CAPACITOR BANK TESTING SP0513

1. PURPOSE AND SCOPE

The purpose of this Standard Work Practice (SWP) is to standardise and prescribe the method for testing Capacitor Banks including capacitors, tuning reactors and inrush limiting reactors.

Where the capacitor bank incorporates integrated CBs, CTs, VTs, surge diverters, isolators or earthswitches then these shall be tested as per their respective SWPs and are excluded from consideration in this SWP.

2. STAFFING RESOURCES

EFM competent in the use of test equipment.

Safety Observer

Required Training and Certificates

Regulatory Training

Course Code	Course Description
2120	Cardio-Pulmonary Resuscitation
2130	Low Voltage Switchboard Rescue
2140	Pole Top Rescue (if required)
2161	Rescue from an Elevating Work Platform (if required)
3131	Pole Testing for Safe Access (if required)

Additional Training

Course Code	Course Description
4430	Safe Entry to High Voltage Enclosures
4435	Individual of a Work Group
4440	Switching Operator Assistant
4445	Switching Operator Lines
4475	Access and / or Test Permit Recipient

3. DOCUMENTATION

Capacitor Bank Manual / Manufacturer's Drawings

Commissioning Tool - Capacitor Bank - 3055093

Construction Tool - Capacitor Bank - 3061860

Electrical Safety Rules 2022 – 6503074

EQL SWMS – Safe Work Method Statements

HazChat – On-site Risk Assessment

Health and Safety P009 – 692225

Substation Primary Plant and Secondary Systems Field Testing – 2902800

Test Equipment Manuals

4. KEY TOOLS AND EQUIPMENT

Test Equipment within calibration date, tested and tagged.

Insulation resistance tester (5000 Volt minimum), multimeter, capacitance bridge, three phase balanced voltage source, single phase current source, high speed recorder (for POW tests).

Safety Barriers.

Switching and Access Operating Equipment – PEDs, Live Line Tester, Class 0 gloves. All equipment to be inspected and confirmed within test date prior to use.

Additional PPE as Required: Leather work gloves, Class 00 gloves, hearing protection, safety eyewear. All PPE to be inspected and confirmed 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 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 HazChat and using EQL SWMS.

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 Capacitor Bank De-energised

All of the tests described in this SWP should be carried out with the capacitor bank de-energised and appropriate control measures in place (e.g. barriers, matting) to prevent inadvertent contact with adjacent live plant or breaching exclusion zones. Furthermore, the Electrical Safety Rules 2022 – 6503074 is applicable at all times for isolation and earthing.

Issue a Test Permit and follow the requirements of the Electrical Safety Rules.

As described in Substation Primary Plant and Secondary Systems Field Testing – 2902800, particular safety risks applicable to capacitors include:

- Contact with high voltage at capacitor bank primary connections.
- High fault current at capacitor bank primary connections.
- Stored energy in charged capacitors.

NOTE:

For capacitors built to IEC 60871: Each capacitor unit shall be provided with means for discharging to 75V or less from initial peak voltage of $\sqrt{2}U_n$. The maximum discharge time is 10 minutes.

For capacitors built to AS 2897: Each capacitor unit shall be provided with means for discharging to 50 V or less in 5 minutes from an initial peak voltage of $\sqrt{2}U_n$. For $U_n \leq 25$ kV, the bank discharges to 50 V or less in 5 minutes. For $U_n > 25$ kV, the bank discharges to 75 V or less in 10 minutes.

For banks whose capacitor units are connected in series: The voltage across the bank terminals may be higher than 75 V after 10 minutes due to the cumulative effect of the residual voltages for each unit. The discharge time to 75 V for the bank should be stated by the manufacturer in the instruction sheet or on a rating plate.

Because one side of a capacitor can is connected to its support frame, the support frame of a capacitor bank can retain a significant charge after the bank is switched off and should therefore be discharged and earthed before contact with the frame is made.

It is also recommended that capacitor cans removed from service are stored with their bushings shorted together (after the appropriate discharge period as stated above) to ensure no residual charge remains.

5.3. Carry Out Secondary Isolation

Evaluate the requirement to carry out secondary isolation of the protection systems (including CB fail) associated with the capacitor bank. In making this evaluation, consideration must be given to the sensitivity of capacitor bank protection (such as unbalance protection) and the potential for a capacitor under test to inadvertently discharge stored energy into a protection system. In most cases secondary isolation of the protection system will be required.

5.4. Record Plant Details

Record identification details of each capacitor unit:

- Manufacturer's name
- Manufacturer's type description
- Manufacturer's serial number
- Year of Manufacture
- Rated Capacitance C_n and measured capacitance as stamped on the nameplate
- Serial number of each capacitor can
- Rated Output Q_n
- Rated Voltage U_n
- Rated Current I_n
- Temperature Category
- Dielectric Fluid

Record identification details of any inrush limiting or tuning reactor:

- Manufacturer's name
- Manufacturer's type description
- Manufacturer's serial number
- Year of Manufacture
- Rated Reactance
- Rated Voltage U_n
- Rated Current I_n

5.5. Visual Inspection of Capacitor Bank Condition

Inspect the external surfaces and ensure the capacitor units and reactors are clean and dry.

Check that primary connections are correct.

Check earthing to capacitor bank mounting frames and enclosure.

5.6. Measure Insulation Resistance

Insulation resistance tests as listed below are to be applied for one-minute duration each. Protection VTs/CTs connected to the bank star point need to be disconnected for these tests. Where several components are connected in parallel, for example capacitor cans, it is not necessary to obtain a separate insulation resistance measurement of each component. To ensure that the capacitor/s being measured have charged sufficiently to allow accurate IR measurement, ensure that the capacitor has been charged by the megger such that there is less than a 5 % change in IR over a 1 minute period.

- HV capacitor terminals to support frame @ 5kV*. Minimum acceptance value for new plant is 1,000 Mohms.

  Where the capacitor bank consists of several capacitor mounting frames insulated from each other, then the insulation resistance from each frame to the HV terminals of the capacitors mounted in that frame shall be tested.

  All of the capacitor terminals (where not connected to the support frame) should be shorted together for this test.

Capacitor bushings connected to the support frame for bonding purposes should be temporarily disconnected from the support frame for this test.

If the capacitor units are single bushing type, this test is not carried out.

- From frame to frame or frame to earth (across support insulators, where applicable) @ 5kV*. Minimum acceptance value for new plant is 1,000 Mohms.
- Across other support insulators (for example inrush reactors, where applicable) @ 5kV*. Minimum acceptance value for new plant is 1,000 Mohms.
- Between terminals of each capacitor unit @ 5kV*. This is a measurement of the internal discharge resistor (if fitted).

* Use 5 kV for plant rated above 3.6 kV. For ratings 3.6 kV or less, use 1 kV.

CAUTION: Ensure that the capacitor units are discharged following the completion of each insulation resistance measurement.

5.7. Measure Capacitance

Measure the capacitance of each individual capacitor unit using a capacitance bridge. The use of any test equipment is to be performed in accordance with the operating instructions specific to the equipment being used. Note that tong type capacitance bridges can normally be used without disconnecting the capacitor units from the bank. It is preferred not to disconnect the capacitor units for measurement in order to avoid inadvertent damage to the capacitor unit bushings. Note that the bushings have strictly specified maximum torque limits which must not be exceeded during tightening of connections.

Alternatively, an AC current source may be connected to inject into a capacitor units in series and the voltage measured across each unit from which the capacitance can be calculated according to the formula: $C = I / (2 \times Pi \times f \times V)$

Where C = capacitance in farads.

V = induced voltage in volts.

I = injected current in amps.

f = frequency of injected current.

Note that the capacitance of each unit is temperature dependant, and the temperature at the time of the test should be recorded. The capacitance measurement should be carried out at a time when the temperature is relatively stable and uniform across the bank. The temperature coefficient for all-film capacitors is approximately -4.5% per 100 degrees C which is significant in the context of out of balance protection.

For capacitor banks sized 30 MVAr or less, the allowable tolerance in capacitance measurement is -0 / + 10%. For banks greater than 30 MVAr, the tolerance is -0 / + 5%.

5.8. Measure Reactance

Where inrush limiting reactors or tuning reactors are fitted, measure the reactance of the reactors. The preferred method is to inject a high AC current (as determined by test equipment limitations) and measure the voltage induced across the reactor, from which the reactance can be calculated according to the formula: $Z = V / I$

Where Z = reactance in ohms.

V = induced voltage in volts.

I = injected current in amps.

This formula ignores the resistive component of the impedance, which is a valid simplification for typical reactors (the Q of a typical air cored reactor exceeds 40).

For air cored reactors, it is preferable that this measurement is carried out at a current that induces a voltage of at least 10% of the rated voltage of the reactor.

Three phase injection must be used to measure the reactance of three phase iron cored reactors or significant inaccuracies will be introduced by the magnetic path.

The allowable tolerance is +/- 5% of rated reactance, provided that any unit in a three phase set does not deviate from the average of all three units by more than +/- 2%.

5.9. Carry Out High Voltage Test

High voltage DC and AC testing of capacitors is only required if specifically requested by the asset owner, and is normally only requested if there are specific manufacturing or batch issues to be resolved. Alternatively, it may be required at the discretion of the commissioning engineer when a de-commissioned bank is being returned to service.

A capacitor shall withstand a DC Test voltage applied for 10 seconds between the primary terminals. The voltage level to be applied is: $U_{test} = U_n \times 4.3 \times 0.75$

Where U_{test} = applied test voltage.

U_n = capacitor rated voltage.

Note a 75% derating factor has been applied since this test is a repeat test after delivery.

The capacitor shall also withstand a 1 minute power frequency withstand test of a test voltage applied between the capacitor terminals and earth. For 12 kV rated capacitors, the test voltage is 75% of 28 kV. Refer to IEC 60871 or AS 2897 for other ratings.

The requirements of the test are satisfied if no disruptive discharge occurs.

CAUTION: Ensure that the capacitor units are discharged following the completion of high voltage testing.

Following the high voltage test, repeat the insulation resistance measurements to confirm insulation integrity.

5.10. Check Balancing of Each Bank

Carry out a check of the balance of each bank by entering the measured capacitance values for each can into an appropriate balancing programme. Where necessary swap cans to achieve acceptable balancing of the bank.

5.11. Carry Out Primary Injection

Provided bank balancing has been confirmed with a balancing programme it should not be necessary to primary inject a capacitor bank to confirm balance prior to energising.

Primary injection may however be carried out to check operation of balance protection or bank unit protection schemes (e.g. high impedance differential protection) by bridging out the bank capacitor cans and using a low voltage current source to inject through appropriate CTs.

Depending on the bank configuration single phase injection (rather than three phases) may be required to obtain sufficient current.

When deciding on an appropriate primary injection configuration, take note that an earthed bank starpoint may provide an alternative return path for any local LV neutral/ground currents. An earthed star point may also cause an RCD trip – note that an RCD must not be bypassed without putting in place alternative safety precautions.

The voltage used for primary injection must be sufficient to give meaningful results, particularly on the secondary side of CTs.

If primary injection is required to confirm that the capacitor bank balance is correct, it should be carried out at a time when the temperature is relatively stable and uniform across the bank. Apply a balanced 3 phase source to the input terminals of the bank and measure:

a) The voltage applied to each phase (phase to phase and phase to neutral).

b) Each phase line current.

c) The voltage of the capacitor bank star point relative to neutral.

d) The voltage/current measured at the out of balance protection.

e) The secondary current from each metering/protection CT core.

Confirm that any out of balance current/voltage, when scaled from the primary injection test voltage to actual rated voltage, is below the threshold required for an out of balance alarm or trip to occur. Rebalancing of the bank may be required if the out of balance current/voltage is excessive.

If bank tuning is critical, such as in a bank tuned to reject audio frequency load control signals, then the primary injection should be repeated using a variable frequency current source. The tuned frequency is determined by measuring the frequency at which a voltage maximum (for a parallel tuned rejection filter) or voltage minimum (for a series tuned absorption filter) occurs. Alternatively, the current and voltage can be fed into an oscilloscope in XY mode – the resulting lissajous figure will be a flat line when tuned frequency is reached.

A three phase injection voltage of 433 volts will produce approximately 2 amps per MVAr in an 11 kV bank. For other voltage ratings, refer to the following table:

Bank Rated Voltage (kV)	Full Load Current in Amps per MVAr	Injected Amps per MVAr at 433V
11	52	2
22	26	0.5
33	17.5	0.23
66	8.8	0.058
132	4.4	0.014
275	2.1	0.003

5.12. Complete Pre-commissioning Checklist

A capacitor bank being placed in service for the first time requires that the following items are checked (if applicable) prior to energisation:

- Check sheet metal work is free from transport damage and assembled correctly.
- Check that all permanently fixed panels are properly bolted in position.
- Check all door fittings are tight and that the doors swing freely and close and seal securely.
- Check door locks operate properly.
- Check overall appearance and paintwork is clean and free from scratch marks.
- Check the unit has been installed correctly to prevent vermin access.
- Check all control cable terminations are correct and tight.
- Check capacitors and bushings are clean and free from damage or leaks.

- Check that busbar connections have been torqued correctly.
- Check that capacitor bushing connections have been torqued correctly.
- Check earth connections from main earth to cubicle (minimum of 2 separate connections), mounting frames, earth bars and other equipment are securely fixed. Ductor main earth connections at 50 A – maximum resistance 0.5 ohms.
- Check all doors and covers have earth strap fitted.
- Check that all power cable connections fitted to capacitors, reactors, CTs, VTs and switchgear are installed correctly and torqued correctly.
- Check that mounting frames are correctly bonded to the appropriate capacitor bushing as per the manufacturer's drawings. No mounting frames should be "floating".
- Check all HV equipment has specified phase to phase and phase to earth clearance.
- Check earth switch operation.
- Check isolator operation.
- Complete commissioning tests on the circuit breaker, isolator, earth switch, current transformers, voltage transformers and incoming power cable as per their respective SWPs.
- Check operation of discharge timers and electrical interlocking with control systems and HV circuit breakers and switches capable of energising the bank.
- Check operation of point on wave relays, including adaptive capability of the POW relays.
- Check mechanical interlocking system (e.g. castel key system) works correctly and that instructions/diagram showing operation of the system is fixed to the unit.
- Ensure interlock system keys are provided.
- Check cubicle lighting operation.
- Check the heater operation.
- Check all fuses/links are in place.
- Check all CT secondary links are closed.
- Check external fences and gates.
- Check that all labels/nameplates are in place:
  - operational nameplates
  - manufacturer's nameplate
  - high voltage warning signs, including access procedure/warning sign adjacent to fence entry point
  - where operation of the capacitor bank internal isolator does not disconnect HV from a compartment (for example the incoming HV cable terminations), warning signs advising to *isolate elsewhere* should be affixed to such compartments
  - control cubicle components (switches, protection relays, auxiliary relays, fuses and links).
- Record asset management plant details for SAP/MIMS.
- Ensure that MSDS for capacitor dielectric fluid is on-site.
- Check operation of all control and protection functions.

5.13. Energise and Carry Out On Load Tests

Following energisation, record secondary voltages and currents (magnitudes and phase angles) on all protection and metering secondary circuits, including phase, residual and out of balance measurements.

Prove and record correct operation and adaptivity of point on wave switching devices. Several test energisings may be necessary.