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Insulation Coordination for UHV Gas Insulated Substation

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***Abstract--* Gas insulated substations provide a best solution to the problem of reduced land availability in the metropolitan areas and have been functioning for more than 30 years around the world. These substations have to maintain high reliability in operation and thus risk of failures due to overvoltages must be kept to minimum. It is observed that GIS technology has also made inroad to the UHV segment. However this inroad has given rise to several challenges which majorly include the GIS Insulation design. The insulation coordination study thus forms a very important aspect in substation design stage. When it comes to the insulation coordination for UHV GIS, it differs in majority from EHV levels as VFTO phenomena is observed to higher extent in UHV levels. This paper discusses the modeling of UHV GIS and presents a novel algorithm for the analysis of Insulation coordination based upon the obtained results from simulation studies. The results obtained have been validated based upon comparison with IEC 62271-203 prescribed voltage levels.**

Index Terms: Insulation Coordination, Lightning impulse withstand voltage (LIWV),VFTO, Withstand level

I. Introduction

GIS provide a best solution to the problem of reduced land availability in the metropolitan areas and have been functioning for more than 30 years around the world. These substations have to maintain high reliability in operation and thus risk of failures due to overvoltage must be kept to minimum[4].

A recent trend of Power system shows the increasing acceptance to UHV levels upto 1200kV in India considering the reliability and low loss performance. GIS systems also have to cope up with this trend of power markets. Depending upon the substation layouts and locations the substations are either cable connected or either connected to an overhead line (OHL). Based upon these configurations the lightning performance, disconnector switching performance is highly important. The switching performance also holds an upper hand in UHV GIS systems which should be analyzed in every aspect. It is also known that mostly the GIS substations are indoor type; this thus differentiates the Insulation level requirement of AIS from GIS. Insulation itself forms the weak link in case of GIS applications and does have a detrimental effect upon the PF withstand voltages and the Lightning impulse withstand voltages. In case of UHV GIS the VFTO phenomena is a major parameter that has a decisive effect on the GIS insulation selection and suitable substation design. VFTO originates due to the disconnector switching process and does lead to elevated voltages upto 3pu in severe cases but this is characterized by short time durations (usually in nano seconds). However such short time durations of transients have a severe impact on the overall system design as the insulation is stressed severely due to the reflection and refracted waves originating from the point of VFTO origin in the disconnector. Thus, VFTO analysis is required for all EHV substations to be setup. This paper discusses the insulation coordination process for UHV GIS considering the disconnector operation process [4].

II. VFTO in UHV GIS

The operation of disconnector is a major factor that contributes to VFTO.As the operation of switching is slow in nature it leads to the origin of severe strikes and restrikes and the the desired switching activity is completed . As this time duration of voltage collapse is very small (nano seconds) this leads to the origin of travelling waves in GIS. The originated waves travel along the enclosures and conductors and lead to multiple reflections and refractions. This is the origin of VFTO activity in GIS[3].

As the system voltage increases the overall value for lightning impulse withstand voltage to the system voltage becomes lower. This leads to a very high impact on the system insulation design.

Thus from the above discussion it can be easily concluded that the VFTOs in GIS forms a key parameter while the insulation design and insulation coordination calculations are to be conducted. Other comparable events include the operation of circuit breaker, occurrence of line to ground faults which may lead to transients but these are less comparable to the strikes and restrikes occurring due to the slow speed of operation of the disconnector. The transients usually are characterized by their high frequencies and short durations of occurrence usually nano seconds. Internal VFTO cause high stress of the insulation system. It has been found that, particularly at 420 kV and higher system voltage levels, disruptive discharges to earth might occur when switching small capacitive currents with gas-insulated DS. The development of an earth fault by branching of the leader during DS switching depends on parameters such as voltage, gap distance, electrode geometry, contact speed, gas pressure and magnitude and frequency of VFTO. A proper design of the DS has shown, that in practice earth faults can be eliminated. The geometry of the gap, the disconnector contact design are of important consideration in VFTO analysis study.

III. Lightning Impulse Withstand Voltage versus VFTO in UHV GIS Perspective

A comparative study carried for system voltage versus Lightning impulse withstand voltage and VFTO shows that as the system voltage increases the overall difference between the LIWV and VFTO decreases. Hence, VFTO can become the limiting dielectric stress which defines the dimensions in certain cases[2].

The following chart shows a comparative study of LIWV and VFTO with increasing system voltage.

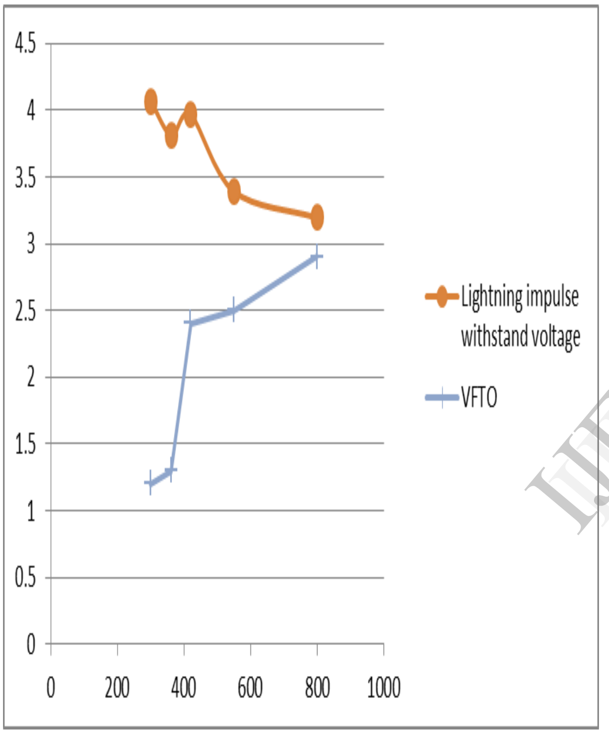

Fig 1: Comparitive study between LIWV and VFTO

A study conducted for VFTO analysis shows that the difference between VFTO and LIWV reduces with voltage. From the above graph it was observed that the VFTO value for 400kV GIS ranged from 2.1 to 2.5pu whereas the LIWV value is observed to be 3.8 to 4.2pu whereas as the voltage value increase to 800kV, the VFTO value GIS ranged from 3.5 to 4.5pu whereas the LIWV value is observed to be 3.8 to 4.5pu, thus it can be inferred that the VFTO analysis study can be extended for Insulation cordination process in UHV GIS.

IV. Classification of VFTO in UHV GIS:

The switching operation in gas-insulated substations leads to formation of VFTOs in UHV GIS. The VFTO propagation generally occurs in following two types:

- Internal transient voltages
- External transient voltages

The Internal transient voltages are generally associated with stressing of the internal insulation and the external transient voltages Stresses and electromagnetic interference (EMI) in secondary equipment and Stresses in connected equipment like Inductive voltage transformers and current transformers

V. Insulation Coordination: Algorithmic Approach

Considering the overall experience in Insulation design and its coordination for UHV GIS substation, the procedure of Insulation coordination generally tends to follow the following steps considering the analysis of VFTO:

The following is an algorithmic representation of the Insulation coordination process which is adopted for system analysis in this paper:

Step 1: System Modeling.
Step2: Calculation of maximum peak value of the VFTO component for the GIS and the connected equipment.
Step 3: Validate the model. (If results are ok proceed to step 4 else return to step 1)
Step 4: The trapped charge behavior of disconnector if known shall be considered else a value of -1pu shall be considered.
Step 5: Consideration of coordination factors Kc in calculation
Step 6: Consideration of Safety factor
Step 7: Consideration atmospheric correction factor,
Step 8: Application test conversion factor to the system
Step 9: Compare the obtained value with LIWV level
Step 10: If the LIWV level < VFTO calculated proceed to step 11 else proceed to step 12
Step 11: No damping measure required
Step 12: Damping measure should be adopted

The next sections will discuss the insulation coordination process adopted for a UHV GIS substation as per the algorithmic approach above:

VI. Modelling of UHV GIS

The modeling process for UHV GIS is done following the two phase line model approach. Herein the different components are modeled as follows[9]:

1. Disconnector: The open position of the disconnector is modeled as a series capacitor demonstrating capacitance between contacts of the disconnector. The spark between opening and closing of the disconnector is modeled as a non-linear resistance. The self-inductance and Capacitance is found to be 95 and 300 m/micro sec.

2. Bushing: The bushing is modeled as a distributed parameter transmission line with surge impedance of 20 ohms and a shunt capacitance to ground of 20pF
3. Earth Strip: The earth strips are modeled as single phase transmission line with surge impedance and travel time.
4. Models for other equipment: The different bus ducts, spacers, breakers, earth switches are modeled as capacitance to ground with different values [8].

The following is the EMTP model of 800kV UHV GIS considered for analysis of VFTO occurrence.

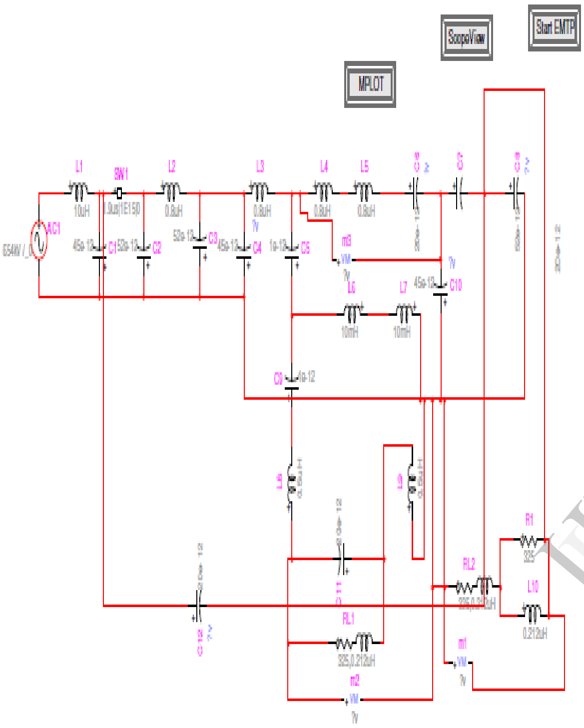

Fig 2: Model of 800kV GIS

VII. SIMULATION RESULTS

The simulation results for UHV GIS model are observed as follows:

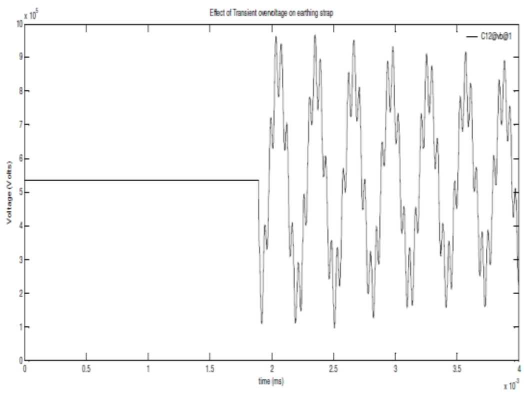

Fig 3: VFTO occurrence in Disconnector switch

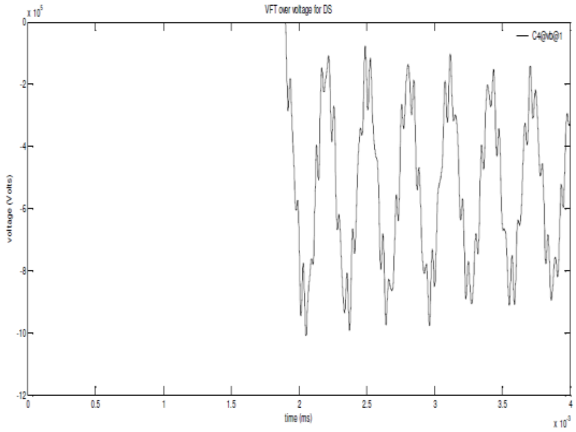

Fig 4: Effect of VFTO occurrence on GIS Bushing

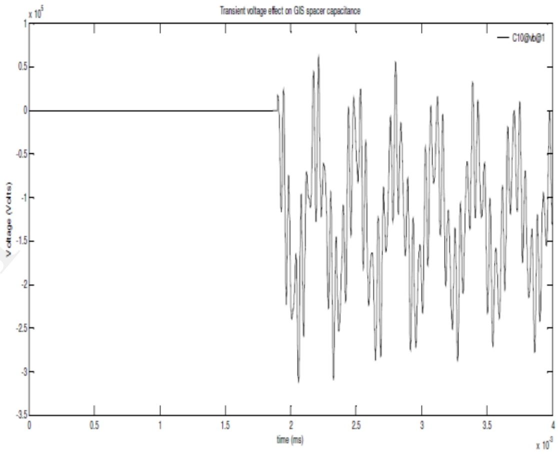

Fig 5: Effect of VFTO occurrence on Spacers

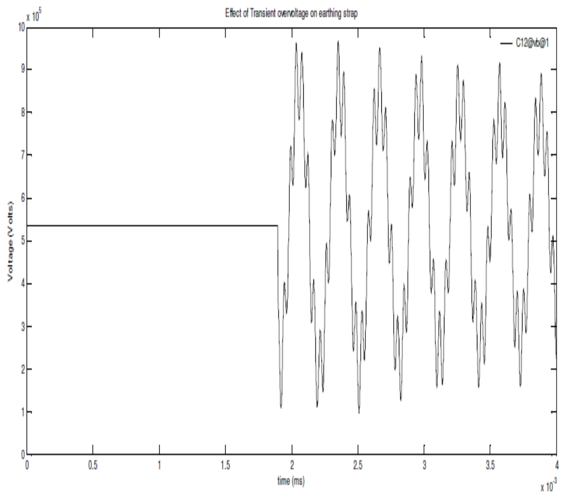

Fig 6: Effect of VFTO occurrence on Earth straps

IV. CALCULATIONS FOR INSULATION COORDINATION OF UHV GIS

Device	Overvoltage (volts)	Overvoltage (PU)
busduct	1313.4	2.01
bushing	92.3	0.14
spacer	527	0.81
earth strap	569	0.87
spacer	90.3	0.14
Insulating flange	49.7	0.08
DE	874	1.34

Fig 6: Observed overvoltages in GIS modules

From the simulation it as observed that the max. Overvoltage was below 2.01 PU. Hence temporary overvoltage is taken to be 1312.97kVp. By application of coordination factor and other factors mentioned in the algorithm, the values of internal and external overvoltages are found to be

	Overvoltage	
Voltages(kV)	***Internal***	***External***
phase to earth	1174.39	974.79
phase to phase	1764.52	1464.62

From the above results the phase to earth overvoltage for Internal as well as external insulation is well below the standard value as per prescribed by IEC 71-1,thus no further corrective and preventive action is required

In the cases the values for obtained Internal and external overvoltages are higher than LIWV then the following measures are required:

1) Damping shunt resistor
2) Coupling capacitors
3) Wave trappers
4) Ferrite rings
5) Design of Disconnectors with low TCV

V. CONCLUSION

VFTO simulation is an important instrument in the calculations for overvoltage required in the insulation co-ordination process. As the accuracy of the study depends upon the model of each module of the substation. The results should always be verified by accurate measurements.

If the calculated VFTO is higher than withstand level, special measures should be always adopted to mitigate the overall effects of these overvoltage. It is concluded from the above study that VFTO can become the maximum dielectric stress in certain cases and define the overall GIS dimensions in such cases.

VI. REFERENCES

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