Analysis of Electromagnetic Transients in Secondary Circuits due to Disconnector Switching in 400 kV Air-Insulated Substation

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Abstract-- The paper describes the electromagnetic transients caused by disconnector switching in 400 kV air-insulated substation. Transient overvoltages in the secondary circuits of capacitor voltage transformer (CVT) were calculated using the EMTP-ATP software. The transfer of electromagnetic transients through substation's grounding grid was analysed in order to determine the overvoltages at the terminals of protective relays located in control (relay) room. The overvoltages in secondary circuits, caused by disconnector switchings, were recorded during the on-site testing.

Keywords: disconnector switching, secondary circuits, electromagnetic transients, transferred overvoltages.

I. INTRODUCTION

SECONDARY equipment in HV substation is highly sensitive to transient electromagnetic disturbances due to disconnector switching operations. Opening and closing of disconnector produces electromagnetic transients with a very fast rate of rise [1], [2]. These transients can be particularly harmful to microprocessor-based electronic equipment located near the HV switching devices.

HV disconnectors have a negligible current interrupting capability (≤ 0.5 A) which includes the capacitive charging currents of bushing, busbars, connective leads, very short lengths of cables and of the capacitive voltage transformers (CVT) [3]. A disconnector operates only after a circuit-breaker has already opened the corresponding switchyard section, which represents a capacitive load. When the slow moving contacts of a disconnector close or open, numerous pre-strikes or re-strikes occur between the contacts (Fig. 1). These highfrequency phenomena are coupled with the secondary circuits as a result of various mechanisms. Electromagnetic disturbances are transmitted to secondary circuits through stray capacitances between the high-voltage conductors and the grounding system, followed by the galvanic connection between the grounding system and the secondary circuits (Fig. 2). High-frequency transient current flowing in the grounding system generates potential differences every time when a

strike occurs between disconnector's contacts.



Fig. 1. Voltages associated with disconnector switching: (a) simple scheme of a substation; (b) voltage waveform on disconnector due to opening of the contacts



Fig. 2. Coupling mechanisms between high voltage and low voltage circuit

In case of large secondary circuits, the potential differences are in the form of longitudinal voltages between the terminal and the enclosure of the equipment. Depending on the type of secondary circuits used and the way they are laid, differential voltages may also occur. Such a coupling mechanism has a special effect on the secondary circuits of instrument transformers, and particularly on the connected instruments, since these circuits are always directly connected to the grounding system. Another important factor which also has to be taken into account is the linking of these circuits through the internal capacitances of the instrument transformers.

II. MODELLING OF 400 kV Substation

Fig. 3 shows a part of 400 kV substation used for the

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analysis of the disconnector switching.



Fig. 3. A part of 400 kV substation used for analysis of disconnector switching

Switching the transmission line bay from main to auxiliary busbar system and vice versa was analysed. In this case the CVT and the auxiliary busbars represent capacitive load which is switched by disconnector in line bay. The model for the analysis of the disconnector switching in EMTP/ATP software is depicted in Fig. 4. CVT in one phase was represented with the following elements [4]: two capacitors C_1 and C_2 connected in series on the primary side; compensating inductor (R_C , L_C , C_C); step-down transformer (primary winding R_P , L_P , C_P ; secondary winding R_S , L_S , C_S); stray capacitance between primary and secondary windings C_{PS} ; burden 4.6 VA (726 Ω). Stray capacitance between primary and secondary windings has a significant influence on the transient response of the CVT for frequencies above 10 kHz (Fig. 5).

The transfer of electromagnetic transients through substation's grounding grid was analysed in order to determine the overvoltages at the terminals of protective relays located in the control/relay room. Disturbances transferred across the grounding system can cause a malfunction of electronic

equipment that is electrically connected to the grounding system. The model of the grounding system is important in order to analyse its effects during various disturbances. Fig. 6 shows the configuration of substation grounding grid between CVT and relay control/room.



Fig. 5. Influence of stray capacitance C_{PS} between primary and secondary windings on CVT transfer function frequency response (calculated in EMTP)



Fig. 6. Substation grounding grid between CVT and control/relay room RK15A



Fig. 4. EMTP-ATP model for analysis of disconnector switching

The grounding mesh was represented using a JMarti frequency dependent cable model. The mutual coupling between grounding system components was taken into account by treating them as different phases of a cable.



Fig. 7. A small part of substation grounding grid modelled in EMTP-ATP

The relay room RK15A is located 40 m away from CVT. The parameters of grounding system are shown in Table I.

TABLE I PARAMETERS OF THE GROUNDING SYSTEM	IN 400 KV SUBSTATION
Material	Copper wire
Specific resistance (Ω mm ² /m)	0.0169
Cross section (mm ²)	120
Soil resistivity (Ω m)	300

Soil resistivity (Ωm) Burial depth (m)

The auxiliary busbar system was modelled with frequency dependent JMarti model [5] and bus support insulators with capacitances to the ground [6]. The electrical and geometrical parameters of the auxiliary busbar system are shown in Table II.

0.8

TABLE II Electrical and Geometrical Parameters of Auxiliary Busbar System

R _{in} (cm)	R _{out} (cm)	DC resistance (mΩ/km)	Height above ground (m)	Length (m)	Spacing between phases (m)
10.2	11	6.285	12.66	171.4	6

The equivalent network from the "source side" of disconnector was represented by a voltage source and a short-

circuit impedances. Arc resistance of 2 Ω between the disconnector's contacts was assumed in simulations.

III. CALCULATION OF OVERVOLTAGES IN SECONDARY CIRCUITS DUE TO DISCONNECTOR SWITCHING

A flashover in case of 2 p.u. voltage between opening contacts of disconnector as the worst theoretical case was analysed. In real operation the flashover occurs at lower voltage differences and the corresponding overvoltages are lower. Secondary burden was 4.6 VA (726 Ω). Figs. 8-11 show calculation results in case of disconnector opening.









Fig. 10. Current through connection of CVT on grounding grid





When closing disconnector the flashover was simulated at the voltage difference of 1 p.u. between closing contacts. Calculated overvoltage amplitudes in case of disconnector opening and closing are shown in Table III.

TABLE III CALCULATION RESULTS

Disconnector switching operation	Closing	Opening	
U_{max} on HV side of CVT (C_1)	613.6 kV	920.2 kV	
U_{max} on LV side of CVT (C_2)	39.6 kV	59.6 kV	
$U_{\rm max}$ on 100/ $\sqrt{3}$ V side of CVT	377.4 V	669.2 V	
Impulse current I_{max} on CVT connection to grounding grid	691.1 A	1382 A	
Grounding potential on CVT connection to grounding grid	719.7 V	1438 V	
Grounding potential in relay/control room RK15A	150.7 V	300.4 V	

Overvoltages on secondary side of CVT are lower than 1.6 kV which is the highest permissible value in [7]. High frequency disturbances that occur in secondary circuits could disturb the normal operation of microprocessor-based electronic equipment. Transferred overvoltages increase with the decrease of CVT secondary burden. Fig. 13 shows transferred overvoltage on CVT secondary for burden 1 VA in case of disconnector opening.



 U_{max} =1436.5 V; f=330 kHz (burden 1 VA – 3.33 k Ω)

The influence of CVT secondary burden on transferred overvoltage amplitudes is shown in Table IV.

This analysed example represents the "worst case" scenario.

TABLE IV INFLUENCE OF BURDEN ON OVERVOLTAGE AMPLITUDES TRANSFERRED TO CVT SECONDARY

C TT BECOMBINET						
CVT secondary	Disconnector	Disconnector				
burden	closing	opening				
1 VA	772.4 V	1436.5 V				
2.5 VA	531.3 V	925.8 V				
4.6 VA	377.4 V	669.2 V				

High frequency transients generate potential differences in the grounding grid and cause longitudinal overvoltages. To reduce

the longitudinal voltage, shielding and multiple grounding of secondary circuits are necessary.

By applying the previously described approach it is possible to estimate the overvoltage amplitudes in secondary circuits in designing process of high voltage substation.

IV. DISCONNECTOR SWITCHING IN 400 KV SUBSTATION – ON-SITE TESTING

On-site test circuit for measurement of transients caused by disconnector switching in 400 kV substation is shown in Fig. 14.



Fig. 14. On-site test circuit for measurement of transients caused by disconnector switching

Switching of CVT T25L3 on main busbars was performed with disconnector Q2L3. CVT secondary is connected to the equipment in the relay room with 66 m long measuring cable. The measurements of overvoltages in secondary circuits were conducted in the relay/control room RK403 with digital oscilloscope (500 MHz, 1 GS/s). Transients due to disconnector opening and closing were recorded.

A. Disconnector closing

Fig. 15 shows overvoltages at the end of the measuring cable in relay room due to disconnector closing. Voltage at the end of the measuring cable exceeded value of 96 V.

Fig. 16 shows overvoltages on grounded cable sheath due to disconnector closing. Numerous flashovers between disconnector contacts (21 recorded) cause high frequency overvoltages on grounded cable sheath.

B. Disconnector opening

Fig. 17 shows overvoltages at the end of the measuring cable in relay room due to disconnector opening. Voltage at the end of the measuring cable exceeded value of 96 V.

Fig. 18 shows overvoltages on grounded cable sheath due to disconnector opening. Measured overvoltage amplitudes in secondary circuits are lower than 200 V, which is well below permissible value of 1.6 kV. The dominant frequency of overvoltages is around 350 kHz.



Fig. 15. a) Overvoltages at the end of the measuring cable in relay room due to disconnector closing; b) overvoltage caused by single flashover marked red on figure a)





Fig. 17. a) Overvoltages at the end of the measuring cable in relay room due to disconnector opening; b) overvoltage caused by single flashover marked red on figure a)



Fig. 16. a) Overvoltages on grounded cable sheath due to disconnector closing; b) overvoltage caused by single flashover marked red on figure a)

Fig. 18. a) Overvoltages on grounded cable sheath due to disconnector opening; b) overvoltage caused by single flashover marked red on figure a)

V. CONCLUSIONS

The opening and closing of disconnector could produce electromagnetic transients with a very fast rate of rise, which in some cases could be particularly harmful to microprocessor-based electronic equipment located near the HV switching devices. Special attention should be paid to overvoltages transferred to the secondary circuits.

The transferred transients in the secondary circuits were estimated in the designing process of high voltage substation. The transfer of electromagnetic transients through substation's grounding grid was analysed in order to determine the overvoltages at the terminals of protective relays located in control (relay) room. Transferred overvoltages were highest in the case of lowest CVT secondary burden. Stray capacitance between CVT primary and secondary windings has a great influence on the transient response at high frequencies. This parameter is of primary importance in the frequency range of 10 kHz - 1 MHz.

On-site tests performed in test operation of a real substation demonstrated that the amplitudes of measured transferred overvoltages were not critical in the case of disconnector switching the CVT.

VI. REFERENCES

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