VOLTAGE TRANSFORMER TESTING SWP

1. PURPOSE AND SCOPE

The purpose of this Standard Work Practice (SWP) is to provide guidelines for testing methods for Capacitive and Inductive Voltage Transformers. These methods can be used for new and refurbished transformers, maintenance testing or condition assessment testing.

Refer to the following locations for specific testing regimes:

- For new or refurbished construction's, refer to the Construction and Commissioning Tools.
- For standard maintenance testing, refer to the JAMIT job cards and the Standard for Preventative Maintenance Program.
- For CVT Condition Assessment testing, refer to SP0508R02 CVT Diagnostic Testing Reference
- For all other Condition Assessment testing, consult the appropriate Commissioning and Maintenance or Substation Maintenance engineer or officer for guidance. Non-standard testing requires appropriate RPEQ approval.

The requirements for Revenue Metering applications are not included in this SWP.

Specialist testing for ferro-resonance or harmonic response is not included in this SWP.

2. STAFFING RESOURCES

Adequate staffing resources with the competencies to safely complete the required tasks as per MN000301R165: 8 Level Field Test Competency.

These competencies can be gained from, but not limited to any or all of the following:-

- Qualifying as an Electrical Fitter Mechanic
- Qualifying as a Technical Service Person
- Practicing as an RPEQ Electrical Engineer
- Training in the safe use of relevant test equipment.

Requirement for all live work:

- Safety Observer (required for all "live work" as defined in the ESO Code of Practice for Electrical Work)

All resources are required to:

- Have appropriate Switching and Access authorisations for the roles they are required to perform and have the ability to assess and maintain relevant exclusion zones from exposed live electrical apparatus.
- Hold current licences for any vehicles and equipment they may be required to operate.

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.

3. DOCUMENTATION

CS000501F115. Daily/Task Risk Management Plan

ES000901R102. Health and Safety Risk Control Guide

SP0508R01. Voltage Transformer Testing Job Safety Analysis

SP0508C03. Voltage Transformer Testing Competency Assessment

SP0508C06. Construction Tool – Voltage Transformer

SP0508C05. Commissioning Tool – Voltage Transformer

SP0508R02. CVT Diagnostic Testing Reference

CVT Test Equipment Specific Document

SP0506. Substation Primary Plant and Secondary Systems Field Testing SWP

STNW1160. Standard for Maintenance Acceptance Criteria

MN000301R172. Doble DLA Testing

MPD 600 Test Procedure

P53. Operate the Network Enterprise Process

AS 1243-1982 – Voltage transformers for measurement and protection.

AS 60044.2-2007 – Instrument transformers – Inductive voltage transformers.

AS 60044.3-2004 – Instrument transformers – Combined transformers.

AS 60044.5-2004 – Instrument transformers – Capacitive voltage transformers.

Test Equipment Manuals.

Voltage Transformer Manual / Manufacturer's Drawings.

4. KEY TOOLS AND EQUIPMENT

Test Equipment within calibration date, tested and tagged: Insulation Resistance tester, Micro-ohmmeter, High Voltage test set, Digital Voltmeter, CVT test set, Ratiometer or Primary Injection Voltage source, Phase Angle meter and Ohmmeter, Omicron Votano and VB02.

Safety Barriers and warning signs.

HVIA Operating Equipment: PEDs, Live Line Tester, Class 0 gloves. All equipment is to be inspected and confirmed in good working condition and within test date prior to use.

Standard PPE: Full-length high visibility protective cotton clothing, safety footwear and helmet.

Additional PPE as required: Leather work gloves, class 00 gloves, hearing protection, safety eyewear. All PPE is to be inspected and confirmed in good working condition and within test date (where applicable) prior to use.

Sun protection to be used when working outdoors.

5. WORK PRACTICE STEPS

5.1. Carry Out an Onsite 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 the **Daily / Task Workplace Risk Management Plan** (CS000501F115) and using the **Health and Safety Risk Control Guide** reference document (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. All Work to be done with Voltage Transformer De-Energised

All of the tests described in this SWP should be carried out with the VT de-energised from the network and appropriate control measures in place (eg barriers, matting) to prevent inadvertent contact with adjacent live plant or breaching exclusion zones. P53 Operate the Network Process is applicable at all times for isolation and earthing where the VT forms part of the network. A Test Permit will be required for most testing to allow removal of earths and injection of lethal voltages / currents.

Where a VT is not part of the electrical network (e.g. greenfield or workshop testing), sufficient safety measures must be applied to ensure no person can contact plant during testing and all plant is earthed after HV testing prior to person's contacting the plant.

As described in Substation Primary Plant and Secondary Systems Field Testing SWP SP0506 particular safety risks applicable to bus assemblies including:

- Contact with high voltage at VT primary connections.
- High fault current at VT primary connections.
- High fault current at VT secondary terminals, particularly unfused wiring between secondary terminals and marshalling box / secondary fuses.
- Unearthed VT secondary winding.
- Open DLA test terminal.
- A1 terminal of Primary winding not earthed correctly.
- Induced voltages and currents from nearby energised / loaded plant.
- Stored energy in capacitive dividers.

5.3. Assessment Criteria

Unless otherwise stated, refer to STNW1160 Standard for Maintenance Acceptance Criteria for applied test voltages and currents as well as acceptance test results for each test. Standard values may also be defined in the Construction and Commissioning Tools, JAMIT job cards or Operational Updates. For any conflicts, consult either the Commissioning and Maintenance or Substation Maintenance teams.

Variations of test voltages, currents and acceptable test result values can only be made with appropriate RPEQ approval.

5.4. Record Identification Details

Identification details are to be recorded in the Construction / Commissioning Tools, JAMIT job cards, etc. as required. These details are critical to ensure traceability of test results against plant and correct asset details in corporate databases which generate maintenance service tasks.

Some typical details to confirm are:

- Manufacturer's name, manufacturer's type description and manufacturer's serial number.
- Plant/Asset number.
- Description, ie. Magnetic, Capacitive etc.
- Rated transformation ratios (multiple secondary cores).
- Classification of all ratios.

- Rated burden.
- Rated voltage level and insulation level.
- Rated frequency.

5.5. Visual Inspection of Voltage Transformer Condition

Prior to any electrical testing, complete a visual inspection on the voltage transformer, its structure, earthing, etc. to confirm it is fit for testing. Refer to the specific construction / commissioning tool or JAMIT job cards for specific checks.

If the VT is a new installation, confirm that all construction items outlined in the Construction Tool and manufacturer installation instructions have been completed.

Some basic inspections include:

- Ensure external surfaces are clean, dry and damage free.
- Look for external oil leaks, leaks into secondary connection boxes or EMU cases. Note that an oil leak in some CVTs can cause oil to transfer between the capacitive stack and the EMU without an external leak being visible.
- Confirm oil/gas levels are acceptable.
- Confirm primary and secondary connections are correct, tight and correctly (new) / adequately (existing) labelled.
- Confirm any DLA tap covers are in place.
- Confirm primary and secondary earthing is in place and correct. For CVT's, ensure the primary earth is either directly connected to earth or connected via power line carrier communication equipment.
- Confirm structure earthing is in place and correct.
- Confirm if there are any external short from primary to earth (fuse wire is commonly used on CVT's during transport and installation to prevent charging capacitor stack)

CAUTION – A1 Terminal Earthing is critical

Before beginning any testing, particularly primary voltage injection, it is important to ensure that the A1 terminal on the primary winding has been earthed. For CVTs, the A1 terminal may be earthed directly or via the carrier line matching unit (where fitted). If the A1 terminal is disconnected for testing (eg insulation resistance measurement) then it must be reconnected immediately afterwards.

If the A1 terminal is left disconnected when the VT/CVT is energised, high voltage will be apparent on this terminal which poses a serious safety risk to staff.

A1 terminal inadvertently left disconnected

5.6. Oil / Gas Tests and Samples

Testing the insulating oil or gas medium is required to ensure the insulation performs as intended by the manufacturer. If plant is electrically tested or put into service with unknown insulation qualities, permanent damage to the plant can occur either during testing or while in service. If the plant is put into service with non-satisfactory oil or gas, it could result in explosive failure.

All oil handling and filling is to be completed as per MN000301R173 Insulating Oil Equipment and Handling process and the equipment manual.

Samples are only to be taken if the VT is designed to be sampled. Confirm with the equipment manual to confirm if possible.

All SF6 gas handling is to be completed as per BS001404R140 Management of SF_6 Gas and its By-Products and STNW1117 Standard for Handling of Sulphur Hexafluoride (SF_6). Gas samples are required from:

- Gas in bottle
- Gas VT shipped with (if sufficient pressure)
- Gas in VT after filling
- Gas in VT 24hrs or greater after filling

While filling equipment is connected to plant, complete oil or gas alarms and lock out functions which are dependent on gas pressure or oil levels. Function check to the terminals of the VT relays so further function checking can be completed from this location.

Oil or gas levels are to be re-checked after all oil and gas tests and samples have been taken to confirm still within specifications.

Oil and gas samples may be required to provide a benchmark for future testing. If required, take a sample as per the approved process and forward to Powerlink for analysis.

Below are typical situations were on site tests may be required to confirm the integrity of the oil or gas prior to completing any electrical testing.

Installation	Oil	Gas
New plant with no filling required at site	No (Note 1)	Yes
New plant with filling required at site	Yes (Note 1)	Yes
Refurbished / intrusively maintained plant	Yes	Yes (Note 2)
Existing plant with no re-filling at site	No	No
Existing plant re-filled at site	Yes (Note 3)	Yes

Note 1: Only sample hermetically sealed units that are designed to be sampled. Consult manufacturer manuals or Substation Maintenance for further information if required.
Note 2: Desiccant's may also need to be replaced if intrusive maintenance has been completed on SF_6 filled equipment.
Note 3: If only minor oil level top up, on site oil test not required. If refill required due to leak on plant that is supposed to be hermetically sealed, it is no longer hermetically sealed and should be treated as if it's not sealed. Consult Substation Maintenance to have MST's created.

5.7. Measure Primary and Secondary Winding Insulation Resistance

DC Insulation resistance tests (DCIR or IR) are one of the easiest and quickest ways to confirm phase to ground and winding to winding insulation integrity. It helps determine the health of the insulation between components that are not supposed to be electrically connected. DCIR does not test the inter-turn insulation.

A product of DCIR tests is the polarisation index (PI). This is a ratio of the 10 minute over 1 minute DCIR test results (PI = R10 / R1). PI helps distinguish between large charging and absorption currents (non-destructive) with leakage currents (likely destructive). As PI is a ratio, it is also not temperature dependent where as a single DCIR reading is. PI is typically only completed on HV insulation due to the larger charging and absorption currents that can be expected. As such, most HV insulation requires a 1 minute and 10 minute DCIR reading. A 5 minute reading can also be helpful in trending the DCIR increase over time. PI is not relevant when DCIR values are high as the factors such as temperature and leakage currents are not greatly affecting readings.

DC insulation tests are to be carried out between all windings of the VT and earth. Winding terminals are to be shorted together to ensure the whole winding is at the correct voltage. Applied voltages and allowable limits are specified in STNW1160 Standard for Maintenance Acceptance Criteria (see note below on test voltages based on neutral bushing voltage rating).

Test arrangements include:

- HV to all Secondaries and Earth (guard halfway down insulator).
- Each Secondary to all other Secondaries and HV and Earth (no guard).
- For CVT's, EMU Earth to Primary and all Secondaries and Carrier and Earth.

IR testing often requires lifting of primary and secondary earths. All earths are to be replaced immediately after testing is completed and confirmed correctly in place.

If IR testing of the primary winding cannot be carried out because the neutral / star point is permanently connected to earth, then an alternate high voltage insulation assessment must be carried out. This will be preferably a separate source partial discharge test.

The test voltage used during IR testing depends on the voltage rating of the neutral bushing. If the insulation can be confirmed to be uniform (ie from the nameplate or equipment manual) or the rated voltage is low enough, then system voltages are to be used to determine the test voltage as per STNW1160. If a 3 phase VT has a floating star point which is not accessible, for the purpose of IR testing the star point can be considered to be rated at the voltage of the primary terminals.

If the voltage rating of the neutral bushing cannot be determined or is known to have an earthed primary neutral, then for the purpose of IR testing the VT should be considered as non-uniformly insulated with a normally earthed neutral. Refer to STNW1160 for reduced voltage limits.

In some cases, a DCIR test set may not be able to apply the specified test voltage (e.g. test set can test at 500V, 1kV, 2.5kV and 5kV but test voltage specified as 2kV or 3kV). In these cases, consult either Commissioning and Maintenance or Substation Maintenance group for clarification. Typically, if a 2kV or 3kV test voltage is specified and the options available are 2.5kV or 5kV, a 2.5kV test will be specified.

If the VT is installed as part of a larger apparatus (e.g. inside transformer or metal clad switchboard), it is to be disconnected as much as practical. If required, parts of the other apparatus can be included in the IR test but this must be commented on in the test report.

All 1, 5 and 10 minute DCIR measurements are to be recorded on the appropriate test form. Where required, PI values should be calculated. Results are to be evaluated against STNW1160 criteria.

5.8. Measure Primary And Secondary Winding Resistance

Measurement of the winding resistance helps identify any high resistance joints that may be present in the circuit. This could identify internal or external issues with wiring, crimps, terminals or connectors. High resistance joints can create inaccuracies in VT measurements, hot spots, be an indication of loose wiring (internal or external) or be a sign of poor manufacturing. It can also be used as a comparison against similar windings to gain confidence in the materials and manufacturing techniques used as quality products and manufacturing should produce similar results.

The winding resistance measurements can also be used to calculate the voltage drop across the winding when a full burden is attached. As such, the winding resistance test can also confirm the ratio of the VT at full burden assuming negligible change in magnetising current from the test voltage to the full rated voltage. This assumption is valid if the ratio test voltage is >5% of the rated voltage for protection class VT’s or >80% for metering class VT’s.

Record the temperature and lead resistance at time of testing so that actual winding resistance at 75°C can be calculated. If measurements are taken at the VT marshalling box, the size of the secondary wiring and an approximate length of the cabling between the VT and marshalling box should be recorded.

Preference is to measure phase to earth winding resistances. However, if it is not possible (e.g. delta winding, no earth reference on star point) measure the phase to phase winding resistance. A comment on the test report shall be made that this was the test method.

The preferred method for an inductive VT is to use a high precision ohmmeter to measure the resistance of the primary and secondary windings. For multiple secondary cores, all cores should be tested. Omicron Votano's can be used for IVT's but this is not the preferred option.

For a new capacitive VT or when doing condition assessments, the preferred method is to use an Omicron Votano which will calculate a secondary winding resistance from the various tests it runs. A high precision ohmmeter can also be used if a Votano is not available or if measurements are for standard maintenance. A primary winding resistance is not applicable to CVT's.

Winding resistances are considered acceptable if they match manufacturer test results and are similar between phases and other VT's of the same make and model. The VT ratio error and rated burden can be used to calculate an upper limit of the allowable secondary winding resistance. General requirements are specified in STNW1160.

5.9. Measure Ratio and Phase Displacement

The accuracy of a VT is paramount to its performance within the network. Inaccuracies can result inaccuracies in protection or metering devices which can lead to unsafe situations or incorrect charges applied to customers. Accuracy limits for the ratio and phase displacements are defined in the IEC and AS standards. There are additional requirements for revenue metering VT's within industry requirements but these are outside the scope of this document.

Ratio tests are completed to ensure plant is within the allowable limits for the intent of the VT. Incorrect ratios can be the result of a number of things such as poor manufacturing, inappropriate materials or inter-turn winding faults. The phase displacement is the result of errors introduced from the magnetic circuit of the VT.

Ratio tests are preferred to be completed as phase to ground measurements. If testing a 3 phase device with a delta winding or no access to the neutral, a phase to phase measurement is to be completed. This is to be noted on the test report.

The preferred method of measuring the ratio of an IVT is with a high precision ratiometer. Votano's can be used however are not preferred.

The preferred method of measuring the ratio of a new CVT or during condition assessments is with an Omicron Votano. A high precision ratiometer can be used if a Votano is not available or if the test is completed for standard maintenance.

The Votano may be unsuitable for VTs with high excitation current (eg Koncar VPU-72.5 VT due to an air gap in the magnetic circuit). In these cases, a Votano is not to be used.

Ratio testing must be completed with the IVT or CVT intact as supplied. No components are to be removed for testing (e.g. EMU's and damping circuits must be included). The exception to this is if required for detailed condition assessments.

When completing this test there should be no secondary burden connected to the VT apart from the burden applied by the measuring instrument itself.

Generally more accurate results are obtained as a higher voltage is applied to the primary winding. Although 100V or 240V is a common ratiometer output voltage, it may be necessary to apply several thousand volts to obtain an accurate ratio measurement. The voltage applied is to be greater than 5% of rated primary voltage to get an accurate assessment.

For example, a protection class CVT has a specified accuracy at 2% applied HV voltage which is twice the error compared to 5% applied HV voltage ie a 132kV VT may need 3.8kV applied to the HV side to obtain an accurate ratio result.

Note: Due to field test equipment limitations it will often not be possible to apply sufficient voltage to the VT as specified in AS 1243 / AS 60044, in these cases use a primary voltage as high as practicable but be aware that the test results obtained are a verification of ratio only and do not demonstrate compliance with composite error designation.

Results are considered acceptable if they are within the specifications of the VT nameplate.

5.10. Carry out Separate Source Power Frequency Withstand Testing

HV withstand tests are completed to confirm the phase to ground and primary to secondary insulation with respect to the primary insulation. This is a pass / fail test to give confidence the primary insulation can handle any expected transients on the network cause from high voltages and switching transients.

A HV withstand test does not test the inter-turn insulation or basic insulation level / lightning impulse withstand voltage.

Secondary system withstand tests are also specified in the IEC / AS standards however are not completed by Ergon as they are deemed not required. This test should be completed on new plant by the manufacturer and are a low risk for existing plant that is refurbished.

A VT shall withstand a power-frequency test voltage applied for 1 minute between all primary terminals connected together and earth. All secondary winding terminals, core (if there is a special earth terminal), frame, case (if any) should be earthed during this test. Three phase devices are to have all phases connected together and tested as one. Single phase devices are be tested individually.

Primary to Secondary plus earth insulation resistance measurement are to be completed both before and after any HV withstand testing to confirm insulation integrity and detect any changes as a result of the testing. It is expected these results should be similar. Any large reductions in DCIR should be raised with Commissioning and Maintenance or Substation Maintenance.

All earths are to be replaced immediately after testing is completed and confirmed correctly in place.

Power-frequency withstand tests are required on site as described below:

a) Where no power frequency withstand testing has been carried out at the manufacturer’s works – Apply 100% test levels.

b) If the VT is aged, refurbished or subsequent assembly of the HV chamber / bushings is required on site - Apply 80% test levels.

c) Where power frequency withstand testing has been carried out at the manufacturer’s works and no on-site assembly of the insulating component is required – No power frequency withstand test is required.

Refer to the table below for power frequency withstand test voltage values up to U_R = 72.5 kV. Where U_R >72.5 kV, refer to AS 60044.2 Table 4 for applicable test values.

For VTs with an earthed star point or earthed neutral on the HV winding, it is necessary to disconnect the earthed end of the primary winding before carrying out a power frequency withstand test. Ensure that the entire winding including the neutral end bushing is rated for the test voltage to be used, otherwise the withstand test must be limited to a voltage of 3 kV for new equipment or 2.5 kV for aged equipment. If unsure, Commissioning and Maintenance or Substation Maintenance is to be consulted.

Where a HV withstand test is required but only a limited voltage can be applied, an induced voltage test is required. Partial discharge testing may be an alternative however this will not apply the same voltage stresses on the VT and is not the preferred option.

U_{Rated}	U_{test}	
	100%	**80%**
3.6kV	10kV	8kV
7.2kV	20kV	16kV
12kV	28kV	22.4kV
24kV	50kV	40kV
36kV	70kV	56kV
72.5kV	140kV	112kV

Where the test set is limited with the voltage it can apply (typically 50 kV test set where 56 kV needed or 100 kV test set where 112 kV is needed), then a reduced voltage, prolonged time test may be applied as per AS 2067-1984 Table 11. Commissioning and Maintenance or Substation Maintenance is to be consulted prior to any reduced voltage / prolonged time tests are completed.

Leakage currents during the withstand test are to be recorded for information purposes and comparison. The requirements of the test are satisfied if no disruptive discharge occurs (i.e. anything that causes total breakdown of the insulation).

5.11. Carry out Induced Voltage Withstand Testing

Induced voltage withstand tests are used to test the primary inter-turn insulation as well as the phase to ground and primary to secondary winding insulation where HV withstand tests cannot be completed. Just like HV withstand tests, this is a pass / fail test.

The test is completed by back energising the secondary terminals to induce the required power frequency withstand voltage on the primary terminals. The VT is to be connected as it will in normal service condition. This is very important with regards to earthing on the primary and secondary side which is to be as it would in normal operating conditions. The frame, case (if any), core (if there is a special earth terminal) shall be earthed during this test.

For a 3 phase VT, all three phases are to be energised from a 3 phase source to induce normal electrical fields and not overstress neutral connections. Single phase VT's are to be tested separately.

During testing, the voltage is to be measured from the primary terminals. Measuring voltages on the secondary and scaling up as per the VT ratio is not acceptable due to voltage drop across the windings and inaccuracies in measurements being amplified. If testing a 3 phase device, it is preferable to have identical loads on the primary side to ensure equal voltage drop across the windings.

Induced over voltage tests typically increase the frequency of the applied voltage to avoid saturation of the core and reduce secondary currents. Due to the higher frequency, the test time can also be reduced. As a rule of thumb, limit the short term secondary current to no more than 3 x the current in the secondary when carrying rated burden. For example, a 100 VA 63.5 V winding should not be subjected to more than 3 x 100/63.5 = 4.7 Amps. Typical alternative frequency and times are as per the table below. The preferred frequency is 400 Hz to have the most reduction in secondary currents.

Test Voltage Frequency	Duration (sec)
50 Hz	60
100 Hz	60
200 Hz	30
400 Hz	15

Leakage currents during the induced voltage test are to be recorded for information purposes and comparison. The requirements of the test are satisfied if no disruptive discharge occurs (i.e. anything that causes total breakdown of the insulation).

5.12. Partial Discharge Testing

Partial discharge (PD) testing is used to find a number of defects within the devise such as voids in insulation, loose connections, loose nuts and bolts, poor earthing and many other defects. Voltages are typically applied to the primary conductors however this can identify defects within the secondary and earthing systems. Likewise, in some cases induced voltage (secondary injection) methods are used. This can still identify issues with the primary insulation (although PD measurements must always be taken on the primary winding).

It is important to note that all applied values are based on the plant MAXIMUM or RATED value and NOT the nominal value. For example, 11 kV nominal apparatus will actually have a 12 kV rated voltage. All applied voltages for PD testing are to be based off the 12 kV value.

Partial discharge testing is to be completed with the plant in its final service condition. This is especially important for the earthing of both the primary and secondary windings and the device itself and support structures. All secondary loads are to be disconnected and it is preferable to disconnect as much of the primary circuit as possible. It is preferable for VT’s inside metal clad switchboards to be tested in position to identify any surrounding sources of PD not directly connected to the VT (e.g. isolator arms, switchboard cladding).

Testing requires the application of a number of different voltages. These are:

- 1.3 U_R - Prestress: This overstress the insulation to initiate any PD that may have an inception voltage close to the rated voltage but an extinction voltage below nominal voltage.
- 1.1 U_R - Test 1: This is the typically applied test voltage to ensure safety margins for any PD activity expected in operation. This slightly over stresses the insulation to provide a safety margin and indicate future performance. This may not align to IEC standards for individual devices but is the most common overall test (e.g. AS 62271.200).
- 1.0 U_R - Test 2: This is the most realistic operating scenario for plant. If any PD occurs within this test voltage, it can be expected it is present when the plant is in service.

IEC / AS 60044.2 and 60044.3 2007 actually specify PD test voltages as 1.2 U_R or 1.2 U_R / √3. These voltages will typically only be requested if there are contractual issues, normally on new plant.

At times, there may be issues achieving the required test voltages based on the test set available. An example might be if you have a 50 kV test set and a 72.5 kV single phase device. The prestress requirement is 1.3 x 72.5 kV / 1.732 = 54.4 kV. This means the test set cannot apply the full prestress voltage. Another example is having a 22 kV single phase VT requiring a 16.5 kV prestress but only having a 15 kV test set. In these cases, consult the Commissioning and Maintenance or Substation Maintenance teams to determine if it's suitable to accept reduced prestress voltages or if alternative test sets are to be sourced. These options may require approval from the Asset Owners depending on any commercial or safety implications.

For higher rated equipment, typically greater than 72.5 kV, it can become quite costly to complete partial discharge testing. If Ergon does not have the equipment to complete testing due to the high voltages required, testing is to be negotiated with the asset owners.

A full understanding of partial discharge testing is outside the scope of this document. For further information on partial discharge testing, refer to Ergon's Partial Discharge Testing Strategy and other partial discharge documents or consult Commissioning and Maintenance or Substation Maintenance teams.

Single phase VT's

Single phase devices are always tests at $U_R/\sqrt{3}$ values as there is no need to test phase to phase insulation. Testing is completed by energising the phase under test with all other phases earthed (unless sufficient air clearances as per AS 2067). Secondaries are to be open circuit with one terminal earthed.

1. 5-10 sec 1-2kV for background reading
2. 10 sec at 1.3 U_R/sqrt(3) for prestress
3. 30 sec at 1.1 U_R/sqrt(3) for Test 1
4. 30 sec at 1.0 U_R/sqrt(3) for Test 2
5. 5-10 sec 1-2kV for background reading

While induced voltage (secondary injection) test methods are possible for single phase devices, the fact all measurements are required on the primary winding makes it highly unlikely that a crew will have a rated PD measuring capacitor but not a rated primary voltage injection source. As such, induced voltage PD testing is not the preferred option for single phase devices.

Three phase VTs

3 phase VT's require both the phase to phase and phase to earth insulation tested. It is impractical to apply $1.1U_R$ to a single phase as this saturates the cores and may risk damage to the neutral / star point insulation. Also, during PD testing the voltage distribution in the VT winding should be representative of the voltage distribution seen in service as far as possible. As such, a number of options are available for testing 3 phase VT's.

In some cases, what appears to be a 3 phase VT may actually be three single phase VT's in a common compartment (e.g. Areva / Schneider WSA switchboard VT's). If it can be proven that the VT's actually have no common insulation, they can be treated as single phase VT's.

Option 1: Three Phase Primary Voltages. Apply a 3 phase source, 120 degrees apart to the primary side of the VT. PD measurements can be either taken singularly or on all phases at once.

All voltages below are ***phase to phase*** values. Individual test sets will likely inject phase to ground voltages 120 deg apart to produce the required values. Measuring capacitors are to be connected phase to ground with all ground connections to a common point.

1. 5-10 sec 1-2kV for background reading
2. 10 sec at 1.3 U_R for prestress
3. 30 sec at 1.1 U_R for Test 1
4. 30 sec at 1.0 U_R for Test 2
5. 5-10 sec 1-2kV for background reading

It is recognised that in a substation environment Option 1 will normally not be practical

Option 2: Two Phase Primary Voltages. If a sufficient 3 phase source is not available or impractical, use 2 phase testing to confirm both the phase to earth and phase to phase insulation. The phase under test is energised at full phase to ground voltages with another energised at a reduced voltage, 180 degrees from the test phase to produce the correct phase to phase stress while not overstressing the neutral.[1] The third phase is left floating. PD measurements are to be taken on the phase under full phase to ground stress.

All voltages below are ***phase to ground*** values unless stated otherwise.

1. 5-10 sec 1-2kV for background reading (both phases)
2. 10 sec at 1.3 U_R (phase to phase) for prestress
   a. Phase under test at 1.3 U_R/sqrt(3)
   b. Second phase at 1.3 U_R/sqrt(3) x 0.732
3. 30 sec at 1.1 U_R (phase to phase) for Test 1
   a. Phase under test at 1.1 U_R/sqrt(3)
   b. Second phase at 1.1 U_R/sqrt(3) x 0.732
4. 30 sec at 1.0 U_R (phase to phase) for Test 2
   a. Phase under test at 1.0 U_R/sqrt(3)
   b. Second phase at 1.0 U_R/sqrt(3) x 0.732
5. 5-10 sec 1-2kV for background reading

Measurements required are:

[1] If the HV neutral is normally earthed, then it should be left earthed for this test and will not be overstressed. If the HV neutral is un-earthed and cannot be earthed for testing, then the asymmetric 2 phase test voltage will subject the neutral to a voltage displacement. For Ur of 24 kV (or less) this displacement is within the voltage rating of the neutral end. For Ur = 36 kV, this displacement is 3.06 kV (for test 1) and is considered acceptable. Note that overstressing the neutral during testing could cause partial discharge which could be mistaken as a VT fault rather than a test method limitation.

Test	Measurement Phase	A phase voltage	B phase voltage	B phase voltage
A 1	A	1.1 UR/sqrt(3)	1.1 UR/sqrt(3) x 0.732	Floating
A 2	A	1.0 UR/sqrt(3)	1.0 UR/sqrt(3) x 0.732	Floating
B 1	B	Floating	1.1 UR/sqrt(3)	1.1 UR/sqrt(3) x 0.732
B 2	B	Floating	1.0 UR/sqrt(3)	1.0 UR/sqrt(3) x 0.732
C 1	C	1.1 UR/sqrt(3) x 0.732	Floating	1.1 UR/sqrt(3)
C 2	C	1.0 UR/sqrt(3) x 0.732	Floating	1.0 UR/sqrt(3)

Option 2 is normally the most practical option in a substation environment

Option 3: 3 Phase Back Energisation. It is possible to back energise the VT as per the induced voltage test method to perform partial discharge testing. Voltages are to be at 50 Hz. Identical loads must be place on the primary terminal (i.e. 3 coupling capacitors) to ensure identical voltage drop across the windings and no neutral displacement. All PD and voltage measurements are to be taken on the primary winding. Voltages applied to the secondary are to produce voltages on the primary as required.

All test voltages and durations on the primary winding are to be as per 3 phase testing Option 1.

Note that a PD free LV source is required – Doble F6150's are unsuitable as a back energisation source.

Subject to RPEQ approval and on a case by case basis, where three or two phase energisation of a three phase VT is not possible, single phase testing may be completed by energising each phase in turn with the other two phases and neutral (where accessible) earthed. Where the star point / neutral can be earthed, this will test the phase to earth insulation of the winding and the HV bushing. Where the star point / neutral is not earthed, this will only test the HV bushing. If the star point is not earthed, the star point / neutral may float beyond its rated voltage and produce PD that may not be a genuine fault in service condition. This test method may also damage the insulation at this location. Phase to phase insulation is never fully stressed under this test method.

All partial discharge testing is considered acceptable as per limits defined in STNW1160 during Test 1 values. Any discharges that occur during Test 2 values is considered a defect. Diagnostic and identification of partial discharge patterns may be required to determine if any observed patterns are destructive or not however it is expected that no discharges should occur regardless.

5.13. Dielectric Loss Angle and Capacitance Testing

Dielectric Loss Angle Testing (DLA) is a high voltage test measurement that is used to assess the condition of insulation by measuring the losses and angles associated with the insulation. It also provides a capacitive and resistive value on the insulation that can be used for further comparison and evaluation. Other names for this test include Dielectric Dissipation Factor (DDF) and Power Factor (PF).

By taking a number of different measurements and grounding, guarding or un-grounding certain section, it is possible to measure the integrity of a number of sections of the VT.

As with all high voltage testing of VT's, applied voltage levels are to be limited to the rating of the insulation. If it is uniformly insulated, apply voltages as appropriate to the rated voltage. If the insulation is non-uniformly wound (refer to the nameplate or equipment manual), then limit any applied voltages to 3 kV for new plant or 2.5 kV for aged plant.

Where possible, measurements are to be taken at a number of voltage to look for inception of partial discharge or "tip up". This will typically be tested at 2 kV steps until the test voltage is reached. This is only required on the C_H reading.

11 kV equipment is currently expected to be tested at 10 kV phase to ground as per STNW1160 section 4.2 depending on the bottom end bushing. While this puts the phase to ground insulation under considerably greater stress than normal operating conditions, history has shown that it is not detrimental to the health of the insulation and provides earlier indicators to insulation failure on Ergon's most common voltage.

The Doble M4000 and Omicron TD1 User Manuals provide very good information about DLA theory, test set up and what is being tested. This level of information is beyond the scope of this document. It is expected anyone completing DLA testing use these manuals to ensure correct testing. The Doble DLA Testing - MN000301R172 also contains information about DLA testing and processes.

C_H is the most useful indicator of insulation quality in oil filled VTs. C_{HL} is normally low because the windings are not concentrically wound, and/or there is a screen between the HV and HV windings. C_H + C_{HL} should be measured as a cross check of C_H. C_L is not required since this insulation is LV only.

If a DLA tap is present on the insulation (typically 66 kV equipment and above), it is possible to take C_1 and C_2 DLA readings of the primary insulation. The C1 reading is essential for detecting deterioration of the primary insulation and associated grading foils, whereas the C2 reading provides an early warning indicator or deterioration and moisture ingress

Typical DLA readings for a VT include:

- C_H GST
- C_H + C_{HL} GST
- C_1 UST (If DLA tap present)
- C_2 GST Guard (If DLA tap present)

DLA testing is not normally carried out on Voltage Transformers as a commissioning or maintenance test for the following reasons:

- There is no widely accepted criteria for pass/fail, particularly for epoxy/resin VTs.
- The different neutral configurations (solidly earthed, floating, inaccessible neutral, reduced voltage rating on neutral bushing) mean that a high voltage DLA test is not always possible.

DLA testing is therefore never specified for epoxy/resin VTs, and is only specified as an investigative test on oil VTs where there are indications of a voltage dependent defect in the VT, or where there are suspected systemic problems with a particular make/model

Capacitance and DLA tests are carried out as routine test for CVT's, however stack capacitance / DLA can only be properly measured if the EMU can be disconnected. This means it is not practical to complete this test once CVT's are fully assembled. As a result, measurement of the stack capacitance is not a commissioning or maintenance test.

Any test results produced by the Omicron TD1 are to be sent to the email address OmicronTestResults@ergon.com.au. They are also to be uploaded to the Omicron Primary Test Manager Servers as per the required process.

Similarly, any test results produced by the Doble M4000 are to be sent to the email address DobleTestResults@ergon.com.au. DLA test results of VTs is highly dependent on the design and construction of the VT. As such, it is difficult to have generic criteria for acceptable DLA values. STNW1160 however does provide criteria however it is expected any results should be compared against results for similar devices. This might require input from Doble or Omicron who will have a larger database of test results.

5.14. Omicron Votano

The Omicron Votano is a manufacturer specific test device that runs a series of diagnostic tests on voltage transformers to build a mathematical model of the device. These tests can produce things like ratio, winding resistance, excitation and short circuit impedance measurement test results.

There are a number of common issue and limitations with the Omicron Votano that have associated risks with them. This includes the disconnection of a number of wires in the VT to complete the suite of tests and a number of devices that cannot be tested with the Votano. As a result of this, Omicron Votano's are only used where these issues are outweighed by the benefits provided by the test set.

Votano's are primarily used on CVT's for both new installations and condition assessments on aged CVT's. There are a number of benefits the Omicron Votano provide including assessing the health of the capacitance stacks offers which is why they are the preferred test option.

Votano's are not preferred for new IVT's or standard maintenance testing as conventional test methods sufficiently assess the health of the IVT and test equipment is simple and readily available. They may be used on IVT's for condition assessments after consultation with Commissioning and Maintenance or Substation Maintenance groups.

Refer to CVT Test Equipment Specific Document and manufacturer manuals for more details on how to use the Omicron Votano.

Any test results produced by the Omicron Voltano are to be sent to the email address OmicronTestResults@ergon.com.au. They are also to be uploaded to the Omicron Primary Test Manager Servers as per the required process.

Test results are acceptable if they are within the limits defined by STNW1160 or if no limits are provided, as per Omicron recommendations.

5.15. Omicron DIRANA

DIRANA testing can be completed on oil filled VT's to determine the moisture content of internal components such as oil, paper and pressboard. It can also measure capacitances within the device and provide DLA readings however these are typically not used by themselves for diagnostics and are more used for confirmation of other test results.

DIRARNA tests are normally only instigated following poor oil results or for condition assessments. DIRANA testing can be helpful when a wet VT has had an oil replacement and it is desired to see how much moisture is in other components.

DIRANA testing is very useful for hermetically sealed units that should not be oil sampled.

Refer to Omicron manuals for the correct connection and operation of the DIRANA test device.

Any test results produced by the Omicron DIRANA are to be sent to the email address OmicronTestResults@ergon.com.au. They are also to be uploaded to the Omicron Primary Test Manager Servers as per the required process.

Test results are acceptable if they are within the limits defined by STNW1160 or if no limits are provided, as per Omicron recommendations.

5.16. Online PD Testing

Online partial discharge testing is a non-intrusive, in service test method that can be used for early detection of faults. There are a number of techniques such as EA Technology's UltraTEV+ and Doble's AIA/DFA100, PDS100 and DFA300. Testing can be completed on both indoor and outdoor equipment of any insulation type although an appropriate test method is to be used.

Online PD testing is often used on hermetically sealed VT's that cannot have oil samples taken. This test is specified for new oil filled equipment that cannot have oil samples taken. It is expected all SF_6 gas filled equipment will be capable of testing the gas and as such, online PD testing is not a suitable substitute for gas tests.

Specific instructions for online PD testing for maintenance or condition assessments are outside the scope of this SWP. Follow the various Online PD testing references and guides for safe online PD testing or consult Commissioning and Maintenance or Substation Maintenance.

Indoor VT's

- Use UltraTEV+ in TEV mode against metal clad switchboard
- Use UltraTEV+ in UltraTEV mode with magnetic coupler attached against metal clad switchboard.
- Use Doble AIA/DFA100 or DFA300 with the appropriate sensor fitted against metal clad switchboard.
    - R3a Oil filled sensor for oil filled VT's
    - R15a SF6 sensor for all SF6 gas VT's
    - R6a General sensor for everything else

Outdoor VT's

- Use PDS100/DFA300 in close proximity to VT's
- Use Doble AIA/DFA100 or DFA300 with the appropriate sensor fitted against bottom of the VT tank.
    - R3a Oil filled sensor for oil filled VT's
    - R15a SF6 sensor for all SF6 gas VT's
    - R6a General sensor for everything else
- Use Doble AIA/DFA100 or DFA300 with the appropriate sensor fitted and wave guides (up to 66kV plant only) attached on the primary conductors of the.
    - R6a General sensor for everything

Test results are acceptable if they are within the limits defined by STNW1160 or if no limits are provided, as per test equipment manufacturer recommendations.

5.17. Insulation Condition Assessment of VTs

Condition assessments on

Below are some generally preferred condition assessment methods for certain VT's.

Insulation condition assessment of oil insulated inductive VTs is:

- Online Partial Discharge (optional)
- Insulation Resistance
- Offline Partial Discharge
- Dirana
- Oil Test (if not hermetically sealed)

Insulation condition assessment of epoxy/resin insulated inductive VTs is:

- Online Partial Discharge (optional)
- Insulation Resistance
- Partial Discharge (off line)

Insulation condition assessment of CVTs is:

- Online Partial Discharge (optional)
- Insulation Resistance
- Oil Test of EMU (if not hermetically sealed)[2]
- Offline Partial Discharge
- Omicron Votano Tests

5.18. Complete Pre-commissioning Checklist

A requirement for a voltage transformer being placed in service for the first time, after refurbishment or after any wiring has been disturbed is that all checklists nominated in the Construction and Commissioning Tools have been completed.

6. FINALISATION

Prior to finalisation of testing, ensure that:

1) Any primary or secondary connections disturbed during testing have been reinstated to the correct configuration.
2) All test leads have been disconnected.
3) HV, LV and structure earthing are as per design.
4) Site conditions have been left in an appropriate condition.

[2] Oil testing of EMU is particularly useful for CVTs that have systemic sealing issues and moisture ingress is suspected. In most cases discoloured oil in the sight glass correlates to low IR readings of the EMU

7. POST ENERGISATION TASKS

Following energisation of new or refurbished plant, it is expected the following tests will be required:

- On-line PD test. These tests can detect gross insulation defects as well as faults in the neutral terminal earthing and EMU's. This requirement is particularly important for oil filled plant where samples are not possible (e.g. hermetically sealed with no allowance for sampling).
- If required, phase out the VT secondaries with any existing VT's
- Complete on load checks for any protection or metering devices supplied by the VT.
  NOTE: Any directional protection devices are expected to have non-directional or unit protection elements in place until on loads confirm correct directionality of the protection device.
- For new oil filled VT's that can be oil sampled, ensure that an MST has been created by the AMO to oil sample after 6 months of operation (if applicable).
- That all test results / data has been stored as required.
- Any amendments to databases have been forwarded to the Asset Maintenance Officer to capture.