Current status and development VSC-based HVDC technologies in power system of Russian Federation

A.DROZDOV **A.KISELEV** **O.SUSLOVA**
Ltd. «SPC Saurus Energo» **Ltd. «SPC Saurus Energo»** **JSC «STC UPS»**
Russian Federation

SUMMARY

VSC based HVDC System already widely used in electric power systems all over the world. In Russia scientific research and engineering works on creation of basic elements, systems and prospective technologies for VSC based DC Transmission System and STATCOM was started in 2003-2006. This paper provides a description of VSC projects which were held in Russian power system and its impact on system unavailability is also described. The major challenges and technical difficulties facing developers are analyzed. Priority aims regarding the future development of these applications in Russia and potential application fields are given.

One of the areas of R&D works was the development of reactive power compensator STATCOM, as a basic element for the development of VSC technology. From 2006 to 2010 series of works on design, development and implementation of STATCOM at Vyborg converter substation were carried out. The obtained experience in theoretical research, engineering, base technologies, equipment development and testing allowed to start developing of more complex projects of VSC based HVDC technology in the power range up to 200 MW.

At the end of August 2014 during the commissioning of Mogocha back-to-back VSC transmission test of one of two parallel VSC link was fulfilled. At the time when the back-to-back Mogocha interconnection was conceived, there were no electrical interconnections between the Far East and Siberia power grids. For the first time in the history Russian power system from Kaliningrad to Vladivostok has been fully connected and operated in "integrated" mode. AC networks to which Mogocha back-to-back VSC is connected, are characterized by low short-circuit ratio, prevailing traction load of the Trans-Baikal Railway and significant deviations of electric power quality. NPC VSC with 3 level topology occurred to be the best solution in relevant unique and adverse electrical conditions due to its dc voltage balancing abilities and independent control of active and reactive power. The most challenging task was to design a high voltage valve with series IGBT connection. Special bench test were carry out to proof a capability of design to withstand short circuit current through DC capacitor and IGBT valve. Complete control system was carefully tested through

A.Drozdov@saurus.ru

physical simulator in all modes of back-to-back operation. For future algorithms elaboration special digital simulation platform was developed and realized in HDL on high performance FPGA with time step 200ns. Considerable R&D progress in VSC equipment, IGBT valve design and advancements in testing technologies allows implementation of different HVDC projects in wide power range.

Nevertheless VSC-based HVDC technologies haven't yet been widespread in Russia. This can be explained by the fact that power grid interconnections are provided by powerful AC grid 330-750kV and due to absence of regions with distinct disproportion in power generation and consumption.

One of the possible future applications of VSC-based HVDC technologies is electrical power supply for small energy systems, which are isolated from Unified power system of Russia, located in the Russia's Far North and Far East, such as Yakutia, Chukotka, Magadan, Kamchatka and Sakhalin AC networks, Norilsk-Taimyr network. Another possible application area is power supply of cities (for example, Moscow) for increasing of reliability and short circuit current limitation.

KEYWORDS

VSC, STATCOM, Back-To-Back, Mogocha, Unified power system of Russia, short circuit current limitation, testing, commissioning

1.INTRODUCTION

HVDC transmission technologies have been widely developed and applied all over the world. In Russia R&D works for FACTS and equipment for FACTS was launched in 2003-2006. A series of static voltage compensators (SVC) and controlled shunt reactors (CSR) were commissioned into operation. The Russian's first CTATCOM demonstration project was developed from 2006 to 2010 and was commissioned into operation at Vyborg converter substation. Development was carried out in All-Union Electric Power Research Institute (VNIIE) under the leadership of Professor Valery Kochkin.

Full R&D cycle, including calculations of steady-state and transient processes, development and tasting of power equipment, control systems was organized. The obtained experience in theoretical research, engineering, base technologies, equipment development and testing and well established team allowed to start developing of more complex projects of VSC based HVDC technology in the power range up to 200 MW.

Mogocha VSC-based back-to-back for Trans-Baikal converter substation was developed from 2010 to 2013. Integrated testing of the equipment and commissioning were successfully completed in 2014-2015.

2.VYBORG STATCOM OPERATION HISTORY

The Vyborg back-to-back HVDC link, providing the asynchronous connection between power networks of Russia (330 kV AC voltage) and Finland (400 kV AC voltage), is in operation since 1981, consists of four parallel High Voltage Converter Unit (HVCU), each Unit has rated transmission capacity of 355 MW [1,2]. The first Russian's IGBT based STATCOM demonstration project was commissioned into operation at Vyborg substation in 2010. Its purpose was to provide reactive power and dynamic voltage support during transients in power grids of Russia and Finland.

The main objective for Vyborg STATCOM demonstration project was the accumulation of operating experience, regarding both reliability of the power equipment and its impact on the electrical networks. Besides it, STATCOM was considered as the basic unit for future FACTS.

STATCOM has 18 IGBT valves arranged in a three-level circuit topology, two series-connected capacitor banks on the DC side, three phase reactors, single-loop liquid valve cooling system, digital control and protection system, high-frequency broadband filter. The microprocessor control and protection system was designed and tested using the physical simulator. The IGBTs used in valves have a voltage rating of 2.5 kV, current rating of 4 kA. STATCOM has a rated dynamic reactive capacity of ±50 Mvar, AC line voltage rating of 15.75 kV and RMS phase current of 1840 A at nominal rating.

STATCOM system testing was performed in December 2011. The commissioning program included opetation with AC network having voltage rating of 11 kV and 15.75 kV. Typical tests were performed during converter operation: energization of the DC equipment, check that the DC voltage is controlled to its reference voltage, check hardware and software protection functions for DC voltage equipment. Load tests were performed for both generation and consumption modes. Performances of overcurrent valve protection, operation of cooling systems were checked. Tests were performed in manual control mode and automatic control mode both from automatic control system and Power Flow Controllers of converter substation. STATCOM dynamic performances were tested under operation in parallel with synchronous compensator. Transient time from consumption to generation mode and backwards was 0.2 s. Current harmonics were measured during 72 hours for various operation modes of STATCOM. The magnitudes of the current harmonics injected into AC grid 400 kV were evaluated.

System tests showed that STATCOM can be effectively used as a high-speed device for reactive power and voltage control together with the synchronous compensators, installed at the substation. However during 1st year of operation STATCOM showed bad reliability. The main problem was IGBT valves, which have low EMI noise immunity. Due to this drawback a lot of IGBT failed. In 2012 STATCOM was in operation for 2736 hours, there have been three forced outages: due to the faults in IGBT valve, to the failure in the cooling system of valves, and due to tripping of protection of DC side equipment. In order to improve the reliability of the equipment it was suggested to reduce the operational voltage from 15.75kV to 11 kV and after that failures of IGBT came to acceptable level.

3. MOGOCHA BACK-TO-BACK VSC

Mogocha back-to-back VSC was developed by a team of Russian scientists and engineers. This project embodies modern trends of VSC-based HVDC technologies, which are now widely used in the world. Full cycle of development (R&D), shipping, factory and system tests was fulfilled by Russian engineers.

Mogocha back-to-back VSC interconnects the Far East and Siberia power grids, nominal AC voltage 220 kV. Complete DC system, which is rated 240 MVA, consists of two parallel VSC links, nominal active power 200 MW. In the Mogocha VSC the IGBT valves are arranged in a three-phase three-level bridge, with converter transformer 220/38.5 kV.

Power link 220 kV Holbon - Mogocha - Skovorodino, interconnecting two power grids, is distant from the major power stations over a distance of 700 km and has a prevailing traction load of the Trans-Baikal railway. Consequently, AC networks to which back-to-back VSC is connected, are characterized by low short-circuit ratio and significant deviations of electric power quality. The presence of the back-to-back VSC has stabilized voltage at each interconnection point without additional means of reactive power compensation (Fig. 1).

A particularly important aspect is the possibility of voltage balancing. Electricity consumer with motor load, in particular oil pumping stations, located along power transit, have problems in operation of their equipment. Unbalanced and non-sinusoidal voltage leads to increased engine heating and wearing, interrupting the process at any tripping event. By using of voltage balancing algorithms in control system of back-to-back VSC Mogocha, it was possible to improve significantly the quality of voltage, which was noted by the main consumers. Results of commissioning tests has shown good transient behaviour of VCS during reclosure cycles (Fig.2), short-circuits in AC systems 220 kV, extremely unsymmetrical modes.

At the present moment works on relay protection and emergency control schemes of Power link 220 kV Holbon – Mogocha- Skovorodino for back-to-back mode are finalizing. The converters operate as VAR compensators and provide the AC voltage balance.

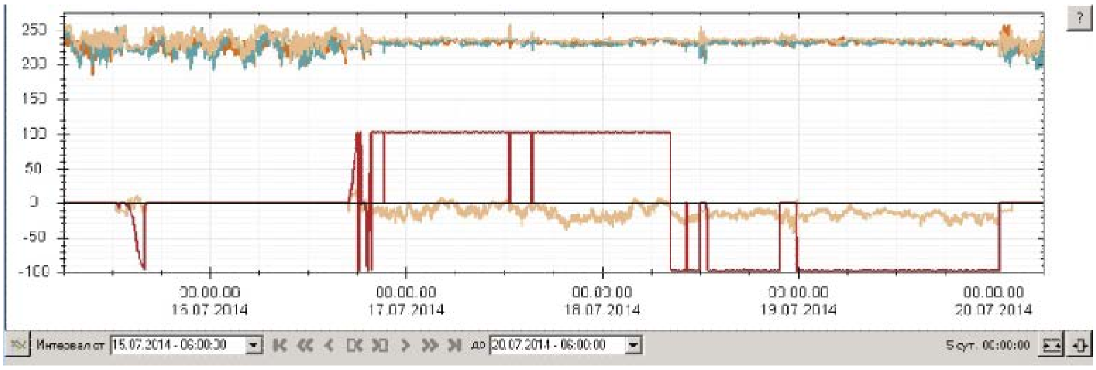

Figure 1 – Commision tests 72 hours, back-to-back operates in circular mode (top – RMS voltage 220 kV bus Uab,Ubc,Uca , bottom – red - P (MW) , yeallow –Q (Mvar)

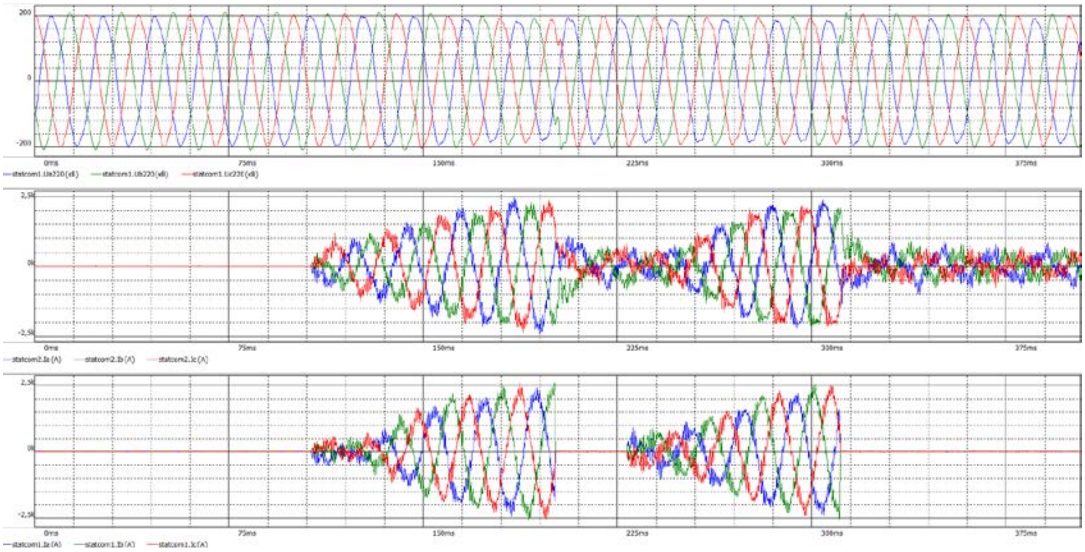

Figure 2 – Back-to-back behavior during reclosure cycle in circular mode, current protection setting of VSC1 reduced to 2.5 kA: top – phase voltage 220 kV Ua, Ub, Uc; middle – VSC2 phase currents; bottom – VSC1 phase currents

4. RESEARCHES AND DEVELOPMENT OF VSC EQUIPMENT

4.1. High voltage IGBT valve development

Before the development of converter equipment for Mogocha back-to-back HVDC was started, the maintenance and operation experience of VSC STATCOM, which is installed at Vyborg substation, were carefully studied. Based on this information the control system and IGBT drivers were drastically reworked. The control system was specially developed in modular type and provided a unified platform for control and protection for different types of high voltage converters, such as LCC, MMC, 3L-VSC and SVC. The latest advances in DSP and FPGA techniques was applied and implemented in the platform. This gives ultimate performance and exceptional reliability to create, debug, and run any algorithms in real-time mode. For Mogocha back-to-back it was developed and produced the set of 25 cubicles connected with each other with fiber optic. The control system is redundant – only one system active, while the other one is in “hot standby”. The control and valve protection system made with triple redundancy.

IGBT drivers were specially developed to have a high immunity to EMI. It supplied with power from a single IGBT cell when a voltage applied to IGBT valve. An intelligence system realized in drivers provides uniform distribution of voltage across valve IGBT cells in steady state and during transients. Data exchange between drivers and control unit based on fiber optic. Bandwidth of fiber channels and high speed data processing in valve control and protection unit allows commutate valve safely even if short circuit current through valve and DC capacitor occurred.

4.2 VSC equipment testing

When designing and developing of Mogocha VSC back-to-back special attention was paid to the testing equipment. A series of bench testing units for standard and factory tests of drivers, IGBT valves, assembled equipment and control and protection system were developed.

The entire amount of standard and factory tests of VSC equipment defined in IEC 62501 has been carefully analyzed and arranged as follows:

- bench tests of individual transistor cell, including testing of the dielectric strength, control the on /off functioning of transistor cell in both directions, as well as testing the proper functioning and parameters of control circuits, protection and alarm systems;
- assembly control of high voltage transistor valve (IGBT valve);
- hydraulic tests of IGBT valve;
- static high-voltage tests of IGBT valve;
- surge tests of IGBT valve;
- stress tests of IGBT valve;
- testing of valve device assembly.

Complete testing of developed control system was fulfilled to confirm all new technical solutions. All modules passed through series of factory tests and then everything was assambled and integarted in lab as in real project for full scale testing. For this purpose special bench testing unit containing the three-phase physical simulator of the VSC link, model of the adjacent AC grids and control panel were developed for full scale testing of control system. IGBT drivers of simulator were adapted for connection to the control system using fiber optics. Full cycle testing included analog measurment, control calculation and pulse firing were made on simualtor with scale 1 : 100.

4.3 Development of MMC technology

In some application fields the MMC technology has technical advantages. For carrying out rapid implementation of the MMC projects control system was developed and tested with physical simulator of the MMC [3]. Control system of MMC is based on the same hardware platform as back-to-back VSC and thus can be enlarged without restriction on protection or control.

Another field of concern is the development of real time digital simulators for MMC simulation. Digital simulator has advantages compared with physical simulators: lower cost, less development time, flexibility and more opportunities for implementation of operation modes of the converter and the adjacent networks. This simulator can be used both at the design stage and at the trial or commercial operation stages.

Digital model of the MMC with adjacent power grid was developed firstly in math equations and then realized on high performance FPGA in HDL. The experiments showed similar values in results obtained both on physical and digital models.

5. POTENTIAL APPLICATIONS OF VSC-BASED HVDC IN RUSSIA

5.1 General description of Russian Unified Power System

Russian Unified Power System (UPS) consists of 7 regional united power grids - Siberia, Ural, Mid-Volga, South, Central and North-West, which are interconnected with 220 – 750 kV overhead lines and East power grid.

In Russia there are a few isolated AC networks: Norilsk-Taimyr Power network, located in the Russia's Far North on the Taimyr half island, several power networks located on the Far East: Chukotka, Magadan, Kamchatka and Sakhalin AC networks. There are some regions with low energy consumption located on the Far East and Siberia, having no central power supply.

Up to the present moment East power grid had no electrical interconnection with other power grids. Configuration of electrical network and location of generating sources in eastern part of Siberia power grid make impossible parallel synchronous operation of Siberia and East power grids.

AC network of Trans-Baikal area, located on eastern part of Siberia, is deficient, which impedes the full industrial development of the region, in particular the mining and metallurgical manufactures. Neighboring Amur AC network (East power grid) has energy surplus almost 2.5GW. Consumption does not exceed 1.5 GW, while the installed capacity of the Amur region is almost 4 GW.

Interconnection of East and Siberia power grids is necessary measure for increasing reliability of energy supply of Trans-Baikal railway and other consumes in Trans-Baikal and Amur region, providing technological connection of new consumers, enabling participation of economic agents of East power grid in total Russian wholesale electricity market. VSC Mogocha project is first step to interconnection of East and Siberia power grids.

5.2. Back-to-back VSC link Hani

Next step in the development of the VSC-based HVDC technologies is creation of back-to-back VSC on the northern power link between the Far East and Siberia power grids at Substation 220 kV Hani. The aim of this project is increasing reliability and transmission capacity of DC link connecting East and Siberia power grids. Power link is located along the Baikal-Amur Railway and the network parameters are similar to those at Mogocha. Thus, the preferred option is VSC back-to-back. Commissioning of VSC Hani is planned in 2019.

5.3. Power supply of isolated and passive AC networks

It was mentioned above that in Russia there are a few isolated AC networks located in Far East and Siberia where the cost of fuel delivery is very high. At the present time some options for connection of isolated AC networks to UPS of Russia are considering.

In particular, the connection of Norilsk-Taimyr power system to Siberia power grid in order to increase reliability of power supply, stimulate the development of new minefields and the construction of mining and processing plant, the development of social infrastructure is under study. Projects of long power transmission lines from the Kolyma hydroelectric power station in Magadan region for the power supply of Chukotka are also analyzing. Among the studied options for these purposes - cable and overhead HVDC power transmission using VSC technology.

5.4. Application of VSC-based HVDC technologies in networks of cities for increasing of reliability of power supply and short circuit current limitation

In electrical network of Moscow city there is a problem of limiting short-circuit current. One of the widely used measure for short-circuit currents limitation is sectionalizing of power system, which may cause malfunctions of the power supply as showed blackout in Moscow in 2005.One of the possible measures is power system sectionalizing with use of HVDC. In urban areas with lack of free territory design driver is substation overall dimension, which is key factor to select the modular multilevel VSC.

Researches performed by the Moscow institute "Energosetproject" have shown that installation of the back-to-backs with total capacity of 2000 MW at four points of Moscow power grid 220 kV and current-limiting device 40 ohms at 500 kV Substation Beskudnikovo will reduce the levels of short circuit currents to values not exceeding 63 kA. In this case Moscow power grid 220 kV will be split into three parts, interconnected with controlled HVDC back-to-back.

Without the use of current-limiting device at 500 kV Substation Beskudnikovo the problem of limitation of short circuit currents may be solved effectively by installation of the back-to-backs with total capacity of 2400 MW at five point of Moscow power grid 220 kV. In this case Moscow power grid 220 kV will be split into four parts, interconnected with controlled HVDC back-to-back.

CONCLUSION

The Mogocha Back-To-Back VSC HVDC allows to exchange power between isolated energy system of Siberia and East. It becomes the first HVDC installation based on VSC in Russian’s power grid. A lot of efforts were made by Russian scientists and engineers to bring this, relatively unique technology, to life. The main challenging task to create reliable IGBT valve with series IGBT connection was successfully accomplished. This task required creation of modular high performance redundant control and protection system which provides the platform for future VSC MMC applications.

Extensive tests and investigations in HVDC VSC technology continue to run in parallel with researches on impact of this technology on power grid, especially in proper coordination of conventional AC relay protections and HVDC protection. Current status of those development shows, that existing challenges have a great impact on total project cost and time. Some new projects still in feasibility study, and while the total cost of HVDC equipment continue to decline, the necessity to take into consideration technical and economic aspects for power grid companies, is challenging task.

BIBLIOGRAPHY

[1] G. Tsfasman, A.Mazurenko, A. Mordcovich, A.Tarasov, E.Zmaznof and others. New integrated control and protection system for Vyborg back-to-back YVDC link. Cigre 2008, paper B4-102, Aug.2008, Paris

[2] Static reactive power compensators for electric networks. Collection of articles. Edited by Kochkin V.I. Moscow, Alex-KM, 2010.

[3] Drozdov A, Kiselev A, Matinyan A. MMC application for power quality improvement in PPC with unbalanced varying load, ELECTRO № 1/2014