IMPACT OF THE DARFIELD EARTHQUAKE ON THE ELECTRICAL POWER SYSTEM INFRASTRUCTURE

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SUMMARY

This paper gives a brief summary of the performance of the electrical infrastructure in the earthquake that struck Christchurch and surrounding regions on 4th September 2010.

INTRODUCTION

The 7.1 magnitude earthquake that struck Christchurch and surrounding regions at 4:36 am on Saturday morning (4 September) caused a loss of electricity supply to most customers in Christchurch and surrounding region. However, electricity was restored to major Transpower supply points by 8:32am with Orion and MainPower progressively restoring supply to most of the city by the end of the day. This was only possible due to lack of significant damage to substation equipment, which would have required days or weeks to fix, at both the transmission and distribution level.

The transmission system is owned and operated by Transpower. Their high voltage network (220 kV, 110 kV and 66 kV) delivers electricity to Grid Exit Points (GXPs) where the Lines companies (Orion and MainPower in Christchurch area) take over reticulating it to customers through their zone and district substations. Transmission is at high voltage for both technical and economic reasons and the voltage is stepped down in a number of stages by transformers, by both Transpower and Lines Companies.

Data on the performance of the electrical infrastructure was obtained from TransPower, Orion & MainPower, as either an event report or email report. Site inspection of Papanui substation was conducted with the assistance of TransPower staff, due to the liquefaction at this site. The electrical infrastructure was inspected in a few other places.

NATIONAL GRID PERSPECTIVE (TRANSPOWER)

Protection relays, known in the industry as Buchholtz relays (Figure 1), provide essential protection for transformers. The three conditions they detect are: gas accumulation, loss of oil and oil surges. When an electrical fault occurs within the transformer, gas forms rapidly causing an oil surge. Early Buchholtz relay used mercury switches to detect surges.

***Figure 1:** Buchholtz relay that is between the transformer tank and conservator.*

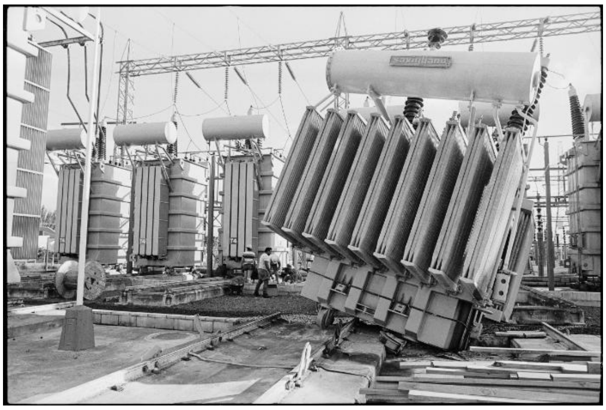

***Figure 2:** Workmen are dwarfed by a 20-tonne transformer toppled from its mountings at Edgecumbe substation. Photograph taken 4th March 1987 by Evening Post staff photographer John Nicholson (courtesy: Alexander Turnbull Library).*

Unfortunately seismic events caused the mercury to move and trip the transformer. Transpower subsequently installed seismic blocking devices to block the operation of Buchholz mercury switches during earthquakes. Buchholtz devices have now been mostly updated over time to replace the mercury switches with reed switches which are less sensitive to seismic events. Buchholtz devices also have baffles to minimise incorrect operation during seismic events but they can potentially operate for large surges caused by seismic events. Some Transpower transformers use mercury switches as part of over-temperature protection. The initial earthquake jolt resulted in some transformers tripping due to the mercury moving in their over-temperature protection devices. This

***Figure 3:** Seismic restraint on transformers (Papanui Substation).*

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(a) Terminal span showing Phase that failed *(b) Spring tensioner on terminal span*

Figure 4: Terminal span Islington-Papanui.

resulted in partial loss of supply in Transpower's network.

One lesson learnt from the Edgecumbe earthquake in 1987 was the need for seismic restraints on the transformers (see Figure 2). These have been fitted to transformers, as shown in Figure 3, and ensured no transformers toppled off their foundations. This was true for both Transpower and the Lines companies. The use of flexible cables rather than solid conductors to make connections between the busbars and substation equipment also allows some flexing without breakage.

Although the ground movement has displaced some pylons 3 to 4 metres the HV overhead transmission lines were reasonably resilient, with only one terminal span breaking and a tripping of the other circuit on the pylon. This caused the loss of supply from Transpower's Papanui GXP to Orion. Even though anchoring of one phase of a terminal span broke, the conductors stayed attached. Figure 4(a) shows the terminal span that broke while Figure 4(b) shows how the terminal span is connected via a spring tensioner. Figure 5 shows evidence of fault rupture near a HV pylon. The movement has resulted in extra stresses on conductors and towers.

Clashing of conductors during the earthquake also occurred on both Transpower and Lines companies' overhead lines. These caused temporary faults which often activated the protection system, switching off the line.

Only minor damage occurred at most of Transpower's substations (cracks, broken windows, loose items falling), with the base of one surge diverter breaking at Islington. At Papanui substation, liquefaction occurred and the transformer bunding moved and in one case cracked (shown in Figure 6). Bunding is a containment system so that if a transformer leaks oil it will not enter the ground.

Transpower's approach was to inspect all equipment and transmission lines prior to returning them to service. Following restoration, all substations were inspected and thermographic surveys completed to ensure no hot spots. Regular daily inspections are continuing due to the ongoing aftershocks.

LINES COMPANIES PERSPECTIVE (ORION & MAINPOWER)

The Lines companies Orion and MainPower had the same issue with their transformers tripping due to the oil surge protection. If protection relay switches off equipment, such as transformers, an inspection must be made to ensure there is no physical damage and it is safe to reenergize, and this inspection takes time.

Orion took an active part in the Centre of Advanced Engineering Lifelines study (CAE, *Risks and Realities: A*

Figure 5: Fault rupture near a 220 kV pylon.

Figure 6: Crack in the bunding (Papanui Substation).

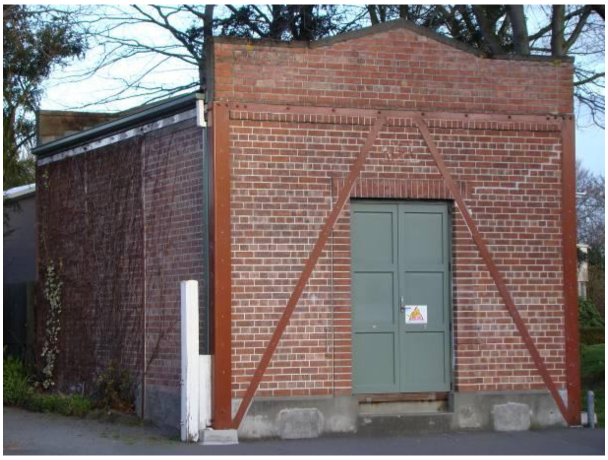

Figure 7: Zone substation with seismic strengthening.

Multidisciplinary Approach to the Vulnerability of Lifelines to Natural Hazards, Nov. 1997), and acted on many of the recommendations of this study. This study investigated the vulnerability of the infrastructure serving metropolitan Christchurch (including Lyttelton). The work was undertaken by the Christchurch Engineering Lifelines Group whose objectives were:

1. To identify the vulnerability of engineering lifeline services to damage from earthquakes, flooding, tsunami and meteorological hazards.
2. To identify practical engineering strategies for reducing the risk or impact of such damage and for providing for reinstatement following such events.
3. To communicate the issues to people involved in the management of these services and to raise the awareness of the public to their importance.

Orion has been actively pursuing a policy of earthquake (and storm) hardening their electrical network. Zone substation transformer foundations have been reviewed and upgraded as necessary (with oil containment) and the many network centre building substations in urban Christchurch (many using old brick construction) have been strengthened. An example of seismic strengthening is shown in Figure 7. Pole mounted structures/transformers have been reviewed and upgraded as necessary to withstand earthquakes. The result of this work was that only a few major Orion substations were affected by the earthquake, and these occurred where there was significant ground and/or foundation movement. None of these affected the immediate operational capacity of the network.

Orion reports that there was also minor damage to some overhead lines in the rural area due to whipping of the poles and conductors which damaged insulators and broke some weaker/smaller conductors, especially those made of copper. Land movement and liquefaction have caused some poles to lean but in most cases did not cause an interruption of supply. The earthquake has left some poles leaning (see Figure 8), putting more tension on some spans and making others slacker, but the system kept operating remarkably well.

Underground cable faults are always more difficult and time consuming to fix than overhead lines and the higher the voltage level the more customers the fault will affect. One of Orion's major concern is the health of their oil filled 66 kV cables which supply major zone substations in the urban area as these cables have very long repair times and potentially could affect a large number of customers. So far Orion has not detected any electrical or physical damage to these cables which are monitored by trending the cable oil pressure. The majority of the damage is in the 11 kV and low voltage cables in areas where there has been major ground disturbance. Many of these cables appear to have faulted in multiple locations making it very difficult to repair. Once one fault is fixed another is discovered a few metres further up the road.

MainPower has been continually working over the last 15 years to upgrade zone substation transformer seismic restraints as this was a lesson learnt from Edgecumbe earthquake. This work resulted in the 4th September earthquake causing a few tools to drop off their racks but no real damage at zone substations. Also mutual aide agreements, strengthened following earlier snow storms, meant the MainPower was able to utilise cable fault location equipment, staff and cable jointers, from other network companies especially from Marlborough Lines and Electricity Ashburton (although all offered their support).

As expected MainPower's major damage has been due to land movement from liquefaction. The overhead network generally stood up well and was repaired very quickly. Initial faults were due to conductor clashes, poles leaning severely, two 100 kVA transformer poles tipping over at Kairaki Beach, conductors off insulators, and EDO (Explosive DropOut) fuses being broken. Most overhead areas had power restored on the 4th September with the remainder on the following day. A number of heavy poles e.g. concrete poles and wooden transformer poles, sunk significantly requiring immediate or short term rectification. There will be ongoing work for the next few months straightening and repositioning lines in areas of significant ground movement but this will not affect availability other than for short planned outages required for the work. Reliability in high winds will have been compromised until this work is completed, and some ground clearances are reduced.

Underground cables are understandably more affected by land

Figure 8: Lean on Pole due to liquefaction (Halswell).

Figure 9: Linesmen at work repairing overhead lines (10 September 2010).

movement than overhead lines. MainPower suffered approximately seventeen 11 kV cable faults. The faults have been due to sideways forces and stretching and often damage is seen over several metres around the immediate fault. Due to the distributed nature of the damage and obvious significant ground movement in areas on the same cable section as the fault, MainPower is replacing approximately 3 km of 11kV cable in 11 cable sections. Several cables have been pulled back from the ring main unit switchgear they were terminated on, requiring them to be excavated and eased or re-terminated. In one case the cable termination pulled 500 mm clear of the switchgear terminals causing some arcing damage. Two ground mounted transformer pads have also moved significantly putting excessive stress on HV and LV cables and this will require replacement. Low voltage cable damage has been minimal with approx 100 m requiring replacement.

Underground cables were damaged in areas where there was major ground movement but there seems no easy way to prevent this except to move to overhead lines. However, overhead lines are prone to storm damage as well as being hit by vehicles.

CONCLUSIONS

It appears that the policy of earthquake (and storm) hardening the electrical network has paid off as there was no significant damage to major zone substation or GXPs. There was minor damage to overhead lines but these were easily fixed.

There is a need for a more quantitative investigation into the performance of the electrical infrastructure. For example, collecting data on the number and location of substations in the affected areas and the level of damage they suffered. Similarly the length of cable & overhead lines in affected areas compared to the length needing replacing would be useful information.

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