTs) was controlled by Pulse Width Modulation (PWM) to improve the output voltage waveform. The circuit arrangement is shown in Figure 3, together with the output voltage waveform.

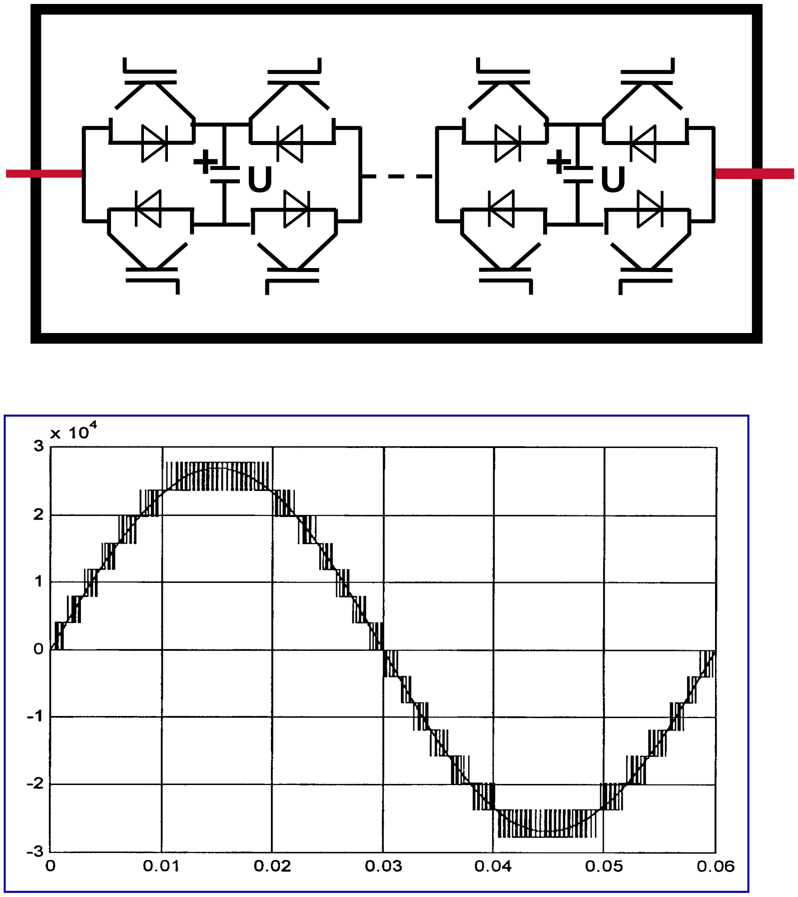

Figure 3 Chain-link converter with PWM control and output voltage waveform

VSC Development for HVDC applications

Based on the experience gained from these developments, AREVA has chosen a circuit based on this chain-link topology for use in HVDC applications. Investigations on PWM control of series connected IGBT devices indicated the need for RC (snubber) circuits to share voltage across potentially hundreds of devices and significant losses in the semi-conductor devices, hence this approach was not adopted. The topology of a chain circuit, with only three links for simplicity of presentation, is shown in Figure 4. Around each of the distributed DC capacitors an arrangement of four IGBTs provides the switching to create the voltage steps, which will make up an AC voltage waveform.

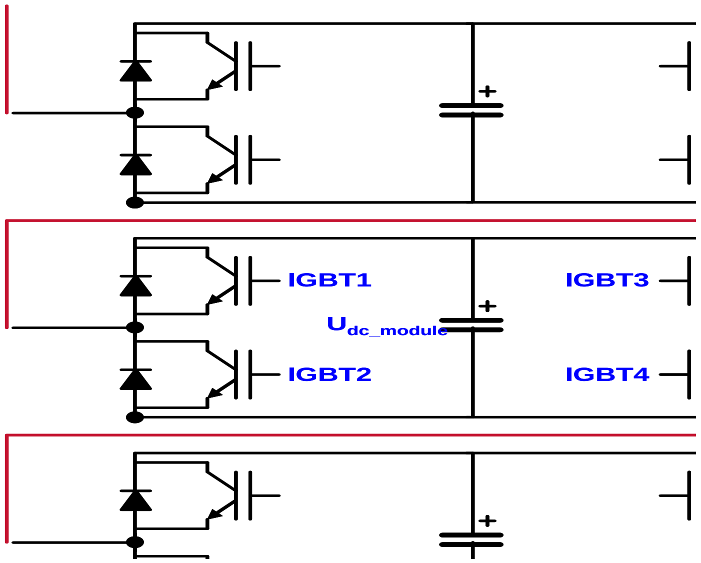

Figure 5 Arrangement of three links of the chain

By connecting a number of such links in series per phase a stepped output AC voltage can be created, as shown in Figure 6. In this case only 6 links are shown for simplicity.

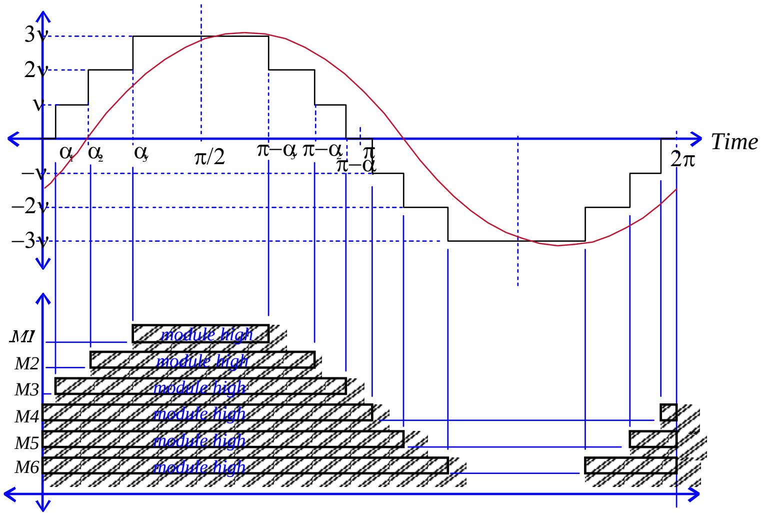

Figure 6 Output voltage waveform

Thus the same concept is used as indicated in Figure 1 to generate the AC voltage waveform. With sufficient links in the chain the voltage waveform will be sufficiently sinusoidal to avoid the need for any harmonic filtering. Although only two switching devices could be used to achieve the necessary control of the converter [Ref 4], the use of a full bridge arrangement as shown in Figure 5, can provide some additional benefits. The output from the chain link circuit can be of either polarity as required. This would make such a VSC converter ideal for connection to a line commutated converter system, e.g. as a low power tap connection onto an existing "classic" HVDC scheme. The additional IGBT devices in the circuit can be used to provide protection against DC side faults, which otherwise would require a fast acting thyristor to provide protection.

VSC HVDC Development Methodology

A three stage development methodology was adopted to move from the conceptual stage to the practical implementation of a VSC HVDC scheme

Stage 1 – Mathematical modelling

The development of the circuit topology and the control techniques necessary to create a functioning VSC HVDC system, were modelled using MATLAB/SIMULINK. This allowed rapid evaluation of new circuit and control concepts to reach a solution which met all of the required operational criteria. A typical example of a study is shown in Figure 7.

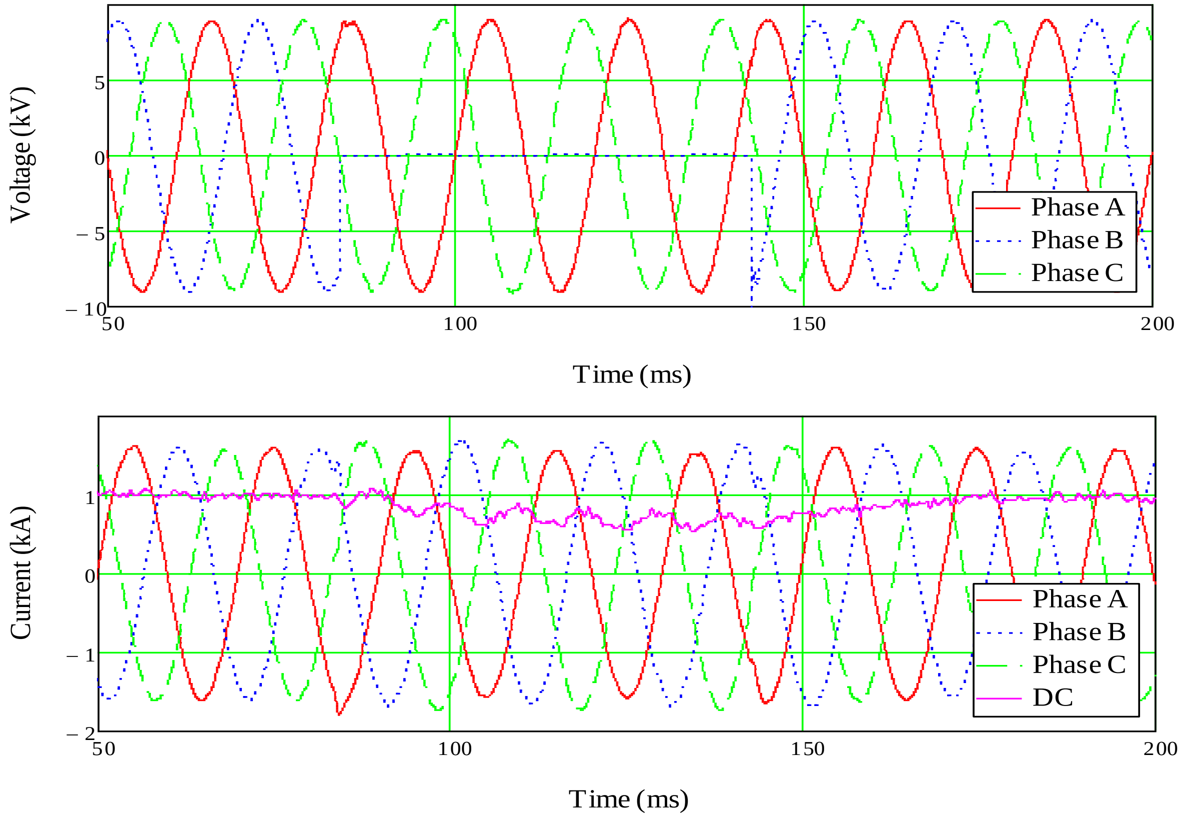

Figure 7: Converter operation during single phase to ground fault

This illustrates to behaviour of the converter during a single phase to ground fault lasting for 3 cycles. Following the fault the converter rapidly recovers to the pre-fault condition and resumes stable operation. Extensive studies have been performed for normal operation and fault conditions to ensure that the control system maintains stability under all cases. Parallel studies have been performed using PSCAD/EMTDC to develop suitable models in that widely used program.

Stage 2 Simulator Laboratory

A low power (2kW) analogue simulator of a VSC transmission scheme has been built in order to prove the control concepts using real components, rather than rely only on mathematical models. A three phase (230V) AC supply system connects to the converters via a star/star connected transformer. The system and transformer impedances are adjustable. A three phase converter, comprising 16 links per half phase, as Figure 5, connects to the DC circuit. This can model an OHL transmission system, a cable system or a back – to – back system. Fault throwing switches are provided on the AC and DC systems to test the behaviour of the controls during the same types of faults studied on MATLAB. The control software is directly imported from the MATLAB model onto a National Instruments LabView controller. Thus any issues raised from testing the Simulator can be studied on MATLAB and the new control algorithms rapidly re-imported into the Simulator controller.

In its initial phase of operation the Simulator will be used to prove that the VSC concepts are valid and that stable operation of a VSC HVDC scheme can be achieved using a real, albeit reduced scale, equipment. Ultimately the LabView controller will be replaced by AREVA's normal HVDC Series 5 controller, running the same software. At this point the development moves from concept proving to equipment proving.

Stage 3 25MVA Demonstrator

In order to prove the equipment that will be offered in a commercial project, a 25MVA demonstrator is being build at AREVA's facility in Stafford, UK. A simplified single line diagram of the Demonstrator is shown in Figure 8. The demonstrator will be connected to the 11kV distribution system, via dedicated circuit breakers. A bank of three single phase 11/11kV transformers, each 8.33MVA rated will couple the power electronic converters to the AC system. These transformers can be configured to have 11kV star or delta secondary windings to allow investigation of different connection arrangements. The chain link converters consist of 16 links per half phase, i.e. 32 links per phase. Each link uses a 3.3kV rated IGBT which can switch 1200A. The DC capacitors are rated at 2.4kV DC. The rectifier and inverter converters are coupled via two DC reactors as shown in Figure 8. These are part of the main converter topology, so effectively the Demonstrator will operate in a back – to – back mode. No AC side harmonic filter equipment is envisaged, calculations indicating that even with only

32 links per phase, the harmonic distortion will be within acceptable limits on the 11kV distribution system. Each link in the converter is identical to that which will be offered in a full scale commercial project. Similarly the Series 5 controller, with full dual lane redundancy as per normal HVDC practice, is the same as a commercial project. Although built on a reduced power, the Demonstrator will use and prove the same equipment as a full scale project.

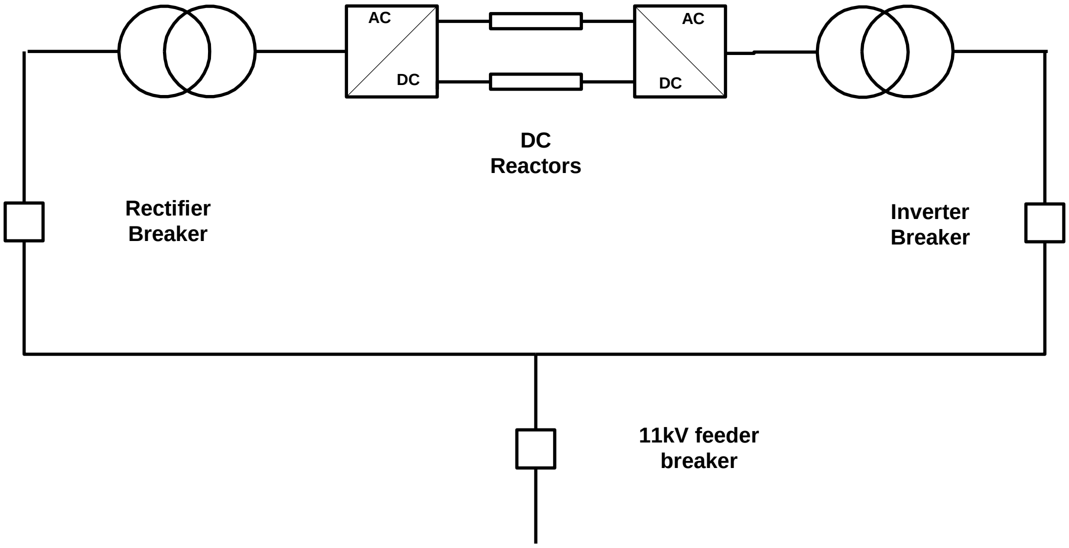

Figure 9 Simplified single line diagram of 25MVA Demonstrator

The demonstrator is designed to test all of the components in a round power arrangement, i.e. only the losses of the demonstrator need to be supplied from the 11kV distribution system. However, any residual harmonics from the rectifier and the inverter will both enter the feeder system.

Conclusions

Based on its long experience in VSC equipment for FACTS applications AREVA is developing a new converter technology using the same chain link concepts as previously employed. The individual components of each links are based on industry standard equipment, IGBTs, DC capacitors, etc. such that the principle innovations are in the control and protection systems employed. Initial computer simulation has shown that the concepts are proven and that a stable and robust HVDC system can be implemented using chain link technology. An analogue Simulator laboratory has been established to further prove the design concepts, using real components and operating under a widely available controller. This controller will ultimately be replaced by the AREVA Series 5 control and protection system, implementing the new control algorithms. In parallel a 25MVA Demonstrator of the technology is being built. This uses the same equipment as will be used for a commercial project, but with lower numbers of links in the chain compatible with the lower DC voltage.

References

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