“A Method of Selecting On-line Condition Monitoring for Substation Power Equipment.”

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Power System Solutions

Basis of Presentation

- Canadian Electricity Association (CEA) CEA Project No. 485T1049 “On-line Condition Monitoring of Substation Power Equipment - Utility Needs” January 1997.
- Draft IEEE C37.10.1 “Guide to Selecting Monitoring for Power Circuit Breakers”

Broader View of Monitoring

- View in context of substation automation
  - On-line condition monitoring
  - SCADA
  - Intelligent electronic devices (IED)
  - Automated meter reading (AMR) (customer & system)
  - Environmental data
  - Combine above to leverage greater value from individual monitoring investments and goals

Substation/Transmission Automation

- Means of combining data to improve available information
- Means of extracting data to gain relevant information and avoid duplication of monitoring
- Means of directing information to most appropriate location/user (i.e. operations, maintenance, business, etc.)

Purposes of Monitoring

- Reduce or avoid forced outages,
- Improve safety to personnel and the environment,
- Improve equipment or power system utilization,
- Improve equipment or power system availability, (and reliability), and
- Optimize maintenance costs

Basis of Selecting Monitoring

- Principles of Reliability Centered Maintenance (RCM) including:
  - Failure Modes and Effects (Criticality) Analysis FMEA or FME(C)A
- Value-based Asset Management
- Review of failure statistics
- Combine existing available & new signals
- Commercially products available ?

Reliability Centered Maintenance

- Directed at preservation of function
- Intended as a logic structure for value based maintenance selection
- Technique can be used to identify design improvements and select monitoring

Reliability Centered Maintenance

- Select RCM system boundaries and interfaces
- Define functions
- Failure Modes, Effects, Criticality Analysis
- Match appropriate maintenance and inspection tasks to failure causes (RCM)
- Match on-line condition monitoring to failure characteristic (Monitor Selection)

Failure Modes and Effects (Criticality) Analysis - FME(C)A

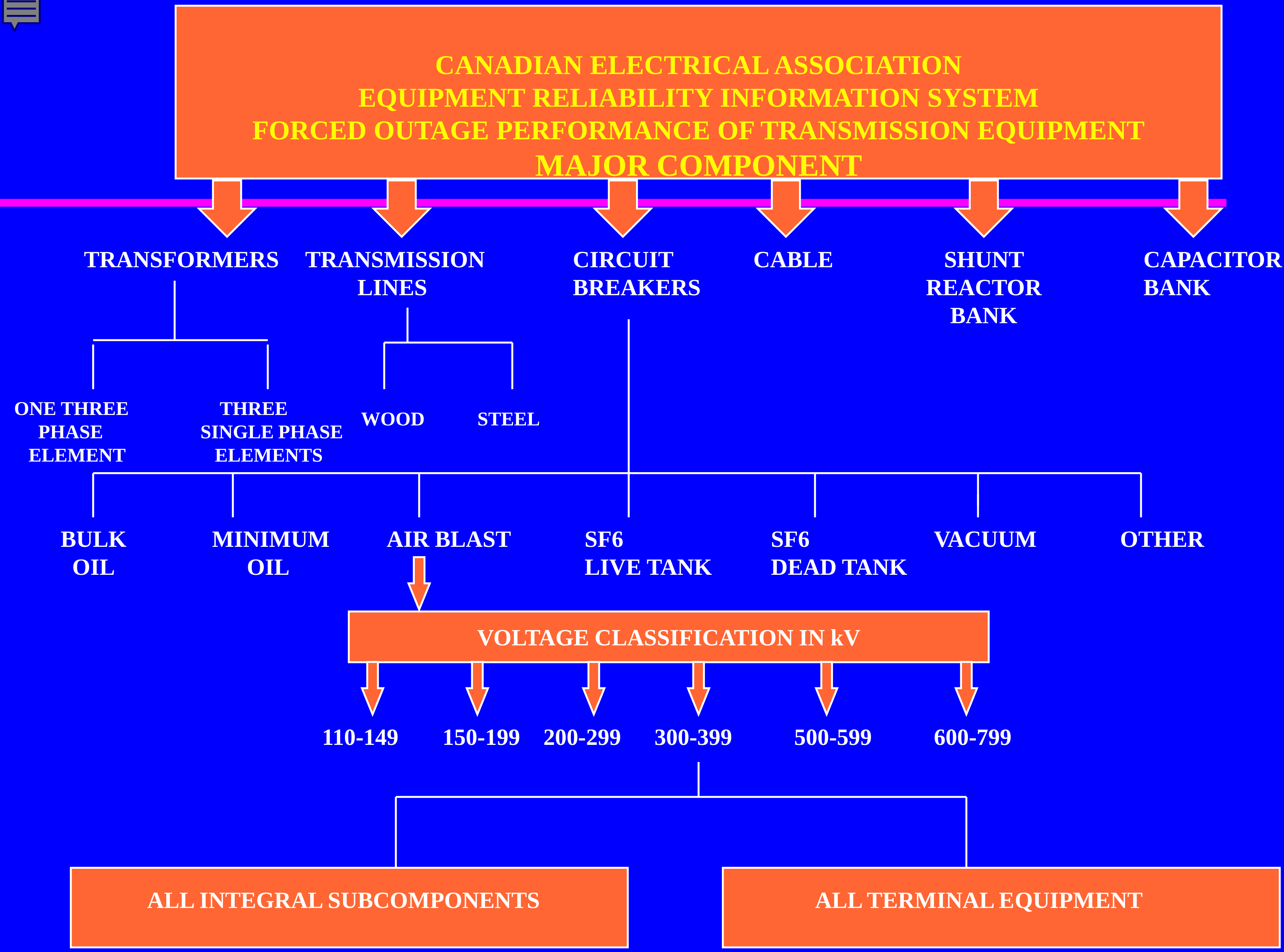
- Identify functions
- Identify failure modes
- Identify failure causes
- Identify effects of failure modes
- Identify criticality or risk
- Select on-line monitoring to match characteristic of developing failure cause(s)

Risk Matrix

Risk Matrix (Risk ≡ probability * consequences)					
	Probability				
Consequence	**I Frequent**	**II Probable**	**III Occasional**	**IV Remote**	**V Improbable**
1 Catastrophic	**A**	**A**	**A**	**B**	**B**
2 Critical	**A**	**A**	**B**	**B**	**C**
3 Moderate	**A**	**B**	**B**	**C**	**C**
4 Negligible	**B**	**C**	**C**	**C**	**C**

Failure Statistics Sources

- CEA Forced Outage Performance of Transmission Equipment for 5 yr periods
- CIGRE Circuit Breaker and Transformer Surveys
- IEEE 463-1990 "Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems"


CANADIAN ELECTRICAL ASSOCIATION
EQUIPMENT RELIABILITY INFORMATION SYSTEM
FORCED OUTAGE PERFORMANCE OF TRANSMISSION EQUIPMENT
MAJOR COMPONENT
TRANSFORMERS
TRANSMISSION LINES
CIRCUIT BREAKERS
CABLE
SHUNT REACTOR BANK
CAPACITOR BANK
ONE THREE PHASE ELEMENT
THREE SINGLE PHASE ELEMENTS
WOOD
STEEL
BULK OIL
MINIMUM OIL
AIR BLAST
SF6 LIVE TANK
SF6 DEAD TANK
VACUUM
OTHER
VOLTAGE CLASSIFICATION IN kV
110-149
150-199
200-299
300-399
500-599
600-799
ALL INTEGRAL SUBCOMPONENTS
ALL TERMINAL EQUIPMENT

Combining of Signals (example)

interrupter gas **pressure**
interrupter gas **temperature**

•interrupter **gas density**

with the addition of **time**

•interrupter **gas density**
•gas **leakage rate**
•prediction of **fill time**

Value Based (Cost/Benefit) Analysis

- Areas of Value (Cost & Benefit)
  - Inspection
  - Maintenance
  - Consequences of Failure
- Important to include ALL costs since this forms the "pool of costs" that can be reduced by monitoring

Inspection Costs Considerations

- Actual inspection labor
- Travel time and costs
- Contractor services
- Training time and costs
- Reporting & analyzing results, technical and management support of inspection activity
- Support personnel

Maintenance Costs Considerations

- Power system outage costs e.G. Increased losses, loss of revenue
- Actual maintenance labor
- Travel time and costs
- Contractor services
- Training time and costs

Maintenance Costs Consideration (cont'd)

- spare parts management, procurement, warehousing, delivery, interest
- preparation of power system switching schedules and orders, issuing of safe work permits   Power system switching effort, installation and removal of workers protective grounding
- power system outage costs e.g. increased losses, loss of revenue

Failure Resolution Considerations

- Actual failure analysis, rebuild/repair labor
- Travel time and costs
- Contractor services
- Power system outage costs, e.g. increased losses, loss of revenue
- “In” and “Out” costs of failed equipment and replacement equipment, transportation

Conclusions

- Significant benefits to appropriately applied monitoring
- Need timely information - not more data
- Make better use of existing signals & data
- Condition monitoring is a joint effort between manufacturers (OEM and 3rd parties, utilities (equipment, P&C, communications) and software developers

Conclusions

- RCM & FMEA (and later RCFA) provide logic structure for application of monitoring
- Significant benefit to standards - particularly “transducers”, communications protocol & data management

Recommendations

- Individual on-line monitoring efforts need to integrate with the larger and longer term issues of substation and transmission automation.
- Utilities need to define long term desired outcomes for on-line monitoring

Recommendations

- Apply condition monitoring in context of RCM and FME(C)A
  - Use Reliability Centered Maintenance (RCM), a concept *directed at preserving function*
  - Use Failure Mode & Effects Criticality Analysis (FMECA) *directed at identifying specific failure causes of functional failure modes*, suggested as a strategy for identifying and selecting condition monitoring opportunities

Recommendations

- Develop standards for hardware, software and communications protocols
- Incorporate future on-line condition monitoring into integrated substation automation – SCADA, metering, data collection, and protection & controls

Recommendations

- Continue to extract or develop information from available data within the substation
- Make better use of existing data supplement ed with additional “easily obtained” data/information
- Expert systems need to be developed for on-line monitoring to translate data rapidly into recommended action.

Recommendations

- Optimize costs with ability to use a stepped or modular approach to on-line condition monitoring implementation.
- Develop improved monitoring sensors

Recommendations

- Standardize and expand on failure / diagnostics reporting
- Further research on failure mechanisms and failure patterns (associated time to failure and “degree of warning” knowledge)

References

- CEA Project No. 485T1049 On-line Condition Monitoring of Substation Power Equipment - Utility Needs” January 1997
- CEA Forced Outage Performance of Transmission Equipment for Periods January 1, 1988 to December 31, 1992

References

- IEEE C37.10.1 **draft** "Guide for selecting monitoring for Power Circuit Breakers"
  - Aimed at guiding users in the selection and application of monitoring to circuit breakers.
  - Based on **FMEA**, **Risk** management and **Economic** analysis
  - Draft stage

References

- CSA CAN/CSA-Q634-M91“Risk Analysis Requirements and Guidelines”
- IEC 812 “Analysis techniques for system reliability - Procedure for failure mode and effects analysis (FMEA)”
- IEC 1025 “Fault tree analysis (FTA)”

References

- “The First International enquiry on Circuit Breaker Failures & Defects in Service” *ELECTRA* No. 79, Dec 1985, pp 21 - 91. {20,000 circuit breakers of all types >63 kV for the years 1974 through 1977; (77,892 circuit-breaker-years)}

References

- "Final Report of the Second International Enquiry on High Voltage Circuit Breaker Failures", CIGRE Working Group 13.06 Report, June 1994. {18,000 single pressure SF6 circuit breakers >63 kV for the years 1988 to 1991; (70,708 circuit-breaker-years)}

References

- “An International Survey on Failures in Large Power Transformers in Service” - Final report of Working Group 05 of CIGRE Study Committee 12 (Transformers), published in *Electra* No. 88, January 1983.

References

- IEEE 463-1990 “Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems”

References

- IEEE C37.10-1996 “Guide for circuit breaker diagnostics and failure investigation”
- IEEE 1325-1996 “Recommended practice for reporting failure data for power circuit breakers”

References

- ANSI/IEEE C57.117-1986 (Reaff 1992), "Guide for Reporting Failure Data for Power Transformers and Shunt Reactors on Electric Power Systems"
- ANSI/IEEE C57.125-1991, "Guide for Failure Investigation, Documentation, and Analysis for Power Transformer and Shunt Reactor"

Reference

- “Assessment of Reliability Worth in Electric Power Systems in Canada” (NSERC Strategic Grant STR0045005 Prepared by the Power System Research Group, University of Saskatchewan, June 1993)