BEST PRACTICES FOR MAINTAINING POWER TRANSFORMERS

AAPPA FALL PROFESSIONAL DEVELOPMENT CONFERENCE

HALIFAX, N.S.
NOVEMBER 19, 2010

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OUTLINE

- Why maintain equipment ?
- Factors influencing maintenance decisions
- Maintenance strategies
- Asset management
- Equipment inventory and records
- Maintenance practices
- Life of a transformer
- Transformer inspections and testing
- Switchgear
- Thermovision
- UPS Systems and standby generators

WHY DO MAINTENANCE ?

- Safety
- Fires
- Reliability
- Risk / Insurance
- Extend the life of the asset
- Environmental
  - Oil Spills
  - PCB ?

FACTORS INFLUENCING MAINTENANCE DECISIONS

- Budgets
- Redundancy of equipment / systems
- Availability of spare parts / equipment
- Training of personnel – outsourcing
- Back up supplies
  - Generators
  - UPS

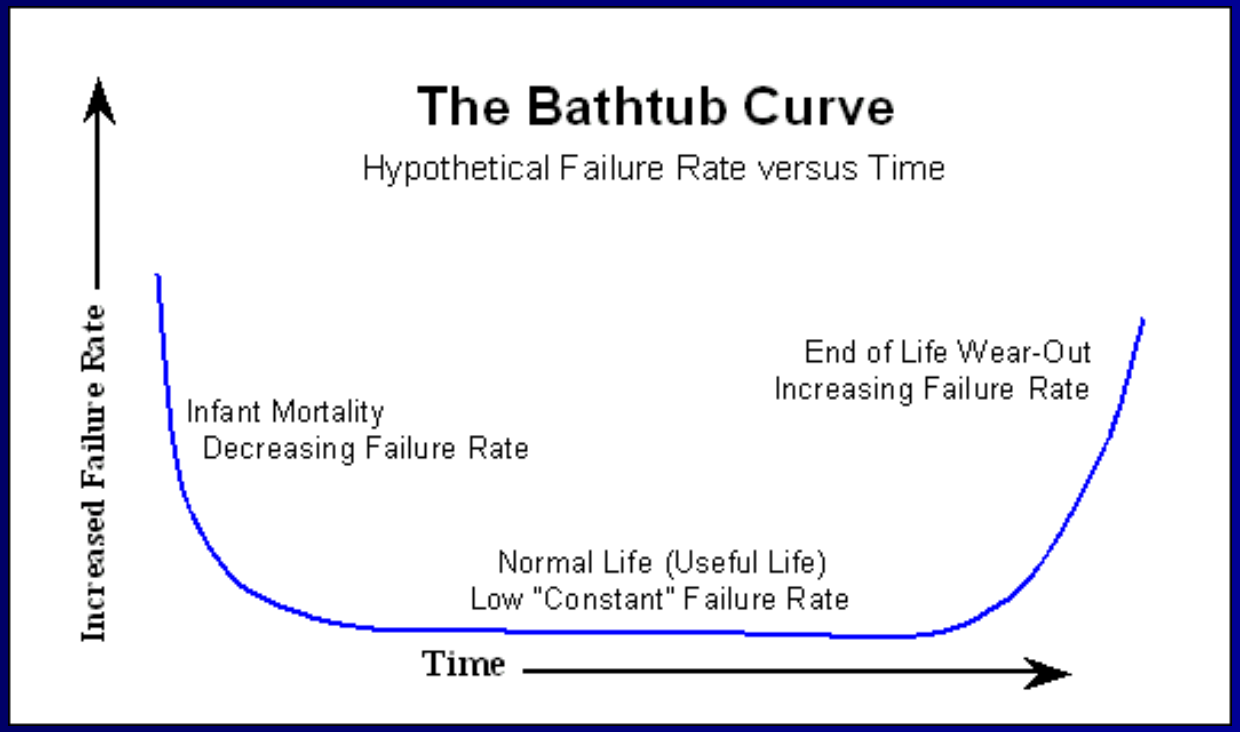
Maintenance Strategies

- Preventative Maintenance (PM)
- Corrective Maintenance (CM)
- Predictive Maintenance (PD)
- Reliability Centered Maintenance (RCM)
- Condition Based Maintenance (CBM)
- Run To Failure (RTF)

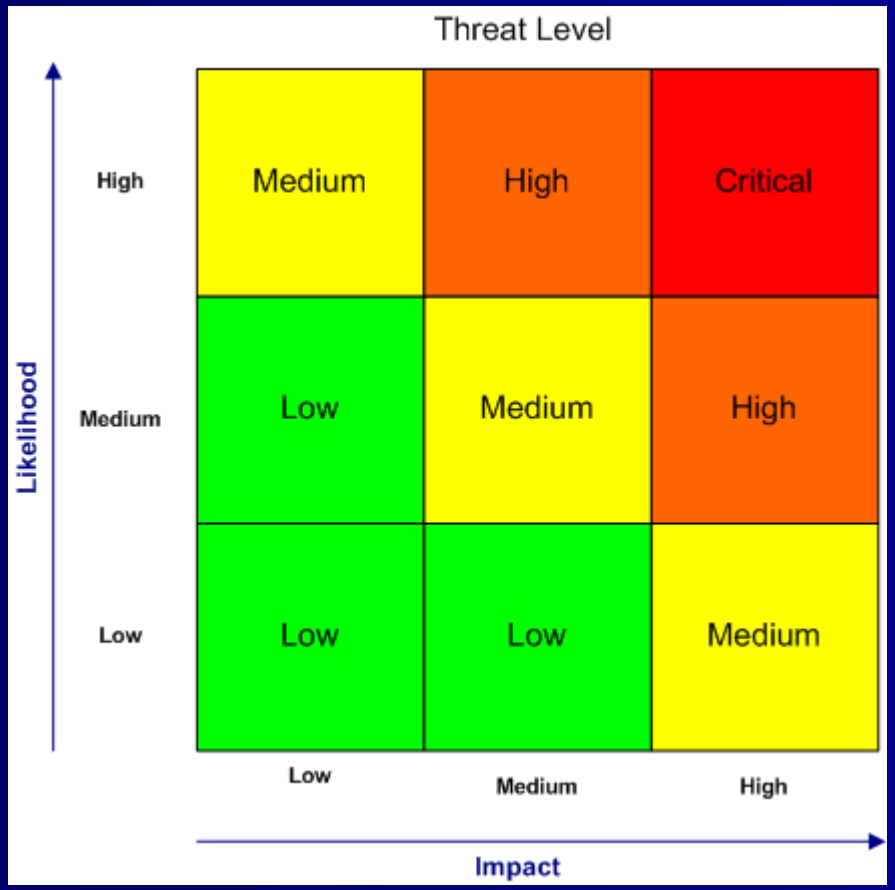
ASSET MANAGEMENT

- Management of physical assets including selection, acquisition, maintenance, inspection and renewal of these assets
- Minimize “life cycle costs” of the assets
- Critical factors such as risk and business continuity are considered in decision making process
- May include some or all of PM, PD, CM, CBM and RTF
- Includes spare parts and spare equipment inventories

BATHTUB CURVE



Risk : Probability–Consequences Matrix



EQUIPMENT RECORDS AND INVENTORIES

- Know what equipment you have and where it is
- Keep accurate drawings – most recent revisions only
- OEM manuals – recommendations for maintenance
- Commissioning records – keep for future reference
- Maintenance records – keep for trending
- Keep records in centralized depository
- Computerized Maintenance Management Systems (CMMS)
- Don’t rely on individual’s knowledge and memory

MAINTENANCE PRACTICES

- Develop a program of inspections and tests and stick to it
- Written procedures and checklists
- Should be performed by trained, knowledgeable personnel
- Safety of personnel must be considered

LIFE OF A TRANSFORMER

- End of life defined as “ That state of an insulation system where dielectric stress or short circuit stress or mechanical movement, which could occur in normal service, would cause an electrical failure”
- Insulation systems consist of paper insulation and mineral oil
- Natural aging or deterioration of insulation is a time function of temperature, moisture content and oxygen content
- With modern insulation systems, and basic maintenance, the moisture and oxygen content can be minimized
- Temperature is then the controlling factor in insulation life
- Temperature is a function of transformer loading and ambient temperatures

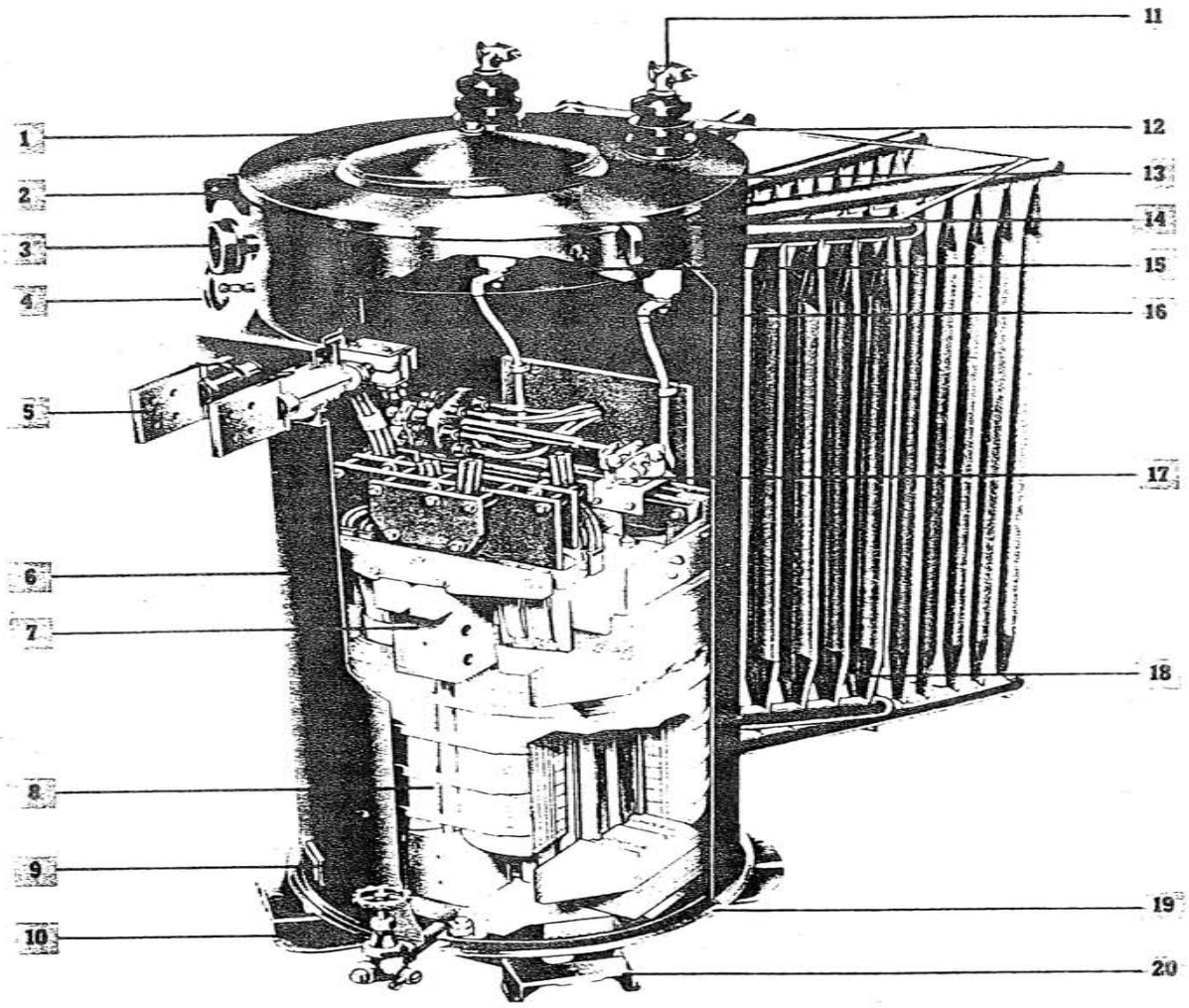
LIFE OF A TRANSFORMER – Cont'd

- Modern paper insulation has an average temperature rise limit of 65 degC, based on 30 degC ambient temperature
- Paper insulation reaches "end of life" when the paper has lost 50% of it's tensile strength
- If transformer is continually operated at nameplate rating and 30 degC ambient temperature, the paper will lose 50 % of it's tensile strength in 7.42 years
- Aging of paper is a cumulative effect. Operating above these temperatures will increase normal aging, while operating below these temperatures will decrease normal aging
- For every 10 degC warmer a transformer is operated, the life of the insulation is halved
- Keeping transformers cool will extend their normal life
- Most power transformers should last approximately 40 years, distribution class transformers slightly less
- Older transformers were built with more insulation than today's units

LIFE OF A TRANSFORMER – Cont'd

- Other factors can decrease or end the life of a transformer
  - Lightning (high electrical stress)
  - Switching transient voltages (high electrical stress)
  - Through faults (mechanical stresses)
  - Poor oil quality

Failures



1. Welded-on tank top
2. Lifting lugs
3. Liquid-level indicator
4. Dial-type oil thermometer
5. Low-voltage bushings and bus connections
6. Tank shell
7. Maple end frames
8. Core and coil
9. Copper-faced tank grounding pad
10. Combination oil drain, bottom filter press connection and sampling valve
11. High-voltage terminals
12. High-voltage bushings
13. Handhole cover
14. Pressure-vacuum gage connection
15. Gas space
16. Location of upper filter press connection
17. Tap changer (external operating handle not shown)
18. Cooling tubes
19. Closure weld
20. Base

Fig. 1. Oil-Immersed three-phase transformer (Class OA/FA/FOA).

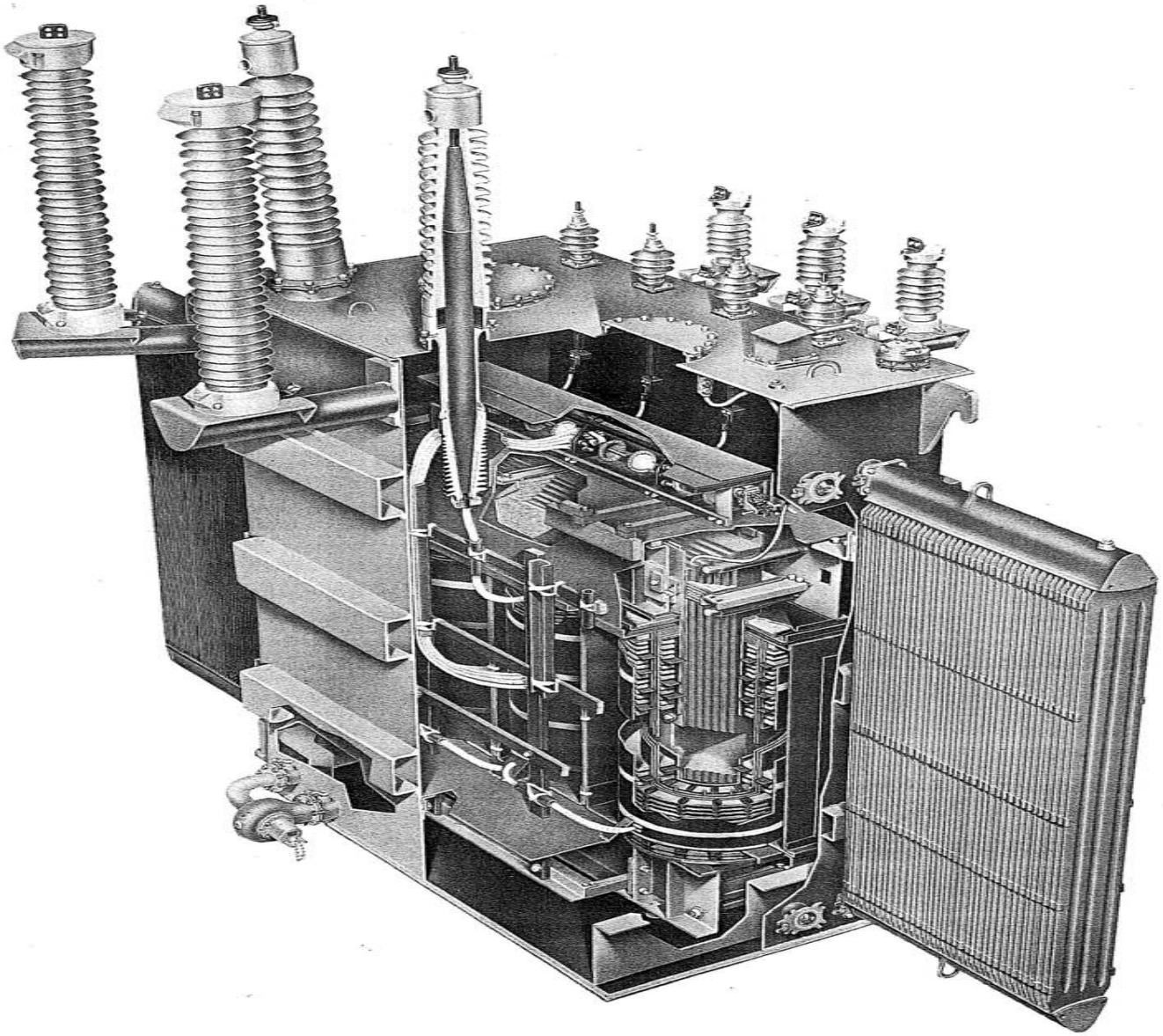


Figure 1-2 Type SL Core Form Transformer

Transformer Inspections- in Service

- Ensure personnel are trained and aware of risks – Safety First
- Use itemized check list
- Have previous inspection sheets for comparison
- Performed at regular intervals

Transformer Inspections

- Check for leaks
- Check for rust
- Inspect bushings for damage or cracks
- Record temperature gauge readings
- Check oil level gauges
- Check pressure/vacuum gauges
- Cleanliness of tank and radiators
- Operation of fans (if equipped)
- Grounding connections intact
- Check for visual signs of overheating on connections
- Check condition of desicant breather, replace desicant if pink

Transformer Inspections- Cont'd

- If transformers are located in a vault:
  - Cooling vents open and unobstructed
  - Floor drains free of debris
  - Water on floor
  - Lights working
  - Forced ventilation (if equipped) is operational

Gauges


SWITCH SETTING
40
80
120
0
160
RESET
WINDING TEMPERATURE °C


0
50
-50
100
-100
kP
150
ASHCROFT


DV
TC
7200

Dry Type Transformer Inspections

- Perform inspections with transformer out of service and grounded
- Inspect for dust accumulation
- Vacuum dust out of cooling ducts. If dust is very thick, use low pressure dry air to blow dust away. Do not blow further into winding
- Check fans for proper operation
- Check for any carbon tracking on conductors/insulation
- Check for discoloration of conductor

Oil Sampling

- Prior to sampling oil, ensure that oil sample will not lower oil level to dangerous level or impede convectional oil cooling flow
- Normally need 1-2 liters for representative sample
- Drain enough (1 liter) to flush any debris or stagnant oil from valve
- Sample should be obtained in clean, dry sample containers
- If transformer has small volume of oil, have clean replacement oil on hand to top up transformer
- Can be done energized by trained personnel using extreme caution
- Never sample oil from energized transformer if tank in “vacuum” condition

Oil Testing

Electrical

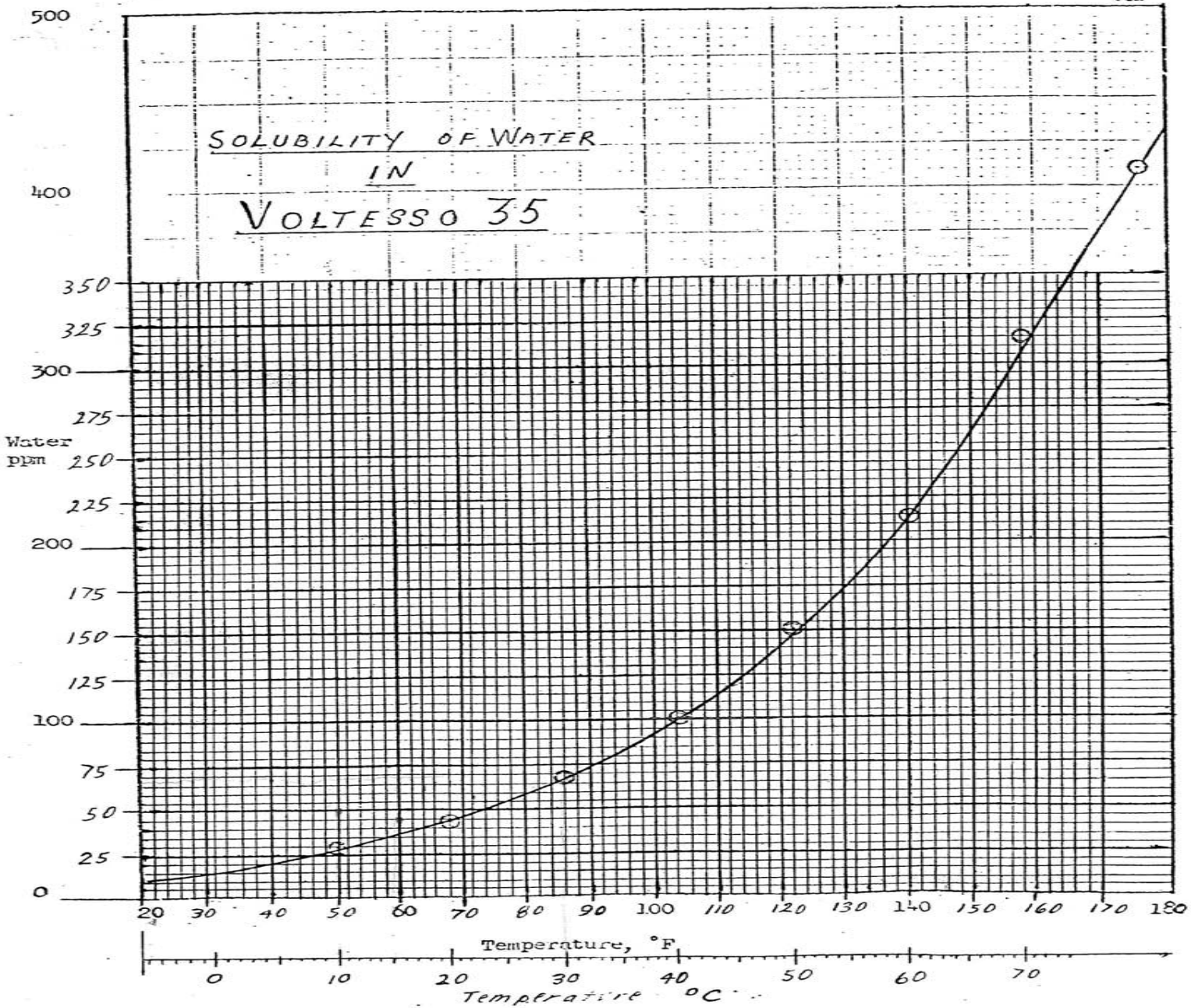
Dielectric breakdown –	ASTM D1816	> 26kV
Power Factor	ASTM D924	<0.5 %

Chemical

Interfacial Tension	ASTM D971	>24 dynes/cm
Acidity	ASTM D974	<0.1
Water content	ASTM D1533	<30PPM @20 degC
Furans	ASTM D5837	<500 PPB

SOLUBILITY OF WATER IN INSULATING OIL

SOURCE: TRIESTE SPECIALTY OIL MEETING, 1964.



Dissolved Gas in Oil (DGA)

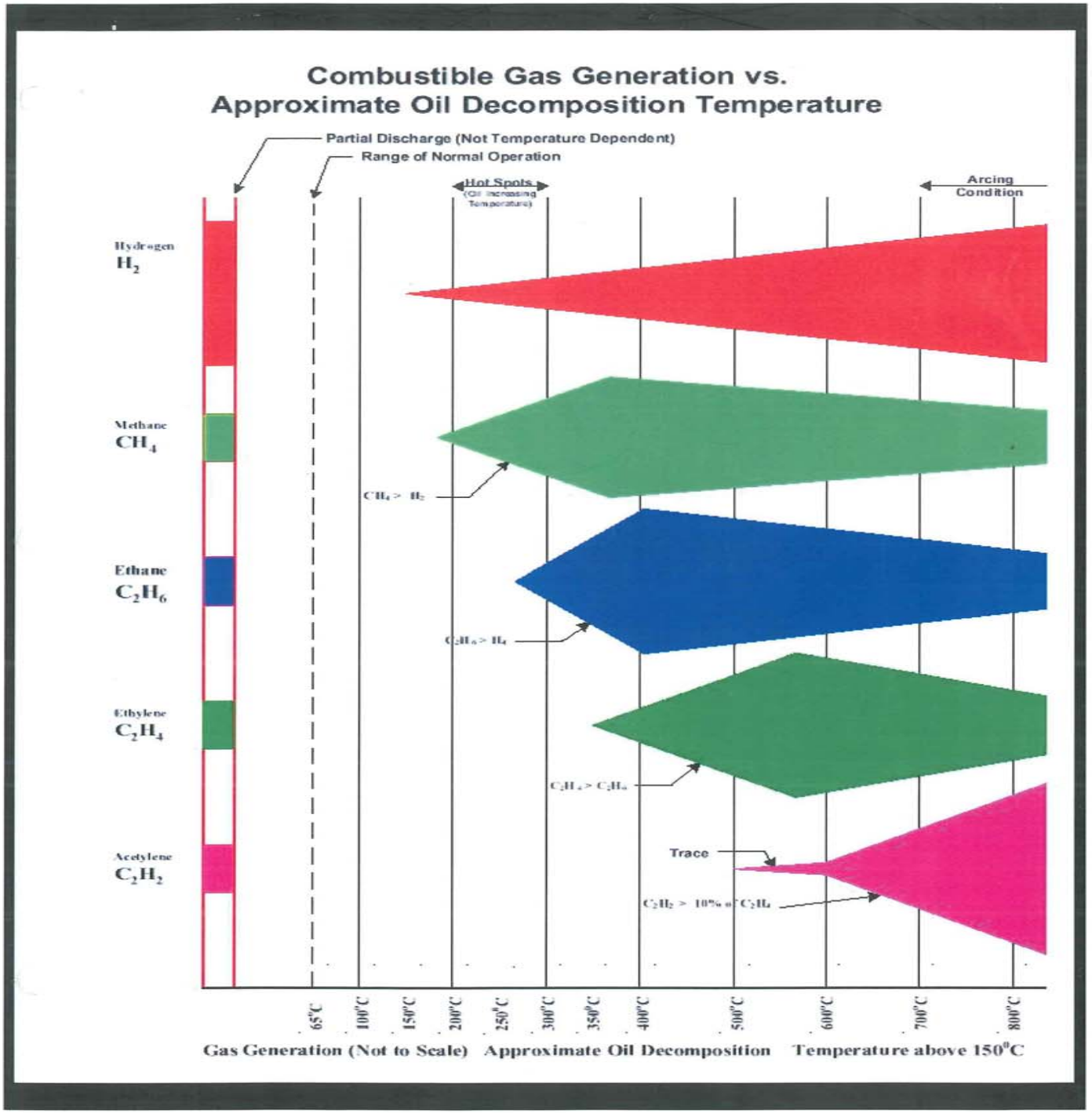
- Taken with 30 cc syringe and adapters to connect to valve
- Syringe should be flushed with clean oil prior to sampling
- Only trained personnel to take samples
- Can be sampled energized with caution
- Never take sample if transformer under vacuum
- Samples sent to lab for testing on gas chromatograph
- Many analysis techniques – most labs provide analysis with test report. Software available for advanced analysis
- Samples should be taken yearly and observed for trending

DGA

- DGA can be used to determine the health of a transformer much like a doctor uses blood tests to determine the health of a patient
- When oil is subjected to heat at different temperatures, different hydrocarbon gasses are produced
- Analysis can be used to detect “hot metal” connections, arcing, partial discharge, and paper degradation
- Most combustible gasses are produced in small quantities in healthy transformers. By trending the increases in these gasses, you can determine the severity of the problem
- Any acetylene (C_2H_2) is cause for concern (arcing under oil)
- Many published standards (IEEE, IEC, CIGRE) that give limits for individual gasses
- Interpretation as much of an art as a science

DGA Cont'd

- Many analysis techniques use ratios of key gasses to determine severity and relative origin of fault
- Can not pinpoint exact location of fault. Diagnostic (electrical) tests required for this
- Can be used to detect problems in on-load tapchangers as well
- General condition of paper insulation given by CO2 to CO ratio (less than 3 or greater than 10 cause for concern)


Combustible Gas Generation vs.
Approximate Oil Decomposition Temperature
Partial Discharge (Not Temperature Dependent)
Range of Normal Operation
Hot Spots
(Oil Increasing Temperature)
Arcing Condition
Hydrogen
H_2
Methane
CH_4
$CH_4 > H_2$
Ethane
C_2H_6
$C_2H_6 > H_4$
Ethylene
C_2H_4
$C_2H_4 > C_2H_6$
Acetylene
C_2H_2
Trace
C_2H_2 > 10% of C_2H_4
65°C
100°C
150°C
200°C
250°C
300°C
350°C
400°C
500°C
600°C
700°C
800°C
Gas Generation (Not to Scale)
Approximate Oil Decomposition
Temperature above 150°C

Duval Triangle

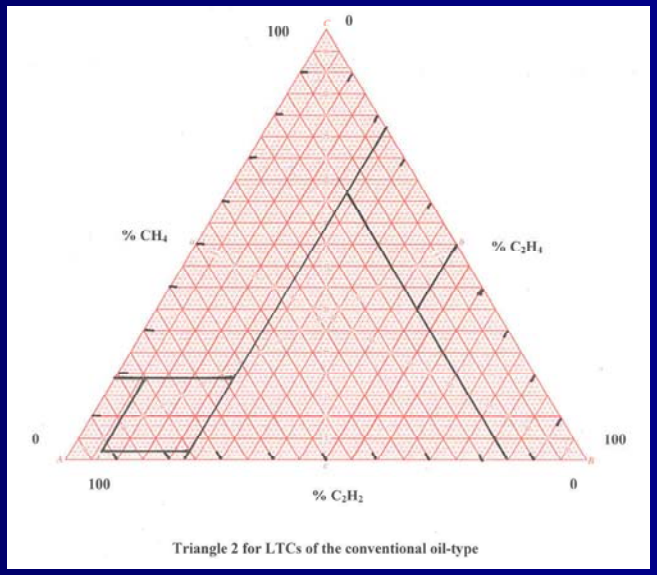
THE DUVAL TRIANGLE 2 FOR LOAD TAP CHANGERS FILLED WITH MINERAL OIL

ppm CH4	10	% CH4	10.0	Fault	N
ppm C2H4	15	% C2H4	15.0		
ppm C2H2	75	% C2H2	75.0		

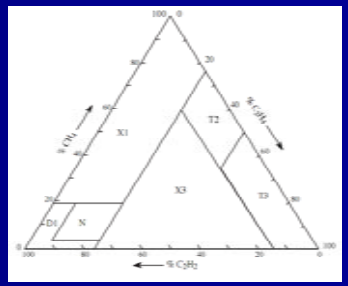
N = Normal operation
T3 = Severe thermal fault T3 (T > 700°C), heavy coking
T2 = Severe thermal fault T2 (300 < T < 700°C), coking
X3 = Fault T3 or T2 in progress, or abnormal severe arcing D2
D1 = Abnormal arcing D1
X1 = Abnormal arcing D1 or thermal fault in progress

Triangle 2 applies to conventional LTCs where normal operation involves only arc breaking in oil
When normal operation also involves resistor heating in oil, the normal operation zone is located in a different part of the triangle (X3)

The triangular coordinates calculated above can be plotted in the graph below to see visually with more precision where the DGA point is located in the triangle.
Also, to follow the evolution of the DGA point with time in an LTC. For that purpose, print this page and plot manually the successive DGA points.
An electronic version of this graph is in preparation.



Triangle 2 for LTCs of the conventional oil-type



Electrical Testing

- Electrical testing is performed with the transformer de-energized and isolated from sources of energy
- Caution must be taken to ensure that when test voltages are applied that personnel are clear of all transformer bushings
- Requires specialized test equipment
- Performed by trained , qualified personnel

Electrical Tests

- DC insulation tests (Megger)
- AC insulation tests (Doble)
- Bushings and lightning arresters can be tested as well
- Winding resistance
- Turns ratio

Switchgear

- Includes circuit breakers, disconnect switches, and fuses
- Failures of breakers and switches are often due to lack of use
- Breakers are mechanical devices and most problems are mechanical in nature
- Breaker mechanisms may require lubrication (consult OEM manuals)
- Only use lubricants recommended by manufacturer
- Maintenance may involve operating and lubricating breaker mechanism
- Thermovision is excellent tool for detecting defects in switches and breaker contacts
- High current (100 amps) contact resistance tests are very useful in detecting poor contact

Thermovision Scans

- One of the most useful tools in detecting problems in electrical systems
- Should be performed by certified thermographers
- Sophisticated, expensive equipment, but there are budget priced, user friendly models on the market
- Equipment must be energized for accurate measurements
- Analysis performed using reference points
- In three phase systems, compare temperatures between all three phases
- Very useful in detecting poor connections due to improper tightening of bolts, dis-similar metals, or poor selection of fastening hardware
  - All electrical connections should be tightened to proper torque values

Thermovision Cont'd

- Most users employ a rating system to grade severity of overheating problem
- Scans should be performed at peak loading conditions for best results
- When comparing results with previous results, loading conditions should be the same
- Can be used to detect poor cooling in transformer radiators
- Can be used to detect overheating of on-load tap changers

APPENDIX I - TEMPERATURE PRIORITY CODE LIMITS

Apparatus/ Component	Reference Point	Priority Code Limits in °C (above reference)			
		D	C	B	A
Transformer (Bushing)	Bus	2	2.1-10	>10	>35
Air Insulated Switches (Contact)	Bus	20	20-35	>35	>50
Circuit Breaker (Bushing)	Bus	2	2.1-10	>10	>35
C.T. Connection Terminals	--	5	-	-	>10
Clamps, Connectors, Compression Pads	Bus	2	2.1-10	>10	>35
Surge Arresters	Bus	2	2.1-5	>5	>10
Capacitors:					
Power Transformer	Bus	2	2.1-5	>5	>10
C.V.T./PT	Bus	2	-	-	>5
Cable Terminations	Cable Sheath	2	2.1-5	>5	>10
Terminals	Conductor	2	2.1-5	>5	>10
Reactors	--	5	-	-	>10

NOTE: These values are guidelines only. Operator experience and common sense must also be relied upon for making a qualitative analysis instead of a quantitative analysis under some circumstances.

Standby Generators and UPS Systems

- Biggest problem with these systems is failure to start when needed
- Systems should be tested for starting at least yearly
- Batteries for UPS systems have normal life of about 5 years or less
- Batteries can be tested for capacity
- Usually performed by specialty contractors

Spares

- Spare equipment or components should be kept for critical equipment
- Delivery of new equipment to replace failed equipment may be weeks to several months

QUESTIONS ????