A STUDY OF SWITCHING OVERVOLTAGES ON BLOCK POWER TRANSFORMER

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Abstract. During three years two failures occurred with power block transformer 400000/500 on Bureya hydroelectric power plant. One suggestion on the causes of failures was connected with exposure to high frequency overvoltage which could be generated by SF_6 circuit breaker. It was the reason to carry out switching overvoltages by means of experimental measurement.
Analysis of overvoltage magnitudes showed they were significantly below than the test voltage with the shape of standard switching impulse. But the initial part of transient process was very interesting by oscillations caused by pre-breakdowns in gaps of SF_6 circuit breaker.
There was no overvoltages at transformer switching-off. The discharge of transformer winding (after switching-off) differed from sine wave due to nonlinearity inductance of power transformer and the non-linear active losses in core.

Introduction. During three there were two failures of one phase of power block transformer 500 kV on Bureiskaya HPP. In the first case, the failure was caused by the breakdown of HV winding turn insulation. In the second case, a breakdown of oil occurred in the adapter of bushing of 500 kV (figure1).

Figure 1: the transformer view after the second failure

One of the assumptions about the causes of failures has been associated with exposure to high-frequency voltage oscillations which SF6 circuit breaker could initiate at transformer switching-on. For this reason, it was decided to measure the actual levels of switching overvoltages.

The object of research. Part of the single-line diagram of Bureya HPP connection with the external network is shown in Figure 2.

Block transformers T3-T4 are connected with GIS-500 through the cable line CL-1 of 880 m length. Cable (type 2XS (FL) 2Y1×800RM/150) was manufactured with XLPE insulation. GIS-500 of type ELK-3 (manufacturer – ABB company) was designed by the scheme of the hexagon. In the 500-kV switchgear infest two joint generating blocks G3-G4, G5-G6, autotransformer and three overhead lines 500 kV. The single-pole SF_6 circuit breakers of type ELK SP3 are used in GIS-500.

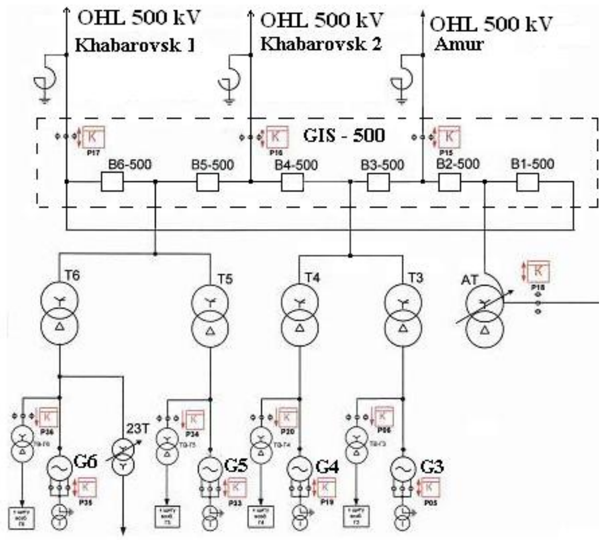


Figure 2: Part of the circuit of Bureya HPP connection with the external network

The generators G5-G6 operated in the time of the experiment and generators G3-G4 were turned off, i.e. block transformers T3-T4 were unloaded and switched at their separate or parallel connection. Block transformers T3 and T4 were switched by SF_6 circuit breakers B3 and B4 to ensure the various configurations of switching schemes. In total, there were 4 series of experiments and three switching on and off were in each case.

Measurement technique. The capacitive division was used for high voltage measurement (Figure 3). The capacitance of bushing main insulation C1 played role of upper arm of voltage divider. The capacitance C3 and additional capacitor was used as low voltage arm of voltage divider. The output signals were transmitted through coaxial cables to the inputs of a digital oscilloscope Tektronix DPO 3014. The oscilloscope was placed in a metal casing and was powered by battery.

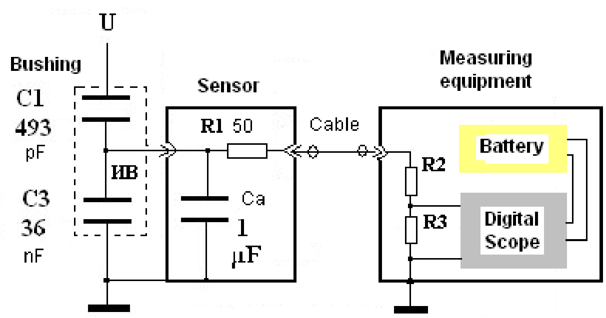


Figure 3: diagram of HV mesurements.

Switching-on. Analysis of the waveforms has shown that the overvoltage affected on T4 were significantly lower than the test volt age switching pulse [1]. Amplitudes of the overvoltages were, 465-620 kV at switching-on pair T4-T3 and 450-700 kV with disconnected T3.

The transient process was interested mainly by high-frequency oscillations. Figure 4a shows the original waveform overvoltages and Figure 4b - the initial part of the transition process.

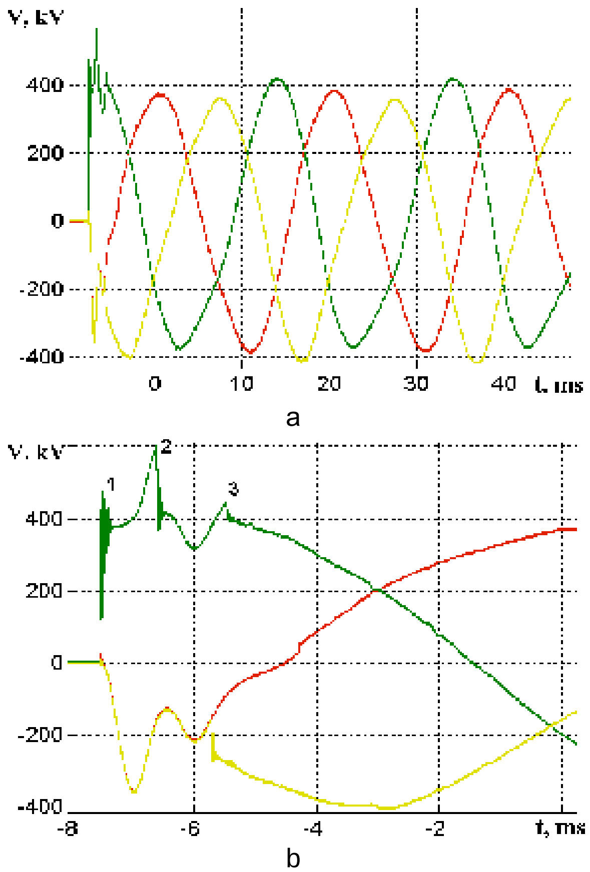


Figure 4: Waveforms of voltages on T4 winding (a) and their initial parts (b).

The three characteristic stages are in waveform of phase voltage “B”. They may be characterized by their amplitude and frequency spectrum. It is important that the process of final switching-on the transformer by GIS-500 did not occur instantaneously but after some time period (point 3 in Figure 4, b).

The presence of several pre-breakdown gap in circuit breaker has been suggested as a basic version of the occurrence of specific sites in the voltage curve. The possibility of their occurrence does not contradict with the physical notions of the SF_6 circuit breaker. But the fact of the arc channel extinction after pre-breakdown surprises. It can be explained by a small value of current and a change in its polarity resulting from transients.

Let’s consider the successive stages of the phase B switching-on and try to explain their physical pattern. For this aim the modeling of processes was made with the help of ATP-EMTP software. The simulation diagram is shown in Figure 5.

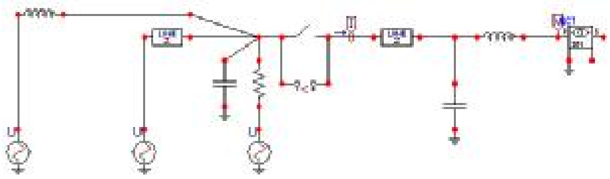


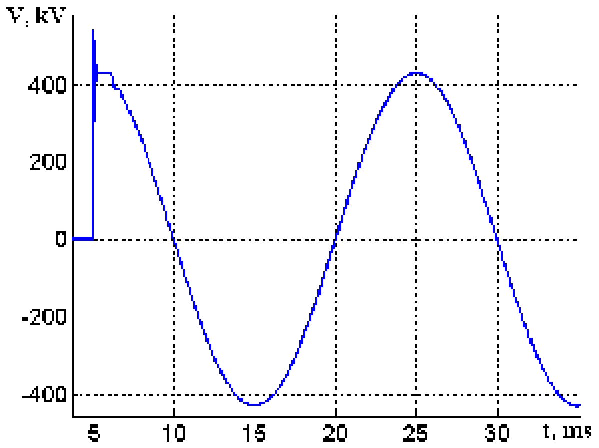
Figure 5: Calculation scheme for study of switching processes.

There were calculated the voltage on the transformer (Figure 6), the current through the circuit breaker (Figure 7) and the voltage between the contacts of the circuit breaker (Figure 8). The numbering of plots in Figures 6-8 corresponds to the numbering in Figure 4.

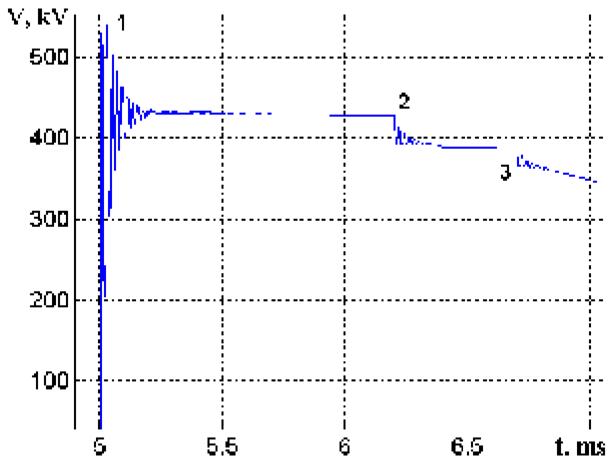
Stage 1 (site 1 in the waveforms on Figure 4b and Figure 6b): at the approaching of breaker contacts intercontact gap breaks, an arc is ignited and the decaying transient appears with a frequency which is determined by the parameters of the loop "capacitance GIS-500 - capacity of the cable - inductance of the transformer circuit (oscillation frequency f = 46.6 kHz).

After about 0.2 ms the current through the switch is reduced by the transition to a steady value (Figure 7b), the ionization in arc channel decreases and the conditions appear for channel extinction. Channel of the first breakdown is extinguished and the voltage between the switch begins to recover (Figure 8b). Voltage recovery time is between the end of the site 1 and the start of site 2 and is approximately 1 ms.

Stage 2 (site 2 in the waveforms Figure 6b and Figure 8b): at this moment the electric connection between the breaker contacts appears, and a damped transition process repeats again.



a



b

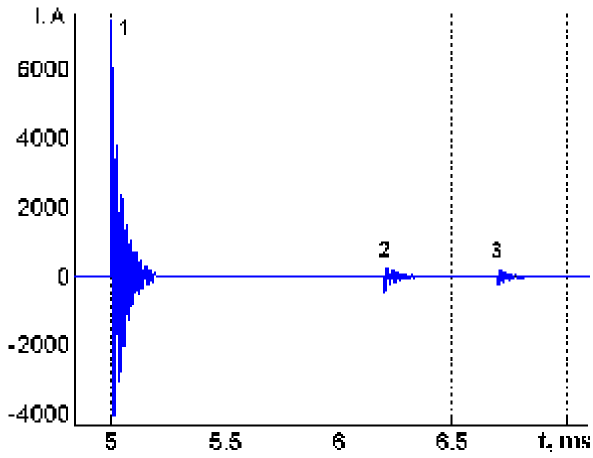
Figure 6: Waveform of the voltage on transformer (a) and its initial part (b)

The voltage is reduced to a lower value compared with site 1, because the distance between the breaker contacts becomes smaller.

It should be noted some differences in the waveforms in Figure 4 and Figure 6. At the first arc extinction, in the interval between the end of site 1 and the beginning of site 2, the voltage on phase "B" varies according to the voltage on the remaining phases. This indicates the magnetic coupling between all phases. When simulating a single-phase formulation of such a connection is not and the voltage in this region remains unchanged. It is only slightly undermined due the active losses in cables and transformers. This also explains the lower amplitude of the second phase of the simulation.

The considered sections are in good agreement with the sine of the working voltage at the moments of the contacts breaking. This fact at least does not contradict to suggested version of the transient process.

The surges measured in other experiments show that the fundamental character of the transient process is not much different. Basic, distinctive point is that the angles of switching-on vary in different experiments. Respectively, the number of sites with high-frequency oscillations and the amplitude of the surge change too.



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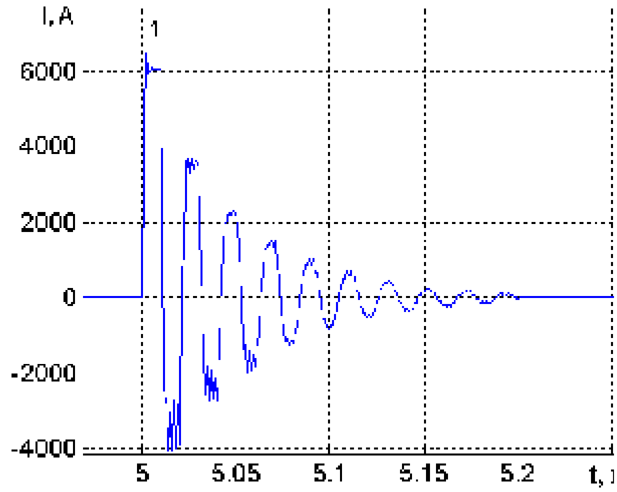


b

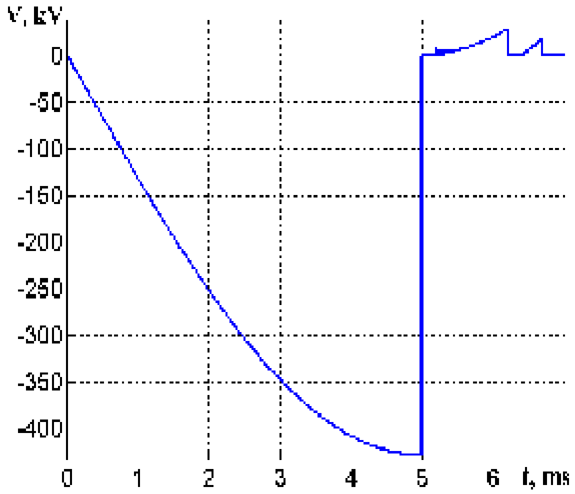
Figure 7: Waveform of the current through the circuit breaker (a) and its initial part (b)

Switching-off. There were practically not overvoltages at idling transformers switching-off. The waveforms (Figure 9) can be explained as follows.

During switching-off the circuit breaker disconnect the contour which contains the nonlinear inductance of power transformer and capacitance of the cable. A lot of energy has been stored in the capacitance of cable and in the magnetic system of transformer. It is gradually spent on active losses in elements of circuit. In this case, if the inductance of the transformer was linear - that would take place well-known process in the discharge RLC-circuit. However, the process of self-discharge capacity of HV winding of the transformer is different from the sine wave, but also has a damped character due to nonlinearity of the inductance of the power transformer as well as from the nonlinear dependence of the active losses in the magnetic system.

Conclusions.

The main result of the work consists in the fact that amplitudes of the switching surges were much smaller than the test voltage. But this conclusion should be taken with reasonable optimism.



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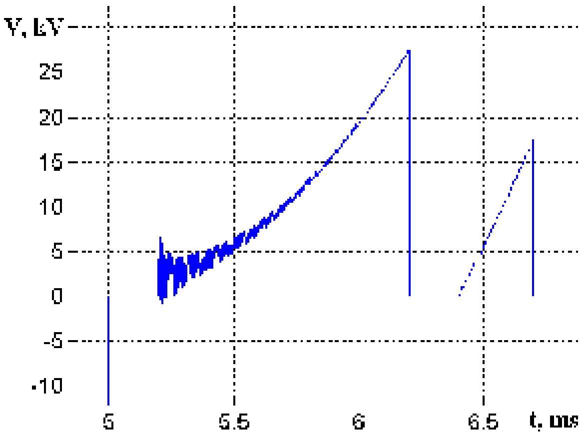

b

Figure 8: Waveform of the voltage on the circuit breaker (a) and its initial part (b)

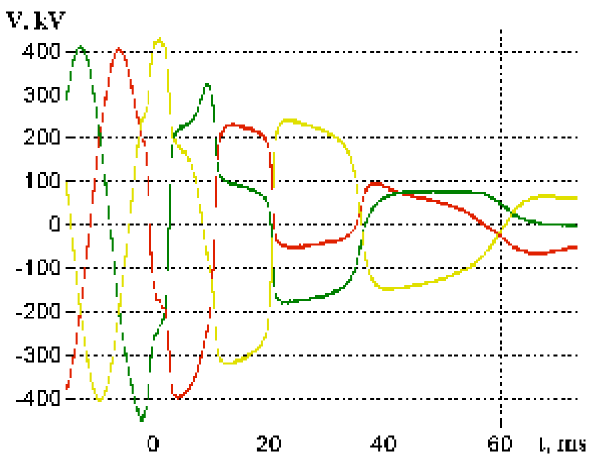

Figure 9: Waveforms of the phase voltages during transformer switching-off

First, not all normal and, especially, emergency operating modes were simulated.
Secondly, the shape of switching overvoltages is very different from the standard wave test voltage 250/2500 μs. There are high steepness of voltage rise (up to 450 kV/μs) and high frequency voltage oscillations (tens of kilohertz). They may affect on transformer electrical insulation.
Thirdly, the measurement of overvoltages relative to external terminals of the transformer winding does not represent the processes occurring inside the winding. For example, authors of [2] have shown voltage resonance and almost 4-fold excess of voltage in the windings with respect to the voltage on external terminals. Consideration of the processes occurring inside the windings is a difficult task in operation. A calculation is difficult without modeling of geometry of the windings and insulation system. It is obvious that to solve these problems is difficult without the participation of the manufacturer.

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[2] M. Florkowski, J. Furgal. Terminal based recognition of resonance overvoltages in transformer windings. Proceedings of the 16-th International symposium on High Voltage engineering, Innes House, Johannesburg, 2009. – Paper A1.