Managing the Next Generation of Cook Strait HVDC Cables

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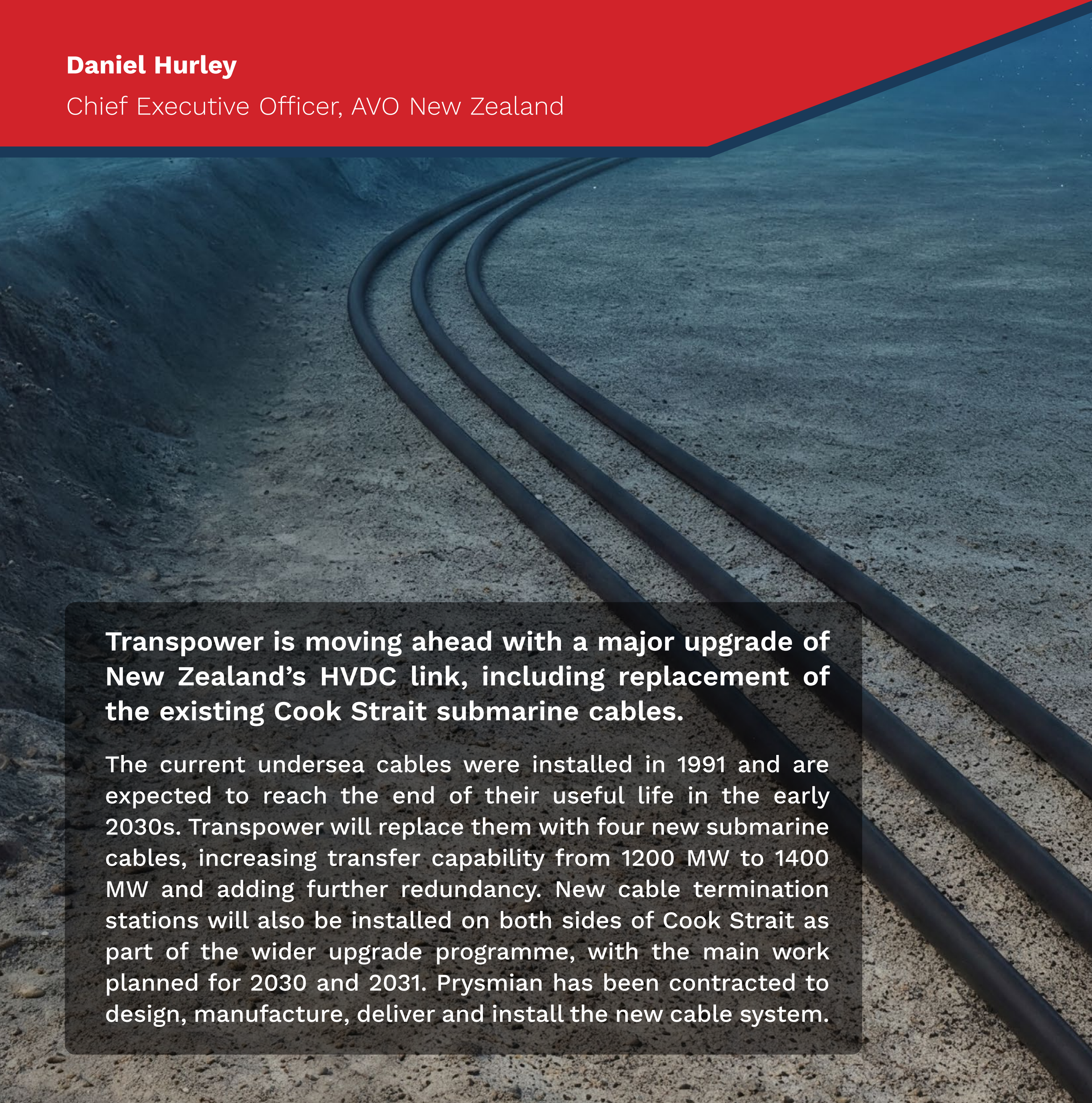


Transpower is moving ahead with a major upgrade of New Zealand's HVDC link, including replacement of the existing Cook Strait submarine cables.

The current undersea cables were installed in 1991 and are expected to reach the end of their useful life in the early 2030s. Transpower will replace them with four new submarine cables, increasing transfer capability from 1200 MW to 1400 MW and adding further redundancy. New cable termination stations will also be installed on both sides of Cook Strait as part of the wider upgrade programme, with the main work planned for 2030 and 2031. Prysmian has been contracted to design, manufacture, deliver and install the new cable system.

This is a significant investment in a piece of infrastructure that is critical to the New Zealand power system.

From a testing and asset-management point of view, it also raises an important issue. Once the new cables are installed, how do we make sure we understand their condition, and how prepared are we to deal with a cable fault if one occurs?

For a system such as the Cook Strait HVDC link, fault location and condition monitoring should be considered during the design and commissioning phase, rather than after the first serious problem.

These are not just long versions of normal power cables

Most network companies in New Zealand are familiar with cable fault location. There is generally good experience with TDR, surge methods, sheath testing and fault pinpointing on distribution cables.

Very long HV and HVDC cables are different.

Their capacitance is much higher, signal attenuation becomes more significant, fault voltages can be much higher and the amount of stored energy can be substantial. The cable behaves as a distributed electrical system, so capacitance, impedance and propagation velocity all start to have a major influence on what can be measured and how useful that measurement is.

Megger's work on long HVAC and HVDC cables makes the point that conventional MV fault-location equipment cannot simply be applied to these systems in the same way. Long cables require a combination of methods and, importantly, equipment designed to handle the electrical characteristics of the cable itself.

That is particularly relevant to Cook Strait.

If a distribution cable fails, the effect is usually localised. A restriction on the HVDC link affects the ability to transfer generation between the South and North Islands. Transpower describes the link as a critical part of New Zealand's national infrastructure, and the new cable programme is specifically intended to improve both capacity and resilience.

Cable management therefore needs to be viewed as part of system resilience.

Get a good fingerprint at commissioning

One of the most useful things that can be done with a new cable system is to establish good baseline measurements while the cable is known to be healthy.

TDR is an obvious example.

A Time Domain Reflectometer sends a low-voltage pulse into the cable and measures reflections caused by changes in impedance. On a long cable these reflections can show terminations, joints, changes in cable construction and other features along the route.

The important part is not just taking the measurement. It is keeping it.

A good commissioning TDR trace gives the operator a known reference. If the cable develops a fault 10 or 20 years later, there is something to compare the new measurement against.

On a cable as important as the Cook Strait link, these traces should form part of the permanent asset record.

The same applies to cable section lengths, propagation velocity, termination information, route data and any other useful measurements taken during commissioning.

MeggerBook is one example of how this data can be managed. Measurements from compatible cable-test equipment can be assigned to a cable asset and stored chronologically, allowing earlier results to be reviewed alongside later measurements. The cable editor can also store cable sections and route information.

The key point is simple. If a fault occurs in the future, the engineers trying to find it should not be starting with a blank sheet of paper.

Monitoring should be part of the discussion

The new cable system also gives Transpower the opportunity to look at what should be monitored continuously rather than relying entirely on periodic inspection and offline testing.

Terminations and other cable interfaces are obvious areas of interest.

These are locations where different materials, electrical connections and mechanical interfaces come together. Temperature, screen currents and other electrical quantities can provide useful information about how these parts of the cable system are behaving.

Megger's Greenlight cable monitoring system is one example of this approach. It uses passive sensors installed at joints and terminations, with data brought back over optical fibre to an interrogator at the substation. The system can monitor phase current, screen current and spot temperature without needing local control power at each sensing point.

For the Cook Strait installation, the value would be in establishing what normal looks like and then watching for change.

A termination that is slightly warmer than another may not mean much by itself. A termination whose temperature begins changing relative to load, or whose screen-current behaviour starts to move away from comparable locations, is much more interesting.

That is where continuous monitoring becomes useful. It gives the operator the ability to look for developing behaviour rather than waiting for a fixed alarm limit to be exceeded.

Not every part of the cable needs to be instrumented, and the final monitoring philosophy should be based on the cable design and Transpower's maintenance strategy. But these decisions are much easier to make before commissioning than after the cable is in service.

Fault location needs more than one method

Even with good monitoring, cable faults will always remain possible.

This is where fault preparedness becomes important.

There is no single method that will locate every type of cable fault.

A low-resistance fault may show clearly on a TDR. A high-resistance fault may not. Some faults only become apparent at higher voltage. Sheath faults are different again.

For long HV cables, Megger describes the fault-location process as four main stages:

1. fault identification
2. fault conditioning or conversion where required
3. fault prelocation
4. final pinpointing

The actual method used depends on the fault.

TDR should generally be one of the first tools used because it is low voltage and non-destructive. If the fault creates a clear impedance change, a useful distance can sometimes be obtained very quickly.

Where that does not work, other methods may be required, including Arc Reflection Method, ICE, decay techniques, high-voltage bridge measurements or fault conversion.

That is why Megger's long-cable fault-location range includes several different technologies rather than one instrument. The transmission-grid overview includes long-range TDR, high-voltage bridge systems, high-energy fault-location systems and audio-frequency methods, each aimed at a different part of the process.

For Cook Strait, the important question is not which one instrument is required.

The important question is what combination of methods will work on the final cable system.

What a dedicated HVDC fault-response system looks like

This is where the Megger R550 becomes particularly relevant.

The R550 is not a portable cable fault locator in the normal sense. It is a **fully integrated, containerised fault-location system designed specifically for very long EHV and HVDC cables**.

The equipment is built into a dedicated container that can be located at, or close to, the cable termination site. Instead of trying to assemble a collection of high-voltage sources, switching equipment, TDRs, surge equipment and discharge systems after a fault has occurred, the R550 brings the main functions together into one centrally controlled installation.

The container includes a high-voltage unit, a high-performance fault-conditioning section, a high-voltage surge unit, a dedicated high-energy discharge system, the cable connection compartment and a separate operator room. The HV section is climate controlled, and automatic motorised HV switching means different operating modes can be selected without repeatedly changing the high-voltage circuit by hand. Remote access and control are also built into the system.

In practical terms, it is designed to support most of the fault-location process from one installation.

That includes initial fault identification, prelocation, fault conversion where required and support for final pinpointing. Methods available within the wider system include TDR, Arc Reflection Method, ICE, decay and surge techniques.

The significance is not just what the equipment can do. It is that the whole arrangement can sit ready for use.

For an HVDC interconnector, that has obvious advantages. The test connections can be engineered in advance. The discharge capability can be matched to the cable. The operating team can be trained on the actual system before a fault occurs. Equipment does not first have to be sourced, transported to site, connected and configured while the interconnector is already out of service.

761 km – Viking Link world record
in TDR measurement (Megger 2023)

That is the philosophy Megger applied on Viking Link, the 761 km, ±525 kV HVDC interconnector between Denmark and the United Kingdom. Dedicated R550 container systems were supplied as part of the cable fault-response capability rather than fault location being treated as something to arrange after an outage.

One of the more notable results from that project was a TDR measurement over the full 761 km cable system.

That is impressive, but the more useful lesson for New Zealand is that the capability was matched to the cable before it was needed.

For Cook Strait, it does not automatically follow that exactly the same R550 configuration would be required. The final answer depends on the Prysmian cable design, cable capacitance, testable sections, available access and the fault scenarios Transpower wants to be prepared for.

But it does raise an important point. For an asset of this importance, specialist HVDC fault-location capability can be treated as site infrastructure that sits ready to go, rather than as emergency test equipment that has to be found after the event.

Stored energy needs to be engineered properly

Stored energy is one of the major differences between fault location on a normal distribution cable and fault location on a very long HVDC cable.

Any long cable charged during testing behaves as a large capacitor.

The amount of energy involved depends on the cable capacitance and the applied voltage. On a long HVDC cable this can become significant very quickly.

It is therefore not enough to ask whether a test set can generate the required voltage. The system also needs to discharge the cable safely afterwards.

Megger's technical paper identifies three main electrical hazards during long-cable fault location: operating-system voltage, induced voltage and voltage introduced by the test equipment. Isolation, proving dead, earthing and correct management of the test circuit are fundamental.

This is one reason the R550 has a substantial dedicated discharge section rather than treating discharge as a minor accessory function.

Megger specifies discharge capability up to 3.6 MJ, with scalable energy ratings available so the system can be matched to the cable length and capacitance.

We cannot assume the new Cook Strait system will require that level of capability.

The correct requirement will depend on the final cable design, capacitance, cable length and how individual sections can be isolated for testing.

But these values need to be known.

Maximum operating voltage alone does not tell us enough about the fault-location system that will ultimately be required.

Finding the electrical distance is only part of the job

Submarine cable faults create another problem.

A TDR or bridge measurement may tell us that the fault is a certain electrical distance from one end of the cable. That is useful, but it does not necessarily tell the repair team exactly where to position a vessel.

The electrical result needs to be related back to the physical cable route.

This is where good installation records become extremely important.

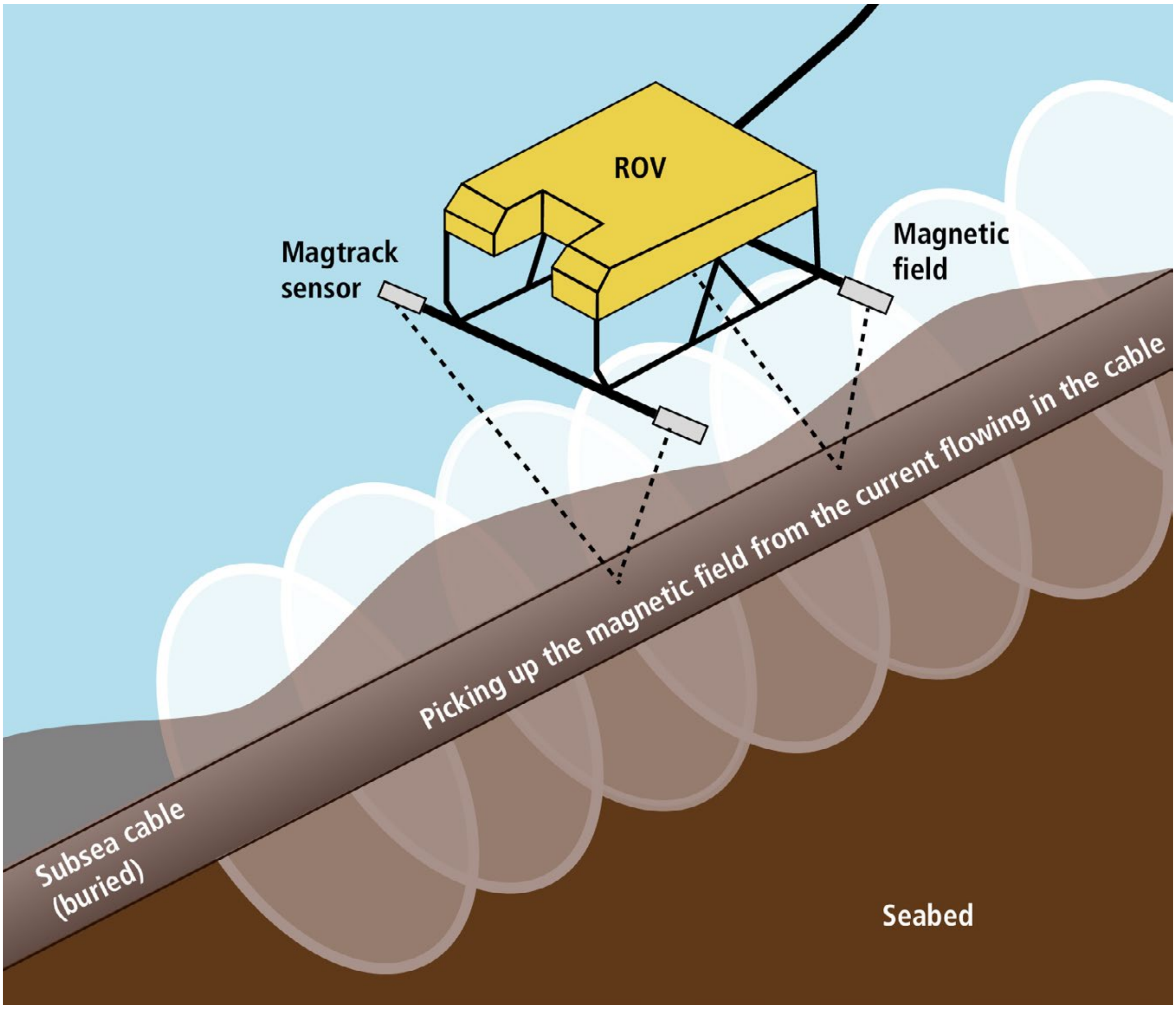
The operator needs to understand the cable section lengths, route changes, actual laid position and the relationship between electrical cable length and geographical distance.

For subsea work, route tracing and specialist cable tracking methods may also be required.

The Megger transmission-grid material includes Hummingbird and Magtrack systems alongside conventional TDR and bridge methods because prelocation and physical location are different jobs.

For Cook Strait, the marine side of any repair is likely to be one of the most expensive and time-consuming parts of the job.

Anything that reduces uncertainty before a cable vessel is mobilised is valuable.



What should be decided before 2030?

The cable fault strategy does not need to wait until the cables are commissioned.

There are several things worth working through while the project is still being developed:

- What baseline measurements will be recorded at commissioning?
- How will TDR fingerprints be stored and maintained?
- What permanent monitoring will be installed at the termination stations or other suitable locations?
- What will the capacitance and stored energy of each testable cable section be?
- What test access will be provided at the new termination stations?
- Which fault-location methods are expected to work for the final cable design?
- How will electrical fault distance be matched to the installed marine route?
- Should a dedicated containerised fault-location system be permanently located at one of the termination sites?

- What equipment needs to be permanently available in New Zealand?
- What specialist capability could reasonably be mobilised from overseas?
- Who will be trained to carry out the work?
- What data will an overseas specialist need if they are called in during an outage?

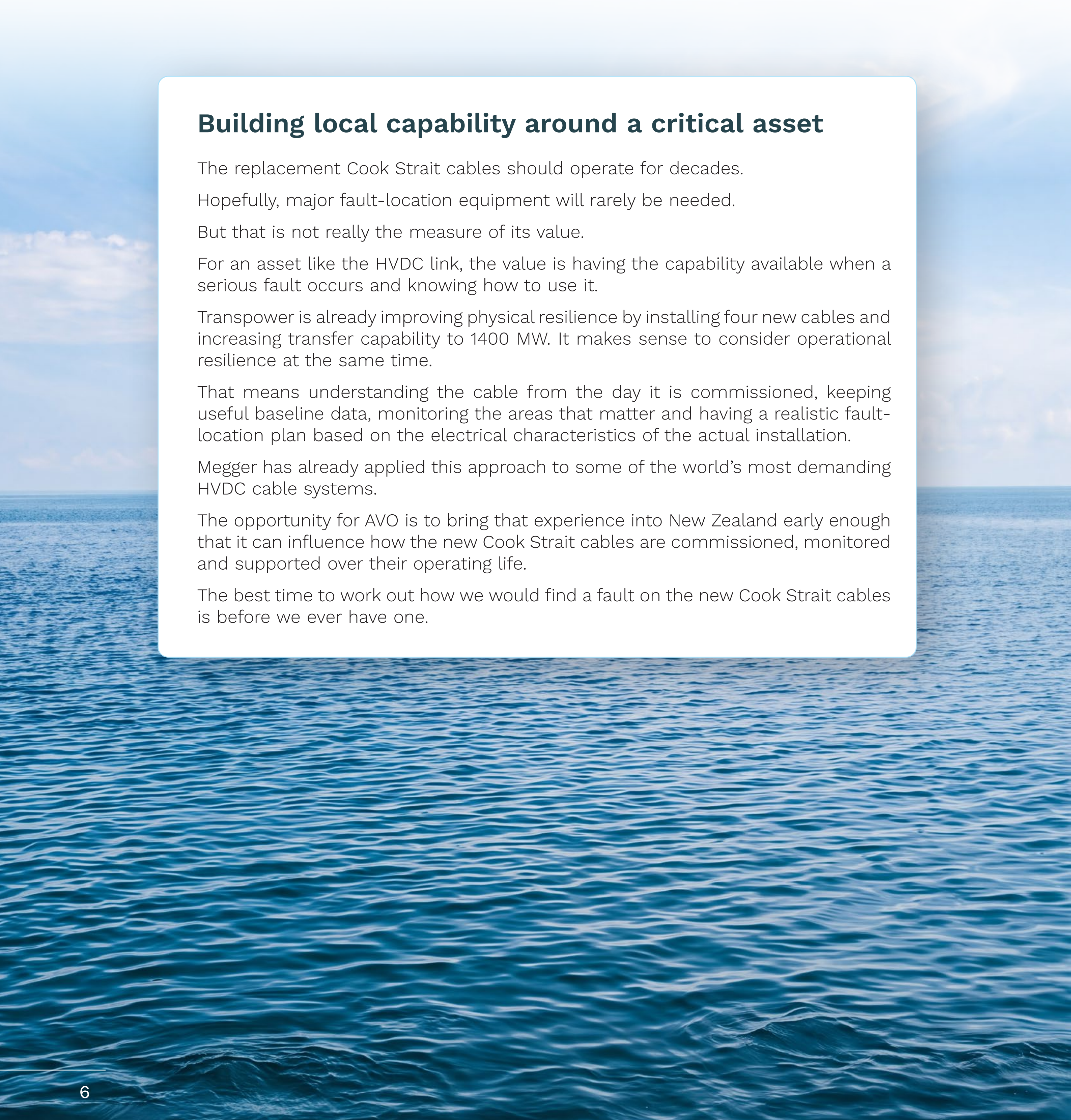
These are the areas where AVO New Zealand can add value.

Our role is not simply to take a Megger product developed overseas and offer it into the New Zealand market.

The useful part is taking what Megger has learned from long HVDC projects and working out what actually applies to Cook Strait.

That could involve a dedicated R550-type fault-response system. It could involve permanent cable monitoring. It could involve a combination of locally held equipment and specialist capability that can be mobilised when required. It should certainly involve making sure useful baseline information is captured during commissioning and that future testing access has been considered in the termination-station design.

The final solution needs to be based on the actual cable.



Building local capability around a critical asset

The replacement Cook Strait cables should operate for decades.

Hopefully, major fault-location equipment will rarely be needed.

But that is not really the measure of its value.

For an asset like the HVDC link, the value is having the capability available when a serious fault occurs and knowing how to use it.

Transpower is already improving physical resilience by installing four new cables and increasing transfer capability to 1400 MW. It makes sense to consider operational resilience at the same time.

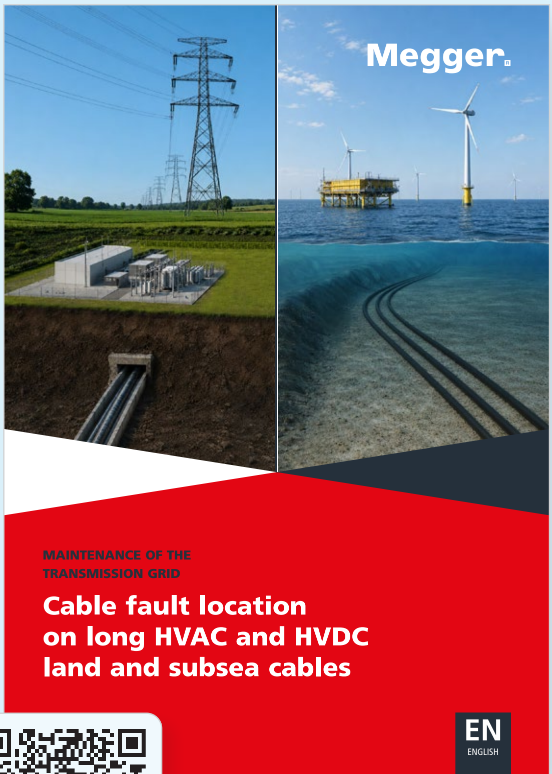
That means understanding the cable from the day it is commissioned, keeping useful baseline data, monitoring the areas that matter and having a realistic fault-location plan based on the electrical characteristics of the actual installation.

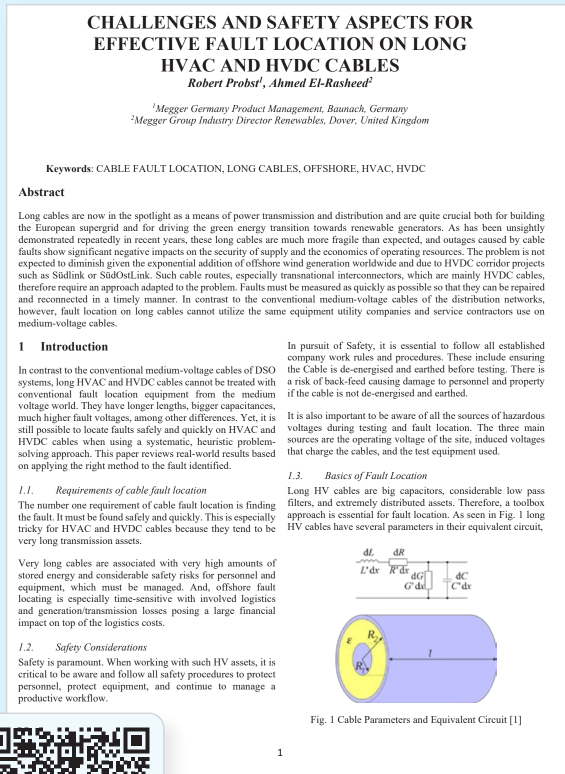
Megger has already applied this approach to some of the world's most demanding HVDC cable systems.

The opportunity for AVO is to bring that experience into New Zealand early enough that it can influence how the new Cook Strait cables are commissioned, monitored and supported over their operating life.

The best time to work out how we would find a fault on the new Cook Strait cables is before we ever have one.

Further Reading





CHALLENGES AND SAFETY ASPECTS FOR EFFECTIVE FAULT LOCATION ON LONG HVAC AND HVDC CABLES

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Abstract

Long cables are now in the spotlight as a means of power transmission and distribution and are quite crucial both for building the European supergrid and for driving the green energy transition towards renewable generators. As has been unsightly demonstrated repeatedly in recent years, these long cables are much more fragile than expected, and outages caused by cable faults show significant negative impacts on the security of supply and the economics of operating resources. The problem is not expected to diminish given the exponential addition of offshore wind generation worldwide and due to HVDC corridor projects such as Südlink or SüdOstLink. Such cable routes, especially transnational interconnectors, which are mainly HVDC cables, therefore require an approach adapted to the problem. Faults must be measured as quickly as possible so that they can be repaired and reconnected in a timely manner. In contrast to the conventional medium-voltage cables of the distribution networks, however, fault location on long cables cannot utilize the same equipment utility companies and service contractors use on medium-voltage cables.

1 Introduction

In contrast to the conventional medium-voltage cables of DSO systems, long HVAC and HVDC cables cannot be treated with conventional fault location equipment from the medium voltage world. They have longer lengths, bigger capacitances, much higher fault voltages, among other differences. Yet, it is still possible to locate faults safely and quickly on HVAC and HVDC cables when using a systematic, heuristic problem-solving approach. This paper reviews real-world results based on applying the right method to the fault identified.

1.1. Requirements of cable fault location

The number one requirement of cable fault location is finding the fault. It must be found safely and quickly. This is especially tricky for HVAC and HVDC cables because they tend to be very long transmission assets.

Very long cables are associated with very high amounts of stored energy and considerable safety risks for personnel and equipment, which must be managed. And, offshore fault locating is especially time-sensitive with involved logistics and generation/transmission losses posing a large financial impact on top of the logistics costs.

1.2. Safety Considerations

Safety is paramount. When working with such HV assets, it is critical to be aware and follow all safety procedures to protect personnel, protect equipment, and continue to manage a productive workflow.

In pursuit of Safety, it is essential to follow all established company work rules and procedures. These include ensuring the Cable is de-energised and earthed before testing. There is a risk of back-feed causing damage to personnel and property if the cable is not de-energised and earthed.

It is also important to be aware of all the sources of hazardous voltages during testing and fault location. The three main sources are the operating voltage of the site, induced voltages that charge the cables, and the test equipment used.

1.3. Basics of Fault Location

Long HV cables are big capacitors, considerable low pass filters, and extremely distributed assets. Therefore, a toolbox approach is essential for fault location. As seen in Fig. 1 long HV cables have several parameters in their equivalent circuit,

Fig. 1 Cable Parameters and Equivalent Circuit [1]

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