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TECHNICAL BROCHURE
WG C4.302

Insulation co-ordination related to internal insulation of gas insulated systems with SF_6 and N_2/SF_6 gas mixtures under AC condition

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Introduction

WG C4.302 focuses on the following study items of gas insulated system, mainly gas insulated Switchgear (GIS), but also gas insulated line (GIL), regarding insulation co-ordination related to internal insulation to make up the lack of information concerning "dielectric withstand characteristics of electrical insulation":

a) Conversion of field overvoltage to standard impulse waveform,

b) Combined safety factors in IEC60071-1,

c) In-service ageing of insulation,

d) V-t characteristics from the point of view as to whether there is sufficient information available for insulation co-ordination,

e) Influence of a prestress voltage on the insulation withstand,

f) Conversion factors relating to voltages above and below which switching impulse or power frequency tests may be substituted for each other,

g) Site testing.

Gas insulated system, which enables compactness and high reliability of the equipment, has now world-wide issues such as in-service ageing of the equipment, further compactness with high reliability and environmental problem to reduce SF_6 emission into the atmosphere.

On the other hand, the insulation techniques for gas insulated systems have been progressed steadily in the field of equipment reliability and insulation co-ordination.

This brochure reviews and discusses insulation co-ordination related to internal insulation of gas insulated equipment in SF_6 and also some aspects of N_2/SF_6 gas mixtures under AC condition, considering the above issues and referring to the latest research on the insulation properties and techniques.

Scope of Studies

Insulation co-ordination for the determination of rated or standard insulation level is given in IEC 60071-1. The process consists of four steps of calculating (1) representative voltages and overvoltages U_{rp}, (2) co-ordination withstand voltages U_{cw}, (3) required withstand voltages U_{rw}, (4) rated or standard insulation level: set of U_w.

Some essential factors such as co-ordination factor K_c in the step (2), altitude correction factors K_a (or atmospheric correction factor K_t) and safety factor K_s in the step (3), and test conversion factor K_{tc} in the step (4) are applied in the above insulation co-ordination process.

This brochure introduces a method of conversion in shape of field overvoltage to standard impulse waveform to determine representative voltages and overvoltages U_{rp}, and also deals with the safety factor K_s and the test conversion factor K_{tc} from the following viewpoints. ● ● ●

Regarding the safety factor K_s, the study on ageing of insulation performance during the long operation is essential. The influence of prestress voltages such as AC or DC on insulation performance of GIS is also important to evaluate "other unknown factors" in the safety factor K_s, since the prestress effects have not been well discussed for the latest power equipment applying IEC 62271-203.

The test conversion factors should also be reviewed for the equipment applying SF_6, reflecting the recent data on the insulation properties to develop the latest compact equipment. Also, there is a demand for the test conversion factor in N_2/SF_6 gas mixtures, since (GIL) applying the gas mixtures is now in service operation. Considering the above, the following items are discussed in the brochure.

Conversion in Shape of Field Overvoltage to Standard Impulse Waveform in Determining Representative Overvoltages for GIS

In the chapter 3, a conversion method of field overvoltage to standard impulse waveform is introduced, which is effective to determine the representative voltages and overvoltages U_{rp} for GIS, referring to the recent experimental and analytical studies.

From the results of lightning surge and disconnector switching surge analyses and measurements of ultra high voltage (UHV: 1000kV) and 500kV substations, representative non-standard impulse waveforms were extracted. The rise time of the wave crest is, as a whole, 0.1 - 1.0μs.

(a) Waveform A: Pulse-shaped waveform
(b) Waveform B: The wave crest has a steep pulse-shaped part, and the wave tail is flat (Ratio between peak and flat part: 0.7 - 0.9)
(c) Waveform C: A damped oscillatory waveform whose first wave is a maximum (Frequency: 0.5 - 5.0 MHz)
(d) Waveform D: A damped oscillatory waveform whose second wave is the crest value (Frequency: 0.5 - 5.0 MHz)
(e) Waveform E: Double-frequency oscillatory waveform (Lower frequency: Approx. 1.0 MHz, Upper frequency: Approx. 5.0 MHz)

The waveform was resolved into elements including each oscillatory wave, the flat part, and so on. The crest value that was converted into an equivalent standard lightning impulse waveform as the overall waveform was calculated.

It is found that the insulation requirements could not be as severe as those of the standard lightning impulse waveform, since the decay of the field overvoltage is generally large. Consequently, it could be possible in some cases to use lower withstand test voltages for GIS using SF_6.

In-service Ageing in Safety Factor

In the chapter 4, the in-service ageing in safety factor is studied based on the recent data, discussing the insulation performance of GIS after 50 years service life.

The long-term performance of the insulation system in GIS during the 50 years service life is gained from a consideration using the two parameter Weibull distribution together with the statistical coefficients n and a representing the V-t and V-N characteristics:

$$P(V,t) = 1\text{-}\exp[-(V/V_s)^m (t/t_s)^a]$$

$$\text{or } P(V,N) = 1\text{-}\exp[-(V/V_s)^m (N/N_s)^a], \quad m = n \times a$$

$P(V,t)$ and $P(V,N)$ is the cumulative breakdown probability dependent on breakdown voltages V and time to breakdown t or number of voltage application N. The values of m and a are the shape parameters of V and t or N, respectively. The value of n gives the gradient $-1/n$ of V-t and V-N characteristics.

Furthermore, the insulation performance after 50 years operation is estimated by the respective ageing factor.

From the above mentioned consideration the following can be derived: The puncture field E_{50y} of the bulk material of insulators after 50 years operation of 5.9 - 7.0 kVrms/mm is larger than the maximum working stress 5 kVrms/mm reported in the literature, which shows that epoxy insulators would have enough performance even after 50 years operation. The sufficient insulation performance is also confirmed by the facts that the critical field for ageing is 12 kVrms/mm during a long-term operation.

Regarding the performance of interface between insulator surface and SF_6 gas, the reduction rate during 50 years is negligibly small, since the value is at most 6% for both lightning impulse (LI) and switching impulse (SI) voltage application.

As to the long-term performance of SF_6 gas under clean and particle contamination, the reduction rate of 20% and 22% is not critical again, since in the case of AC stress the reduction could be covered by the ●●●

design margin *s* generally defined as the following Equation:

s = (minimum breakdown electric field of the system) / (design electric field) (A)

It is concluded that a GIS insulation system of a proper design has a service life of 50 years and in the recent reports no significant ageing is recognized in the actual GIS after long-term operations. However, some other aspects such as metallic particles generation from the contacts, mechanical/thermal performance and gas seal performance should also be considered in a practical GIS.

Influence of Prestress Voltage on Insulation Withstand of GIS

In the chapter 5, the influence of AC and DC prestress on insulation performance of GIS applying IEC 62271-203 is discussed, using the experimental results on insulation characteristics under impulse voltages superimposed to AC or DC.

Reduction of LI breakdown voltage is not observed when the superimposed AC component is within 70% of AC breakdown voltage (about 60% of LI breakdown voltage) for the three kinds of samples of sparkover, surface flashover and puncture. Therefore, there is no need to consider the influence of AC prestress on a GIS insulation performance under good quality control conditions up to the voltage class of 800kV and also UHV.

The influence of DC prestress on a GIS insulation performance is summarized in Fig. 1 (a) and (b), which shows the negative critical DC trapped charges U_{dc} that could lower the dielectric strength of a GIS. Here, the parameter *s* in the figures shows the design margin defined in the equation (A). The value of 1 p.u. corresponds to the crest value of the rated voltage. The figures suggest the following three points:

The effect of small particles contamination under industrial clean conditions is greater than that of charge accumulation on spacer surface in terms of the influence of DC prestress on a GIS performance.

The influence of DC prestress with charge accumulation on spacer surface could be neglected if an appropriate insulation design margin *s* is taken for a GIS.

The influence of DC prestress with small particles contamination under industrial clean conditions could be prevented by applying a thin dielectric coating such as epoxy resin and phthalic acid ester resin on the inner surface of GIS enclosure.

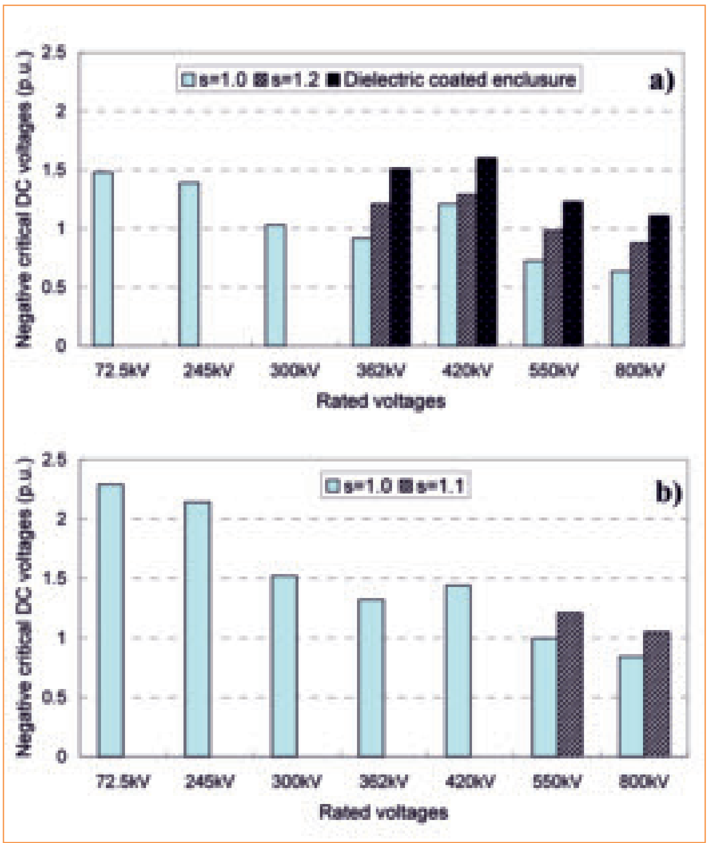

Fig. 1: Negative critical DC trapped charges that lower the dielectric strength of GIS
a) With small particles contamination under industrial clean conditions
b) With charge accumulation on spacer surface

Test Conversion Factors in SF_6 and N_2/SF_6 Gas Mixtures

The test conversion factors in SF_6 and in N_2/SF_6 gas mixtures are studied in the chapter 6. Reviewing the most critical stress for the equipment when applying IEC 62271-203, the essential tests among lightning impulse, switching impulse and AC voltage tests are discussed.

Fig. 2 (a) and (b) show the comparison between the rated withstand voltages and the voltages calculated by the test conversion factors under quasi-uniform field in SF_6 and in N_2/SF_6 gas mixtures, respectively. The values of lightning impulse withstand voltage (LIWV), switching impulse withstand voltage (SIWV) and AC withstand voltage (ACWV) are referred to those at the rated voltage of 550 kV of IEC 62271-203. ● ● ●

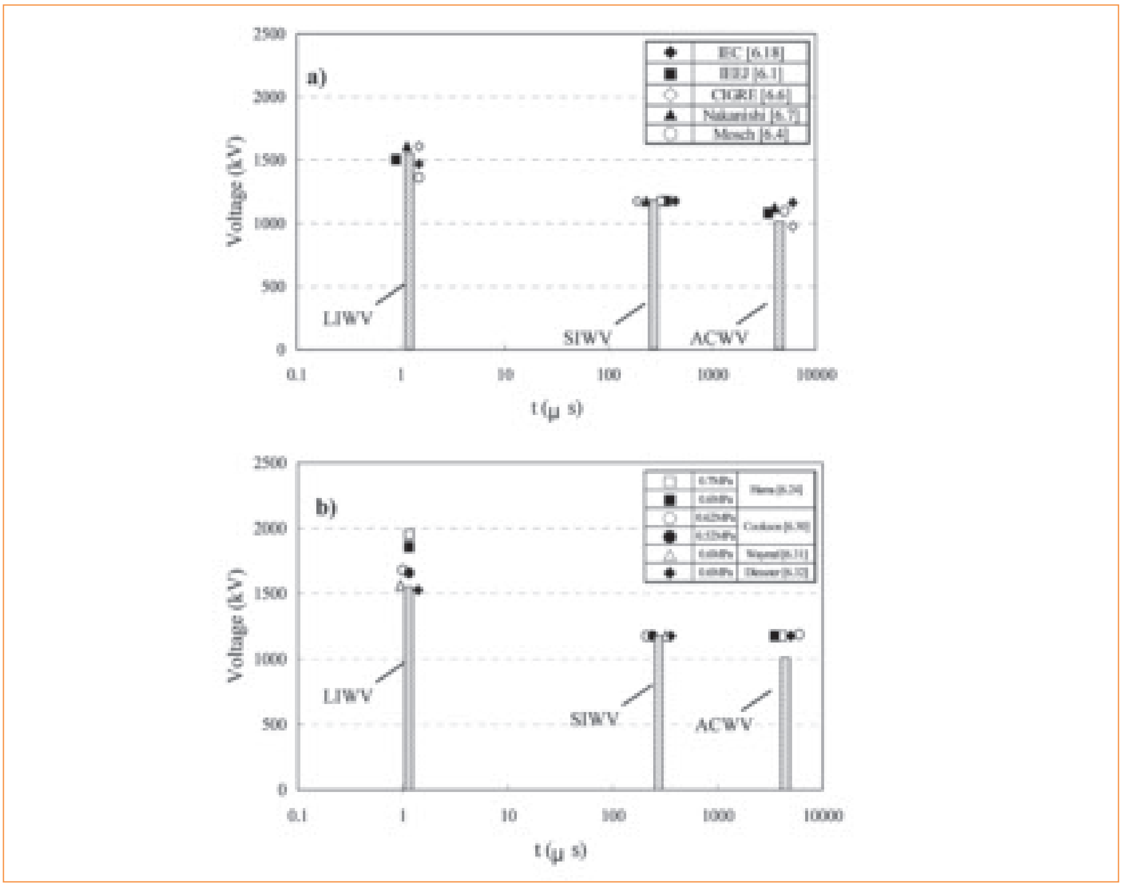

Fig. 2: Comparison between the rated withstand voltage (LIWV, SIWV and ACWV at 550kV of IEC 62271203) and the voltages calculated by the conversion factors under quasi-uniform field in SF_6 and in N_2/SF_6 gas mixtures. The number in the square brackets shows the reference in the brochure.
a) in SF_6 b) in SF_6/N_2 gas mixtures

Without the defects such as particle contamination and local field concentration at triple junction, LIWV is basically the most critical to the equipment applying SF_6. On the other hand, with the defects in SF_6, LI- and AC-voltage tests are essential to find out the defects in the equipment, while SI-voltage test could be eliminated due to corona stabilization effects.

However, for the equipment applying N_2/SF_6 gas mixtures and without the defects, SIWV is the most critical stress in the Range II (300 kV or higher) of the IEC, while LIWV is basically the most critical in the Range I (245 kV or lower).

Site Testing

In the chapter 7, the difference of GIS site testing between IEC 62271-203 and other standards such as IEEE Std C37.122-1993 and JEC-2350-2005 (Standard of the Japanese electrotechnical committee: Gas insulated switchgear) is described in terms of purpose, test procedure and testing philosophy.

Regarding the purpose of the site testing, there is not an essential difference between them. However, the test procedure and test voltage are different between IEC 62271-203/IEEE Std C37.122-1993 and JEC-2350-2005.

Conclusions and Further Work

Finally, in the chapter 8, the essential remarks of each chapter are briefly summarized. The studies on a GIS regarding insulation co-ordination related to internal insulation are useful to make up the lack of information concerning "dielectric withstand characteristics of electrical insulation". The results would contribute to the further compactness of a GIS with high reliability and to the reduction of SF_6 emission into the atmosphere.

As the next step, this work will be extended to internal insulation of oil-paper insulated systems.