THE MEASUREMENT OF HIGH FREQUENCY DISTURBANCES IN SLOVENIAN SUBSTATIONS

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ABSTRACT

The paper presents the situation of in-situ electromagnetic compatibility testing in substations. The method for in-situ measurement of high frequency disturbances and usefulness of such measurement in substations is presented. The need for establishing the criteria for electromagnetic compatibility assessment is indicated.

INTRODUCTION

Electromagnetic compatibility needs to be ensured in substations for their reliable operation. Substations have to be built so that the level of interferences that occurs due to lightning, switching manoeuvres in primary and secondary circuits, earth faults, electrostatic discharges and radio transmitters does not exceed the EMC compatibility level of a particular electromagnetic environment, which depends on the interference level and the immunity level of secondary equipment.

The basic requirements for electromagnetic compatibility in substations are determined in the standard [1]. Mitigation measures of reducing electromagnetic disturbances inside substations are published in the technical report [2, 3] and more detailed instructions are given in guidelines [4]. Additional requirements which affect good engineering practice entail the recommendations as stated in the paper [5].

Emission and immunity for many types of equipment are defined in specific product standards and for devices that are not covered by any of the product standards in the generic standards.

There are many existing standardised procedures for testing emission and immunity of equipment in laboratory environment during the certification procedure, such as the IEC 61000-4 immunity test standard series. Some of these standards were specifically designed for simulating the conducted interferences during switching transients (e.g. IEC 61000-4-4 Electrical fast transient/burst immunity test, or IEC 61000-4-12 Ring wave immunity test, or IEC 61000-4-18 Oscillatory wave immunity test). However, in standardisation, there is a lack of standardised test procedures or detailed guidelines for in-situ electromagnetic compatibility testing to determine the electromagnetic compatibility levels in substations due to interferences generated during switching operations in normal operation without the simulation of transient phenomena with the test generator but with actual interference sources.

Post installation tests on equipment in its final installed conditions are mentioned in IEC 61000-4-4, which simultaneously determines that the preferred test method is that of type tests performed in laboratories.

In laboratories, each device is tested at the immunity limit, which is specified for that device in the product standard or in the generic standard. The emission limit at normal operation is also determined for each device. Every device for installation in a substation is designed to operate optimally in a given electromagnetic environment for which it was intended.

The problem with electromagnetic compatibility provision may occur when a particular device is assembled into equipment such as secondary equipment (e.g. equipment for control, protection, measurement, data acquisition, IT systems, DC supply, telecommunication, supervisory systems). On individual electromagnetic environment (levels of interferences that may occur) has a great influence also the design and the quality of the implementation of individual segments (e.g. secondary circuits, equipotential bonding system, earthing system). In the case of switching manoeuvres or different faults or lightning there is a risk that electromagnetic interferences arise and this situation may change the electromagnetic environment. In such conditions it can be questioned if the equipment will still be able to operate normally or whether it will work at all. Due to this reason the compatibility level at which the equipment will operate normally in individual electromagnetic environment must be defined and also the compatibility margin in individual location (e.g. relay room, control room, telecommunication room) must be defined.

The margin level of electromagnetic compatibility in the absolute measurement scale is set by the type test levels of equipment that need to comply with the demands which are set in the standard – and its technical specifications [6].

To find out if in substation electromagnetic compatibility is provided, it is recommendable to make in-situ EMC testing on the complete installation (e.g. secondary circuits). In-situ EMC testing of the complete installation recommends the CIGRE document EMC within Power Plants and Substations [4] but the test procedures are not clearly stated. There is no specification of the levels of interferences (overvoltage) in normal operation at which electromagnetic compatibility is provided in different electromagnetic environments, respectively locations.

There are no guidelines or criteria for in-situ EMC immunity testing and for evaluating the levels of measured overvoltage in existing standards..

IN-SITU EMC TESTING

The difference between the standard test method in a laboratory and the in-situ test method established at the Milan Vidmar Electric Power Research Institute is in the method of generating interferences. In the case of evaluating the immunity level with the standard test method, which is performed in laboratory, disturbance (transient phenomena) is simulated with the interference test generator with exactly defined characteristics (determined in standards). In the procedure of in-situ EMC test presented in the paper, disturbances are generated with actual interference sources that are in substations (e.g. disconnector switching).

In-situ test procedure established at the Milan Vidmar Electric Power Research Institute consists of measuring transient overvoltage (common mode voltage i.e. asymmetrical voltage) on secondary equipment terminals during switching (e.g. disconnector, circuit breaker and mainly in MV switchyards - controlled earth fault). This means that measured disturbances in circuits and on equipment are exactly such as when the equipment is exposed during the operation of the substation.

Locations of measurements are chosen with regard to the importance of the circuit inside the equipment and with regard to the importance of equipment inside the substation. Such circuits are secondary circuits of current and voltage transformers (e.g. control, protection and measurement). For such measurements we need oscilloscopes and voltage probes with sufficient bandwidth. Oscilloscopes do not disturb the proper operation of secondary systems during the measurements but one has to be very cautious when applying probes on terminals in order not to cause any damage or fault.

Measured overvoltage with its characteristics corresponds to the damped oscillatory wave (IEC 61000-4-18) and ring wave IEC 61000-4-12). Overvoltage is measured in control rooms or relay kiosks in enclosures of secondary circuits of current transformers (CT) cores and voltage transformers (VT) windings (Figure 1) between the terminal of the circuit to the terminal of the equipotential bonding system (Figure 2) or directly to the earthing terminal. Switching operations with selector switch disconnectors Q1 or Q2 and feeder disconnector Q9 (Figure 1) are performed in the same bay (e.g. feeder, transformer) as measurements of high frequency disturbances. Switching operations with disconnectors and circuit breakers are used to simulate disturbances (to energise and deenergise equipment - without load), the equipment of which is exposed in normal operation of substation. Circuit breaker in the feeder bay, in the substation where measurements are made, is switched off but the powerline is energised. In the case of switching operations with selector switch disconnectors busbars are live. In the case of measurements in transformer bay circuit breaker in the measured bay is switched off to achieve a no load state.

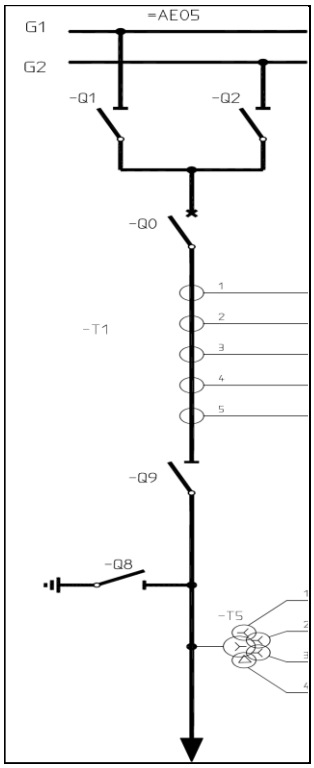

Figure 1: Single-pole scheme of feeder bay

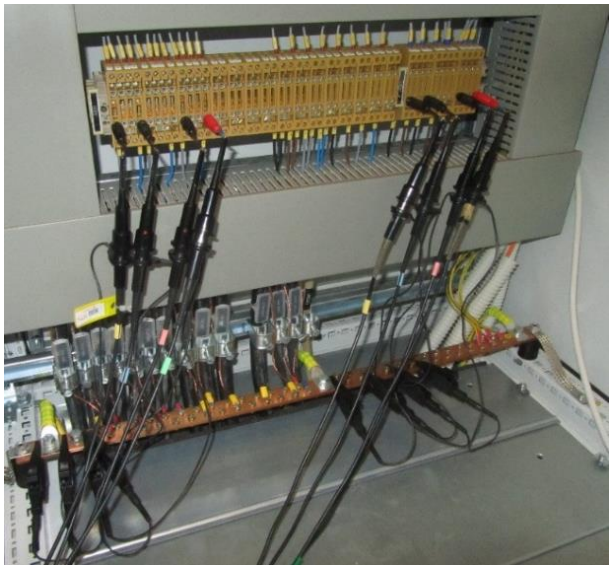

Figure 2: The principle of high voltage probes connection

The criterion for determining the allowable overvoltage that could occur during switching manoeuvres with disconnectors in a given electromagnetic environment (e.g. control room, relay kiosk, switchyard) was set. For

the control room this criterion provides that the overvoltage may not exceed 210 V and for switchyards and relay kiosks 520 V [7]. Such values were specified because it is assumed that in the event of a failure 4 to 5 times higher disturbances could occur than at switching manoeuvres. Such disturbances could reach the standard type test level at which the equipment installed in substation is tested.

Electromagnetic compatibility in a substation is guaranteed in the case that the measured values are smaller than those laid down by the criteria.

The question is what to do when the measured value exceeds the value defined by the criteria, as is shown in Figure 3. Therefore, the criterion needs to be improved.

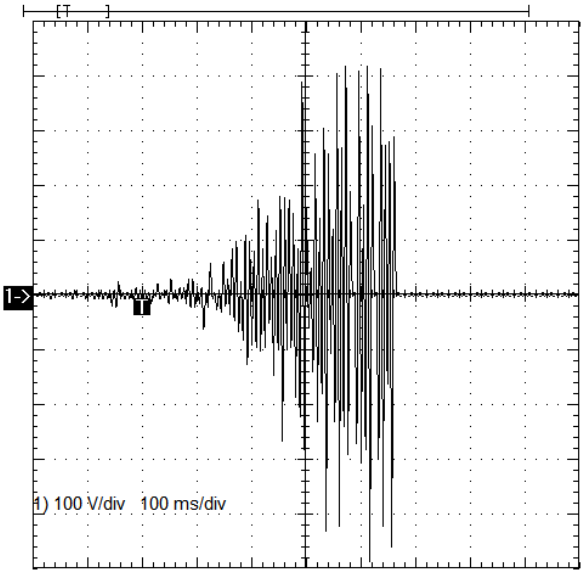

Figure 3: Overvoltage on input port of distance protection relay (at the opening of the disconnector)

THE USEFULNESS OF IN-SITU EMC TESTING

With the in–situ measurements it is possible to check if electromagnetic compatibility in substation is ensured. Therefore, it is possible to get an insight into the state of the electromagnetic compatibility. Secondary devices are tested in laboratories at levels determined by standards (e.g. generic or product), but when installed in the substation they are exposed to a real situation. Each substation is unique due to various influencing factors:

- the geometric relationship between the HV and MV part of the substation and the secondary circuits,
- the material for earthing and equipotential bonding system,
- the quality of the implementation of the secondary circuits,
- the quality of the implementation of equipotential bonding system,
- the quality of the implementation of earthing system,
- the type of instrument transformers,
- the selection of appropriate equipment.

Therefore, interferences (when equipment is exposed in normal operation or at defects) have different levels from those provided in the type tests which are made in laboratories.

The results of high frequency disturbances (transient overvoltage) measurements in a new or reconstructed substation give information on:

- the level of interferences in the existing configuration of the complete installation (e.g. secondary circuits),
- the actual effectiveness of the measures for the interferences mitigation,
- earthing system condition from the high frequency interferences aspect,
- the responses of the secondary equipment in the case of interferences and thus their actual compliance with the electromagnetic environment in which they are embedded.

The implementation of such a measurement is also useful before substation reconstruction, as it gives the investor/owner the information for proper choosing of secondary equipment and for appropriate measures for interferences mitigation. If made periodically it also gives an insight into the aging process of the earthing system and measures for interferences mitigation from the high frequency interferences point of view.

If we do measurements on different locations in substation we can receive the information about the transmission and the attenuation of electromagnetic interferences between different locations.

During normal operation, the levels of electromagnetic disturbances in individual electromagnetic environments (at which the parts of substation are classified) should be significantly lower than the test levels at which equipment is typically tested to achieve the desired compatibility margin.

The levels of disturbances are difficult to precisely predict in advance because the quality of mitigation measures installation also influences the size of interferences. Therefore, the actual level of interferences can be obtained only by in-situ EMC testing. Consequently, it cannot be done as a type test.

THE PRESENTATION OF MEASURED HIGH FREQUENCY DISTURBANCES IN SIMILARLY DESIGNED SUBSTATIONS

Overvoltage is the consequence of electromagnetic disturbances in substations and it can appear in circuits of secondary systems. The basic measure to ensure electromagnetic compatibility is to reduce overvoltage by equipotential bonding at the lowest possible impedance of the earthing network.

Until now, measurements have been conducted in more than 30 substations in Slovenia; even several times in some of them. To illustrate, we expose the results of

measuring high frequency disturbances (overvoltage) in the control room of two air-insulated similarly designed substations (110/20 kV):

- the material for earthing network - galvanised steel,
- equipotential bonding system (hierarchical system of bonding bars),
- cables for secondary circuits with shield,
- the bonding of cable shield into equipotential bonding system on both sides of cable,
- parallel earthing conductor routing along cables of secondary circuits.

In both substations there are two types of circuits – control (ctrl), which feed the bay computer, and distance protection (dp). In each substation, measurements of maximum overvoltage amplitude were made in two bays (i.e. bay 1, bay 2) in secondary circuits (L1, L2, L3 and neutral conductor N and NL3) of CT and VT.

The measured overvoltage for the VT secondary circuits for the substation A is shown in Figure 4 and in Figure 5 for the substation B, respectively. Similarly, Figure 6 presents CT secondary circuits in the substation A, and Figure 7 shows data for substation B.

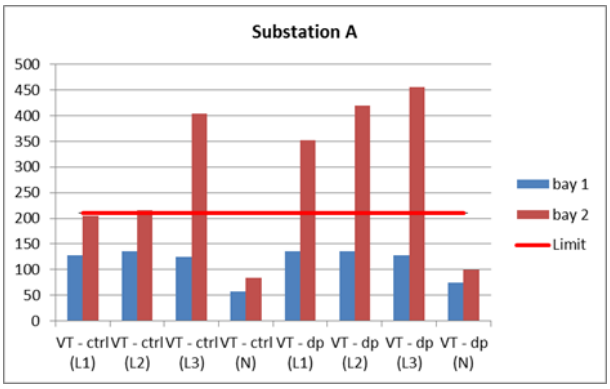

Figure 4: Overvoltage in VT circuits in substation A

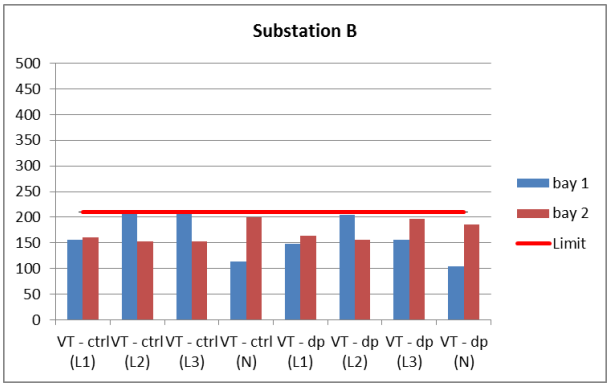

Figure 5: Overvoltage in VT circuits in substation B

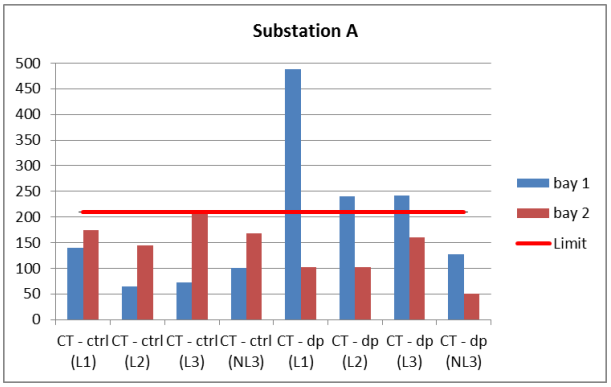

Figure 6: Overvoltage in CT circuits in substation A

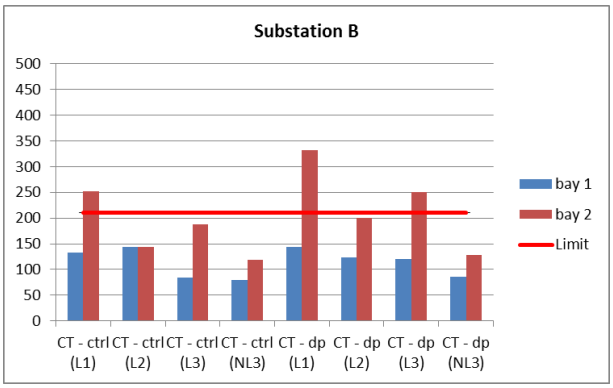

Figure 7: Overvoltage in CT circuits in substation B

Figure 4 shows considerable difference (more than 100%) between bays in substation A, while differences in substation B in Figure 5 are much smaller. Also, the values in Figure 4 exceed the limit while in Figure 5 they do not. A similar situation can be seen in Figure 6 for substation A and in Figure 7 for substation B. From Figures 4 to 7 it can be seen that in some cases there is also a great difference between control and distance protection circuits.

Differences, shown in Figures 4 to 7, are the reason why any laboratory like type tests of substations are not possible since those great differences are present despite similarly designed substations with incorporated all main mitigation measures for electromagnetic compatibility provision. This is exactly the reason why in-situ tests should be done – to find weak spots and make necessary repair or additional mitigation measures or just to confirm proper design and quality of installation.

From Figures 4 to 7 it is evident that the criterion for determining the maximum permissible overvoltage needs to be improved. So far criterion incorporates only immunity type test level and the safety margin. With the existing criterion it is not possible to confirm if the electromagnetic compatibility in the substation, where the overvoltages in secondary circuits are so different, is provided.

Moreover, in some substations, the measured values reach a type test value (the level at which the equipment is tested) or even exceeds it. Due to that reason and due to measured different overvoltage in secondary circuits it is evident that only a type test of equipment in the laboratory is not enough to evaluate the electromagnetic compatibility provision of a substation but it is advisable to perform in–situ EMC testing.

CONCLUSION

Standards and guidelines do not specify the levels of interferences (overvoltage on circuits of secondary systems) in normal operation of substations at which electromagnetic compatibility is provided in different electromagnetic environments, respectively locations. If such standardised procedures would exist, the owner or manager could assess the establishment of electromagnetic compatibility. Because these procedures are not available, owners/managers must rely on the incorporation of adequately tested equipment for specific electromagnetic environment. Their other assumption is based on the expectation that the planned mitigation measures for electromagnetic compatibility provision are fully completed according to the best engineering practices.

From the results of the measured overvoltage, it is evident that quite great differences exist in measured amplitudes despite similarly designed substations´ earthing system and equipotential bonding system, which clearly shows that the improved criterion is indeed necessary. An improved criterion should distinguish between different electromagnetic compatibility levels in substations and include the influence of primary equipment (e.g. instrument transformers), the quality of installation of the earthing system and the equipotential bonding system, the compatibility margin and also the type test level of secondary equipment.

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