456
TECHNICAL BROCHURE
WG A3.22

# **Background of Technical Specifications** for Substation Equipment exceeding 800 kV AC

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## Introduction

In 2008, CIGRÉ WG A3.22 published Technical Brochure 362: "Technical Requirements for Substation Equipment exceeding 800 kV AC". A second TB is now available which further develops the background information and, where appropriate, presents recommendations for the international specification and standardization of UHV equipment.

As the studies of WG A3.22 are based on only a few examples of UHV projects, some subtle modifications to earlier conclusions and recommendations are incorporated in this document however these are both minor and limited. Such refinements will, doubtless, continue as service experience with UHV systems increases. Indeed, since January 6th, 2009, in China, a single circuit 1100 kV overhead line system with three substations has been in full operation and this is sure to provide valuable data over the coming years.

Based on the information available to date the following key areas have been addressed by WG A3.22.

## Insulation Coordination

UHV technology is characterized by a need to minimise the sizes, weights, costs and environmental impacts of the overhead lines and substations and hence to develop projects which are feasible from an economic, societal and technical point of view. The UHV voltages presently standardized by IEC are some 50% higher than those for system voltages of the 800 kV class, however since insulation strength per metre decreases with the length of the air gap (particularly for switching impulses under wet conditions) simple extrapolation of the dielectric requirements would lead to disproportionately large structures. By means of the application of a number of new technologies and new analysis techniques, utilities are able to reduce the dielectric requirements to values that lead to much smaller structures. This results in insulation levels that are not far from the levels applied at the 800 kV class (figure 1). In Japan the towers of the UHV OH-lines are only 77% of the size that would be necessary if insulation levels would have been extrapolated directly from the lower voltage classes (figure 2).

Technologies used to reduce the insulation levels include surge arresters with a lower ratio between LIPL/SIPL and COV (Continuous Operating Voltage). By applying multi-column arresters and/or a number of arresters in parallel, the ratio can be further decreased. Closing resistors are used to control slow front overvoltages (SFO) during closing and re-closing overhead lines.

SFOs generated in healthy lines on the source side of a fault-clearing circuit-breaker are typically most severe for low probability events such as two and three

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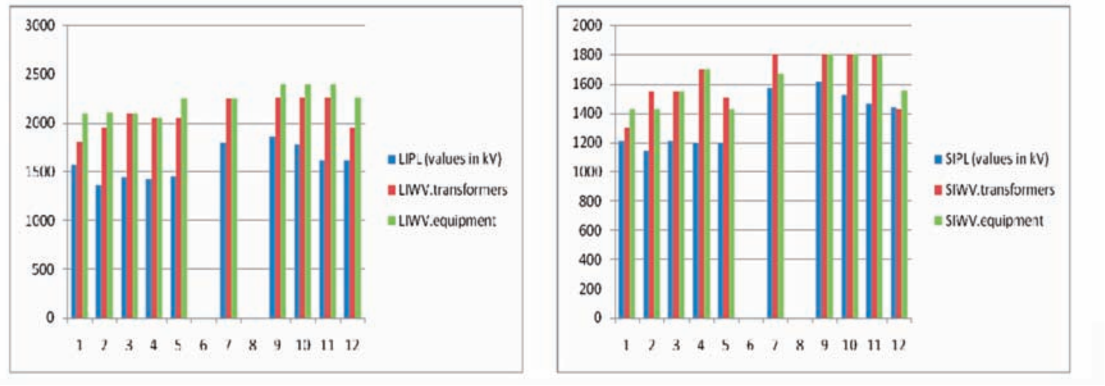

Figure 1: LIPL/LIWV (left) and SIPL/SIWV (right) for 800 kV (1-5), 1050 kV(7), 1200 kV(9,10), 1100 kV(11,12)

phase ground faults. Despite their low probability of occurrence in UHV systems, opening resistors are used to reduce opening SFO due to the potential consequences of successive breakdown which may affect the whole system. Techniques such as the application of transmission line arresters (TLA), and/or controlled switching may be used to control SFOs in future.

Shielding of overhead lines, improved earth return conditions and other countermeasures against backflashover lead to a better lightning withstand performance. When necessary, damping resistors in GIS disconnectors, can reduce the amplitude of VFTO-phenomena that otherwise may exceed the LIWV of the switchgear.

As can be seen in figure 1, reduced margins between LIWL and LIPL, and between SIWL and SIPL, help to explain why insulation levels for UHV are not far from those for 800 kV. By applying advanced calculation and simulation techniques utilities are able to assess the critical conditions and events that need to be considered when designing UHV systems and ensure that these are consistent with their policies regarding design risk.

## Transient Recovery Voltages (TRV)

One of the most important findings for UHV networks is that the surge impedance of overhead lines is less than the standardized 450 Ω. Large multi-conductor bundles that do not collapse before current interruption under short-circuit conditions means that a surge impedance of 300 Ω is realistic for all cases; a value of 330 Ω is recommended. Based on this value and on information available on the number of overhead lines and equipment in an UHV substation it has been concluded that the parameters that define the first part of the TRV envelope for test duties T100, T60, T30, T10 and

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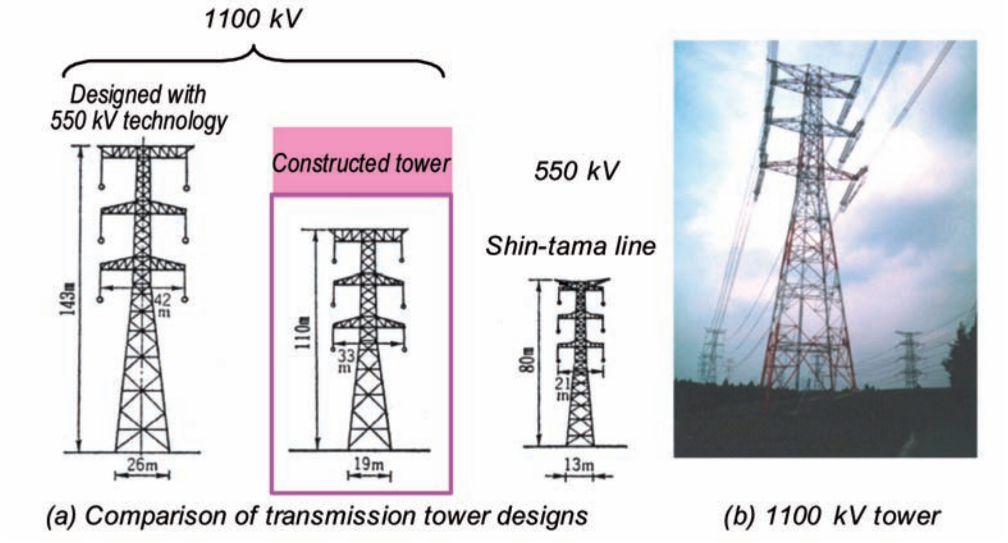

(a) Comparison of transmission tower designs

(b) 1100 kV tower

Figure 2: Reduced size of TEPCO's 1100 kV towers

SLF should be the same for UHV as they are for lower rated voltages.

Conversely, the specification of the peak and time to peak of the TRV envelope must change due to the influence of the low damping of the travelling waves, the physical dimensions of the UHV network and the large ontribution of power transformers to the short-circuit currents. These aspects lead to a higher amplitude factor $k_{af}$, a lower ratio between $t_2$ and $t_1$ (corresponding to the second and first knee-point in the TRV envelope) and a lower first-pole-to-clear factor $k_{pp}$.

Simulations demonstrate that MOSAs have a reducing impact on the peak values of the TRV. The example of figure 3 shows the situation for a line corresponding to the equivalent surge impedance of T100 (90 Ω) and only one MOSA at the source side of the circuit-breaker. In case of UHV, more MOSAs are typically applied than the number of line circuits and the surge arrester characteristic becomes flatter meaning that the intersection point will anyway be lower than SIPL at 2 kA.

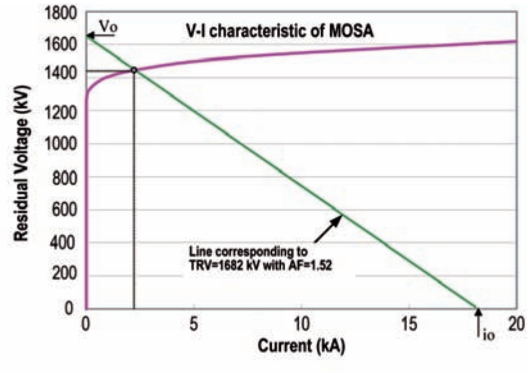

Figure 3 Intersection of system response line with MOSA characteristic(s)

It is recommended to adapt the TRV parameters as shown in Table 1.

The given recommendations cover long line faults as well as transformer-limited faults (TLF). In the latter case the rate of rise (steepness) of the TRV (RRRV) and the time to peak ($t_3$) are determined by the transformer impedance and its equivalent surge capacitance, which is recommended to be specified as a fixed value of 9 nF.

Should UHV AIS substations be constructed the effects of the Initial TRV (ITRV) due to traveling waves within the substation must also be considered. ITRV conditions at 100% of the rated short-circuit current are covered by the short-line fault test duty at 90% of the rated short-circuit current when no time delay is applied at the line side. Such a conclusion applies for terminal faults, as the busbar surge impedance is 300 Ω or less, while the line surge impedance is specified to be 330 Ω.

With respect to capacitive current switching, especially unloaded line switching, studies reveal that the voltage factors to define the peak value of the TRV can be kept similar to those for lower rated voltages (i.e. 1.2 under normal conditions and 1.4 under earth fault conditions). The initial part, though, is more severe due to the Ferranti-effect, thus leading possibly to larger arcing times and less dielectric stress to the circuit-breaker.

## Opening and closing resistors

Opening and/or closing resistors may be applied to a circuit-breaker in order to reduce switching overvoltages. Examples of the effects & specification of opening resistors are discussed however; no specific recommendations for the resistor value or thermal capacity can be given. The effects of opening resistors on terminal faults, long line faults, short-line faults, out-of-phase switching and capacitive switching are addressed.

In the TB attention is paid to type test methods for UHV circuit-breakers, equipped with opening resistors.

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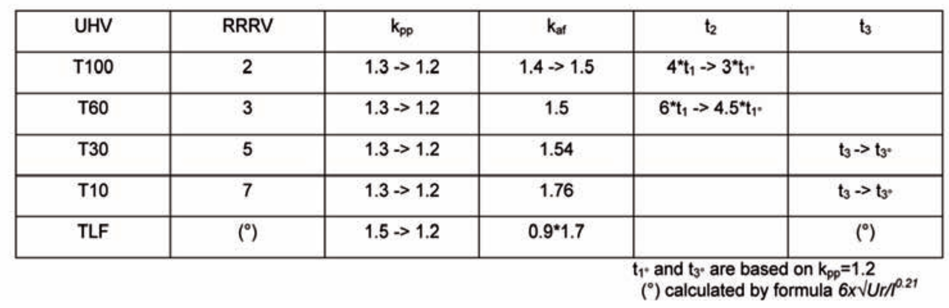

| UHV | RRRV | $k_{pp}$ | $k_{af}$ | $t_2$ | $t_3$ |
|---|---|---|---|---|---|
| T100 | 2 | 1.3 -> 1.2 | 1.4 -> 1.5 | $4^*t_1$ -> $3^*t_{1*}$ | |
| T60 | 3 | 1.3 -> 1.2 | 1.5 | $6^*t_1$ -> $4.5^*t_{1*}$ | |
| T30 | 5 | 1.3 -> 1.2 | 1.54 | | $t_3$ -> $t_{3*}$ |
| T10 | 7 | 1.3 -> 1.2 | 1.76 | | $t_3$ -> $t_{3*}$ |
| TLF | (°) | 1.5 -> 1.2 | 0.9*1.7 | | (°) |

$t_{1*}$ and $t_{3*}$ are based on $k_{pp}$=1.2
(°) calculated by formula $6x\sqrt{Ur/I}^{0.21}$

Table 1: UHV TRV requirements in relation to 800 kV requirements

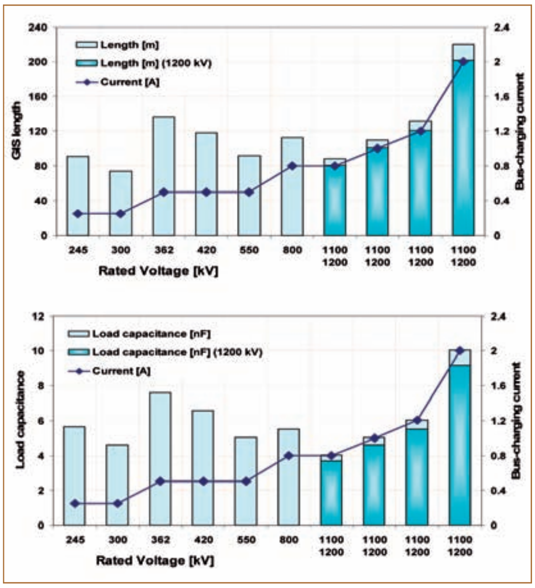

Figure 4: Dependency of bus-charging current, load capacitance and equivalent busbar length on rated voltage as per IEC 62271-102

## Disconnector and earthing switches

The specified currents and related voltages for the bus-transfer duty and bus-charging current switching duty are relatively high. Figure 4 shows the load capacitance and the equivalent length of GIS for different voltage levels depending on the specified bus-charging current. Bus-transfer currents have to be defined in dependence of the actual current ratings, the type of substation and the maximum loop length.

As WG A3.22 has insufficient information to make an analysis or recommendations regarding the switching of electromagnetic and electrostatic induced currents on overhead lines with earthing switches.

The charging/discharging of busbar sections by disconnectors in GIS causes a large number of re-strikes and pre-strikes and the associated generation of VFTO (very fast transient over-voltages) at frequencies up to tens of MHz. Depending on trapped charge conditions, the high frequency voltages may reach amplitudes that could endanger the insulation of the GIS and directly connected equipment.

As shown in figure 6, this phenomenon is more severe at UHV than at 800 kV and, when necessary, a counter measure is the application of a damping resistor to the disconnectors.

## Secondary arc extinction and High Speed Grounding Switches (HSGS)

Options to control secondary arc currents during SPAR include 4-leg shunt reactors to limit the secondary arc current such that it will extinguish within a reasonably short time, special schemes to switch off the shunt reactor(s) of healthy phases or the application of HSGSs (high speed grounding switch) to by-pass and extinguish the secondary arc. The optimum choice depends on a number of factors such as line length & configuration, dynamic stability requirements and the combination of line faults to be coHSGSs are in the process of being standardized within IEC.

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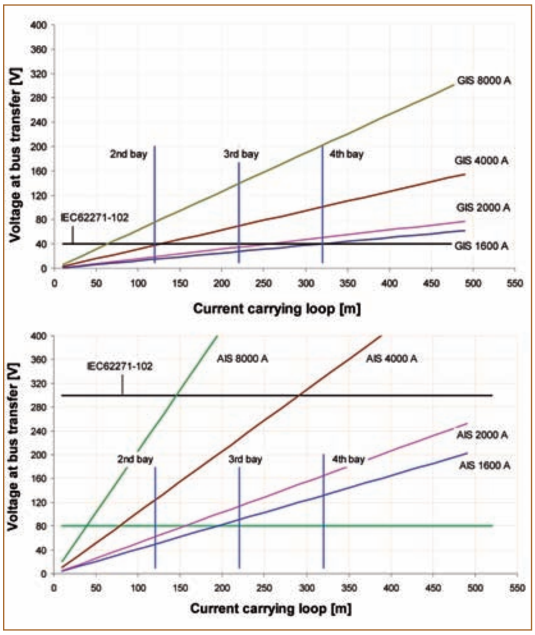

Figure 5: Bus transfer voltage as a function of length of GIS and AIS/MTS current carrying loop

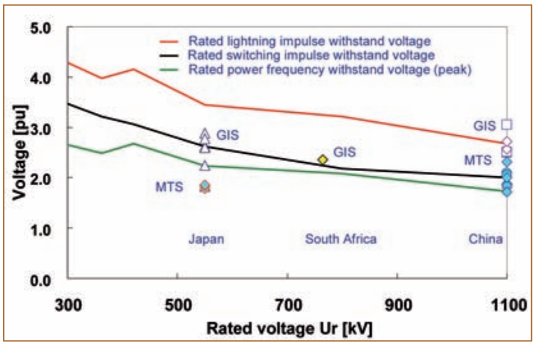

Figure 6: Comparison of VFTO between GIS and MTS

## Metal-Oxide Surge Arresters (MOSA)

Surge arresters designed and applied to limit overvoltages to the lowest possible levels are seen to be one of the most important tools for the insulation co-ordination in UHV systems. However, the requirements on the arresters with respect to protection levels, energy and voltage withstand capabilities are demanding for the industry. Some features are more specific for UHV arresters and need special attention. Items, which are not considered to be fully covered in existing standards are insulation withstand test, long duration current impulse withstand tests, switching surge operating duty test and energy withstand test for multi-column arresters, short-circuit and mechanical tests for the very tall structures, voltage grading check methods taking into consideration the internal and external grading components, more adequate pollution tests suitable for long polymeric housings for UHV MOSA.

## Instrument transformers

Conventional instrument transformers for UHV-AIS have large drawbacks related to size and weight making non-conventional instrument transformers (NCIT) more likely to be applied. Detailed consideration of the future use of NCIT, both at UHV and elsewhere, is dealt with elsewhere in SC A3.

## Factory, laboratory and field testing experience

Testing of UHV equipment presents unique challenges which have been addressed in a variety of ways. A number of new techniques & methods are summarized in the TB. ■

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