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Testing of 400 kV GIS

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SUMMARY

The 400 kV transmission grid backbone in Ireland is designed to cater for critical periods of low loading. The original design parameters were set on the basis of low projections of energy usage in the late 1970's as a result of high oil prices and economic recession at the time. Due to this critical under dampening, the lightning impulse (BIL) and switching impulse (SIL) levels for the transmission system were selected for the equivalent to that of a 550 kV transmission system. While energy demand and bulk transmission grew in the intervening years, the later effect of renewable generation, primarily connected to the lower voltage distribution systems, has led to frequent periods of low demand. During night valley periods up to 50 % of demand is often meet from renewable sources at embedded distribution level. The 400 kV system is relied on for frequency support and spinning reserve in the case of sudden loss of renewable generation, but lightly loaded for significant periods. The associated primary Gas Insulated Switchgear substations, when lightly loaded, may be more critically at risk of dielectric failure due to high Transient Recovery Voltages incurred during switching events. Dielectric failures of GIS invariably lead to forced outages of a greater amount of HV plant due to the protection schemes employed and compactness of the switchgear itself.

As a result of recent experiences in new GIS installations in Ireland, ESB International has developed more stringent criteria for type, factory routine and in particular site tests after installation.in the specifications prepared for its parent company ESB, the transmission asset owner in Ireland. Specific tests and procedures, in addition to IEC standard tests according to 62271-203, have been carried out in multiple installations to date. These specific test requirements have been performed on a range of GIS installations from different manufacturers at various rated voltage levels. Some notable issues that the tests are designed

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to provide reassurance against include internally leaking insulators, intermittent partial discharge sources, particle generation from switching operation and latent manufacturing defects that may pass normal routine factory testing.

KEYWORDS

Gas Insulated Switchgear	(GIS)
Lightning Impulse Withstand voltage	(BIL)
Switching Impulse Withstand	(SIL)
Transient Recovery Voltage	(TRV)
Site Testing	
Factory Testing	
Flashover	
Partial Discharge	

Introduction

Ireland has a weak 400 kV transmission system, two lines connecting a generating station on the west coast to the main load centre on the east coast and due to this, the specified TRV and BIL levels for the 400 kV system are those normally used on a 550 kV transmission system. The consequence of dielectric failure presents a greater risk for GIS switchgear at this voltage level leading to more stringent requirements for the design specification, testing and site quality assurance.

Specification

Specifying exactly what is required with respect to quality and expected performance of manufacturers' equipment is not a straight-forward task. As part of ESB International's technical and quality management process a dedicated team monitor, log and track all high voltage plant issues, regardless of age or asset type, in a database. This Primary Plant Log trends all equipment failures, common quality issues and defects. It provides a historical record of all issues whose mitigation or elimination is an objective in every revision of the equipment specification. The detailed specifications include key manufacturing quality checkpoints or tests to ensure that previously known manufacturing defects on previous equipment are detected in any new order. The specific number of mechanical operations for switching devices,, corrosion protection tests and other specific checks are specified according to equipment type and the relevant defect history.

VT Supplier / Selection

Following an open tender for 400 kV GIS switchgear, submissions from several major suppliers were technically and commercially evaluated. Several manufacturers opted to offer 400 kV rated voltage switchgear but type tested to 550 kV insulation withstand levels. The order was given to a manufacturer offering a compact 400 kV design which provided the lowest total cost of ownership for the customer due to its size.

During initial tests of the prototype GIS voltage transformer, two flashovers occurred. Both were due to dust or particles on the inner surface of the insulator. Investigation with the manufacturer and root cause analysis found the barrier insulator to be the main cause of any test failures during production of all VT types. These barrier insulators are commonly free-issued by the GIS manufacturer to the manufacturer of the VT. The insulator design used can influence the risk and rate of routine test failures. Conical barriers with raised surface profiles are deemed a lesser risk as particles are not retained as easily on the insulator surface.

The VT to be used on the GIS was based on the design for a 420 kV rated voltage unit. The housing used was identical to that used to meet 420 kV insulation levels. The VT manufacturer redesigned the active part only i.e. the primary winding insulation design and the shape of the high voltage electrode (grading ring) to achieve the 550 kV insulation levels required. The width of the insulation foil used on the primary winding was increased to enlarge the insulation distance between the conductor, core and inner surface of the compartment. By increasing the width of the insulation foil layers that contain channels to hold SF6 gas, the effective insulation distance has been increased and considered similar to the effect of adding sheds to AIS insulators. The shape of the HV electrode or grading ring was adjusted for the increased stress and coated with layers of dielectric paint to achieve an even and smooth surface to ensure a uniform electric field.

The HV withstand test was carried out at 710 kV per IEC 62271-203 insulation level for 550 kV rated voltage. Negligible PD was observed at the 1.2 times rated voltage level (phase to ground) for single-phase enclosed equipment. A maximum allowable partial discharge level of 2 pC was applied to the new equipment. The IEC limit is currently 10 pC therefore an increased quality margin over the IEC requirement was obtained.

GIS Type Testing

During the initial design review the manufacturing facility was inspected. A 400 kV bay was demonstrated and tested at the higher BIL level. Internal flashovers resulted at several barrier insulators. This was found to be due to incorrectly placed or incorrectly sized corona shields installed for the increased dielectric withstand requirement. Several points were also subject to dielectric field overstress due to particles formed during incorrect cleaning or mechanical operations.

The dielectric insulation design was revised with changes to the profile of the insulators and increased SF6 pressure..

Factory Acceptance Testing

Three complete GIS bays were presented for the factory customer acceptance tests in accordance with the agreed protocol. The bays chosen composed the three main variants of feeder, transformer and busbar coupler bays required by the client. Routine tests performed on the three bays were conducted in accordance with IEC 62271-1, IEC 62271-100, IEC 62271-203 and the customer specification.

The following routine tests were performed as agreed with the manufacturer prior to the Factory Acceptance Test (FAT);

- Mechanical tests of the circuit breaker and all disconnector and earth drives
- Contact resistance measurement of the circuit breaker and disconnectors
- Gas tightness tests
- High voltage withstand tests with partial discharge measurement
- Customer-specific functional test of the control and operation systems

In accordance with the customer specification the HV withstand tests were performed at insulation levels corresponding to 550 kV rated voltage, i.e. 710 kV.

During FAT testing there were six failures. One was due to incorrect assembly – a 400 kV endcap installed instead of 550 kV type. The other five flashovers and PD events were due to particles and/or voids in the insulators.

Site Testing

Due to flashovers and partial discharge issues picked up with GIS in other installations the customer specification required an extra 200 mechanical operations to be carried out on all units as a standard mechanical conditioning procedure before any dielectric test. This is to ensure that all possible particles are formed and removed before the final on-site HV test. Successful completion of the procedure also provides some confirmation that there are no switch or contact misalignments. After the 200 operations the manufacturer must open and clean a number of sample compartments to check whether excessive particle generation has occurred.

All on site tests were done generally as per IEC requirements, but with longer conditioned time according to the below table and lower threshold acceptance criteria for partial discharge detections.

Test parameters

Conditioning	230 kV >= 10 minutes
Conditioning	381 kV >= 10 minutes
Conditioning	500 kV >= 2 minutes
Test voltage	560 kV 1 minute
PD test voltage	381 kV n minutes
Frequency range	69 Hz – 179 Hz

	Phase-to-earth and between phases	Across open switching device and/or isolating distance	Phase-to-earth and across open switching device	Between phases	Across isolating distance	Phase-to-earth and between phases	Across open switching device and/or isolating distance (Notes 1 and 2)
420	520	610	950	1 425	900(+345)	1 300	1 300(+240)
			1 050	1 575		1 425	1 425(+240)
550	620	800	1 050	1 680	900(+450)	1 425	1 425(+315)
			1 175	1 760		1 550	1 550(+315)

Table indicating values for 420 kV and customer requested values at 550 kV

During the site testing there were fourteen occurrences of flashover or partial discharge. The reason for almost all the occurrences were due to metallic particles inside the gas compartments or due to voids within the insulators.

After replacement and cleaning of the affected sections / chambers, the tests were repeated and then passed the required IEC clause of the HV tests.

Conclusion

The drive to reduce cost has encouraged many manufacturers to reduce the size of their equipment which implies that these designs have lower thresholds of dielectric insulation margin. As very limited room for error in the manufacturing process and procedures are allowed this means that the slightest anomaly or intolerance can cause dielectric failure.. ESB International has noted an increasing trend of dielectric breakdown in new compact GIS types during factory routine tests and on site HV withstand tests after installation. A sizable number of failures have all occurred at close to nominal system voltage therefore decreasing the confidence of the asset owner in enduring any system disturbances or expected switching overvoltages.

IEC specifications should include a minimum design margin on the test levels for all GIS switchgear. ESB International specifically would like to see a higher number of mechanical tests to be performed on the equipment prior to factory and site testing to minimise the increased threat posed by particles. A larger number of switching operations should also be performed after installation to disturb or shake out particles and increase the effectiveness of the on-site dielectric tests.

On-site HV withstand tests should be performed for longer durations at 1.1 or 1.2 Un following the PD test voltage in order to better simulate increases above nominal system voltage that may be expected during valley periods due to the impact of embedded renewable generation. Switching operations during the increased soak period to simulate network switching events are advised to disturb any possible particles and trapped charges. The effectiveness of the GIS earthing for Transient Enclosure Voltage rises can also be confirmed in this manner. Parameters for equipment to pass factory and site tests should be rigid and clear in order to ensure no errors in specification interpretation. An acceptability criteria for dielectric failures incurred during on site tests should be considered by the purchaser. Failures due to incorrect assembly, while undesired are not necessarily indicative of material defects. Unexplained dielectric breakdowns in critical areas such as circuit breakers and other compartments with switching devices should however trigger a re-examination of the dielectric design margins.

BIBLIOGRAPHY

[1] Review of 400 kV GIS Voltage Transformer Supplier Trench Bamberg – October 2014

[2] IEC 62271-1

[3] IEC 62271-100

[4] IEC 62271-203

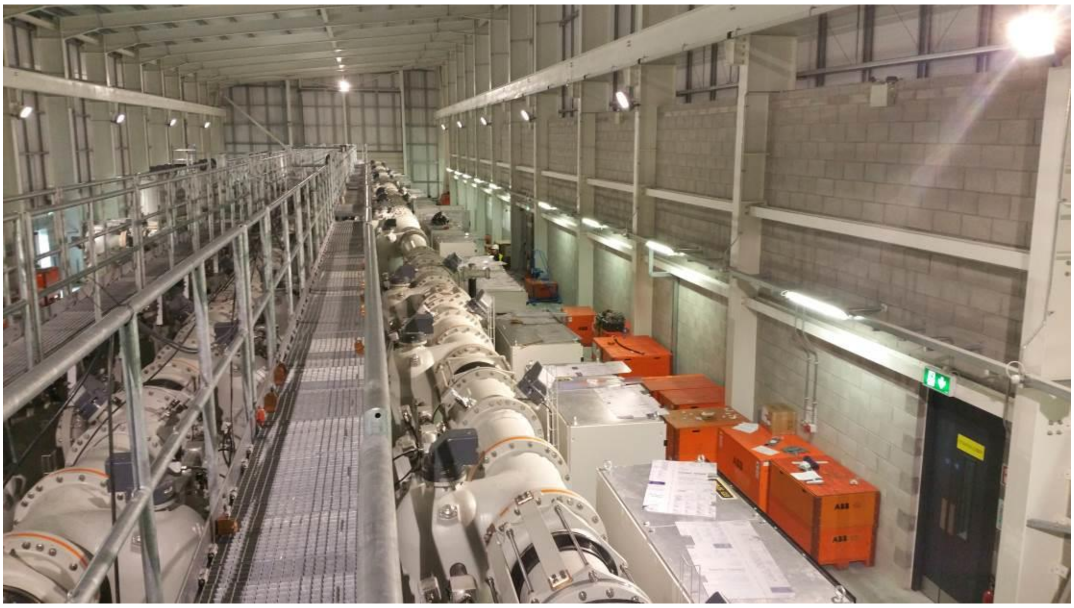
[5] ESB specification 18124.

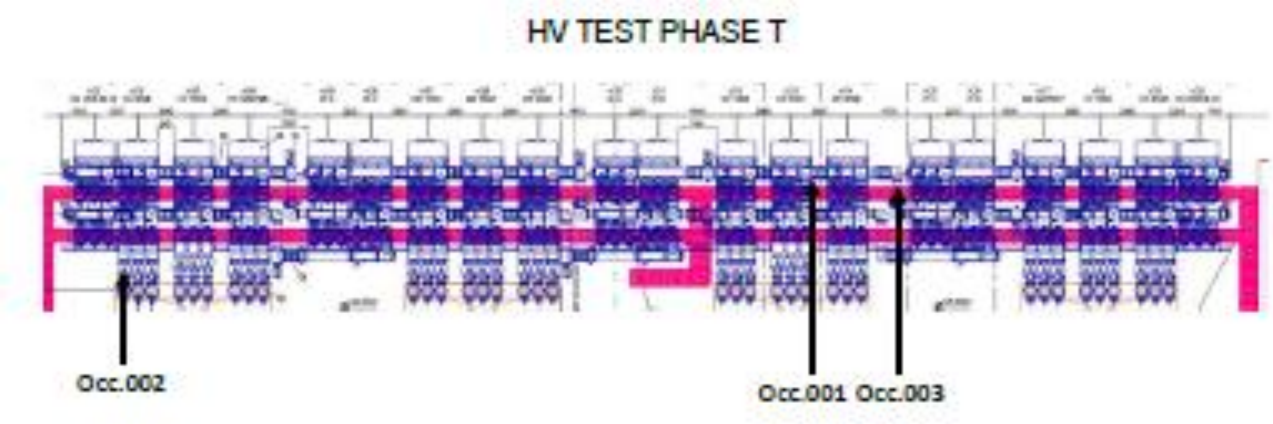
Appendix A: Photos

Right and below – HV Resonance test set used for site testing.

Right – failure on insulator during site High Voltage test

Below: Moneypoint finished installation





Top: HV test layout, below 3D model of 400 kV GIS