SPECIAL HEAT CYCLE VOLTAGE TEST of 275kV XLPE CABLE SYSTEM

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ABSTRACT: An extended "special" heat cycle voltage factory test was a specified requirement for the 275kV XLPE cable to be installed for a major infrastructure project "Adelaide Central Reinforcement (ACR)" by ElectraNet.

The need for the new circuit was for compliance with regulatory requirements meet energy forecast demands and internationally accepted reliability standards for the City of Adelaide, South Australia. Commissioning is due in September 2011.

The project involves the manufacture, delivery and installation of an approximately 18km long 275kV underground cable circuit terminating in SF6 switchgear at a new 275/66kV substation being constructed adjacent to the city's CBD (central business district).

The route comprises a wide range of installation conditions including direct laid cable, long ducted sections, purpose built bridges, cable installed on existing bridges, directional drilled situations and micro-tunnels - all necessary to negotiate available space in congested areas occupied by other infrastructure and services.

The cable system incorporates a condition monitoring system which monitors cable temperature and operating parameters and determines dynamic rating.

Partial discharge (PD) sensors are installed at all joints and terminations to make possible "off-line" PD measurement at commissioning, at end of warranty period and, as deemed necessary by the asset owner during the cable system's 40 year expected life.

The pre-qualification tender specification included mandatory conditions requiring compliance with IEC 62067 and that the nominated cable system be subjected to a special heat cycle voltage factory test. The special test comprised a trial assembly incorporating all types of contracted cables and associated accessories were subjected to a heating cycle voltage test for 70 days while continuously subjected to $2U_0$ and temperature cycles of up to105±2°C for minimum 120 minutes per cycle. The trial assembly has simulated the planned in-situ installation conditions.

During the course of the special test, the trial assembly was monitored with respect to temperature, applied voltage and the level of partial discharges by using the condition monitoring system (CMS) designed for field installation.

After the heating cycle test the trial assembly was subjected to a step-up voltage breakdown test followed by a detailed investigation of disassembled cable accessories to verify the impact of the electrical and thermal stresses and determine the degree of accelerated ageing.

During the step-up voltage test the time of voltage application was set to verify the life expectancy "n-factor" as stated by the cable system suppliers.

INTRODUCTION

An 18km long 275kV underground cable system is currently being installed in the city of Adelaide in Australia. The cable system consists of cable and accessories from two separate manufacturers.

The route comprises a wide range of installation conditions including direct laid cable, long ducted sections, purpose built bridge, cable installed on existing bridges, directional drilled ducts, all generally in flat formation.

Cable condition is monitored using partial discharge (PD) sensors fitted at each joint or termination and a DTS system with direct input to a dynamic rating system (DRS).

While there is general industry acceptance that the maximum continuous and emergency operating temperatures of XLPE insulated cables are 90℃ and 105℃ respectively, IEC 62067 does not require testing at temperature values above 90 to 95℃ (for Prequalification(PQ) test) and 95 to 100℃ (for Type test). In practice, these tests are usually performed as close as possible to the lower end of the specified temperature range.

On the other hand North American standards stipulate testing to 105℃ and specification AEIC CS9-06 stipulates specific durations.

The specification for the 275kV cable system in Adelaide included requirements for overload operation for nominated periods and cumulative times over the cable operational life.

To verify compliance to the maximum continuous and overload operating temperatures and durations, a Special Test was specified.

The test concept was, in many respects, similar to the IEC 62067 Type test but of an extended testing period and at a higher testing temperature intended to verify that the offered cable system has been designed to comply with system operating requirements and to confirm that it will provide the expected reliability under normal and overload operating conditions.

The number of loading cycles was based on CIGRE (WG B1-06) reported experience that the XLPE thermal shrinkage would stabilize after a certain number of heating-cooling cycles, generally in the range of up to 60 to 80 heat cycles.

The Special Test assembly included cables and cable accessories installed to simulate planned installation conditions. The assembly was subjected to elevated thermal and voltage stresses by applying 24 hour heating cycles of 105±2℃ (two hours per cycle) while continuously maintaining the installation at $2U_0$ over a 70 (seventy) day testing period.

CABLE SYSTEM RATING PARAMETERS

- Rated Voltage $U_0/U/U_m$: 160/275/300 kV
- Continuous Cyclic Current Rating at Load Factor 70%: 750 MVA
- Cyclic Overload Current Rating at (Load Factor 70% for 72 Hours: 900 MVA
- Continuous Overload (Emergency) Current Rating at Load Factor 100% for 8 Hours: 1080 MVA

MAIN CONSTRUCTION PARTICULARS OF CABLE SYSTEM

The cables supplied comprise;

- 2000mm^2 Cu Milliken Conductor
- Conductor Screen
- 25mm XLPE Insulation
- Insulation Screen
- Longitudinal Water-blocking
- Corrugated Al Sheath
- Bitumen Layer / MDPE Anticorrosion Sheath
- Double Brass Tape Anti-termite Protection
- Black MDPE Outer Sheath with Graphite Coating

Cable Accessories included;

- Indoor (GIS) Termination (Silicone Rubber Inner Insulation - Dry Type)
- Outdoor Termination (Silicone Rubber Stress Cone - Porcelain Insulator – Fluid Filled)
- Insulated Joint (Silicone Rubber Pre-moulded Type)

TEST ASSEMBLY ARRANGEMENTS

Special Test Assembly Layout

The assembly was erected in an outdoor test facility located in Gumi Factory, Korea.

The test assembly layout comprised two components (i) the main loop which included all cable circuit main components and (ii) the reference cable loop as shown in Fig. 1.

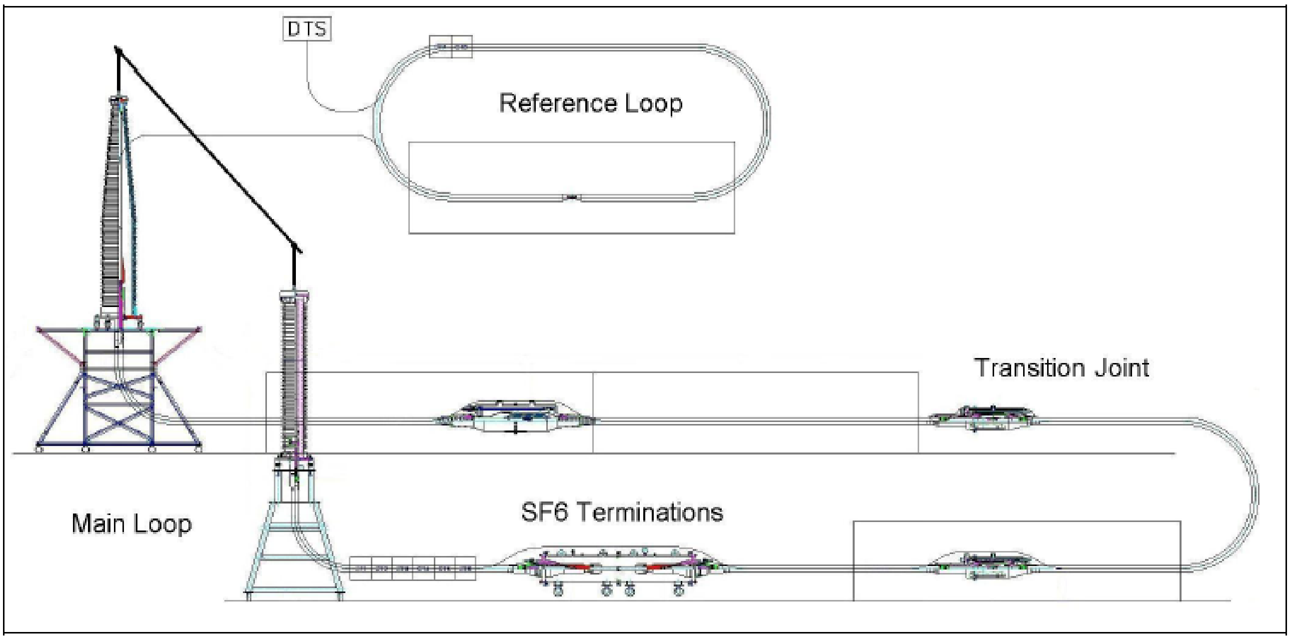

Fig. 1 Test Assembly – Main and Reference Cable Loops

Cable joints and terminations were assembled in accordance with the jointing instructions by the experienced jointers designated for the project.

Sensors to measure partial discharge (PD) were fitted to all joints and terminations.

The installation environment of the two loops included several elements of the site installation environments; i.e. cable installed in air, direct buried in ground and ducts embankments.

Direct buried conditions were simulated by burying the cable and joints in sand-filled boxes (Refer to Fig. 2).

Fig. 2 Test Assembly – Assembled and After Filling with Sand and Fitment of Covers

The main loop was set by jointing in series the 5 (five) cable sections and cable accessories. An aerial busbar connector between the two outdoor terminations closed the loop and connected the main loop to the HV test source.

The reference loop comprised a closed loop of cable only, with some installed in air and some direct buried. No voltage was applied to this loop.

Conductor heating was achieved by inducing a loop current using several current transformers placed on each cable loop and controlled by an automated system.

The reference loop current and conductor and sheath temperatures were measured and used to control the induced current required in the main loop to achieve the required heating cycle temperature profile.

The test was performed during summer months and exposed sections of the test assembly were protected against environmental conditions (wind, solar radiation, external heat influence, etc.) by suitable screens.

TESTING SEQUENCE

In preparation for the performance of the Special Test the selected cable sections were subjected to the following tests:

a) Electrical Tests

- AC voltage tests
- PD test at ambient temperature
- Tan δ measurement
- Measurement of electrical resistance between cable insulation screen and metallic sheath
- Measurement of semi-conducting screen resistivity

The results of all electrical tests were within specified limits.

b) Non-electrical tests

The tests listed in Table 1 were performed to verify the maximum test temperature (105±2°C) applied during the Special Test was within acceptable limits and would not affect the crystalline structure of the XLPE or cause internal physical deformation.

The results verified that the maximum test temperature was acceptable.

The sequence of tests carried out as part of the Special Test and the results are summarized in Table 2.

Table 1 Non-electrical Tests and Results

No	Test Performed	Test Result
1	Size measurement of voids, metallic particles and micro-defects in XLPE insulation and at the interface with semi-conducting screens.	All results within specified limits. No metallic particles detected.
2	Deformation of XLPE plus semiconducting screens due to mechanical pressure with temperature. (Measured at 10℃ intervals up to 120°C)	Deformation of ≤ 3.1% for temperatures up to 110°C. Deformation of 11.4% at 120°C.
3	Radial volumetric expansion of XLPE insulation diameter with temperature	Linear expansion to 3.3% at 120°C. (2.1% at 105°C)
4	Verification of XLPE crystalline melting point temperature. (Differential Scanning Calorimetry test)	Measured crystalline melting point temperature of 108.5°C

Table 2 Special Test Sequence and Test Results

No	Test Performed	Test Results
1	Heating Cycle (8 hour heating from ambient temperature to 105°C followed by a 16 hour natural cooling to ambient temperature). The cable conductor was held at approx. 105°C for minimum 2h per heating cycle for 70 consecutive cycles. During the heating cycles the trial assembly was continuously maintained 2Uo (346kV).	No breakdown
2	During the 70 heating cycles, weekly measurement of partial discharges (PD) at ambient and high temperature (105°C) at 2Uo.	No PD recorded from the test assembly when measured with 5pC PD resolution.
3	Following the completion of the 70 heating cycles, 1050kV impulse voltage test (10 positive and 10 negative impulses) was applied to the entire assembly at approx. 105℃.	No breakdown occurred.
4	Following the impulse voltage test, measurement of partial discharges (PD) at ambient and high temperature (105°C) at 1.5Uo, 1.73Uo, 2Uo and 2.5Uo.	No PD recorded from the test assembly when measured with 5pC PD resolution.
5	Step-up AC breakdown voltage test was applied to the entire assembly after the impulse voltage test at the following voltage steps: 400; 500 and 600kV. Each voltage step was applied over one 24 hour heating cycle. The test was stopped at 600kV due to AC voltage transformer power limitation.	No breakdown occurred.
6	Step-up impulse voltage breakdown test (10 positive and 10 negative impulses). The voltage was raised by 100kV steps from 1100kV. The test was stopped at 1600kV due to rating limitation of the impulse generator.	No breakdown occurred.
7	Accelerated step-up AC voltage breakdown test. The voltage was applied only to the Transition Joint. All other component parts of the trial assembly were removed. A 350kV AC voltage was applied and increased in 50kV steps with each step held for 60 minutes.	The breakdown occurred in the cable joint at 950kV after 15 minutes of voltage application.
8	Dissection and visual inspection of all joints and terminations (other than the transition joint which was tested to destruction). Samples of XLPE were taken for microscopic examination.	No evidence of material degradation was detected.

EVALUATION OF TEST RESULTS

All preliminary tests and each sequence of the Special Test were completed satisfactorily without incident or failures.

At the completion of the heating cycle voltage test all cable accessories were dissected and visually examined. No evidence of electrical discharges, change of XLPE natural color or development of treeing formations were observed in the insulation or at the interface of cable insulation with the stress cones of cable joints and terminations.

A light change of color of joint conductor ferrules, due to heating current, was observed.

CONCLUSIONS

The Special Test verified the ability of the cable system components to operate at maximum overload operating temperature of 105℃ for the specified electrical and cyclic thermal loading.

The combination of the heating and electrical tests and final accelerated AC step-up voltage breakdown at 950kV indicates an acceptable margin in the design of the cable system components with respect to high electrical and thermal stresses.

Application of temperature and voltage stress in excess of “PQ” and “type test” requirements demonstrated the suitability of the design and construction of the transition joint.

REFERENCES

1. IEC60840 – Power cables with extruded insulation and their accessories for rated voltages 30kV (Um = 36kV) up to 150kV (Um = 170kV) – Test methods and requirements

2. IEC 62067 – Power cables with extruded insulation and their accessories for rated voltages above 150kV (Um = 170kV) up to 500kV (Um = 550kV) – Test methods and requirements

3. AEIC CS9-06 – Specification for extruded insulation power cables and their accessories rated above 46kV through 345kVac

4. CIGRE B1-06 – Revision of qualification procedures for HV and EHV extruded underground cable systems

5. Brincourt, Dorison, – “Thermo-mechanical behaviour of 400kV synthetic cables”, JICABLE 99

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