

Electromagnetic compatibility in various kinds of substations in Croatian transmission networks and mitigation measures

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SUMMARY

In the last two decades have been studied the conditions of electromagnetic compatibility (EMC) in different kind of substations in transmission networks of Croatia. Investigations have been done by measuring method using special measuring technique and also by computing simulations. In this paper will be shown conditions of EMC which have been studied by measuring method during normal or fault switching operations of disconnectors and circuit breakers. Conditions of EMC with particular stress on transient voltages in secondary circuits within various kind of transmission network objects have been carefully studied (AIS, GIS, old and new substation design type, rated voltages from 110 kV to 400 kV).

In the paper will be given the review of some main data from those investigations made in the long period of time. Then main findings will be given and the differences in EMC conditions will be shown taking into account various parameters such as: design details of substations (distances, cable types, protective measures etc.). Also, it will be given a review of measuring methods and tools (oscilloscopes with low and deep acquisition memory, statistical tools for data processing, etc.). Generally, it was shown that overvoltage in secondary equipment follows normal or Gaussian statistical distribution from which some typical data have been taken, such as 98% - probability values etc.

Consequently, different kind of the mitigation measures have been proposed in cases of high overvoltages in secondary circuits. Typically, changes in earthing systems, in cable sheets connections etc. have been proposed to utilities. All proposed measures have been tested by measuring methods too and the effects have been very satisfactory in ensuring EMC conditions within substations. Some most interesting ways in reducing high level of TEVR in GIS substations will be shown in pictures.

Given results and effects of mitigation measures in Croatian transmission network substations clearly show that the best method is experimental investigation which usually was followed by some necessary mitigation measures which ensure the conditions of EMC within substations according to international standards and recommendations.

KEYWORDS

Electromagnetic compatibility, High voltage, Substation, Transmission network, Mitigation measure, Disconnector, Switching operation, Measurements, Statistical analysis

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1. INTRODUCTION

In the last 25 years the discipline “Electromagnetic compatibility” (Abb.: EMC) become one important part of design and testing within power substations and power plants [1]. In Croatian electric power system the study of EMC questions passed the way from the first methodology studies [2] and first measurements in high voltage (HV) substations [5, 6] to the mature discipline. The first serious study started practically along with introducing 400 kV voltage in power transmission network.

As have been known, the main problem with EM incompatibility of some electrical equipment in power substations are transient overvoltages in primary or secondary circuits due to lightning strokes, switching operations and different kinds of faults. Overvoltages due to earth faults and lightning strokes are relatively infrequent and in primary circuits they are in majority cases successful suppressed by using of MO arresters and switching control measures.

The most important thing for the occurrence of transients, special in secondary circuits, is automatic or intentional switching of HV disconnectors and circuits breakers, (Fig. 1).



Fig. 1 Arc between contacts of disconnector in AIS 400 kV substation Tumbri, near Zagreb

Travelling current and voltage waves due to disconnector switching influence on sensitive measuring, protective and control circuits. The main part of influence is coming through the measuring transformers because of specific kind of conjugation between primary and secondary circuits (inductive and capacitive). In some cases conductive and radiated components are significant, too.



Fig. 2 View on one of the GIS 110 kV substation Dobri in which EMC conditions have been investigated

It is important to point out the great significance of transient overvoltages in GIS substations, although all AIS substations are not immune on them. But in GIS and in apparatus with compressed SF₆ enclosed by metal cylinders, very high frequency overvoltages are spread in the form of complicated travelling waves, which after few reflections are transferring into very high frequency (up to 50 MHz) and low damped oscillations. The main characteristics of those very fast transients (VFTO) are very steep wave fronts (typical rise time 3 to 5 ns). Such waves may cause significant transient overvoltages in secondary circuits, very high transient voltage rise of metal enclosure (TEVR) and significant transient ground potential rise (TGPR) on different parts of grounding system.

In the beginning of research the EMC problems in Croatian transmission networks it was decided after introducing the first important theoretical studies [4] that the very useful method for determining the level, wave shape, kind and main causes of transient overvoltages are direct measurements within high voltage substations. One of those main reasons for this conclusion is complex structure of substations usually inconvenient for computation, special in secondary circuits.

2. EXPERIMENTAL INVESTIGATIONS OF TRANSIENT OVERVOLTAGES IN SECONDARY CIRCUITS OF “AIS & GIS” SUBSTATIONS IN CROATIA

2.1 Description of measurements

For experimental study of transient overvoltages it was chosen a typical test configurations of substations which are showed on next two figures (one of 400 kV AIS substations on Fig. 3 and one of 110 kV GIS substations, Fig. 4). In each configuration measuring of transients have been done during disconnectors switching “On” and “Off” on different parts of substations.

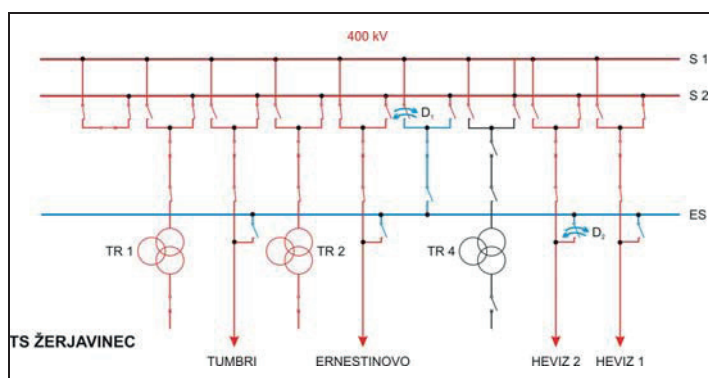


Fig. 3 400 kV AIS substation Žerjavinec with locations of disconnectors which have been switched on and off

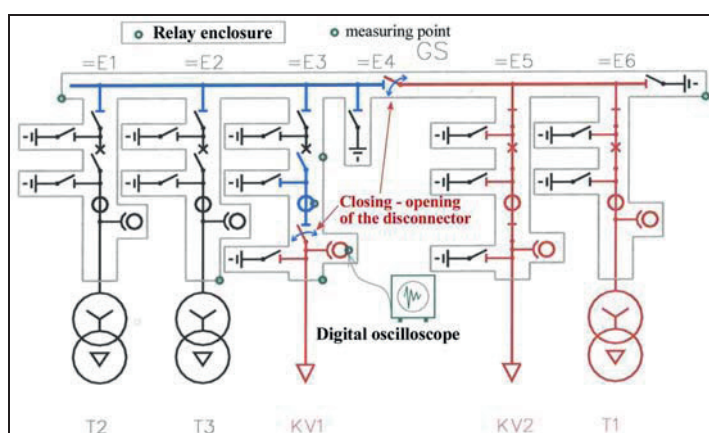


Fig. 4 GIS substation 110 kV Dobri with location of disconnectors during EMC investigation

In AIS substation as a most dangerous was chosen switching of unloaded auxiliary bus-bars (Fig. 3), but in GIS the section of enclosed busbars with sectional disconnecter (Fig. 4).

For each type of measurement the choice of measuring-acquisition equipment was based of expected amplitude and frequency spectrum of studied transients. Because of that are chosen modern digital-storage oscilloscopes with frequency bandwidth of 500 MHz, sample rate from 0.5 to 1 Gs/sec. Also it was necessary to take the instruments with very deep acquisition memory and high voltage measuring probe with 250 MHz frequency bandwidth. Measurements have been done on measuring points in secondary equipment cubicles (Fig. 5a and 5b), but in GIS substations on different points of metal enclosure, additionally.



Fig. 5a Detail of measuring equipment

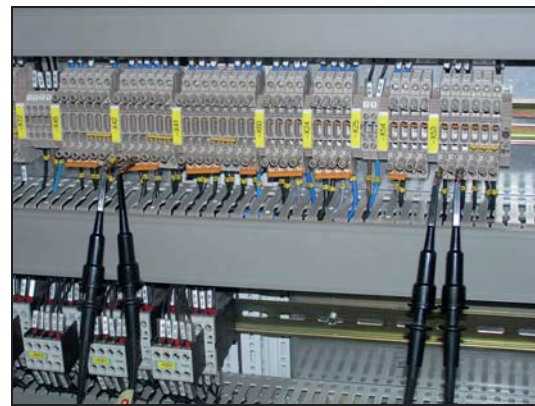


Fig. 5b Measurements points in relay cubicle

Furthermore, because of stochastic nature of transients measurements have been repeated several times in the same configuration due to statistical processing of collected samples. In intention to find maximum values of transients in each switching cycles it was used sequential memory mode of oscilloscope.

2.2 Review of results

The first results of measurements and studies conducted in AIS type of 400 kV substations showed desirable level of overvoltages in secondary circuits in 400 kV substations which was less than $2 \text{ kV}_{\text{peak}}$ [5, 6]. In some specific cases the level of overvoltages exceeded $3 \text{ kV}_{\text{peak}}$ and it was to required to make additional EMC measures already through the building process it was found lower level of overvoltages in secondary circuits [3, 10, 12]. On Fig. 6a is shown typical oscillogram of overvoltages in secondary circuits in one of new 400 kV AIS substation. For comparison Fig. 6b shows measured overvoltage in secondary circuits investigated within 110 kV GIS type of substation.

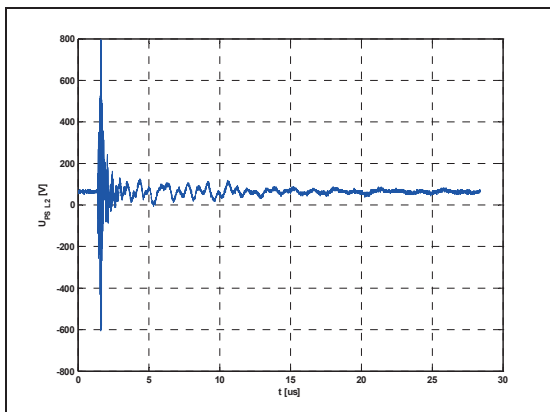


Fig. 6a Transient in AIS 400 kV Žerjavinec

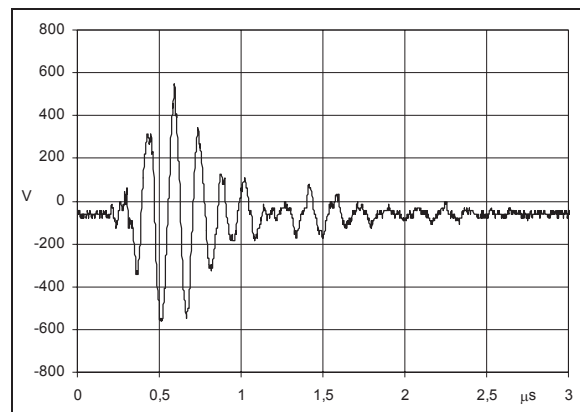


Fig. 6b Overvoltage in 110 kV GIS Dobri

In GIS substations besides of amplitude level more care have to be taken on frequency range of transient overvoltages (usually 5-20 times higher than for AIS) due to some specific properties of GIS (very steep overvoltages, small design distances, superposition of TEVR etc.) In that sense more experimental studies have been performed in Croatian GIS substations in past several years with statistical evaluation of measuring results special because of higher risk of undesirable disturbances in secondary circuits.

In table 2.1 it is given the summary of results of the highest overvoltages recorded in different points of one of representative 110 kV GIS substations during disconnecter switching.

Table 2.1 Overview of the highest overvoltages values recorded in different points of GIS Substation 110 kV Dobri (in town Split), during disconnectors switching-„Switching off” (peak overvoltages values and number of measurements at each measuring point) (red sheded: overvoltages measured in secondary circuits)

Measuring point	Reference point	U _{peak}	E1 (Q1)-TR1 Disconnecter, busbar side	E3 (Q0)-KAŠT Switch	E3 (Q1)-KAŠT Disconnecter, busbar side	E3 (Q9)-KAŠT Line disconnecter	E4 (Q11)-SAB Busbar section disconnecter	E5 (Q1)-SUČ Disconnecter, busbar side	E5 (Q9)-SUČ Line disconnecter	E6 (Q1)-TR2 Disconnecter, busbar side
Enclosure-T1	M1	2.438 V (16)					1.750V (11)			2.438 V (5)
Enclosure -T1a	M1	8.438 V (41)	2.969 V (4)	3.125 V (1)	5.438 V (10)	3.813 V (9)	3.813 V (9)		8.438 V (5)	3.813 V (3)
Enclosure -T2	M1	13.750 V (36)		4.063 V (1)	6.750 V (10)		1.781 V (12)		13.750 V (5)	5.063 V (8)
Enclosure -T3	M1	2.250 V (15)					1.563V (11)			2.250 (4)
Enclosure -T3a	M1	3.500 V (22)	2.125 V (4)			2.875 V (9)	3.500 V (9)			
Enclosure -T4	M1	6.000 V (15)					6.000 V (11)			4.019 (4)
Enclosure -T4a	M1	16.456 V (55)	1.425 V (2)	5.450 V (1)	3.363 V (8)	16.456 V (10)	3.450 V (25)	3.925 V (1)	5.700 V (5)	4.163 V (3)
Enclosure -T4b	M1	9.531 V (41)	1.188 V (2)	4.000 V (1)	4.250 V (9)	9.531 V (10)	2.594 V (10)	3.063 V (1)	4.000 V (5)	4.775 V (3)
Enclosure -T4c	M1	2.969 V (15)					2.969 V (15)			
Enclosure -T5	M1	7.313 V (14)					7.313 V (14)			
Enclosure -T6	M1	5.438 V (14)					5.438 V (14)			
SK-Kaštel	M-E3	1.161 V (82)			651 V (36)	1.161 V (40)				734 V (6)
SK-Sučidar	M-E5	1.198 V (56)	693 V (16)				1.198 V (40)			
SK-T1	M-E1	938 V (53)					917 V (44)			938 V (9)
SK-T2	M-E6	1.646 V (60)					1.646 V (60)			

The highest peak overvoltages measured on different points of secondary circuits are not exceeding value of 2 kV_{peak}, but the measured values of transient enclosure voltage rise (TEVR) are significant on some points of enclosure. The last findings lead to introduction of various kinds of mitigation measures.

3. MITIGATION MEASURES FOR EMC FULFILMENT IN SUBSTATIONS

In accordance with presented results and some other studies [7, 8] it was made in each tested substation evaluation of fulfilment of EMC conditions. In old generation of AIS 400 kV substations it was concluded that disconnecter switching could lead to high transient overvoltages in secondary circuits. In those cases it was necessary to reduce them to levels to assure safe and truly operation of sensitive electronic devices. Desirable level of overvoltages was concluded to be less than 2 kV_{peak}.

New generation of AIS and GIS type substation fulfil that and other EMC conditions generally. But, all higher levels of transients cannot be completely eliminated. This is particularly related to transient enclosure voltage rise (TEVR) in GIS type substations which is unique for GIS and can be in some worst cases also significant for disturbances in secondary circuits and EMC condition in related substation.

In that sense and as for example on Fig. 7 is done principal scheme three different kinds of earthing both sides of enclosure-cable connection in tested GIS which have been experimental investigated to quantify the differences and efficiency in decreasing level of TEVR during disconnecter switching, [7, 8].

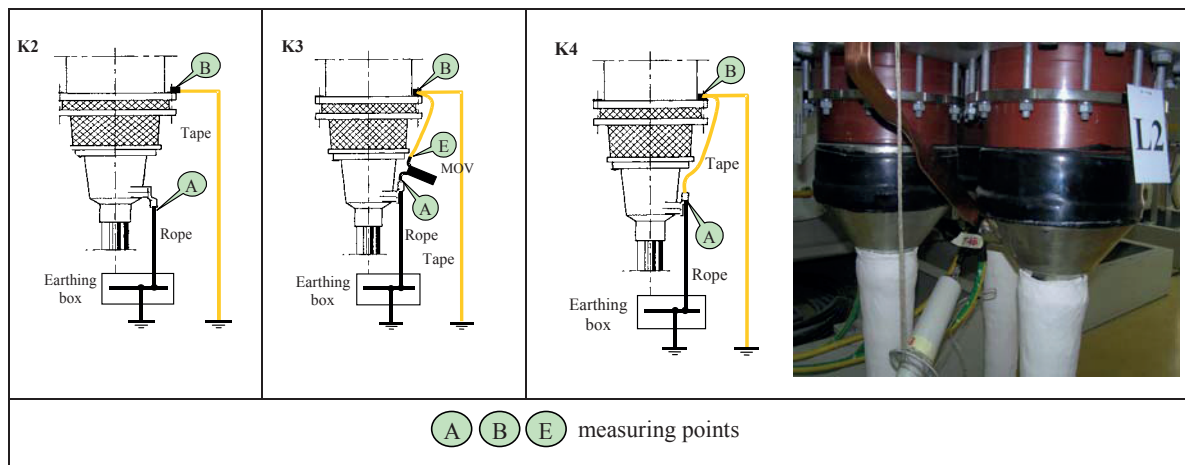


Fig. 7. Test configurations to determine efficiency of different kinds of earthing interconnected GIS enclosure and cable terminals on TEVR level

Measurements have been repeated several times in the same configurations to get representative samples for farther statistical evaluation. Summary of statistical evaluated results is described as bar diagrams Fig. 8 (left part of figure). From the diagrams is evident the influence of low inductance earthing on both sides of enclosure-cable interconnection in significant mitigation TEVR in tested GIS.

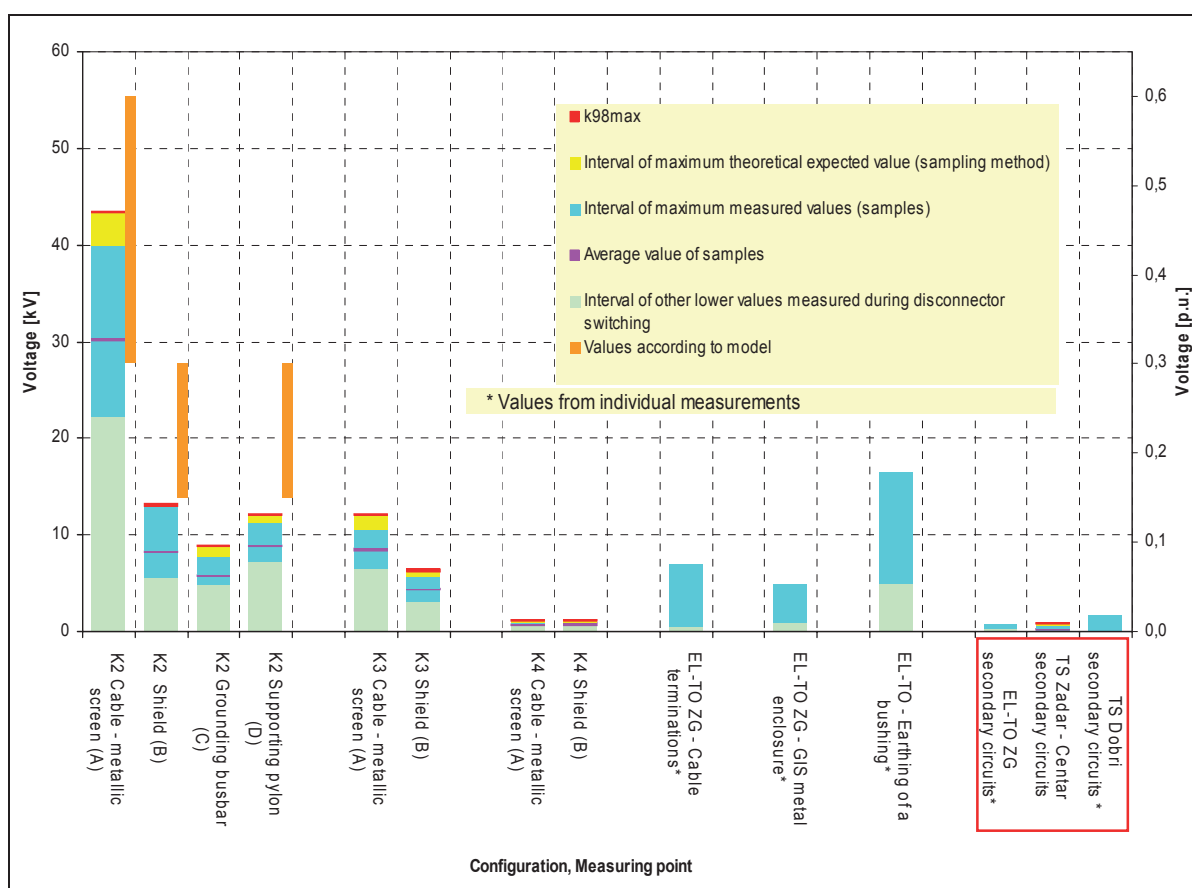


Fig. 7. Summary of results of tested configurations to determine efficiency of different kinds of earthing interconnected GIS enclosure and cable terminals on TEVR level; Transient overvoltages in secondary circuits measured in three different GIS substations (in red frame)

But sometimes it is difficult and expensive to carry out enough effective measures. Because of that the most effective way is to predict ways for reducing of overvoltages already in the phase of design of new substations. In that sense experiences with measurements in existing substations are essential.

4. MAIN CONCLUSIONS AND LESSONS LEARNED

Some main conclusions from measuring investigations of transient overvoltages in secondary circuits in different kind of Croatian 110 kV and 400 kV substations may be briefly stated as follows.

1. Overvoltages within old types of AIS substations are generally higher and often need reductions
2. GIS substations showed lower level of peak values of transient overvoltages in comparison to AIS substations, but generally have higher frequency range and some specific problems (TEVR)
3. Various mitigation measures undertaken after first measurements showed good suppressive effects
4. It was decided to carry out measuring investigations in all type of substations periodically and according to IEC and other regulations
5. Computing methods of investigations of EMC conditions is considered as useful in design phase for new substations and may be validated only through measuring investigations with special and sophisticated equipment.

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