Engineering College of Technology.

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Testing, Commissioning and Maintenance of Electrical Equipment (esp. switchgear)

Wednesday 28th January 2026

Presented by

Steve Mackay PhD | ECT & EIT Managing Principal

UKPRN: 10089771

Common Questions/FAQs

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UKPRN: 10089771

Introduction – Presenter

Steve Mackay

ECT & EIT Managing Principal

Introduction – Presenter

Steve Mackay

FIE(Aust) CPEng GCC BSc (ElecEng), BSc (Hons), MBA, MMR, PhD

How entrepreneurship and resilience define me.

- My passion for engineering and education has led me into many entrepreneurial ventures.
- My curiosity drives me to study and learn every day – AI is a key tool.
- This love for education means that I truly admire high quality teaching and dedicated teachers who put students at the centre of all they do.
- Through my career I have overcome a huge number of failures and set-backs and I believe my resilience has assisted me through these times; it has enabled me to look ahead with optimism.
- As we face unprecedented weather extremes our communal resilience is being tested. I believe tackling population growth, weak economies, pollution, exploitation and climate change will present our greatest engineering challenges and opportunities.

Agenda

1	Today’s objective
2	Asset Management Context for Maintenance
3	Insulation Condition+DC insulation tests+PD fundamentals
4	Contact Resistance + thermal condition monitoring
5	Breaker Operating mechanisms/trip circuit/timing/motion analysis
6	SF_6 condition monitoring
7	Maintenance Procedures
8	Oil Testing
9	Installations/Safety Mechanisms

1. Today's Objective

This webinar covers the essential steps involved in preparing electrical equipment for safe and reliable operation. It explains key testing methods, inspection procedures, and commissioning workflows used across industrial and commercial settings. Attendees will gain practical knowledge of standards, documentation, and best practices that ensure equipment performance and compliance.

Commissioning is about proving correct installation + correct operation + correct protection + correct documentation ----> before first energization.

Key takeaways from this webinar:

- Commissioning Essentials – Learn the critical steps required before equipment is energised and placed into service.
- Testing Methods – Understand common electrical testing techniques and their importance in identifying faults.
- Safety & Compliance – Gain insights into standards, documentation, and best practices for reliable commissioning.

Commissioning Workflow – high level

1) Pre-commissioning: drawings, settings, permits, LOTO (Lock-out/Tag-out), inspection, torque/terminations
2) Cold checks: insulation resistance/PI, contact resistance, CT/VT checks, wiring continuity
3) Functional checks: interlocks, mimic, indications, control circuits, alarms
4) Protection: secondary injection, logic, trip tests, end-to-end (where relevant)
5) Energisation plan: hold points, roles, comms, ‘go/no-go’ criteria
6) Handover: as-left settings, test reports, baseline records, punch list closure

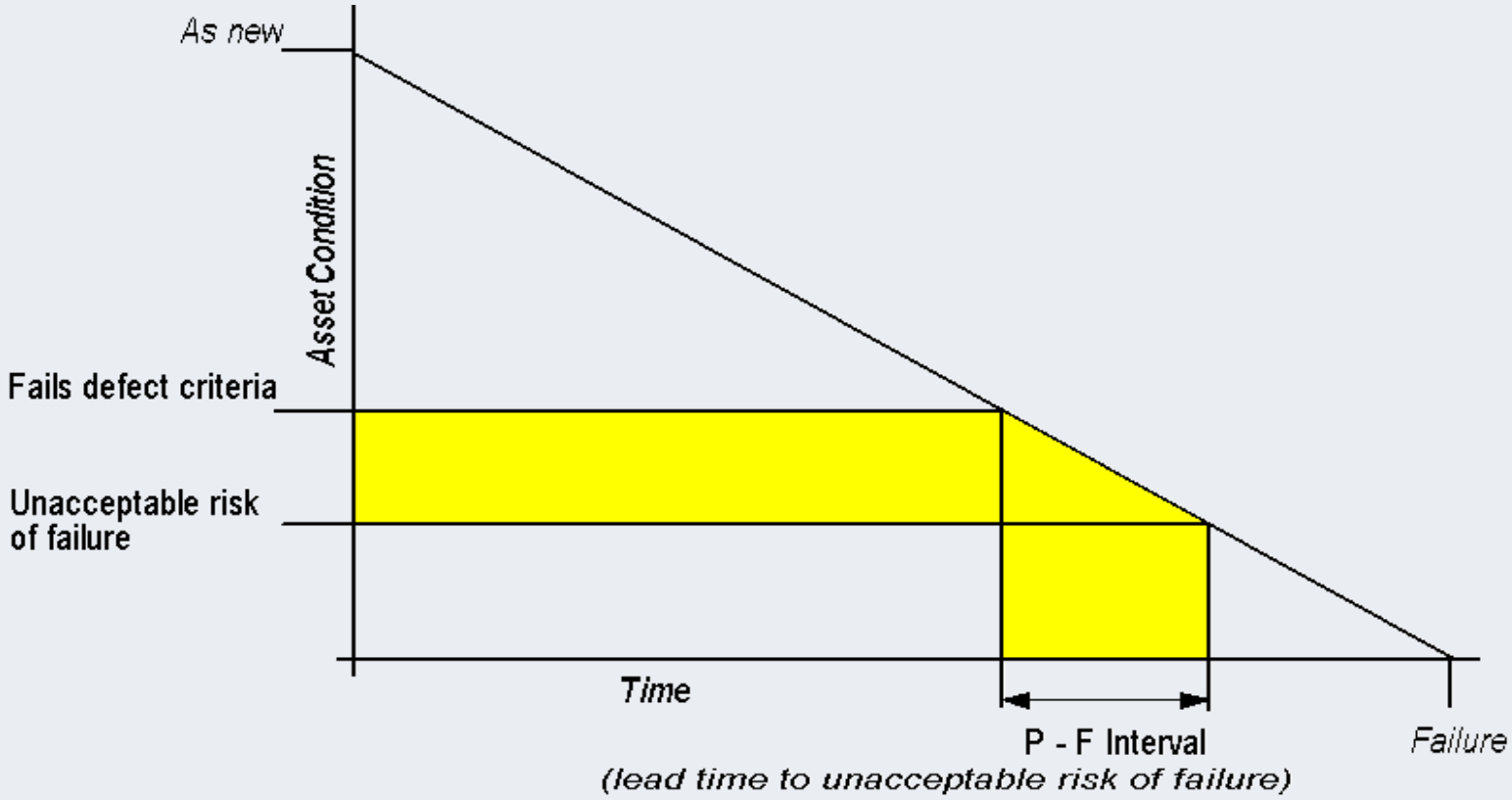
Testing, Commissioning and Maintenance of Electrical Equipment with a focus on switchgear

2.Asset Management Context for Maintenance

Asset Registers

Manufacturer	Type	Voltage Rating
Current rating	Short Circuit rating	Type of operating mechanism
Method of interruption	Auxiliary supply voltage	Telecontrol whether fitted
Circuit name	VT details	CT ratios
Protection details	Date of installation	Date of last inspection
Date of last maintenance	Historic defects	Condition measurements taken at last maintenance

Condition Based Maintenance (CBM)



Relationship of asset condition to time

Reliability Centered maintenance (RCM)

Failure Modes and Effects Analysis (FMEA) or sometimes the Failure Modes, Effects and Criticality Analysis (FMECA)

RISK MATRIX

Risk = Probability of occurrence of an event x consequences of that event

Consequence	Probability				
Ranking	1. Frequent	2. Probable	3. Occasional	4. Remote	5. Improbable
1 Catastrophic	A	A	A	B	B
2. Critical	A	A	B	B	C
3. Moderate	A	B	B	C	C
4. Negligible	A	B	C	C	C

Risk Matrix (cont)

Level of Risk	Description of Risk
A	High
B	Moderate
C	Low

RCM analysis implementation

1. Functions and Performance Standards
2. Functional Failures
3. Failure Modes
4. Failure Effects
5. Criticality Categories
6. Task Types

3. Insulation Condition + DC Insulation tests + PD fundamentals

Switchgear inspection methodologies

- Health of insulation
- Wear and tear of mechanical components
- Proper functioning of the breaker
- Field Reality – Most commissioning failures are *workmanship and secondary wiring*, not the primary plant: loose lugs, wrong CT polarity, interlock mis-build, missing earth bonds, and incorrect settings files

Insulation deterioration

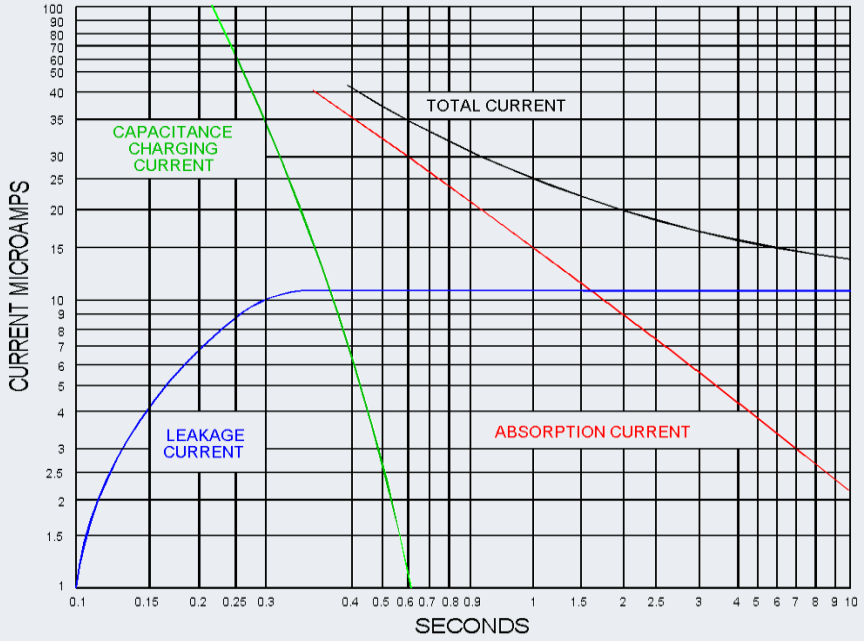
- Excessive temperature
- Moisture
- Ageing
- Accumulation of airborne dirt
- Excessive vibration or shock loading

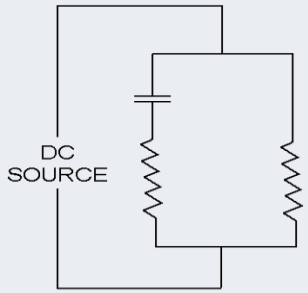
Insulation deterioration (cont)

Current flowing through insulator (and which will be very small) is made up of three components:

1. Capacitance charging current
2. Dielectric absorption current
3. Irreversible leakage current

DC insulation test – graph and equivalent circuit





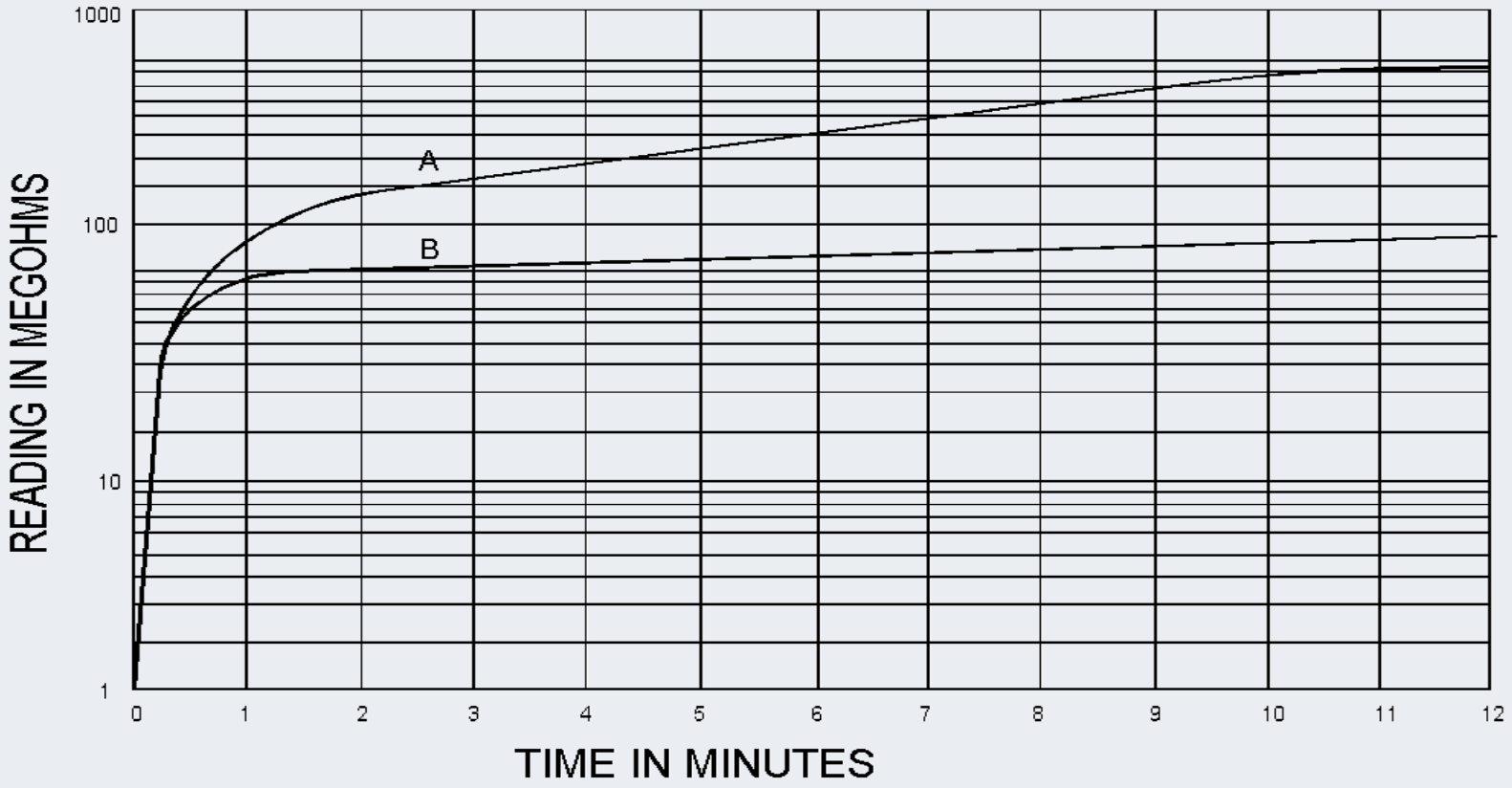
Don’t misread an Insulation Resistance (IR) test

Record **temperature & humidity** — IR is not comparable without conditions.”

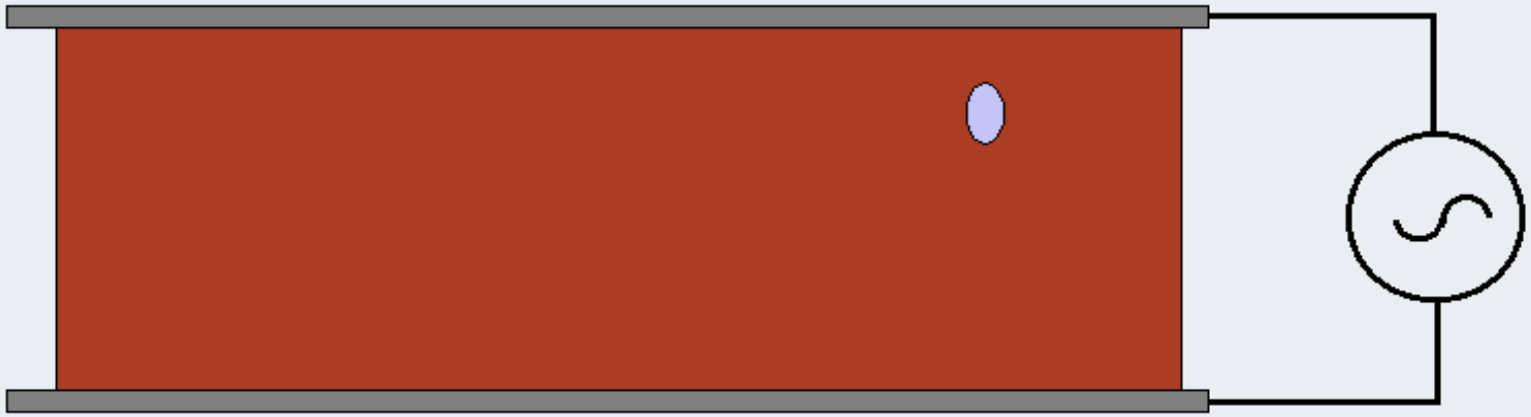
Trend against **baseline** (new/clean/dry) more than chasing absolute numbers.”

If IR is low: isolate the cause (surface contamination vs internal moisture vs damaged insulation).

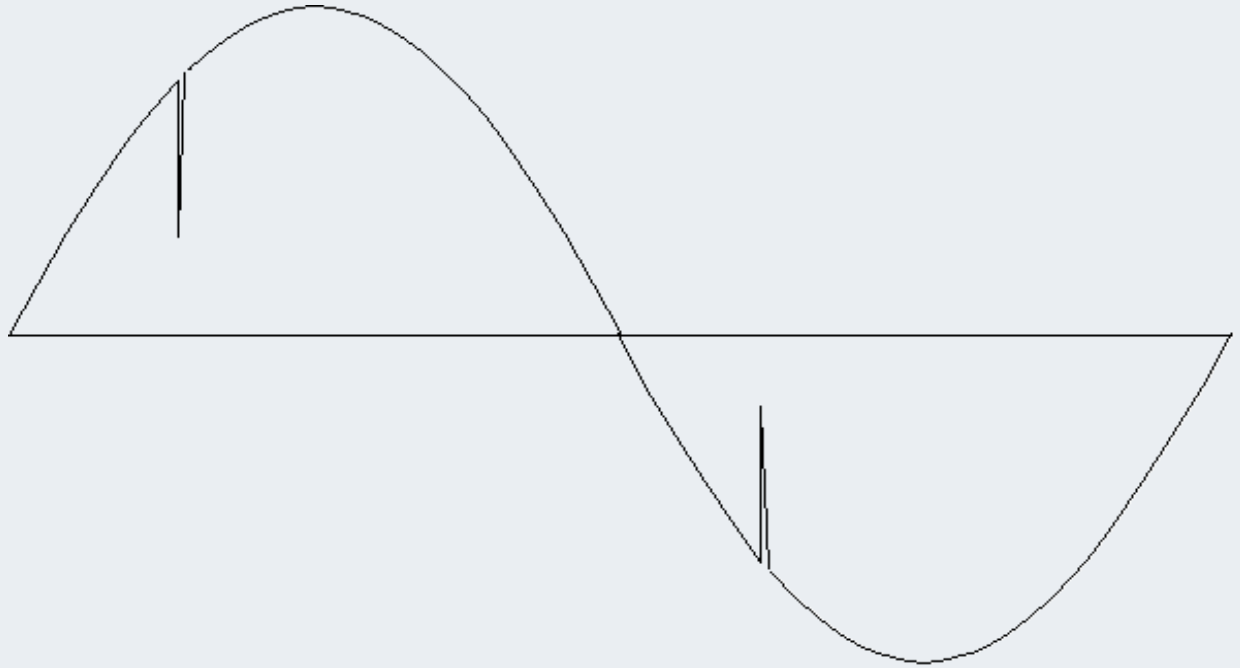
Dielectric absorption curve



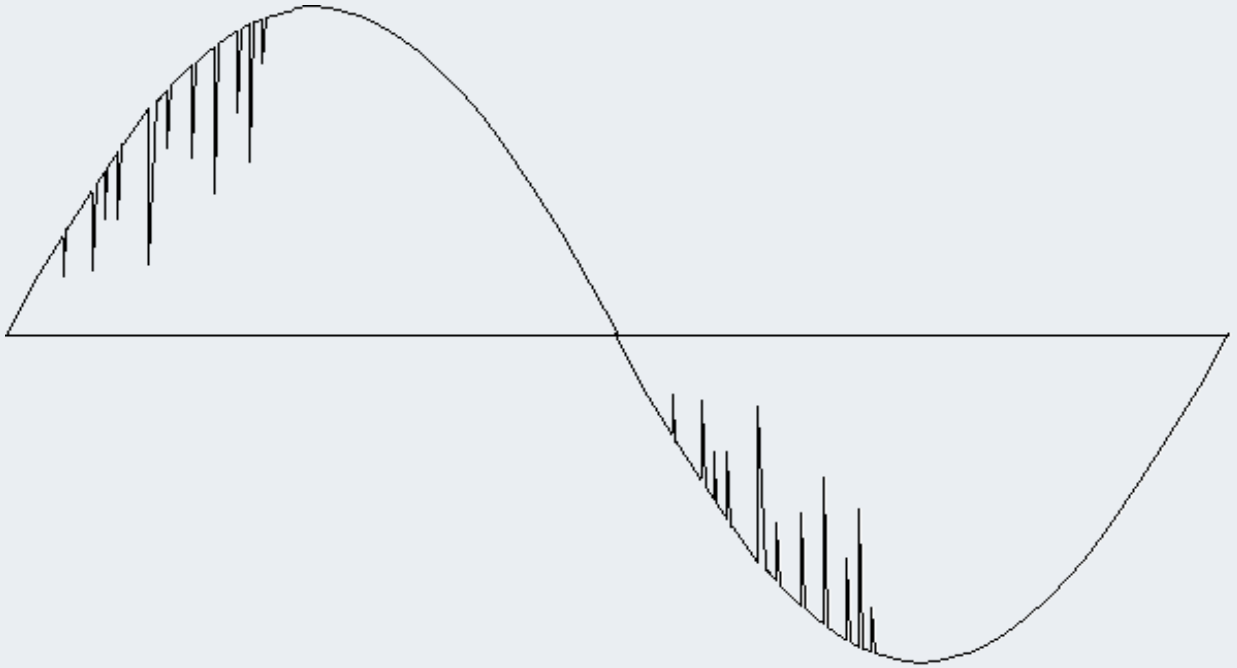
Imperfect insulation under voltage stress



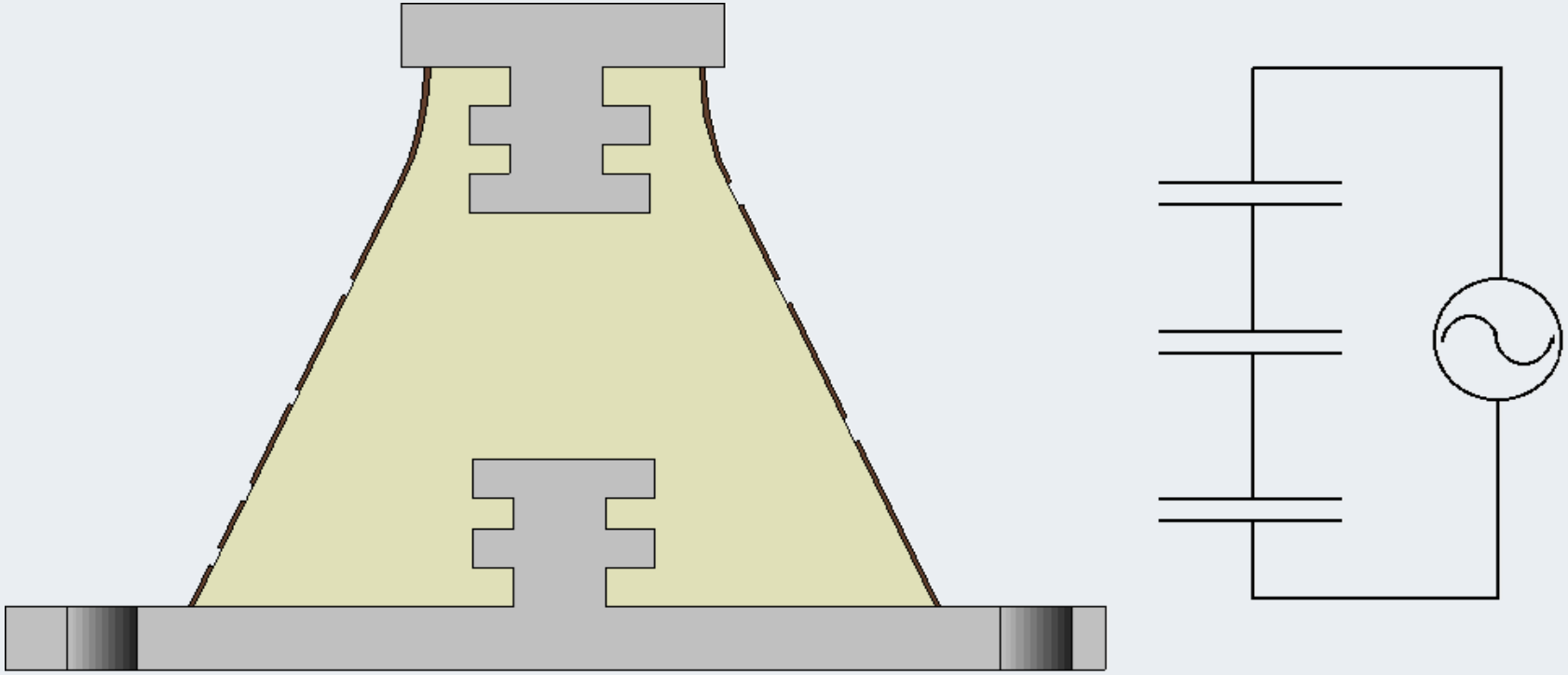
Partial discharges occurring during voltage cycle



Signal from multiple partial discharge sites



Partial discharge from contaminated bushing with equivalent



Analysis of recorded waveforms

Can detect the following:

- Inside solid insulation
- Between a conductor and solid insulation
- Between insulating material and ground
- Surface tracking
- Arcing and sparking
- PD is best treated as a trend+location problem
  - is it getting worse ?
  - Where is it ?

Correlate with load/temperature and switching events

Short term PD monitoring

(1 - 2 hours). This duration of testing simply allows a more accurate measurement by removing short-term variations

Semi-permanent monitoring

- **(1 - 3 days).** This length of monitoring allows measurement of variations of PD with load, that is, component temperature and mechanical stress
- Useful for older installations with high levels of PD activity

Continuous monitoring

- Measures long-term trends in PD activity and may be combined with an alarm facility
- Due to cost, continuous monitoring can only be justified for critical, high value installations with high cost of failure

Partial discharge levels

- Low
- Moderate
- Elevated
- Critical

- Indicative Only – Thresholds are method and OEM/site-specific – trend vs baseline is key.
- Make it defensible: Indicative only – thresholds depend on method (TEV/UHF/Acoustic), enclosure type and site base line.
- Alarm on change-rate as well as magnitude.

Partial discharge in switchgear (contd)

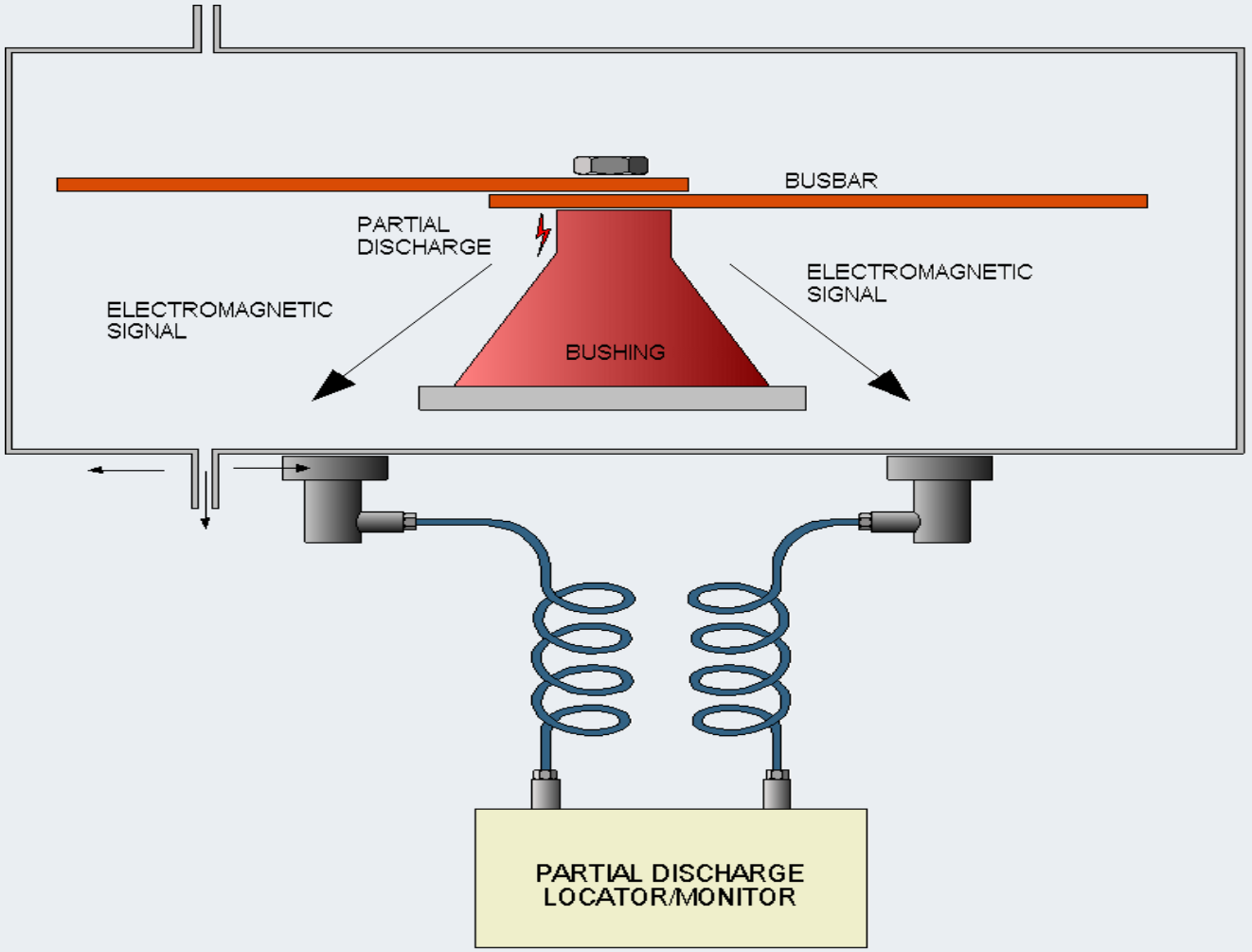
Locations in switchgear known to be common sources of PD:

- Internal faults in VTs
- Busbar support insulators
- Cable terminations
- Through bushings
- Internal faults in CTs

Partial discharge in switchgear (cont)

- Points where a conductor at medium or high voltage is close to earthed metal
- Surface contamination including moisture
- Conductor under floating potential
- Arcing contacts of circuit breaker
- Arcing at isolating contacts
- Loose connections including loose earthing connections

Locating partial discharge sites by TEV



Partial Discharge testing by acoustic methods

Hand held acoustic probe (Detectaids Ltd.)

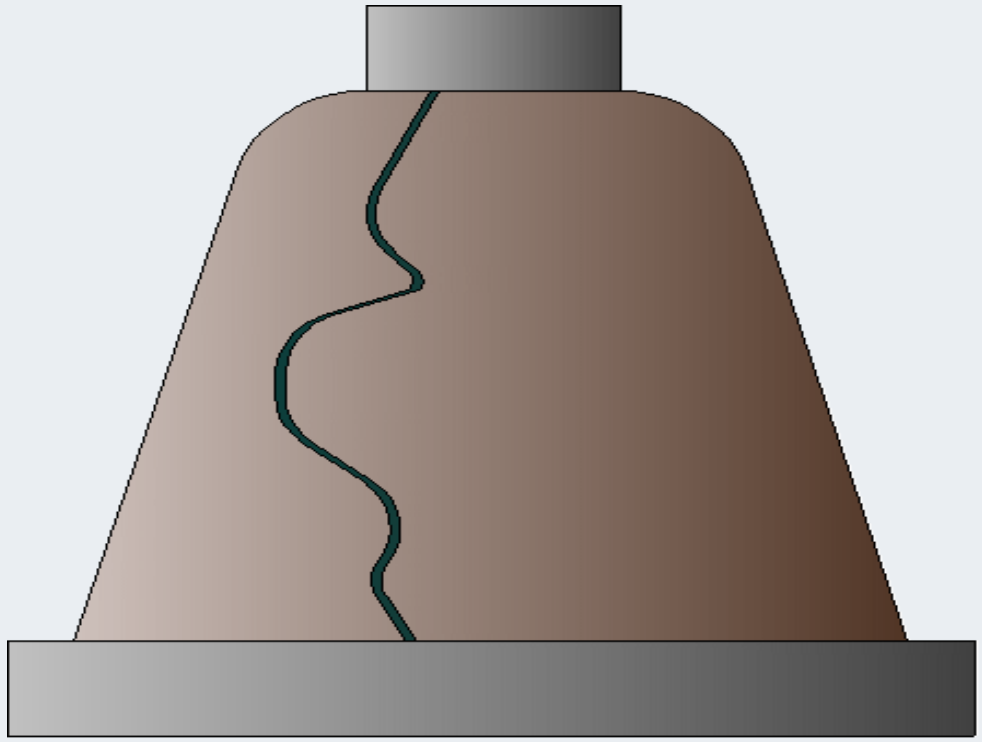
- Monitoring of Partial Discharge by electrical methods has limitations that coupling capacitors may not be available, difficult to connect
- Monitoring may be carried out by an acoustic method

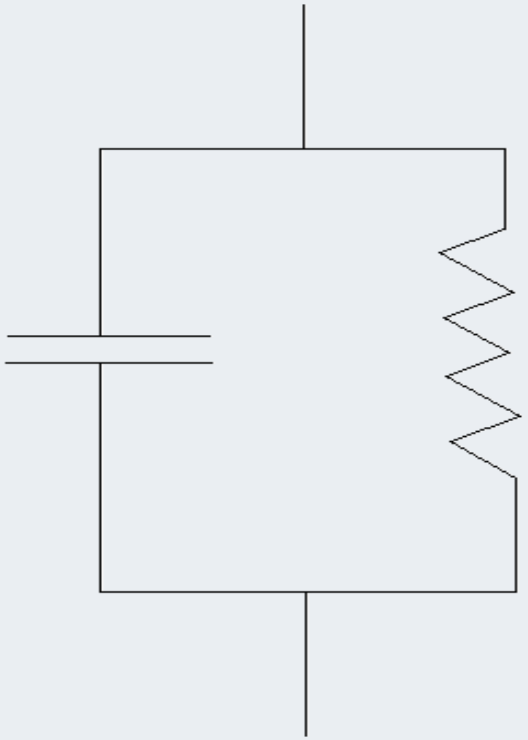
Portable PD test equipment advantages

- Measuring can be carried out at any time, it is not necessary to take the switchgear off line
- Even where the electrical (radio frequency) signal from a Partial Discharge is suppressed by the metal enclosure, some sound signal may escape

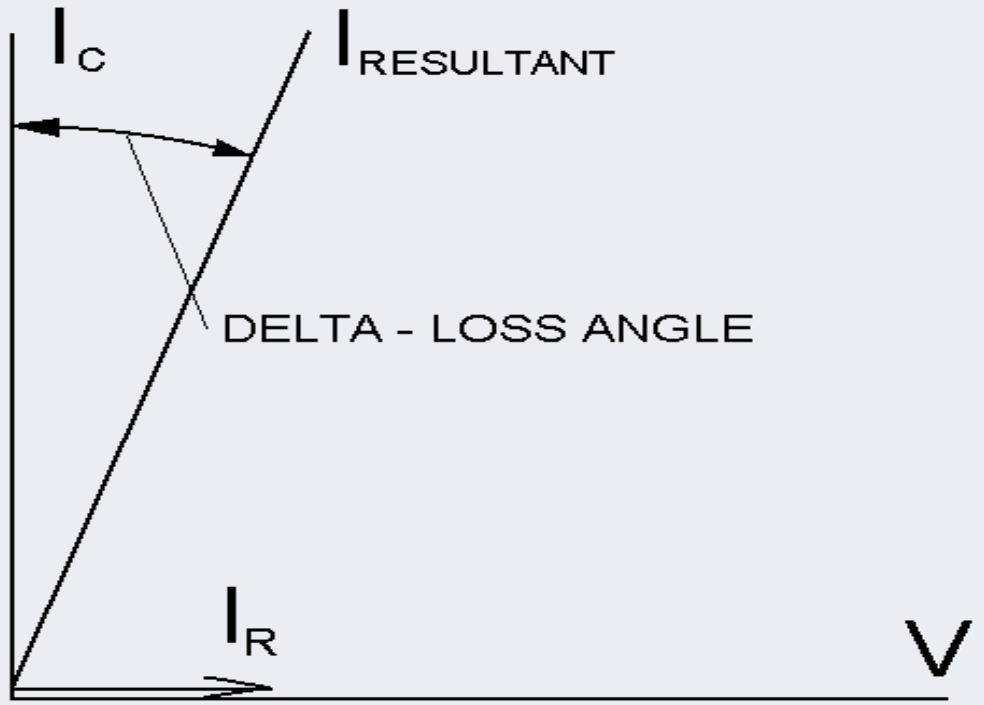
Hand held acoustic probe by Detectaids Ltd

Cracked bushing and equivalent circuit

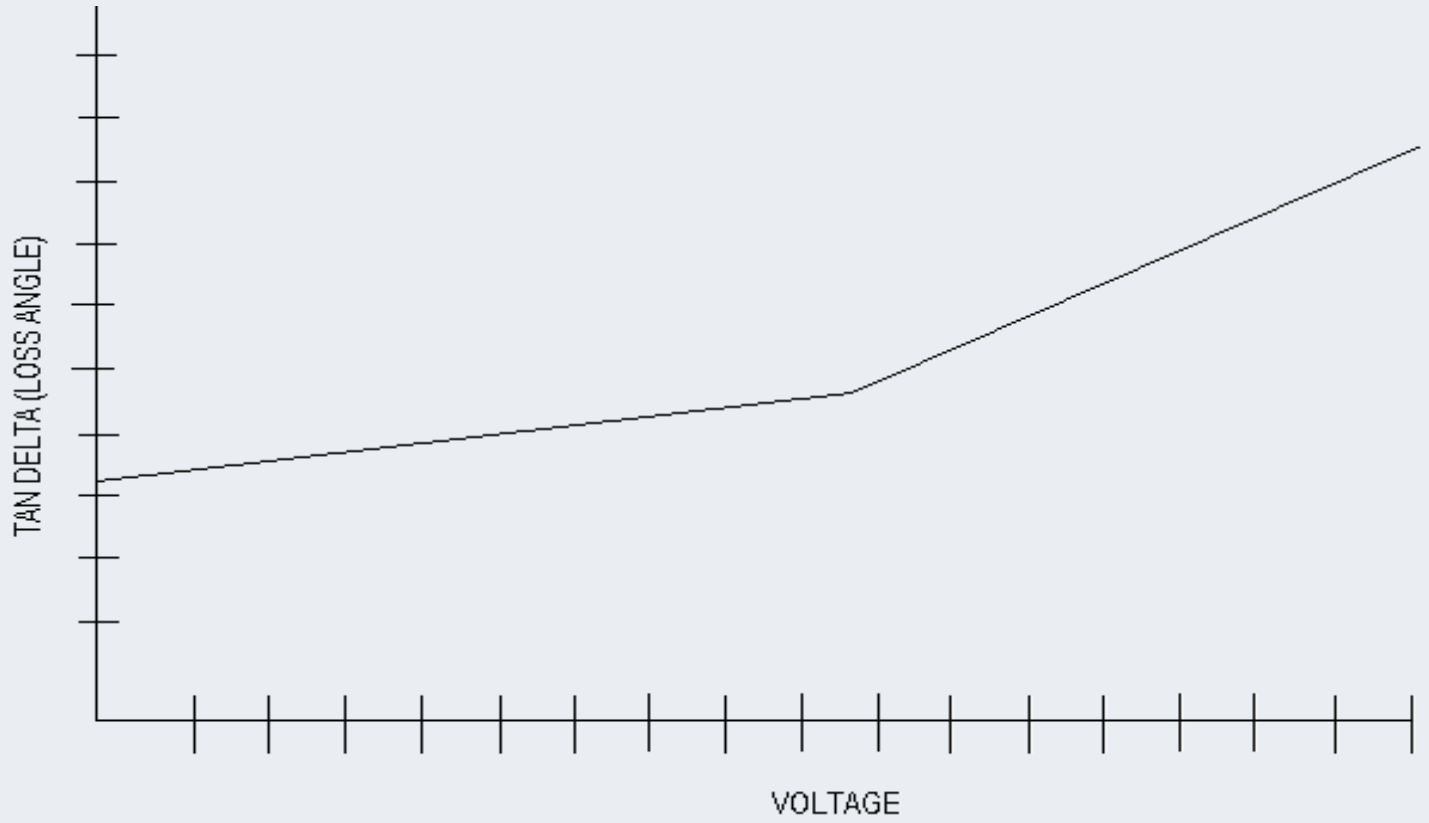




Vector diagram – Tan delta



Increase of Tan Delta with voltage

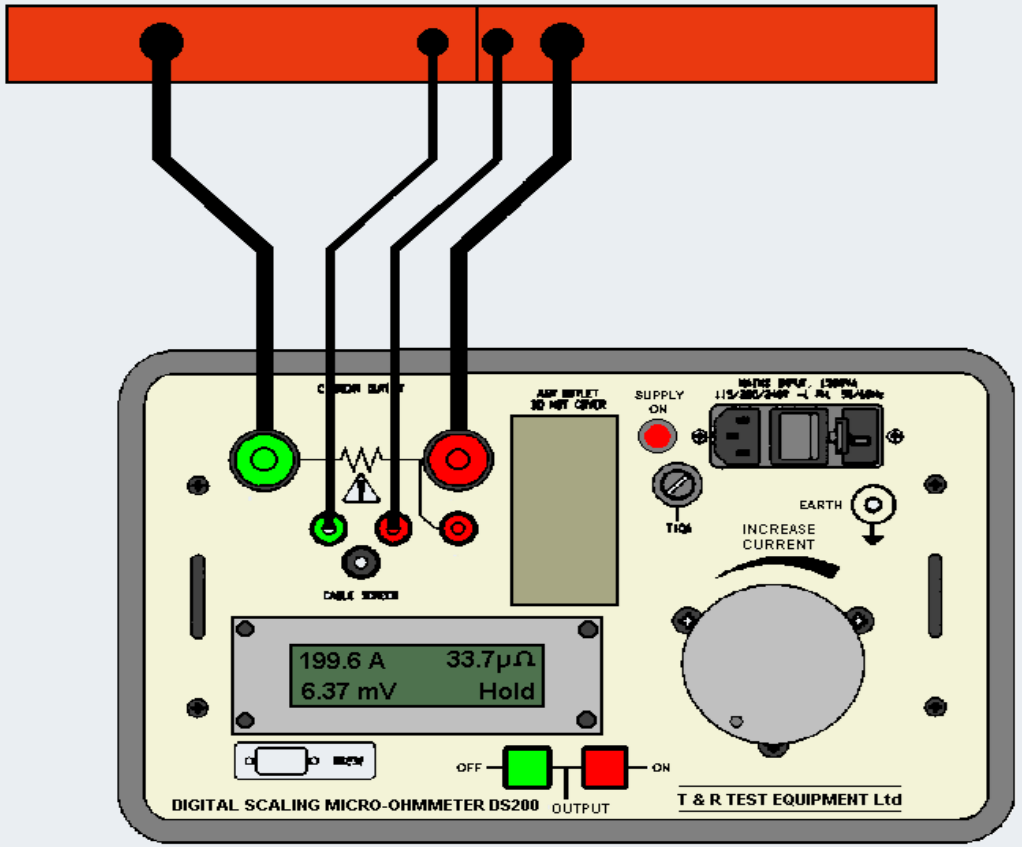


4. Contact Resistance + Thermal Condition Monitoring

What matters…..

- Compare **phase-to-phase symmetry** (imbalance is often the first clue).
- Measure **as-found vs as-left** (cleaning/adjustment should show improvement).
- Always note test current, lead compensation method, and joint temperature.

High current, contact resistance test set



Suggested limits for contact resistance for circuit breakers

Contact resistance limit			
Rated Voltage kV	Rated Current A	In vacuum or gas	In oil
5-15	600	100	
	1200	50	
	2000	50	
7.2-15	600	600	300

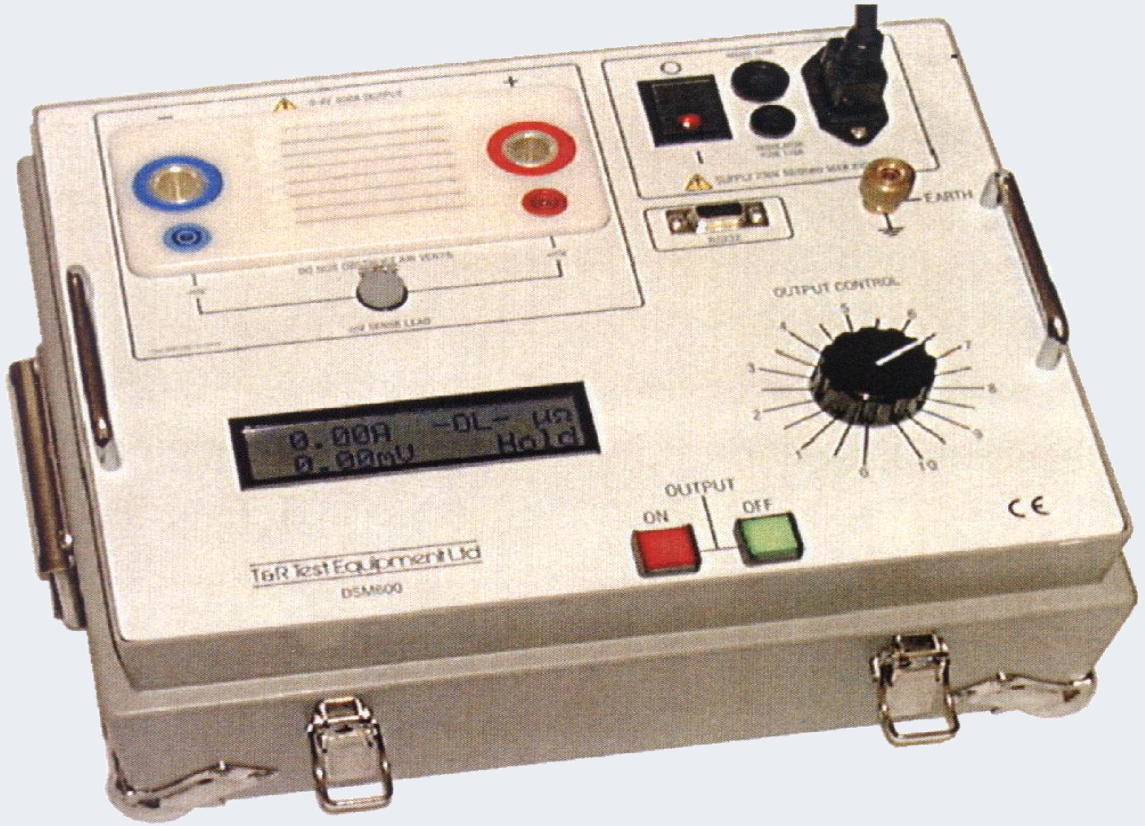
Suggested limits for contact resistance for circuit breakers (contd)

Rated Voltage kV	Rated Current A	In vacuum or gas	In oil
7.2-15	1200		150
	2000		75
	4000		40
23-24	All		500
46	All		700

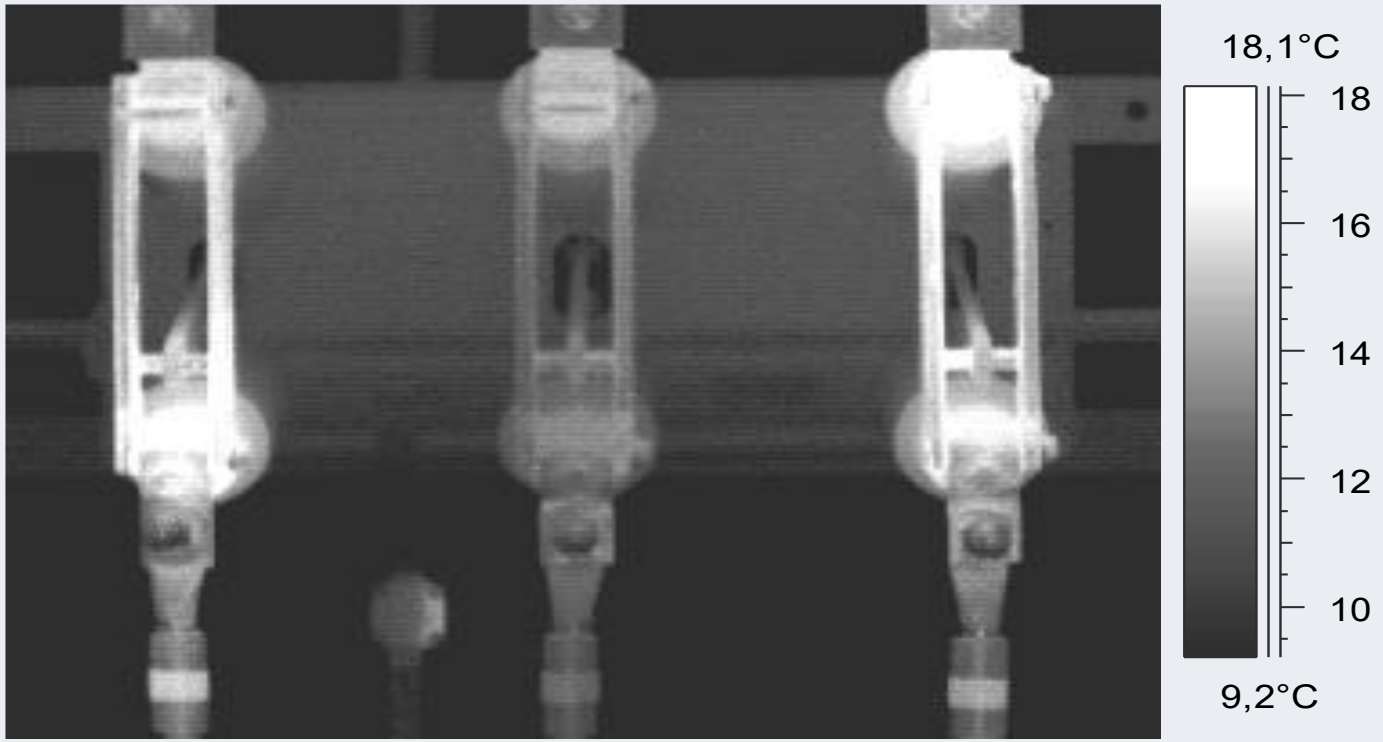
Suggested limits for contact resistance for circuit breakers (contd)

Rated Voltage kV	Rated Current A	In vacuum or gas	In oil
69	600		500
	1200		500
	2000		100
115-230	All		800

K&R Contact micro-ohm meter



Thermal grey scale image of air break disconnector



FLIR SYSTEMS Model Thermacam PM695

5. Breaker Operating Mechanism / trip cct / timing / motion analysis

Trip coil monitoring

- Statistically trip mechanism and trip coils are responsible for most failures to operate
- Improper lubrication or lubrication that has dried out and gone solid, freezing the mechanism
- Shorted turns in the trip coil, mainly due to deteriorated winding insulation
- Faulty secondary wiring and secondary wiring contacts

Trip coil monitoring (contd)

- Seized bearings
- Defective latch mechanisms
- Corrosion especially rust
- Incorrect adjustment of trip latch mechanism

Trip coil monitoring (contd)

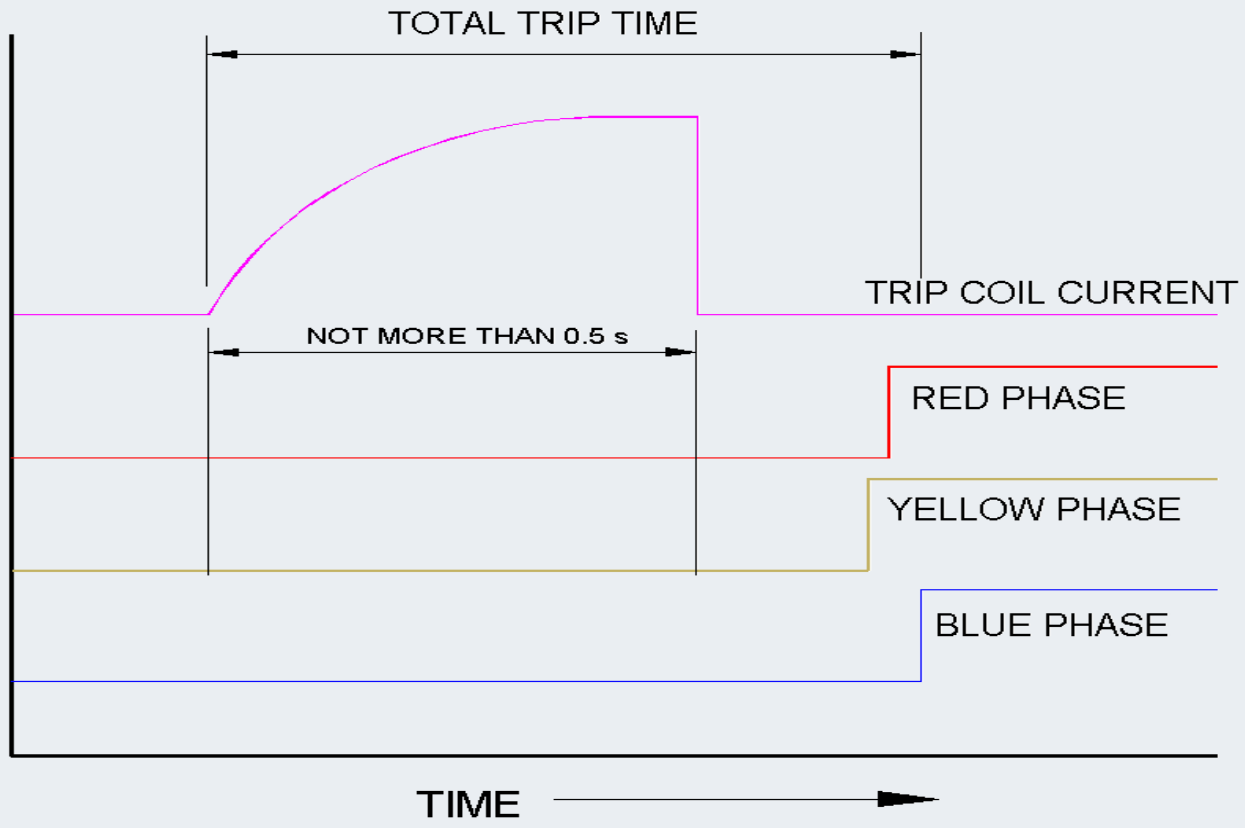
- Ideally CB should be speed (time) tested when first installed
- Common Acceptance Check: breaker trips down to ~70% of rated control supply (verify OEM/utility spec)
- Trip pulse normally only 500ms
- Trip circuit supervision constantly supervises integrity of trip circuit

Commissioning Proof Point

- The ‘money test’ is: **does the protection actually trip the breaker** under realistic control supply conditions?

- Prove the full trip path:
- relay output → wiring → trip coil → mechanism → main contact separation.

Trip coil current and main contact opening

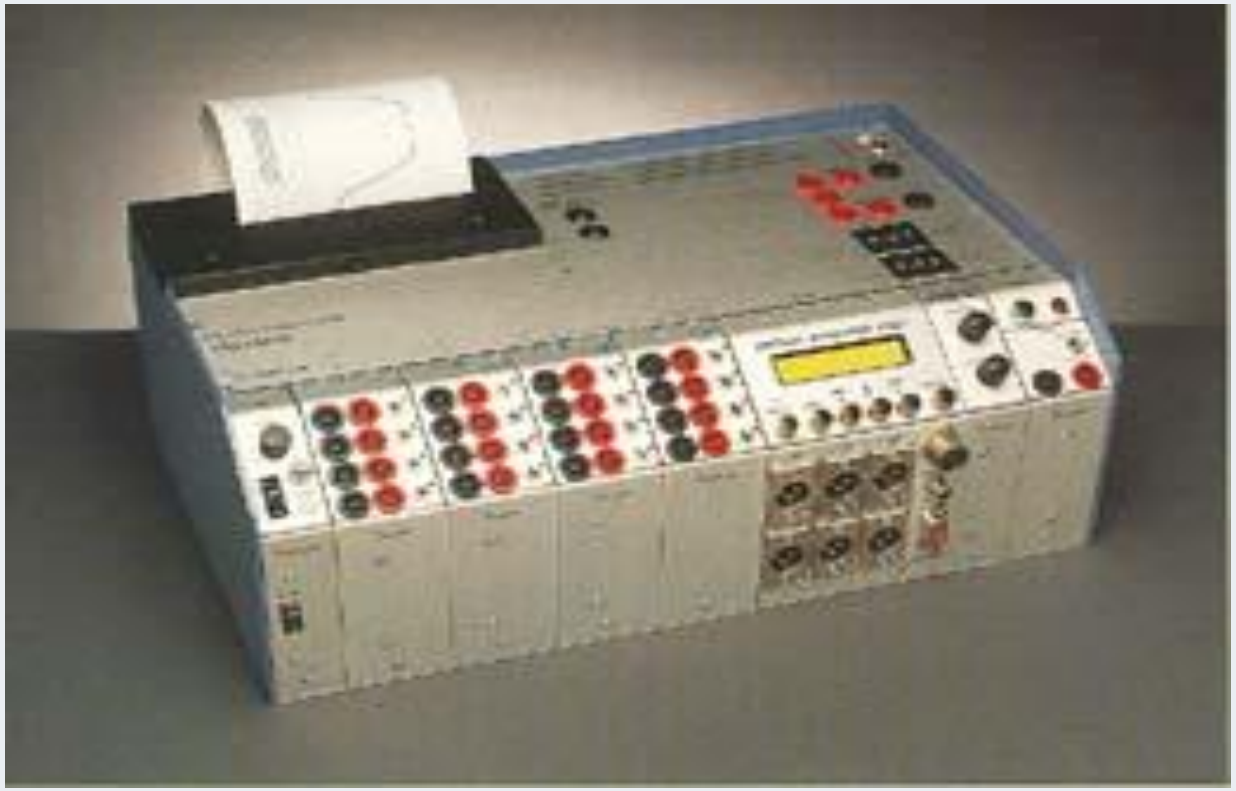


TCT – Trip Coil Tester by RES

- User settable 5 to 95% of coil input voltage
- Setting accuracy 2%
- 80 A capability
- Reversible polarity
- Overload protection
- Trip coil burnout protection (0.5 s limit)

TCT Trip coil tester by Relay Engineering Services (RES)

TM1600 motion analyzer by Programma



TM1600 motion analyzer by Programma

Motion Analyser measures the CB's complete timing cycle:

- Timing channels record opening and closing of main contacts, resistor contacts, and voltage contacts
- Up to 24 timed channels are available
- Slave units can expand number of channels

SF_6 gas monitoring

Some designs use absorbents/filters; in all cases purity and moisture control are critical.

Purity may degrade due to contamination by:

- Oxygen
- Moisture
- Acidity (mainly as Hydrogen Fluoride)

6. SF_6 Condition Monitoring

Teledyne 3010TAC Oxygen in gas analyzer

Shaw SDDLG moisture in gas analyzer

Anachem HF-1000 acidity in gas analyzer

7. Maintenance Procedures

Switchgear maintenance procedures

- Most procedures are combinations of:
- **Generic requirements** (applicable to the class of switchgear e.g. OCB, fuse switch…)
- **Type specific requirements** (applicable to make and model) – service bulletins may apply

Switchgear maintenance procedures

Example of a generic maintenance instruction

- Lighting – portable lighting required to supplement fixed lighting
- Safe exit from substation – check exits
- Tools and equipment – insulated tools and ‘special’ tools may be needed
- Safe working - power closing devices disabled (telecontrol)
- Environmental protection - erect temporary shelters – outdoor gear
- Protection from live LV equipment (insulating sheets)

Switchgear maintenance procedures (contd)

- **Cleaning materials** – approved materials only
- **Unit identification** – clearly identify and check
- **Cleanliness** – lint free cloths, dust down area
- **Cleaning down oil filled switchgear** – spray down gear with clean oil, (don't create a mist)
- **Avoiding the ingress of moisture** (or wind borne debris)
- **Solvents** – some solvents damage insulation

Maintenance Items specific to distribution switchgear

- Position indicators and oil level indicator windows
- Arc gaps - check gaps if fitted
- Earth bonding continuity
- Shutters and locking devices
- Interlocks

Knowledge of interlocking requirements

Maintenance Items specific to distribution switchgear (contd)

- Ventilation – ensure unrestricted airflow
- Functional test
- Equipment heating and lighting
- Lifting devices
- Equipment tools, spares and test instruments
- Tripping and closing supplies
- Cable boxes, compound filled busbar chambers, band joints and endcaps

Maintenance Items specific to distribution switchgear (contd)

- Test Access Covers (normally opened more frequently – check gaskets)
- Fuses and Fuseholders
- Fastenings (check all locknuts, washers, split-pins)
- Weather protection (whenever covers are disturbed or filling points opened – need re-sealing)
- Test on completion of maintenance (hi-pot , millivolt)
- NOTE ON POLYCHLORINATED BIPHENYLS (PCBs) (toxic 50 ppm)

Problems that may be found during switchgear maintenance

- Inspect for keys, bolts (especially fibre), nuts, cotter pins, roll pins, etc. that have come loose
- Inspect for wood operating rods, supports, or guides to come loose from clamps or mountings
- Look for broken welds

Problems that may be found during switchgear maintenance (contd)

- On oil circuit breakers, look for contact burning. Where found, contacts will need to be reshaped or replaced.
- Look at densified wood (Permali) operating arms particularly those in oil, where they can absorb moisture and start to track across the surface.

Problems that may be found during switchgear maintenance (cont)

- On oil switchgear, look for carbon or sludge to form and accumulate in interrupter or on bushings
- On oil switchgear, look for burning or erosion on arc control devices, interrupter parts and barriers
- Look at bushings and gaskets that they are in good condition. In most cases, gaskets should be replaced

Documentation Discipline

- Commissioning/maintenance value comes from records:
- test sheets, settings files, as-built updates, photos of terminations, and a clear punch list.

- If it isn’t documented, it didn’t happen.

8. Oil Testing (Oil CBs/transformers)

Need for oil testing

- Oxidation (due to high operating temperatures) causes sludge
- Deterioration of oil dielectric properties
- Oil-filled equipment/Transformer life-time depends on operating temperature (every 10ºC rise over maximum permitted temperature reduces the life by half)
- Necessary to avoid transformer failure

Oil dielectric test

- Collect sample oil and immerse the electrodes with 2.5 mm gap
- Apply the high voltage and increase till flashover, which is called Break Down Voltage (BDV)
- Standard value 30 kV but new oil may have up to 80 kV
- Take sample of five or six readings

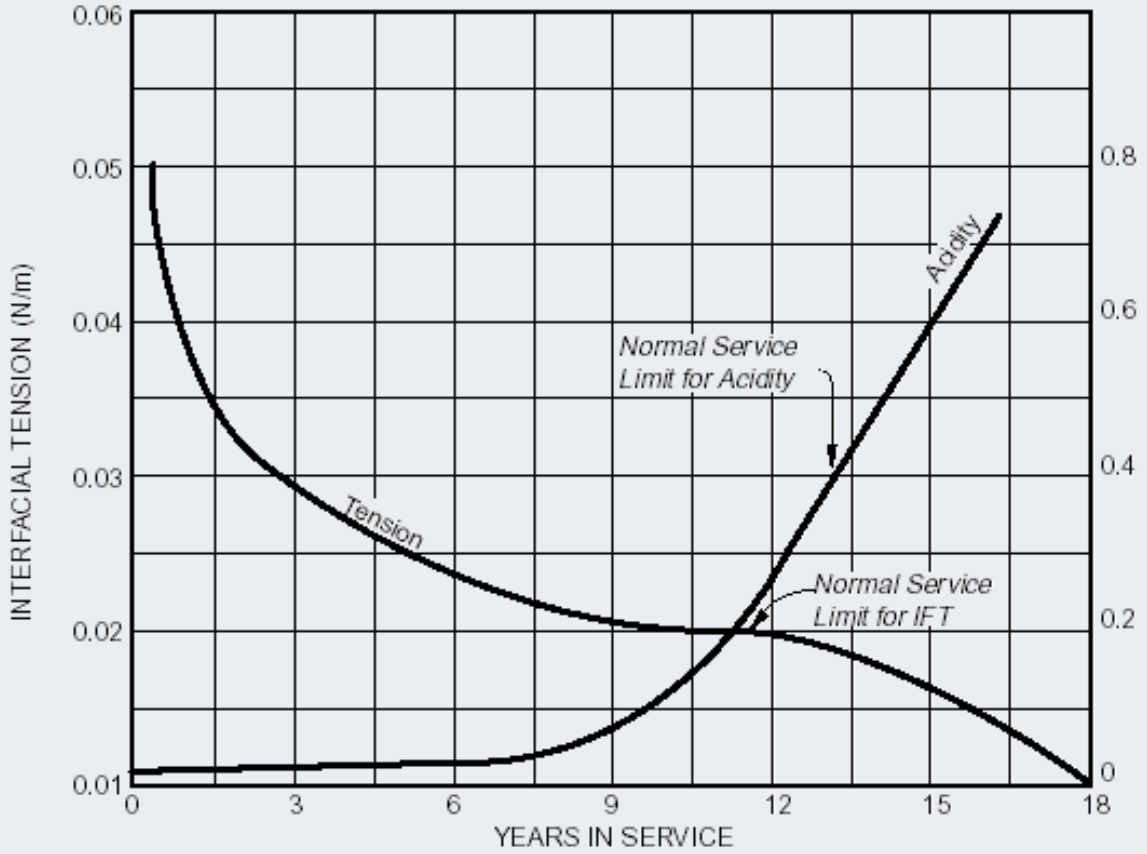
Test on acidity

- Acids formed during oxidation affect oil's dielectric properties and circulation
- Deteriorates cellulose used in the transformer
- Quantity of base needed to neutralize acid per gm of oil + the quantity per unit weight is called the Acid neutralization number
- KOH is the base used and the unit is in mg KOH/gm
- 0.03 to 0.05 acceptable and value beyond 0.10 is unacceptable

Interfacial tension test

- Pure oil floats on water maintaining a minimum surface tension
- Normal value around 50 dynes/cm
- Values below 30 dynes/cm unacceptable
- On energizing value decreases due to dissolution of varnish, etc (subsequent fall is due to oil deterioration)
- Values of 18 dynes/cm may indicate sludge formation

Changes in IFT & Acidity



Colour

- Specified by a number and lower the value the better
- Impurities change the color of oil
- Typical values are
  #1 STRAW COLOR
  #2 PALE YELLOW
  #3 YELLOW
  #4 ORANGE
  #5 RED-BROWN
  #6 BROWN

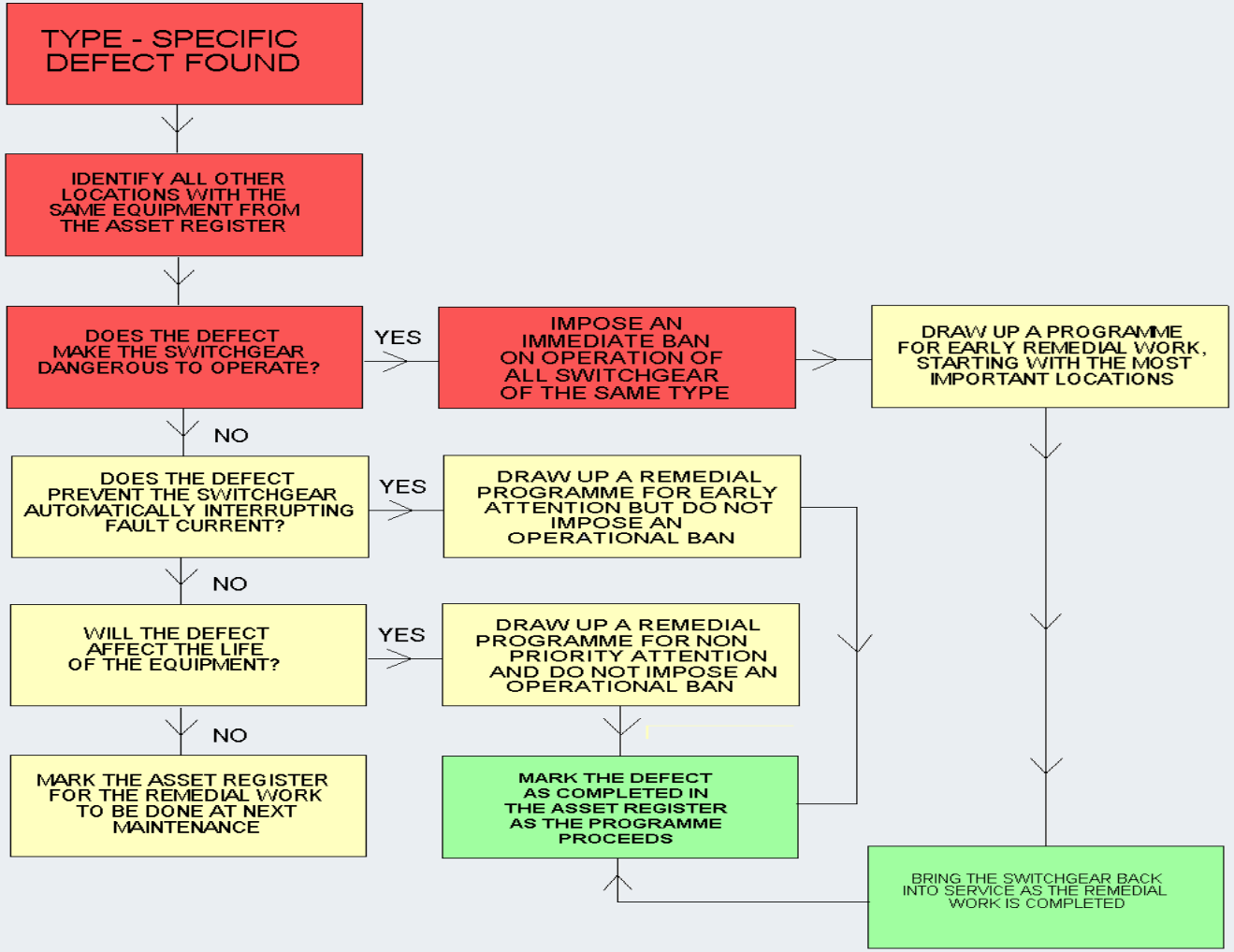
Specific gravity

- Use hydrometer for testing
- Normal value 0.91 and may come down to 0.85 during course of service
- Lower than 0.85 may indicate presence of paraffins
- Some times lubricants getting mixed may give higher value (making the result unreliable)

Other tests

- Flash Point – temperature at which the oil may release vapors that may ignite
- Viscosity – decides the extent of impurities and the ability of oil to circulate for cooling
- Pour Point – below which the oil may become solid (become useless)
- Resistance – lower value indicates the presence of moisture and contaminants

Action diagram for type-specific switchgear defect

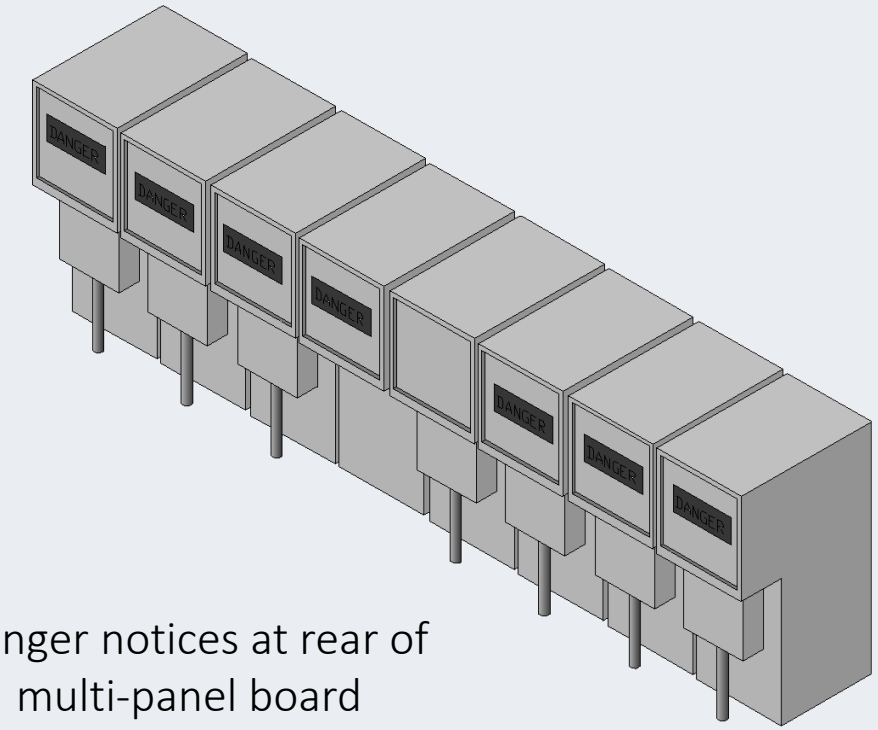


9. Installations/Safety Mechanisms

Switchgear installations

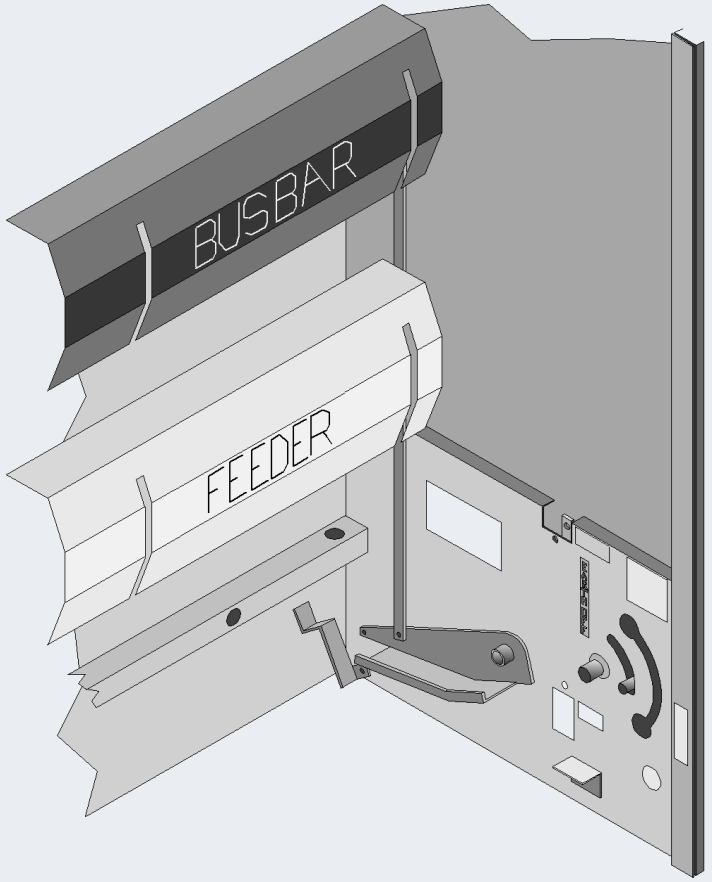
Special precautions when working on switchgear

- Rear access
- Work on main contacts and safety shutters
- Failure to lock

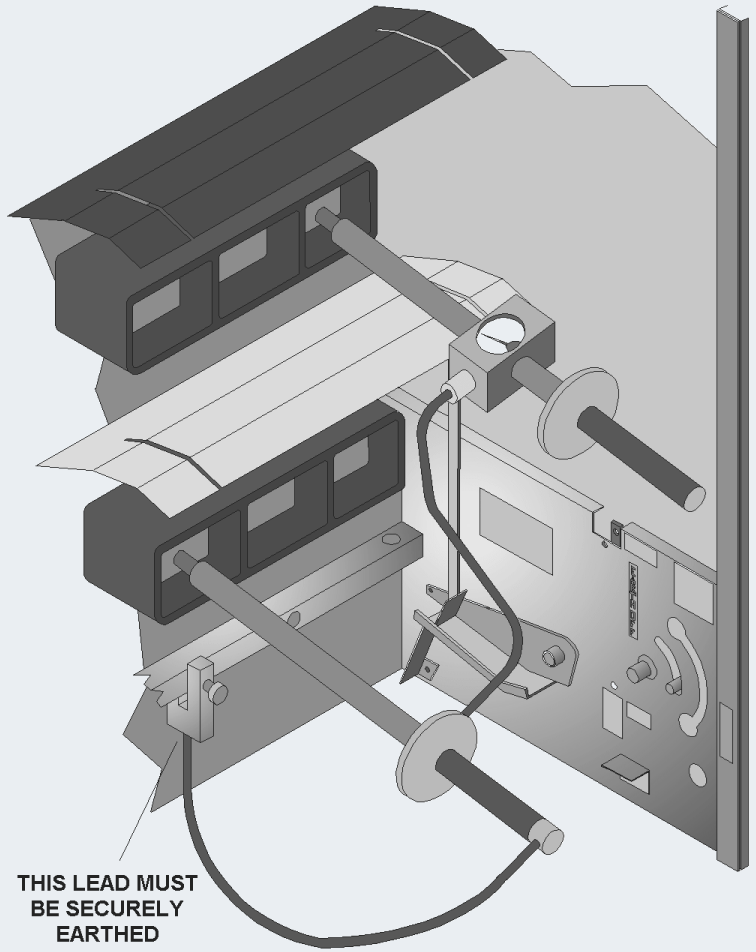


Danger notices at rear of multi-panel board

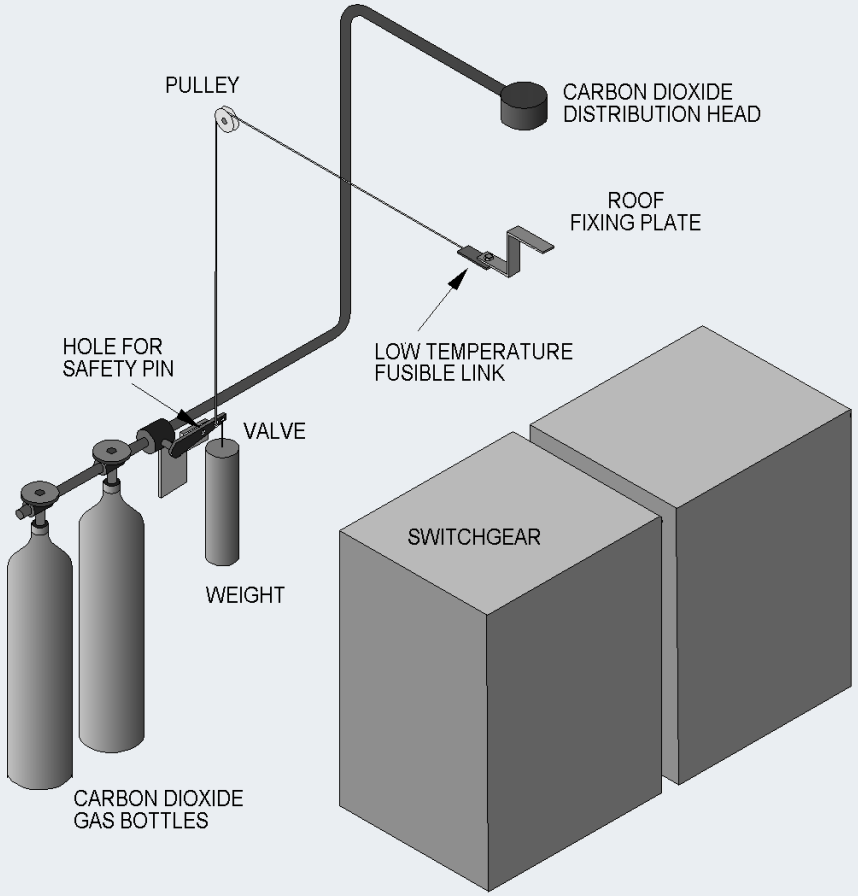
Contact shutter safety mechanisms



Phasing out



Fire protection in substations



CO_2 type fire extinguishing system

CO_2 is Hazardous to Personnel

Ensure Alarms, delays, signage and procedures

Fire protection in substations

Top 8 Commissioning Gotchas

- CT polarity/ratio wrong (and discovered only after nuisance trips)
- Trip circuit supervision not proven end-to-end
- Interlocks defeated and not reinstated
- Secondary wiring loose or ferrules missing
- Incorrect relay settings file / wrong revision
- VT fuses / links / test blocks left in test position
- Earth bonds loose (especially doors and cable boxes)
- No baseline: IR/PD/contact resistance not recorded for future trending

Q&A

Thank You!

UKPRN: 10089771

Upcoming Courses

Engineering College of Technology (ECT) *UK-Recognised Qualifications*	Start Date
Bachelor of Engineering (Honours) in Industrial Automation	16 February 2026
Bachelor of Engineering (Honours) in Electrical Engineering	16 February 2026
Master of Science (Power System Analysis and Renewable Integration)	9 February 2026
Master of Science (Industrial Automation and Instrumentation Control)	9 February 2026

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