21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

B4-308

CIGRE 2018

Operation experience of back-to-back HVDC station based on voltage source converters for interconnection of non-synchronous power systems with significant voltage distortion.

A. DROZDOV, A. KISELEV
SAURUS ENERGO LLC
Russia

I.A. KOSOLAPOV, Yu.G. SHAKARIAN, M.V. PESHKOV, Yu.A. DEMENTIEV
Research and Development Center of the Federal Grid Company of the Unified Energy System Joint-Stock Company
Russia

SUMMARY

This paper presents the main results after first years of operation of the voltage source back-to-back HVDC converters located at the Mogocha substation. The converters connect unsynchronized energy systems of East- and Siberia in Russia at 220 kV Mogocha substation. Investigations were made and resulting data on characteristics of neighboring 220 kV power networks, the features of their operation and influence caused by electrical load consumers are described. The analysis of significant deviations in neighboring power grids 220 kV is made and the results of implementation and operation of specified control algorithms adapted to real operating conditions are shown, as well as limitations of HVDC VSC arising when there are significant deviations in electric power quality. Different graphs showing behavior of special algorithms for control, protection and automation under real operating conditions of power system are shown. Recommendations are given on the maintenance of HVDC and protection settings and general questions on harmonization of mutual influence of powerful electricity load from consumer's side and range of reliable operation of HVDC.

KEYWORDS

Back-to-back HVDC converter, VSC operation, negative voltage sequence, IGBT pulses deblocking.

a.drozdov@saurus.ru

CHARACTERISTIC OF NEIGHBORING POWER SYSTEMS.

The electrical power systems of East and Siberia operate independently. The electrification at point of systems division is done by two-circuit 220 kV OHL called Kholbon-Mogocha-Skovorodino and has a length of more than 1000 km. The connection is mainly used for electrification of Trans-Baikal railway, oil and gas transmission systems and other local consumers. The high and regular unbalances between voltages caused by low short-circuit ratio and mainly by single phase load of neighboring railroad, causes restrictions in power supply and large number of emergency shutdowns of equipment.
There is only two nearest power station from Siberia side which are Kharanorskaya and Chita thermal power plants at a distance about 600 km . From Far East side nearest power plant are Neryungrinskaya station and power plants of the Amur power system at a distance about 500 km. There are no intermediate generating sources with a sufficient power in region of back-to-back HVDC converter installation. The East side includes three 220 kV substations and 17 intermediate substations, connected to each other by successive sections of 220 kV overhead lines.
Reliability of power supply of consumers, receiving electricity from this power transmission is insufficient due to the forced division of power transmission into two independent parts. One part of the power transmission is connected with the grid in Siberia, and the second with the energy system of the East.
Parallel operation of these two systems is impossible because of the low margin of static stability, which leads to the appearance of the asynchronous process, if the rate of irregular fluctuations in the electrical load increases more then 150-200 MW.
Division of power transmission connecting energy systems of Siberia and East is carried out at a certain base station. In the case of dividing the power at the substation 220 kV Mogocha when outputting in the repair of any 220 kV lines, emergency shutdown of any of the lines leads to the interruption of the energy supply from one to 12 substations in the section Kholbon – Mogocha and from one to 8 substations at section Mogocha – Skovorodino.
Prior to the construction of HVDC back-to-back the power systems operated in isolation from each other, so it was not possible to provide reliable electricity supply of traction substations and oil/gas pumping stations.
To improve the reliability and quality of power supply of consumers located on the border of two energy systems, it was decided to realize interconnection of power systems of Siberia and East of the existing 220-kV lines by asynchronous connection technology of HVDC with rated power 200 MW. (Figure 1).

Figure 1 – Location of back-to-back HVDC converter substation

DESCRIPTION OF HVDC BACK-TO-BACK AT 220 kV MOGOCHA SUBSTATION.

Installation of HVDC back-to-back at Mogocha substation is the first HVDC project in Russia since 30 years and it has great significance for electrical industry in Russia due to unique operating conditions of neighboring power grids[1]. After successful commissioning it was put into trial operation for the first time in Russia in 2014 year.
There are two back-to-back HVDC converter blocks, each installed in separated building. Back-to-back has two voltage source converter units which are connected to each over by a common DC bus. The capacity of each block is 120 MVA, resulting into total installed capacity of 480 MVA. VSC units are connected to the 220kV power grid through 4 transformers 220kV/38.5kV and splitting busbars 220 kV. AC-side filters, phase reactors, capacitors on DC side, control and protection system and other auxiliary subsystems, shown in Fig. 1. Voltage source converters has a three-level topology with high-voltage IGBT valves controlled by PWM through fiber optic channel and powered by voltage from valve level. In addition to operation in back-to-back mode, each VSC unit can operate in STATCOM mode with ± 66.6 MVAr. This mode makes it possible to use the VSC during power grid maintenance period as a stabilizer of voltage levels with a total power of ± 266 MVar.
The change in direction and magnitude of transmitted power in the emergency power control (EPC) mode can be done in 0.15 s.

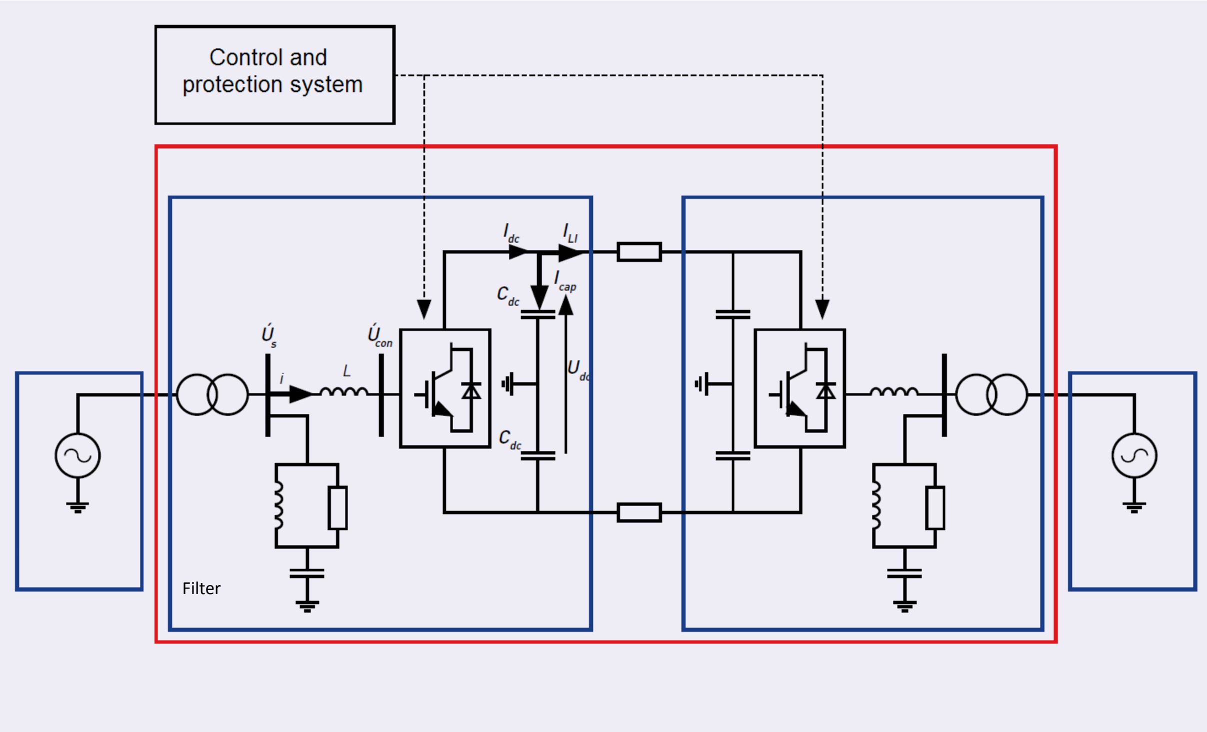

Figure 2 – Schematic diagram of back-to-back HVDC converter

RELIABILITY STUDY OF HVDC OPERATION.

The operation experience has shown that a high impact on the HVDC converter reliability is caused by the power quality of the AC grid. Due to the traction load of the railway system, the rated values for power quality parameters are significantly exceeded.. At the point of common coupling (PCC) the negative phase sequence voltage V_2 reaches 17%, and voltage deviations reach 19%. The values of total harmonic distortion (THD) of voltage K_U reach 20%. The increase of freight traffic and the power demand of electric locomotives, decreased the power quality even further. Long-term operation modes of the network were detected with an excess of total harmonic distortion (THD) in one phase up to 30%. Additionally, frequent voltage dips, associated with the railway operation and AC grid trips in spring-summer period due to thunderstorm activity.

An example of disconnection of HVDC associated with deterioration of power quality is shown in Fig. 3 and Fig. 4. According to the trend data (Fig. 3) operation mode of 220kV network changed dramatically at 03:16. During almost 2 hours period significant voltage deviations and asymmetry were observed. Addition, in this operating period, a significant distortion of sinusoidal voltage of the 3rd harmonic was also seen in the network. Fig. 4 shows scope data of phase-to-ground voltages on 220 kV buses on substation from the Far East and their analysis. The third harmonic in phase B reaches 41%.

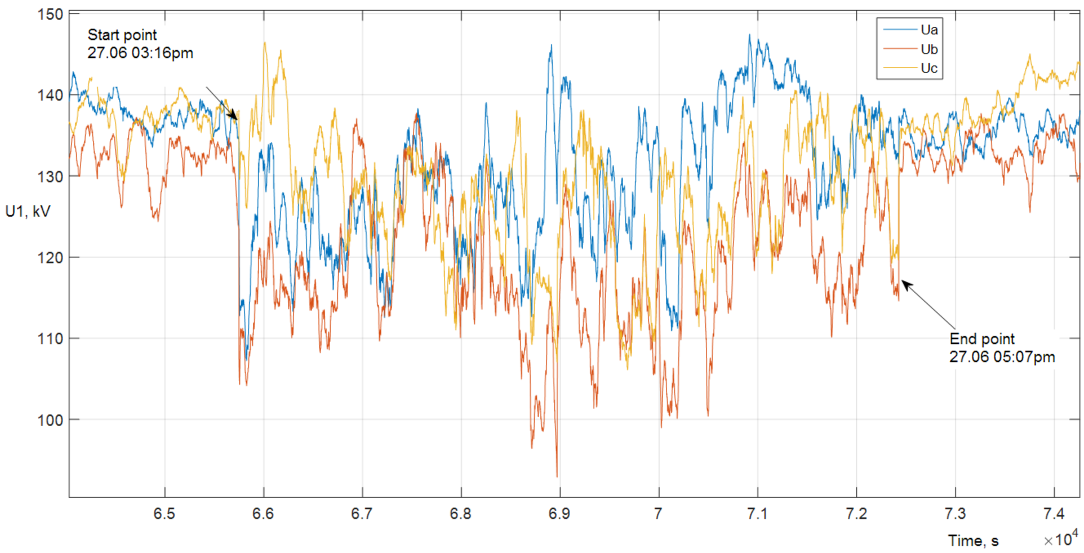

Figure 3 – High deviations of the phase-to ground voltages (rms) in 220 kV grid during a 2 hours period.

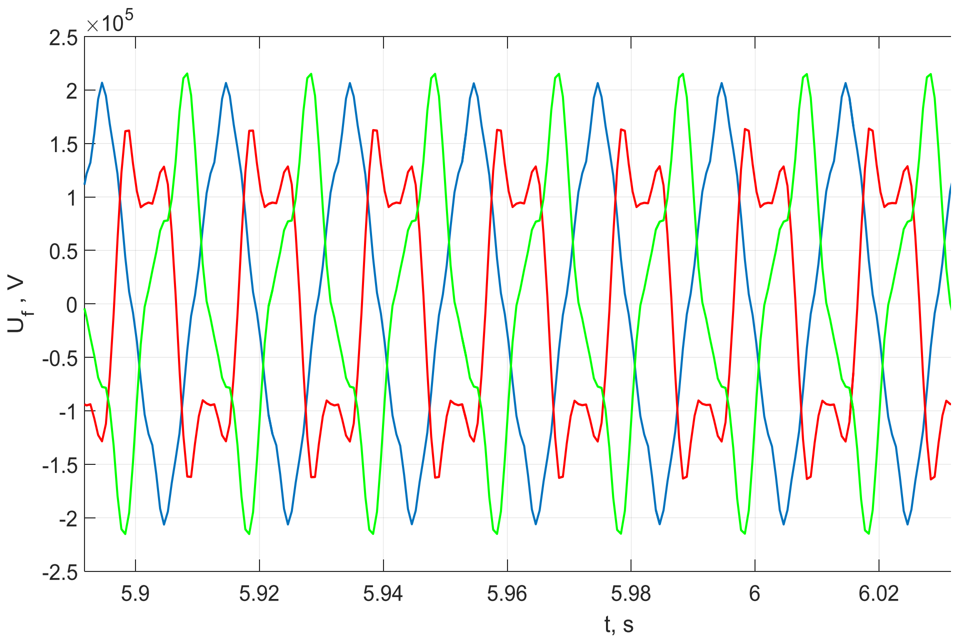

Figure 4 – Phase voltages on 220 kV lines, 3rd harmonic reaches 41%.

To increase the reliability of HVDC operation in prevailing conditions of the AC network operation and to prevent converter protection, additional studies were performed. Based on the study results an enhancement of control and protection algorithms and automatic converter deblocking were implemented. Additionally, a limitation function of HVDC in case of significant harmonics and asymmetry in 220kV network were specified.

ENHANCEMENT FOR HVDC CONTROL ALGORITHMS.

The basic control algorithms for HVDC converter were developed during the design stage. Changes were made to the software:

1. Enhancement and acceleration of software protection;
2. Introduction of 4 cycles of automatic converter deblocking;
3. Power limiting function based on measurements of currents magnitude;
4. Adaptive current control algorithms during converter deblocking;
5. Adaptive voltage balancing algorithm for DC capacitors.

Figure 5 shows a typical form of valve currents I_{valve} at a transmission power of 50 MW and generation of reactive power + 33MVAr which are non-sinusoidal due to harmonics. Calculated values of the current amplitudes are 1050 A for active current and 705 A for reactive, while the actual current amplitude value in phase C reaches 2500A. An increase in transmission power, increases the valve current to the protective value of the high-voltage IGBTs of 4000 A, causing a disconnection of the HVDC converter.

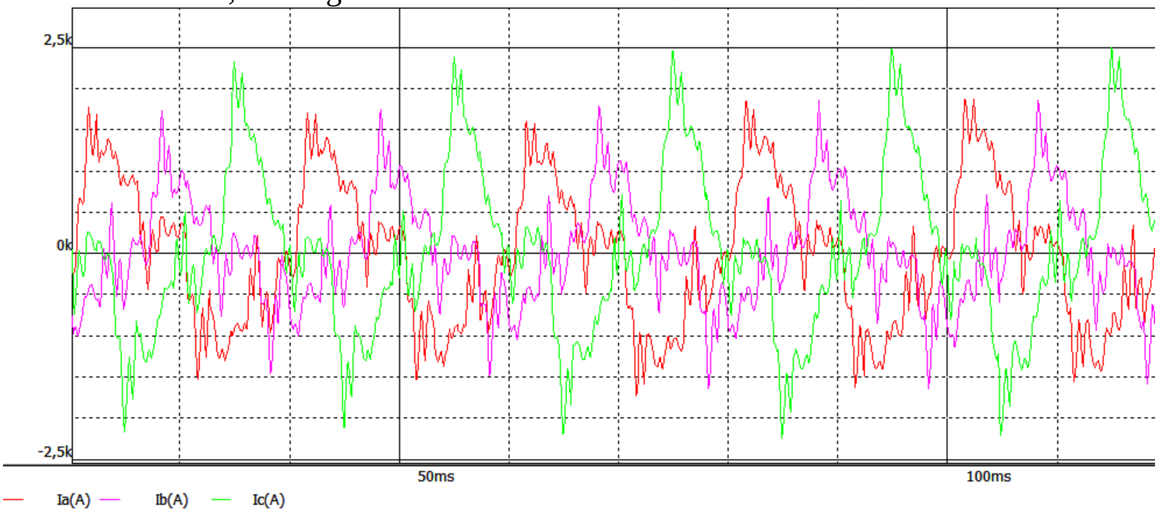

Figure 5 – Typical operation currents of 3-level VSC HVDC, caused by the presence of distortions in power grid (active power 50 MW).

In order to increase the reliability of HVDC operation in the described mode, a power limiting algorithm was developed. The algorithm is activated when the predefined threshold value of current amplitude is reached, which is 120% of rated current. This helps to take into account actual asymmetry and higher harmonics of the current. There are well known algorithms for collinear limitation of output currents and other sequential constraint algorithms. They have been investigated, but have not shown required efficiency. To take into account the dependence on various parameters: the actual voltage in 220 kV network, the direction of transmission of active power, the currents load in phases, an algorithm was proposed to limit active and reactive current realized in the form of tabular machine. The current limitation/de-energizing signal is generated by detecting the maximum amplitude of current in the phase for one period of power grid, acting on limitation of active and/or reactive current, taking into account rated voltage deviation for 220 kV lines.
Modifications were added to logic of operation of maximum-current protection, which takes

into account close-bye run-up of heavy electric locomotives. A “zero-cycle” for automatic of converter deblocking is introduced, the main purpose of which is a quick restart of IGBT control pulses after the operation of converter protection caused by a high distortion of AC grid voltage and subsequent transient process. It was determined, that such a transient process in AC network lasts for about 20 ms, but an appropriate control reaction during this transient event is not possible. The main task was to maximally quickly and reliably turn on VSC IGBT valve pulses, under consideration for actual voltage levels on DC capacitor bank and the quality of main voltage.

To coordinate the protection of HVDC with AC lines protections and automation devices, the scheme of operation of automatic deblocking of IGBT control pulses was extended, which in final implementation allowed 3 cycles of deblocking - the 1st stage of deblocking with a time of 0.4 s, 2nd stage of deblocking with a time of 4 s, the 3rd stage of deblocking with a time of 9 s. The deblocking algorithms recovery time is 2 sec.

During operation of HVDC, it was found that the average amount deblocking of IGBT valve pulses in normal power supply scheme is no more than 3 times a day. In repairing modes of operation in 220kV power network the amount of algorithms acting can reach 20-30 times a day, while the success of algorithm is close to 100%. The work of the 1st and 2nd stages of automatic IGBT deblocking is usually associated with the appearance of sudden dynamic changes in 220 kV network parameters, such as remote faults, no more than 1-2 times a day during the repair period, and about 1 time per week under normal operation.

CONCLUSION

The results of the first years of HVDC back-to-back operation on 220 kV Mogocha substation shows that despite of complex conditions in neighboring power grid, which worsened due to main consumers load increase, stable operation of HVDC based on 3-level VSC is possible. The benefits of using VSC for voltage level stabilization on 220kV grid allowed the disconnection of modular power supplies, which has been previously used as generators forming low voltage grid for railroad automatic interlock and auxiliary devices. Reliability of power supply for the traction substations of Transbaikalian section of the Trans-Siberian railway and the power quality improvements allowed the operation of heavy trains.

The increase of railway traffic has led to a significant change of loads. This change required a further research on capabilities of HVDC converter to ensure a stable operation under conditions of significant voltage deviations. The algorithms of HVDC operation were specified and implemented, taking into account limitations of existing equipment. This results in increased reliability of operation both in transmission and STATCOM mode. The power quality of electrical energy, including unbalance and harmonic distortion of 220 kV voltage, are significantly improved. In some special modes of operation of 220 kV grid, the power of HVDC is not sufficient to completely compensate distortion in the network. In these modes, power limitation algorithm works, implementation of which and other enhancement in control system software, increased the reliability of HVDC in actual prevailing operating conditions of the neighboring 220 kV networks.

BIBLIOGRAPHY

[1] A.Drozdov, A.Kiselev, O.Suslova. Current status and development VSC-based HVDC technologies in power system of Russian Federation. CIGRE HVDC AND POWER ELECTRONICS INTERNATIONAL COLLOQUIUM, Agra, India, 2015