

Testing and Maintenance of Electrical Equipment with a focus on switchgear




by Steve Mackay

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Overall Presentation

Many people assume (wrongly) that inspecting, testing, maintenance and commissioning is a fairly straightforward process and is simply a rubber stamp confirmation of a so-called outstanding design.

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Objectives

- Review switchgear diagnostics, testing and maintenance



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Topics

- Asset records
- Condition based maintenance (CBM)
- Reliability centered maintenance (RCM)
- Switchgear inspection methodologies
- Diagnostic techniques
- Principles of circuit breaker maintenance

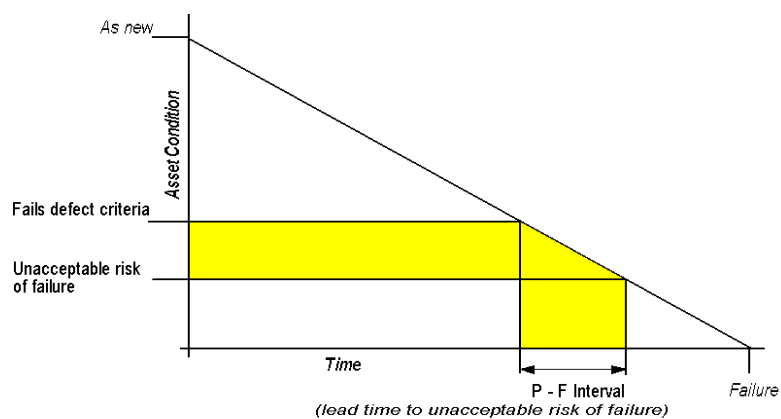
Asset Registers

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

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Condition Based Maintenance (CBM)



Relationship of asset condition to time

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Reliability Centered maintenance (RCM)

Failure Modes Effects Analysis
(FMEA) or sometimes the
Failure Modes Effects Critical
Analysis (FMECA)

RISK MATRIX

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

Consequence	Probability				
	1. Frequent	2. Probable	3. Occasional	4. Remote	5. Improbable
Ranking					
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	
B	Moderate
C	Low

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RCM analysis implementation

1. Objectives of maintenance defined by functions of asset and associated desired performance standards
2. Inability of asset to meet desired standard of performance known as functional failure. Can only be identified after functions, performance standards of asset have been defined
3. After identifying functional failures, failure modes are identified which are reasonably likely to cause loss of each function
4. Failure effects describe what will happen if any of failure modes did occur
5. In what way does each failure matter? Criticality of failure. RCM classifies these into four groups: hidden failure, safety and environmental, operational and non-operational
6. Process of analyzing functions, functional failures, failure modes and criticality (FMEA/FMECA) yields opportunities for improving performance and safety
7. RCM recognizes three major categories of preventive tasks as follows:
 - Scheduled on-condition tasks - which employ condition-based or predictive maintenance
 - Scheduled restoration
 - Scheduled discard tasks

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Switchgear inspection methodologies

- Health of insulation
- Wear and tear of mechanical components
- Proper functioning of the breaker

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Insulation deterioration

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

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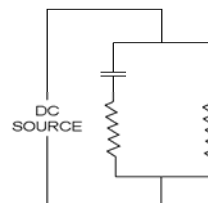
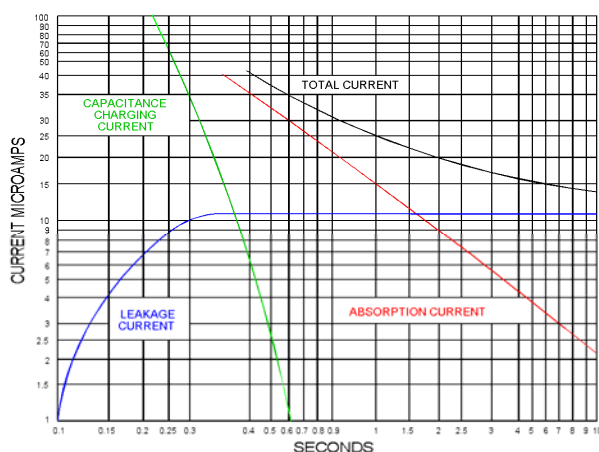


Insulation deterioration (cont)

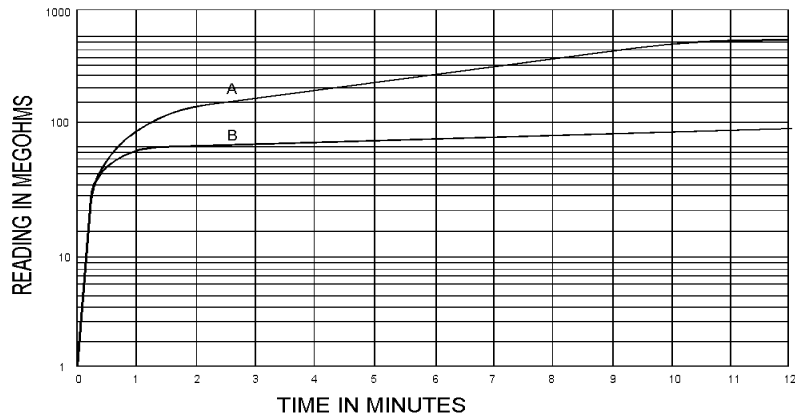
Current flowing through insulator (and which will be very small) is made up of three components:

- Capacitance charging current
- Dielectric absorption current
- Irreversible leakage current

DC insulation test – graph and equivalent circuit



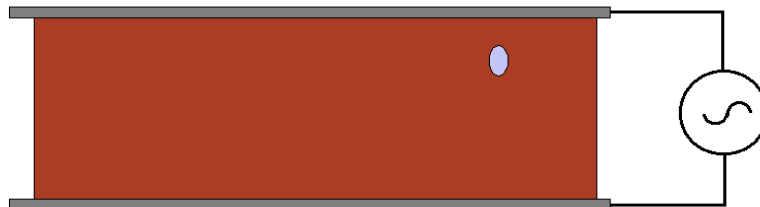
Dielectric absorption curve



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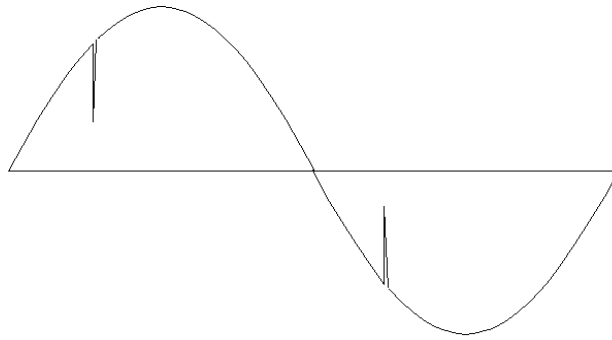
Imperfect insulation under voltage stress



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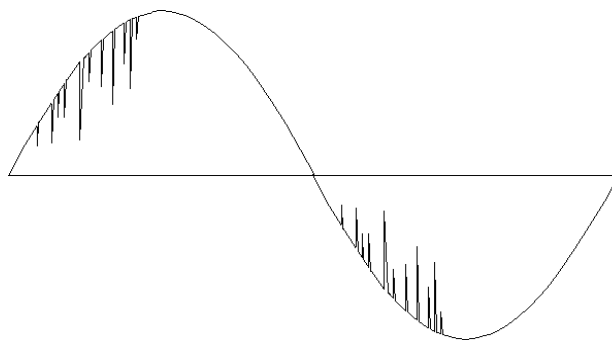
Partial discharges occurring during voltage cycle



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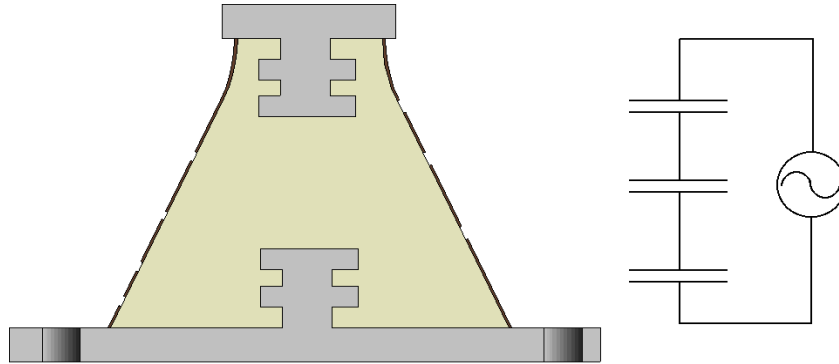
Signal from multiple partial discharge sites



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Partial discharge from contaminated bushing with equivalent



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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

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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

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

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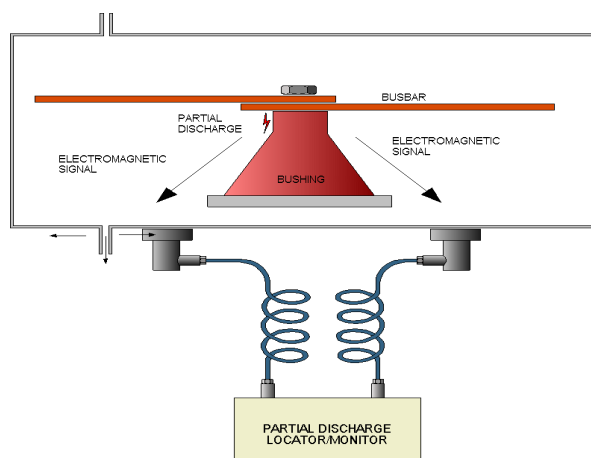
Partial discharge in switchgear (contd)

- 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

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Locating partial discharge sites by TEV



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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

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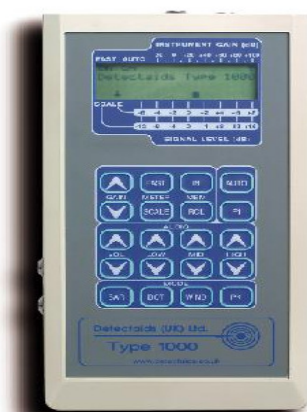
Portable PD test equipment advantages

- 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

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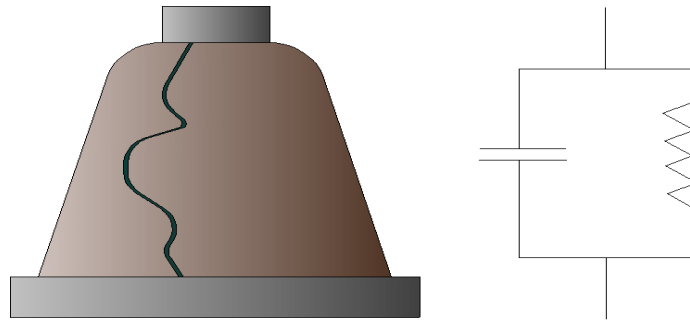
Hand held acoustic probe by Detectaids Ltd



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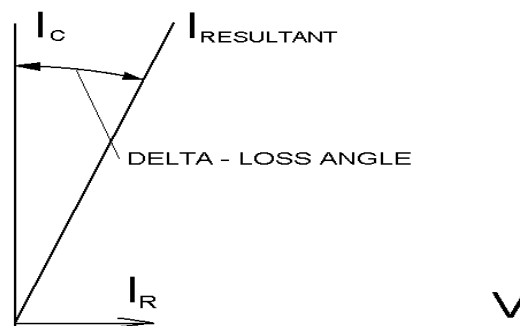
Cracked bushing and equivalent circuit



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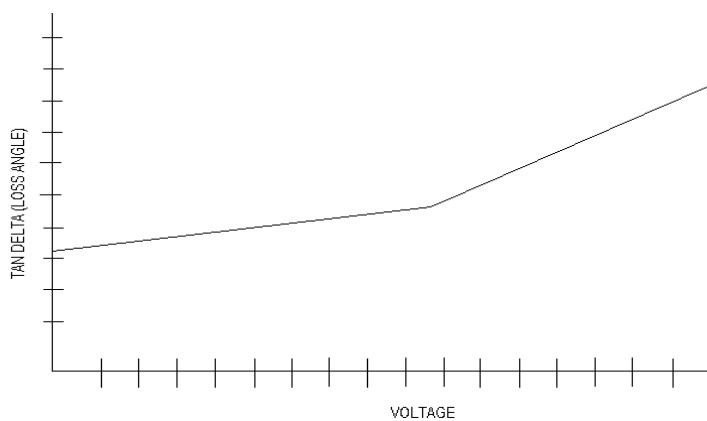
Vector diagram – Tan delta



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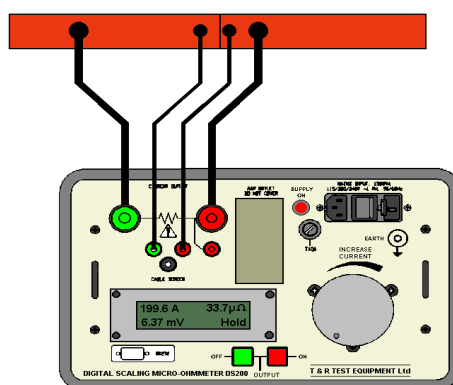
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Increase of Tan Delta with voltage



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High current, contact resistance test set



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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

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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

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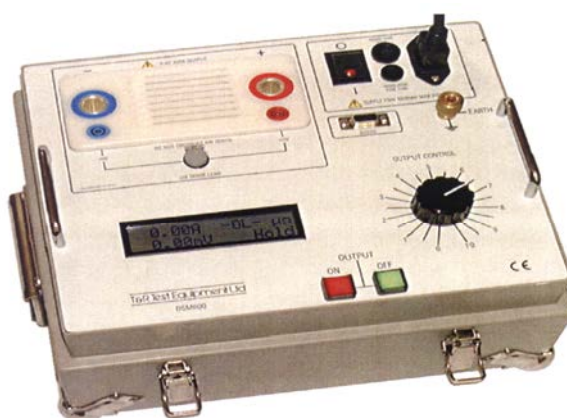
Suggested limits for contact resistance for circuit breakers (contd)

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

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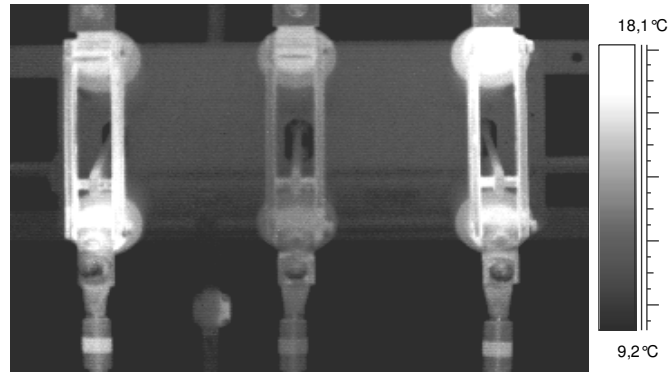
K&R Contact micro-ohm meter



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Thermal grey scale image of air break disconnect



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FLIR SYSTEMS Model Thermacam PM695



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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

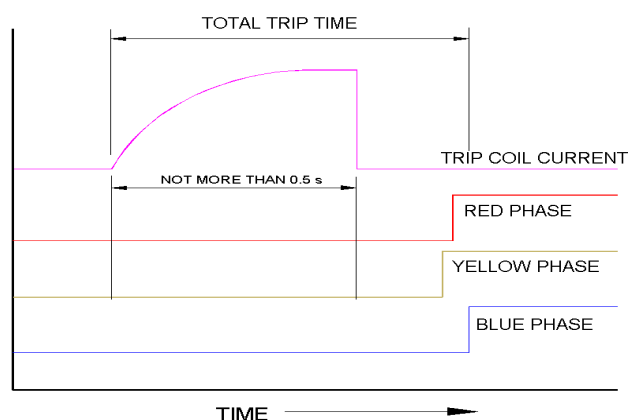
Trip coil monitoring (contd)

- 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
- CB should trip at 70% of battery voltage (IEC spec) – in case of busstrip
- Trip pulse normally only 500ms
- Trip circuit supervision constantly supervises integrity of trip circuit

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)

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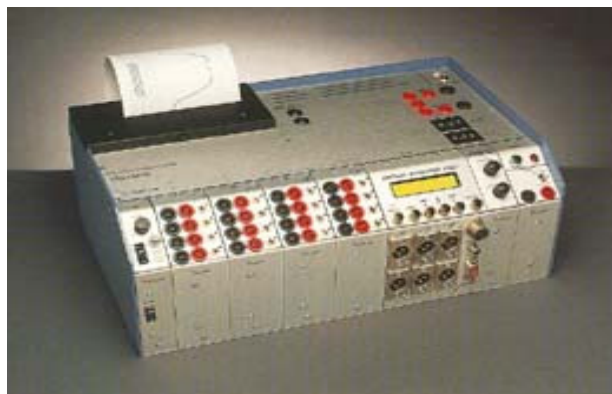
TCT Trip coil tester by Relay Engineering Services (RES)



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TM1600 motion analyzer by Programma



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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

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SF₆ gas monitoring

- Ability of SF₆ to extinguish arcs is dependant on purity normally the gas purity is maintained by a 'molecular sieve'
- Purity may degrade due to contamination by:
 - Oxygen
 - Moisture
 - Acidity (mainly as Hydrogen Fluoride)

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Teledyne 3010TAC Oxygen in gas analyzer



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Shaw SDDLG moisture in gas analyzer



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Anachem HF-1000 acidity in gas analyzer



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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

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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**

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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

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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)

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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 (Permalin) 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 (contd)

- 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

Need for oil testing

- Oxidation (due to high operating temperatures) causes sludge
- Deterioration of oil dielectric properties
- Transformer life time depends on operating temperature (every 10°C 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



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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

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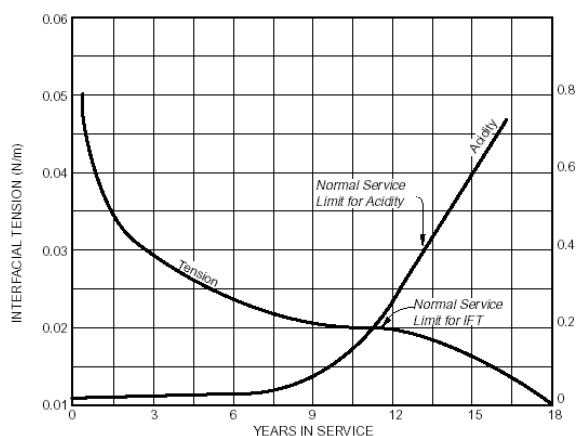
Interfacial tension test

- 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 0.18 dynes/cm may indicate sludge formation

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Changes in IFT & Acidity



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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

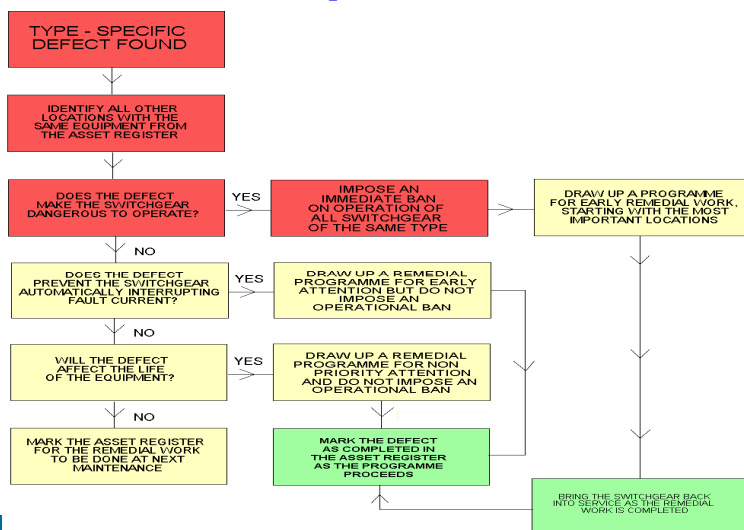
Specific gravity

- 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

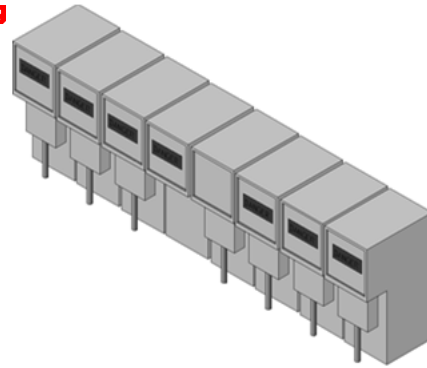
Action diagram for type-specific switchgear defect



Switchgear installations

Special precautions when working on switchgear

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

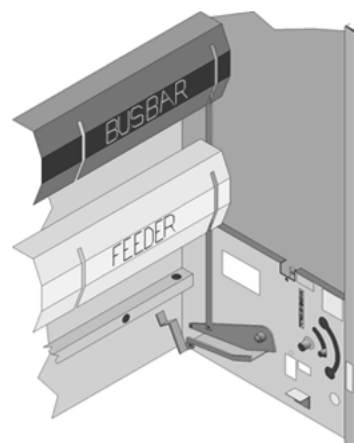


Danger notices at rear of multi-panel board

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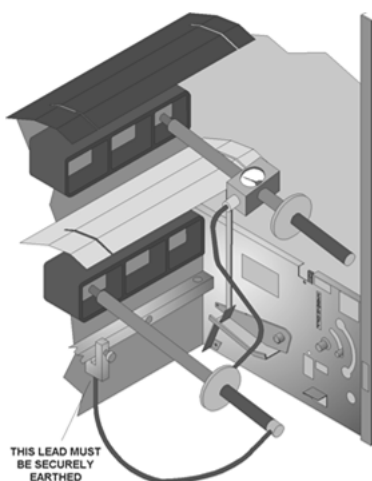
Contact shutter safety mechanisms



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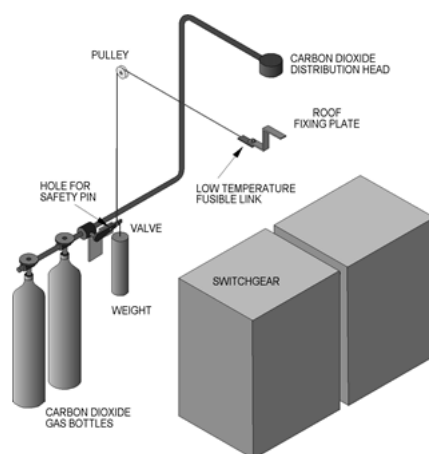
Phasing out



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Fire protection in substations



CO2 type fire extinguishing system

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Fire protection in substations



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