Current Switching with High Voltage Air Disconnector

Salih Carsimamovic[1], Zijad Bajramovic[1], Miroslav Ljevak[2], Meludin Veledar[3], Nijaz Halilhodzic[4]

Abstract. In the paper are presented results of switching overvoltages investigations, produced by operations of air disconnector rated voltage 220 kV. Measurements of these switching overvoltages are performed in the air-insulated substation HPP Grabovica on River Neretva, which is an important object for operation of electric power system of Bosnia and Herzegovina. Investigations of operating of air disconnector type Centre-Break were performed in order to determine switching overvoltage levels that can lead to relay tripping in HPP Grabovica. During operations of disconnector (synchronization or disconnecting of generator from network) malfunctions of signalling devices and burning of supply units of protection relays were appeared. Also, results of computer simulations using EMTP-ATP [1] are presented.

Key words: Switching overvoltages, air disconnector, air insulated substations, secondary circuits.

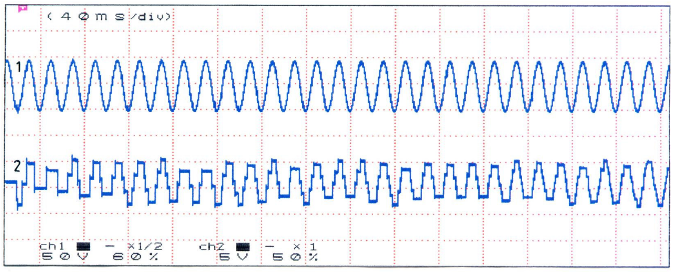
I. INTRODUCTION

Switching operation in power stations and substations, high-voltage faults and lightning cause high levels of high frequency overvoltages that can be coupled with low voltage secondary circuits and electronic equipment unless they are suitably protected. The function of high-voltage air-break disconnectors is to provide electrical isolation of one part of the switchgear. Disconnector's standards define a negligible current interrupting capability (≤0.5 A) or a voltage between the contacts if it is not significantly changed. These values of currents include the capacitive charging currents of bushing, bus bars, connectors, very short lengths of cables and the current of voltage instrument transformers. Disconnector's contacts in air-insulated substations (AIS) are moving slowly causing numerous strikes and restrikes between contacts. When the contacts are closed, the capacitive charging current flowing through the contacts ranges from $0.017 \cdot 10^{-3}$ to $1.1 \cdot 10^{-3}$ A/m for voltage levels 72.5 - 500 kV [2], depending on the rated voltage and length of bus, which is switched. Strikes and restrikes occur as soon as the dielectric strength of the air between contacts is exceeded by overvoltage. The distance between contacts, the contacts geometry and relative atmospheric condition defines the overvoltage at the instant of strike. Every strike causes high-frequency currents tending to equalize potentials at the contacts. When the current is interrupted, the voltages at the source side and the loading side will oscillate independently. The source side will follow the power frequency while the loading side will remain at the trapped voltage. As soon as the voltage between contacts exceeds the dielectric strength of the air, at that distance the restrike will occur, and so on.

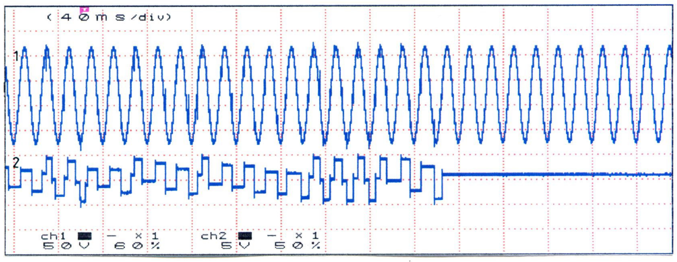
Successive strikes occurring during the closing and opening operations of the off-loaded bus by the disconnector are shown in Fig. 1 *a* and *b*, respectively.

When closing takes place, the first strike will occur at the maximum value of the source voltage. Its values can be positive or negative. As the time passes a series of successive strikes will keep occurring at reduced amplitude, until the contacts touch. The highest transient overvoltage therefore occurs during the initial pre-arc, Fig.1 *a*.

When the disconnector opening, restrikes occur because of the very small initial clearance between the contacts. At the transient beginning, the intervals between particular strikes are on the order of a millisecond, while just before the last strike; the period can reach about one half of cycle at power frequency, Fig. 1 *b*.



a)



b)

Fig. 1. The voltage due to the disconnector switching
a) Disconnector closing, b) Disconnector opening
1-source side voltage, 2- load side voltage

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[1] Faculty of Electrical Engineering, University of Sarajevo, Zmaja od Bosne bb, 71000 Sarajevo, Bosnia and Herzegovina (e-mail: csalih@bih.net.ba ; z.bajramovic@kfbih.com)

[2] Energoinvest- Sarajevo, H.Cemerlica 2, 71000 Sarajevo, Bosnia and Herzegovina (e-mail: miroslav.ljevak@smartnet.ba)

[3] ABB Representation for B&H, Zmaja od Bosne bb. TPC Sentada, 71000 Sarajevo, Bosnia and Herzegovina (e-mail: meludin.veledar@hr.abb.com)

[4] Public Enterprise Elektroprivreda BiH, HPP on Neretva, Jaroslava Cernija 1, 88420 Jablanica, Bosnia and Herzegovina (e-mail: hekonjic@bih.net.ba)

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During the switching time of operations of disconnectors at HPP Grabovica up to 500 restrikes were registered. In paper [3] there are up to 5000 restrike registered during switching operation of the disconnector. The maximum value of voltages and maximum value of the wave front increasing will take place at the maximum distance between contacts. For the purpose of the investigation of the insulation strength and induction of electromagnetic interferences (EMI), the most important are the first few strikes during the closing operation or the last few strikes during the opening operation. Each individual strike causes a travelling wave with the basic frequency on the order 0.5 MHz (330 kHz-600 kHz). Very fast transient overvoltage due to the closing operation of the disconnector at the load side of the test circuit is shown in Fig. 2.

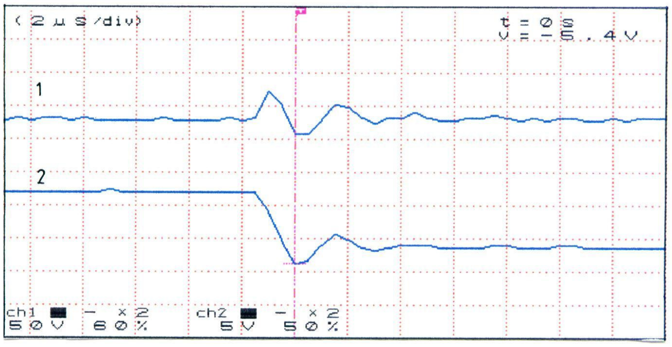

Fig. 2. Very fast transient overvoltage due to the closing operation
Channel 1- source side voltage
Channel 2-load side voltage

These high-frequency phenomena are coupled with the secondary circuits as a result of various mechanisms. The strongest interference is exerted by the stray capacities between the high-voltage conductors and the grounding system, followed by the metallic link between the grounding system and the secondary circuits. High-frequency transient current flowing in the grounding system generates potential differences, every time when a strike occurs between disconnector's contacts. In large secondary circuits, the potential differences are in the form of longitudinal voltages between the equipment inputs and the equipment enclosures. 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 galvanic ally linked to the grounding system. Another factor, which cannot be discounted, is the linking of these circuits to the primary plant via the internal capacities of the instrument transformers [4].

Interference levels in secondary circuits of air-insulated substations during switching disconnectors depend on following parameters:

-the transient voltages and currents generated by the switching operation;

-the voltage level of the substation;

-the relative position of the source of disturbances and susceptor;

-The nature of the grounding network;

-the cable type (shielded or unshielded);

-the way the shields are grounded.

There are two main modes of coupling secondary circuits with primary circuits [3, 5]:

a) Electromagnetic or EM coupling, which can be split into three sub-categories; inductive, capacitive and radiative. The most important source of EM coupling is the propagating current and voltage waves on bus bars and power lines during high-voltage switching operations by disconnectors;
b) Common impedance coupling, as a result of coupling caused by the sharing of a lumped impedance common to both the source and susceptor circuits.

Common mode voltages, i.e., voltages measured between conductors and local ground, represent the main parameter used for assessing equipment immunity. The difficulty of comparing data comes from the fact that different authors performed measurements at different places (some measurements were made at the closest point to the disconnector being operated whereas others made measurements in the vicinity of the auxiliary equipment, i.e. in the relay room). Little information is available about the grounding practice of the neutral conductor in CT or VT circuits, the quality and grounding of the sable shields as well as how the measurements have been performed. Therefore, the measured levels have to be analyzed very carefully before comparison and drawing any conclusions [5].

Results of up to date measured common mode voltages at secondary circuits of CVT, CT and VT are presented in the paper [5]. There are maximum levels of the common mode voltages ranging from 100 V_{peak} up to 2.5 kV_{peak} in the shields of the secondary circuits cables of the CT and VT. Results show that measured values of the common mode voltages at CT/CV secondary circuits, 220 kV ratings, range from Ucm=0.32 kV_{peak} [6] up to Ucm=0.85 kV_{peak} [7]. Results shown in paper [3] are for measured common mode voltages from 3-4 kV during switching operation by disconnector in 150 kV switchgear up to 6-10 kV at 400 kV switchgear.

II. RESULTS OF EXPERIMENTAL MEASUREMENTS ON SITE

The last ten years of extensive analysis of disconnector and circuit breakers generated EMI measurements that have confirmed that disconnector operation with off-loaded busbar is the most important and typical source of interference in secondary circuits of substations. Measurements of switching overvoltages generated during disconnector operation in the air insulated substation HPP Grabovica on the river Neretva were performed. HPP Grabovica is an important object for operating of electric power system of Bosnia and Herzegovina. Investigations of operating of air disconnector type Centre-Break were performed in order to determine switching overvoltage levels that can lead to relay tripping in HPP Grabovica [8]. During operations of disconnector (synchronization or disconnecting of generator from network) malfunctions of signalling devices and burning of supply units of protection relays were appeared. Malfunctioning of auxiliary circuits were manifested by tripping relay of differential protection of the generator, phase '4'- signalization on relay box 'ZB I' and signalling 'fire' in 35 kV control panel. At the same time sparking between primary terminals of the current transformer (CT) was occurred. Malfunctioning of signalling circuits were lower (not eliminated) with installing shielded cables.

Also, independent of switching operation of air insulated disconnectors, during synchronization of generator AG1 on network, it's happened that one of the pole of 220 kV circuit breaker failures. In this case generator AG1 worked in motor regime. Because of that, HPP Grabovica plans to install circuit breakers on generator's voltage (10,5 kV) [9].

The field tests were performed at the test circuit at HPP Grabovica, Fig. 3.

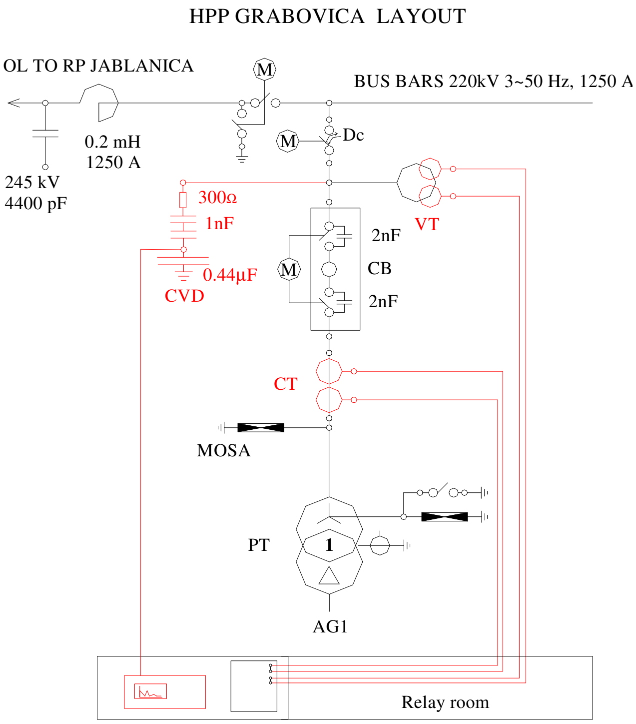

Fig. 3. The considered test circuit
VT-voltage transformer (220/√3/0.1/√3/0.1/√3 kV), CT-current transformer (200/1/1 A), CVD-capacitive voltage divider, CB-circuit breaker with two interrupting chambers and parallel capacitors (SF_6 220 kV, 1600 A), Dc-disconnector (220 kV, 1250 A), MOSA-metal oxide surge arrester (U_r=199,5 kV, 10 kA), PT-power transformer (64 MVA, 242/10,5±5% kV, YD5), AG1-generator 1 (64 MVA, 10,5±5% kV)

The recorded wave shape of the overvoltage at the load side is shown in Fig. 4. The overvoltage factors at busbar, *k*, were recorded up to 1.16 p.u. with the dominant frequency of considered transient f_d equal to 0.536 MHz. Common mode voltages, Ucm, at VT were up to 708 V_{peak}, with dominant frequency equal to 1.31 MHz.

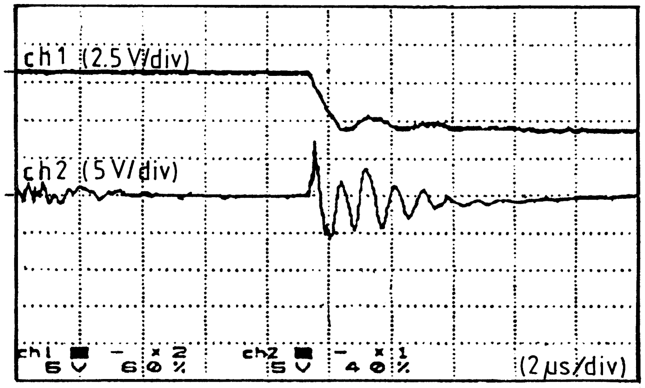

Fig. 4. Waveshape of the overvoltage
Channel 1-voltage at CVD; ch 1 (2.5 V/div), probe 1x100, ratio 455
Channel 2-voltages at secondary of VT; ch 2 (5 V/div), probe 1x100

III. MODELING OF THE TEST CIRCUIT

Computer simulations were performed on the model of test circuit containing elements drawn in Fig. 5. Overvoltages at busbars were calculated during disconnector closing operations, for the same substation layout on which measurements were carried out.

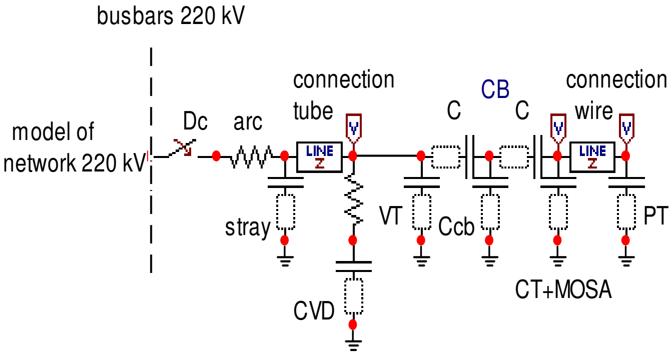

Fig. 5. Model of the test circuit
Arc-4 Ω; stray-200 pF; connection tube Z=370 Ω; CVD-R=300 Ω, C=1 nF; VT-500 pF; CB-2 capacitors, each C≅2 nF, (capacitance of open contacts, each C≅20 pF), Ccb=100 pF; CT-500 pF; MOSA-100 pF; connection wire Z=440 Ω; PT-3.5 nF

The waveshape of simulated overvoltage surge at load side is given in Fig. 6. The difference between magnitudes of measured and simulated overvoltages is 5 %. The dominant frequency of simulated overvoltage is 0.620 MHz. Comparison between results of measured and calculated overvoltages certified a good agreement of obtained values.

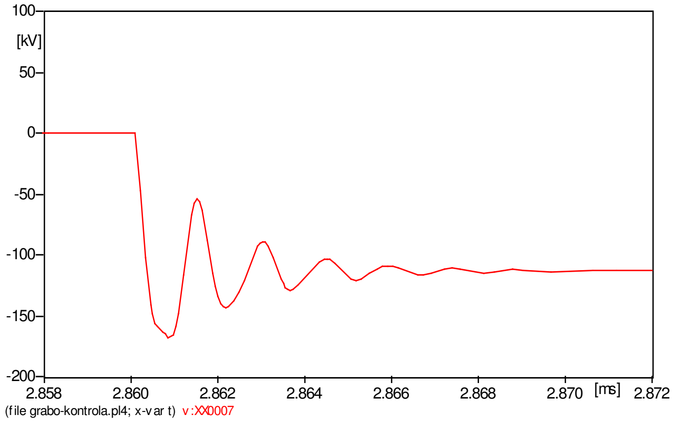

Fig. 6. Waveshape of simulated overvoltage surge

When the Capacitive Voltage Divider (CVD) was excluded, there were higher values of calculated overvoltages (15% higher on amplitude and 6 % on frequency). Capacitive divider due to primary resistor equal to 300 Ω and primary capacitance equal to 1 nF influences on overvoltage at the same measurement point causing attenuation and damping of transient overvoltrages.

In order to reduce EMI in secondary circuits the best way is to reduce sources of interference emission during switching of air insulated disconnector. One of the ways of reducing is to install disconnecting circuit breakers. Substation disconnectors isolate circuit breakers from rest of the system during maintenance and repair. The maintenance requirements for modern SF_6 high voltage circuit breakers are lower than maintenance demands made on disconnectors, which means one of reasons for disconnectors removed. Installing disconnecting circuit breaker there are no needs for switching operation of disconnectors. With disconnecting circuit breakers it is still possible to isolate the line, but low maintenance requirements means it is no longer necessary to isolate the circuit breaker. The disconnecting breaker had to be designed to safety lock in the open position, and to meet all voltage withstanding capabilities and safety requirements of disconnectors.

Another way of reducing sources of interference emission is to install circuit breaker without parallel capacitors to contacts. This suggestion is based on analyses performed on three circuit models:

a) model of CB with two breaking chambers and paralel capacitors and VT on netvork side of CB;
b) model of CB with two breaking chambers and without paralel capacitors and VT on netvork side of CB
c) model of CB with two breaking chambers and without paralel capacitors and VT on generator side of CB

Magnitudes of simulated overvoltages are presented in Table I. Voltages are measured in point of connection of VT, CT and PT.

TABLE I
MAGNITUDES OF SIMULATED OVERVOLTAGES

Connection point Circuit model	VT	CT	PT
a) model of CB with two breaking chambers and paralel capacitors and VT on netvork side of CB	169 kV f=620 kHz	47 kV f=1,1 MHz	51 kV f=620 kHz
b) model of CB with two breaking chambers and without paralel capacitors and VT on netvork side of CB	177 kV f=900 kHz	560 V f=1,4 MHz	165 V f=1,4 MHz
c) model of CB with two breaking chambers and without paralel capacitors and VT on generator side of CB	320 V f=1,1 MHz	320 V f=1,1 MHz	160 V f=1,1 MHz

Overvoltages on generator side of 220 kV CB during switching of disconnectors could be up to 320 V in the case of installing instrument voltage transformer (VT) on generator side of CB without parallel capacitors (near instrument current transformer CT). This case causes installing of circuit breaker at generator’s voltage (10,5 kV) for synchronization of generator to network (better conditions for synchronization). This solution of installing circuit breakers on generator’s voltage resulted from problems have occurred during synchronization of generatror with current 220 kV CB.

IV. CONCLUSION

Switching overvoltages due to disconnector operations have been analysed on the existing 220 kV AIS on HPP Grabovica. Measurements and calculations were conducted on the characteristic points in AIS, in order to determine the level of the EMI.

The result of measurements has shown that high frequency voltages on busbars occur with amplitudes up to 1.16 p.u. (233 kV_{peak}) and the dominant frequencies up to 0.6 MHz.

The difference between magnitudes of measured and calculated overvoltages is 5 % and 15.6 % on frequency.

Measured common mode voltages at secondary circuits were from 430 V up to 708 V.

CVD influences on overvoltages at the same measurement point on busbars causing attenuation and damping of transient overvoltages.

Comparison of the transient computer simulations with field measurements showed that calculations could be used for assessment of the transient overvoltages due to disconnector switching.

In order to reduce EMI in secondary circuits, it is suggested to install switching modules and disconnecting circuit breakers [10] or to install circuit breakers without parallel capacitors to contacts.

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