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Paper Title: Bricks and Mortar, Fire and Water – Protecting Power Transformers at Meridian Energy's Ohau A Power Station

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Figure 1: Ohau A transformer platform before project

Figure 2: Ohau A transformer platform after project

1 Abstract

Transformer fires and explosions are rare but destructive events that can take days to bring under control. At a hydro station the consequences are severe and mitigation options are limited for existing plant by the space available and site layout.

This paper charts an engineering journey spanning two decades to understand and address the risks of a transformer fire and explosion at Ohau A hydro power station. The project is presented in three parts; understanding the risks, designing the solutions and construction.

The first part looks at the evolving appreciation for the consequences of a destructive transformer fire and explosion and the effects on adjacent buildings and transformers of that failure. The fundamental risks of fire and oil spreading are presented along with a site specific analysis of how they could transpire. This included the consequences of polluting an internationally renowned rowing venue downstream.

The second part covers the design implementation of a multi-faceted fire strategy. This included the challenges faced in the design being:

- Complicated shapes of the reinforced masonry fire enclosures taking into account overhead conductor clearance, and a fire rated pre-cast concrete canopy required to minimise fire radiation effects as far as practicable.
- Maintaining service access whilst increasing oil and firefighting water containment volume.
- Retrofitting a custom designed and sourced isolated phase busbar (IPB) oil separation barrier between the transformer and the power house.
- Augmentation of the existing oil interception system and new equipment allowing removal of oil from a burning transformer.

The final part covers the further unique challenges presented during site works and lessons learned in overcoming them. These included labour intensive work from scaffolding on a cold south facing transformer platform with live adjacent 220 kV circuits, and providing temporary transformer containment during construction. The inconsistencies between industry guides and codes of practice for this type of work are summarised. The benefits and challenges presented by blockwork construction are detailed.

The design was repeatedly challenged and the helpful insights gained during construction are presented.

2 Introduction

A large multi-disciplinary project was recently completed at Meridian Energy's Ohau A hydro power station. The goal of the project was to address the various risks posed by a generator step up transformer fire.

3 Background

Fully commissioned in 1979, Ohau A is the first station in Meridian Energy's Waitaki hydro scheme. It is located near Twizel and fed from lakes Pukaki and Ohau via a pair of canals. The station feeds water into lake Ruataniwha, an internationally renowned rowing venue. The hydrology is tightly linked to downstream stations Ohau B and C with minimal storage in-between. A prolonged unit outage at Ohau A results in a capacity loss equivalent to a unit outage at both downstream stations.

The station consists of four 66 MW Litostroj Francis turbines driving 73.3 MVA Rade Koncar synchronous generators. The terminal voltage of 13.2 kV is stepped up to the 220 kV grid voltage through four 73.3 MVA Tyree water cooled (OFWF) power transformers. The transformers are positioned on a concrete platform on the downstream side of the station overhanging the tailrace. Each transformer has an oil volume of approximately 20,000 L.

4 Risk assessment of fire at Ohau A

Transformer fires at power generation sites are rare. The most notable one in recent history was the Huntly fire in 1999 shown in Figure 3. The fire was quenched after 36 hours due to the significant amount of burning material. Despite being perched above an aggregate filled bund equipped with an oil interception system, trace amounts of transformer oil still entered the neighbouring river (O'Sullivan, 1999).

Figure 3: Huntly transformer fire with deluge system operating (O'Sullivan, 1999)

There is ample fuel available to sustain a transformer fire. Mineral oil which is commonly used as an insulating medium has a flash point between 110 and 170 °C. Even if the oil completely leaves the tank during an explosion, insulating materials impregnated with oil such as paper and pressboard will continue to burn.

The most likely source of ignition is an internal fault within the tank. Under these circumstances the flash point of mineral oil is almost guaranteed to be exceeded (Gordon, Chang, Enright, & Lynch, 2010). External events can be a source of ignition such as vehicle fires, bushfires, arson and failure of neighbouring equipment.

4.1 Previous work

Early efforts to mitigate the consequences of a transformer failure focused on oil containment and interception. Solutions were designed to mitigate the consequences from an oil leak during maintenance or a benign failure. The understanding of the risks developed over time and was informed by events such as Huntly. The designs now considered the more likely scenario of an explosive transformer failure and the subsequent fire.

New fire protection measures were implemented at a former Meridian hydro station Tekapo B. This was a challenging site for the fire service to gain access and posed unique risks being surrounded on all sides by lake Pukaki. This project was followed by similar projects at Benmore and Aviemore power stations.

4.2 Site specific risks identified

The likelihood of a destructive transformer failure increases with age but is also highly likely during first energisation following maintenance. This applies not only to the transformers but individual components such as bushings, terminations and auxiliary equipment. Good asset management practised reduce the likelihood of a transformer fire as far as reasonably practical, however if a fire occurs the potential consequences are severe enough to warrant further risk mitigation.

The existing concrete walls and high bay windows between the machine hall and transformers provided no guarantee of any fire or explosion resistance and were not designed originally to do so. Flexible rubber joints in the cooling water pipes were not fire rated and would likely fail during a fire and flood the bund. This would overwhelm the oil containment system before the unit cooling water shuts down.

The existing transformer bunds shown in Figure 4 had been sized to contain the maximum expected spill from any one unit and had no provision for firefighting water. The bund water drainage pipework running to an oil separator was equipped with automatic shutoff valves to isolate the oil in the bund in the event of a transformer trip. This created a risk of an oil pool fire forming in the bund. The removable steel bund gates were sealed with a liquid sealant almost guaranteed to fail in a fire.

Figure 4: Old transformer bunds with steel gates

The IPB penetrations into the power house were susceptible to failure in a fire due to the flexible rubber expansion bellow connecting the transformer to the powerhouse and aluminium construction of the enclosure. Additionally any burning oil leaking from the transformer LV bushings or a ruptured tank leak near this connection could find its way directly into the station.

5 Design implementation of fire strategy

The chosen design elements were focused on limiting the consequences of a burning transformer by mitigating the following risks:

1. Risk of fire spreading to adjacent transformers;
2. Risk of fire spreading to the powerhouse;
3. Risk of hot or burning oil entering the powerhouse.
4. Risk of spilt oil making its way into Lake Ruataniwha, an internationally known rowing venue

The design supported a fire strategy of containing the fire and oil for the duration of the burn time, removing fuel from the fire to reduce the burn time where practical and enabling firefighters to take action without exacerbating the problem.

5.1 Protective fire enclosures

Concrete enclosures were constructed to provide radiation and blast protection around the existing transformers. The fundamental design requirements for such an enclosure are described in an earlier EEA paper (Gordon, Chang, Enright, & Lynch, 2010). The transformers did not need to be relocated to achieve the required clearance to the machine hall wall. A canopy was designed to direct heat and combustion by-products away from the station and a fire barrier was designed for the upper level windows.

5.2 Oil removal and containment upgrade

New bunds with a larger capacity were designed to comply with recommendations from NFPA 850. This included capacity to contain all oil within the transformer and 10 minutes of firefighting water. The bund drainage was re-designed to passively drain oil into a holding tank, reducing the risk of an oil pool fire. A further drainage valve was installed to enable oil removal from the tank of a burning transformer and reduce the burn time.

5.3 IPB oil barrier

A custom IPB seal off bushing was designed to serve as an oil barrier between the transformer LV bushings and the power house. A type tested barrier was not possible because the OEM was no longer in business. The barrier was designed from first principles such that it could be retrofitted on site. Another challenge was material selection as a true fire rated material was not available. A porcelain material was deemed impractical. The barrier was cast from a sheet moulding compound, often used in industrial applications. Manufacture was undertaken by an IPB supplier in China to a high standard, and the reasonableness of their cost made it easy to justify the employment of an independent factory QA inspector prior to dispatch.

6 Construction

The vast majority of the works were conducted during four unit outages between April 2016 and April 2017. The site works were conducted simultaneously with a unit excitation upgrade and planned maintenance activities.

6.1 Block-work firewall construction

Blockwork construction above a certain height has to be performed in stages or lifts to prevent a blowout of the bottom layer as the concrete is poured in. The first lift was laid by a team of brick layers from the ground and the remaining two lifts were laid from scaffolding during unit outages.

The most challenging health and safety risk to manage was the proximity of live 220 kV conductors to the work party. This risk was eliminated during high risk tasks such as scaffolding by scheduling short unit outages timed to suit favourable market conditions between demand peaks. At other times the works were carefully managed with safety observers and barriers. A 3D model of the scaffold was produced to predict the clearances to neighbouring unit live lines as shown in Figure 6.

A review of the compliance of the work methodology with regulations and industry guides was conducted after receiving a safety alert from another generator using scaffolding around transformers. An ambiguity was found stemming from the mandate in the Electricity (Safety) Regulations 2010 to comply with the safe distances in Electrical Code of Practice (ECP) 34 were scaffolding is classified as a structure. The applicable distances for 220kV, are 6.5m vertically above and 4.5m in any direction from the platform as shown in Figure 5. The Safety Manuals – Electricity Industry (SM-EIs) provide minimum approach distances to live conductors that apply to people and not to structures.

The ambiguity arises because ECP 34 implies up to a 7.9m diagonal distance may be required from the scaffolding platform to the conductor even though all workers on the platform were outside the 4m MAD to 220 kV specified in SM-EI part 2. The SM-EIs do not provide an allowance for mobile plant to be constructed within ECP 34 distances (see rule 3.712) but do have an allowance for mobile plant (see rule 3.713). This implies that laying blocks from mobile plant whilst impractical would comply with ECP 34 and the SM-EIs.

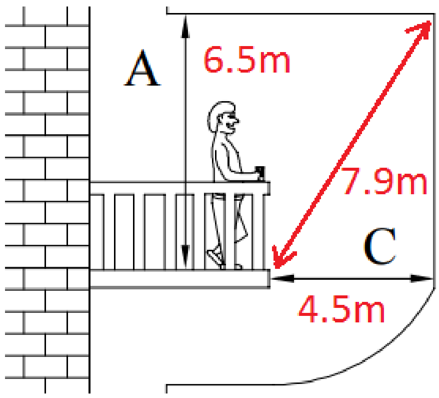

Figure 5: Minimum clearances specified in ECP34

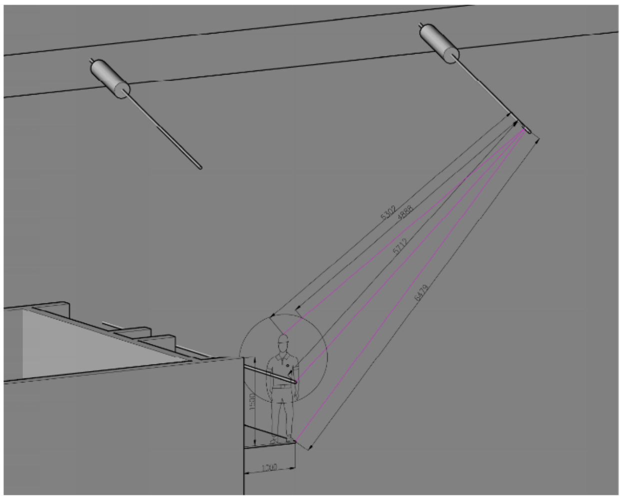

Figure 6: 3D model of scaffold and clearances to 220 kV lines

A major dimensional issue was found early on where a corner section of the firewall intersected with a large access hatch. The design was modified to avoid the hatch causing minimum disruption to the programme. This was possible due to the inherent flexibility of blockwork construction.

Wet and cold weather was a significant challenge during some of the works and a source of project delays. The south facing transformer platform received minimal winter sunshine and was often coated in a thin layer of ice. Blocks could not be laid on wet days nor on excessively cold days due to wet or frozen mortar. The contractor partially mitigated this risk by shrink wrapping the scaffold.

The cold weather presented further challenges with concrete curing times slowing to a crawl below 10 °C. The final installation of the pre-cast canopy was contingent upon the supporting concrete pour attaining a minimum compressive strength. Conditions were so cold adequate curing was not guaranteed. To prevent delays, supporting props were installed to hold the canopy. Final compressive test results of sample concrete cylinders were just within the requirements after days of curing.

Figure 7: Winter working conditions

Figure 8: Wrapped scaffolding

During one outage the scaffolder misinterpreted a site instruction and significantly bent 18 structural reinforcing bars to make room for a scaffold platform. The fix could have involved considerable delay but an industry best practise method involving application of heat was used to straighten the bars (CCANZ, 2005). The end result was considered significantly stronger than the alternative fixes.

Figure 9: Bent reinforcing steel

Figure 10: Re-bending with heat

The pre-cast canopy installation was conducted with a crane positioned on the platform under a temporary outage on the neighbouring unit. The lift involved careful coordination between multiple parties and generation outages and was conducted smoothly on each of the four units.

6.2 Oil drainage pipework installation and commissioning

The new transformer drain valve pipework required core drilling through the transformer platform in the presence of numerous embedded services of unknown locations. The exact locations of critical pipework and cabling was ascertained accurately by a ground penetrating radar scan through the 1 m thick platform.

The second challenge was priming the pipe between the transformer tank and the new drain valve without displacing an air bubble into the transformer. This section of pipe was vacuum primed which had not been specified in the original design brief. Some of the joints were modified to make them vacuum rated and a vacuum filling procedure was developed to complete the installation.

Figure 11: Pre-cast canopy installation

Figure 12: Emergency oil drain valve

Figure 13: Drain valve transformer connection

6.3 Isolated Phase Busbar modifications

The majority of the IPB modifications were completed before firewall construction began. The existing IPB enclosure was cut/removed, a mounting flange welded in place, the circular busbar replaced with round extruded busbar so that a good seal could be achieved and the barrier bolted in place. Attention to detail during the design and manufacturing process paid dividends allowing a smooth installation process.

Figure 14: Cut IPB enclosure and busbar

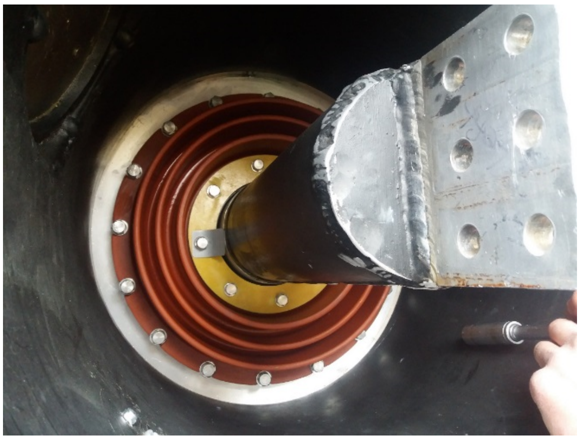

Figure 15: Fully installed oil barrier

6.4 Power House Window Fire Rating

This item of scope presented the greatest savings from the original budget. The original design spec called for a fire proofing solution that would not change the appearance of the building so internally mounted fire board was proposed. The contractor suggested installing exterior mounted aerated concrete panels from the existing walkway to save scaffolding costs. Panels were raised up using a forklift then transported along the platform using a custom built trolley. The original design requirement was relaxed as there would be little difference in the appearance of the building. The time and cost savings were significant and a number of project risks were eliminated using this approach.

Figure 16: Completed Speedwall® window protection showing transport trolley on left

7 Lessons learned

Many ideas for major savings came from the contractor with potential for more savings if they had been involved earlier in the design process. Early contractor involvement is being used on some complex future Meridian projects to approach design with constructability in mind.

3D scanning proved to be an important tool during the design stage when dealing with complicated features. The models continued to serve as a good reference point during construction for tasks like estimations of electrical clearances.

Parallel construction of the first lift of blocks on all transformers from the ground proved to be more challenging than thought. This approach required numerous small outages and temporary oil containment measures without the necessary fire rating. This temporarily reduced plant availability at three hydro stations and increased the consequences of a transformer failure whilst construction works were undertaken. Similar future projects will be conducted on one unit under outage at a time.

8 Conclusions and future projects

A large multidisciplinary project was recently completed at Ohau A power station to mitigate the risks posed by a transformer fire. A range of solutions were designed to mitigate these risks and support a comprehensive fire strategy. The main features of the design were concrete masonry fire enclosures to protect the power station and neighbouring unit transformers. This was backed up by upgraded oil containment capacity and facilities to remove fuel from the fire by draining oil from the bund and transformer into safe storage. An oil barrier was designed for retrofitting into the isolated phase busbar to prevent oil ingress into the station. The construction works presented numerous challenges foreseen and unforeseen. The works were impacted by the cold weather in many ways including concrete curing delays and icy conditions. The risk posed by the proximity of 220 kV lines had to be closely managed including use of multiple unit outages when mitigating the risk was not practical. The end result was an installation providing a significant barrier against the key risks posed by a transformer fire. The project was completed on time, under budget and with zero lost time injuries. The lessons learned will carry forward into an upcoming fire protection project at Ohau B and C power stations.

9 References

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