Cigre Webinar-Tutorial

Joint Working Group Cigre/Cired A3.43

Tools for lifecycle management of T&D switchgear based on data from condition monitoring systems

Nicolas GADACZ

For power system expertise

A3.43 Webinar-Tutorial

Contents

- Introduction, Literature Review
- Condition indicators of T&D switchgear
- Tools and criteria for lifecycle management – focus on Health Index
- Compliance with digital substation, data management
- User experiences of end-of-life T&D switchgear
- Future needs and trends
- Q&A

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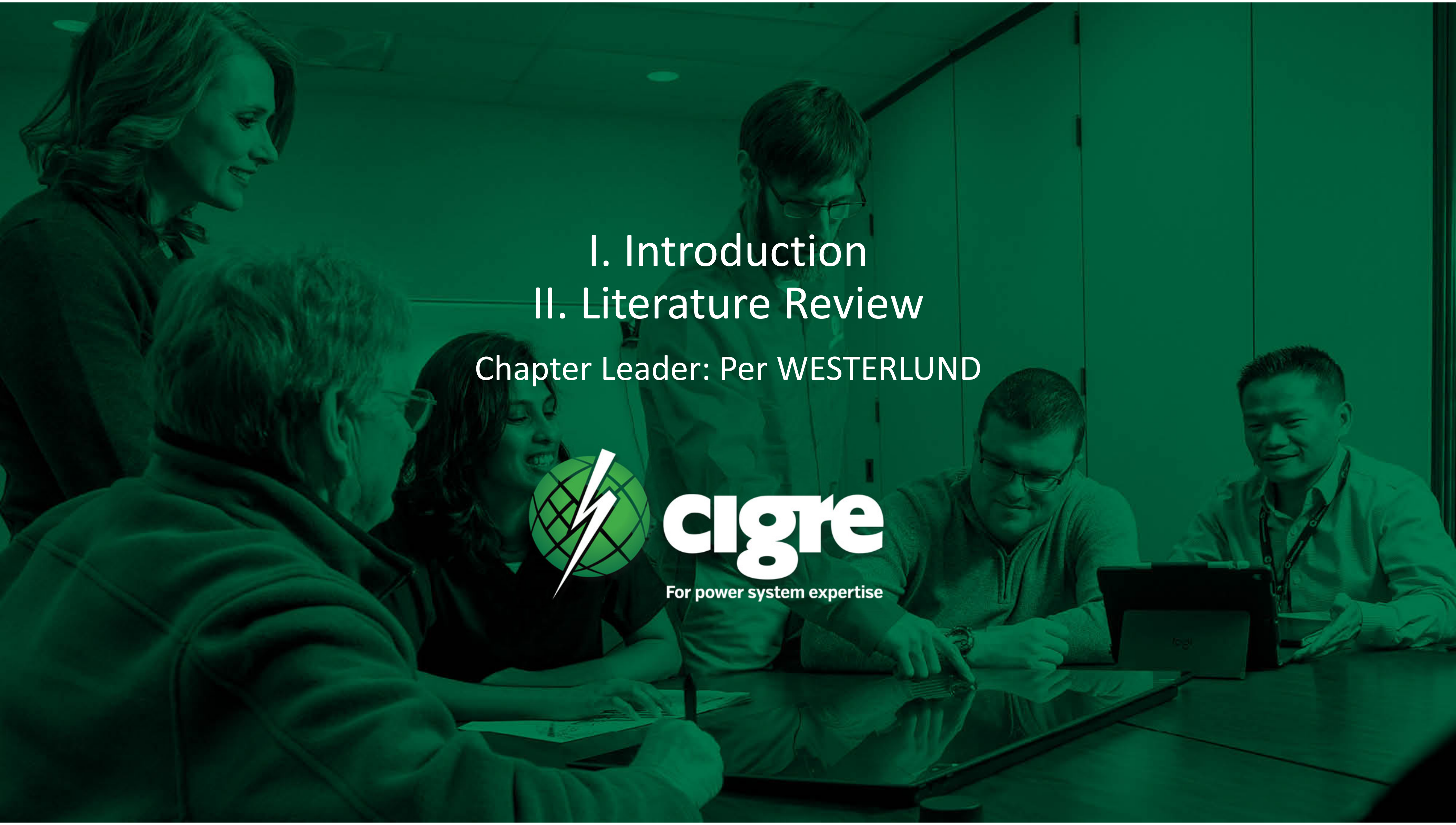
I. Introduction
II. Literature Review

Chapter Leader: Per WESTERLUND



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WG A3.43 - "*Tools for lifecycle management of T&D switchgear based on data from condition monitoring systems***"**

Scope

1. Identify critical condition indicators of T&D switchgear
2. Providing user's experiences of using continuous condition monitoring systems and periodic diagnostics into the existing T&D switchgear
3. Establish criteria for development of an analytical tool for Switchgear Health Index (SHI)
4. Provide user's experiences of end-of-life of T&D switchgear
5. Identify future trends in end-of-life management
6. Compliance with digital substation for collecting data via process bus (SC B5 support)

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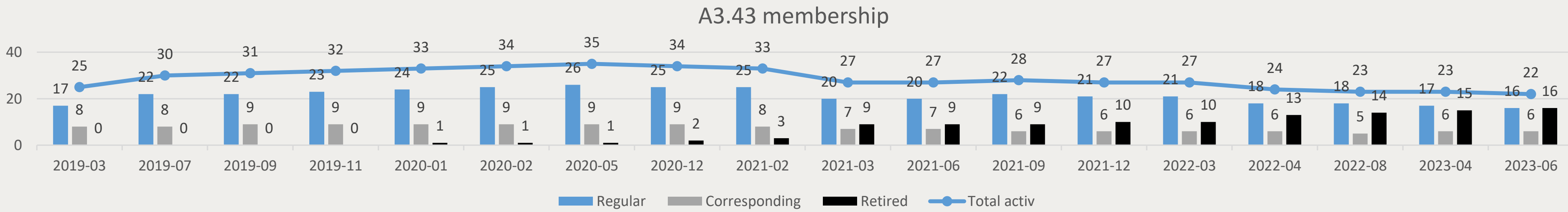
WG A3.43

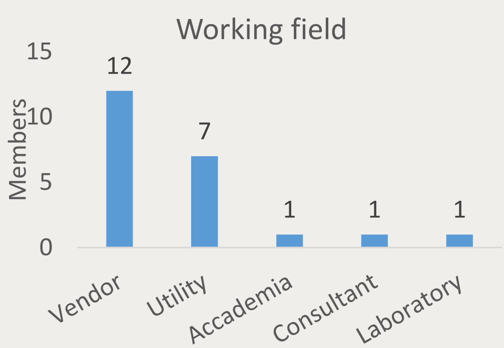
Kick-off meeting in Klaus (AT) hosted by Omicron, March 2019

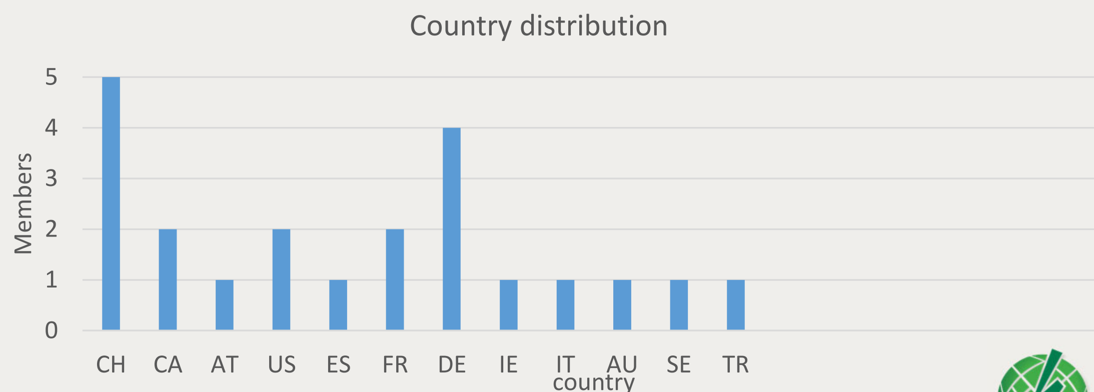
Meeting in Baden (CH) hosted by AXPO, Nov. 2022

WG A3.43: Membership

Present status: 22 members, 16 regulars, 6 corresponding, 17 retired







WG A3.43: Membership

1	Regular (convener)	Nicola	Gariboldi	CH	Qualitrol
2	Regular (secretary)	Javier	Mantilla	CH	Hyundai-electric
3	Regular	Bernd	Schuepferling	DE	Siemens AG
4	Regular	Albert	Livshitz	US	CE Power Engineered Services
5	Corresponding	Sébastien	Poirier	CA	Hydro-Québec Research Institute (IREQ)
6	Regular	Andreas	Nenning	AT	Omiconenergy
7	Regular	Venanzio	Ferraro	FR	Schneider-electric
8	Corresponding	Alex	Apostolov	US	Omiconenergy
8	Regular	Enrico	Adler	DE	Siemens AG
10	Regular	Dan	Catanase	IE	ESB International
11	Regular	Alberto	Sironi	IT	CESI Testing and Certification
12	Regular	Bastian	Wölke	DE	Westnetz GmbH
13	Regular	Ian Paul	Gilbert	ES	Ormazabal Corporate Technology
14	Regular	Alexander	Herrera	DE	Omiconenergy
15	Regular	Nicolas	Gadacz	FR	GE Renewable Energy
16	Regular	Emrah	KILIÇ	TR	TEİAS
17	Regular	Francesco	Pisu	CH	Pfiffner
18	Corresponding	Ankur	Maheshwari	AU	Western Power in Perth, Australia.
19	Regular	Ryszard	Pater	CA	Hydro-Québec Research Institute (IREQ)
20	Corresponding	Per	Westerlund	SE	KTH
21	Corresponding	Thomas	Frey	CH	Axpo
22	Corresponding	Kedar	Pandya	CH	Hyundai-electric

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WG A3.43: Meetings

16 meetings until now

- ✓ 1st Meeting: Mar 2019 — Klaus Omicron - A
- ✓ 2nd Meeting: Jul 2019 — Dublin ESB - IR
- ✓ 3rd Meeting: Sep 2019 — Montreal IREQ - CA
- ✓ 4th Meeting: Feb 2020 — Milan CESI - IT
- ✓ 5th Meeting: Jun 2020 — Online
- ✓ 6th Meeting: Aug 2020 — Online
- ✓ 7th Meeting: Dec 2020 — Online
- ✓ 8th Meeting: Feb 2021 — Online
- ✓ 9th Meeting: Jun 2021 — Online
- ✓ 10th Meeting: Sep 2021 — Online
- ✓ 11th Meeting: Dec 2021 — Online
- ✓ 12th Meeting: Mar 2022 — Online
- ✓ 13th Meeting: June2022 — Piteå - SE and online
- ✓ 14th Meeting: Aug 2022 — Paris – FR and online
- ✓ 15th Meeting: Nov 2022 — Baden – CH and online
- ✓ 16th Meeting: Mar 2023 — Lyon – FR and online
- ✓ 17th Meeting: Jun 2023 — Berlin – DE and online
- ✓ 18th Meeting: Sep 2023 — Klaus – AT and online
- ✓ 19th Meeting: Nov. 2023 — Istanbul – TK and online

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Background and Context to Scope

4 main technical brochures for Switchgear Monitoring:

2000 - TB 167 "User guide for the application of monitoring and diagnostic techniques for switching equipment for rated voltage 72.5 kV and above"
➔ **which measured parameters are most effective to monitor the breaker functions**

2011 - TB 462 "Obtaining Value from On-Line Substation Condition Monitoring"
➔ **guides to for an economic evaluation**

2012 - TB 510 "Final Report of the 2004 - 2007 International Enquiry on Reliability of High Voltage Equipment - part 2 Reliability of High Voltage SF6 Circuit Breakers"
➔ **valuable information on failure frequency and modes distribution**

2018 - TB 737 "Non-intrusive methods for condition assessment of distribution and transmission switchgear "
➔ **catalogue of monitoring non-intrusive methods to select from.**

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Background and Context to Scope

The next logical question was:

What to do with the collected data to best manage the switchgear life?

Equipment considered in this TB for consistency with the work done in TB737:

- Transmission and Distribution Circuit Breakers
- Reclosers
- Fault Interrupters, based on different technologies (i.e. gas, vacuum, oil etc.)
- Disconnectors, load switches are also included.

HVDC breakers are out of the scope of the present brochure.

Background and Context to Scope

Main focus:

- How to assess switchgear conditions
  - Mechanical
  - Dielectric
  - Electrical wear
  - Auxiliary circuit degradation…
- What it is done presently by utilities (interviews)
- What are the manufacturers recommending
- Compatibility with Digital Substation (B5)
- Future needs and evolution

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Background and Context to Scope

Not in the scope:

- **Decision structure based on risk and economic impact methods**
  They are part of the common knowledge - Already covered by TB 462
- **Definition of Health index.**
  It was already defined in TB 858 (B3.48) for the whole substation

Aim of this Working Group to "feed" the system with high quality information, which can make it more efficient and reliable.

Structure of the Technical Brochure

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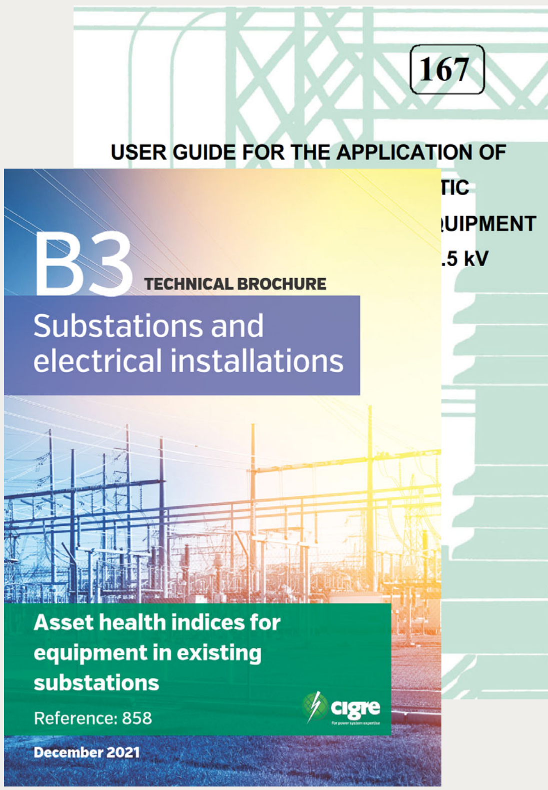
Literature review summary



TB 167 - 2000

Tells which measured Parameters are most effective to monitor the breaker functions

TB 462 – 2011

Provides different methods how to calculate the value of a monitoring system

TB 510 - 2012

Reports the Major and Minor Failure rate frequency

Shows which components fails

TB 737 - 2018

55 non-intrusive or minimal Intrusive condition indicators

TB 723 – 2018

Practical aspects of on-site measurements of SF6 gas

TB 858 – 2021

The Asset Health Index (AHI) is therefore a snapshot indication of health in terms of likelihood to fail."

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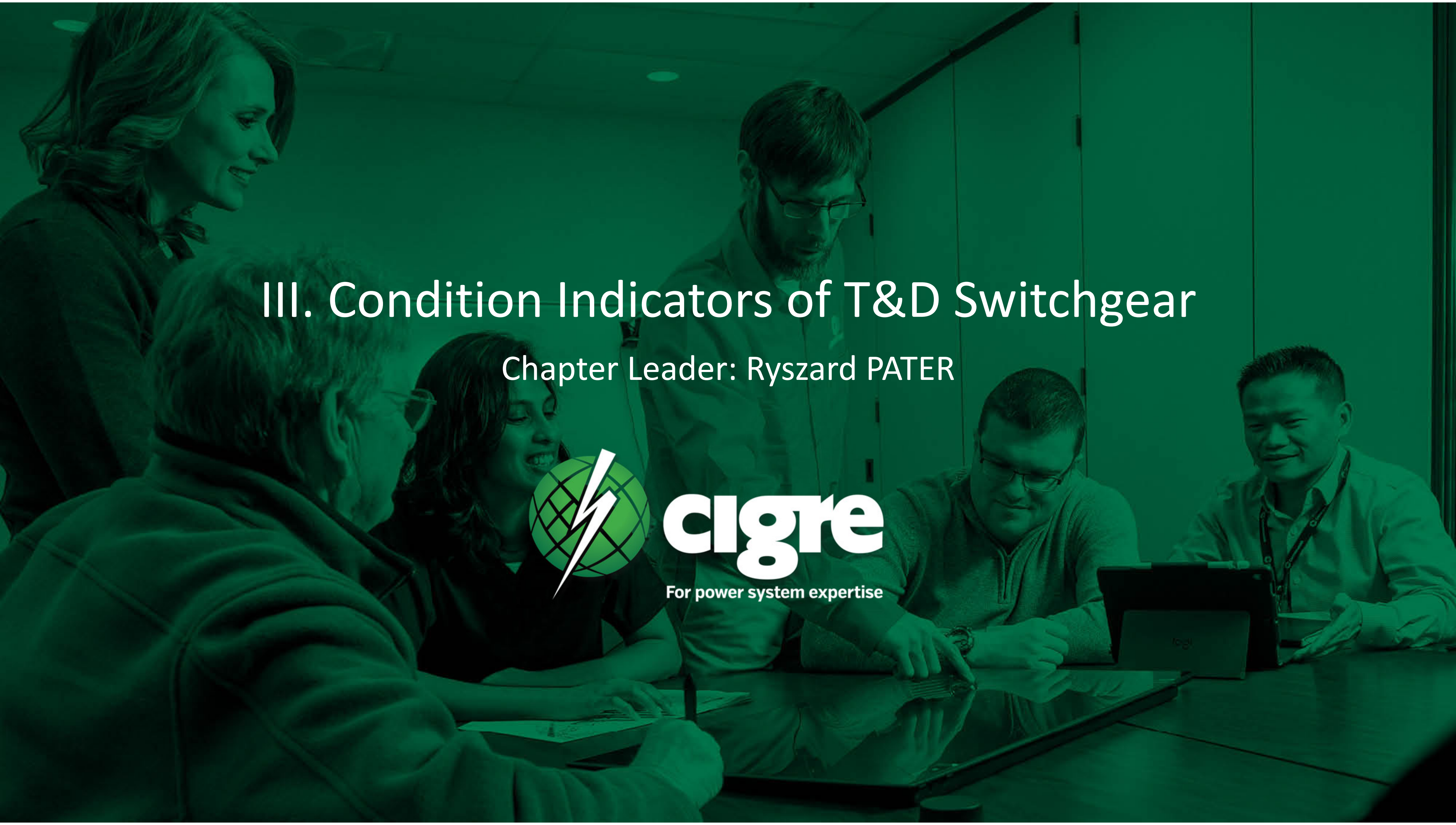
III. Condition Indicators of T&D Switchgear

Chapter Leader: Ryszard PATER



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Condition Indicators of T&D Switchgear - Introduction

- The goal of Chapter 3 is to define the framework for switchgear diagnostics
- The precise definition and terminology is particularly important when integrating information from heterogeneous sources
- Condition indicators (CI) are the central elements of diagnostics
  - Condition Indicator is a quantitative or qualitative value related to the condition of one part or one function of switchgear
- How to obtain the condition indicators?
  - The measurements of physical signals are essentials for obtaining CI
- How to use the condition indicators as a decision tool?
  - Converting the CI to symptoms and relating them to the degradation mechanisms is required for successful diagnosis

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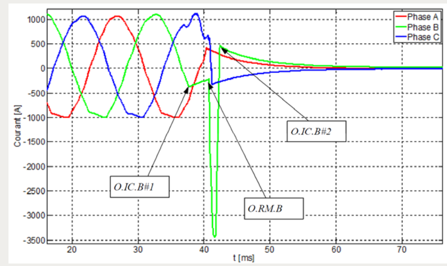
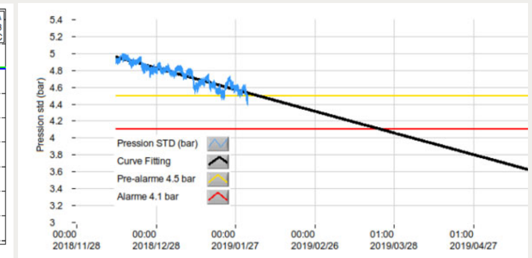
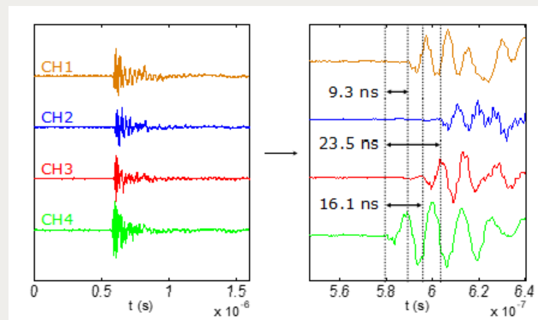
Condition Indicators of T&D Switchgear - Condition measurements

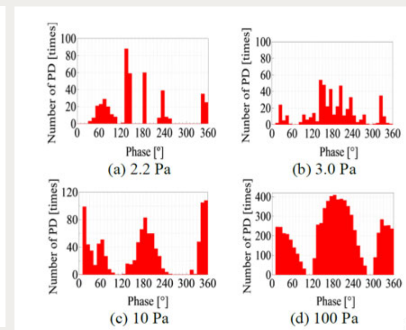
Types of measurements are:

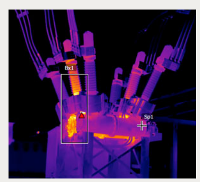
- oscillograms (20kHz)
- stream of sampling values (in digital relays)
- temporal series (regular timing samples)
- single physical values
- state values (dry contacts)
- qualitative values (e.g., high, medium, low)
- cumulative statistics, counts, etc.
- visual inspections and photos or videos
- special measurements such as
  - high resolution (1GHz) oscillograms of EM emissions dues to switching or partial discharges,
  - radiations and imaging: x-ray, ultraviolet, infrared and microwave

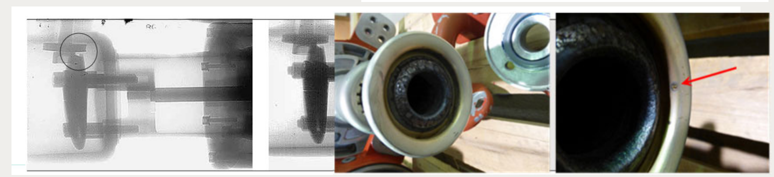












Condition Indicators of T&D Switchgear - Diagnostic methods

- Diagnostic method is a **technology to obtain one or several condition indicators**, based on condition measurements, diagnostic tests or inspections, including sensors and acquisition system, software, signal processing, algorithms, data analysis and visualization tools, etc.
- The condition indicators are usually expressed in quantitative (numerical) or qualitative values. Many diagnostic methods, however, provide as an outcome the images (infrared or x-ray), the reports (text, photo or video) and the more complex information which we call “profile”.
- Profile is defined as a representation in outline or as a distinctive combination of characteristics
- In diagnostics we define several profiles: coil current profile, contact travel profile, etc.
- Actual diagnostic process
  - Users to deal with multiple diagnostic systems and specific, often proprietary, software
  - Missing user-friendly, comprehensive asset management tool considering diagnostics
  - Diagnostic methods generally hide important information which could be reused, integration of information is done at the interpretation level

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Condition Indicators of T&D Switchgear – Indicators and symptoms

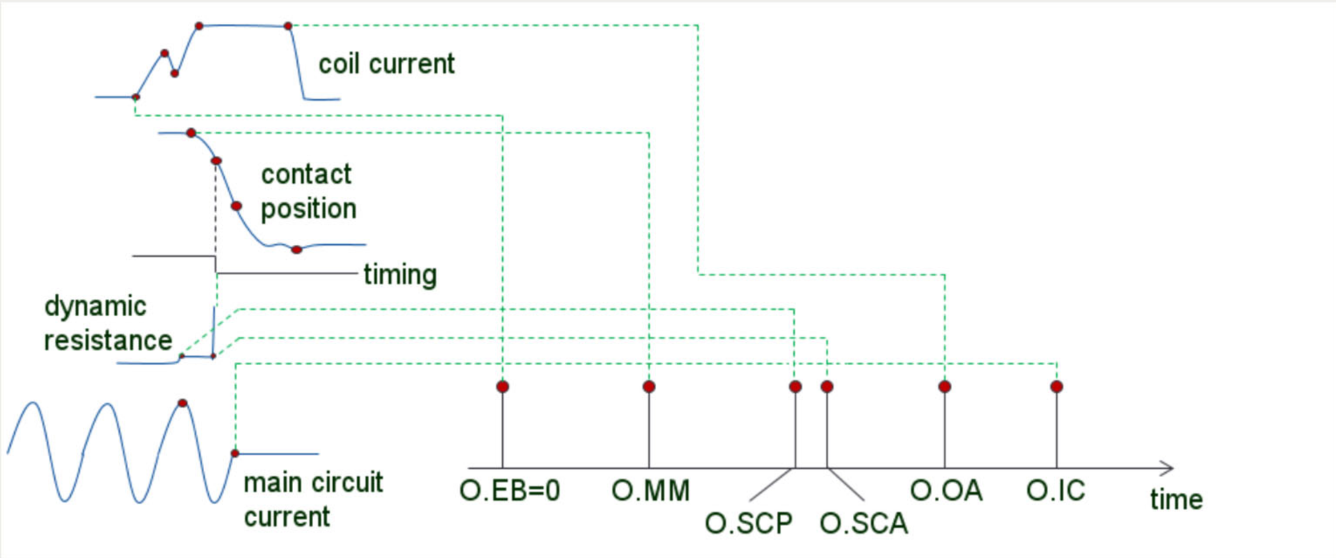
Condition indicator	Diagnostic method [A3.32]	Type o value	Condition indicator	Diagnostic method [A3.32]	Type o value
Timing of auxiliary contacts	Timing	numerical [s]	Gas Dew point	Gas Condition	profile
Number of operations (counter)	Operations Tracking	numerical [count]	Gas condition (purity, by-products, etc.)	Gas Condition	profile
Recharging time (of the op. mechanism)	Drive Mechanism	numerical [s]	Oil condition (insulation)	Oil Condition	profile
Number of recharges without op. (hydr.)	Drive Mechanism	numerical [count]	Contact travel profile	Travel Recording	profile
Coil voltage	Control and aux. circuits	numerical [V]	Stored energy (spring position, pressure)	Drive Mechanism	profile
Coil current profile	Coil Current	profile	Occurrence of re-ignitions or restrikes	Transient EM Emissions	numerical [x/nb], bool
Opening time	Timing (mech. off-duty)	numerical [s]	Partial Discharge Measurement	Partial Discharge	profile
Closing time	Timing (mech. off-duty)	numerical [s]	Xray imaging	Radiographic	imaging
Motor Current Profile	Drive Mechanism	profile	Infrared Thermography	Infrared Thermography	imaging
Ambient Temperature	Temperature	numerical [Celsius]	Vibroacoustic analysis	Vibration	profile
Cabinet temperature and temp. rise	Temperature	numerical [Celsius]	Bounces of primary contacts while closing	Timing (mech. off-duty)	numerical [s] or bool
Auxiliary Voltage	Control and aux. circuits	numerical [V]	Static Contact Resistance	Contact Resistance	numerical [Ohm]
Heater Voltage / Current	Control and aux. circuits	numerical [V]	Dynamic Contact Resistance	Contact Resistance	numerical [Ohm]
Gas Pressure / Density	Gas Condition	profile	Contact wipe (penetration of main contacts)	Travel Recording	numerical [Ohm]
Gas leak (detection / rate)	Gas Condition	profile	Number of fault operations	Operations Tracking	numerical [count]
Arcing time	Timing (elect. in service)	numerical [s]	Malfunctioning or alarm in contr. Switching	Control and aux. circuits	qualitative
Break time	Timing (elect. in service)	numerical [s]	Grading capacitor - capacitance and tan δ	Power Factor / Capac.	numerical [pF, rad]
Pre-arcing time	Timing (elect. in service)	numerical [s]	Circuit Breaker capacitance and tan δ	Power Factor / Capac.	numerical [pF, rad]
Make time	Timing (elect. in service)	numerical [s]	Visual inspection	Visual Inspection	text, photo or video
Cumulative interrupted current (I^2*t)	Operations Tracking	numerical [wear]			

- Symptom is the sign of the potential problem; it is defined as a condition indicator having a value out of threshold
- For numerical type CI, the definition of threshold is straightforward
- For images and profiles, the more complex criteria are required

Condition Indicators of T&D Switchgear – Sequence of event

Notation and algorithms

O.FCC.A.M1 - end of movement of main contacts of module 1 in phase A
F.PCA.B.M1.E2#1 - prestrike in module 1, element 2 in pole B
O.RM.A.M1.E2 = 55 ms - restrike occurred at 55 ms from the beginning
F.MCA.A.M2.E1 = n(47.3; 0.9) - value could be a distribution, n for normal
Max {F.MCA.p} <= "1/4 of a cycle", p = A, B, C simultaneity of poles, IEC 62271-100 §5.101



Condition Indicators of T&D Switchgear – Integration of diagnostics

- A comprehensive data structure with underlying protocol is proposed to store, exchange and analyze any data gathered during a CB operation
- A distributed system for monitoring CBs with simple sensors or monitoring devices contributing to a common data structure is possible
- Data interoperability for heterogeneous data analysis (from different systems) in a common and coherent environment is ensured
- Models are described on how to apply this data structure to evaluate condition indicators and statistical analysis
- This data structure is aimed to be eventually implemented in IEC 61850
- This research is ongoing. Further development and applications are expected.

Correlation Table

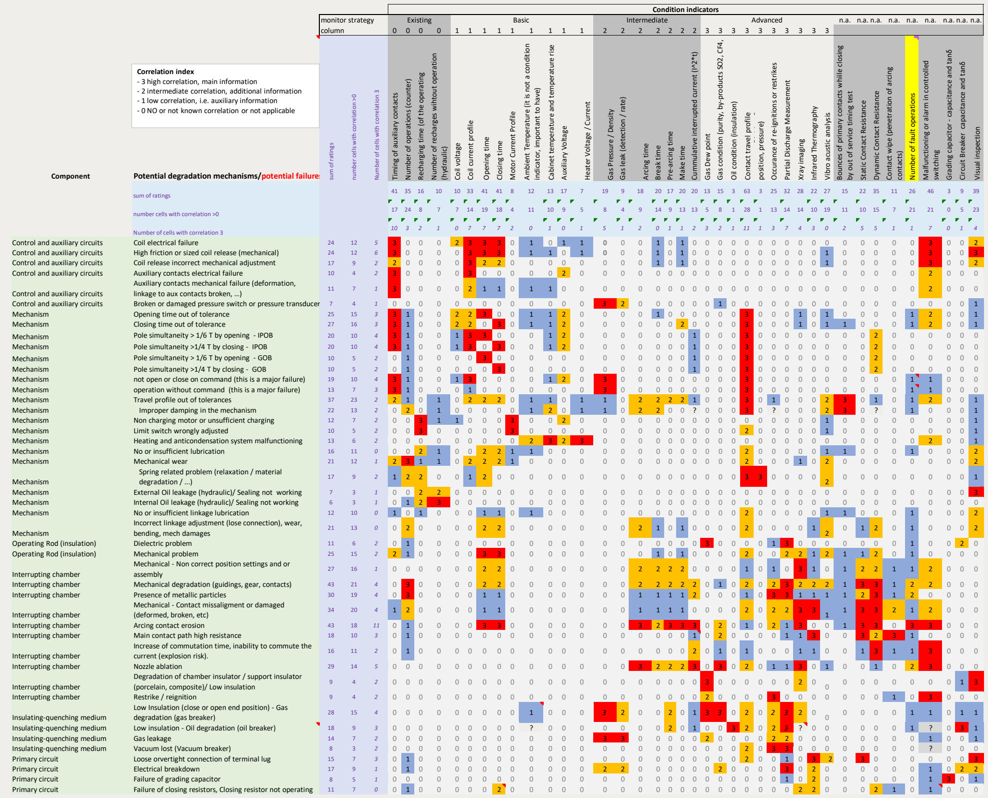
- 39 condition indicators
- 46 pot. degradation mech.
- 4 correlation levels

Correlation level

3	high correlation, main information
2	intermediate correlation, additional information
1	low correlation, i.e. auxiliary information
0	NO or not known correlation or not applicable

Condition indicators

Potential degradation mechanisms



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Correlation Table

46 potential degradation mechanisms

Grouped by:

1. Control and auxiliary circuits
2. Mechanism
3. Operating Rod (insulation)
4. Interrupting chamber
5. Insulating-quenching medium
6. Primary circuit

	Control and auxiliary circuits	Coil electrical failure
	Control and auxiliary circuits	High friction or sized coil release (mechanical)
	Control and auxiliary circuits	Coil release incorrect mechanical adjustment
1	Control and auxiliary circuits	Auxiliary contacts electrical failure
	Control and auxiliary circuits	Auxiliary contacts mechanical failure (deformation, linkage to aux contacts broken, …)
	Control and auxiliary circuits	Broken or damaged pressure switch or pressure transducer
	Mechanism	Opening time out of tolerance
	Mechanism	Closing time out of tolerance
	Mechanism	Pole simultaneity > 1/6 T by opening - IPOB
	Mechanism	Pole simultaneity >1/4 T by closing - IPOB
	Mechanism	Pole simultaneity > 1/6 T by opening - GOB
	Mechanism	Pole simultaneity >1/4 T by closing - GOB
2	Mechanism	not open or close on command (this is a major failure)
	Mechanism	operation without command (this is a major failure)
	Mechanism	Travel profile out of tolerances
	Mechanism	Improper damping in the mechanism
	Mechanism	Non charging motor or unsufficient charging
	Mechanism	Limit switch wrongly adjusted
	Mechanism	Heating and anticondensation system malfunctioning
	Mechanism	No or insufficient lubrication
	Mechanism	Mechanical wear
	Mechanism	Spring related problem (relaxation / material degradation / …)
	Mechanism	External Oil leakage (hydraulic)/ Sealing not working
	Mechanism	Internal Oil leakage (hydraulic)/ Sealing not working
	Mechanism	No or insufficient linkage lubrication
	Mechanism	Incorrect linkage adjustment (lose connection), wear, bending, mech damages
3	Operating Rod (insulation)	Dielectric problem
	Operating Rod (insulation)	Mechanical problem
	Interrupting chamber	Mechanical - Non correct position settings and or assembly
	Interrupting chamber	Mechanical degradation (guidings, gear, contacts)
	Interrupting chamber	Presence of metallic particles
4	Interrupting chamber	Mechanical - Contact missaligment or damaged (deformed, broken, etc)
	Interrupting chamber	Arcing contact erosion
	Interrupting chamber	Main contact path high resistance
	Interrupting chamber	Increase of commutation time, inability to commute the current (explosion risk).
	Interrupting chamber	Nozzle ablation
	Interrupting chamber	Degradation of chamber insulator / support insulator (porcelain, composite)/ Low insulation
	Interrupting chamber	Restrike / reignition
	Insulating-quenching medium	Low Insulation (close or open end position) - Gas degradation (gas breaker)
5	Insulating-quenching medium	Low insulation - Oil degradation (oil breaker)
	Insulating-quenching medium	Gas leakage
	Insulating-quenching medium	Vacuum lost (Vacuum breaker)
	Primary circuit	Loose overtight connection of terminal lug
	Primary circuit	Electrical breakdown
6	Primary circuit	Failure of grading capacitor
	Primary circuit	Failure of closing resistors, Closing resistor not operating

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Correlation Table

39 Condition indicators

Existing				Basic									Intermediate							Advanced										n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Timing of auxiliary contacts	Number of operations (counter)	Recharging time (of the operating	Number of recharges wihtout operation (hydraulic)	Coil voltage	Coil current profile	Opening time	Closing time	Motor Current Profile	Ambient Temperature (it is not a condition indicator, important to have)	Cabinet temperature and temperature rise	Auxiliary Voltage	Heater Voltage / Current	Gas Pressure / Density	Gas leak (detection / rate)	Arcing time	Break time	Pre-arcing time	Make time	Cummulative interrupted current (I^2*t)	Gas Dew point	Gas condition (purity, by-products SO2, CF4,	Oil condition (insulation)	Contact travel profile	position, pressure)	Occurance of re-ignitions or restrikes	Partial Discharge Measurement	Xray imaging	Infrared Thermography	Vibro acustic analysis	Bounces of primary contacts while closing by out of service timing test	Static Contact Resistance	Dynamic Contact Resistance	Contact wipe (penetration of main contacts)	Number of fault operations	Malfunctioning or alarm in controlled switching	Grading capacitor - capacitance and tanδ	Circuit Breaker capacitance and tanδ	Visual inspection

Ranked as:

- Existing available parameters (now in a typical breaker)
  - What it is possible to achieve with existing available signals without any transducer/sensor
  - Effort: software, storage and communication if online.
- Basic/minimum
  - Every primary function covered. Independent from breaker technology.
  - Effort: adding the required sensors, non-intrusive, interpretation tool.
- Intermediate
  - Additional information to enhance the assessment of degradation mechanisms.
  - Effort: Installation of more complex sensors, extra wiring in the substation to connect the sensors, maybe intrusive. Synchronization requirements among remote signals acquired by different devices. More complex data processing and / or data interpretation
- Advanced
  - Best assessment possible adding little more accuracy or marginally important condition indicators or adding a condition indicator which is more difficult to install o assess.
  - Effort: Best sensor possible independently on the effort to install and assess it, deep understanding of the specific circuit breaker technology / design to get the best possible assessment. Most complex data processing and / or data interpretation tool.

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Correlation Table

For every crossing the correlation has been assigned

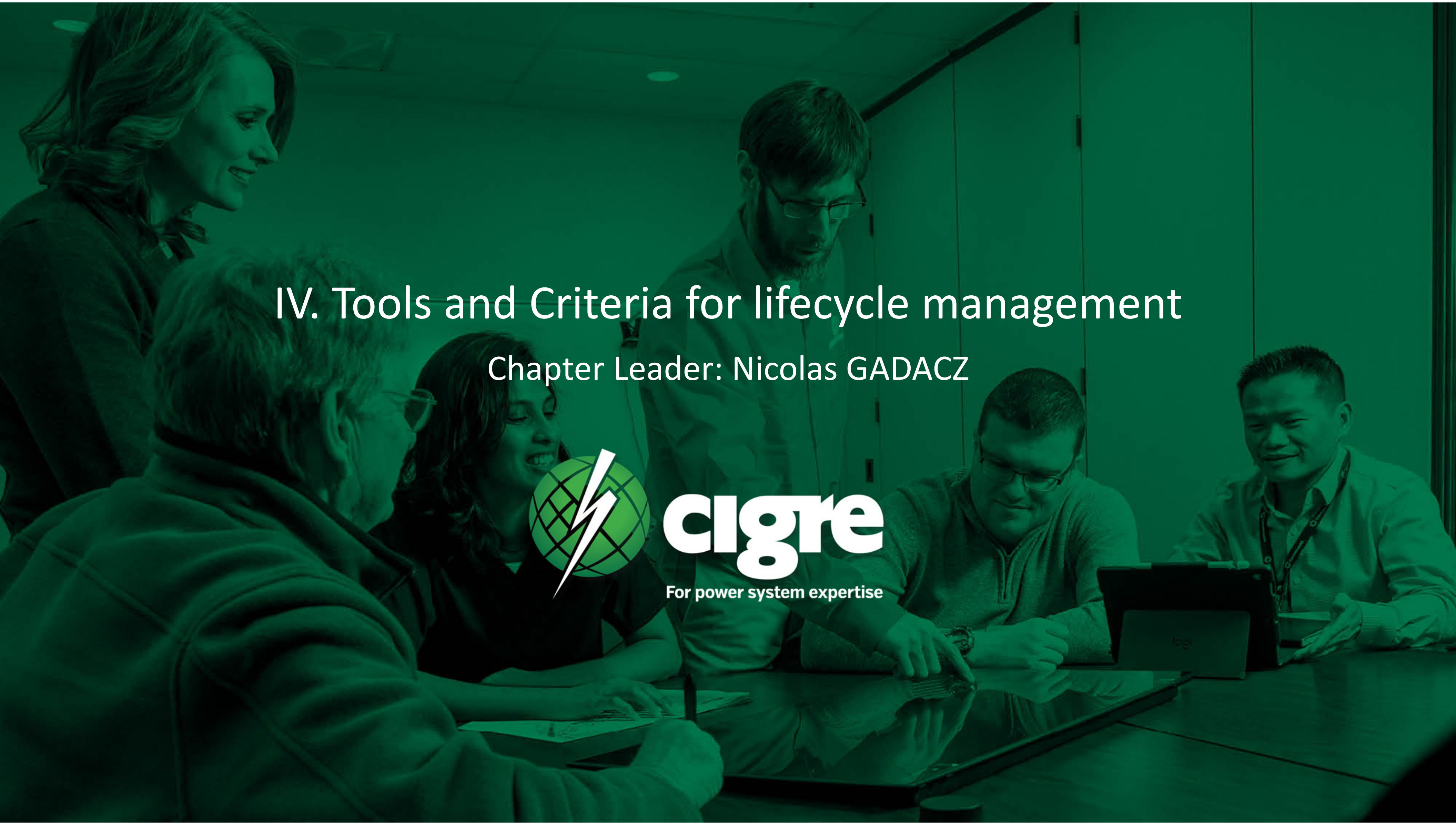
Correlation level

3	high correlation, main information
2	intermediate correlation, additional information
1	low correlation, i.e. auxiliary information
0	NO or not known correlation or not applicable

Component	Potential degradation mechanisms/potential failure	Timing of auxiliary contacts	Number of operations (counter)	Recharging time (of the operating	Number of recharges wihtout operation (hydraulic)	Coil voltage	**Coil current profile**	Opening time	Closing time	Motor Current Profile	Ambient Temperature (it is not a condition indicator, important to have)
Control and auxiliary circuits	Coil electrical failure										
Control and auxiliary circuits	High friction or sized coil release (mechanical)										
Control and auxiliary circuits	**Coil release incorrect mechanical adjustment**						?				
Control and auxiliary circuits	Auxiliary contacts electrical failure										
Control and auxiliary circuits	Auxiliary contacts mechanical failure (deformation, linkage to aux contacts broken, …)										
Control and auxiliary circuits	Broken or damaged pressure switch or pressure transducer										

IV. Tools and Criteria for lifecycle management

Chapter Leader: Nicolas GADACZ



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Tools and criteria for lifecycle management - FMEA

Failure mode and effects analysis

Very well known tool to identify failure modes and mitigate them during design

Link between potential failures (FMEA) and degradation mechanisms (matrix)

Link between potential causes (FMEA) and condition indicators (matrix)

→ It can be done at utility level and used as a complementary tool for Health Index computation

Sub-Assembly	Functions
Drive	• Keep the fully open position • Keep the fully closed position • Must open and close with the defined timing and velocities

Drive Functions	Drive Failures
The drive must **keep** the fully open position	The drive **does not keep** the open position
The drive must **keep** the fully closed position	The drive **does not keep** the closed position
The drive must open and close with the defined timing and velocity	The drive **does not open and close** with the defined timing and velocity

FMEA rev.	Potential Failure Mode	Potential Causes	Effects of Failures	Higher Level Effect	System Level Effect	Probability	Severity	Detection	Risk	Further Investigations	Mitigation Requirements
1.1	Breakdown	Gas density low	Insulator damage		Interrupter does not act as "perfect" insulator	2	4	1	8	Surface quality	Increased filling pressure and/or improve the sealing

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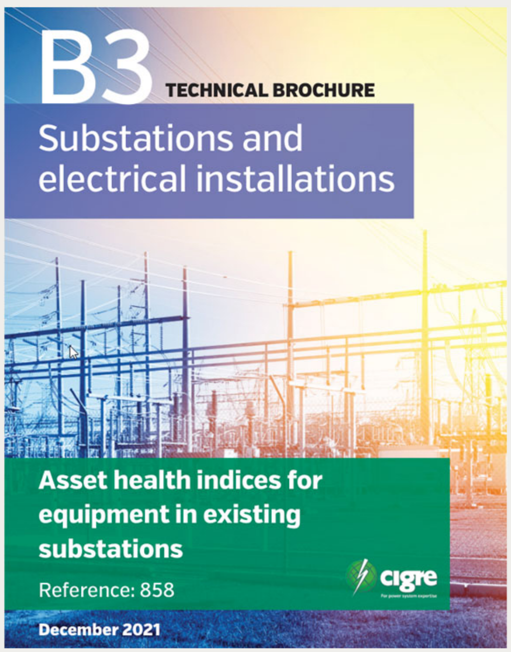
Tools and criteria for lifecycle management – Health Index

How do we **get value** from condition indicators performances assessment?

How to **use data** gathered on a monitored switchgear in a relevant way?



Re-introducing, using and illustrating the concept of "Health Index" (HI) for Switchgear

As defined in TB 858

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J. SMIT
G. BALZER
R. CLERC
P. CREGO
L. DARIAN
A. GOYVAERTS
N. KAISER
C. KOMIYA

Tools and criteria for lifecycle management – Health Index

Purpose of the methodology: position each asset in this table

SHI	Health Index [%]	Comprehension
1 Very good condition	0-5	Continue with inspect and test schedule.
2 Good condition	5-10	Continue with inspect and test schedule.
3 Fair condition	10-25	Intervention to be planned (Maintain, Refurbishment etc)
4 Poor condition	25-50	Some scores are above caution level. Expected life short, Replacement is needed
5 Critical condition	50-100	Some scores are above warning level. Can no longer be operated, immediate action is needed

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Tools and criteria for lifecycle management – Health Index

8 steps to achieve a comprehensive SHI assessment:

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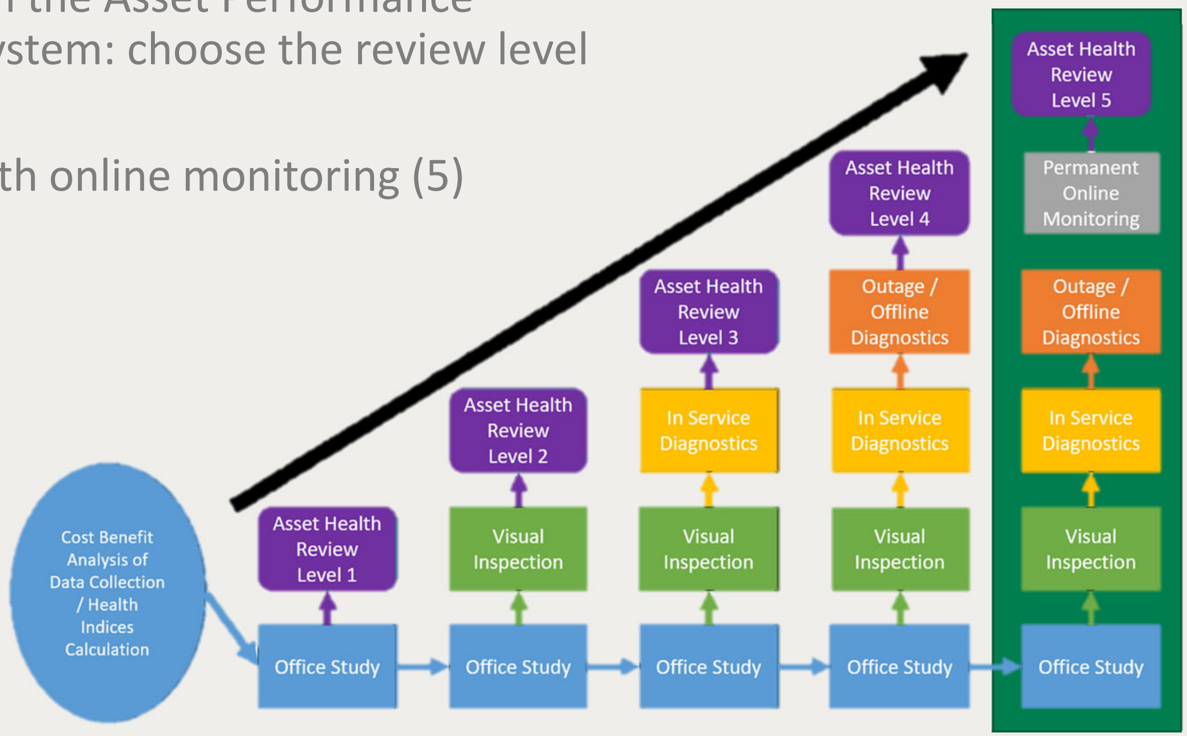
Tools and criteria for lifecycle management – Health Index

For each asset in the Asset Performance Management System: choose the review level from 1 to 5

A3.43 scope: with online monitoring (5)



Scope of A3.43

Tools and criteria for lifecycle management – Health Index

Choose a set of condition indicators that will be used to compute the Switchgear Health Index

Recommendations:

- Select at least 1 condition indicator per primary function to get a relevant overall SHI
- Make sure you evaluate the detectability of each condition indicator (= easiness to detect a change in the condition indicator)

Condition Indicator	Correlation to primary function	Detectability (score 1..10)
Make/Break/Arcing time	Switching function	3
Contact resistance of primary path	Carrying function	5
I2T recording	Switching/Carrying functions	3
Primary circuit insulation resistance	Insulating function	4
Gas leak rate	Switching function	2
Control circuit insulation resistance	Switching function	7

The example has been simplified for this presentation

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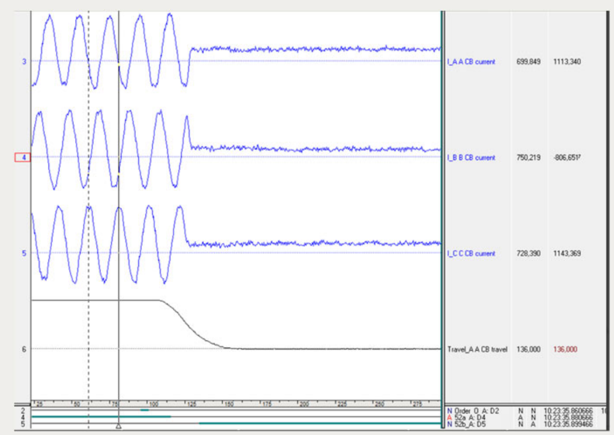
Tools and criteria for lifecycle management – Health Index

Examples of data collection:

- Perform visual inspection of gas pressure or gas density, even if provided by the online monitoring system
  - Enables gas leak detection
  - Overpressure or insufficient gas level can also be detected
- Retreive archive files from online monitoring systems, including alarm history, operation timing data, gas data on a regular basis

An review level 5 does not mean visual inspection is not performed from time to time to complement online monitoring



Tools and criteria for lifecycle management – Health Index

In this simplified view, each condition indicator has been attributed a score based on its value compared to expected normal, alert and alarm values.

Condition Indicator	Correlation to primary Function	Measured value	Score
Gas pressure	Insulation	8.35 bar	0
Gas density	Insulation	45 g/l	0
Gas leak rate	Insulation	0.2%	0
Coil current (opening and closing)	Control Circuit	1.5 A	1
Coil resistance	Control Circuit	38 ohms	1
Number of operations	Mechanical Operations	2600	1
Main Contacts Opening speed	Mechanical Operations	3.0 m/s	2
Arcing contact wear	Arcing contacts	300 kA^2.s	2
Spring recharging time (for each operation)	Spring mechanism	14 s	2

This table has been simplified for this presentation

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Tools and criteria for lifecycle management – Health Index

For each primary function, the Health Index (HI) is computed and using the worst possible score, evaluated on a % scale. On this circuit breaker, the indicator is “poor condition”, and taking a look at each primary functions HI, it is possible to take mitigation actions on different levels:

- Act on the asset
- Act on the primary function of the asset

→ Take decisions based on knowledge of the current state of the asset

Primary function	Score	Worst possible score	HI (%)
Insulation	2	8	25%
Control Circuit	2	8	25%
Mechanical Operations	9	16	57%
Arcing Contacts	2	2	100%
Spring Mechanism	5	6	84%

Overall SHI: 45% - “poor condition”

This table has been simplified for this presentation

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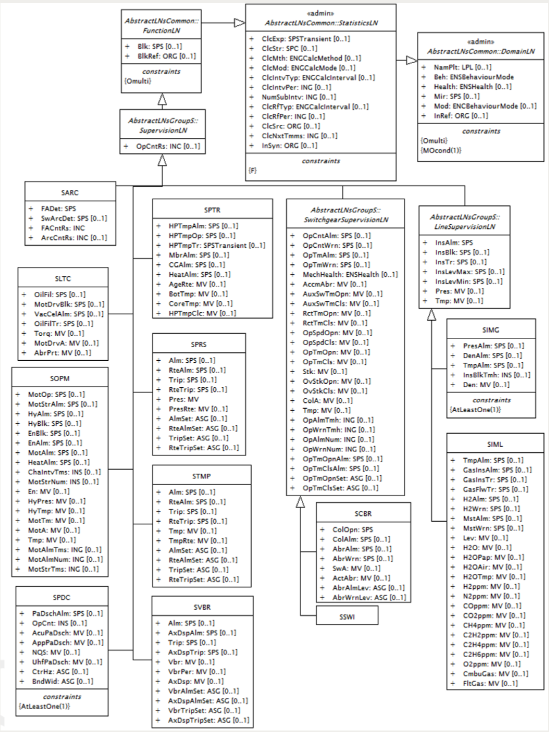
V. Compliance with Digital Substations data management

Chapter Leader: Andreas NENNING

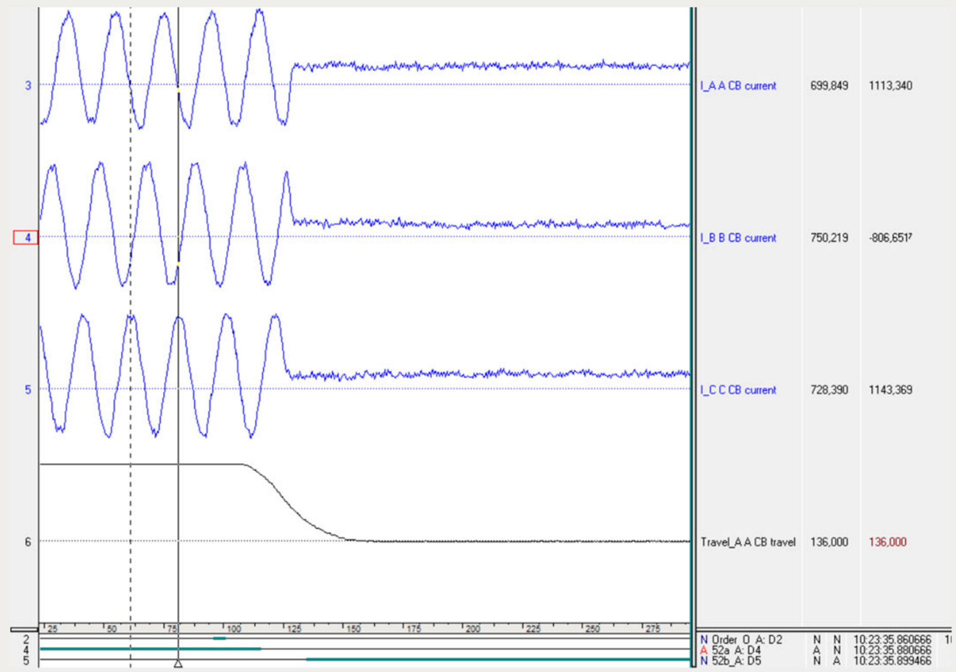
Standardized Communication Interface

- Automation and Industry Standards
  - Profibus, Modbus, CANbus
- Dedicated Power Industry Standards
  - COMTRADE
  - Common Information Model (CIM)
  - IEC 61850



COMTRADE files

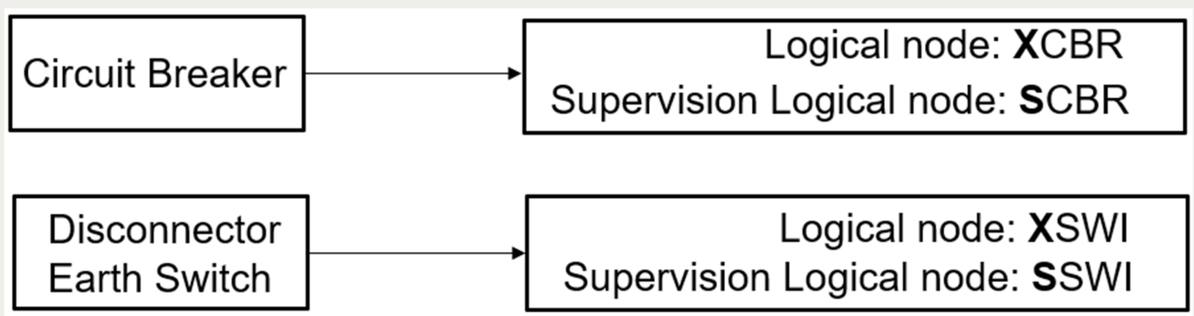
- COMTRADE stays for
  - Common format for transient data
- Used on Intelligent Electronic Devices (IED)
  - Disturbance / fault recorders
  - Monitoring devices
- Standardized
  - IEC 60255-24
  - IEEE C37-111



IEC 61850

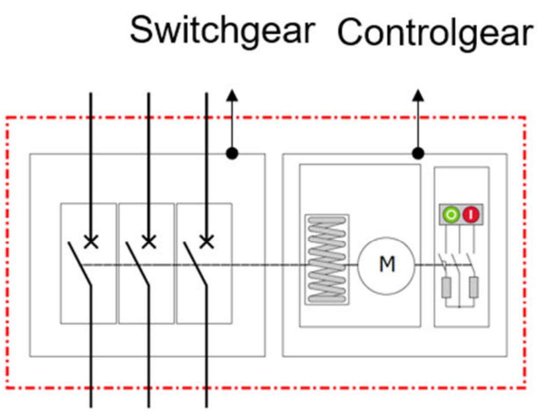
Standard series includes:

- Data models → called Logical Nodes (LN)
- Services
- System configuration language



IEC 61850 – Current Implementation of LN SCBR

Real World | Digital World [Logical Node Name]



→ Circuit Breaker [SCBR]

> Operation time open/close [OpTmOpn / OpTmCls]
> Operation speed open/close [OpSpdOpn / OpSpdCls]
> Auxiliary switches timing open/close [AuxSwTmOpn / AuxSwTmCls]
> Reaction time open/close [RctTmOpn / RctTmCls]
> Overstroke open/close [OvStkOpn / OvStkCls]
> Contact stroke [Stk]
> Coil current [ColA]
> Cumulated abrasion [AccAbr]

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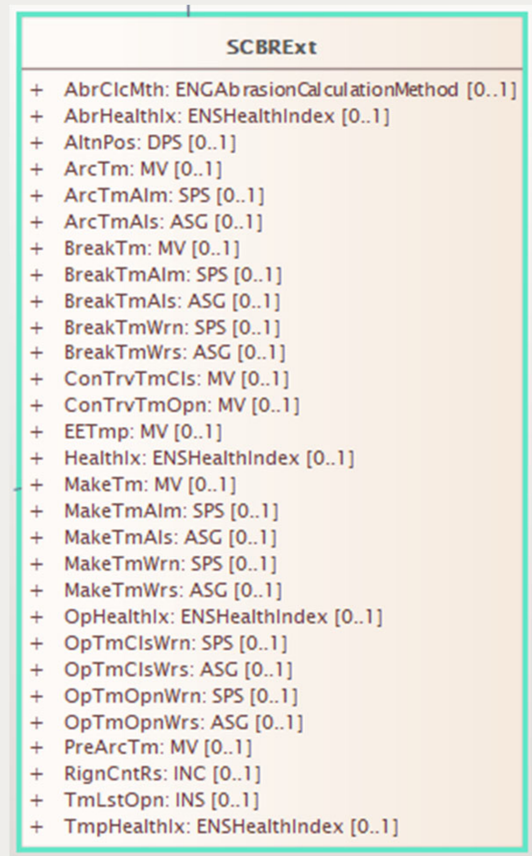
Logical Node Evolution

- IEC Working Group 90-3
  - created extensions to Logical Nodes

- Extension to LN SCBR → SCBRExt
  - AbrHealthIx
  - OpHealthIx
  - TmpHealthIx
  - ArcTm
  - BreakTm
  - MakeTm



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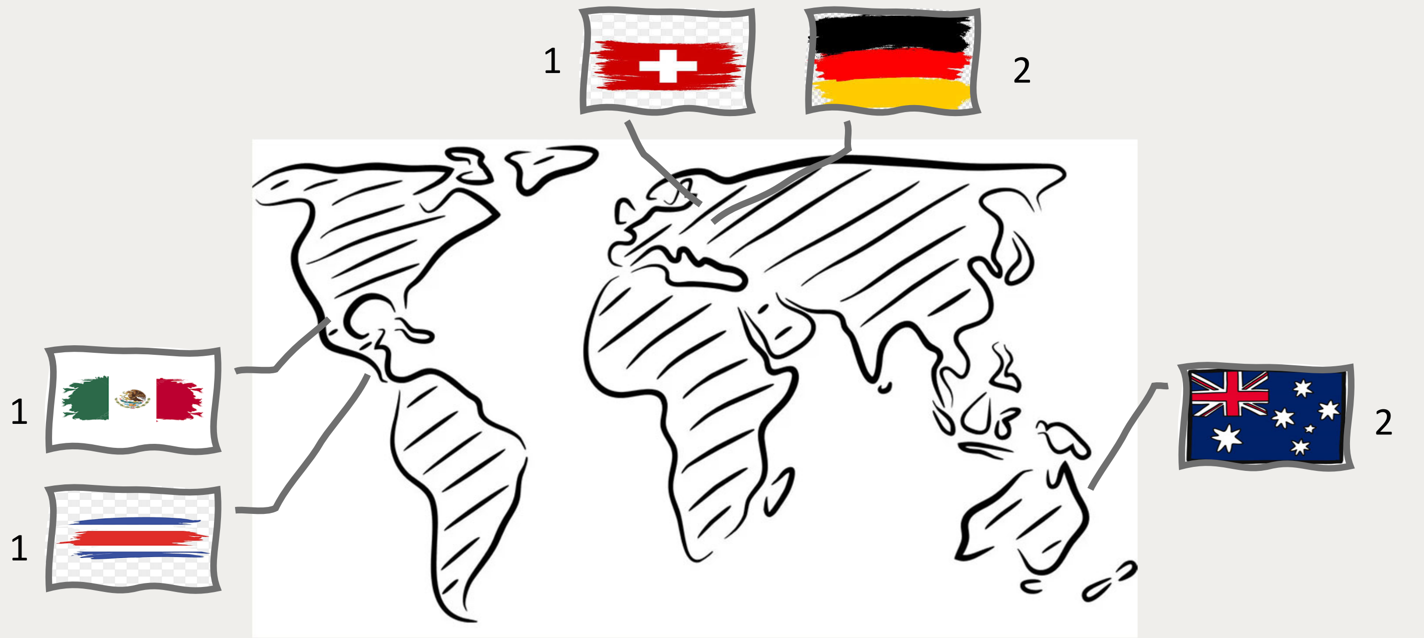
VI. User experiences of end-of-life T&D switchgear

Chapter Leader: Alexander HERRERA

User's experiences of end-of-life of T&D switchgear

Interviews TSO and DSO from different parts of the world

7 Utilities interviewed until now



User’s experiences of end-of-life of T&D switchgear

Interview structured around the following main points:

- Monitoring systems
- Maintenance strategy
- End-of-life decisions
- Asset performance process
- Future trends
- Next steps

User’s experiences of end-of-life of T&D switchgear

Example of questions asked

1. Please describe your asset fleet. [Kind of assets: transformers, CB, overhead lines, …]
2. Can you provide some more details about your switchgear? [Amount, Age, CB types, Insulation medium, Avg. amount of CB operations per year]
3. Do you perform offline monitoring or condition assessment measurements on switchgear? [What test methods? Timing tests, Contact Resistance, Motion analysis, SF6; How often?, on which kind of circuit breakers, protecting which kind of assets]
4. Do you use online and offline monitoring systems together? [Motivation? How do you decide which approach is used on which asset?]
5. Do you have a maintenance strategy in place? [What kind? Run to failure, time-based, condition-based, predictive, …]
6. Do you have end-of-life experience with your assets? [% of assets reaching end-of-life every year, …]
7. Do you have an Asset Performance Process in place? [e.g. Inventory - Assess Condition – Determine Health Index – Maintain / replace, …]
8. Do you use some kind of “Health Index” within this process? [How do you calculate such index]

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Main outcomes

- Condition Based Maintenance & on-line monitoring applied to Transformers and GIS
- Time Based Maintenance is still quite common for Switchgear.
- Condition Based Maintenance mainly relying on periodic Off-line periodic diagnostic.
- On-line monitoring systems only installed on critical assets with strategic importance
- Main concern: monitoring system life-time shorter than asset life-time (factor2)
- Beside specific asset replaced based on condition, End-of-life decision is mainly driven by the asset age:
  - 40 years average
  - 60 years for GIS application
  - 20-25 years for secondary equipment
- Asset performance process is different from every company, still in learning phase with frequent changes and upgrades

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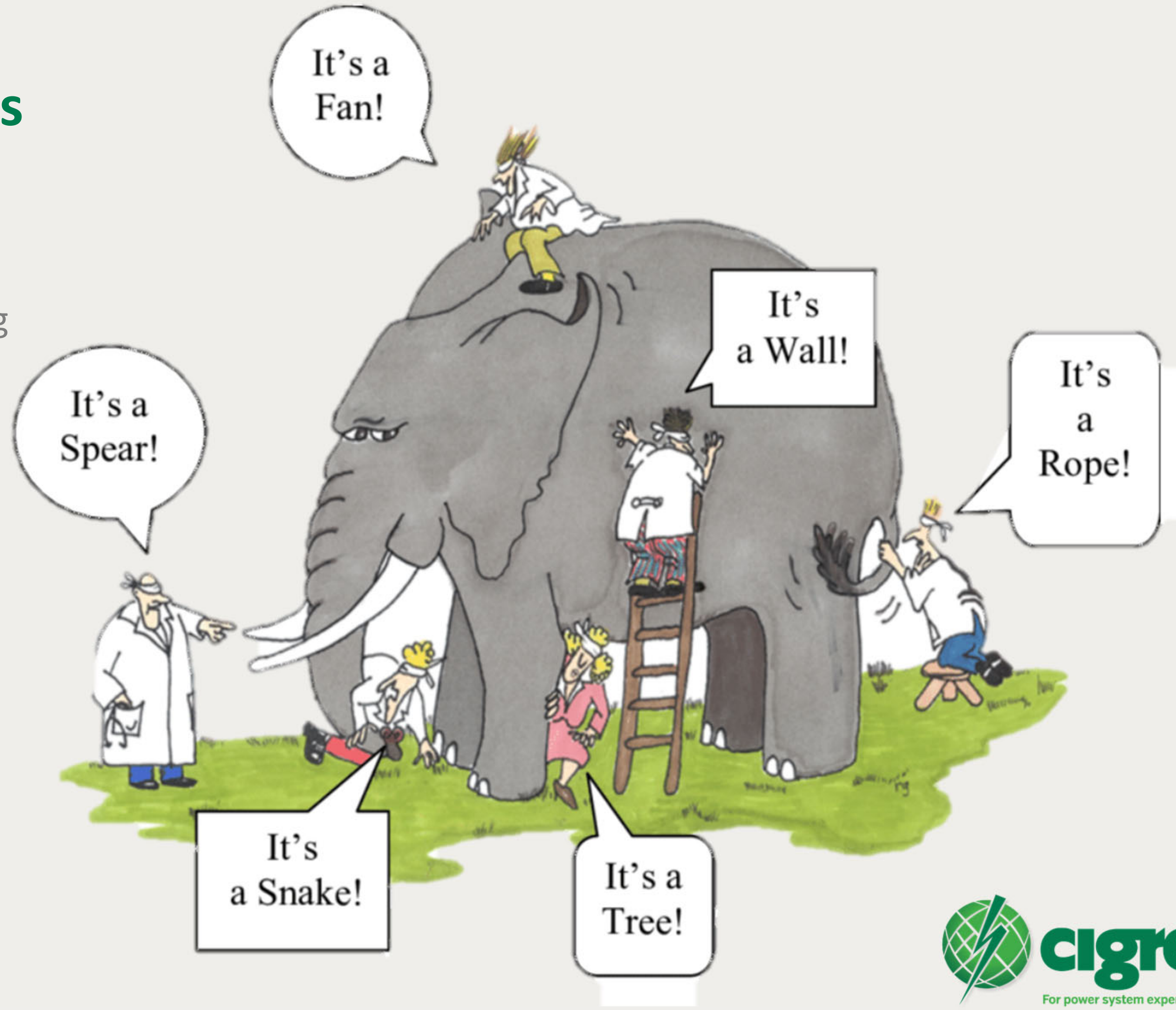
VII. Future needs and trends

Chapter Leader: Javier MANTILLA

Future Needs and Trends

Artificial Intelligence

Use of AI in data analysis and interpretation in condition monitoring



Future Needs and Trends

Data Management

i. Availability, collection, processing and selection:
   - The amount of information, formats and frequency will keep being a variable. Hardware and storage capacity will be a challenge.
   - Exhaustive data collection. Strict requirements (measured quantities, sampling frequency, storage, etc.) defined according to the application.
   - Increased availability of historical data for training AI and ML models with higher accuracy requirements.

ii. Literacy
   - Increase literacy in AI and ML applications in power systems as they become widespread.

iii. Governance
   - Established structure and regulations constantly evolving to accommodate new data and applications.

iv. Legacy
   - More efforts and tools required as AI penetrates all aspects of the T&D industry.

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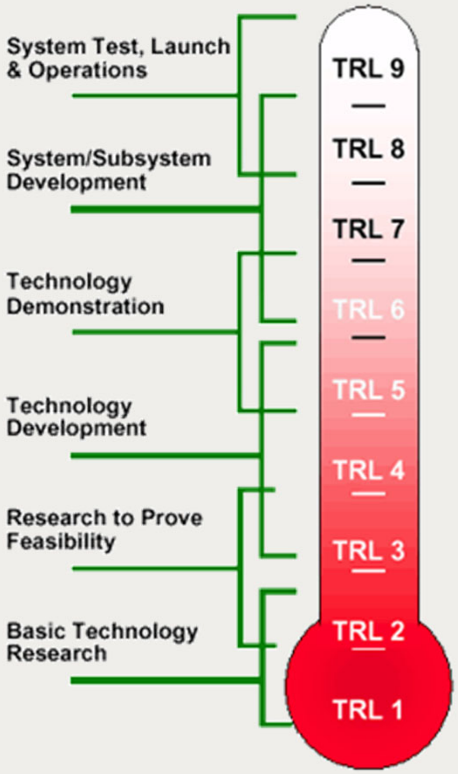
Future Needs and Trends

Machine Learning

i. The main challenge addressed is the constant evolutive nature to the tools (e.g. software, hardware) and the perceived and real level of maturity that could be asymmetric depending on the application.

ii. The tools use and acceptance also present a challenge. What is good today might/likely not be tomorrow. Risk of confusion…



Future Needs and Trends

Cybersecurity

i. Cybersecurity
   - Power systems must be resilient to cyber-attacks of different nature, defined in the STRIDE threat model.

ii. Data collection and storage

iii. Others/ongoing…

Top 10 industries targeted 2019 vs. 2020

Top 10 industries ranked by attack volume, 2020 vs. 2019 | Source: IBM Security X-Force

Sector	2020 rank	2019 rank
Finance and insurance	1	1
Manufacturing	2	8
Energy	3	9
Retail	4	2
Professional services	5	5
Government	6	6
Healthcare	7	10
Media	8	4
Transportation	9	3
Education	10	7

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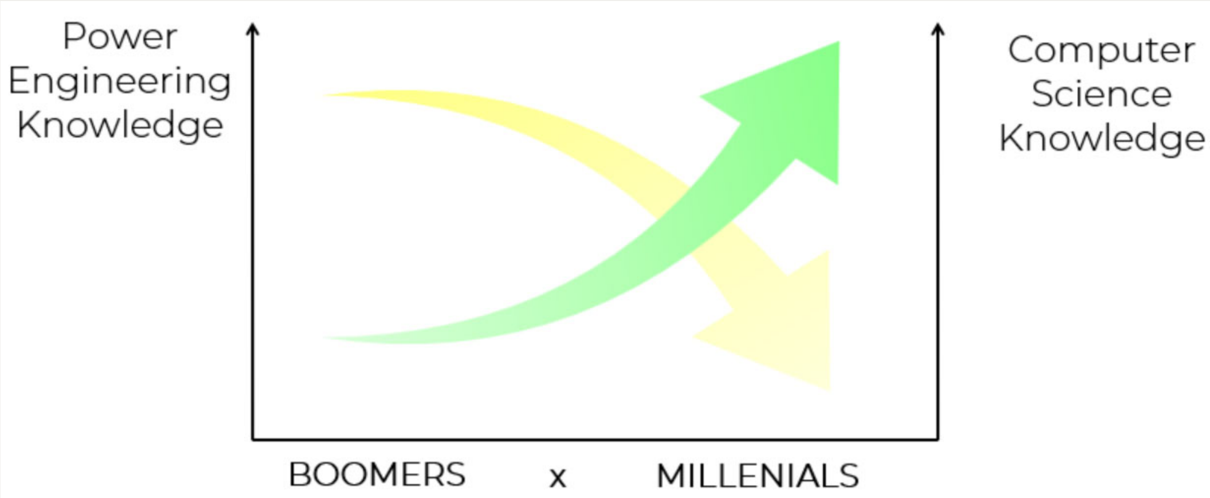
Future Needs and Trends

Expertise renewal



'The industry environment has changed radically in the last years. There used to be a large powerful workforce and a depth of knowledge with limited computer power. Now there are large powerful computers and a small workforce with a limited depth of knowledge' [TB 737]

Future Needs and Trends

Ethics

There is not yet consensus on what constitutes "Ethical AI": just as there are very many ethical schools in philosophy, each of which with their own definition of what is "ethical".

Main topics addressed:

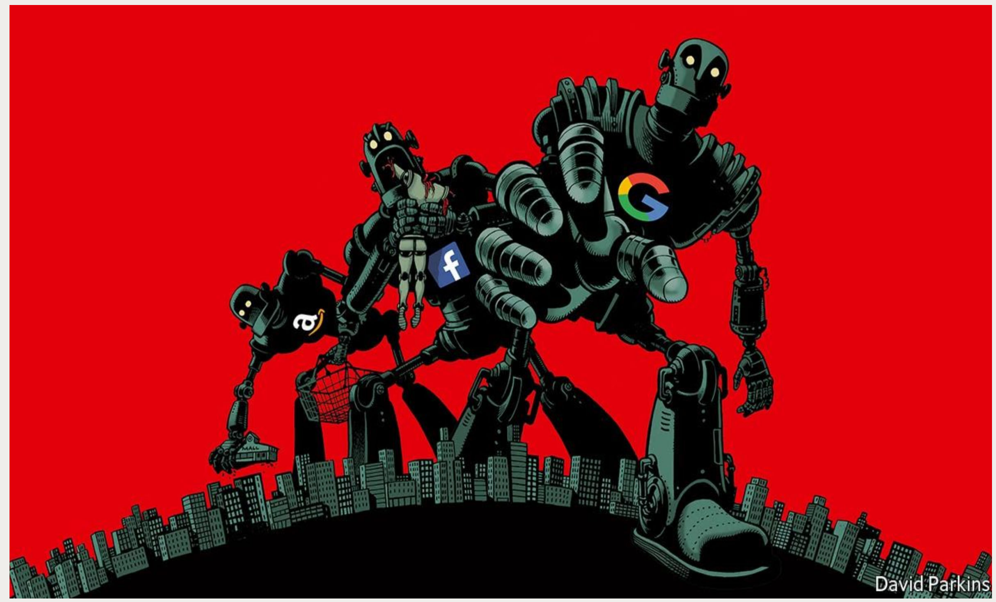
i. Privacy
   - Applications of AI techniques to power systems must comply with strict data privacy requirements to prevent all possible sorts of data breaches.

ii. Monopolistic AI

iii. Ownership (Web 3.0)

iv. Environmental

v. Others/ongoing…



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Outlook

- 1st Technical Brochure Draft by May 2024
- Presence at Paris Session 2024

Milestone	Planned	Forecast	Actual Date
Initial Approval from Technical Committee			Nov 2018
Final Draft TB for SC review	Jun 2021	Dec 2022	
Electra Article	Sep 2021	Mar 2023	
Final draft	Dec 2021	June 2023	
Technical Brochure published	Mar 2022	Dec 2023	
Tutorial Presentation	Jun 2022	March 2024	

Q&A session

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