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330KV CABLE SYSTEM FOR THE METROGRID PROJECT IN SYDNEY AUSTRALIA

S.L. Jones*, G. Bucea, T. Barnes
TransGrid (Australia)

M. Mitani, Y. Matsuda, A. Jinno
J-Power Systems Corp. (Japan)

Summary

One of the major challenges associated with the continuous expansion and modernisation of the city of Sydney is the implementation of suitable infrastructure projects to meet the forecast electricity demand at internationally accepted reliability standards.

This paper describes the technical challenges encountered during the implementation stages of a 28km 330kV cable circuit installed along a difficult and environmentally sensitive route. The cable system is monitored by a comprehensive condition monitoring system and the installation was designed to achieve a low-level electro-magnetic field in residential areas.

Key Words

SCFF cable – PPLP insulated cable – EHV – EMF Test– Dynamic Bending Test – Temperature Profile Test – Condition Monitoring System – Cable Rating

1 INTRODUCTION

The 330kV cable circuit, recently commissioned by TransGrid, is the major component of the MetroGrid Project designed to reinforce the power supply system to the city of Sydney. The new circuit was required, as the peak demand for electricity has increased at a rate of approximately 4% per annum in recent years.

The single cable circuit connects an existing 330/132kV Sub-station, located in southern Sydney area, and a new 330/132kV indoor substation built in the Sydney central business district (CBD).

Due to the importance of this circuit and the encountered challenges the cable system was thoroughly tested to verify its performance under planned installation and operation conditions.

The dynamic bending test, introduced by TransGrid, was designed to simulate the magnitude of dynamic mechanical loads exercised during cable laying while the electro-magnetic field (EMF) and temperature profile tests were performed to assess the EMF magnitude and cable rating when installed in variable conditions and configurations.

The condition monitoring system (CMS) architecture introduced new and innovative functions designed to supervise and control the operating parameters of the cable and to limit the impact of a cable failure due to any cause and under any possible adverse conditions.

*steven.jones@transgrid.com.au

2 QUALIFICATION AND SELECTION OF CABLE SUPPLIERS

The MetroGrid Project imposed significant demands on the selection, design, testing and installation of a 330kV power cable circuit to best meet the project requirements. On this basis it was decided to apply a two stage tendering process:

1) To pre-qualify a number of manufacturers adequately experienced to supply and install an EHV power cable, and

2) Invitation to the pre-qualified suppliers to tender for project implementation.

Four out of thirteen competing cable manufacturers were pre-qualified to tender for supply and installation of the cable system. An SCFF-PPLP (Self-Contained Fluid-Filled - Polypropylene/Paper Laminate) cable was selected from 29 offers that included the most advanced technologies such as XLPE, SCFF-paper and PPLP insulated cables and gas insulated lines (GIL).

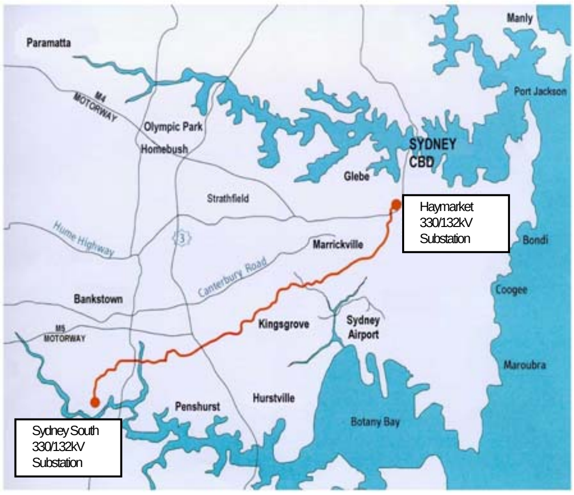

Fig. 1. 330kV Cable Route between Sydney South and Haymarket 330/132kV Substations

At all stages, the offers were compared using predetermined evaluation criteria. The selected SCFF-PPLP cable best met the requirements of a highly reliable 28km single circuit cable to be installed along a difficult and challenging route.

3 CABLE ROUTE

The cable route selection criteria and the overall feasibility study were based on cost-effective solutions and on the minimisation of impacts on the environment and community. An environmental impact study (EIS) was developed to identify the best route option for construction and operation of the cable. The EIS took into consideration the impact on flora and fauna, land use, water quality, geotechnical and soil conditions, traffic and parking, archaeology and heritage, safety and hazards, EMF and social and economic benefits.

Table I - Cable System Data

Parameter /Attributes	Value/ Data
System Voltage	330 kV rms
Maximum Voltage	362kV rms
Lightning / Switching Impulse	1175 / 950kV
Fault Current	43.8 kA for 1 sec.
Continuous Current Rating (Cyclic)	750 MVA
Overload Current Rating (Cyclic) for 3 consecutive days	900 MVA

The 28km cable route shown in Fig.1 was selected in consultation with public bodies whose property or infrastructure would have been affected. The route, mainly located in roadways and public lands, included some of the most diverse terrain conditions such as rocky sections of Sydney South National Park, heavily trafficked and winding roads and multiple crossings of waterways, major roads and railway systems. In addition, the existing underground utilities and other industrial, social and residential developments in conjunction with the minimization of EMF in close proximity to residences and other social establishments was another challenging aspect of route selection.

To overcome the route difficulties across the congested area of the Sydney CBD to Haymarket Substation the cable route included a 3.6km long and 3.2m diameter ventilated tunnel.

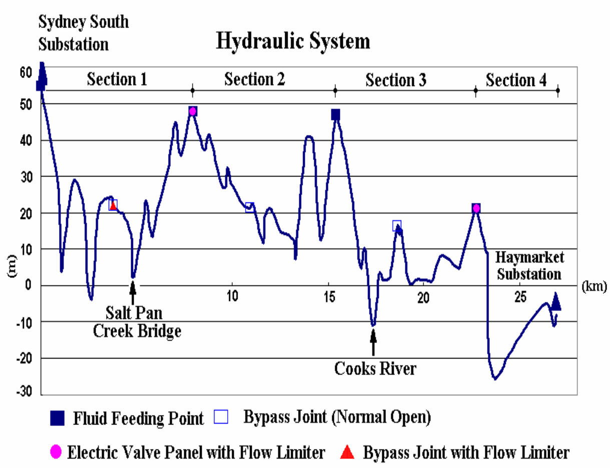

Fig. 2. Hydraulic Profile of Cable Route

4 CABLE SYSTEM DESIGN

The cable design and associated cable accessories were designed to comply with system parameters shown in Table I, route profile shown in Fig.2, environmental parameters and installation conditions. The main features of the selected design are shown below.

The cable construction, as shown in Fig. 3, included a PPLP insulated 1,600mm^2 copper conductor of six-segment compacted Milliken design. The high grade PPLP insulating tapes made of isostatic polypropylene and deionised water washed Kraft paper were lapped to provide an optimum balance between the cable flexibility and insulation stability under dynamic loads. The cable core was incorporated in a robust corrugated aluminium sheath (2.4mm thick), designed to withstand the maximum static fluid pressure of 980 kPa. The sheath is protected against corrosion by a layer of bituminous compound and a 4mm thick MDPE covering sheath. The cable is further protected against the termite attack by an extruded Nylon 12 jacket and provided with an external sacrificial sheath of MDPE or flame retardant PVC in direct buried or tunnel installations.

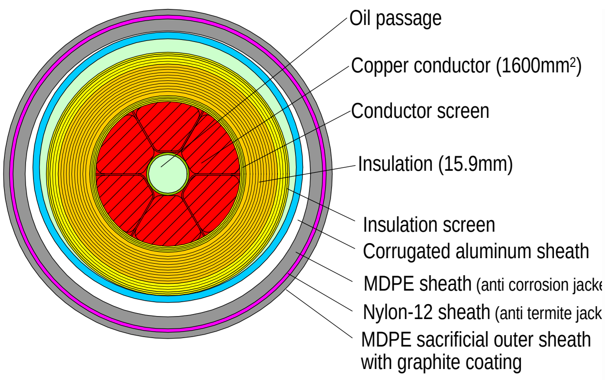

Fig. 3. 330 kV PPLP Cable

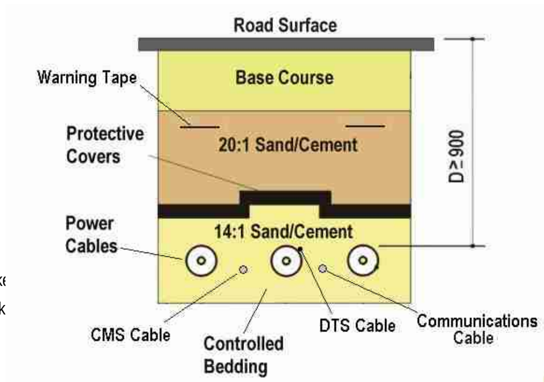

Fig. 4. Installation of Cable Circuit in Flat Formation

The 330 kV cable circuit was installed in controlled bedding and back-filling materials such as sand/cement mixes of selected thermal resistivity.

The single-core cables were installed in flat formation, as shown in Fig. 4, and in some particular cases in trefoil formation to reduce the EMF magnitude.

A cable snaking system was applied either side of each joint bay to eliminate cable-core movement due to the wave-riding phenomena induced by vehicular traffic and/or temperature cycles.

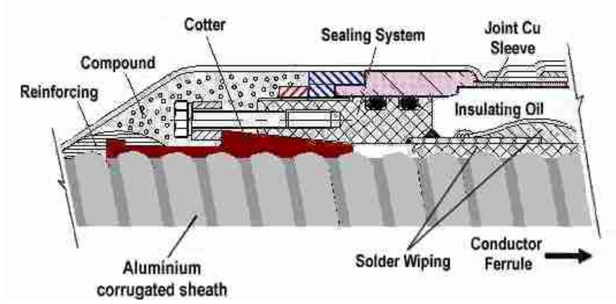

Fig. 5. Internal Wiping System

All joints and terminations were sealed to the cable aluminum sheath by an internal wiping system as shown in Fig. 5. TransGrid has used this system over the past 25 years with excellent results, i.e. no recorded leaks.

Phase-segregated hydraulic circuits were connected to fluid tanks at both ends, except Haymarket substation, where no fluid tanks were installed for fire security reasons.

A synthetic fluid (Linear Alkyle Benzene) that is readily biodegradable, in accordance with the provisions of the OECD 301 Guideline, was used for impregnation of cable insulation.

For increased security and to reduce the volume variation of cable fluid with the ambient temperature change all fluid-feeding tanks were installed underground.

No fluid stop-joints (SJ) or fluid tanks were installed in the cable tunnel.

The three longest hydraulic sections, about 8 km each, were sectionalized by additional fluid SJ to provide increased control and flexibility in locating and managing fluid-leaks under fault conditions. Under normal operation these joints are by-passed by an external valve system, which are locally activated to sectionalize the hydraulic circuits.

Monitoring of the three level pressure alarm and tripping functions was implemented by the use of pressure gauges and switches duplicated by a pressure transducer monitoring system. Differential pressure gauges were installed to accurately measure the sudden pressure variations as a result of system failures. In addition the differential pressure is calculated based on transducer recordings.

In order to limit the amount of fluid leaking from the cable, if the cable sheath is punctured, the gauge panels from the ends of hydraulic circuits and by-passed SJ were provided with flow limiters (FL) designed to reduce the flow rate of impregnating fluid from cable system to the minimum amount sufficient for normal operation. Furthermore electrical valves were installed between the fluid-feeding tanks and the cable to isolate the fluid supply in case of cable hydraulic system failure along the route. The valves are activated by the CMS functions or by the operator.

The link boxes installed were made of stainless steel and designed to be explosion proof. These were provided with high rating ZnO surge arresters designed to withstand the maintenance voltage test (5kVdc) of the cable anti-corrosion jacket without being disconnected from the cable metallic sheath.

A distributed temperature sensing (DTS) system consisting of two single-mode and two multi-mode fibers installed in a stainless steel tube, was attached to the 330kV cable centre-phase. The CMS optical fiber cable (30 cores) was installed in a separate conduit as per Fig. 4.

5 TESTING OF CABLE SYSTEM

5.1 Standard Tests

The contracted cable system has been extensively tested during the entire project implementation in accordance with industry practice. The test program included the testing of raw materials and of manufactured cable and accessories. All tests met the specified requirements.

It is worth mentioning that the type test assembly, consisting of three sections of cable connected by a SJ and a straight through joint and terminated by SF6 sealing ends, was installed outdoors by simulating the actual field installation conditions. The type test assembly was tested as shown in Table II in accordance with the contract specification.

Table II - Type Test Requirements

Test Items	Procedure and Requirements
Bending test	3 times bending
Pressure test	2 times of maximum designed static pressure (1,960 kPa) for 6 hours, on the condition that the other section was maintained at minimum operating pressure of 20 kPa.
DLA/Temperature test	Max 0.0014 at 190kV and 95 ^{o}C
Dielectric security test	430 kV/24Hours
Load cycle test with thermal stability test	253 kV (1.33 Uo), 20 Cycles, with max. conductor temp. of 95–100 ^{o}C.
Switching impulse voltage test	± 10 shots / 950kV with conductor temp. of 90-95 ^{o}C
Lightning voltage test	± 10 shots / 1175kV with conductor temp. of 90-95^{o}C
AC voltage test after impulse test	AC 325 kV for 15 minutes
Test on anti-corrosion sheath and joints	Lightning voltage test of ± 10times / 120 kV
Lightning voltage breakdown (BD) test on cable	No BD at ± 10shots of 1525kV
AC voltage BD test on cable	No breakdown at AC 500kV after 24 hours

Due to the quality of both the cable and cable accessories, the breakdown condition was not achieved even when the type test assembly was subjected to 1,525kV impulse and then to 500kV AC for 24 hours.

5.2 Special Tests

In addition to the above tests, TransGrid specified a number of special tests for the particular MetroGrid project requirements.

5.2.1 Dynamic Bending Test (TransGrid Test)

The scope of this test was to certify that the proposed cable type was suitably designed for installation along some specific cable route sections, which included multiple horizontal and vertical bends in the range of up to 120°.

The test conditions (Table III) were determined to simulate the most severe laying conditions along the cable route.

Approximately 15m of the cable was pulled four times along a test setup consisting of five horizontal 90° bends. The cable was rotated after the first pull by 180°, then 90°, and finally 180° to replicate a total of twenty right angle (90°) bends in horizontal and vertical planes, as shown in Fig. 6.

At the completion of the bending tests, the cable sample was subjected to electrical tests as per Table IV. The impulse voltage test was increased in steps of 50kV to breakdown, which occurred at 1,575 kV, i.e. 400kV above the type test specification.

After the electrical breakdown test the cable sample was dissected and investigated. The test proved that the cable metallic sheath, the condition and stability of PPLP tapes, and cable conductor were not notably affected by the number of bends, bending radius and sidewall pulling stresses.

Table III - Dynamic Bending Test Parameters

Items	Values
Minimum Bending Radius	2.45m
Maximum Side Wall Pressure	4.9kN/m
Pulling Tension	12kN
Number of Bending Cycles	Total 20

Fig. 6. Dynamic Bending Test Layout

Table IV - Electrical Test after Dynamic Bending Test

Test Items	Procedure and Requirements
Dielectric Loss Angle	Max 0.0014
Dielectric Security Test	430kV / 24 Hours
Lightning Impulse Test	±10 times / 1175kV
AC Voltage Test after Impulse Test	AC 325 kV /15 minutes
Further Impulse Tests	1575 kV (breakdown)

5.2.2 EMF Experiment

Notwithstanding intense international research over the past two decades there remain significant community concerns into possible health effects resulting from exposure to EMF.

A policy of prudent avoidance has been adopted within the Australian electricity supply industry for some time. This policy suggests, “Where new transmission or distribution facilities are constructed, steps are taken to do what can be done without undue inconvenience and at modest cost to avert the possible risk from exposure”. Guided by this policy it was decided to investigate practical means to reduce the magnitude of external magnetic fields in the vicinity of the 330kV cable circuit.

The experiment was set to perform the following tasks:
- Evaluate the available techniques to calculate and control the EMF produced by single-core power cable systems.
- Identify new materials and new methodologies to reduce the EMF produced by cable installations.
- Compare the actual and calculated EMF amplitude based on specific EMF management solutions.
- Verify the impact of EMF shielding systems on cable temperature (cable rating) and costing.

A trial installation, consisting of a short section of 330kV 1,600mm^2 cable circuit installed in diverse configurations was set-up and magnetic shielding methods were applied as shown in Fig. 7. The cables were laid in flat and trefoil formations at variable spacing with the metallic sheaths connected in single-point or solid bonding systems.

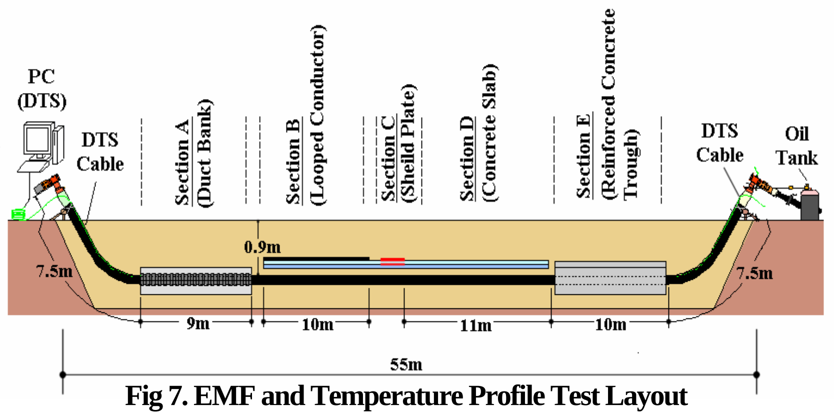

Fig 7. EMF and Temperature Profile Test Layout

Shielding techniques based on the effects of eddy and induced currents were evaluated using copper plates, steel-reinforced concrete troughs, steel-reinforced concrete slabs, parallel-looped copper conductors and newly developed high permeability materials.

It was verified that the shielding effect varied with the spacing and configuration of the three single core cables and that the EMF shielding techniques based on the effect of eddy or induced currents was not efficient if the geometrical configuration of the cable circuit was not suitably selected.

Based on the results of this experiment the following strategy for EMF reduction was established:

1) Increase the distance of the cable from houses, schools or any other social establishments.
2) Reduce the spacing between the cable phases as allowed by thermal rating
3) Install cable phases in a trefoil (triangular) formation
4) Install magnetic field shielding system

All four-strategy components were used at specific locations on the cable route.

5.2.3 Cable Temperature Profile Tests

The Cable Temperature Profile Test was carried out in conjunction with the EMF experiment. The trial installation was maintained at constant and balanced load of 1,310A for about two months until the thermal equilibrium was reached.

The scope of the test was to determine the temperature rise of the cable (conductor and outer sheath) and the applied EMF shielding systems when installed in actual conditions such as direct buried in ground, in ducts or concrete troughs.

The test set-up was designed to facilitate the temperature measurement of the cable conductor and cable outer sheath, of surrounding environment and EMF shielding elements. It was observed that the temperature rise in the EMF shielding was quite low and its impact on cable rating was insignificant.

In addition, the test helped to verify the software program designed to calculate the dynamic cable rating and to verify and calibrate the DTS system against thermocouple recordings. The measured and calculated temperature variations of cable conductor and outer sheath, carried out at one metre interval along the 45m trial installation, showed differences of less than 2°C, proving that the software designed to calculate the dynamic ratings was accurate.

6 CONDITION MONITORING SYSTEM (CMS)

The CMS was designed to acquire, record and evaluate parameters that relate to electrical, physical and environmental conditions linked to the 330kV cable system. It covers the following major functions:

1) Temperature monitoring and prediction (Table V)

Table V. Temperature Monitoring and Prediction Functions

Mode	Function
Real-time display	• Temperature distribution at 10 min interval • Highest temperature point update at 10 min interval
Prediction of continuous, short term and emergency loadings	• Load at steady state condition • Peak overload • Magnitude and duration of Cyclic Overload
Data processing based on short-term history	• Cable temperature distribution • Cable temperature versus time • Variation of thermal resistance of soil with temperature
Data processing based on long-term history	• Statistical recording of cumulative hours versus conductor temperature category

2) Fluid Pressure monitoring:

- Real-time monitoring
- Measured pressure and alarm condition
- Differential pressure between two phases and/or between both ends of selected hydraulic section (for earliest detection of fluid leakage)
- Fluid volume level of each hydraulic section
- Relationship of oil volume level of tanks between two selected hydraulic sections.
- Fluid volume difference from predicted value (deviation from predicted volume)
- Pressure tank temperature

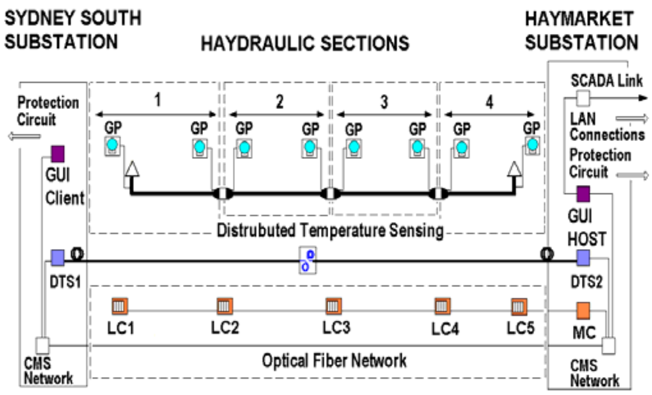

Fig. 8. Diagrammatic Representation of CMS Functions

3) Optional Database function (data manually input from keyboard)
- Sequential record of events and remedial actions
- Residual gas pressure (RGP) and Dissolved gas analysis (DGA)
- Electrical and physical properties of impregnated fluid
- 330kV cable core movement
- System Drawing and maintenance records

The CMS consists of control equipment located at the two interconnected substations (cable ends), local control (LC) units installed at each end of hydraulic circuits and a dedicated communication system (optical fibres) linking each component, shown in Fig. 8.

The main elements of the CMS are:

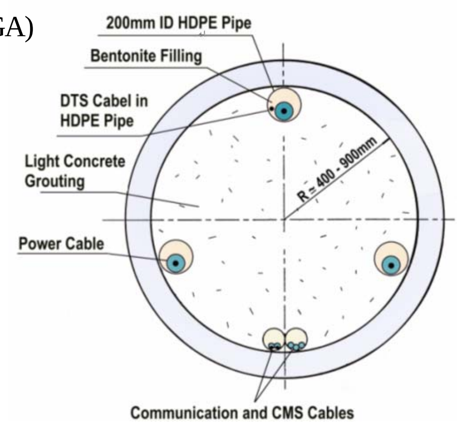

Fig. 9. Cable Installation in Micro-tunnel

- Host Computer, the "brain" of the system, located at Haymarket Substation, and the User Interface at Sydney South (Client GUI)
- LC units designed to communicate data between the pressure gauge panels, valves, temperature sensing devices and the Host Computer (GUI Host).
- DTS for continuous monitoring of cable and environment temperatures
- Optical transmission equipment for data transmission between the Host computer, LC and GUI Client.
- Interface equipment to communicate data to external systems such as SCADA, cable protection system and the TransGrid LAN to facilitate access to authorised users.

7 INSTALLATION OF CABLE AND ACCESSORIES

7.1 Cable Installation

The installation of the cable circuit in standard direct buried conditions was frequently challenged by local circumstances and obstacles, which were overcome by installing the circuit in duct embankments, micro-tunnels, concrete troughs, directional-drilled ducts, on bridges and in tunnels. The following installation methods were applied at most critical sections of the route:

- Directional-drilled ducts and suspended bridges at water crossings. On the bridges the cables were snaked in flat formation and incorporated in fire retardant troughs.
- Case-bore (micro-tunnel) mainly for under crossings of railway lines (Fig. 9).
- A 3.2m diameter tunnel, 3.6km in length, across the inner CBD area to access the Haymarket Substation.

Synchronized motorized-rollers and caterpillar machines to ensure the pulling tension and sidewall pressure remained within the proven safe limits identified during the dynamic bending test.

Owing to the properties of PPLP cable and transport limitations, the average unit length of land cable sections was 690m while for the tunnel they were as long as 1,320m.

7.2 Installation of Cable Accessories

The jointing work was performed under fully controlled environmental conditions in enclosures provided with air filtering and conditioning system. The air relative humidity was maintained below 65%. The jointing staff that were verified and authorized during the type tests and dynamic bending tests performed the work.

The vacuuming and impregnation processes were based on very strict testing parameters in relation to the level and duration of vacuum, drop test dynamics (duration, magnitude and recovery time) and quality of impregnating fluid by measurement of residual gas pressure (RGP), dissolved gas analysis (DGA), water content and electrical and chemical properties.

It should be noted that while the presence of combustible gases was totally excluded from the impregnating fluid, the measured “Total Gas Content” varied between 100 to 1000ppm and the RGP between 133Pa (1.0 mmHg) and 500Pa, which are 5 to 10 times lower than expected values. Water content varied within a similar pattern.

8 CONCLUSIONS

The MetroGrid Project has imposed significant demands on the selection, design, testing and installation of a long 330kV power cable circuit. These challenges have been met through innovative features providing a successful project outcome.

The dynamic bending test, EMF experiment and the temperature profile test, were introduced in addition to the industry standard tests. These tests were performed to confirm that the cable would meet the required test levels for reliable performance after installation on a difficult route.

The EMF mitigation methods applied during installation were based on actual tests results that verified analytical EMF calculations for the project. The real-time cable rating software was also confirmed during tests against measured cable and environmental parameters.

The project team paid extreme care to all aspects and all stages of project implementation to ensure a cable installation that will achieve a high standard of reliability.

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