Champlain Hudson Power Express, Inc.
Case 10-T-0139

Request No.:	DPS-90	Date of Request:	September 14, 2010
Requested By:	Edward Schrom and Richard Quimby	Reply Date:	September 24, 2010
Subject:	Forced outages - splices	Witness:	Roger Rosenqvist

REQUEST:

For the 3 cable projects referred to in the response to DPS-32, what has been the failure rate of the splices, the time it took to find them, and the time to make repairs? Explain your answer.

RESPONSE:

The three cable projects referenced were MurrayLink, Cross Sound and TransBay.

MurrayLink

Power transmission on the MurrayLink project in Australia commenced in early August 2002 and full commercial operation started on October 1, 2002. There have been no failures to date in any of the close to 400 prefabricated DC cable joints that are installed in the 177 km (110 miles) long (all underground) MurrayLink cable circuit. On December 22, 2002, there was a forced outage due to a DC cable fault in the MurrayLink system. The DC cable fault, which was on a cable segment in-between two splice locations, caused an outage of the MurrayLink between December 22 and 28, 2002. The project owner's and ABB's joint investigation concluded that the DC cable fault was most likely due to localized external damage to the cable that had accidentally been inflicted during installation. Information on cable fault location is provided in the attachments to this response. Please refer to the attached paper that was presented at the CIGRE Session 2004 for additional detailed information regarding the MurrayLink project. Since the completion of the repair of the cable circuit in 2002, there have been no other cable faults.

Cross-Sound

The Cross-Sound project has two sets of field splices, i.e., one set of submarine-to-underground transition splices at each submarine cable landing site. From the transition splice, the underground cables that extend into the converter buildings, were installed in continuous lengths without field splices. The commissioning of the Cross-Sound project was completed in early August 2002. There have been no DC cable or joint failures in the Cross-Sound project to date.

TransBay

The TransBay project was commissioned in mid-2010 and there have been no failures to date.

Name of Person
Preparing Response: Roger Rosenqvist Date: September 24, 2010

ABB Power Technologies

High Voltage Cables | **Technical report**

Reg.nr	
Ref No	ML/03-0003, rev A

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Info. copy-För kännedom	Customer´s ref.-Best.ref. Murray Link	Order
To..Till Murray Link	Subject-Rubrik **Murray Link, 150 kV HVDC Cable Fault location manual**	

CONTENTS

1 GENERAL

This document gives a short description of the fault location theories and the setup of the equipment. All Instruction Manuals or User´s Manuals for the equipment shall also be read and understood before the equipment is used.

These tests include HIGH VOLTAGE EQUIPMENT and shall only be operated of qualified personnel with suitable knowledge. Make sure that the local safety regulations are fulfilled before the test equipment is connected.

The cable terminations shall be disconnected from the converter station before the fault location can start. The station personnel shall do all disconnection in the station area.

2 FAULT LOCATION THEORIES

It is important to perform a fairly fast pre-location for the repair planning. If possible the pre-location could start with an analysis of the TFR records in the converter stations in order to roughly estimate the location of the fault.

2.1 Pre-location of fault

Pre-location with pulse echometer (cable radar)
A fault in the HVDC cable is first located with the impulse generator (Thumper CF70-24) and the Time Domain Refelectometer (TDR 1100).
The thumper creates high voltage impulses and the time required for the pulse to travel forth and back is measured with the Time Domain Refelectometer (TDR 1100).

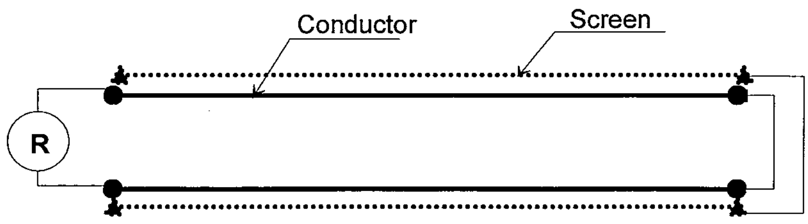
The pulse velosity in the HVDC cable is approximately 164 m/µs. This means that length measurement with the TDR 1100 should be based on a Vp/2 speed of approximately 82 m/µs.
A virgin trace of each cable and the basic set-ups are stored in TDR 1100 memory. This will simplify the fault location because the basic set-ups are restored when one of these traces are recalled from the memory. The virgin traces are also shown in appendix 1.

Low resistance fault near the cable termination may also be located with the TDR 1100 only because it can send low voltage pulses into the cable. Please read the Hipotronics Manual for correct Set Up of this measurement.

Pre-location with short locator (fault location bridge)
A fault in the HVDC cable can also be located with the short locator of type WB20CB. The short locator is a high precision instrument based on the Wheatstone measuring bridge and a measurement with the short locator should give approximately the same distance to the fault as the pulse echometer.

The measuring with the short locator and the pulse echometer will normally differ slightly due to the different measuring methods and somewhat different resistance along the route. The cable link has two different cable designs with 1200 mm^2 and 1400 mm^2 aluminium conductor. This gives a slightly different resistance along the route but the cables have almost indentical wave velocity, which means that the echometer normally will give a somewhat higher measuring accuracy.

The HVDC cables must be connected together at the far end so they form one continuous cable in order to performe a location of the fault with the short locator. Connect the top bolt on each termination with a proper connection wire. The metallic screen on each cable should also be connected in the same way. A sketch of the connections at the far end is shown below.



The following resistance should be measured if the cables are properly connected at the far end.
-resistance through the conductor, 7-9 ohm
-resistance through the metallic screen, 50-70 ohm

A good pre-location has been carried out when approximately the same distance is measured with the two methods, short locator and pulse echometer.

2.2 Fine-location of a fault

The principle for this method is to use the powerful thumper CF70-24 to create a flashover at the fault. The sound from the flashover and/or the magnetic field from the pulse will be picked up with the ground microphones or with earth spikes connected to the receiver HS-DAD.

The Thumper should be adjusted to automatically create approximately five impulses every minute. The ground microphones are placed above the cables approximately 100 m from the pre-located fault. A faded sound from the flashover will be heard in the headphones and arrow indicators on the receiver will point out the direction towards the fault. Follow the cable route until arrows change direction, a louder sound from the flashover will also be heard when you are close to the fault. The arrow indications and the sound will give you the opportunity to locate the fault within a meter.

Recommendable is to use the ground microphones at smooth, clean and flat ground type roads, walking pads etc. Where it is mud, dirt etc. the earth spikes are to be preferred.

3 SET UP AND OPERATION OF EQUIPMENT

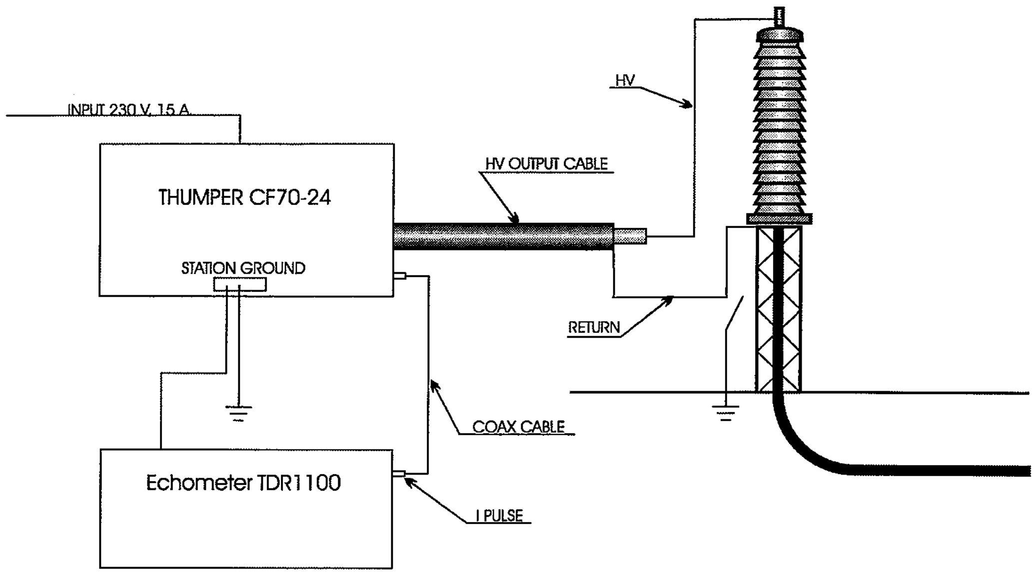
All test equipment should be conneted by Station personnel in order to secure that the local safety regulations are fulfilled.

3.1 Set up of thumper and pulse echometer

EQUIPMENT:	Hipotronics Thumper CF70-24 and Echometer TDR1100.

The Thumper CF70-24 sends high voltage pulses of up to 25 kV into the cable. The Echometer TDR1100 shall be connected with a 50 Ω coaxial cable from the "SURGE PULSE, I PULSE" at the rear panel to the "SCOPE" on the side of the Thumper CF70-24.

Set Up the Test Circuit.
Connect and arrange the Test Circuit according to the figure below. Note the screen/shield on the cable should be disconnected from ground when the cable is tested.



Set Up the Echometer TDR1100.
Make sure the coaxial cable from the CF70-24 is connected to the Input SURGE PULSE/ I-PULSE.

Turn the TDR ON and wait a few minutes until the MAIN MENU appears. Press the button on the right of MAIN MENU twice and the computer shall beep and change to MENU STORAGE. Choose SET-UPS MEMORY and then RECALL SET-UP. Turn the Control Knob to choose the saved virgin curve and press the button to the right of RECALL. You shall now have the correct Set Up for "I PULSE" mode and the vp/2 shall be 80-82 m/µs".
The Balance shall be internal.
Start with GAIN at Maximum, turn the knob maximum in clockwise direction.

Choose Capture A or B and the computer shall beep and wait.
If you have any problems please read the Hipotronics Manual and perform the Set Up from Start and then save it.

Set the Thumper CF70-24 in the mode "CAPACITOR DISCHARGE".
Use the Manual Mode "PULSE" for triggering.

Try with a low voltage of 10-15 kV first to see if you get any reflection. The voltage shall then be increased to max 25 kV and the sound in the Thumper CF70-24 will change from a metallic ping to a discharge sound when the voltage is high enough for a breakdown. Also the curve on the TDR1100 will tell if there is a breakdown.

If the fault is very near, you may have to change the TDR1100 Set Up to a lower Screen Range by clicking ZOOM once to get ZOOM⇔ and then rotate the Control Knob to choose an other Screen. The GAIN may also be reduced if the fault is very near.

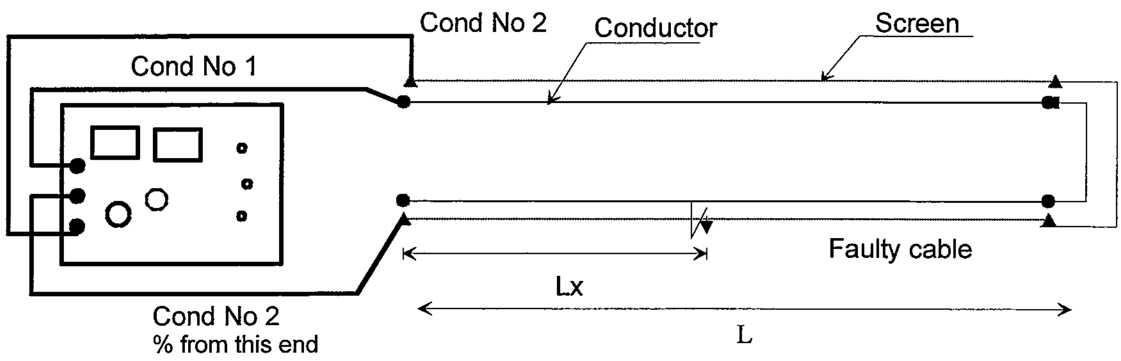
You must use the cursors to measure with when you have a reflection. Place the cursors on the peak of each pulse, which is the most correct way because we measure the current and not the voltage.

Note, the TDR 1100 has been modified in order to trace extra long cables and the read distance should be multiplied with 10.

3.2 Set up of short locator

EQUIPMENT:	Short Locator model WB20CB

The Hipotronics short locator is a high precision instrument based on the Wheatstone measuring bridge. The short locator is simple to use and it should be connected according to the figure below.



Check that the cables are connected together at the far end as described above.
Connect the HV lead to end of the cable conductor.
Connect one end of the metallic screen to “Conductor No2”, black socket.
Connect the other end of the metallic screen to “Conductor No2 % from this end”, white socket.
Turn the AC Power switch to ON position.
Put the function switch to the left “Short Locator On”. The “Short Locator On” indication light will glow.
Set the sensitivity control to minimum.
Set raise voltage control to zero.

Depress HV Hold switch and slowly rise the voltage until a cyclic rise and fall of the voltage appears on the kV meter. If no voltage reading appears, the cable has a low resistance fault. In this case, raise the voltage until a slight deflection (to either side) appears on the null indicator galvanometer.

Rotate the Balance Control slowly until the galvanometer reads zero. Increase the sensitivity and re-null the galvanometer.

The distance to the fault is calculated with the following formula:

$$Lx = \alpha / 100 \times L \text{ (km)}$$

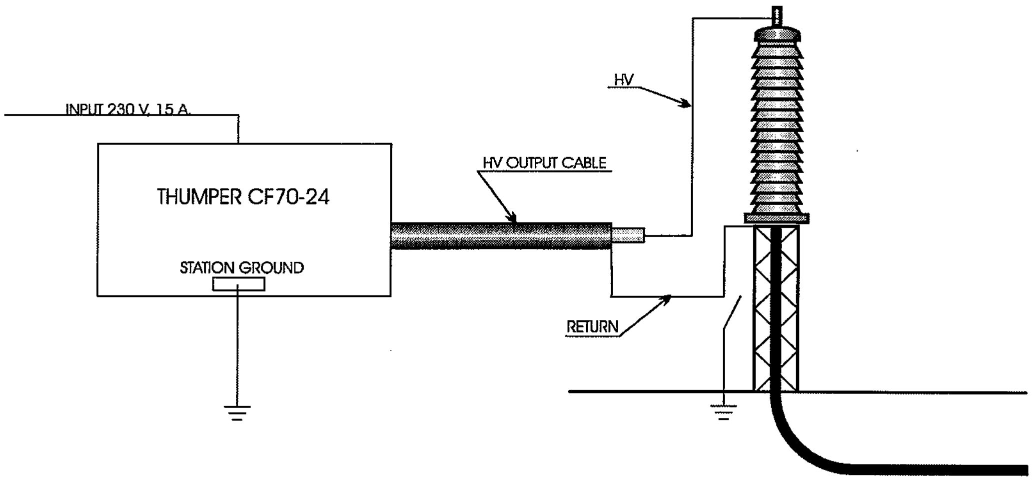
where
α = indicated value on the Balance Control (%)
L = the length of the HVDC cable, 176 km from termination to termination

3.3 Set up of thumper and ground microphones

EQUIPMENT:	Hipotronics Thumper CF70-24 and ground microphones type HS-DAD.

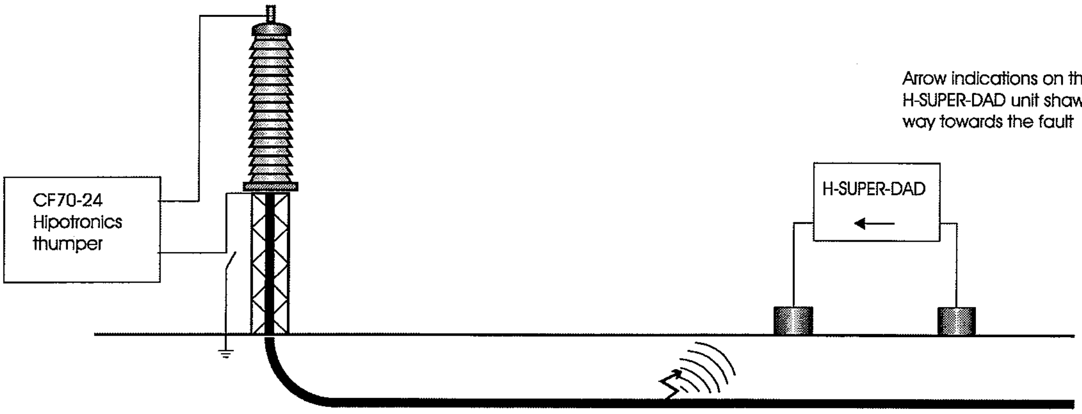
Set up the Hipotronic thunder CF70/24 according to figure below.
The high voltage pulses shall be fed into the cable termination.

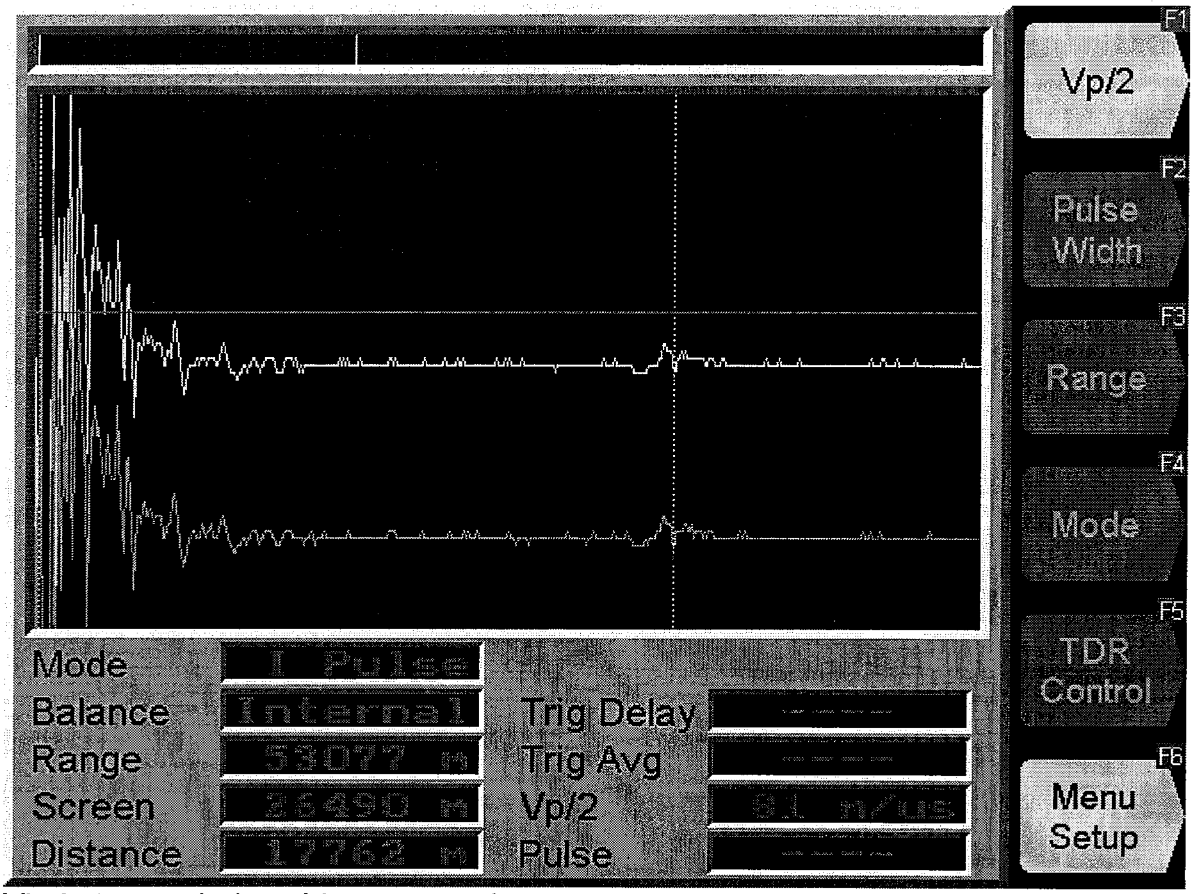
-Set the Thumper on "CAPACITOR DISCHARGE"
-Turn in "ELAPSED TIMER" to start with 5 –7 seconds.
-Turn in "CAP DISCHARGE REP RATE" on "AUTO"
-Set "HIGH VOLTAGE" to position "ON"
-Turn up the voltage regulator "RAISE VOLTAGE" to choosed level, recommended voltage 10-15 kV.



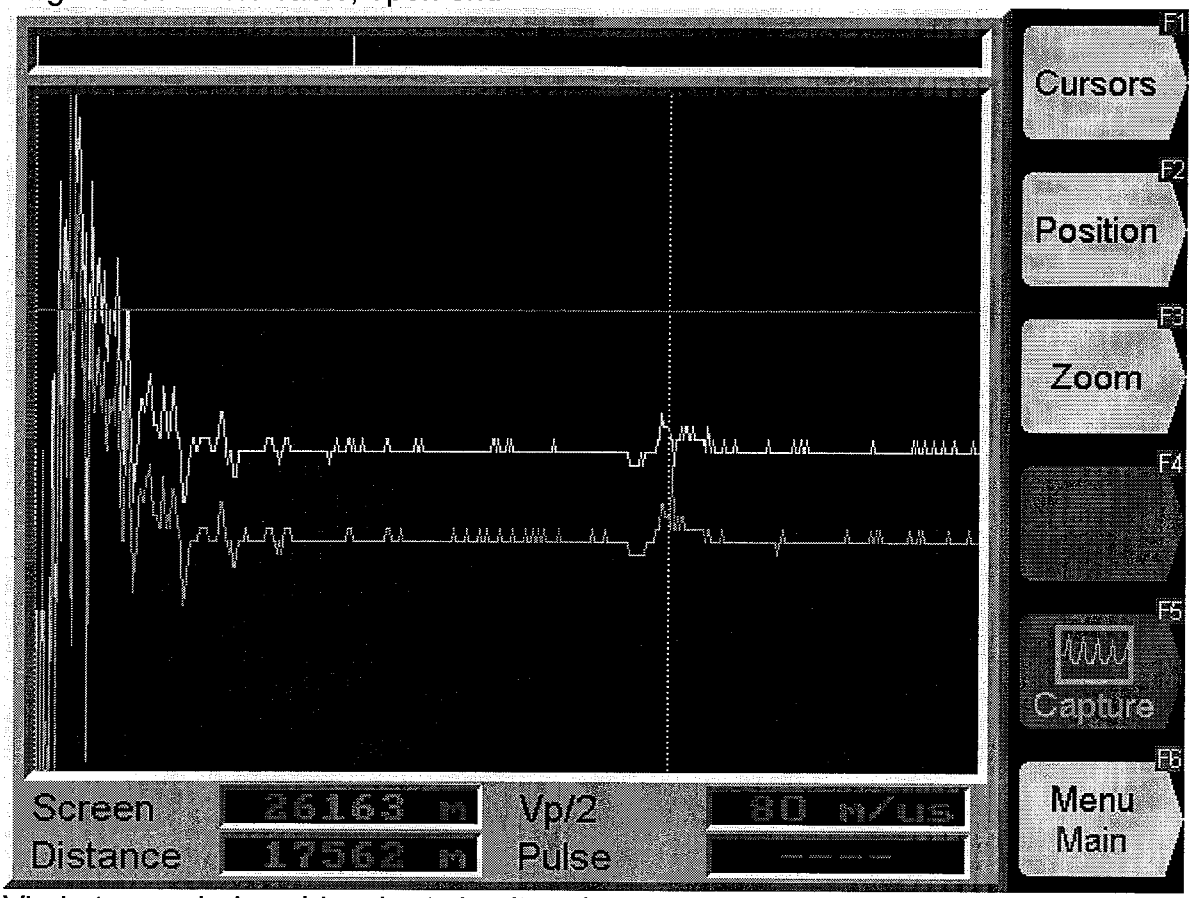
Connect the two microphones to the receiver H-SUPER-D.A.D.
The red microphone should be connected to the right side of the receiver H-SUPER-D.A.D. and the green microphone connected to the left side. This will correspond with the direction to the fault.
Switch the headphone Mono/Stereo switch to Stereo.
Turn on red channel and green channel for locating with two microphones, The LCD should now show channels as "ON".
Start the locating at least 100 m away from the position measured at the pre-locating.
Place the microphones/earth spikes along the cable route, follow the arrow indications towards the fault.

When the arrow indication change direction you have just passed over the fault, pass over the fault from both directions a couple of times and check the arrow indications for an exact position of the fault. See also the figure on next page for fine detection.


Arrow indications on the
H-SUPER-DAD unit shaw the
way towards the fault
H-SUPER-DAD
CF70-24
Hipotronics
thumper



Virgin trace whole cable, open end



Virgin trace whole cable, short circuit end

HIPOTRONICS
THE MEASURE OF A LEADER

CF70 - 12 / -24

Primary Cable Fault Locator

Hipotronics CF Series test systems for fault locating of primary cables consist of a dc proof tester, a burner and a capacitive discharge fault locator (thumper). These self-contained, portable units are rugged, reliable and compact making them ideal for field use. The CF70-12 or –24 has a continuously adjustable impulse rate from three to thirty seconds. Test ratings are a 0-70 kV dc proof test voltage, a 100 mA burn current and a 0-25kV dc capacitive discharge (thumper) voltage.

The units can be used with a high voltage coupler (HVC-4100 Series) and a time domain reflectometer (TDR-1150 or TDR-1170) to quickly provide a specific distance to the fault in feet or meters. This combination of equipment can greatly reduce the amount of high voltage (number of thumps) applied to the cable, resulting in reduced damage or degradation to the cable under test.

Hipotronics Inc. has years of experience in cable fault locating the toughest faults. Our line of cable fault locating equipment is designed and manufactured based upon our field expertise. Whether you use the fault locator alone or with other accessories you've got a powerful tool to help restore power to your customers quickly.

FEATURES

- ☑ **Self-Contained Unit** Features Proof Tester, Burner and Thumper in One
- ☑ **Burn Currents** to 100 mA
- ☑ **Impulse Energies** of up to 7000 Joules
- ☑ **Automatic and Manual** Thumper Mode
- ☑ **Operable** from Line Voltage or Generator
- ☑ **Single HV** Output for All Modes
- ☑ **Zero Start** Interlock
- ☑ **External** Interlock
- ☑ **Mode Indicator** Lights
- ☑ **Electrically Operated** Shorting Solenoids with Mechanical Ground Assurance

BENEFITS

Positive Fault Identification and Location

Isolated Return for Increased Operator Safety

One Unit for all URD Cable Maintenance Testing

User Safety – visual verification of grounding status via face panel window

Repeatable Impulse level

Variable Impulse Rate from 3 to 30 Seconds

APPLICATIONS

- Electrical Utilities
- Test Companies
- Petrochemical Facilities
- Facility Maintenance

TECHNICAL SPECIFICATIONS

General

Input Voltage:	- A 120 V AC, 60Hz - B 220 V AC, 50/60Hz		
Output:	Proof Tester, 0-70 kV dc	Burner, 100 mA	
Capacitor Discharge:	CF70-12, 0-25kV @ 12 µF CF70-24, 0-25kV @ 24 µF	Energy @ 25kV Energy @ 25kV	3750 joules 7000 joules
Metering:	Proof Test Voltage Proof Test Leakage Current Burner Current	0-70 kV dc ± 2% 0-1/10/100 mA ± 2% 0-100 mA	Standard Polarity Negative Output.
Duty Cycle:	Continuous		
Terminations:	Input Line Return and High Voltage Ground	50 ft. (15.2 m) 100 ft. (30.4 m) Ground 25 ft. (7.6 m)	Cable Double Shielded Cable No. 2 Welding Cable
Weight and Dimensions	16"W x 36"H x 50"D (41 x 91 x 127cm)	675 lb (307 kg) Net	894 lb (352 kg) shipping

SCOPE OF SUPPLY

Qty.1 CF70-12 or –24 with terminations as described above

Qty.1 Safety interlock plug

Qty.1 Operations Manual

Qty.1 Calibration Certificate

CONTROL PANEL

ORDERING INFORMATION

System

Cable Fault Locator	**CF70-12-A or B** **CF70-24-A or B**
Cable Fault Locator with only 15 feet of return and HV cable and MC type connector for use with HVC series coupler and 8100 cable rack.	**CF70-12-PT-A or B** **CF70-24-PT-A or B**

Accessories

Spare parts kit for CF70	**SPK1-CF70-12** **SPK1-CF70-24**
Time Domain Reflectometer	**TDR1150** **TDR1170**
HV Coupler for use with the TDR	**HVC4170**
Cable Reels	**8100**

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HIPOTRONICS®
THE MEASURE OF A LEADER

Time Domain Reflectometer

TDR 1170

■ **Hipotronics TDR1170 —** The unique features and new technology used in the TDR 1170 make it the most flexible and easiest to use instrument available for advanced cable fault location. The TDR 1170 features an automatic configuration, which can be modified as necessary. All cable fault data can be stored and retrieved at any time, ensuring time savings, consistency and accuracy from one crew to the next.

The digital TDR 1170 will locate and identify short circuit (bolted) faults, low resistance shunt faults, open circuits, high resistance series faults, wet sections, splices, transformers, cable transitions, and concentric neutral corrosion. To locate high resistance, intermittent and flashover faults, the TDR 1170 is designed to measure in the digital arc reflection, current impulse, voltage decay, and all differential fault locating modes. The selection of fault location method allows the operator to select the method which they are most familiar with or the method that is most appropriate for the type of cable and type of fault that is encountered.

The TDR 1170 requires a high voltage coupler to interface to a cable fault locator (thumper). The cable fault locator then provides the voltage and current to enable the TDR 1170 to quickly and definitively locate cable faults.

Included with the TDR 1170 is a software package to allow the stored data to be viewed on a PC and also be printed and analyzed by office personnel or training teams.

FEATURES

- ☑ **Digital High Voltage** TDR
- ☑ **5 Methods** of Fault Location
  - ☑ **Arc Reflection**
  - ☑ **Impulse Current**
  - ☑ **Voltage Decay**
  - ☑ **Differential Methods**
  - ☑ **Low Voltage**
- ☑ **Color LCD Screen**
- ☑ **PC Software**
- ☑ **SVGA Output** for External Monitor

BENEFITS

Pre-Locate Faults

Diagnose Cable Faults

Easy to Use

Compatible with Common "Thumpers"

Provides Long-Term Storage and Evaluation

Cable System Signature Mapping

Reduce Outage Time

Reduce Cable Damage

Simplified Operator Training

High Voltage Test Business

HIPOTRONICS THE MEASURE OF A LEADER

TECHNICAL SPECIFICATIONS

General

Input Voltage:	90 to 250 V AC, 50/60Hz	VP Range:	98ft./µs to 492ft./µs
Accuracy:	< ± 1% of cable length	Pulse Amplitude:	25 V into 50W
Measuring Range:	1 ft. to 160,000 ft.	Pulse Width:	50ns to 10µs
Units of Measure:	Feet, Yards, Meters	Sample Rate:	12.5 to 30ms
Trigger Delay:	1 to 30ms	Memory Modes:	32 sets of 1 or 3 phase
Setup:	16 setup options	RS232 Port:	Download traces to PC
Monitor: LCD Display 10 inch diag.			

Weights and Dimensions (W x H x D, net weight, ship weight)

Standard 19” rack	19” x 10.5” x 7” (48 x 26 x 18 cm)	18 lbs (8.2 kg)	lbs (kg)

SCOPE OF SUPPLY

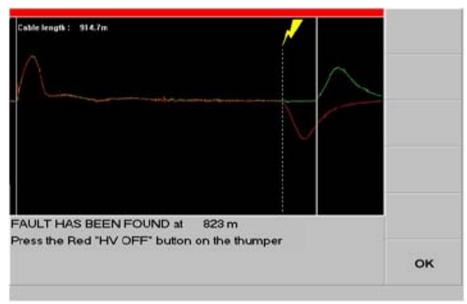
Qty.1 TDR1170 in standard 19” rack mount cabinet

Qty.4 RG58/U BNC-BNC cable

Qty.1 Serial interface cable and input line cord

Qty.1 Operations Manual and TDR-PC interface software

SYSTEM DISPALY



ORDERING INFORMATION

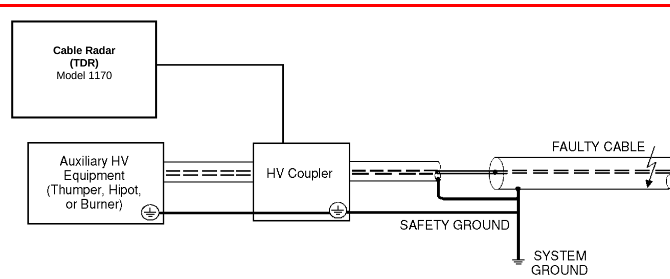
System

Time Domain Reflectometer	**TDR1170-A**
	TDR1170-B

Accessories

HV Coupler	**HVC4100 series**
Cable Fault Locating (Thumper)	**CF or CET series**
Cable Reels	**8100**
Accessory Connectors	

MEASURING SETUP DIAGRAM



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HAEFELY HIGH VOLTAGE TEST | HIPOTRONICS THE MEASURE OF A LEADER | ROBINSON INSTRUMENTS | Tettex INSTRUMENTS | HAEFELY EMC TECHNOLOGY

HIPOTRONICS THE MEASURE OF A LEADER

HVC4000 Series

High Voltage TDR Couplers

The 4000 Series of high voltage couplers allow modern cable fault locators (thumpers) to be used in conjunction with advanced TDR's. The HVC series is uniquely suitable for use with cable fault locators with voltage ratings up to 70kV. When connected to a cable fault locator and a TDR, the coupler enables the operator to reduce his "thumping" and reduce the chances of potential damage by extended duration "thumping". The HVC series allow for the use of the latest methods of fault location and also allow the operator to use a TDR mode that is most suitable for the cable that has failed. The HVC series also allows for quick connection of a low voltage TDR.

FEATURES

- ☑ **Compact** High Voltage Coupler
- ☑ **Compatible** with Virtually all Cable Fault Locators
- ☑ **Interlock Safety** on Mode Selector Switch
- ☑ **Front Mounted** Mode Selector Switch
- ☑ **Female MC** High Voltage Input Connector
- ☑ **Male MC** High Voltage Output Connector
- ☑ **Available** for Use with Thumpers up to 70kV

BENEFITS

Female MC Connector – for easy connection of thumpers

HV Output Cable – rated for voltages of 70kV DC

Couple Advanced TDR's – to Standard Thumpers

Compact – User Friendly Design

Low Voltage – TDR Compatible

TECHNICAL SPECIFICATIONS

General	HVC 4100 -*	HVC 4170CR-*
Cabinet Configuration	Rack Mounted (cabinet)	Rack Mounted (cabinet)
TDR Mounting Configuration	Internal	Internal
Main Input	*-A 120V AC, 50/60Hz *-B 220V AC, 50/60Hz	
High Voltage Range	0-50kV DC	0-70kV DC
Arc Reflection Voltage Range	0-40kV DC	0-40kV DC
Surge Voltage Range	0-50kV DC	0-50kV DC
Maximum Burn Current	100 Amps	100 Amps
Maximum Impulse Energy	3000 Joules	8000 Joules
Temperature Range	-4°F to 122°F (-20°C to 50°C)	-4°F to 122°F (-20°C to 50°C)
Dimensions	31"H x 26"W x 31"D (79cm x 66cm x 31cm)	54"H x 26"W x 31"D (79cm x 66cm x 31cm)
Weights	100lbs (45kg)	250lbs (114kg)

ACCESSORIES

TDR 1170, Time Domain Reflectometer
TDR 1150, Time Domain Reflectometer
CET 2000-* Controlled Energy 2000J Thumper
CF30-8-*, 0-15kV, 900J Hipot/Thumper
CF70-12-*, 0-25kV, 3750J Hipot/Thumper
CF70-24-*, 0-25kV, 7000J Hipot/Thumper

ORDERING INFORMATION

System	
0-50kV coupler	**HVC 4100-A or -B**
0-70kV coupler	**HVC 4170CR-A or -B**

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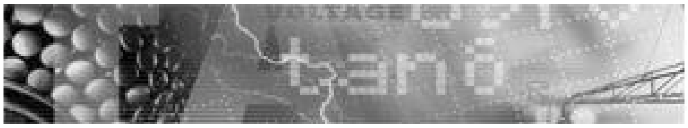
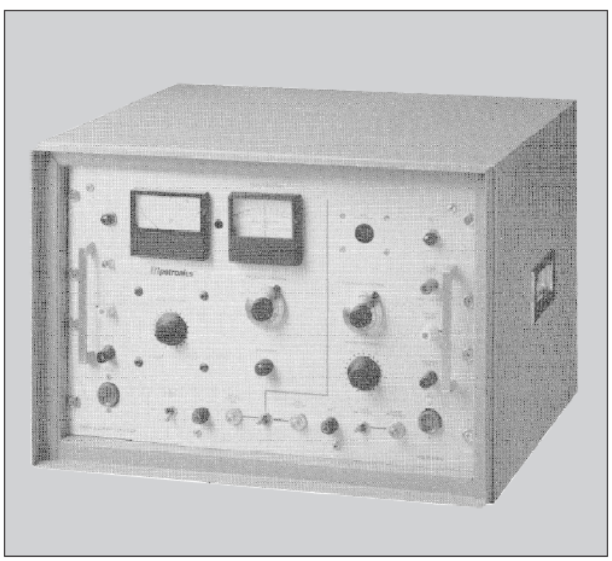


WB20CB

Open and short locator

The WB20CB is a highly accurate instrument designed to detect OPENS in individual conductors and SHORTS between neighboring conductors of various type cable. As an open locator, the WB20CBlocates position of break in one wire of a pair using a 0 to 1 kV AC power supply. As a short locator and high voltage bridge, the unit locates the position of a short between a pair of wires using a 0-20 kV DC power supply. The short can be a copper cross, a high resistance or an infinite resistance high voltage arc.



Model WB20CB
Open and Short Locator

FEATURES

- ☑ **HV Hold –** Requires the user to be at the control panel and holding the HV ON push button to provide a high voltage output for either open or short locating
- ☑ **Ground Meters –** All meter at are ground potential to help guard against shock
- ☑ **Phase Reversal Switch**
- ☑ **Zero Start Interlock -** Ensures that the voltage control adjustment is turned to zero volts when the high voltage transformer is energized.
- ☑ **Gravity Operated Solenoid -** Discharges the test object when the power is turned off. This provides added safety for the operator and theWB20CB.

BENEFITS

Three tests in one unit – Tests for discontinuities (OPENS) in either conductor in a pair of conductors and locates the position of existing SHORTS between the two conductors. Also capable of performing a DC proof test.

Variable HV output – Allows the location of low and high resistance shorts not possible with low voltage Time Domain Reflectometers (TDR s).

Rack Mountable – Easy installation into a 19" rack

NIST traceable – significant cost savings on outside calibrations

APPLICATIONS

The WB20CB is ideal for testing:

- ➔ Telephone cable
- ➔ Power cable
- ➔ Any cables with shielded grounds

TECHNICAL SPECIFICATIONS

Input Voltage	Model number with suffix - A 120V / 60Hz
	Model number with suffix - B 220V / 50Hz
Output For Opens	0 - 1 kV ac at 20mA
Output For Shorts	0 - 20 kV dc at 15mA
Polarity For Shorts	dc negative out, positive ground
Kilovoltmeter For Shorts	0 - 20kV dc, single range, ±2% full scale accuracy
Null Indicators For shorts	0 ±25mV dc, zero center type
Balance Control For Shorts	10 turn, 0.25% potentiometer
Terminations	High Voltage Lead: 5 ft(1.5m) shielded cable (RG58U) with an alligator clip
	Control Leads: (4) 5 ft(1.5m) long rubber insulated test leads with alligator clips
Dimensions	22"W x 30"D x 15"H (55 x 50 x 37 cm)
Weight Net	90 lb (41kg)
Ship	105 lb (48kg)

ORDERING INFORMATION

System

* Designate input voltage. 'A' for 120Vin or 'B' for 220Vin.	**WB20CB-***

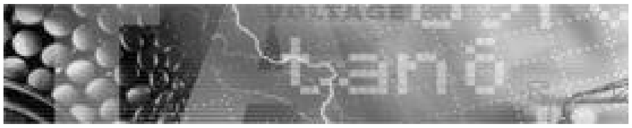
Options

-SPARE PARTS KITS – Catalog nos. SPK1-WB20CB

European Contact
Haefely Test AG
Lehenmattstrasse 353
CH-4028 Basel
Switzerland
☎ + 41 61 373 4111
🖷 + 41 61 373 4912
sales@haefely.com

Locate your local
sales representative at
www.high-voltage-hubbell.com

USA Contact
Hipotronics Inc.
1650 Route 22
PO Box 414
Brewster, NY 10509 USA
☎ + 1 845 279 8091
🖷 + 1 845 279 2467
sales@hipotronics.com



HIPOTRONICS THE MEASURE OF A LEADER

FlashPhone

Digital Acoustic/Ballistic Cable Fault Locator

■ **The *FlashPhone*** Acoustic/ballistic detector is designed to pinpoint the exact location of primary cable fault location when combined with a capacitor impulse discharge unit (thumper). During the flashover at the fault both a magnetic and acoustic signal is generated. There is a time delay between these two signals and the *FlashPhone* displays this signal as a number. The closer you get to the fault will show a decrease in the number that is displayed. The magnetic signal bar graph shows the intensity (magnitude) of the magnetic field, generated by the thumper into the cable fault. It also can be used to locate the correct cable route when the maximum bar deflection (magnitude) is indicated. The microphone is designed to be used with an earth probe for soft ground conditions and the flat ground contact can be used on concrete or asphalt.

The unique combination design of seismic and electronic sensor technology, plus microcomputer technology and digital signal processing is the key to its superior performance and high sensitivity. It is well suited for use with impulse discharge units (thumpers) with low joule energy capabilities.

Features

- ☑ **Seismic/Electronic** combination sensors
- ☑ **Large LCD** display with backlight
- ☑ **Re-chargeable** lithium batteries
- ☑ **Battery** monitor on LCD display
- ☑ **Ballistic** bar graph LCD display
- ☑ **External** automatic battery charger
- ☑ **Watertight** enclosure
- ☑ **Rugged** foam-lined carrying case

Benefits

Simple Operation – only a minimal amount of user training is needed to locate faults

Locates Faults quickly – faults are located with a minimal amount of time and effort

Smart Device – is able to discriminate between audible "thumps" and background noise

Applications

These devices are generally used by:

- ➔ **Electrical Utilities**
- ➔ **Test Companies**
- ➔ **Petrochemical Facilities**
- ➔ **Facility Maintenance**

Technical Specifications

General		Sensor (magnetic/acoustic)	
Operating Temperature	-10ºF - +100ºF	Acoustic Detection	Seismic
Humidity	85%	Input Range (g)	±100g
Power Source	7.4VDC Li-Ion Battery	Sensitivity (PC/g)	1100 ±10%
Amplification Acoustic	75dB Maximum	Resonance Frequency (Hz)	80
Amplification Magnetic	65dB Maximum	Frequency Response (±3dB)	DC – 2kHz
Headset Maximum output Power	700mW	Frequency Range Acoustic	1kHz – 32kHz (High Filter) <=270Hz (Low Filter)

Weights and Dimensions

Case Dimensions	16.00" x 13.00" x 6.87" (40.6 x 33 x 17.4 cm)
System weight	31 lbs

Scope of Supply

- **Controller**
- **Acoustic/Magnetic Pick-up**
- **External Battery Charger**
- **Head Phones**
- **Foam Padded Carrying Case**

Ordering Information

System

Part Number: H-FLASH

Control Panel

European Contact
Haefely Test AG
Lehenmattstrasse 353
CH-4028 Basel
Switzerland
☎ + 41 61 373 4111
🖷 + 41 61 373 4912
sales@haefely.com

Locate your local
sales representative at
www.high-voltage-hubbell.com

USA Contact
Hipotronics Inc.
1650 Route 22
PO Box 414
Brewster, NY 10509 USA
☎ + 1 845 279 8091
🖷 + 1 845 279 2467
sales@hipotronics.com

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http://www.cigre.org

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Session 2004

MURRAYLINK, THE LONGEST UNDERGROUND HVDC CABLE IN THE WORLD

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1. INTRODUCTION

The Murraylink Transmission Company Ltd (MTC) awarded a contract in December 2000 for the turnkey engineering, procurement and construction of the Murraylink Transmission Interconnection Project in Australia. The contract included two complete AC/DC converter stations interconnected by a pair of underground DC cables, a new substation and AC cable interconnections from each converter to the nearby AC switchyard [1].

Figure 1. Murrraylink Geographical Location

Murraylink provides a new directly controllable interconnection between the electricity market regions of Victoria and South Australia. The link is used to transfer power in either direction in response to market price differences. Reliability of the Riverland area electricity supply, which is in the vicinity of Berri, is also vastly improved by the introduction of Murraylink.

Key reasons for the choice of voltage source converter (VSC) based HVDC technology for the project include: 1) the use of a light weight, solid insulated HVDC cable system that could be direct buried, allowing the use of existing rights-of-way and fast permitting/approvals; 2) reactive power control for support of the relatively weak AC networks; 3) compact converter station layout primarily within a standard warehouse-style building, and 4) modular, factory-tested

Figure 2. HVDC station at Red Cliffs

* ABB Power Technologies, HVDC, Sweden; E-mail ingemar.mattsson@se.abb.com

design that allows for a short field testing and commissioning period. The complete development period for Murraylink from project conception to commercial operation was 39 months.

The Murraylink project earned several Australian state and national awards for both environmental and engineering excellence.

2. GENERAL SYSTEM DESCRIPTION

2.1 AC Networks

As illustrated in Figure 3, Murraylink interconnects the AC networks in the states of South Australia and Victoria. These AC networks are contained within two separate market regions. Connection to the South Australia AC transmission system was established through the construction of a new 132 kV substation at Monash. This substation contains two line bays to accommodate the existing 132 kV transmission lines, two 18 Mvar breaker switched shunt capacitor banks, and a bay for connection of a 400 m underground AC cable tie to the Berri converter station.. In Victoria, the Red Cliffs converter station is connected to an existing 220 kV position at the Red Cliffs Terminal Station (RCTS), by a 330 m underground AC cable tie. Three 220 kV transmission lines emanate from RCTS connecting into the transmission network in New South Wales as well as central Victoria.

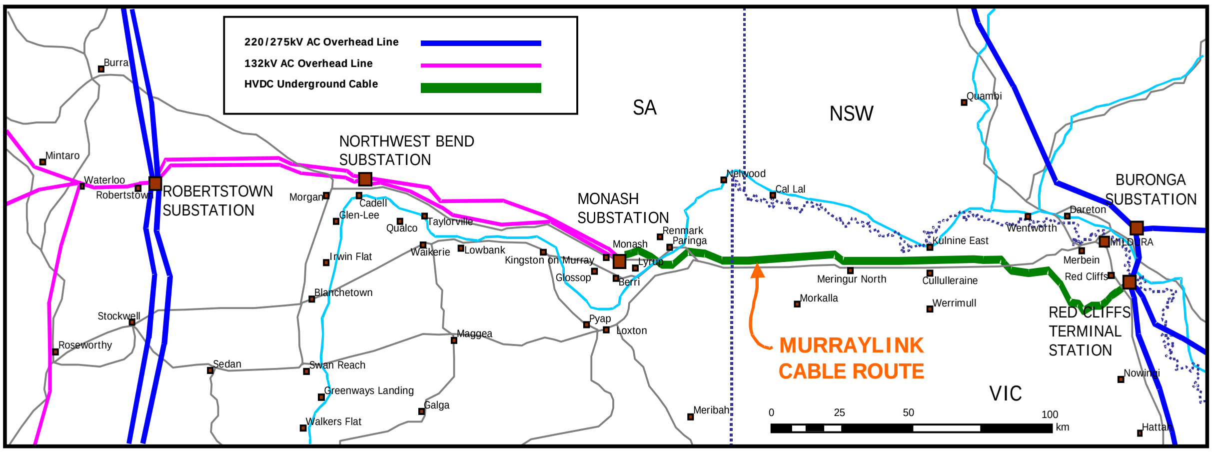


Figure 3. Murraylink AC interconnection locations

Both Murraylink converters are connected to the AC networks at fairly remote locations, consequently short circuit strength of the AC networks is relatively weak. With all local AC transmission lines in service, the approximate three-phase short circuit strengths are:

- Monash 132 kV substation, SA – 450 MVA
- Red Cliffs 220 kV terminal station, Victoria – 1000 MVA

Given the relatively weak interconnection points, the AC voltage control provided by the Murraylink VSCs is very instrumental in supporting real power transfers between the AC networks. Equivalent transfers would not be possible with conventional HVDC technology or an AC tie without addition of variable reactive power support from an SVC or similar device.

A further consequence of the relatively weak connection points is that Murraylink power transfers can be constrained during times of high network load (particularly summer loads). These constraints can be due to either thermal or voltage stability conditions following contingent outage of critical supply-side network elements. In order to increase Murraylink power transfer capability without requiring major physical AC network augmentations, MTC elected to exploit the controllable features of the VSC technology and implement power transfer run-back controls. The run-back schemes monitor the status of remote network elements (circuit breakers, lines and transformers) and, in the event of a remote trip will reduce Murraylink power transfer to relieve post-contingent network loading. Run-back speeds can be designed to accommodate specific outages of critical plant and also future load growth in the surrounding AC networks.

2.2 DC Transmission System

2.2.1 Converter Equipment

The Murraylink converter equipment is very similar to the equipment used for the Cross Sound Cable (CSC) project between New York and Connecticut in the U.S.A. As the number of pages of this publication is limited, the reader is kindly asked to review reference [2] for information on the converter equipment. The following paragraphs will only elaborate on the differences between the two projects.

The Murraylink converter rating is slightly lower than CSC's. The Murraylink converters can deliver 220 MW at the inverter PCC, while CSC delivers 330 MW. The converters can operate in any point within the P-Q diagram shown on Figure 4.

The Murraylink IGBT valves are switched at 1,350 Hz compared to 1,260 Hz for CSC, which result in different tuning frequencies for the AC filters shown on Figure 5.

The limits for DC side harmonics are tighter for Murraylink, which required the addition of a zero-sequence reactor and of a 9th/21st harmonic filter.

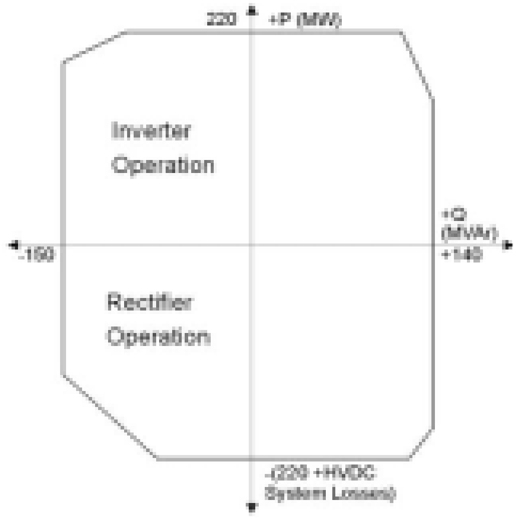


Figure 4 Active and Reactive Control Range

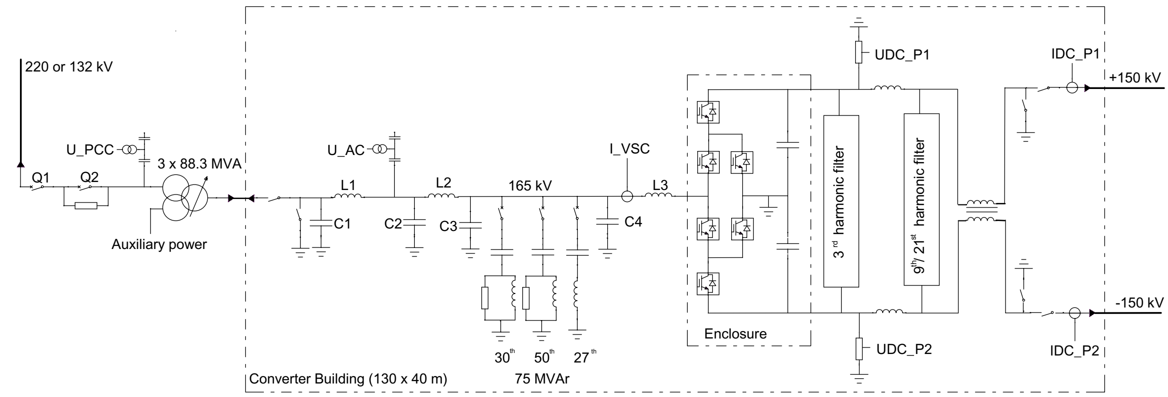


Figure 5. Single Line Diagram of Murraylink

2.2.2 Converter Control and Protection

2.2.2.1 AC voltage control

By using the AC voltage control feature available in the VSC technology, over voltages due to events in the grid could be alleviated. The AC voltages at the Murraylink converters are very sensitive to changes in reactive power flow, due to the high impedances in the network. However, the control is stable in all modes of operation and supports the network voltage during dynamic events.

2.2.2.2 Control Differences compared to Cross Sound Cable Project (CSC)[2]

Although the converter design is similar for both Murraylink and CSC, the Murraylink control system uses sinusoidal pulse width modulation (PWM) without the third harmonic modulation used in CSC. The reason for this is that the active power requirement is less than in CSC. In Murraylink there is no need for sub-synchronous damping control as there are no generators close to the converters.

The use of a long DC cable does not impact on the structure of the DC voltage controller, however the setting is different from CSC. This applies also to the DC voltage balance control since the common mode DC impedance is different from that in CSC. The reason for the different impedance is not only due to the length of the cable, but also to the use of an additional ninth harmonic DC filter and the connection of two AC filters to ground compared to only one in CSC.

2.2.2.3 Similarities to CSC control

In both Murraylink and CSC, one converter controls DC voltage and the other controls active power. It is possible to operate either converter in reactive power control or in AC voltage control independent of which is controlling active power.

The control is duplicated to increase availability with one control active and the other in standby. The design allows interruption free transfer between the two control systems. The protection systems are implemented separately from the converter controls to ensure safe operation.

2.2.3 DC Transmission Cables, Installation and Rating

A completely dry cable system was chosen for the transmission link having cost-effectiveness as a main parameter. The design concept was based on earlier commercial deliveries and the preceding development work has been reported elsewhere [3].

The cable design employed two different aluminium conductor areas, 1200 mm^2 and 1400 mm^2, as the thermal properties of the soil were not uniform along the cable route [4]. Further thermal optimisation would have been possible, but with marginal savings as only two conductor sizes made it possible to use a single joint design for the whole project. The insulation system consists of inner semi-conducting screen, main insulation wall and outer semi-conducting screen where the materials are specially designed for DC applications. The insulation system is covered by a copper wire screen, on top of which a radial water blocking system is applied. The latter consists of a layer of swelling tape and a watertight aluminium/polyethylene laminate. Finally, an HDPE jacket is extruded as an outer protection.

The cable terminations are of an all-dry type using a design with a stress relief cone and weather sheds made of EPDM rubber. No special tools are necessary for the assembly of the terminations. For a cable system with close to 400 joints, as in the Murraylink, a robust and easy-to-mount joint was essential. The chosen design was a one-piece 150 kV pre-fabricated joint that uses a field controlling layer as shown in Figure 6. The field-controlling layer resides between the cable insulation and the insulating material of the joint and has non-linear electrical properties in order to cope with both DC and AC-type conditions such as surges [5].

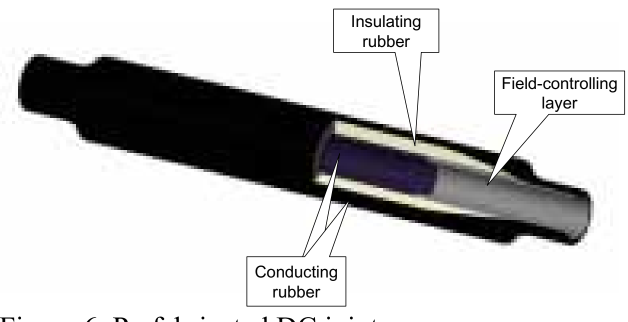


Figure 6. Prefabricated DC joint

Figure 7. Cable-laying machine

The installation of the 177 km long cable system was done at an unprecedented speed in accord with a very strict Environmental Management Plan (even detailing the number of bushes to be trimmed etc.). The laying speed averaged over 1000 m per day with peak speeds up to 3000 m per day, using cable-laying machines as pictured in Figure 7. These speeds were achieved even though the laying was in close proximity to protected vegetation, communication wires and a gas pipeline over a portion of the route. As a result of the meticulous work, the installation was honoured with the 2002 National Case Earth Award for environmental excellence.

3. COMMISSIONING

The installation of the DC transmission cables was completed in early July 2002. These cables were confirmed suitable for transmission testing using portable DC hi-pot and pulse-echo equipment. Converter station installation was completed in late July, 2002. Sub-system testing of the installed converter stations was performed in a period of 4-6 weeks, most of which was completed in parallel with the installation. This short period was possible due to the modular design of the converter sub-systems and pre-testing in the factory.

The converter terminal tests and the transmission tests commenced in early August 2002, after the completion of the sub-system testing. This test period was completed by Sept 30, 2002 except for a few high power test levels that could not be performed due to AC network constraints. High voltage is first applied to each converter station during the terminal tests. Tests are performed to verify protections, controls and switching sequences. Transmission testing is performed following the completion of the terminal testing, again to verify the protections, controls and now the transmission operating modes. Performance measurements were made at the end of the transmission tests period. Parameters measured during the performance tests were step responses, AC and DC side harmonics, losses, audible sound and high voltage transients.

4. STEADY STATE PERFORMANCE

4.1 Audible Sound

According to the contract the measured, tonal adjusted, energy averaged noise level, L_{eq}, generated by the converter station at Red Cliffs must not exceed 36 dB(A). At Berri converter station the target figure was 35 dB(A). These stringent demands resulted in a transformer design with extremely low flux density. The transformers did not exceed 84 dB(A) at maximum network voltage. Measurements at Red Cliffs without the converter station in service showed a higher noise level than the demands. From the sound measurements, it was determined that the transformers in the adjacent existing AC substation are the primary source of this noise. Emissions from the Berri converter station were less than the specified criterion.

4.2 AC Side Harmonics

The connecting utilities stipulated strict limits on AC side harmonics as shown in Table I. The top part of Figure 8 indicates that the requirements were met as the only noticeable increase in AC voltage distortion is at the 29^{th}. In fact the low order harmonics are reduced when the interconnection is in operation. This was not the case at the beginning of the commissioning: the 7^{th} harmonic was problematic but this was quickly resolved by tuning the low order harmonic controllers. Total harmonic distortion (THD) is also reduced (from 1.0 to 0.8%) when the interconnection is in operation. The telephone interference factor (TIF) slightly increases from 10 to 15 when the converters are in operation.

4.3 DC Side Harmonics

Very strict requirements were also specified for the DC side harmonics to prevent telephone interference, which is more probable with underground transmission as telephone cables can come within a few meters of the power cables. The requirements were expressed by a psophometrically weighted rms value of the DC side residual current, namely I_{eq} factor, with a maximum threshold of 200 mA_{rms}. As shown in the bottom part of Figure 8, the major components of the DC side converter current are even harmonics (except the 3^{rd}), which are pole mode. Furthermore the DC cable screen offers a very good shielding as shown on a log scale on the bottom curve. This was measured via Rogowski coils installed around the DC cables. The corresponding value for the psophometrically weighted residual current was 50 mA_{rms}.

Table I – Maximum levels for AC side harmonics

Odd Harmonics Non Triplen		Odd Harmonics Triplen		Even Harmonics	
Order h	D_h (%)	Order h	D_h (%)	Order h	D_h (%)
5	0.625	3	0.625	2	0.31
7	0.625	9	0.625	4	0.31
11	0.625	15	0.20	6	0.31
13	0.625	≥ 21	0.13	8	0.25
17	0.625			10	0.25
19	0.625			≥ 12	0.13
23	0.625				
≥ 25	0.50				
THD (%)		≤0.9			
TIF		<40			

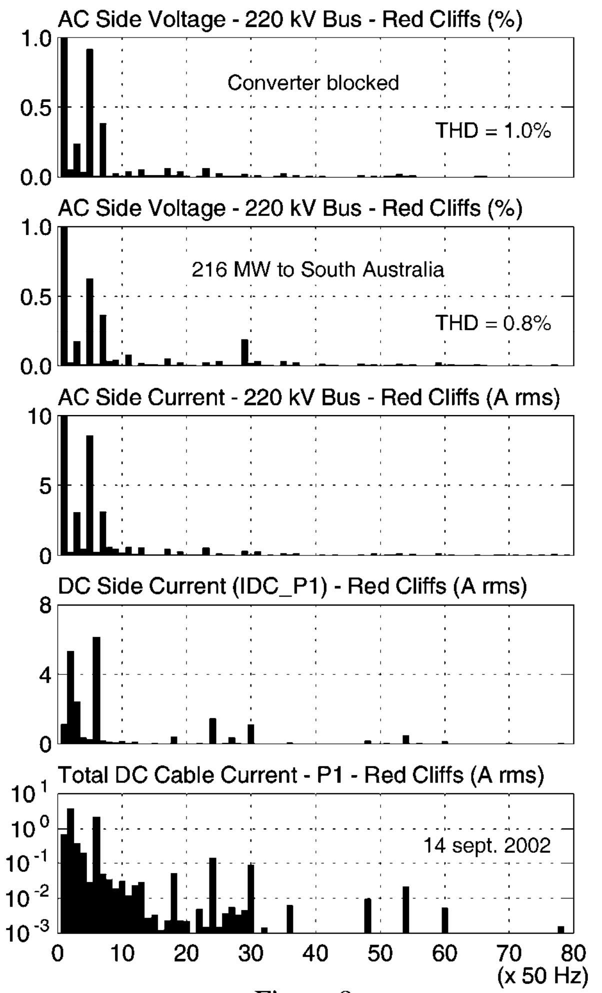


Figure 8
Typical spectra for AC side and DC side harmonics

4.4 Losses

Actual Murraylink transmission system losses were measured during commissioning of the project. All converter station auxiliary power was supplied by the Murraylink power transformer tertiary windings during measurements. The cooling systems for the IGBT valves, phase reactors, building areas and power transformers were operated at maximum to simulate cooling load at 40ºC dry-bulb air temperature. The actual loss curve shown in Figure 9 was created by taking MW values from the 132 kV and 220 kV utility revenue meters at the AC network point of common coupling at each VSC. As seen in Figure 9, actual measured losses were found to be lower then the initial estimated losses based on previous projects, especially at high MW power transfer. The combination of three-level bridge valve design, higher currents and lower switching frequency as used in Murraylink offered better power loss performance than anticipated as compared to the two-level bridge design used in earlier VSC projects such as Directlink [6].

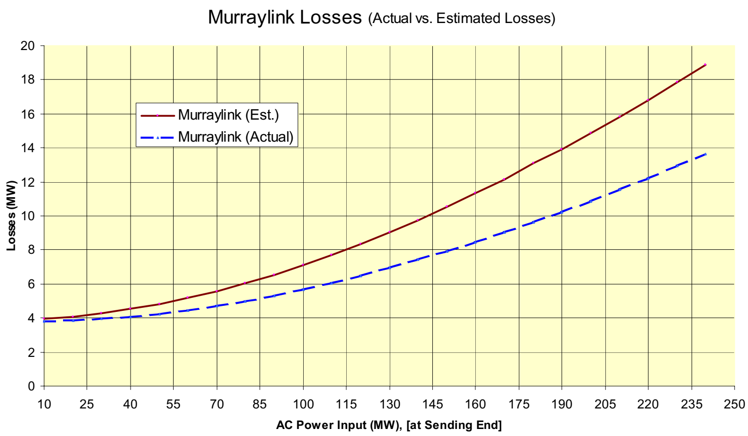


Figure 9. Murraylink Actual and Estimated Losses

5. TRANSIENT PERFORMANCE

With the converters being integrated to the AC substations with very low short circuit strength, special attention had to be paid to the transient behaviour due to frequent operations like converter energisation and converter deblocking. The converter AC voltage regulator would also play a major role during operation.

5.1 Converter energisation

As seen on the single line diagram of Figure 5, the incoming breaker is equipped with pre-insertion resistors to limit the converter energisation transients which consist of converter transformer inrush currents and charging current of the important DC side capacitances made of the DC side capacitors at both ends plus the DC cable capacitance. Figure 10 shows that the energisation transients are indeed very well controlled: the transient AC voltage fluctuation is limited to approximately 2% at Berri. It is noticed also that the steady state voltage change at energisation is limited to approximately 0.3%. This could not have been achieved without the AC filter circuit breakers that allow delay of the AC filter energisation with the converter deblocking.

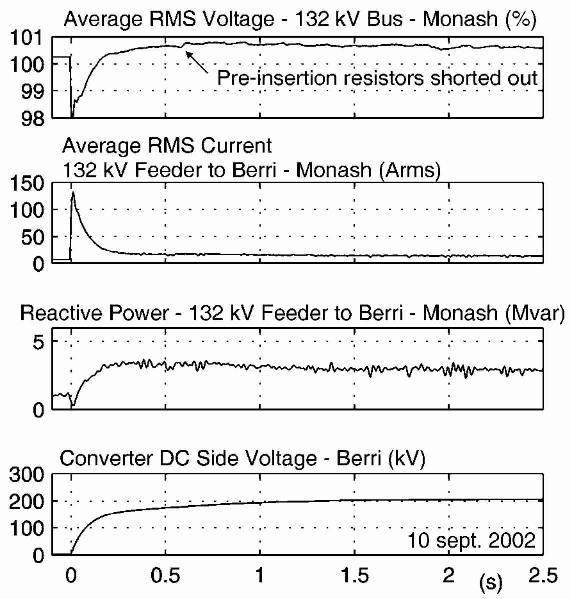


Figure 10
Converter energisation

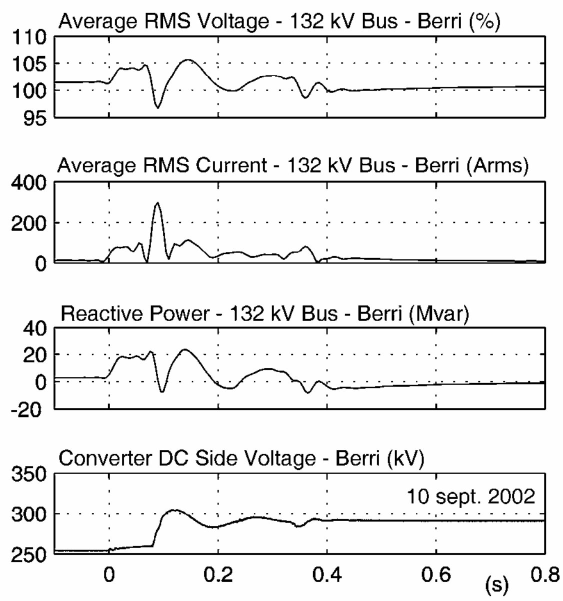


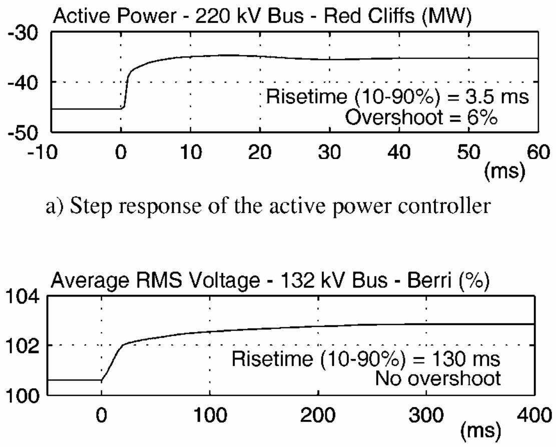
Figure 11
Converter deblocking

5.2 Converter deblocking

This sequence consisting in the release of the valve firing pulses and in the energisation of the three AC filters has been designed to minimize the voltage transients at the PCC. First the AC filter breakers have been equipped with a synchronous closing function to limit the filter energisation transients. Then the various actions have been staggered as seen in Figure 11: the 27th harmonic AC filter is first energized followed 80 ms later by the release of the valve firing in reactive power control with an order of 0 Mvar. The 2nd and 3rd AC filters are brought in respectively 170 and 270 ms later. This whole sequence limits the transient AC voltage excursions to approximately ±4%. Although this is considered adequate, it is believed that this could be further improved if required.

5.3 Step responses

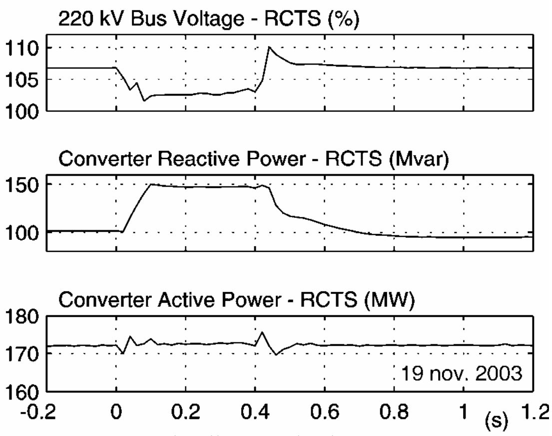
Step responses of various control loops were evaluated during commissioning and the two most pertinent step response tests for system operation are presented in Figure 12. The step response of the active power controller (Figure 12a) exhibits a very fast behaviour (a rise time of 3.5 ms) compared to the conventional HVDC schemes. The AC voltage control (Figure 12b) has been intentionally set on the sluggish side but it could be made much faster if needed.



a) Step response of the active power controller

b) Step response of the AC voltage controller

Figure 12
Step responses



(Data kindly provided by VENCorp)

Figure 13
AC fault on Victorian network

5.4 AC Voltage control

The AC networks are relatively weak, especially in Berri (minimum 232 MVA with one AC line out-of-service). The converters have to run continuously in AC voltage control to reduce the risk of voltage collapse. The presence of the converters has greatly improved the steady state voltage regulation at each interconnection point. Transient behaviour is also improved as shown in Figure 13 for an AC fault. Here the converter went to its full reactive power output while the transmitted power remained unchanged.

6. OPERATIONAL EXPERIENCE

Commercial operation started on Oct 1, 2002. Availability was in the 97% range for the first year of operation. Availability was impacted in the first year of commercial operation by scheduled outages to complete punch list items, complete testing that was delayed due to AC network constraints and by several forced outages. The most serious forced outage was due to a DC transmission cable fault that caused an outage between December 22 – 28, 2002. The cause of the DC cable fault was most likely due to a localized damage during installation.

7. CONCLUSION

The 220 MW Murraylink HVDC interconnection features a 177 km long underground cable, which is the longest high voltage underground cable system in the world. Project implementation was only 22 months after contract signing due to use of easy to install solid dielectric cables, modular VSC based converter equipment and a well-proven control and protection system.

8. REFERENCES

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