Researching the Efficiency of Measures for Decreasing the Transient Enclosure Voltage Rise of the Gas Insulated Switchgears

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Abstract – **Transient enclosure voltage rise (TEVR) of the gas insulated switchgear (GIS) is the result of the very fast transient overvoltages (VFTO) caused by the operation of the switching devices, particularly disconnectors. It is closely connected to the applied solutions of grounding and enclosure interconnections with the grounding system. This paper gives the summary of the characteristic results of the efficiency measures for the decreasing the TEVR. The researches are based on the computer simulations and extensive measurements done on the real switchgear.**

Key words: Transient enclosure voltage rise (TEVR), Very fast transient overvoltages (VFTO), Disconnector, GIS, Grounding.

I. INTRODUCTION

The series of three-pole enclosed SF_6 switchgears (GIS) of the voltage level 123 kV are implemented in the Croatian electrical power network, some of which have been already 20 years in use.

In spite of the fact that before the erection of any object the analyses of the overvoltages with the suggestion for the overvoltage protection have been done, in some cases it has not been paid a sufficient attention (specially in the practical part of the erection) to the TEVR which are the result of VFTO. This is the reason why at some switchgears the frequent flashovers occurred on the characteristic points at the switching operations. The first measurements have given the TEVR values of few tens of kV. The additional tests and improvement measures showed to be necessary.

The problem is often caused by relatively conservative approach to the designing the grounding system of GIS, i.e. not taking into the consideration particularities of the GIS, frequency range of VFTO and the enclosure interconnections with the grounding system [8], [9].

On the other side, today's implementation of the sophisticated equipment in the control, measuring and protection system of every switchgear requires the achievement of very high electromagnetic compatibility in every segment of the switchgear operation. This requires the minimization of such and similar effects.

Related to this, some previously made researches indicated the need for further project comprising the problems of the VFTO and TEVR in the GIS together with the researches on the existing switchgears, taking into account up to now very rich world experiences.

Some of the first research results are presented in this paper.

II. BASIC SUPPOSITION

Every electrical breakdown in the SF_6 gas as insulation media of the GIS is the source of VFTO spreading from the point of their appearing into all directions. At the points of discontinuity such as bushings, cable terminals, enclosure compensation plates, voltage and current measuring transformers and similar, the traveling waves propagate into the outer enclosures and parts of the grounding system causing the TEVR of the GIS. Since the frequency range of the transient reaches also several tens of MHz [1] even very small inductivities of the grounding connections increase the TEVR. Exceeding the "critical" values leads to the audible and visible flashovers.

Apart from the rare and incidental breakdowns in the SF_6 caused by the external overvoltages arriving from the network, the main and dominant source of the VFTO and TEVR are switching devices, specially disconnectors. Due to their relatively slow contact trip, the whole series of the restrikes occur (tens to several hundreds) and each of them generate VFTO [1], [2].

The research is conducted on the configuration of the GIS depicted in the Fig.1. The unloaded bus section is energized or de-energized using the busbar disconnector.

The voltage conditions inside the switchgear at the restrike on the disconnector, where very fast overvoltages occur can be generally expressed by the following equation [3], [4]:

$$V(t,s) = U_{DS} \bullet K(t,s) + U_0 \qquad (1)$$

where:

$V(t,s)$ transient voltage in the time t on the point s,
U_{DS} voltage on the disconnector contacts
U_0 pre-voltage at unloaded side of the disconnector
$K(t,s)$ the standardised factor for the GIS configuration.

The factor $K(t,s)$ does not depend on the voltage circumstances on the disconnector.

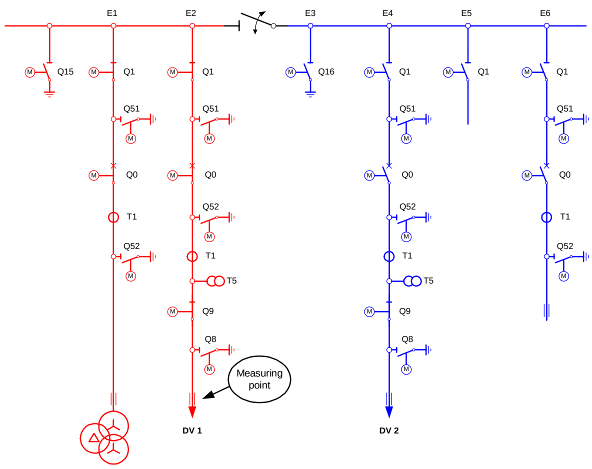

Fig. 1. Configuration of the enclosed switchgear for the test purpose

Values U_{DS} and U_0 are of the statistical nature and connected to the character and the construction of the disconnector (shape of the electrodes, contact trip speed, degree of the voltage asymmetry, breakdown voltages, arc resistance and similar). This causes the statistical nature of the value $V(t,s)$ which by the transmission coefficients is reflected on the outer parts of the enclosure making the TEVR.

In compliance to that, the research was done through:

- computer simulations on the switchgear model in order to state the characteristic values of TEVR (amplitude, frequency range, etc.)
- measuring the TEVR on the characteristic discontinuity points of the GIS and with sufficient repetition due to the statistical nature of the effect
- stating the efficiency of several measures for reducing the TEVR.

III. COMPUTATION OF TRANSIENTS OUTSIDE THE GIS

During preparation for the measurement the computation of the expected external overvoltages has been carried out. Simulations of overvoltages on different parts inside and outside of the substation have been conducted by using the computer program on the model of a three phase enclosed 123 kV substation, which is a common approach in various studies of this phenomenon [5], [6], [7]. For the computations of the overvoltages propagation outside the substation a similar technique of component modeling as in the case of the internal propagation to GIS has been used. Modeling of the earthing system components is more difficult than modeling of the GIS internal elements because of the damping and distortion, but also because of the different earthing structures. Relative simple modeling has been used in the simulation of the high frequency transients. In spite of this fact, the calculations give a qualitative evaluation of present situation and suggest how to improve the earthing system.

The magnitude and frequency of a transient is influenced by the configuration of a connected substation. Arrangement of busbars inside the 123 kV three-phase enclosed substation is shown in Fig. 2. Capacitance and high frequency inductance of the enclosed conductor are calculated from equations (2) and (3):

$$C_1 = \frac{4\pi\varepsilon_r\varepsilon_0}{\ln 4 \dfrac{a^2(\frac{3}{4}D^2 - a^2)^3}{d^2(\frac{27}{64}D^6 - a^6)}} \quad \text{F/m} \qquad (2)$$

$$L_1 = \frac{\mu_0}{4\pi}\ln 4 \frac{a^2(\frac{3}{4}D^2 - a^2)^3}{d^2(\frac{27}{64}D^6 - a^6)} \quad \text{H/m} \qquad (3)$$

where:

ε_r relative gas permittivity (=1),
d the diameter of the inner conductor,
D the inner diameter of the cable enclosure.
a distance between centers of neighboring conductors.

A high frequency surge impedance of the components of a three phase enclosed substations is used in the computations. Further on, it was assumed that the propagation speed of traveling waves inside the substation equals the speed of light although is the actual propagation speed lower due to conductance and dielectrical losses.

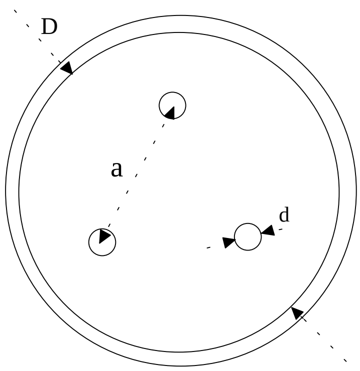

Fig. 2. Arrangement of busbars inside the 123 kV three-phase enclosed substation

The approach from [7] was used in modeling SF_6-air bushings, as well as GIS connections to cables for computations of external overvoltages. Serial branching of surge impedances is modeled as an ideal transformer of transfer ratio 1:1 in calculations performed by ATP-

EMTP program. The same principle is used in modeling the SF_6-air bushing and a connection of the cable termination to GIS:

The GIS enclosure as a part of the external transmission system is modeled as an overhead line which surge impedance can be calculated from the following expression:

$$Z = 60 \ \ln \frac{2h}{r} \quad \Omega \qquad (4)$$

where:

h an average height of the line,

r a radius of the conductor.

The radius of the conductor is the outer radius of the enclosure as well.

For earthing leads modeling, the same approach has been used as in the case of GIS. The earthing leads are modeled as an overhead lines by its surge impedance and a wave traveling time. A surge impedance of earthing leads Fe/Zn 40x3 mm was calculated according to as follows:

$$Z = 60 \ \ln\left(4\sqrt{2}\,\frac{h}{d}\right) \quad \Omega \qquad (5)$$

where:

h an average height of the line,

d a lead width.

Due to very high frequencies external overvoltages are quickly damped, and only small part of them penetrate to distant parts of the earthing system. Because of that, modeling of the main earthing system of the substation does not have much influence on the calculation results. The main earthing system can be modeled as a concentrated inductance and resistance.

The simulation of a disconnector switching has been conducted. This switching operation is accompanied with multiple restrikes between disconnector contacts, that provoke transient voltage rise outside of the substation.

Computed transient voltage rises on the cable sheath and on the GIS enclosure during the restrike are shown on Fig. 3. and Fig. 4. The case is considered in which the GIS enclosure and the cable screens are not directly connected with the short earthing leads or through the varistors. The initial voltage rise on the cable sheath and on the GIS enclosure are of the opposite polarities, so that their instant difference in some cases can cause the breakdown. The initial peak values of transients are higher than the most values recorded in the measurements, as the damping and the distortion are not modeled precisely. The voltage oscillograms obtained from the repeated on-site measurements in the identical conditions differ in the each case, as the character of the whole phenomenon is stochastic. The conducted computations with the help of the simple models have given the qualitative evaluation of the transients with the results on the safe side, i.e. higher computed values than measured.

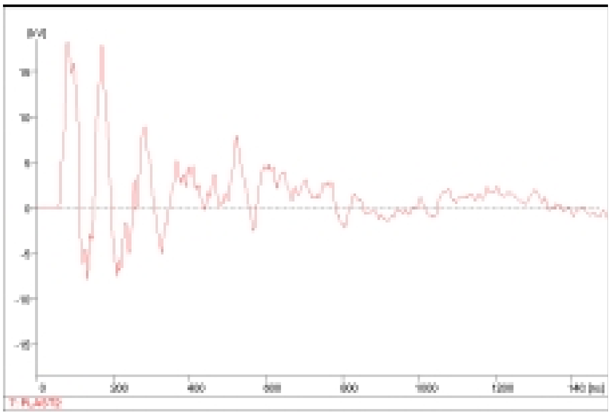

Fig. 3. Calculated voltage on the cable screen.

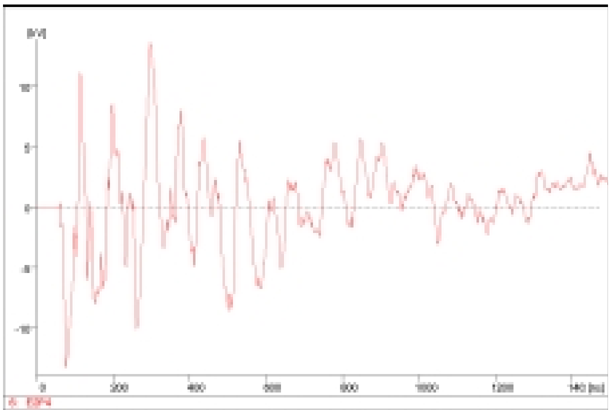

Fig. 4. Calculated voltage on the GIS enclosure.

IV. MEASUREMENTS IN THE SWITCHGEAR

The special attention was given to the preparation and the performance of the measuring the TEVR. The field with the cable connection on the GIS (Fig. 1, left busbar section) was chosen as the characteristic discontinuity point on which the measurements were done (“Measuring point”)

Respecting the results of the previously made computer simulation on the switchgear model (frequency and amplitude specters of the expected measuring values) the modern digital-storage oscilloscopes, sample-rate 100 and 500 MS/s and HV voltage probes with response time less than 10 ns were used for the measurement of the transients, what ensured the credibility of the test results in the frequency range up to approximately 20 MHz. The HF measuring shunt with the width of the frequency scope up to 100 MHz was used for the measuring the impulse currents. Regarding the statistical nature of the transients, the measurements were repeated even 30 times for each measuring configuration due to the further statistical calculations.

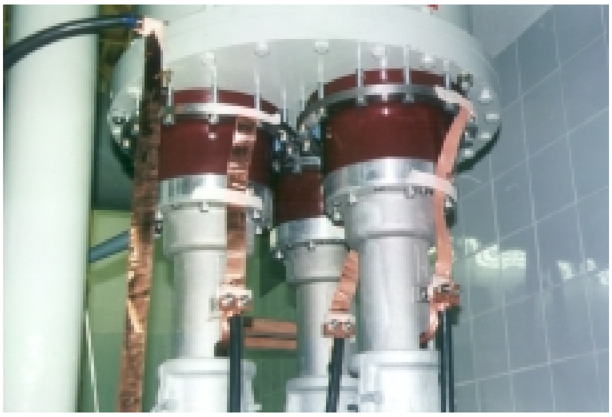

Fig. 5. Detail from testing: interconnected GIS enclosure and cable terminals

At switching the unloaded busbar section by the disconnector the following measuring configurations were comprised:

"a" cable screens on the cable terminations and GIS enclosure grounded but not directly connected;

"b" cable terminations over-bridged by non linear resistors and connected to enclosure; the cable screens additionally connected by one strip each to the grounding.

"c" cable terminations directly connected to enclosure and all together connected to the grounding (Fig.5.).

Also, at each measuring configuration some variations regarding the number of the parallel grounding strips were made.

Beside that it is necessary to point out that as the reference potential the part of the grounding in the GIS floor level was chosen, since it is on the first floor and has very long vertical connection to the basic grounding. In such manner the influence of the induced disturbances in the measuring loop was minimised what was checked prior to the measuring.

V. RESULTS OF THE RESEARCH

The recorded oscillogrames with maximal values of the transients at each disconnector switching operation (first at switching on, last at switching off) are grouped according to the measuring configurations and numerically analysed. Statistic analyses show good correlation between the samples and the roles of the normal distribution what is confirmed by the used statistical tests (χ^2-test, Kolmogorov-test).

Cumulative probability distribution of some samples is given in the Fig. 6 – Fig.10.

As expected, the highest values of the TEVR are recorded in the measuring configuration “a”, specially on the cable screens at the “classical” grounding for short-circuit conditions (area 50 Hz). Over-bridging the cable terminations by the strips the values of the transients are drastically decreased; configuration “c” (Table 1.).

Table 1. Measured mean values

Measuring configuration	Mean values (kV)	
	Enclosure	Screen
"a"	8.5	18
"b"	1.5	6
"c"	0.4	0.4

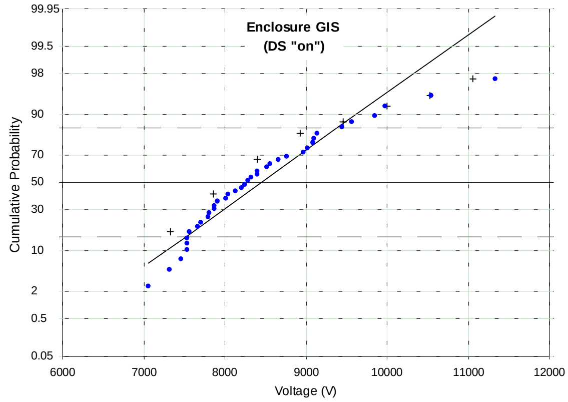

Fig. 6 Voltage distribution of the GIS enclosure at switching on (configuration "a")

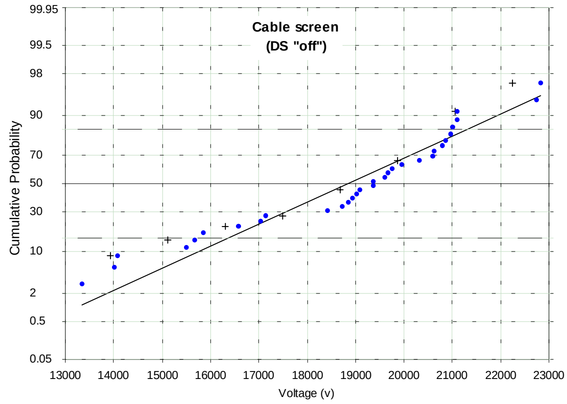

Fig. 7. Voltage distribution on the cable screen at switching off (configuration "a")

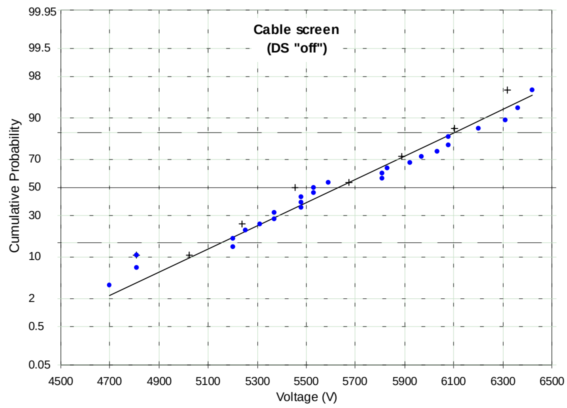

Fig. 8. Voltage distribution on the cable screen at switching off (configuration "b")

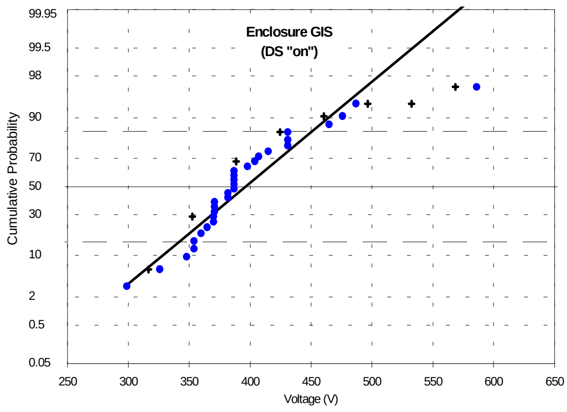

Fig. 9. Voltage distribution on the enclosure GIS at switching on (configuration "c")

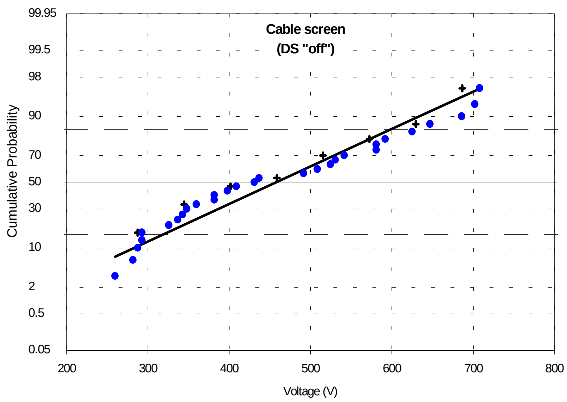

Fig. 10. Voltage distribution on the cable screen at switching off (configuration "c")

The over-bridging the cable terminations by the non-linear resistors can be considered as optimal solution; (configuration “b”) in cases when is necessary to eliminate the circulating compensation currents (a.c. and d.c.).

Comparing the wave shape, frequency and amplitude range of the measured transients with the values obtained by the computer simulations, a good correlation, in the expected limits, can be noticed; Fig. 11 and 12.

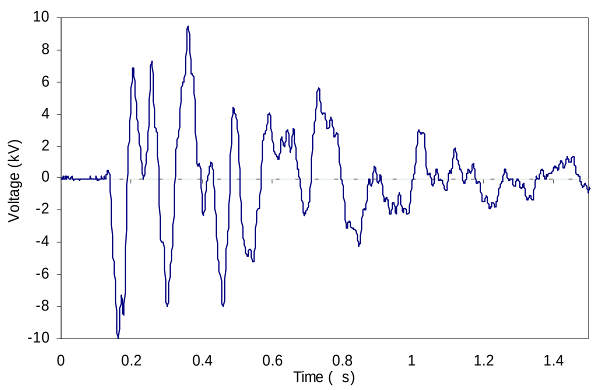

Fig. 11. Measured voltage on the cable screen at switching on (configuration "a")

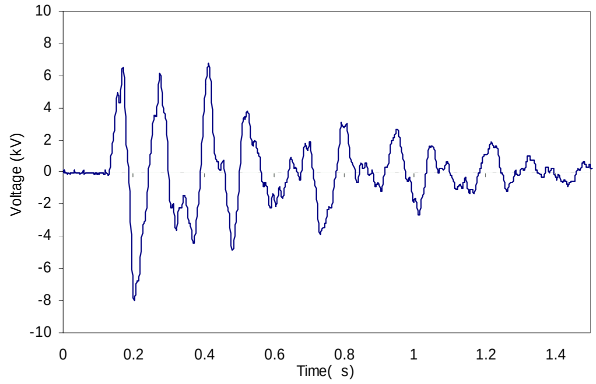

Fig. 12. Measured voltage on the GIS enclosure at switching on (configuration "a")

Beside that, one of the recorded impulse current oscillogrames (Fig. 13) in one of the enclosure’s grounding stripe depicts the high rate of the current change *di/dt* ~ 3-4 (A/ns). This is in the accordance with the results obtained with the set simulation model.

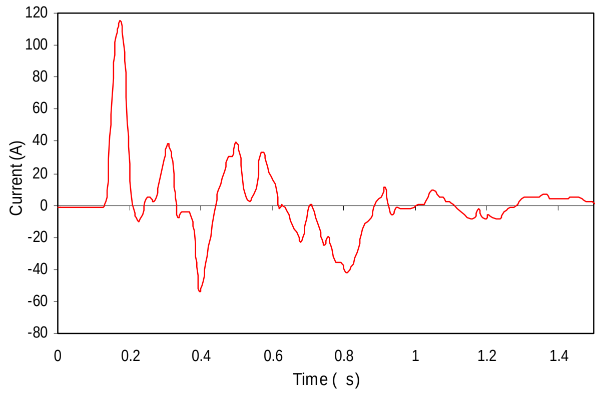

Fig. 13. Measured impulse current through the connection between GIS enclosure and the grounding

VI. CONCLUSION

Frequent flashovers between enclosure parts have been noticed in the service of some GIS. They are provoked by excessive values of TEVR . It is the result of the neglecting the specific requirements and methods of GIS grounding. Such cases apply for the application of additional protecting measures.

The implementation of the sophisticated equipment in the control, measuring and protection system also require the minimisation of TEVR.

The research comprised computer simulations on the switchgear model in order to state the characteristic values of TEVR (amplitude, frequency range, etc.) and measuring the TEVR on the characteristic discontinuity points of the GIS.

The voltage oscillograms recorded in the repeated on-site measurements during the identical conditions differ in the each case, as the character of the whole phenomenon is stochastic. The statistical approach is applied in the research since TEVR is a function of more random variables. Statistical mean values of recorded peak of TEVR are considered.

The conducted computations have given the qualitative evaluation of the transients. The initial peak values of transients are higher than the most values recorded in the measurements, as the damping and the distortion are not modeled precisely.

The highest values of the TEVR are recorded in the case when cable screens and GIS enclosure are separately grounded but not directly connected Over-bridging the cable terminations by the strips drastically decreases the values of the transients on the cable screen from 18 kV to 0.4 kV, and on the enclosure from 8.5 kV to 0.4 kV.

The over-bridging the cable terminations by the non-linear resistors decreases overvoltages several times and it can be considered as acceptable solution in cases when direct connection with the enclosure is not allowed.

VII. REFERENCES

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