New system level EMC performance check for MV power substations under switching transients

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ABSTRACT

Currently, there is a strong demand for cost effective and compact medium voltage (MV) switchgear to turn existing distribution grids into smart energy networks with enhanced capability and sustainable functionality.

This results in switchgear designs continuing to shrink in size while simultaneously operating at increasing voltage levels. From the electromagnetic compatibility (EMC) point of view, this leads to a significantly higher stress on the intelligent electronic devices (IEDs). In other words, the IEDs are increasingly exposed to disturbances well beyond their formerly (type-) tested levels. Therefore, although the IEDs still pass all of their specified EMC type tests, there is a growing risk of electromagnetic interference during their service life.

This paper compares the real-life disturbances due to switching operations with the applied EMC stress during the type tests in the time and frequency domain. It shows the main shortcomings and gives information about their root causes. A practical recommendation for a new and effective approach to EMC performance testing at the system level is provided.

1 INTRODUCTION

In some cases primary and secondary switchgear installations can have an insufficient EMC performance even though they have been tested according to the relevant standards without regard to a specific manufacturer or a product. Since it is especially important to prevent the unintended tripping of protection functions, this paper is focused on the measurement circuits of the IEDs. In particular, the current transformer circuits are investigated because they are used more frequently than voltage transformers.

This paper is based on a large number of site and laboratory experiences, identifying worst case scenarios. These are used as the rudimentary basis for the definition of a new approach for testing the system EMC of MV power substations.

2 ORIGIN OF SWITCHING TRANSIENTS

Switching transients are due to arcing phenomena during switching operations. The arcing itself is characterized by the functional principle of the switch.

For typical vacuum circuit breakers (CB), it is generally known that the level of occurrence as well as the correlating EMC stress of restrikes depends mainly on the load. However, single prestrikes at the CB contacts can also be found during any closing operation independently of the load condition.

Regarding disconnectors, capacitive loads with values of a few tens of picofarads up to some nanofarads are always switched. These values correlate to short lengths of primary conductors inside the switchgear or to power cables of some tens of meters in the case of special bus coupler panels.

Practical experiences have proved the theory that slowly moving disconnectors within bus coupler panels (both longitudinal and transverse couplers) generate the most severe EM disturbances, except for very special and unusual constructions.
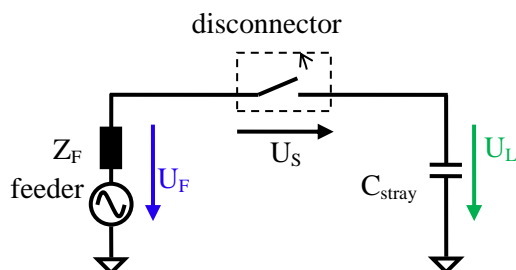

Figure1 - Equivalent circuit diagram of a disconnector opening operation. The voltage across the switch contact represents the insulation capability.
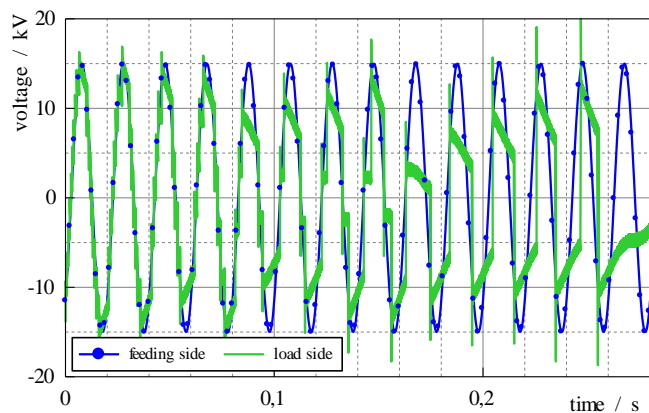
Figure 2 - Voltages during disconnector opening in a bus coupler panel. An expanded view of the transients of a single reloading event is shown later in figure 3.

In this paper, the usual case of a disconnector switching bus coupling MV parts is investigated. Figure 2 shows the voltage signals on both sides of the disconnector according to the equivalent circuit diagram of figure 1.

Every recharging process of the parasitic capacitance causes two travelling waves on the primary conductors, one in each direction. Due to the capacitive coupling in the instrument transformers, the steep edges of the travelling waves cause conducted EM disturbance at the IED inputs. The amplitude of the transient overvoltage at the IED is linearly proportional to the rise time and the peak value of the wave front at the primary terminals of the instrument transformer. In summary, the amplitude of the transient disturbance at the analog measurement inputs of the IED is primarily depending on:

- the operating voltage of the switchgear

  A higher operating voltage leads to higher ignition voltages at the switch contacts, higher wave fronts and higher disturbance amplitudes. For opening operations, the maximum ignition voltage is twice the peak value of the applied line-to-ground voltage.

- the type of switchgear panel

  Practical experiences at different sites have shown that bus coupler panels generate the most severe disturbance. Feeder panels are much less critical, the reasons are given in chapter 5.

- the insulating medium of the disconnector

  Generally, a higher breakdown field strength of the insulation medium causes steeper wave fronts and thus, more spectral contributions at higher frequencies. But, more detailed investigations have shown only small differences between air and SF_6 insulated disconnectors. For comparison, two measurements (with air and SF_6) made under the same ancillary conditions are plotted in figure 3. The rise times of the travelling waves measured at the current transformer's primary clamps have almost the same value of about 15 ns.
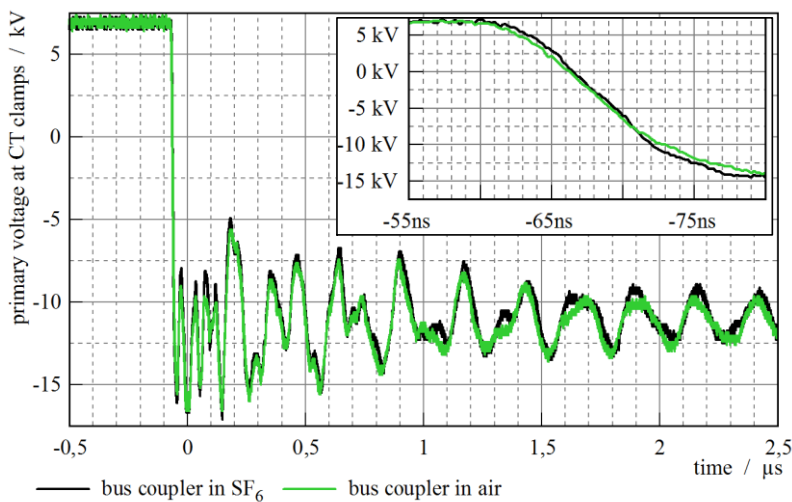

Figure 3 - Comparison of the wave front characteristics due to ignitions at disconnector contacts in air and SF6

The reason for this unexpectedly small deviation could be the poor wave guide characteristics of the substation at higher frequencies.

- the parasitic capacitance of the CT / VT

  Figure 4 shows the equivalent circuit diagram of an analog measurement circuit. It is obvious that larger coupling capacitances cause stronger electromagnetic coupling between the primary and secondary components and result in higher disturbance voltages U_d at the IED inputs.
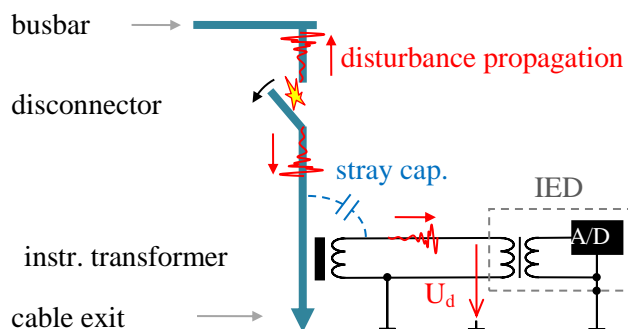
Figure 4 - Disturbance propagation on the primary and secondary parts of a typical switchgear panel.

- the secondary wiring and the IED input
    Assuming that the secondary wires can be described as transmission lines, varying the line lengths or the IED input circuit essentially changes the impedance conditions of the system. Other impedances lead to other disturbance voltage distributions. As a result, the secondary wiring as well as the input impedance of the IED must be taken into account when the interference between the primary side and the IED is considered.

3   EMC REQUIREMENTS FOR IEDS

The market launch of new protection or control units for use in the harsh electromagnetic environment in switchgear assumes that at least the EMC requirements defined in the international standards IEC 62271-1 and IEC 60255-26 are met. For all signal ports (i.e. also for measurement ports) the following immunity requirements are defined:

- Electrical fast transient ("burst") test:

    - level 2 (2 kV), for class B products
    - level 3 (4 kV), for class A products
    - coupled by capacitive coupling clamp (CCC)
    - according to IEC 61000-4-4

- Damped oscillatory wave (DOW):

    - Test level: 1,0 kV common mode (CM)
                     2,5 kV differential mode (DM)
    - Frequencies: 100 kHz and 1 MHz
    - Coupled via coupling/decoupling network (CDN)
    - According to IED 61000-4-18

The listed tests must be passed without any temporary or permanent degradation of the protection, command or control functions.

Regarding these standard test routines, one very essential point has to be considered:

The disturbance voltage occurring at the terminals of the device under test (DUT) is definitely much lower than the specified test voltages (level) in the standards.

Independent of if the test is executed in CM or DM, the test voltage is always divided into three parts, the voltage drops at the generator's internal resistance, at the coupling device (CDN or CCC) and at the DUT. Figure 5 shows the equivalent circuit diagram of a typical burst test as well as the splitting of the test voltage.
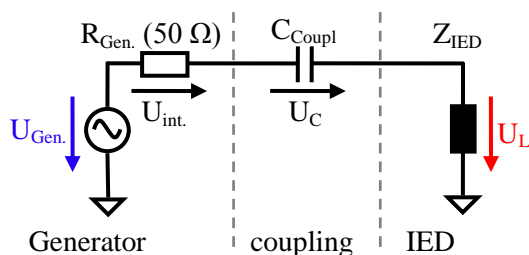

Figure 5 - Voltage drops at an electrical fast transient/burst test.

Since DM disturbance plays a minor role for CT inputs of IEDs, the measurements in figure 6 and 7 show the applied CM test voltages of both burst and DOW immunity testing.
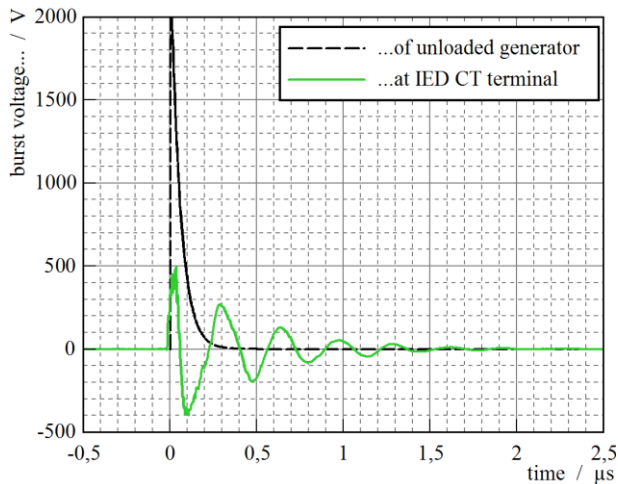
Figure 6 - Measurement of the open circuit and the actually applied test voltage of a fast transient/burst generator. A 1 m CCC was used as coupling device
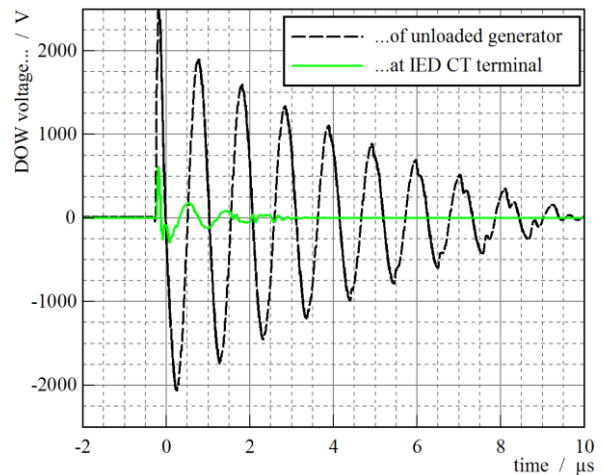

Figure 7- Measurement of the open circuit and the actually applied test voltage of a 1 MHz damped oscillatory wave generator.

The burst test itself can be considered as a broad-band stimulation of the input under test. In this case, a resonance circuit of parasitic elements starts oscillating with its natural frequency of about 3 MHz. Even if such dominant resonances appear, the other frequency contents of the burst waveform are also tested, because they are still present in the rise time of the first voltage edge.

The rise time of the DOW is 75 ns. The DOW test can be regarded as a narrow-band test with one dominating frequency (100 kHz or 1 MHz). Therefore, in this case the measurement of the disturbance voltage at the IED shows mainly the 1 MHz oscillation of the test generator. Natural resonance frequencies are not stimulated due to the limited spectral frequency content in the long rise time of the test signal.

Finally, both measurements show significant differences between the nominal IEC test levels (load voltage of the test generator) and the measured voltage levels at the CT terminal of the IED (much lower). Thus, a burst or DOW test can always confirm only the immunity levels which are measured at the IED inputs.

4   TYPE-TEST VERSUS REAL-LIFE DISTURBANCE

It is a fact that (independent of the IED and switchgear manufacturer) some sites can show electromagnetic interference (EMI) at the IEDs during switching operations in the primary circuits of the medium voltage switchgear. Therefore, there is just one valid explanation:

Today, the electromagnetic stress in service of an IED can be much higher than the previously type tested disturbance levels (higher frequency and/or amplitude).

In order to identify the gaps between real-life and the type-test EMC disturbance a research setup was constructed at the high voltage laboratory at the University of Stuttgart. The setup consists of three switchgear panels, a 90 kVA test transformer for feeding and a power cable of 10 m in length. The switchgear for the test was used in a configuration to simulate the most severe case of a bus coupler panel. One phase of the busbar is energized with 10 kV_{L-GND} by connecting the feeding transformer to the left panel. The disconnector in the mid panel is used for the switching of the primary parts representing the busbar interconnection. The right panel is not used in this test, its disconnector is closed and a dummy plug mounted in the power cable socket. Figure 8 shows the single line diagram of the test setup as well as the disturbance propagation paths and measurement points.
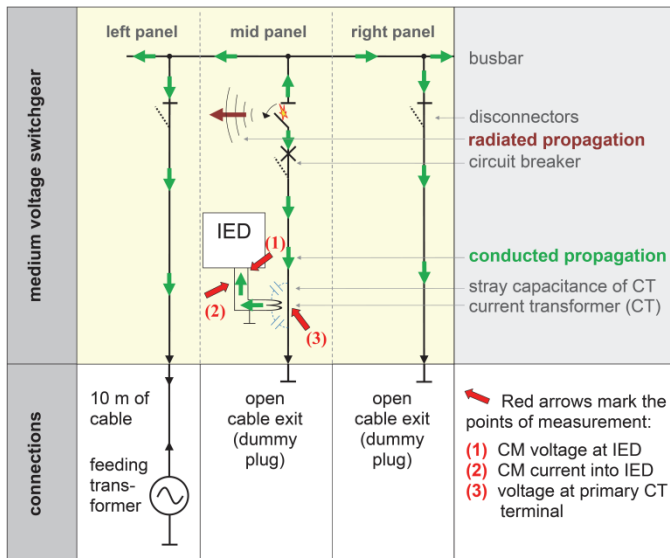
Figure 8- *Single line diagram of the installed test setup at the high voltage laboratory at the University of Suttgart.*

In the mid panel the protection device (IED) and the current transformers (CTs) are installed. The CTs used are 2000 A types to get close to the worst case of a high coupling capacitance (32 pF) due to the high turns ratio and the large secondary winding.

The characterization of the EMC performance was carried out using the disturbance voltage at the IED's CT terminal. Further, the CM disturbance current into the CT port was measured to provide more future possibilities for verification. Figure 9 and figure 10 show the disturbance pulses at the IED due to an opening operation of the mid panel's disconnector.

Viewing the measured voltage signal in Figure 9 without knowing the applied values during the type test, it is seen that the disturbance voltage is just a little bit higher than the nominal burst test of 2 kV defined by the standard. Therefore, the situation spuriously seems to be under control.
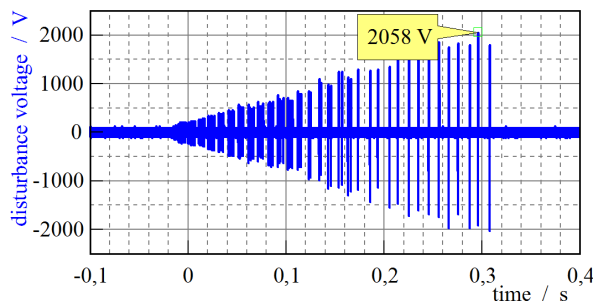

Figure 9 - Measurement of the disturbance voltage during a disconnector opening operation using an oscilloscope in peak-detect mode
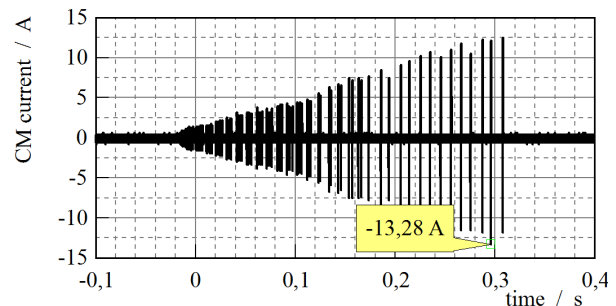

Figure 10 - Measurement of the disturbance current during a disconnector opening operation using an oscilloscope in peak-detect mode.

Executing the electrical fast transient/burst type test according to the standards will show that the applied test voltage at the CT terminal is just about 500 V_{Pk} (see figure 6). As a consequence, the real-life disturbance in service can exceed the tested level by a factor of approximately 4.

The gaps between the real-life and the type-test disturbance can be explored in more detail by transforming the signals into the frequency domain and comparing the amplitude density spectra of the disturbance records. Figure 11 shows there are frequency ranges, where the real-life disturbance is up to 50 dB higher (a factor of 316) than the measured values during the type tests.
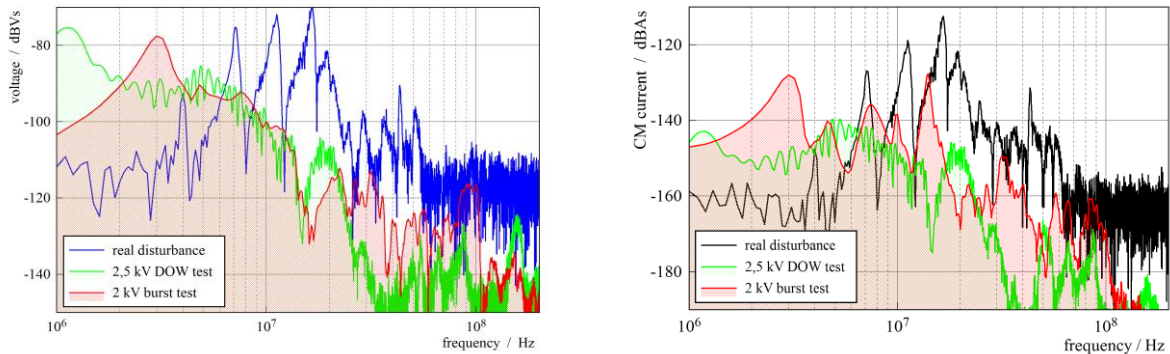
Figure 11 - Comparison of the real-life and typetest disturbance signals in frequency domain.

Remark: For the real-life disturbance in the frequency range above 60 MHz, there is only background noise visible due to the limited vertical resolution of the measurement device (8 bit). The dynamic range was enhanced in the case of the burst and DOW pulses by repeatedly applying and averaging the pulses before transforming them to the frequency domain.

Ultimately, two major problems need to be addressed when relying on the results of the standard EMC type tests:

1. The disturbance levels applied to the IED terminals during the type tests are not known.

2. The expected disturbance, occurring at the IED in service cannot be estimated.

As a conclusion, a new testing method has to be found which takes the two unknown parameters into account. Otherwise, the EMC behavior of switchgear (i.e. combination of any primary and secondary equipment) can neither be estimated nor validated.

5   SUBSTATION EMC TESTS

Based on the findings above, a new approach for a substation EMC test must be derived. The goal of the new test should be to obtain reliable predictions about the internal EMC behavior of the complex electromagnetic system known as switchgear.

Principally, there are different solutions to reach this basic objective:

A. The standardized IEC solution

The first solution is published in the Annex J of the IEC 62271-1 standard. There, an on-site evaluation method for the system EMC of switchgear panels is described. This test is based on real switching operations under high voltage and no load conditions (i.e. equal to the worst case of a bus coupler). The pass/fail criterion is that "the recorded or calculated peak value of induced common-mode voltage, due to switching in the main circuit, should not exceed 1,6 kV for interfaces of the auxiliary and control circuits."

This test is an excellent approach for an on-site estimation of the system EMC. But for a watertight validation, the type-tested disturbance levels should be taken into account in addition to the fixed value of 1,6 kV. Further, this test is time and cost-intensive so that it is rarely applied by manufacturers. Especially as a pre-compliance test during the development stage of a new product it is principally unsuitable.

B. The "sure-fire" approach

To achieve a 100 % EMC validation, the practice is to compare the real switching disturbance of a worst case panel (no load or bus coupler) with the measured susceptibility levels during the type tests in the frequency domain. If the type tested disturbance spectra are above the spectrum of the disturbance due to the worst service case, this test is passed. Recording the different spectra can be realized in the frequency domain by test receivers or spectrum analyzers in the peak detect mode, or in the time domain by adequate probes and oscilloscopes with a minimum bandwidth of 100 MHz (but typically with a reduced dynamic range).

C. The new system level EMC performance test

This new substation EMC test provides the possibility for a time and cost effective evaluation of the EMC performance of medium voltage switchgear. Further, the use of simple methods and the applicability as a pre-compliance test during the development stage of new secondary equipment (or even some kinds of primary products) is provided.

The test is based on the sure-fire approach, but uses some simplifications to reach a high degree of practicability:

- Use of just one panel

    The highest amplitude value of the disturbance at the IED measurement ports due to ignitions at the switch contacts is determined by the highest wave front hitting the instrument transformer. Typically the first wave front due to an ignition is also the highest one, its rise time has maximum values of 15 nanoseconds. Therefore, only reflections in the close electrical vicinity of the instrument transformer can increase the first transient voltage edge. 15 ns correlate to a maximum distance of

$$L = \frac{C_0}{t_r} = \frac{3 * 10\wedge 8 \frac{m}{s}}{15 ns} = 4,5 m$$

    assuming C_0 (speed of light in vacuum) as the propagation speed for transients inside the panel.

    4,5 m is mostly in the range of the own panel, so the neighboring panels are expected to have no influence on the maximum value of the disturbance on the secondary wiring.

- Artificial stimulation of primary parts

    The transient wave front due to the ignition process at the disconnector is replaced by a fast transient/burst pulse. Burst pulses have a similar rise time (5 ns) compared to the dielectric breakdown between the disconnector contacts. Coupling the burst pulses to the primary parts of the switchgear increases their rise times in the same way as for wave fronts from disconnector ignitions (e.g. due to stray capacitance in the CT).
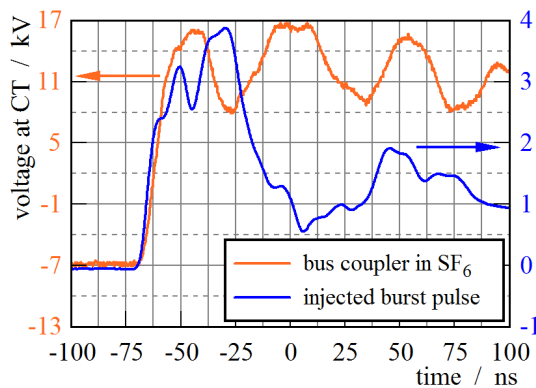

Figure 12 - Comparison of different wave fronts measured at the CT.

    Hence, the transient wave front measured at the instrument transformer is very comparable for injected burst pulses and real ignitions at the disconnector. Major differences are just in the amplitudes. The maximum wave front amplitude due to disconnector ignitions is proportional to the operating voltage of the switchgear, the amplitude of injected burst pulses is adjustable at the test generator, and thus, well known.

- Neglecting substation earthing conditions

    Regarding the common mode noise at analog measurement terminals, the reference ground for the IED is the switchgear chassis potential. For that reason, the connection of the panel to the substation's earthing system has no influence on the EM disturbance values at these ports. The substation grounding has no influence on DM-Dist. due to the same reasons.

- Interpretation of max-values in the time domain

    Presuming that the burst pulses of the EMC type test and the disturbance pulses due to real switching operations have a similar spectrum, the test procedure is going to take over the simplification of the IEC solution and uses just the maximum values of the measured disturbances. This simplification leads to a faster evaluation process (because of measuring in the time domain) but keeps the same reliability of the results. Similar to Annex J of the IEC 62271-1 standard, the "Instrumentation for recording induced voltages should be connected as outlined in IEC 60816".

6   DESCRIPTION OF THE TEST PROCEDURE

The new test procedure is divided into 4 parts. Before starting the test, any existing circuit breaker has to be closed and each disconnector must be in an open position. The cable exits of the panel have to be open, i.e. no loads (even no free-running power cable) are connected.

Step 1: Identification of the tested immunity level

Select a port to be tested and carry out the fast transient/burst test according to the relevant standard (e.g. level 3 / 2 kV for class B devices). Record the peak value of the disturbance voltage at the selected port by adequate instrumentation (minimum bandwidth of 100 MHz) as shown in figure 13 and according to IEC 60816.
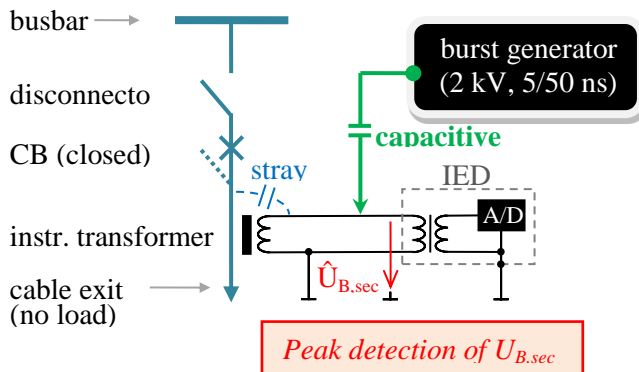

Figure 13- Measurement of the actually applied test level

Step 2: Burst injection on the primary side

Apply 4 kV (level 4) burst pulses on the power cable exit of the switchgear panel. Again, record the peak value of the disturbance voltage coupled to the IED port under test. Figure 14 graphically illustrates this step of the test procedure.
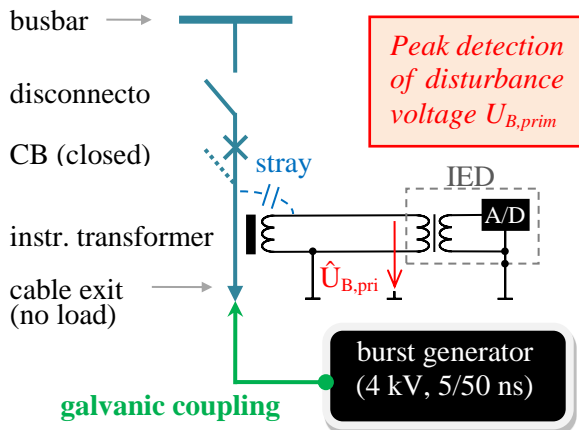

Figure 14- Measurement of the disturbance voltage at the IED during artificial stimulation of the primary side using burst pulses

Step 3: Calculation of the scaling factor

The recorded peak value of the coupled common mode voltage at the port under test has to be multiplied with the disturbance scaling factor

$$k_d = \frac{U_{step,max}}{U_{Burst}} = \frac{U_m \cdot 2 \cdot \sqrt{2} / \sqrt{3}}{U_{Burst}}$$

$U_{step,max}$ represents the voltage step of the highest transient wave front hitting the instrument transformer for an operating line to line voltage of the switchgear of U_m.

Remark: The highest voltage step is calculated on the basis of the maximum ignition voltage between the disconnector contacts as well as on the propagation laws for travelling waves. Due to an ignition at the maximum possible voltage between the switch contacts (U_{Pk-Pk}) two travelling waves start propagating, one in each direction. Both waves start travelling with amplitudes of half the ignition voltage, but with different polarities. The wave which runs into the direction of the instrument transformer will be reflected at the open (unloaded) cable exit. Thus, the first wave front gets doubled (reflection factor = 1) and the transient wave front U_{step} reaches an amplitude equal to the voltage value which had triggered the ignition between the switch contacts.

$$U_{ign,max} = U_{step,max} = U_m \cdot 2 \cdot \sqrt{2} / \sqrt{3}$$

U_{Burst} represents the burst voltage applied to the primary side.

Table 1 gives some examples for scaling factor values for the most usual operating voltages of medium voltage switchgear:

rated voltage U_m	maximum voltage step $U_{step,max}$	injected burst amplitude U_{Burst}	disturbance scaling factor k_d
10 kV	16,3 kV	4 kV	4,1
17 kV	28,3 kV	4 kV	7,1
24 kV	39,1 kV	4 kV	9,8
36 kV	58,8 kV	4 kV	14,7
40,5 kV	66,1 kV	4 kV	16,5

Table 1 – scaling factors for different operating voltages.

Step 4: Interpretation

The interpretation starts with the calculation of the disturbance voltage expected under worst case (bus coupler panel) conditions in service:

$U_{d,exp} = k_d \cdot U_{B,prim}$

The main pass/fail criterion for this test is that the expected disturbance voltage $U_{d,exp}$ does not exceed the tested immunity value $U_{B,sec}$, recorded during the fast transient/burst type test.

Further, the expected disturbance voltage $U_{d,exp}$ should not exceed the maximum tolerated disturbance limit of 1,6 kV defined by the IEC 62271-1 standard.

Only if both criteria are fulfilled, is the test passed.

Remark: Failing this test does not explicitly imply that the IED will have malfunctions in service, but it is an indicator that disturbances can occur outside of the tested range. So, the first approach if this test is failed should always be to increase the burst test level and to check if the IED has a higher immunity level as already tested.

7   VERIFICATION OF THE NEW APPROACH
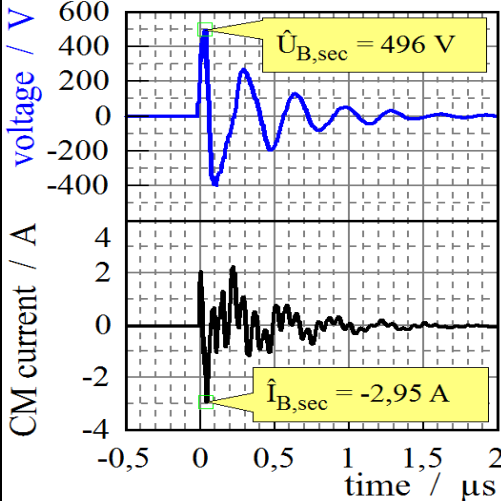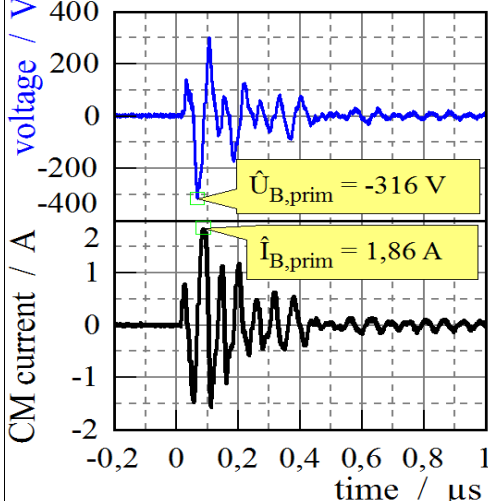
A. Verification 1:

The first verification of this new approach was done using the above introduced test setup. The operating voltage of the switchgear test setup was $10\ kV_{L-GND}$.

From figure 11 it is already known that this setup is not sufficient in terms of the system EMC performance. Over a wide frequency range the spectral density of the real switching disturbance is

much higher than the spectra measured during the type tests. Thus, the new system EMC performance test for this laboratory setup should clearly show up the mismatches.

For an even higher degree of verification, the approach is additionally applied to the CM disturbance current into the tested CT port of the IED.

The results of the new system EMC performance test for the above introduced test setup are as following:

Step 1: Tested immunity level	Step 2: Burst injection on the primary side
Figure 15- Measurement of the applied test level at 2 kV burst application on secondary side.	*Figure 16 - Disturbance measurement at 4 kV burst injection on the primary side.*
Step 3: Scaling factor k_d $$k_d = \frac{U_m \cdot 2 \cdot \sqrt{2} \big/ \sqrt{3}}{U_{Burst}} = 7,1$$	Step 4: Interpretation $\hat{U}_{d,exp} = 7,1 \cdot 316 \text{ V}$ $\qquad = 2244 \text{ V}$ $\qquad > 1,6 \text{ kV (IEC)} > \hat{U}_{B,sec}$ $\Rightarrow$ Test failed !

Comparing the expected disturbance level $\hat{U}_{d,exp}$ = 2244 V to the measured disturbance ($\hat{U}_{d,meas}$ = 2058 V) during the switching operation of figure 9 shows that the disturbance estimation works very well. The deviation of the disturbance voltages is 9 %.

The calculation of the CM disturbance current results in an expected value of $\hat{I}_{d,exp}$ = 7,1 · 1,86 A = 13,21 A. The measured value during the real switching operation of figure 10 was almost the same (13,28 A).

Both, the disturbance voltage and current estimation fit really well to the measurement during the real disconnector operation. Further the test interpretation "failed" is absolutely correct for this switchgear setup, because the gap between the expected and the tested disturbance is very high.
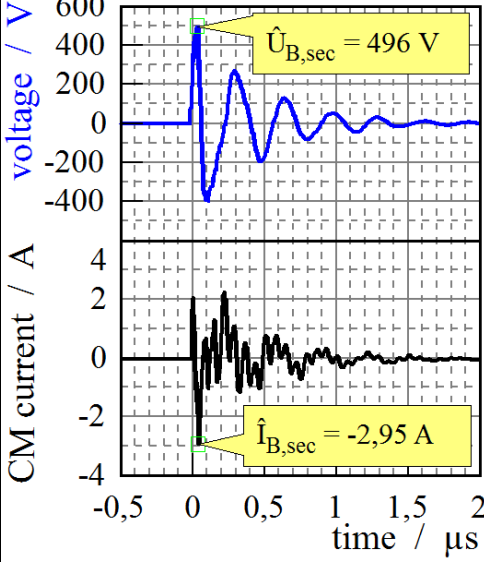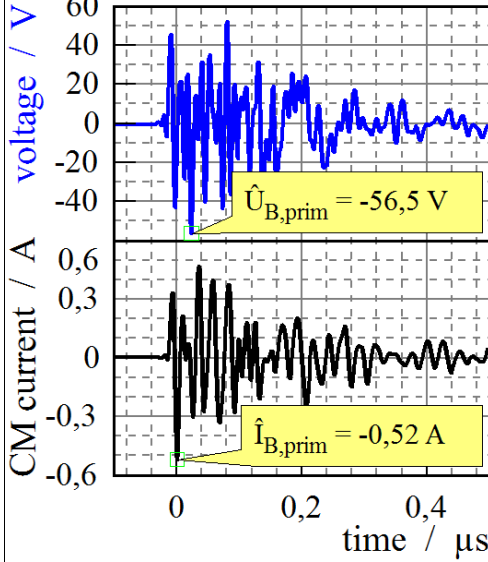
In order to get an idea of how far the compliance limit is fulfilled or not (i.e. the test is passed or failed), the compliance index $\hat{U}_{B,sec}$ / $\hat{U}_{d,exp}$ can be defined. Here, the compliance index has a very small value of 22 % indicates that the test is clearly failed.

In summary, the new test method supplies absolutely representative results for the case of this first verification.

B. Verification 2:

For the second verification again the above introduced test setup was used, but the current transformer was changed to a screened type. All the other equipment was the same. The screened CT has the same turns ratio of 2000, but the parasitic capacitance is reduced to about 2 pF between the primary and secondary winding.

The following values are determined using the new test:

Step 1: Tested immunity level	Step 2: Burst injection on the primary side
$\hat{U}_{B,sec} = 496\ V$ $\hat{I}_{B,sec} = -2{,}95\ A$	$\hat{U}_{B,prim} = -56{,}5\ V$ $\hat{I}_{B,prim} = -0{,}52\ A$
Figure 17- Measurement of the actually applied burst test level, equal to figure 15.	*Figure 18 - Disturbance measurement at 4 kV burst injection on the primary side.*
Step 3: Scaling factor kd $$k_d = \frac{U_m \cdot 2 \cdot \sqrt{2} \big/ \sqrt{3}}{U_{Burst}} = 7{,}1$$	Step 4: Interpretation $\hat{U}_{d,exp} = 7{,}1 \cdot 56{,}5\ V$ $\qquad = 401\ V$ $\qquad < \hat{U}_{B,sec} < 1{,}6\ kV\ (IEC)$ => Test passed !

Once again the calculated values $\hat{U}_{d,exp} = 401\ V$ and $\hat{I}_{d,exp} = 7{,}1 \cdot 0{,}52\ A = 3{,}69\ A$ fit very well the following measurements (figure 19 and figure 20) of the disturbance values during an opening operation of the disconnector. Thus, the estimation algorithm for the real switching disturbance is again proved.
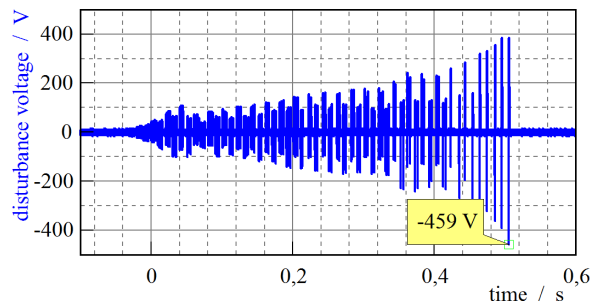

Figure 19 - Measurement of the disturbance voltage during disconnector opening operation and use of a screened current transformer.
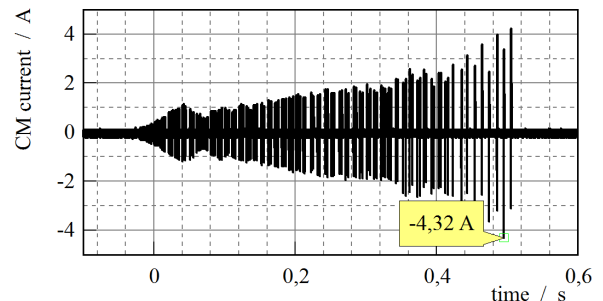

Figure 20 - Measurement of the CM disturbance current during disconnector opening operation and use of a screened current transformer.

As a result the switchgear passes the new EMC test with a compliance index of $\hat{U}_{B,sec} / \hat{U}_{d,exp} = 459$ V / 401 V = 114 %. So, EMC problems due to the analog CT inputs are not expected within the service life, but the safety buffer of 14 % is not that large.

The correctness of this interpretation can be discussed after transforming the different disturbance pulses into the frequency domain and viewing their amplitude density spectra:
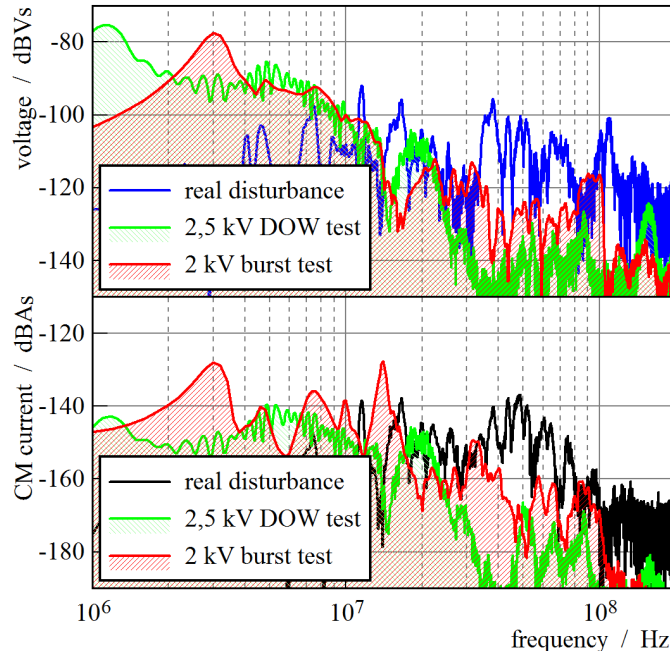

Figure 21 - Comparison of real life and type-test disturbance values in the frequency domain (using a screened CT)

Over the major frequency ranges, the disturbance due to a disconnector operation under high voltage conditions is now within the tested area. But, exceptions can still be found for 2 spot frequencies between 10 MHz and 20 MHz as well as for the frequency range from 30 MHz up to 100 MHz.

Basically, the measurement shows that the screen of the CT works effectively in the frequency range up to about 30 MHz, above that there is no significant disturbance mitigation effect.

Finally, the outcome (based on the comparison in the time domain) that the realistic disturbance is completely covered by the EMC type tests cannot be maintained. Also, an interpretation that there is absolutely no risk of interference is not proved by the frequency domain analysis (figure 21). If the IED has weak points in the frequency range of the exceptions, interferences can also appear. But, having some experience with the compliance index, it should be clear that a value of 114 % is not at all an indication of a high safety margin.

C. Limitations of the new system EMC performance test

The new test method can only work as long as the system has a linear nature. That means, no non-linear components like voltage limiters (varistors, suppressor diodes, etc.) are installed. Even flashovers on the secondary side can be seen as voltage limiters and should be prohibited.

Further, common mode chokes based on ferrite (or similar) materials can also show a non-linear behavior due to saturation effects of the cores. Therefore, the method is not usable for the verification of disturbance mitigation measures where ferrites are used. The verification of the mitigation effects of ferrites needs comparative measurements under real-life conditions, i.e. switching operations at nominal operating voltage.

8   SUMMARY / CONCLUSION

In order to minimize the risk of damaging medium voltage equipment, the proper functioning of all control and protection units should be assured at all times during the service life of MV substations. This includes that, even during switching operations in the main circuits, no unacceptable electromagnetic interference (like protection over- or under-functioning) appears.

It is shown that fulfilling today's normative requirements cannot fully ensure these functional demands. For IED interfaces of the analog measurement circuits, there can be wide gaps between the applied EM stress of type tests and the real-life disturbances during switching operations in service.

In order to close the identified gaps a system level EMC performance test is introduced. The new test method is based on simple means and is highly cost and time efficient. Thus, it can be used

- as an on-site EMC evaluation of switchgear installations.

- as a functional pre-compliance test for switchgear equipment under development.

- for the estimation of transient CM voltages on the auxiliary circuits during switching operations on the primary side.

As the major result, the system level EMC performance test provides information that indicates if the maximum value of the transient overvoltage at the IED terminals is higher or smaller than the type tested level. Further, a compliance index can be indicated which gives an idea for the reliability of the pass/fail interpretation of this test.

In the end, failing this test does not necessarily lead to malfunctions of the IED in service, but it should be understood as an impulse for further EMC activities. For example, higher test levels for the IEDs (level 4 instead of level 3 burst test) could be chosen. If a level 4 burst test does also not cover the expected real-life disturbance values, an optimized voltage or current transformer should be chosen. From the EMC point of view, not every instrument transformer is qualified for use in any kind of switchgear (i.e. especially for higher rated voltages).

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