Strategic Replacement of 220 kV Cable at Taranaki Combined Cycle Station

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***Abstract*—Condition based inspection prompted by thermal monitoring at Taranaki Combined Cycle (TCC) Power Plant in 2008 revealed an unexpected and abnormal buildup of pressure at the 220 kV cable sealing ends. A proactive investigation process led to a series of preliminary inspections and the application of sound engineering judgments to replace the 220 kV cable that linked between the power station and the substation. This paper presents the initial findings from the condition monitoring inspection through to the commissioning of the high voltage cables. Despite the challenges that were encountered the cable was replaced in a timely period. The experience gained during the investigation and replacement of these cables emphasises the importance of condition monitoring and the correct analysis of results in weighing up the financial and operational risks.**

Keywords-high voltage cables, sealing end, condition monitoring, thermal imaging, partial discharge, cable termination, underground cable, overhead line, power station, combined cycle gas turbine.

I. INTRODUCTION

Safe and reliable power generation is vital to ensure continuity of electricity supply to the transmission grid. Contact Energy made a strategic decision to replace an existing 220 kV XLPE 1,300 mm^2 Cu conductor cable system connected to the Taranaki Combined Cycle (TCC) Power Station. The cable was replaced with a 220 kV XLPE 1,600 mm^2 and was considered a high priority due to a number of risks. These risks included personnel safety, damage to existing plant and equipment (including the generator transformer) in the immediate vicinity of the sealing ends and the loss of revenue in the event of a cable failure. A cable failure would have resulted in a lengthy generator outage period. The decision leading to the replacement was initiated by proactive thermal monitoring of the cable terminations. The tests produced alarming results regarding the condition of the 220kV cable between the power station and existing transmission station.

This paper addresses the initial findings from the investigations and risk assessments that ultimately justified the cable replacement. This paper also covers the state of the art installation of the high voltage cable system and the challenges during the installation as well as the commissioning of the cables leading to successful completion of the project.

II. BACKGROUND

Taranaki was the first large-scale combined cycle gas turbine (CCGT) station to be built in New Zealand. Construction began in July 1996, with the plant completed in July 1998. The 367 MW station uses approximately 1.4 million cubic meters of natural gas per day in generation, and at 55.5 percent has one of the best fuel efficiencies of all of New Zealand's thermal stations. Figure 1 shows the overview of the 220 kV cable system and Figure 2 illustrates the aerial view of the cable route – demarcated as a broken black line.

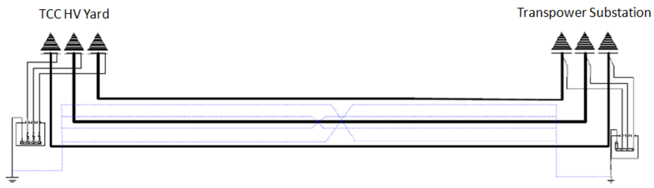

Figure 1: 220 kV Cable System Overview

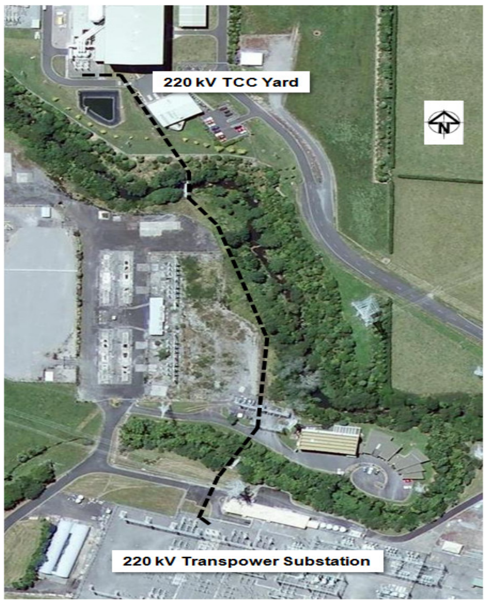

Figure 2: 220kV Cable Route Aerial View

A. Maintaining the Integrity of the Specifications

On 7 April 2008, an abnormal temperature distribution on the yellow phase 220kV outdoor sealing end cable located within the Taranaki Combined Cycle (TCC) Power Station switchyard was recorded. The survey was carried out using a thermal imaging camera as part of the condition monitoring program. The result showed 10 degrees Celcius rise over the ambient temperature at that time as shown in Figure 3. The area of concern is generally known to be a high electrical stressed area and is common that the porcelain within this area to be a number of degrees higher than the porcelain near the top. In this case the yellow phase stands up compared to the other two phases which instigated further assessments and analysis.

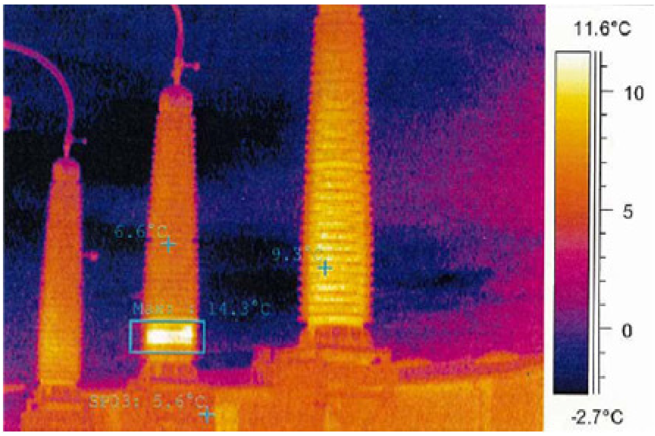

Figure 3: Temperature Rise On Yellow Phase 220kV Sealing End Cable

An investigation of the abnormal heating revealed a buildup of pressure in the yellow and blue phase of the cable sealing ends. Partial discharge results revealed that an abnormal level of activity was detected on the yellow phase when compared to red and blue phases.

Following the tests that were undertaken, the yellow phase cable termination bushing was dismantled at the TCC end of the cable. A constant stream of gas bubbles were seen to escape between the cable semiconductor and the lead sheath. The findings concluded that the sealing ends were in good condition other than the gas entering through the base seal. The source of gas buildup was from the cable. This was later confirmed during the decommissioning when the cable was "spiked". Immediately after "spiking" gas expelled for approximately 15 seconds. The partial discharge testing indicated electrical activity within the cable system which would have been fatal to the installation over time.

The cable was returned to service and a pressure transmitter was installed in the base plate of the yellow phase termination. The gas pressure in the termination increased again over time indicating that the gas from the cable had again escaped through the cable seal. In theory, if the pressure in the cable is greater than the pressure in the sealing end, this could damage the bottom seal causing gas to leak into the sealing end as illustrated in Figure 4 [1]. As indicated, the gas bubbles could cause discharging – the possible reason for partial discharging. The repeated buildup of gas pressure led to in-house discussions regarding risk assessments and mitigation measures.

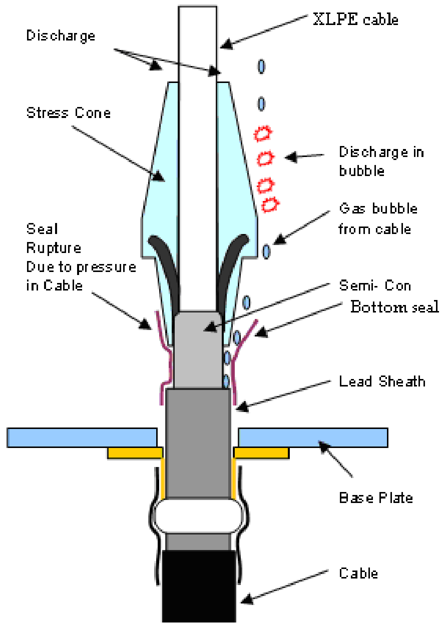

Figure 4: Cable Sealing End Cross Section [1]

III. 220KV CABLE REPLACEMENT DECISION

The possible premature failing condition of the 220kV cable posed a reliability risk to the transfer of energy between the power station and transmission substation. In order to minimise the risk, Contact Energy Limited made a final decision to carry out the 220kV cable replacement. The decision to replace the cable was based on the following factors:

More extensive time consuming laboratory tests would be required to accurately determine the cause of cable gassing. The undertaken accelerated aging simulation test did not represent the actual aging process as there are unknown operational variables to be simulated under laboratory conditions. The applied ageing model was the Inverse Power Law, which predicts a linear relationship between electrical stress and time to failure. The high risk of gas build-up in the cable termination could lead to a catastrophic failure of the porcelain insulator jeopardizing personnel safety and damaging plant in the vicinity.

- The reasons for the gas pressure buildup could not be determined and it was suspected that the main source of buildup was from the cable.
- Abnormal levels of electrical noise found when the partial discharge tests were conducted.
- Presence of combustible gases found in the cable termination oil.

- Cost of lost generation should the cable fail when the electricity prices are high would exceed the cost of replacing the cable.
- Long lead time to repair the existing cable.
- Remaining life-expectancy of the cable is impossible to accurately ascertain due to the absence of total-life condition monitoring, for instance thermal and partial discharge measurements.

In addition to the above factors, the opportunity to replace the cable was limited due to the planned construction of a new Peaker Station in the vicinity of the existing cable route. Beyond a certain time frame, the new station construction schedule prevented any future overhead bypass to be constructed for the replacement of the cable. Considering the above technical unknowns regarding the cable, personnel safety risks, plant damage and cost risks and the time constraint to replace the cable, a new replacement cable would ensure security of supply for the foreseeable life of the power station.

IV. PRECAUTIONARY MEASURES

To protect the plant and equipment in the close proximity of the cable terminations from a catastrophic sealing end failure event, containers were placed at the TCC end and shuttering placed at the Transpower end of the cable.

Prior to the decommissioning of the original cables and the replacement thereof, Contact Energy engaged Transpower to design and install a temporary 220kV circuit to bypass the existing underground cable. The bypass circuit is built to provide continuous connection to the grid either in the event of cable failing and during an extended outage period for the cable replacement.

V. CABLE REPLACEMENT STRATEGIES

Two new cable replacement options have been considered in the cost feasibility studies. The first option is the total replacement of the existing underground cable and the second option is the replacement using a combination of both underground cable and an overhead line. The first option was deemed to be the preferred and a recommended engineering solution. From the possibility of capital cost savings aspect, Option 2 proposed an overhead line route longer than the cable route. It required additional cost for termination bay & accessories and has a higher contingency risks from a maintenance point of view. The maintenance is in the form of corrosion inspections, structural and hardware visual inspections [2].

The cable replacement was aimed to finish before the winter generation season which expected to have a high load profile in winter. Another challenge was to remove the bypass circuit that passes over the neighbouring Gas Peaker Project on a planned date to allow for the construction of cooling towers. Temporary fibre optic cables were laid as a bypass for the power station protection and control signaling prior to the new cable installation.

The replacement cable would benefit from modern day manufacturing technology regarding super-clean insulation, dry curing insulation process and degassing techniques [2].

VI. 220KV CABLE INSTALLATION

Due to the experience with the previous 220kV cable, all attempts were undertaken to reduce the long-term risks – particularly during the installation of the cable. In addition, measures were taken to ensure the warranty of the newly procured cable. This included the employment of specialist supervisory resources during the cable pulling, skilled terminating teams and partial discharge testing specialist. The specialist skill for partial discharge tests were recommended by the cable manufacturer. These partial discharge tests provide an invaluable baseline for future tests against which the cable aging characteristics can be evaluated.

The appointed installation contractor was engaged to compile the cable pulling plan. Due to the design variation along the creek crossing, the revised cable route attributed to additional cable pulling tension. This resulted in an additional expense for the lengthy setup time and additional hardware facilities for the pull-anchorage points. The cable pulling plan was executed to meet the angle of bend, specified pulling tension and minimum spacing criteria. Crushed limestone was used as the cable backfill with compaction density level maintained to meet the specified thermal resistivity of 1.5 K.m/W. The laying of four different types of cables included the 220kV 1,600mm^2 XLPE-insulated cable, two 240mm^2 insulated earth continuity single core cable, protection & control signaling cable and DTS cable for the provision of future cable thermal monitoring.

VII. TERMINATION OF CABLE SEALING ENDS

Safety was the prime focus during the execution of the project. One of the activities that required thorough reviewing was the installation of the 220kV cable sealing ends under live conditions at both the TCC HV Yard and Transpower substation. Live installation was to reduce generation plant outage. The proposed installation required close scrutiny of the installation procedure to maintain safety of working staff within a reduced live line clearance. In addition, the procedure had to prevent damage to the equipment being installed.

To achieve the live working conditions, the foundation within the TCC HV Station was extended by 3.5 m and the sealing end support structures were repositioned by 3.5 m away from the generator transformer. This modification provided the horizontal electrical clearance from the neighbouring isolator. The overhead bypass strain gantry cross-arm in the TCC HV Yard was raised to provide sufficient vertical distance. Actual working dimensions are illustrated in Figure 5. This illustration demarks the terminating enclosure which provided a clean environment for terminating. The greatest installation challenge was to manually raise and position the sealing end porcelain within a 1 m head room.

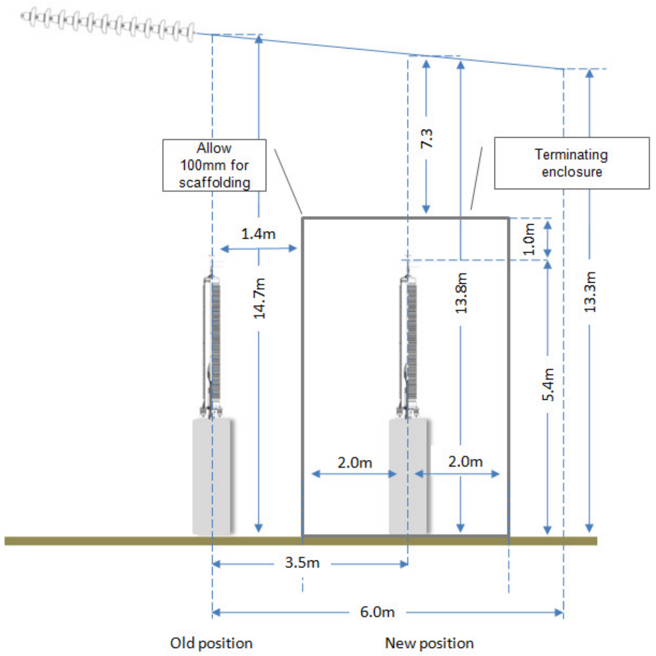

Figure 5: Electrical Clearances for Terminating Cables in TCC HV Yard

The procedure highlights the installation process, identifies the safety and damage risks and thereafter mitigates these risk conditions. The risks cover the scaffolding structure strength, heavy manual lifting, rigging ropes, slip trip fall, insulator damage and reduced electrical clearances. New jumpers were installed from the 220kV cables sealing ends which connect to disconnector 206 at TCC end and disconnector 616 at Transpower end.

VIII. Project Variations

The two primary variations from project initiation were the reconstruction of the existing concrete bridge and the provision for a future service road leading to the bridge. Each is discussed below in detail.

A. Extension of Concrete Bridge

The existing concrete cable bridge over Kahouri stream was modified to provide an adjacent steel cable support bridge. This allowed the existing bridge to accommodate a service road between the TCC and Stratford Peaker Project site. The new bridge also provides a service crossing for raw, demin and waste water, compressed air and power, control and fibre optic cable to the Peaker Project site. Technical considerations in the design of the bridge included:

- prevention of a continuous inductive circuit surrounding the cable,
- accommodating the thermal movement of bridge and cable by means of supporting, and
- earthing to prevent high touch voltages.

As the cables are enclosed in a metal framework, it was important to design the bridge with insulating platforms for preventing circulating currents. This was achieved by providing 3.2 mm Mylar spacers between the steel walking plates and the metal framework. These are illustrated in Figure 6.

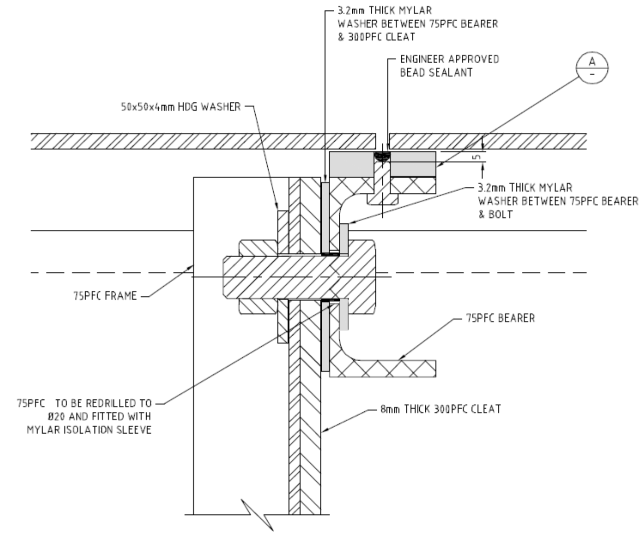

Figure 6: Insulating Steel Platforms

A further variation was accommodating the change in thermal movement of the steel bridge as illustrated in Figure 7. The maximum temperature difference between the cable & the stream crossing is assumed to be 30°C above ambient – this is in excess of actual operating conditions as the 220kV cable will be operating at 1010A and it is protected from solar radiation.

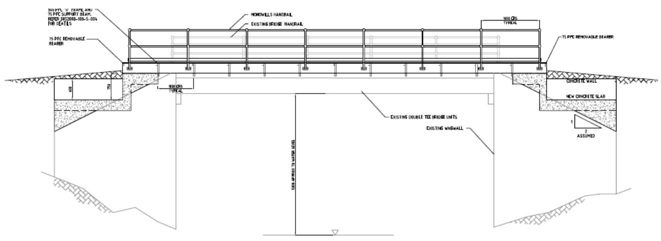

Figure 7: Steel Bridge Modification

The 220kV cable itself is expected to operate at no more than 30°C above ambient temperature. Allowing for a maximum temperature variation from the given conditions of 20 °C produces -10°C & 50°C. The maximum value is well below limits as the maximum cable temperature at ambient of 20°C is 31.3°C when protected from solar radiation. The minimum temperature is expected to never be realised.

The effective yield stress of the cable Aluminium sheath varies for soft temper & 3/4H to H Aluminium. As this information was not available at the time of calculation, the calculations are based on the minimum & maximum values i.e. 35 to 115 MPa.

The principle of the semi flexible installation is that the cable is allowed a small amount of distributed lateral movement to allow for thermal expansion. In addition, there must be slight movement allowed for the underlying bridge support. To achieve the former the cable was waved in a sinusoidal pattern and cable cleats placed at the 0°, 180° and 360° of the waveform. Cleats were allowed to move in the lateral amplitude of the waveform. In addition to cable cleats, short-circuit straps were installed at mid span positions between cable cleats. These were installed to accommodate the lateral repulsive forces experienced on the outer cables from the symmetrical short circuit through fault current. A section of the short-circuit straps is illustrated in Figure 8. Teflon plates were installed between the short-circuit straps and the metal supports to prevent wear of the galvanized metal sections.

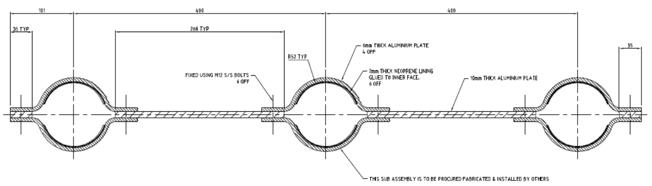

Figure 8: Section of Short-Circuit Strap

The steel bridge presented earthing considerations to reduce touch and step potentials to acceptable levels. A comprehensive earthing system was installed which consisted of earth electrodes at the bridge and all metal sections bonded to earth. The entire steel bridge was connected to remote earth which was the TCC earthmat. The asphalt only the walkway provides additional protection.

B. New Service Road

The extension of the concrete bridge facilitated a service road to be constructed across it as illustrated in Figure 9. This provision required that the cable be temporally buried at a depth deeper than the original design. This was a temporary requirement until the surrounding area near the bridge was excavated to the actual road level.

As the 220 kV cable is a generation supply and is normally loaded at full load, the soil thermal calculations were carried out for *normal continuous* operating conditions. These calculations have been based on *IEC 60287 Electric cables – Calculation of the current rating.*

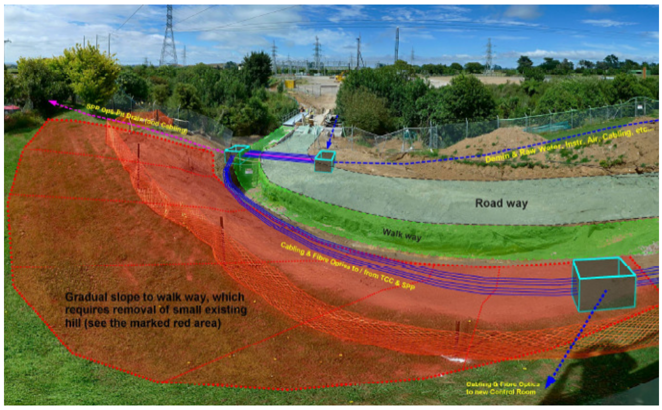

Figure 9: Provision for Service Road Across Bridge

With the initial cable design parameters and the tested soil resistivities, the need to increase the existing ground level above the 220 kV cable in the area of the steel bridge by 900 mm was technically acceptable. This was based on a calculated ampacity of 1 307 A with the actual requirement being only 1 102 A. At this increased ground level the conductor temperature is expected to increase from 50°C to 70°C. This increase is 20°C below the acceptable maximum operating conductor temperature of 90°C.

Figure 10 illustrates the additional backfill required and Figure 11 illustrates the reduced ampacity of the cable with the additional 900 mm backfill.

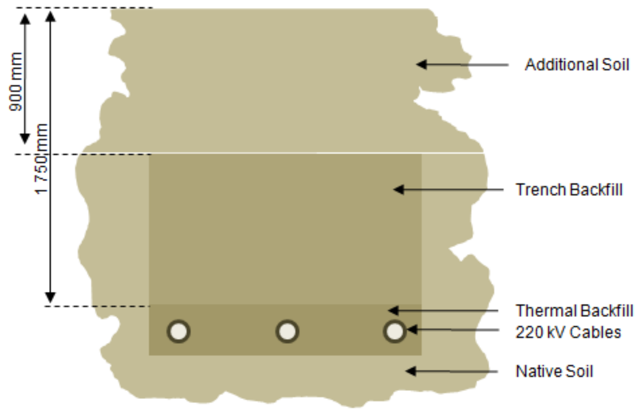

Figure 10: Increasing the Burying Depth

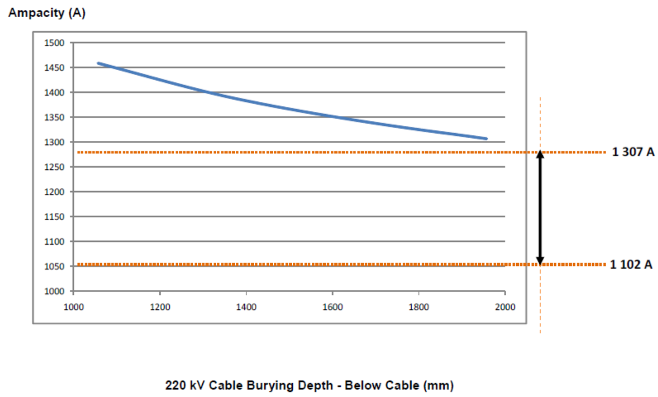

Figure 11: Effect of Increasing Burying Depth [3]

IX. Commissioning

As part of the quality process, there were many witness hold points prior to commissioning of the 220kV cable system. The first part of the project includes the factory acceptance tests, limestone suitability assessment, soil resistivity tests, soil compaction control test, soil moisture density test and termination oil tests.

The pre-outage works, on the other hand, covers cable termination check sheet, fibre optic cable continuity test, 220kV cable sheath test, phase rotation checks, earth continuity test, 48-hour soak test and partial discharge test. Partial discharge (PD) measurements were carried out on site by means of 2 systems. This instrumentation, was capable of acquiring the entire pulse waveform of a large number of PD signals, allowing deep PD analysis to be performed [4]. The analysis includes a post processing phase in order to achieve separation of different PD phenomena, noise rejection and PD identification. The correct PD identification is the prerequisite for any risk assessment and maintenance evaluation. With the acceptance of the tests above, the new 220kV cable system was ready for livening and returned to service on 3 May 2009.

X. Conclusions

The project was completed successfully within time to meet the winter generation and within delivery expectations. This was despite unanticipated work scope changes as well as time constraints set by the Stratford Peaker project. The project required intense and diverse involvement from resources of various backgrounds during the initial investigation phase, installation process, testing and commissioning.

When weighing up the financial and operational risks the decision to replace the 220kV cable system was justified and timely. From a safety point of view, precautionary measures were undertaken such as the installing of explosion-proof wall to protect the equipment in case of sealing ends rupturing and installing a temporary 220kV bypass circuit during the extended outage period of the cable replacement. Other challenge includes the manual termination of cable sealing ends within the vicinity of live equipment with minimum approach distance maintained at all time.

The proactive condition based monitoring did indeed provide early warning and valuable findings regarding the abnormal condition of the cable. This emphasises the importance of condition monitoring and for that reason this project has considered a partial discharge monitoring system and provision of future thermal cable monitoring system.

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