COMMISSIONING TESTS FOR HV UNDERGROUND CABLES (UP TO 33KV) SWP

1. PURPOSE AND SCOPE

The purpose of this Standard Work Practice (SWP) is to standardise and prescribe the method for pre commissioning and commissioning tests on high voltage underground cables. Where new cables are jointed to existing cables the test requirements are modified as described in this SWP to cater for the aged insulation of existing cables.

2. STAFFING RESOURCES

Electrical Fitter and/or Mechanic or Cable joiner.

Competent Assistant.

Safety Observer where required.

Required Training

Staff must be current in all Statutory Training relevant for the task.

All workers must have Completed Field Induction or have recognition of prior Ergon Energy Field Experience.

Contractors must have completed Ergon Energy's Generic Contractor Worker Induction.

Additional Training (as required)

Training Course Description for Authorisations or Certificates.
Switching Operator Lines
Switching Operator Assistant
Safe Entry to High Voltage Enclosures and Authorised
Access / Test Permit Recipient and Authorised
Safe Work in Confined Spaces
* Test HV UG Cables up to 33kV
Confined Space Awareness

*** Note:** This course is part of Cable Joining Training. Staff performing HV Cable Testing should complete this training if not competent.

3. DOCUMENTATION

CS000501F115. Daily/Task Risk Management Plan

ES000901R102. Health and Safety Risk Control Measures

SP0407R01 Commissioning Tests for New HV Cables (up to 33 kV) Job Safety Analysis

SP0407R02 Testing HV Cables Supplementary Information

SP0407R03. Commissioning Test For HV Underground Cable (up to 33kV) SWP SP0407 - Field Instruction

SP0407C01 HV Cable Commissioning Test Report Form

SP0407C04 Commissioning Tool – HV Cables (Up to 33kV)

SP0506. Substation Primary Plant and Secondary Systems Field Testing SWP

SWMS001. Working at Heights - Poles & Ladders

SWMS002. Working at Heights (Mobile Elevated Work Platform

P53. Operate the Network Enterprise Process

AS2067-2008 Substations and High Voltage Installation Exceeding 1 kV a.c.

BS0435:1984

4. KEY TOOLS AND EQUIPMENT (as required)

Pole Rescue Kit.

Switchboard Rescue kit.

Confined Space Monitoring and Rescue equipment.

Roadway warning signs.

Barricading.

Work site communication equipment (e.g. 2-way radio).

An insulated operating stick and tool head.

Insulating Gloves applicable to the task.

Dry chemical fire extinguisher.

5kV Insulation Resistance Tester (10 kV for 12.7/22 and 19/33 kV cables).

Additional Equipment for testing Major Cables

- Very Low Frequency (VLF) high voltage Test Set for XLPE cables;
- DC high voltage test set for Paper Lead cables.

5. TASK STEPS

5.1 On Site Risk Assessment

Prior to performing this activity any hazards associated with prerequisite tasks at the worksite shall be identified and assessed with appropriate control measures implemented and documented in accordance with Daily/Task Risk Management Plan CS000501F115 and using reference document Health and Safety Risk Control Measures ES000901R102.

If any risks cannot be managed or reduced to an acceptable level, do not proceed with the task and seek assistance from your Supervisor.

5.2 Preliminary Steps and Safety Management

Ensure appropriate construction and operational drawings are on hand.

Use correct methods to positively identify the cable to be tested, including ensuring that cable number (where allocated) has been securely attached.

Ensure that the associated switchgear operational nameplates are in place and securely attached.

Ensure test equipment suitable for task. Confirm all test equipment is within current test date, calibrated and operational. Ensure all persons required to use test equipment are competent in its operation.

Assign adequate staffing resources with required competencies to safely complete task.

Persons performing electrical testing must ensure electrical equipment is tested to confirm electrical work performed is electrically safe.

All staff to wear appropriate PPE including applicable class of gloves if required. Ensure class 00 gloves, and insulated mats are used while working on or near exposed live LV parts.

Use roadway warning signs/ barricading to control vehicle and pedestrian traffic around work zone and relevant exclusion zones around live parts.

Ground conditions and potential slip/fall hazards in travel path considered in **CS000501F115 Daily/Task Risk Management Plan.**

Identify locations defined as confined spaces and ensure compliance with confined space entry requirements.

Ensure exclusion zones are maintained at all times while near exposed live parts.

Caution

Where it is identified that barriers or shields cannot prevent contact with the adjacent energised cable terminations (eg Magnefix cable termination kits), all HV within the exclusion zone shall be isolated, tested and earthed in accordance with P53 High Voltage Isolation and Access Procedures prior to gaining access to HV cable terminations.

For other termination kits barriers or shields shall be used to prevent contact with adjacent energised cable terminations.

Confirm cables to be tested are isolated from all HV & LV systems including secondary sources of supply and tagged, and locked where provision is made, in accordance with **P53 Operate the Network Enterprise Process**.

Comply with **SWMS001. Working at Heights - Poles & Ladders** and **SWMS002. Working at Heights - Mobile Elevated Work Platforms** when working aloft.

Ensure ground based persons are clear of drop zone while work is performed aloft.

Use equipment to sample atmosphere and ventilate trenches prior to personnel entry in accordance with confined space entry requirements.

Confirm cable terminations and lightning arresters/surge diverters are unbolted to perform tests where required.

Position "HV Test in Progress" signs at all ends of the HV cable prior to testing. Where public access is possible, position Safety Observer and barricade exposed ends of cable during insulation test.

Refer to **SWP SP0506 Substation Primary Plant and Secondary Systems Field Testing** for information on control of hazards and risks associated with testing of high voltage cables.

In particular, take note of:

- Stored charge in the core under test.
- Stored charge in the sheath of the cable under test.
- Induced stored charge in the sheath and core of cores/cables adjacent to the one under test.

5.3 General

It is noted that the insulating qualities of XLPE are very good, and that except in the case of major insulation damage such as physical puncture by a nail XLPE can withstand many times it's rated voltage without failure (typically > 14 times Uo for new cable).

Most failures of XLPE cable are related to moisture ingress into joints or terminations or incorrectly applied terminations and joints (both workmanship and materials may be inadequate).

One aim of testing of HV cables is to expose, in controlled conditions, any faults that will result in premature failure of the cable and associated terminations.

It has been established that DC high voltage testing of deteriorated XLPE cables can accelerate the deterioration process and lead to a reduction in cable life.

DC high voltage testing of new XLPE cables is not recognised to cause cable deterioration, however in order to adopt a standard approach VLF AC testing is preferred instead of DC high voltage testing for new and aged XLPE cables.

The cable tests described below are to be carried out after installation and termination has been completed.

In addition to the tests outlined below, a sheath integrity test should be done after installation and prior to termination to verify that cable damage during installation has not occurred.

As described in later sections, testing of new or aged paper lead or XLPE cables is as per the following sequence:

- Record information;
- Sheath Test;
- Insulation Resistance Test;
- Phase Out;

- High Voltage Withstand including subsequent IR Test (additional to major cable testing only);
- Final Checks.

Pre-terminated cables such as transformer leads in padmount substations should be tested as per this SWP. They are classed as minor radial cables and do not require a high voltage withstand test.

Regarding the use of DC testing such as insulation resistance or leakage measurement during a high voltage DC withstand, there is a phenomenon called electro endosmosis (evident in older insulation rather than XLPE) that causes a lower IR reading (higher leakage current) when the positive terminal is connected to the grounded side of the insulation being tested.

It is therefore preferred, where the test equipment allows a choice, to connect the positive terminal to the cable screen during test.

5.4 Check and Record Cable Identification.

The outermost surface of cables should be embossed, printed or, in the case of PVC sheath, may be indented, with the manufacturer's name, year of manufacturer, together with the following information.

Cable Designated Voltage	Legend To Be Marked
1.9/3.3 (3.6) kV	Electric Cable 1.9/3.3 kV
3.8/6.6 (7.2) kV	Electric Cable 3.8/6.6 kV
6.35/11 (12) kV	Electric Cable 6.35/11 kV
12.7/22 (24) kV	Electric Cable 12.7/22 kV
19/33 (36) kV	Electric Cable 19/33 kV

Note:

Indications of rated voltages are expressed in the form as shown above designate the following Uo/U (Um).

'Uo' is the r.m.s. voltage to earth of the supply system for which the cable is designed and U is the r.m.s. voltage between phases of the supply system for which the cable is designed. Um is the highest voltage that can be sustained under normal operating conditions at any time.

For multi-core cables, the cores should be identified in one of the following ways:

- By a printed numeral and word on the outer surface of each core eg 1 ONE;
- By a printed word on the outer surface of each core eg RED;
- By colour-marking semi conductive tape or coloured stripes throughout the full length of the cable.

5.5 Verify Sheath Integrity.

A sheath integrity test at a voltage of 1000V dc applied for 1 minute should be carried out with an insulation resistance tester, between the outermost metallic layer and earth. This will identify if there has been any damage to the sheath during/after installation.

Notes:

- The screen shall be isolated at both ends and also at any mid circuit bonding for this test.
- A sheath integrity test should be done after installation (prior to termination) to verify that cable damage during installation has not occurred, and repeated when terminations are complete.
- Some newer cables may have a semi-conductive outer sheath. This is used to provide improved lightning performance and a more reliable mechanism for detecting sheath faults. The semi-conductive HDPE does not require additional bonding to earth.

The reading for cable sheath resistance should be greater than the acceptance value set out below for HDPE sheathed cables.

This test is required for XLPE and paper lead cables.

Distance	250m	500m	1000m	2000m
Cable size	**MΩ**	**MΩ**	**MΩ**	**MΩ**
11kV or less				
400mm^2	250	125	60	30
185 - 240mm^2	300	150	75	37
35mm^2	500	250	125	62
22kV or more				
185 - 630mm^2	500	250	125	62
35mm^2	400	200	100	50

Data is not presently available for cables larger than the cables specified above; however the insulation resistance should not be significantly lower than the figures above.

For PVC sheathed cables, the acceptance value is 1 MΩ.

Earth the screen after test for at least 5 minutes.

Where the prescribed values cannot be achieved the connection arrangement should be first checked.

Where applicable the assistance of a high voltage test specialist may be sought and the Asset Manager must be advised where the value remains low.

The Asset Manager will decide if sheath resistance values lower than the prescribed figures will be accepted.

Cables with a suspected or confirmed sheath fault are not to be energised.

If the cable has two insulated metallic layers (the cable screen and brass tape termite protection) then the insulation between these layers should be tested as well – a further indication of possible cable damage.

Note that this test is not required if these layers are bonded together, for example at joints.

If a section of new cable is joined to an existing cable, the sheath test should be completed prior to bonding of the two screens.

A sheath test of the completed cable should also be carried out for reference, but it is not expected that all aged cables will pass a sheath test.

Caution: Where the cables to be tested are not disconnected from the ABB Safelink RMU the following actions must be taken to minimise the risk of injury or damage:

1. The Earth Switch on any energised ABB Safelink RMU must not be switched from the EARTH to OFF position when the connected HV Electrical Apparatus are under access (i.e. the Busbar of the RMU must be de-energised using double isolation before the Earth Switch can be operated).

2. After operating the Earth Switch the switching operator must visually confirm that the correct switch state is displayed by the indicator. If the indicator is incorrect or in an indeterminate state personnel must stay well clear of the RMU and associated cable(s) and contact the Switching Co-ordinator for further instructions.

5.6 Core Insulation Test

Prior to the high voltage withstand test (if required), the cable shall be tested for insulation resistance (IR).

The test voltage used for the core insulation test is specified in the table below.

Uo/U	New Cables DC Test Voltage (kV ph to earth)	Aged Cables DC Test Voltage (kV ph to earth)
1.9/3.3	1	1
3.8/6.6	1	1
6.35/11	5	5
12.7/22	10	5
19/33	10	5

The core insulation resistance is to be measured A to B+C+E, B to A+C+E, and C to A+B+E;

The insulation resistance shall be recorded 1 minute, 2 minutes and 5 minutes after application of the voltage.

For very long cables it may take longer than 5 minutes for the resistance value to stabilise in which case a final reading is taken and the measurement terminated at 10 minutes.

Conversely, the 2 and 5 minute readings may not be required for short cables if the reading has already stabilised.

No breakdown of the insulation shall occur.

The reading for IR for new XLPE cables should be greater than the acceptance values set out below.

Distance	**250m**	**500m**	**1000m**	**2000m**
Cable size	**GΩ**	**GΩ**	**GΩ**	**GΩ**
11kV or less				
400mm^2	16	8	4	2
185 - 240mm^2	20	10	5	2.5
35mm^2	40	20	10	5
22kV or more				
630mm^2	20	10	5	2.5
185mm^2	35	17	9	4
35mm^2	60	30	15	7.5

Data is not presently available for cables larger than the cables specified above; however the insulation resistance should not be significantly lower than the figures above.

The IR reading for aged XLPE cables should be greater than 1 Gohm.

The cable screen should be earthed during the above measurement.

Earth the cable conductors after test for at least 5 minutes.

Where the prescribed values cannot be achieved the connection arrangement should be first checked.

Termination leakage may need to be ‘guarded’ out of the measurement to ensure accurate results (refer figure 1).

Where applicable the assistance of a high voltage test specialist may be sought and the asset manager must be advised where the value remains low.

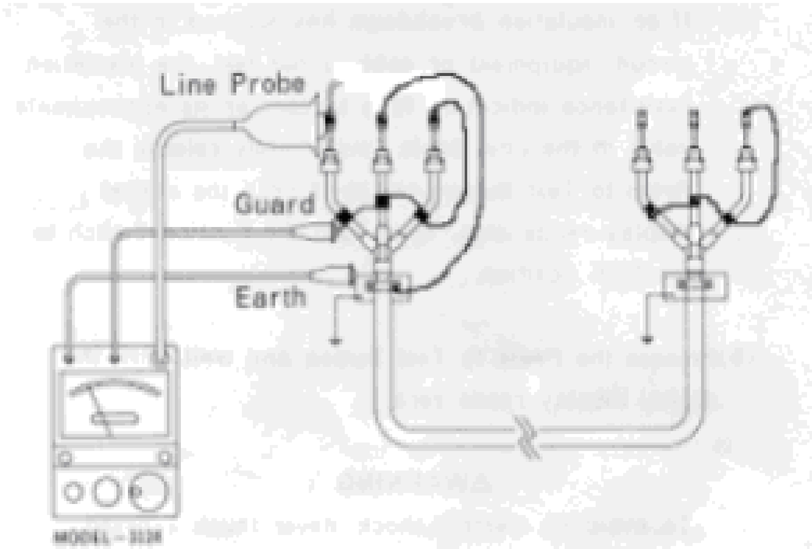
The Asset Manager will decide if insulation resistance values lower than the prescribed figures will be accepted or if remedial works will be undertaken.

How to use the Guard Terminal

In cable insulation tests, wind a conductive wire around insulation of the cable under test and connect it to the Guard Terminal with the Guard Lead as per diagram.

This is to move out the surface leakage resistance of the cable to make the test results accurate.

Figure 1 Typical guard connection



Note:

One of the cores is used to transfer the guarded leakage at the remote end to the meter so that it does not impact on the measured insulation resistance.

5.7 Verify Phasing And Cable Continuity And Prepare Cable For Testing

Verify cable phase identification and continuity by using a continuity tester or diode box.

Ensure that any surge diverters or voltage transformers are disconnected from the cable so as not to impact on insulation resistance measurements or high voltage withstand testing.

5.8 Carry Out High Voltage Withstand Test And Record Leakage Currents.

A routine high voltage withstand test shall be carried out on all major HV underground cables which are defined as:

33kV, 66kV, 110kV and 132kV cables.

22kV cables greater than 185mm^2 Cu or 300mm^2 Al

11kV cables greater than 240mm^2 Cu or 400mm^2 Al

All zone substation cables and feeder exit cables.

A high voltage withstand test is not required on minor radial distribution cables. Categorisation of a cable as a “minor radial cable” will in most cases be self evident.

Prior to any high voltage withstand testing being carried out, check that the cable screen connection to earth has been reinstated and that the test equipment earth is securely connected to this bond. Ensure that the capacitance of the cable under test does not exceed the output capability of the test equipment.

ALL (XLPE and Paper Lead) cable shall be tested with a VLF alternating voltage whose waveform shall approximate a sinusoidal waveform of frequency 0.1 Hz.

NOTE: VLF is the preferred method for testing ALL types of cables. In the past DC has been used on Paper Lead (PILC) cables, DC can still be used on PILC cables but only if VLF testing is unavailable.

The voltage shall be increased gradually and maintained at full value for the specified period. Note that a 30 minute testing period has been specified for XLPE cables on the basis that 89% of cable failures are likely to occur in the first 30 minutes.

The value of test voltage used is specified in the following table for new cables.

This table applies where the cable is ***NOT*** connected to switchgear or where there is no likelihood of overstressing an open point in the switchgear by the application of the test voltage.

Uo/U	DC Test Voltage (kV ph to earth)	DC Test Voltage (kV ph to ph)	VLF Test Voltage (kV peak ph to earth)	50Hz AC Test Voltage (kV RMS ph to earth)	
	15 min	15 min	30 min	1 min	15 min
1.9/3.3	7	10	6	10	6
3.8/6.6	15	20	12	20	12
6.35/11	25	34	19	28	16
12.7/22	50	-	38	50	29
19/33	75	-	57	70	40

In the case of aged cables (say 5 years or older), 75% of the test voltages in the above table should be used.

If the high voltage withstand test voltage would overstress the insulation of connected switchgear, for instance by being applied to one side of an open isolator when the other side of the isolator was energised at system voltage, it is preferred to disconnect the cable from the switchgear.

Alternatively, where this is impractical, a reduced test voltage and duration applies as per the following table.

The below test voltages have been altered to account for the possibility of aged switchgear, so they do not have to be further reduced to account for aged cables.

NOTE: Even though the test voltages (below) are greater than the 75% for aged cables, damage to the cable is mitigated by the reduced testing time.

Uo/U	DC Test Voltage (kV ph to earth)	VLF Test Voltage (kV peak ph to earth)	50Hz AC Test Voltage (kV RMS ph to earth)
	1 min	1 min	1 min
1.9/3.3	6	6	5
3.8/6.6	12	12	11
6.35/11	19	19	14
12.7/22	33	33	24
19/33	45	45	32

For single core screened cables, the test voltage shall be applied between the conductor & metallic screen. Triplex cables shall be considered as three independent single core screened cables.

Where multiple single core cables are being tested simultaneously, the remote ends of the cables should be connected together to limit the surge energy impact should one cable fail during test

Where two or more cables are connected in parallel (in order to obtain a higher current rating), the parallel cores do not have to be tested individually – they should be tested as a single core.

For multicore cables having individual screening of cores, the test voltage shall be applied between each insulated conductor and metallic screen.

The cores shall be tested in the configuration as described in the test report form to stress phase-phase insulation at the crutch whilst stressing the phase-earth insulation.

For multicore cables without individual screening but an overall screen (eg. belted cables) the test voltage shall be applied between each insulated conductor and all adjacent conductors and metallic screen.

The conductors may be suitably connected in groups as described in the test report form to reduce the number of tests.

The cable has passed the high voltage test if no disruptive discharge occurs. Note that some VLF sets may show a reduction in output voltage in the event of cable failure but not trip out – this is still considered a failure and the output voltage should therefore be monitored throughout the test.

Caution – In all cases, cores not under test shall be earthed at all times. Due to capacitive coupling, it is likely that unearthed cores not under test will be charged up by the electric field from the core under test and present a hazard to test staff.

Caution – Some cable boxes may have internal clearances insufficient to withstand the voltage applied during a high voltage withstand test and therefore they will flashover during test. This may also occur if cables are not in their final position during testing – for example lugs not bolted up or boots installed.

As a rule of thumb, allow 1 inch (25mm) per 10 kV RMS test voltage for air insulation during testing. If this clearance cannot be obtained, use additional insulation such as insulated mats where the clearance is reduced.

Heat-shrink tubing or boots rated at the same voltage as the cable are satisfactory, but remember that these are NOT suitable for personal protection from high voltage because they are not regularly tested.

Such insulation therefore should only be used where other personnel safeguards are in place (for example exclusion zones, earthed metallic barriers). As a rule of thumb, allow 1 mm of insulating material per 10 kV RMS test voltage.

Refer to SP0407R02 for further information.

Earth conductors after test for at least 5 minutes.

An alternative to the VLF high voltage withstand test for XLPE cables is to use a one minute or fifteen minute 50 Hz AC high voltage withstand test.

Although technically the 50 Hz withstand is a better test, it is recognised that the difficulty in supplying the associated high level of 50 Hz charging to a cable in a field situation will preclude this test being used in most situations.

The test voltages specified have been derived from AS2067 and AS1824, recognising that the test requirements of AS1429.1 are for routine tests at the manufacturer’s works and may be too onerous for a terminated cable, especially considering any switchgear bushings and bus work that will be subjected to the test voltage.

The 50 Hz AC high voltage withstand test can be useful when a pitch cable box precludes disconnection of a transformer from the cable (in which case 75% of the stated test voltage shall be used).

5.9 Post High Voltage Withstand Test Core Insulation Test

After completion of the high voltage withstand test, the cable shall be re-tested for insulation resistance as per paragraph 5.6. There should be no decrease in insulation resistance due to insulation damage.

It is noted that in a very good insulation system such as XLPE it may take several hours for polarization of the insulation to return to its original state.

During this time the insulation resistance measurement may be significantly lower than the original measurement, however the minimum acceptable values of paragraph 5.6 are still applicable.

5.10 Insulation Condition Diagnostic Assessment

For subtransmission and transmission cables, as well as distribution cables of strategic importance, the Asset Manager (via the Project Manager) may specify that additional testing is required prior to the cable being energised to provide a ‘footprint’ for future management of the cable.

Such tests may include Partial Discharge, Dielectric Dissipation Factor, Internal Relaxation Current, Polarisation Depolarisation Current, Oscillating Wave or other tests.

5.11 Final Checks

Verify, if applicable, that the cable screen earthing has not shorted any frame leakage protection.

Verify that single core cables do not have a continuous ferrous metallic path around them. This may be in the form of cable glands, cable clamps, or cable box entry. Trefoil clamping arrangement is preferred for single core cables.

Verify that the cable screen is earthed at the correct end/s (for new distribution cables both ends will normally be earthed however this must be validated with the design).

Confirm where the design requires one end only to be earthed that any control measures specified for hazardous voltages that may appear at the unearthed screen end under fault conditions are in place.

Such control measures may be signage, insulation, surge diverters or personnel guards/barriers. If the cable has a separate metallic screen and outer metallic termite protection (brass tapes) then the brass tapes should be earthed at the same earth locations as the metallic screen.

Verify that cable assembly has been completed eg surge diverters and/or voltage transformers reconnected, cable lugs securely bolted in place, insulating covers/boots/guards in place, switchgear reassembled.

Verify that the cable number is clearly marked at both ends of the cable and the switchgear associated with the cable has an operational number/name clearly marked.

Verify that cable box clearances meet or exceed the requirements of BS 0435:1984.

Rated Voltage	Enclosure Type	Phase to Phase clearance (mm)	Phase to Earth clearance (mm)
12 kV	Fully Insulated	45	32
	Air Insulated	**127** (184)	**76** (160)
24 kV	Fully Insulated	100	75
	Air Insulated	**242** (322)	**140** (280)
36 kV	Fully Insulated	125	100
	Air Insulated	**356** (437)	**222** (380)

For comparison, AS2067 clearances are shown in brackets and should be used where vermin entry or cable box contamination is possible.

5.12 Finalise Results

For minor cables test results shall be approved by the workgroup supervisor or his delegate.

For major cables the test results are to be approved by the Project Manager or his delegate before the cable is placed into service. In most cases this will be a delegated approval to the supervisor of the cable test team.

A copy of the test results is to be sent to the Project Manager, and a copy retained by the work group carrying out the test. Additionally, a records copy of the test report SP0407C01 is to be emailed to the Ergon e-mail address "Cable Test Results".

The filename of the test report should be the following format:

Location_From_To_CableNumber_Date.doc

Where:-

Location = geographic location eg Smith St

From = source end of cable eg Mareeba Sub

To = destination end of cable eg HVL12

Cable Number = unique cable ID (if allocated)

Date = date of test yyyyymmdd eg 20060129

These results will be subsequently filed at \\ecasd01\Protection\Test Data - (Test-Commissioning-Maintenance)\Region\Cable Tests\Town

5.13 Energise HV Cable

It is preferred that a remote switching device is used to energise any new HV cables (including plant) for the first time*.* The earth fault protection operating time of the cable's protection system may be reduced during the initial cable energisation. Ensure the auto reclose on the feeder is blocked for the duration of the switching.

The remote switching device for energising must have full fault make capabilities. It is envisaged that the remote switching device would be an RMU further upstream at a safe distance from the cable to be energised or a remotely controlled circuit breaker.

Because not all minor HV Cables have to undergo an applied high voltage withstand test as per paragraph 5.8, and where the cable doesn't have to supply customer load within a 24 hour period the cable should be energised and left until supply is required. This will minimise loss of supply or damage should a fault develop

Prior to loading the cable, a phase out must be completed. In a radial system, a phase rotation check must be used in lieu of a phase out.

For **minor HV Cables only** that can't be remotely energised then the following additional measures shall be taken.

- Perform the high voltage withstand as per paragraph 5.8 <u>and/or</u>
- Confirm insulation resistance test was carried out and within tolerances
- Inspect cable terminations to ensure they are not damaged
- Ensure terminations are not porcelain or oil filled *****
- Inspect switching device (e.g. ABS/HV Links) is operational
- Consider the effect of ferroresonance ******
- Close switch

The Switching Operators Assistance will ensure that the switching device closes correctly. If the device doesn't function correctly **<u>DO NOT</u>** attempt to reopen. Comply with the requirements of P53 HV Switching and Access.

*** Caution** – If the terminations are porcelain or oil filled then the cable shall be energised remotely. If this is not possible then a voltage withstand test as per paragraph 5.8 shall be carried out.

**Ferroresonance

In power systems, the most common place to find ferroresonance is with a three phase distribution transformer energised through an underground cable of moderate length. Under no load, or very light load conditions, the capacitance of the cable is sufficient to precipitate ferroresonant behaviour under single phase switching conditions (e.g. the operation of an HV fuse or asynchronous operation of single phase 11kV switches such as a drop-out fuse unit.)

The four most effective methods of controlling ferroresonance are:
a) three-phase switching;
b) single-phase switching at transformers;
c) resistive load on the transformer; and
d) limiting cable length.

Methods (a) and (d) require action on the part of the system designer.
Methods (b) and (c) require special operating procedures to ensure that there is effectively no length of cable being energised or de-energised at the same time as the transformer, or the presence of some load.

Three-phase Switching
The use of ganged three-phase switching is one of the most effective and commonly used methods of avoiding ferroresonance.

Single Phase Switching at Transformers
The practice of switching at the transformer terminals themselves is a particularly effective means of controlling ferroresonance. By doing this, the cable length between the transformer and the switch is essentially zero and the only possible capacitance in the network is that of the internal capacitance of the transformer.
This is a particularly suitable method and can be applied in distribution systems using single-phase switchgear. Where a cable transformer combination is to be energised, the cable only should be energised and then the transformer. Conversely on de-energising, the transformer only should be de-energised first and then the cable. Both sets of switchgear can then be single phase operating.
Since the critical cable length, which is actually proportional to the critical cable capacitance, is inversely proportional to the function of the square of the voltage, the critical capacitance for higher system voltages is quite small and the transformer capacitance can become significant. **Refer Table 1**

Resistive Load on the Transformer
A resistive loading of 2 to 3% is generally sufficient to control ferroresonance. However in a distribution network, alternative supply is often provided by paralleling the low voltage network to adjoining substations. Should the LV network not be disconnected before HV switching, back energisation of the transformer would occur. Therefore this option is generally unavailable. Similarly on commissioning a transformer, there is usually no load available for this option to be used.

Table1

Critical Cable Lengths of 11kV XLPE Insulated Cables (Metres)

Distribution Transformer Size (kVA)		100	200	315	500	750	1000	1500
Cable	mm²							
TRIPLEX	35 Al	12	24	38	60	90	119	179
TRIPLEX	185 Al	7	13	21	51	51	67	101

Critical Cable Lengths of 22kV XLPE Insulated Cables (Metres)

Distribution Transformer Size (kVA)		200	315	500	750	1000	1500
Cable	mm²						
TRIPLEX	35 Al	7	11	18	26	35	53
TRIPLEX	185 Al	4	6	10	15	21	31

Note: The cable lengths given in the above tables are less than the values calculated using the equation. The cables lengths have been adjusted to suit the over voltage withstand capability of the surge arresters.