INNOVATIVE VSC TECHNOLOGY FOR INTEGRATION OF "GREEN ENERGY" - WITHOUT IMPACT ON SYSTEM PROTECTION AND POWER QUALITY

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ABSTRACT

In Europe, wind power is gathering pace. However, even in case of offshore areas with strong winds, wind power is highly fluctuating, which has a significant impact on voltage and frequency stability in the grid. Therefore, "Green Energy" is a an issue for Grid Code compliance and Power Quality in transmission and distribution systems as well. In order to provide Grid Access to offshore wind farms, subjected to fluctuations and often situated far from the coast, it is necessary to find solutions, which can provide the required voltage quality at the point of grid coupling. This will help make the regenerative energy resources fit for the grid, and to connect them according to the conditions of each particular Grid Code. This is where modern power electronics with dynamic fast control comes into play, which makes the grid more flexible, and subsequently able to take in more regenerative and distributed energy sources. A flexible grid such as this is referred to as a "Smart Grid" [1].

INTRODUCTION

Security of power supply (i.e. high reliability, blackout prevention) is the crucial issue while planning and extending power grids, as no society can survive without electric power. In addition to this, for reasons of environmental protection and saving of exhaustible energy resources, the tendency towards sustainability is gaining in importance. The main part in terms of sustainability is played by regenerative sources of energy, particularly those which are completely CO_2 free, such as wind and hydro power.

Power electronics in high-voltage systems is represented by both HVDC (High Voltage Direct Current) and FACTS (Flexible AC Transmission Systems), which also includes Static Var Compensators for voltage stabilization and Grid Code compliance. The state-of-the-art highly flexible Modular Multilevel Converter (MMC) technology for Static Var Compensation (SVC PLUS) makes it possible to easily comply with all the known voltage quality requirements (Grid Codes) for grid access of wind farms as well as for enhancement of transmission and distribution systems. In addition to this, the MMC PLUS technology is used for traction supply with Static Frequency Converters (SFC) and for industrial applications, e.g. for flicker compensation. The field of synergies and applications is therefore boundless.

In the paper, benefits and prospects for security and sustainability of power supply by efficient utilization of electricity will be presented. The technology of SVC PLUS is described and the prospects for security and sustainability of power supply are discussed. Projects for Grid Access of large wind farms from 300 to 630 MW and solutions for enhancement of transmission and distribution systems from 33 kV to 220 kV systems are depicted.

POWER ELECTRONICS MAKES "GREEN ENERGY" FIT FOR THE GRID

Electric power is a matter of survival of the modern society; nowadays everything comes to a halt without it. This holds true even for oil, gas and water supply. Should a wide-area blackout occur, this can bring about disastrous consequences for a whole country. This is the reason why power security is of crucial importance. In view of the anticipated effects of climate change, the criterion of sustainability, which stands for high efficiency of generation, transmission and distribution as well as for efficient consumption of electric power, is additionally coming up. The attempt to achieve these challenging targets implies the global use of renewable power sources such as hydro, wind and solar energy. As far as Europe is concerned, wind power is currently prevailing, for the technologically and economically applicable hydro potential of this region is already being largely exploited. Moreover, the solar power is gradually gaining in importance in southern regions.

Especially wind power plants are subjected to particularly severe fluctuations, which can affect voltage quality to an extent posing threat to grid security. Therefore, grid access of wind farms is subjected to tight security regulations (Grid Codes) capable of supporting the grid during a fault as well as upon it just as in the case of conventional power plants. With this aim in view, Siemens developed an innovative system of dynamic voltage control referred to as SVC PLUS®, which, similar to HVDC PLUS, is based on the new generation of modular as well as compact multilevel converter technology, which poses an important step on the way to a Smart Grid technology [2 to 4].

DYNAMIC VOLTAGE CONTROL FOR TRANSMISSION AND DISTRIBUTION – WITH MULTILEVEL TO HIGH POWER QUALITY

Thyristors are the key components of line-commutated converter systems, particularly in conventional HVDC systems at a transmission capacity of up to 10 GW for one single installation as in the case of future very large Bulk Power projects in China. Owing to their robust technology and low outage rate, thyristors are extremely reliable. Power converters for the needs of FACTS are significantly smaller and their chief goal is to respond to grid processes as quickly as possible.

Thyristors, however, are capable of mains-frequency switching only, self-commutated elements based on high-power transistors, such as IGBT (Insulated Gate Bipolar Transistor) can clock from some hundred Hertz till the kHz range. It is, however, worth mentioning that the higher the switching frequency is, the higher the system losses of the entire installation become [3].

VSC: VOLTAGE-SOURCED CONVERTERS

Power electronics with self-commutated converters is quite reliable with regard to grid access conditions and boasts additional technological advantages [4], and FACTS solutions applying VSC technology are particularly remarkable for their high dynamic functionality. Moreover, due to the fact that less or no compensation filters at all are required, this equipment is far more compact than the line-commutated one. Among other things, the VSC converters require no "leading" system voltage, they can namely generate system voltage themselves, acting as an "electronic generator". Line-commutated thyristors are only capable of switching on the current; the switching-off takes place due to the driving system voltage at the zero-current. On the contrary, self-commutated power electronics with elements which can be switched off is capable of switching on and off when ever needed.

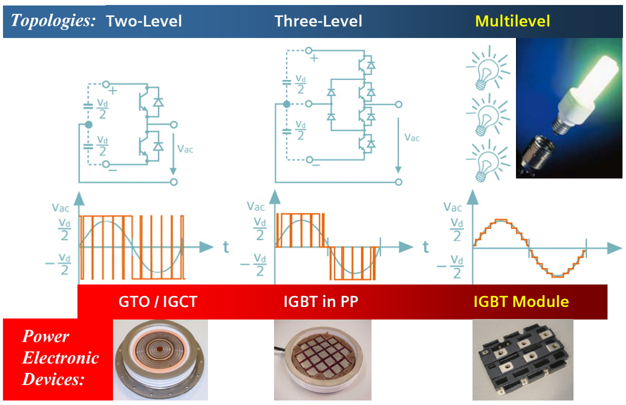

Fig. 1: Multilevel - The Evolution of VSC Technology

The evolution of various VSC technologies including corresponding semi-conductors is depicted in **Fig. 1**.

The VSC technology applied for high-voltage applications in the past was generally based on two or three-level converters which supply the three-phase alternating current connections with two or three voltage levels correspondingly. The direct voltage is clocked by means of pulse-width modulation in such a way that, after massive filtering, the mean value of the clocked voltage gives the sinus waveform close to the required one. The disadvantages of this method are obvious: "hard" switching of high levels of direct voltage means severe transient stresses for power electronics which results in high-frequency radiation which, in its turn, must be correspondingly filtered or shielded. Both the level and the slope of the switching sequence can be reduced, should the system voltage at the output of the converter be commutated in much smaller steps as in the case of two or three-level converters. The smaller the steps are, the cleaner the achieved sinus wave form is and the milder the transient stresses on the components are, which means less shielding and filtering efforts. A converter with multi-step switching of this kind is referred to as a multilevel converter [3 to 4].

PROJECTS AND APPLICATIONS

The first two SVC PLUS units have been commissioned at the end of 2009, at Thanet 300 MW Wind Farm, UK, having each ±35 MVAr of nominal reactive power. Since 2010, three units with ±50 MVAr each have been installed at Greater Gabbard 500 MW Wind farm, UK, and four units with ±50 MVAr will be in operation in 2012 at the 640 MW London Array wind farm. And already before end of the year 2010, 24 units in total were ordered for 13 T&D projects, worldwide.

Fig. 2 shows one of the two SVC-PLUS installations (±50 MVAr) installed at Kikiwa, New Zeeland for Power Quality and Grid Code compliance in High Voltage AC Systems.

Fig. 2: View of one of the two SVC PLUS systems (±50 MVAr) installed at Kikiwa, New Zeeland

Power Quality is the necessity for modern technology to comply with tight Grid Code requirements. In addition to this, SVC PLUS systems with MMC technology are used for traction supply converters and industrial applications. The field of synergies and applications is therefore nearly boundless.

SVC PLUS: SYSTEM CONFIGURATION

Fig. 3 depicts the inside of an SVC PLUS system comprising control and protection system as well as cooling along with the converter equipment. The entire system has a modular structure and can be flexibly configured, what simplifies its standardization.

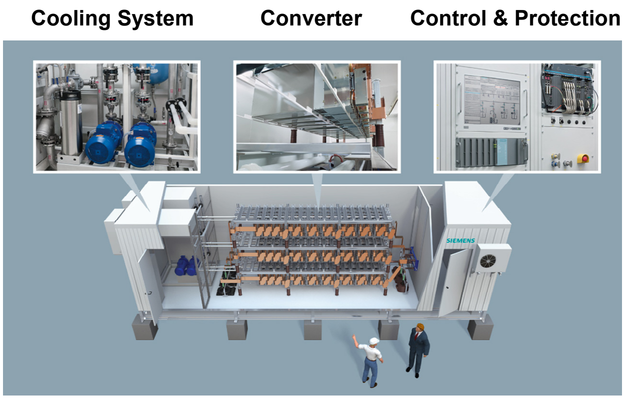

Fig. 3: SVC PLUS – A View of the Technology

Fig. 4 shows a converter module, arranged in an H-circuit of four power IGBTs including control interface ("PlusControl") and a large storage capacitor. The converter modules are interconnected to build the converter. A virtually sinus-shaped multilevel output voltage is to be seen as well. A virtually sinus-shaped multilevel output voltage is to be seen as well. Due to this configuration, the only type of filter required for the SVC PLUS system is a high-frequency band-elimination filter which is a matter of significantly less time and cost as in the case of conventional SVC technology.

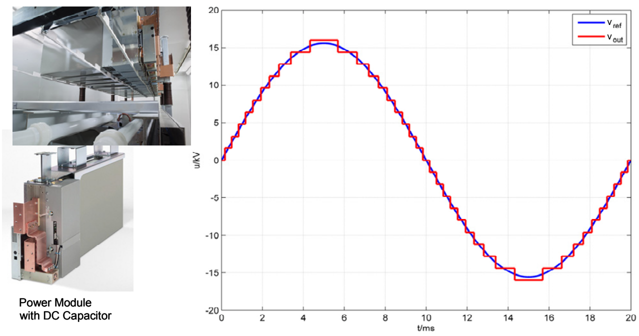

Fig. 4: A converter module including a control interface and a capacitor (right) as well as multilevel output voltage of the SVC Plus equipment.

Due to this configuration, the only type of filter required for the SVC Plus system is a high-frequency band-elimination filter which is a matter of significantly less time and cost as in the case of conventional SVC technology. The total configuration is also much more compact and normally occupies over 50 % less space than a conventional SVC system, ref. to **Fig. 5**.

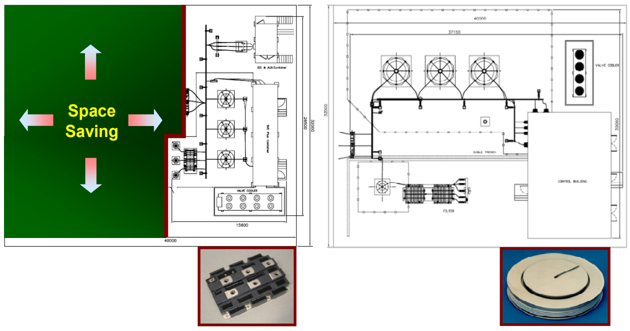

Fig. 5: SVC PLUS (left) vs. SVC "Classic"– Example of Space Savings with each System at 50 MVAr

Fig. 6 illustrates the power quality of an SVC PLUS system in comparison with the classic SVC technology. This state-of-the-art technology makes it possible to easily comply with all the known utility regulations (Grid Codes) in terms of integration of wind power plants as well as grid support.

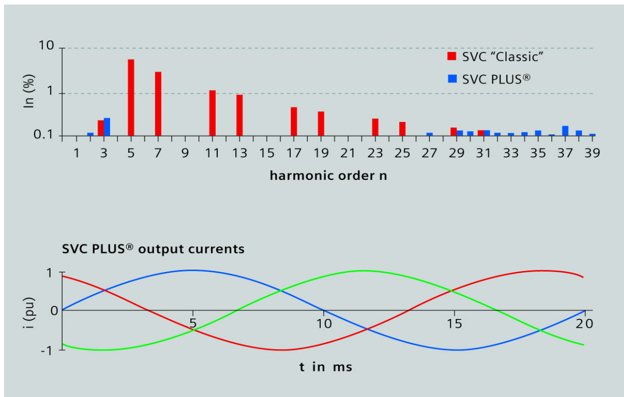

Fig. 6 Harmonics when using an SVC PLUS system compared with "Classic" SVC technology.

Simplified diagrams of both classic SVC and SVC PLUS technology are compared in **Fig. 7**.

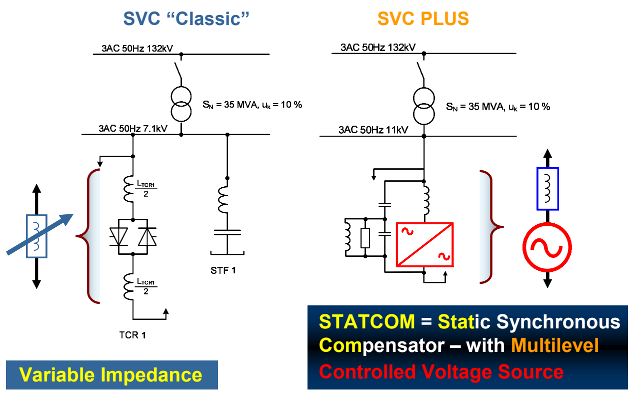

Fig. 7: Single Line Diagram of SVC PLUS in Comparison with SVC "Classic"

While the classic SVC technology makes use of thyristor-controlled and/or thyristor-switched reactors or, under certain circumstances, in combination with thyristor-switched capacitors, in the case of the SVC PLUS, the multilevel converted together with corresponding converter reactors carry out the control.

Converter Control

The converter control respects two principles: Only one module is switched at a time and no change directly from the Plus into the Minus state and vice-versa is done in regular operation. As a consequence, the voltage steps in the converter voltage are limited to the capacitor voltage of a single module. This has immediate advantages from the point of view of equipment design, as high voltage steps combined to the parasitic capacitances of the converter and its connections increases insulation stresses and electromagnetic interference.

The second consequence is that building the converter voltage by small voltage steps and high equivalent switching frequency results in a clean wave form. The MMC technology allows an equivalent switching frequency of several kilohertz, while the individual switching frequency of each module is kept small, e.g. below 200 Hz.

This can be see in the upper oscillogram shown in **Fig. 8**. The small individual switching frequency of the modules follows to a reduction of the overall switching losses of the converter.

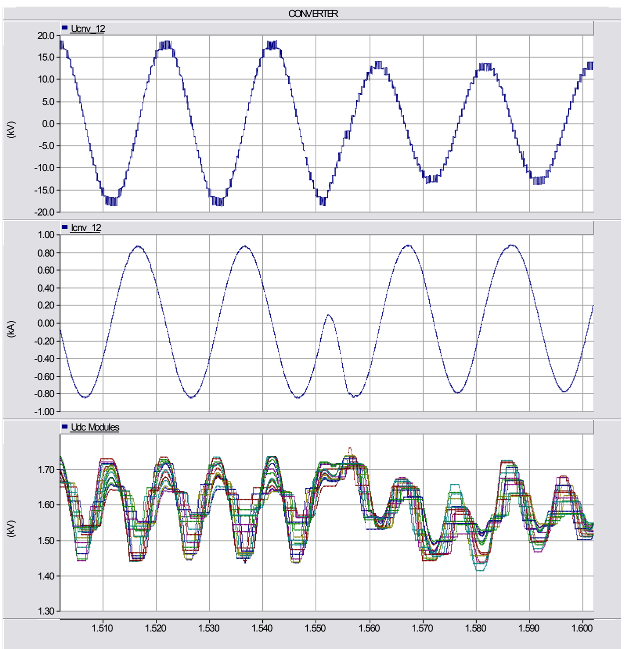

Fig. 8: Converter Voltage, Converter Current and Capacitor Voltage at the Modules of one Phase A

The second trace shows the converter current. The current distortion caused by the voltage steps cannot be seen at the trace and is negligible. The small high frequency content is removed by a small noise filter.

The figure shows a very fast step response on the current order change from +0.5 pu (capacitive operation) to -0.5 pu (inductive operation).

The third oscillogram depicts the voltage at each module capacitor of phase A. The control has the task to select which module will be switched at each time, in order to keep the capacitor voltage of the modules inside a suitable range.

CONCLUSION

Due to its compactness and fast response, the STATCOM presented here has been preferred in several projects with classical SVC applications like network voltage support and for grid access in connection to large wind parks. Due to its short reaction time, it promises to offer improvements for the reduction the flicker effect caused for instance by arc furnaces, for which it has been already preferred as well. But the MMC output voltage is not limited to a sinus and presents high resolution due to the achieved switching frequency. This makes possible to extend the benefits of the MMC to the mitigation of harmonics in the network.

The paper extends the discussion on characteristics and applications of the MMC technology for FACTS.

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