Report on Analysis of Reasons for 500 kV Live-tank SF6 Circuit Breaker HPL-550 Failure at 1150 kV Altai Substation during Short Circuit Interruption at 500 kV Transmission Line Altai – Itatskaya

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During the technological failure at Altai Substation on 26 February 2007, phase A of the circuit breaker HPL 550B2 (B-1106) was destroyed. According to the failure report, on 26 February 2007 at 15:39 the overhead line No.1106 was interrupted by the directional differential protection NDZ-1106 at single-phase short circuit of phase B. After 1.3s overhead line No.1106 was unsuccessfully energized from Altai Substation side (short circuit of phase B was not cleared). Then, during interruption of the overhead line, failure and destruction of B-1106 phase A occurred. Failure oscillograms during three-phase automatic reclosing are shown in Fig. 1. It illustrates line current having a significant DC component which exceeds an AC component.

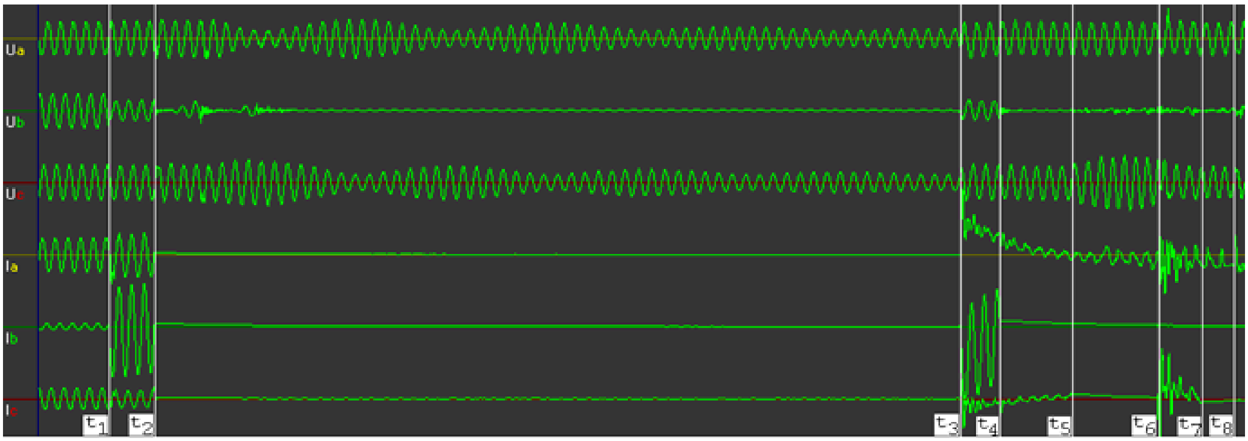


Fig. 1. Failure oscillograms of phase voltages and phase currents at 1150 kV Altai Substation during three-phase automatic reclosing: t_1 – short circuit in phase B; t_2 – three-phase interruption of the overhead line; t_3 – three-phase energization; t_4 – second interruption due to uncleared short circuit in phase B; t_5 – completion of prolonged arc quenching in phase C; t_6 and t_7 – arc reignition and arc quenching in phase C; t_3-t_8 and more – arcing in phase A

Circuit breaker is not designed for interruption of those DC currents. An electric arc between circuit breaker (CB) contacts is not quenched until DC component decays. After DC component decay, an electric arc is also not quenched because of low arc quenching efficiency by that time. Arcing process between CB contacts is observed for about 50 seconds. It results in explosive destruction of a circuit breaker with single phase-to-ground short circuit of phase A. Circuit breaker HPL 550B2 has a design deficiency, namely lack of pressure relief device to prevent explosive destruction.

To explain reasons of circuit breaker failure and to develop recommendations on preventing similar accidents, transient simulations are performed for overhead line switchings. The diagram of the overhead line No.1106 is shown in Fig. 2.

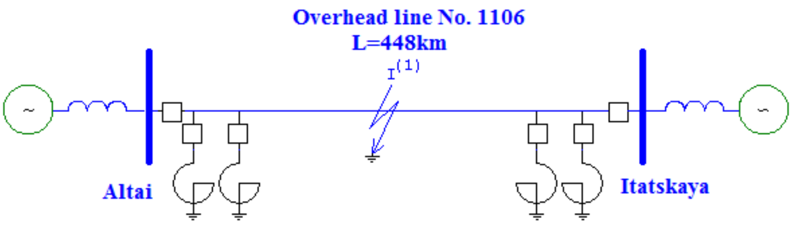


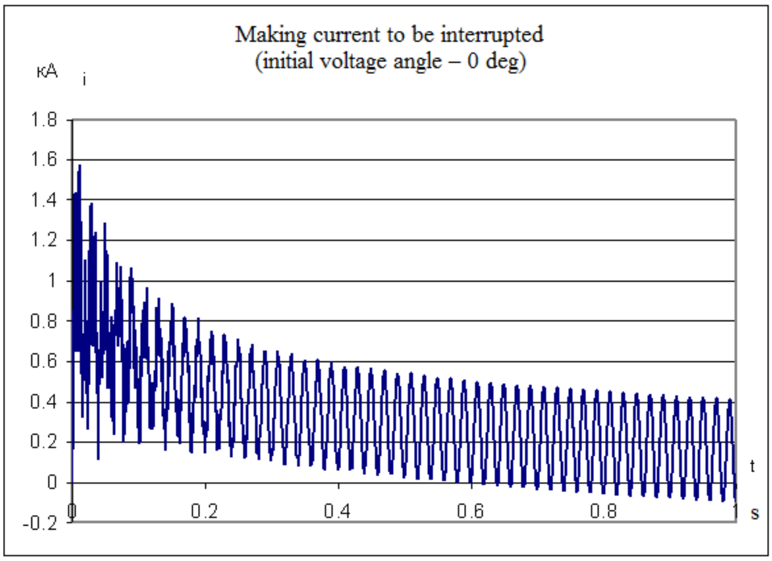
Fig. 2. Equivalent circuit of power transmission
Altai Substation – Itatskaya Substation

Line energization for sinusoidal voltage $E = E_m \sin(\omega t + \varphi_u)$ is accompanied with transient process. In this case, current through a circuit breaker contains a DC component and an AC component which parameters depend on the number of shunt reactors connected to the overhead line, making angle and active losses in a circuit. Main principles are as follows.

1. An initial value of DC current is influenced by the number of reactors connected to the overhead line and depends on a making angle. Decay of DC current is affected by active losses in a circuit.

2. The maximum initial value of DC is observed at making in voltage zero ($\varphi_u = 0$). At making in voltage maximum ($\varphi_u = 90$), DC current through a circuit breaker determined by shunt reactor inductance does not exist (see Fig. 3).

3. A time constant for shunt reactors at the beginning of the overhead line is mainly defined by the ratio between reactor inductance and reactor resistance (i.e. $\tau = L / R$). DC current in reactors at the end of a line (see Fig. 2) decays faster, because a circuit between a source and reactors includes line active resistance. Increase of active losses leads to related decrease of the time constant τ.



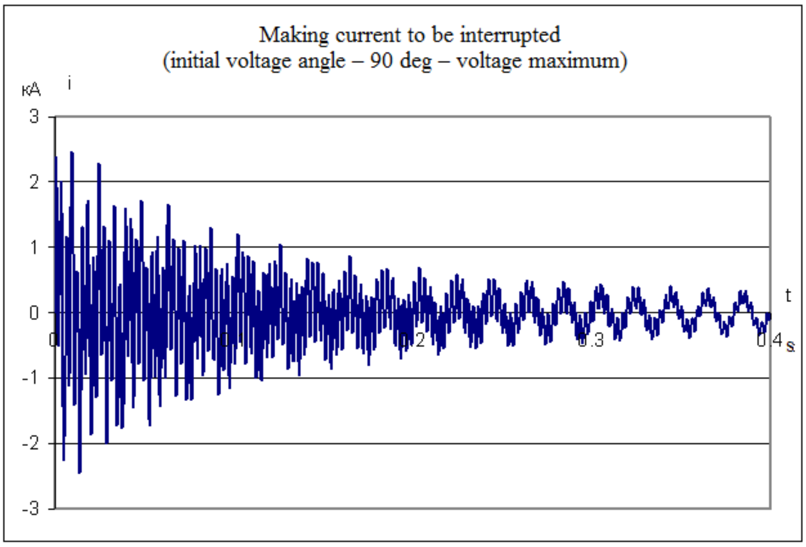


Fig. 3. Current through a circuit breaker with various making angles (4 shunt reactors installed)

Methods for mitigating DC current component under specific network conditions are presented. The first method is synchronized line switching at voltage maximum. The second method is varying circuit inductance by connection or disconnection of some shunt reactors during dead time of three-phase automatic reclosing. Finally, the third method is increasing active losses in the circuit by using pre-insertion resistors. Increase of active losses in the circuit for lowering DC current component can be reached by different ways. Connection techniques of resistors to three network phases of reactors to ground are described. For this purpose, complicated switching circuits with high-speed switching devices are used. The simplest and most effective method is using of circuit breakers with pre-insertion resistors.

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