

Functioning of back-to-back high voltage direct current link model in Tomsk electric power system

A P Maltsev, V E Rudnik, Y Yu Malkova and R A Ufa

School of Energy & Power Engineering, Tomsk Polytechnic University, Tomsk, Russia

E-mail: maltsevalexey@mail.ru

Abstract. In this article the research results of steady-state and dynamic performance of asynchronous back-to-back HVDC link in Tomsk electric power system are presented. It is proposed to use the back-to-back HVDC link to provide an asynchronous link for parallel operation of the North and South parts of Tomsk electric power system. The steady-state stability limit and maximum allowed power flow were defined. Based on this the more effective location and power of back-to-back HVDC link were determined. Therefore, it is shown the application of back-to-back HVDC link decreases the level of short-circuit current, power fluctuations and increases the stability of load operation, especially of motor load at substation.

1. Introduction

High-voltage direct current back-to-back link (back-to-back HVDC) based on static voltage converters with high-speed power fully-controlled semiconductor switches make it possible to effectively solve a number of urgent tasks in the electric power industry [1, 2]:

- integration of non-synchronous operating electric power systems (EPS) and their parts;
- DC power transmission;
- limiting short-circuit currents in the combined EPS and their parts;
- damping of low-frequency oscillations in an EPS and the solution of the related problem of oscillatory stability of the EPS operation.

According to the CIGRE report (Conseil International des Grands Réseaux Electriques – International Council for Large High-Voltage Electrical Systems), 15 back-to-back HVDC link are designed and already in operation, including two projects planned for implementation in Russian EPS [3].

The features and specifics of the functioning of these means significantly change and complicate the processes in the equipment and the dynamic properties of the EPS, respectively, the operating conditions of power equipment, relay protection and emergency automation system. So, the complete and reliable information about these processes is required to provide safety and effective operation of such modern EPS. Due to the inadmissibility of field experiments and the impossibility, due to the complexity of modern EPS, of their adequate physical modeling, the only way to obtain this information is mainly mathematical modeling.

2. Experimental studies of asynchronous back-to-back HVDC link

These studies were conducted on the example of Tomsk EPS (Figure 1). There are two asynchronous operated part of Tomsk EPS – North and South parts. The dividing point is located along the 220 kV transit: Substation (SS) Tomskaya (UES of Siberia) - SS Volodino - PS Parabel - PS Sovetsko-Sosninskaya - Nizhnevartovskaya power plant (UES of the Urals) about 800 km long [3].



In the northern part there are one of the largest load nodes - oil producing companies, in the southern part - one of the main sources of generation. If two parts of the Tomsk region are merged, it will increase the level of reliability in the electric power system, as well as increase the level of energy efficiency [3].

Operational switchings always leads to temporary shutdown of some consumers, and since the share of synchronous motors is large, a non-synchronous activation of the load node is impossible [2, 4].

The process of choosing the power and effective location of the back-to-back HVDC link is required to determine the following parameters:

- the value of the maximum possible emergency unbalance formed by the shutdown of large power units at the station or power lines;
- the value of the maximum permissible flow (MPF) in a controlled section.

The disconnection of a large unit in Tomsk EES is laid in the MPF Krasnoyarsk-Kuzbass-Tomsk and will not affect the power flow for the considered transit [3].

Accordingly, the installed power of the back-to-back HVDC link will depend on the magnitude of the power flow from the UPS of the Urals to the UPS of Siberia, and vice versa, taking into account the communication MPF and the power of the loads of the transit substations [3].

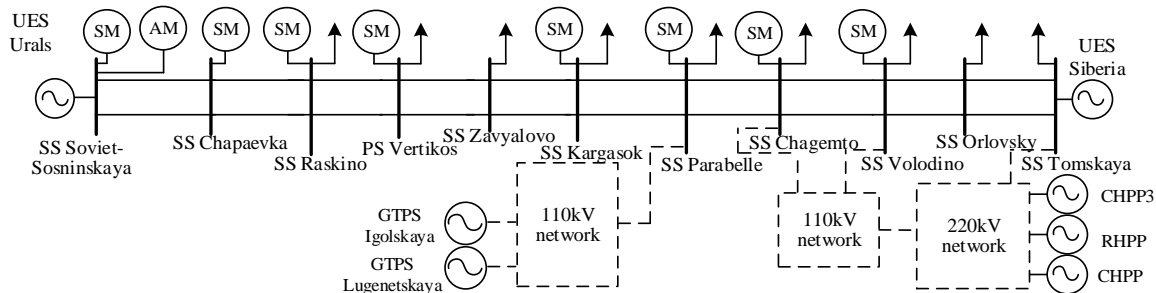


Figure 1. Test scheme of the power system of the Tomsk region: CHPP – Central Heating and Power Plant, RHPP – regional hydroelectric power plant, AM – asynchronous motor, SM – synchronous motor, GTPS – gas turbine power station.

1) Calculate the power of back-to-back HVDC link on Ss Parabel.

Define the MPF transit head sections:

- for Power lines (PL) 220 kV Nizhnevartovsk regional hydroelectric power plant - Ss Sovetsko-Sosninskaya for a normal scheme $P_{p1} = 247$ MW (determined by ECL criterion (emergency current load) PL 220 kV Nizhnevartovsk regional hydroelectric power plant - Ss Sovetsko-Sosninskaya I or II PFM circuit (post-emergency mode) PL 220 kV Nizhnevartovsk regional hydroelectric power plant - Soviet-Sosninskaya II or I chain);

- for Power lines (PL) 220 kV Ss Tomskaya - Ss Volodino for a normal scheme $P_{p2} = 204$ MW (determined by the criterion ECL PL 220 kV Tomskaya - Volodino with a tap on the Orlovka Ss I (II) circuit PEM PL 220 kV Tomskaya - Volodino with tap on Ss Orlovka II (I) chain);

Determination of load power:

- Consumption of the electric network from Ss Sovetsko-Sosninskaya to Ss Kargasok is $P_{n1} = 200$ MW;

- Consumption of the electric network from Ss Tomsk to SS Parabel is $P_{n2} = 170$ MW. At the same time, the total generation of gas turbine power plants averages 50 MW;

The required power of the back-to-back HVDC can be:

- to ensure the flow of active power from Ss 220 Kargasok towards Ss Parabel (from the Ural UES to the UES of Siberia): $P_{\text{back-to-back HVDC}} = P_{p1} - P_{n1} = 247 - 200 = 47$ MW

- to ensure the flow of active power from Ss Parabel towards Ss Sovetsko-Sosninskaya (from the UES of Siberia to the UES of the Urals): $P_{\text{back-to-back HVDC}} = P_{p2} - P_{n2} + 50 = 204 - 170 + 50 = 84$ MW

Accordingly, the recommended installed back-to-back HVDC link capacity is around 100 MW.

2) Calculate the power of back-to-back HVDC link on Ss Sovetsko-Sosninskaya.

Define the MPF transit head sections:

- for Power lines (PL) 220 kV Nizhnevartovsk regional hydroelectric power plant - Ss Sovetsko-Sosninskaya for a normal circuit Pp1 = 247 MW (determined by ECL criterion (emergency current load) PL 220 kV Nizhnevartovsk regional hydroelectric power plant - Ss Sovetsko-Sosninskaya I or II PFM circuit (post-emergency mode) PL 220 kV Nizhnevartovsk regional hydroelectric power plant - Soviet-Sosninskaya II or I chain);

- for Power lines (PL) 220 kV Ss Tomskaya - Ss Volodino for a normal scheme Pp2 = 204 MW (determined by the criterion ECL PL 220 kV Tomskaya - Volodino with a tap on the Orlovka Ss I (II) circuit PEM PL 220 kV Tomskaya - Volodino with tap on Ss Orlovka II (I) chain);

Determination of load power:

- the Ss 220 kV Sovetsko-Sosninskaya load is Pn1 = 125 MW;
- Consumption of a section of the electric network from Ss Tomsk to Ss Chapayevka is Pn2 = 250 MW

The required Pback-to-back HVDC may be:

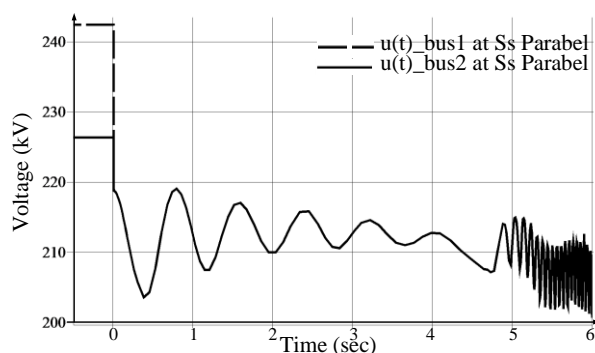
- to ensure the flow of active power from SS 220 Sovetsko-Sosninskaya towards Ss Chapaevka (from the Ural Energy System of the Urals to the Siberia UES): Pp1 - Pn1 = 247 - 125 = 122 MW

- to ensure the flow of active power from Ss Chapaevka towards Ss Sovetsko-Sosninskaya (from the UES of Siberia to the UES of the Urals): Pp2 - Pn2 = 204 - 250 + 50 = 4 MW. Accordingly, the front in this direction is not valid. Accordingly, the recommended installed capacity of the back-to-back HVDC link is around 125 MW.

Thus, after conducting a comparative analysis of the obtained calculations, it can be noted that to ensure the reversibility of power flow through the back-to-back HVDC link, as well as from the point of view of the minimum required power of the back-to-back HVDC link the most expedient is to install back-to-back HVDC link on Ss Parabel.

As a result of tests on a real power system, it was revealed that the scale of measuring the angle between the stress vectors (δ) in the northern and southern parts of the Tomsk EPS is -40° to 50° . Here, the negative value of the angle corresponds to the advance of the voltage of the northern part of the Tomsk EPS, the positive - to the southern part [5].

Thus, the «safe» inclusion on Ss Parabel is possible with $\delta < 45^\circ$, otherwise dynamic stability is disturbed in nearby load nodes, In particular, the engines on Ss Parabel, Ss Chazhemto and Ss Kargasok (Figure 2).



(a)

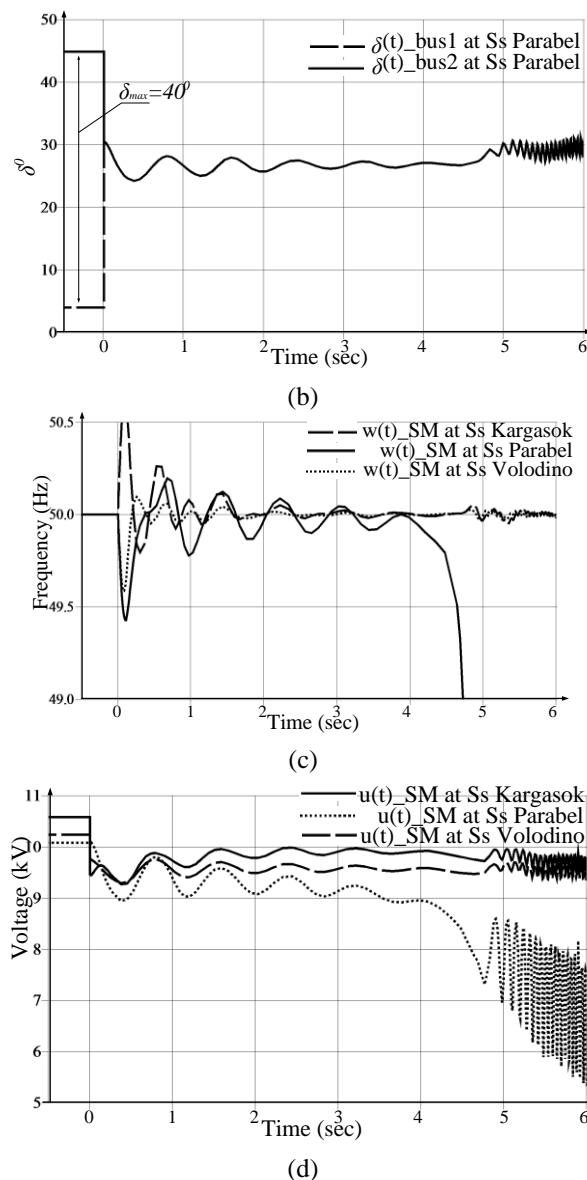


Figure 2. The oscillograms of voltage (a) at $\delta \approx 40^\circ$, voltage angle (b), rotational speed (c) and voltage of electrical machines (d).

Thanks to these conditions, it is possible to combine the parts of the Tomsk EPS by means of automatic reclosing with a synchrocheck function. However, in field tests it was found that such a combination for a long time cannot be performed without a specialized device [5].

According to the presented analysis of the properties and capabilities of the designated back-to-back HVDC link, it is possible to combine parts of the Tomsk EPS using this device, test fragments are presented below.

In Figure 3 the results of the simulation of the inclusion of the parallel operation through the installation of back-to-back HVDC link on Ss Parabel are presented. It is clearly demonstrated the effectiveness of the use of back-to-back HVDC link: even in the worst mode - $\delta \approx 180^\circ$ the union does not disrupt normal operation EPS.

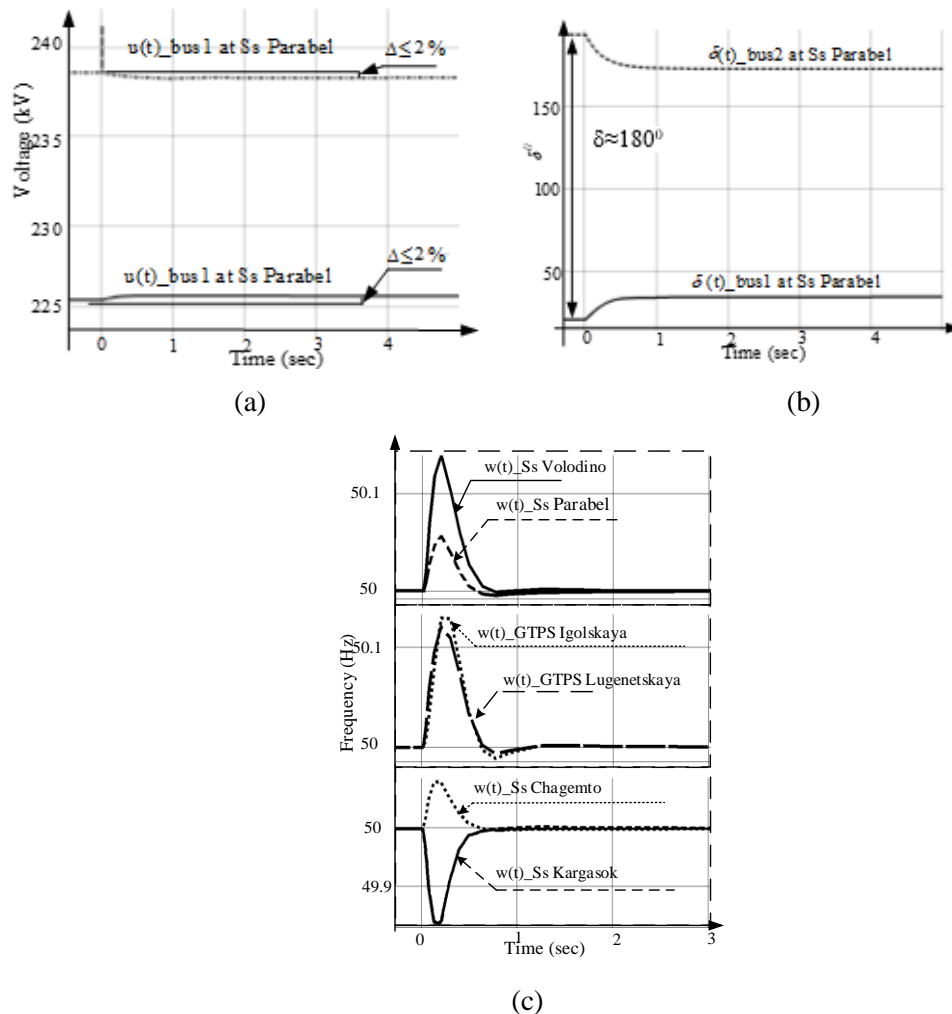


Figure 3. The oscillograms of voltage (a) and voltage angle (b), rotational speed (c).

Also, with the help of back-to-back HVDC link, step-by-step regulation and reversal of active power were carried out, the results of modeling the control processes are reflected in Figures 4: at 1 sec there was a step change in load (with 6 steps); at 6 sec reverse of the transmitted power occurred.

This study shows that back-to-back HVDC link can regulate and change power flow during few milliseconds [4, 6] in case of an accident at a power plant and the subsequent disconnection of the generator, thereby satisfying consumer demands for power without disturbing the parameters of EPS.

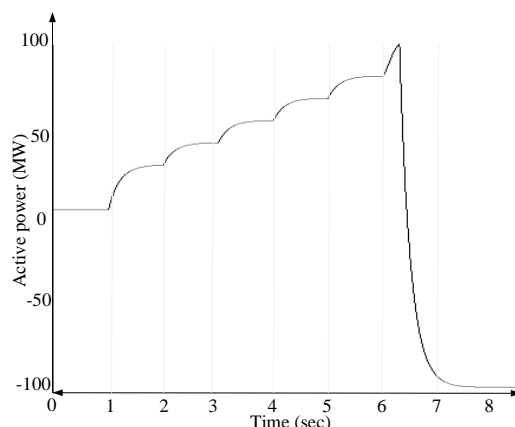


Figure 4. Active power curve, while controlling the transmitted power of the back-to-back HVDC mode.

The results of modeling the processes during short-circuit on the transit of 220 kV show the positive effect of back-to-back HVDC on emergency processes in the EPS (Figure 5). The voltage at the back-to-back HVDC connection point changes slightly, the frequency of oscillations in the system decreases.

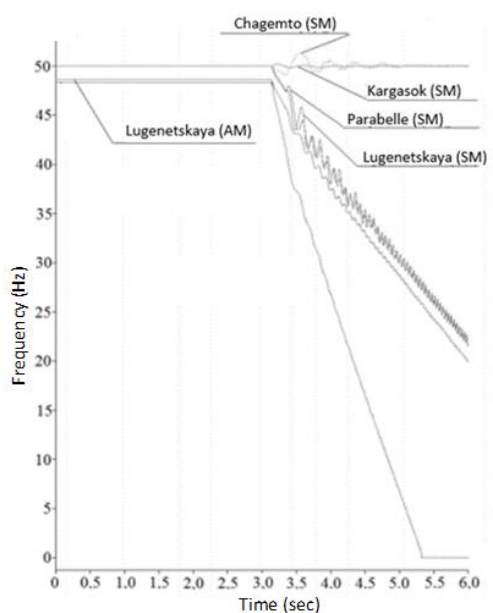


Figure 5. Oscillograms of the speed of rotation of the motors at a short circuit on the transit of 220 kV.

3. Conclusion

The considered option of combining the southern and northern parts of the Tomsk energy system using the back-to-back HVDC link is considered successful. The capabilities of this device allow you to combine at absolutely different angles of stress vectors. The presented results of modeling the processes at short-circuit on the 220 kV transit show the positive effect of the two-position direct current line.

The appropriate power of back-to-back HVDC link was determined in case for installation at Ss Parabel (around 100 MW) and Ss Sovetsko-Sosninsk (around 125 MW). However, after conducting a comparative analysis of the obtained calculations, it can be noted that to ensure the reversibility of power flow through the back-to-back HVDC link, as well as from the point of view of the minimum required power of the back-to-back HVDC link, the most effective installation is at Ss Parabel.

Acknowledgment

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