B1 Themadag 24-09-2025
Maintenance

Connecting the past with the future

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For power system expertise

What Lies Ahead?

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- Minister of Climate and Energy:
  ‘the North sea powerhouse towards the year 2030 up to 21 GW’

CO_2-vrije elektriciteitsproductie, flexibiliteit en regelbaar vermogen

Het kabinet streeft naar een CO_2-vrije elektriciteitssector in 2035.[1] Over de afgelopen jaren zijn meerdere maatregelen genomen die bijdragen aan dit toekomstige doel. Op Europees niveau zorgt het *Emission Trading System (ETS)* voor CO_2-reductie door een afnemend aantal jaarlijks uit te geven emissierechten, welke in 2040 nul zullen zijn. Op nationaal niveau wordt via de Wet verbod op kolen bij elektriciteitsproductie het gebruik van kolen voor elektriciteitsproductie vanaf 2030 verboden. Daarnaast heeft het kabinet de ambitie de uitrol van windenergie op zee flink te versnellen, met als doel de opwekking van 21 GW rond 2030, en worden er voorbereidingen getroffen voor de bouw van twee nieuwe kerncentrales. Al deze maatregelen leiden ertoe dat de CO_2-uitstoot van de elektriciteitssector over de aankomende periode significant zal afnemen. Door (flexibele) elektrificatie van vraagsectoren zal er steeds meer hernieuwbare opwek uit zon en wind benut kunnen worden.

- 4000 km High voltage cable installation ‘in next years’
- New design concepts to speed-up (long lengths, trenchless technologies, etc)

TenneT
26K volgers
2 mnd

⚡ TenneT awards mega contract for high-voltage AC cables in the Netherlands and Germany to eight partners.

The transition from fossil to sustainable energy requires an expansion of the electricity grid. To this end, we will be laying around 900 km of high-voltage connections in Germany and no less than 4,000 km of cable in the Netherlands in the coming years.

We do this together with eight partners. They will supply and install AC power cables for the 110, 150, 220 and 380 kV onshore high voltage connections in Germany and the Netherlands. The total value of this project is estimated at 1.5 billion euros.

Soon we will be able to install longer cables of up to 5,000 meters in one piece. For comparison: now that is still 1,500 meters. A huge step forward! This will reduce the impact on the environment during construction and reduce the risk of disruptions. 🌳

- The electricity network will double in size

CEO TenneT: Een op drie straten gaat open

Redactie • 27 oktober 2024 10:54

Nederland ondergaat de komende jaren een gigantische verbouwing. Althans, als het ligt aan Manon van Beek, de CEO van netbeheerder TenneT. “Het wordt één van de grootste verbouwingen van Nederland. De Deltawerken vallen er bij in het niet", zegt Van Beek in WNL Op Zondag op NPO1.

Het stroomnet in Nederland is overvol en om dit uit te breiden, moet het land flink op de schop. "We gaan het netwerk verdubbelen. We gaan 700 projecten doen in Nederland. Eén op de drie straten gaat open."

Hiervoor is naast vergunningen volgens Van Beek ook veel ruimte nodig. "We hebben het net helemaal in kaart gebruikt. Als je kijkt naar ons bedrijf, hebben tot 2045 4000 voetbalvelden aan ruimte nodig".

Challenge

‘Wat ons hier heeft gebracht, zal ons niet verder brengen’

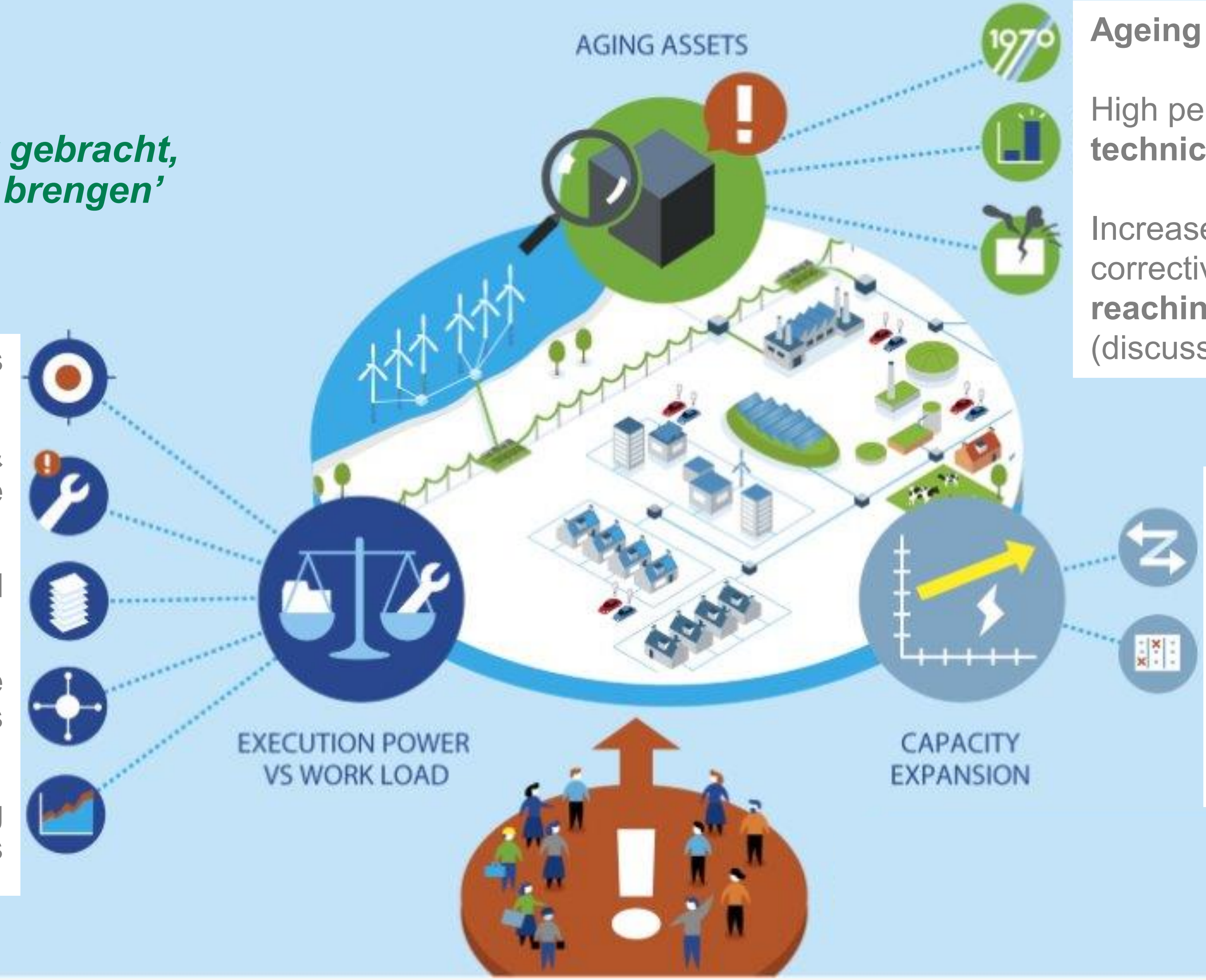
Meeting **reliability** targets

Meeting asset & operational **performance**

Increasing **workload**

Fewer **planned outage** possibilities

Increasing **risk of backlog** with available resources



Ageing asset population

High percentage already **beyond technical design life**

Increased **risk of failures** and corrective actions; also, due to **reaching 100% of capacity** (discussion about overloading)

Increase of installed base due to energy transition

New system concepts (long lengths, installation in ducts, tunnels, etc)

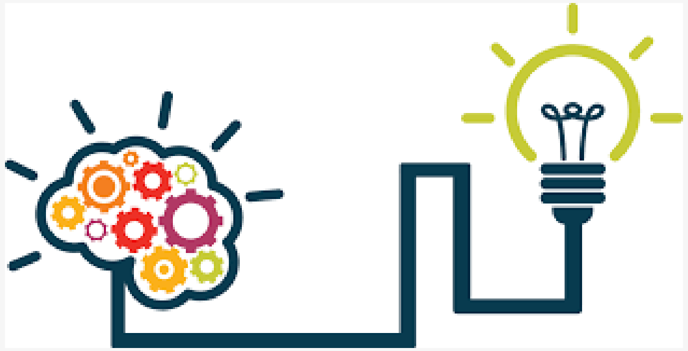
Potential introduction of **quality issues** due to speeding-up

Tools

TB 912
Condition evaluation &
Lifetime strategy

TB 825
Maintenance of
HV cable systems

TB 773
Fault Location
on Land and Submarine Links (AC & DC)



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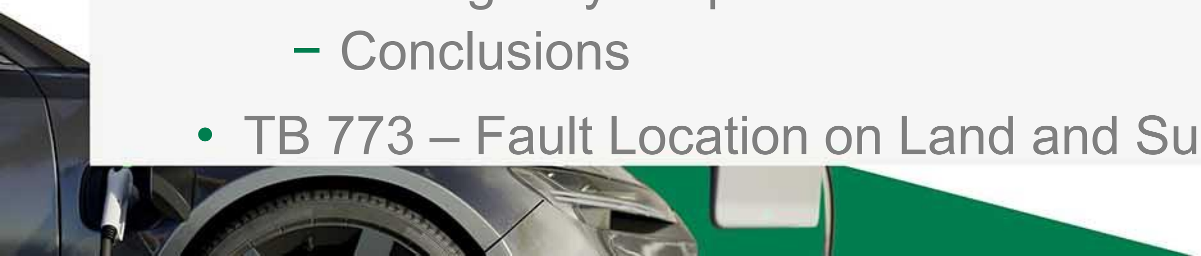

Condition evaluation and lifetime strategy of HV cable systems

TB 912

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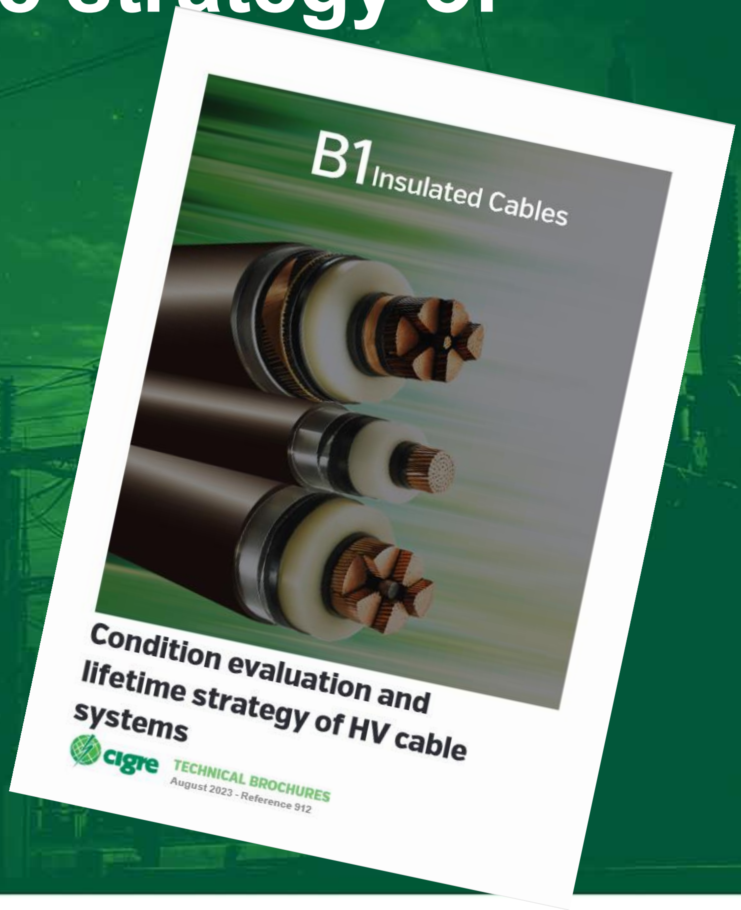
For power system expertise



Introduction

Overview of Lifetime Management Strategies

AM framework ISO 55000

National standards[1]

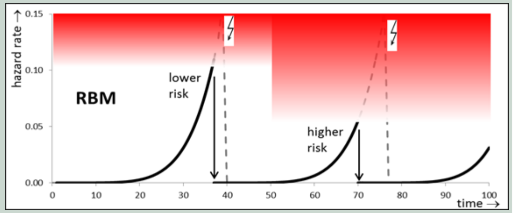
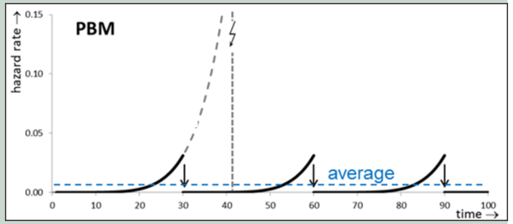
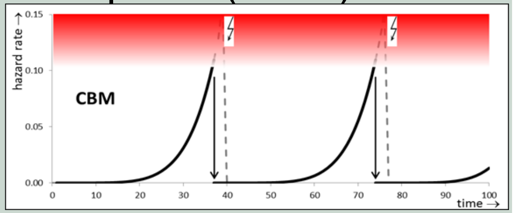
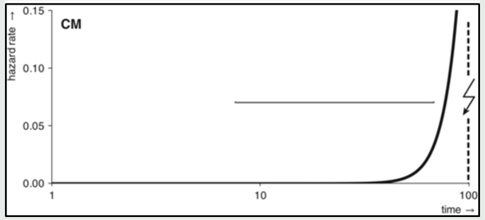
Maintenance:
'all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function'

- Get an insight into and an understanding of the risks inherent in the systems
- Define maintenance activities to minimize the risks
- Reduce maintenance activities and optimize required resources (as much as necessary, as little as possible)
- Reduce unplanned outages due to component failures and increase reliability
- Increase safety and environmental integrity

[1] e.g. DIN VDE0109, DIN31051, NEN-EN13306,ect

Classification of Lifetime Management Strategies

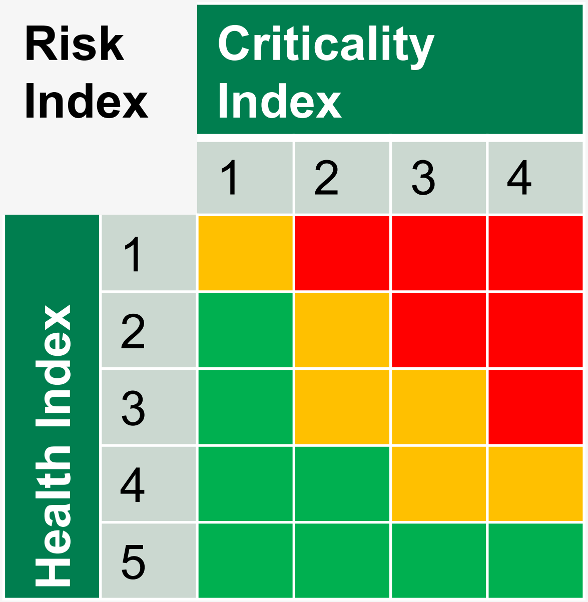
Overview of Lifetime Management Strategies

	Condition known	Condition unknown
Criticality known	**RCM** **Reliability Centered Maintenance** • Consideration of condition and criticality • Optimal usage of asset • Highest effort for setting up the maintenance system  	**TBM** **Time Based Maintenance** • Suitable for assets with time-dependent ageing behaviour • Periodic activities based on schedule • Prioritization based on criticality • Might lead to premature decommissioning 
Criticality unknown	**CBM** **Condition Based Maintenance** • Condition assessment required (Data!) • No consideration of asset criticality  	**CM** **Corrective Maintenance** • Action taken only in case of an event • Suitable for assets with low criticality 

Reliability Centered Maintenance (I/II)

Overview of Lifetime Management Strategies

- Risk Index (RI): indicator based on **condition** and **criticality** of an asset
  - Condition assessed by means of a **Health Index (HI)**
  - Criticality assessed by means of a **Criticality Index (CI)**



- Typical aspects contributing to the Health Index:
  - **Static data** – system length, design, cable age
  - **Statistical data –** failure rate, failure events
  - **Condition data –** diagnostic tests, laboratory tests
  - **Operational data** – loading vs. time (→ Arrhenius, IPM), maintenance

- Information about **condition** is key for RCM and CBM:
  On-line measurements/ Inspections; off-line diagnostics; desktop study

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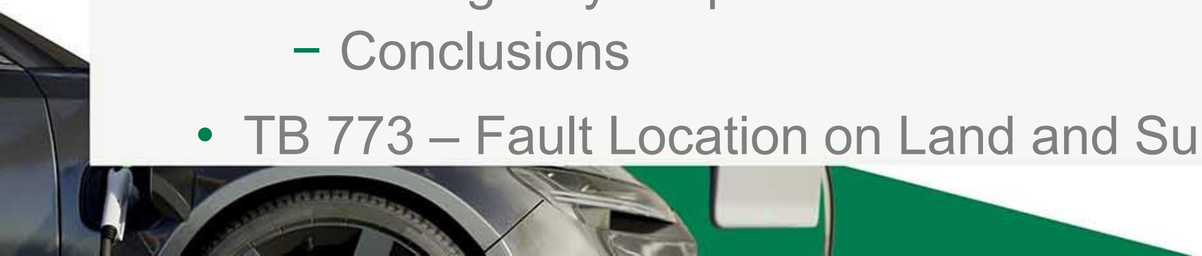


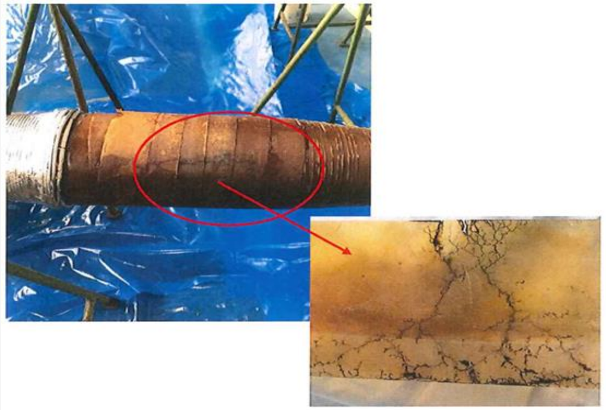
Overview (I/II)
Possible Reasons for End of Life (EoL)

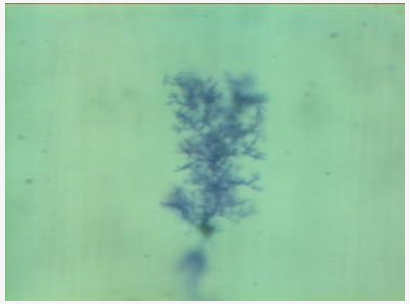
End of Life (EoL):
'moment in time when cable system is decommissioned'

Criteria

Criticality index ← Non-Technical

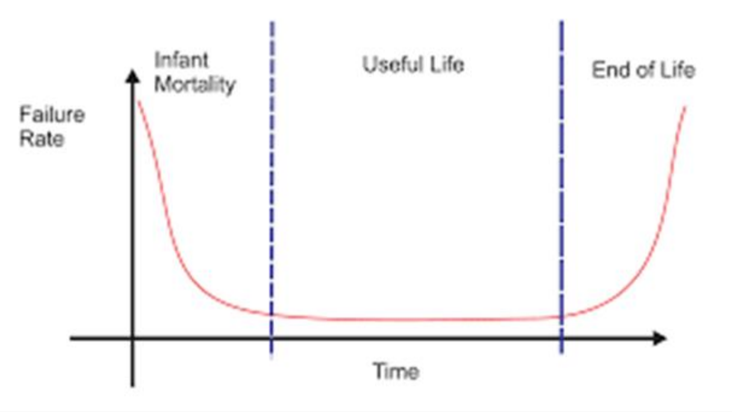
Health index ← Technical





Overview (II/II)
Possible Reasons for End of Life (EoL)

- **Technical criteria:** associated with ageing and degradation of the cable system
  - **Failure modes**:
    - Classified by FME(C)A for all different components (cable/ joint/ terminations) in the system and different technologies (fluid filled/ mass impregnated/ extruded)
- **Non-technical criteria:** external factors influencing the decision for EoL
  - **Economic** reasons:
    - maintenance cost (**OPEX**) vs. replacement cost (**CAPEX**)
    - economical impact of a failure: missing revenues, penalties



  - **Strategic** reasons:
    - unacceptable **consequences** in case of failure
    - Increasing failure rate
    - change of the **nominal technical characteristics** of the installation
    - change of **regulatory requirement** in terms of the environment (e.g. pollution caused by an oil filled cable)
    - **Window of opportunity** for replacement

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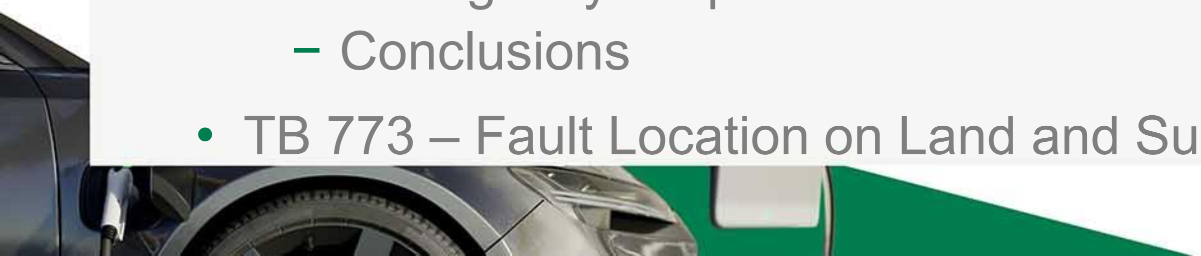
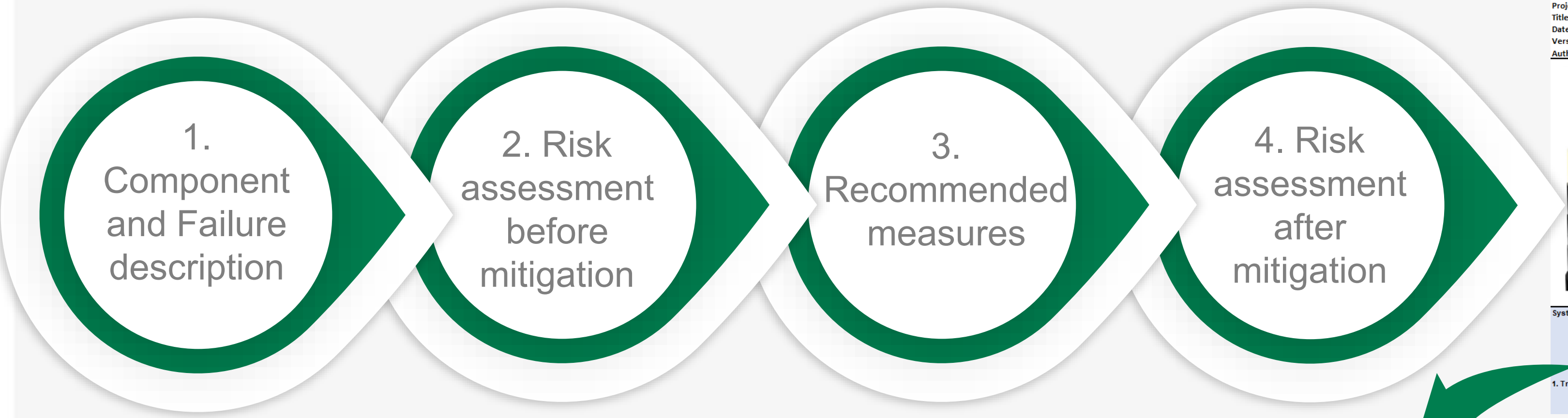
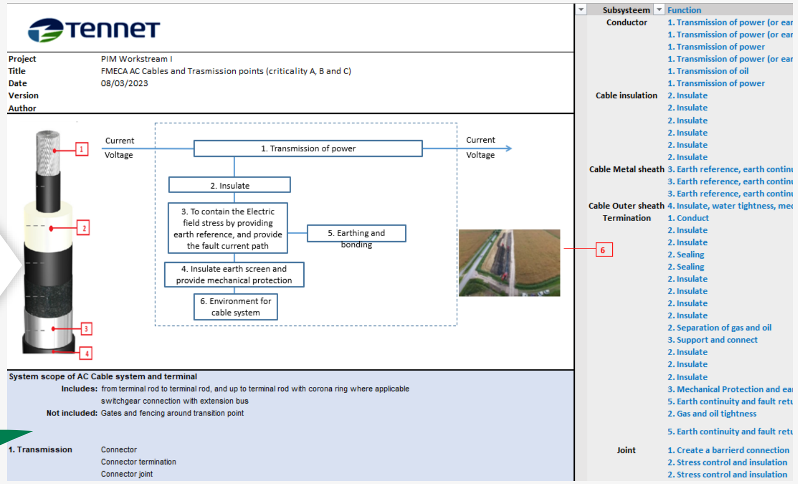


FMECA: TenneT Example (I/II)

Possible Reasons for End of Life




TenneT

Project	PIM Workstream I
Title	FMECA AC Cables and Trasmission points (criticality A, B and C)
Date	08/03/2023
Version	
Author	

System scope of AC Cable system and terminal

Includes: from terminal rod to terminal rod, and up to terminal rod with corona ring where applicable
switchgear connection with extension bus

Not included: Gates and fencing around transition point

1. Transmission	Connector
	Connector termination
	Connector joint

Subsysteem	Function
Conductor	1. Transmission of power (or ear
	1. Transmission of power (or ear
	1. Transmission of power
	1. Transmission of power (or ear
	1. Transmission of oil
	1. Transmission of power
Cable insulation	2. Insulate
	2. Insulate
	2. Insulate
	2. Insulate
	2. Insulate
	2. Insulate
Cable Metal sheath	3. Earth reference, earth contin
	3. Earth reference, earth contin
	3. Earth reference, earth contin
Cable Outer sheath	4. Insulate, water tightness, mec
Termination	1. Conduct
	2. Insulate
	2. Insulate
	2. Sealing
	2. Sealing
	2. Insulate
	2. Insulate
	2. Insulate
	2. Insulate
	2. Separation of gas and oil
	3. Support and connect
	2. Insulate
	2. Insulate
	2. Insulate
	3. Mechanical Protection and ea
	5. Earth continuity and fault retu
	2. Gas and oil tightness
	5. Earth continuity and fault retu
Joint	1. Create a barrierd connection
	2. Stress control and insulation
	2. Stress control and insulation

Component	Subcomponent	7. Function (of the component)	8. Failure Mode (Problem)	9. Failure Cause	10. Internal Effects (on component)	11. System Effects (on Gridnode or Cable)
Cable insulation	XLPE Cable insulation	2. Insulate	Degradation of the insulator layers Breakdown (BRD)	XLPE cable insulation temperature becomes too high due to being continuously overloaded.	Degradation failure	Failure of the cable system
Cable Metal sheath	XLPE Cable Metal Sheath	3. Earth reference, earth continuouty, short circuit withstand, water/gas/oil tighness, mechanical protection	Mechanical damage (excavation, drilling, etc) Structural Deficiency (STD)	XLPE metal cable sheet 'lead/aluminium' layer becomes damaged due to mechanical forces.	Water ingress	Initially degradation of the underlying layers and eventually breakdown, resulting in failure of the cable system.
Termination	Top Connector	Conduct	Fails to function as intended (FTI) Overheating (OHE)	Loose connection with cable conductor.	Compromised connection and overheating resulting in mechanical damage	Failure of termination

Every 3 years FMECA studies are updated

TENNET RISK MATRIX (ASSETS)			IMPACT 1 Minor	2 Small	3 Moderate	4 Considerable	5 Serious	6 Extreme
RESULT AREAS	Secure supply	Outage/Imbalance (SO)	See outage tables in Annex D risk matrix policy	See outage tables in Annex D risk matrix policy	See outage tables in Annex D risk matrix policy	See outage tables in Annex D risk matrix policy	See outage tables in Annex D risk matrix policy	See outage tables in Annex D risk matrix policy
		System Operations corrected overload	< 250 MVA	250 - 500 MVA	500 - 750 MVA	750 MVA - 1 GVA	1 - 1.5 GVA	> 1.5 GVA
	Engage stakeholders		Official complaint and/or internal unrest	Unrest in sector and/or minor media attention	Multiple official complaints	Regional political attention and/or negative position papers by NGO's	National media headline and/or national political attention	Long time national political attention
	Safety		Minor injury with first aid	Medical treatment by a general practitioner	Absence due to injury	Absence due to injury > 7 wk	Permanent injury	Casualty
	Financial		< 10K€	10 - 100 K€	100 K€ - 1 M€	1 - 10 M€	10 - 100 M€	> 100 M€
	Environment		Minor, possible to recover within limited time frame	Small, possible to recover	Moderate, difficult to recover	Considerable, very difficult to recover	Serious, hardly possible to recover	Extreme, not possible to recover
	Compliance		Complaints of violating rules	Formal request for information from authority or regulator	Formal warning or investigation	Fine or liability < 10 M€	Fine or liability > 10 M€ and/or instruction by regulator and/or criminal law procedure	Fine or liability > 100 M€ and/or criminal law sanction and/or rejection of license to operate
LIKELIHOOD	6 Almost certain	More than once a year	Low	Medium	High	Very High	Critical	Critical
	5 Likely	Once every 1 - 10 years	Neglectable	Low	Medium	High	Very High	Critical
	4 Probable	Once every 10 - 100 years	Neglectable	Neglectable	Low	Medium	High	Very High
	3 Possible	Once every 100 - 1000 years	Neglectable	Neglectable	Neglectable	Low	Medium	High
	2 Unlikely	Once every 1000 - 10,000 years	Neglectable	Neglectable	Neglectable	Neglectable	Low	Medium
	1 Hardly possible	Less than once every 10,000 years	Neglectable	Neglectable	Neglectable	Neglectable	Neglectable	Low

NEN-IEC 60812
MIL-STD-1629A
SAE J1739

FMECA: TenneT Example (II/II)

Possible Reasons for End of Life

FMECA leads to an updated
TenneT Maintenance Strategy (TMS)
and TenneT Maintenance Guideline (ToR)

Input for the Health Index

- Condition Indicators
- Do the right things
- Optimal frequencies
- Time & Resources efficient

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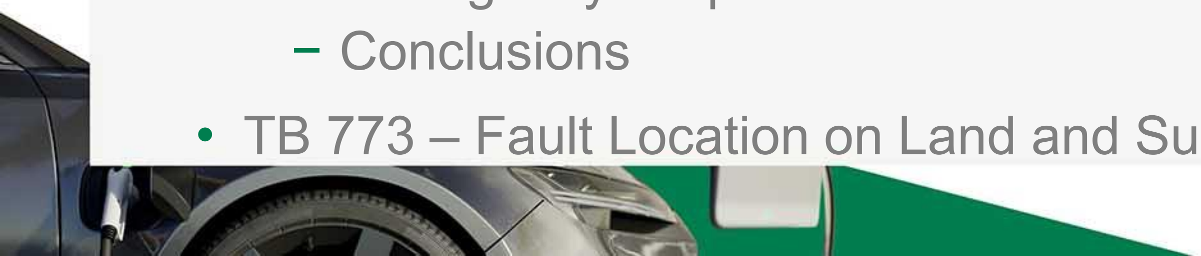


What is Health Indexing (HI)?
Proposed Method

- The Health Index technique gives guidance to assess the:
  - **Technical condition**
  - **Probability of failure**
  - **Remaining life**

  NB: HI method could incorporate **uncertainties** associated with:
    - Quantity and reliability of available data
    - Choice of weighting factors
    - Complexity and reliability of underlying models

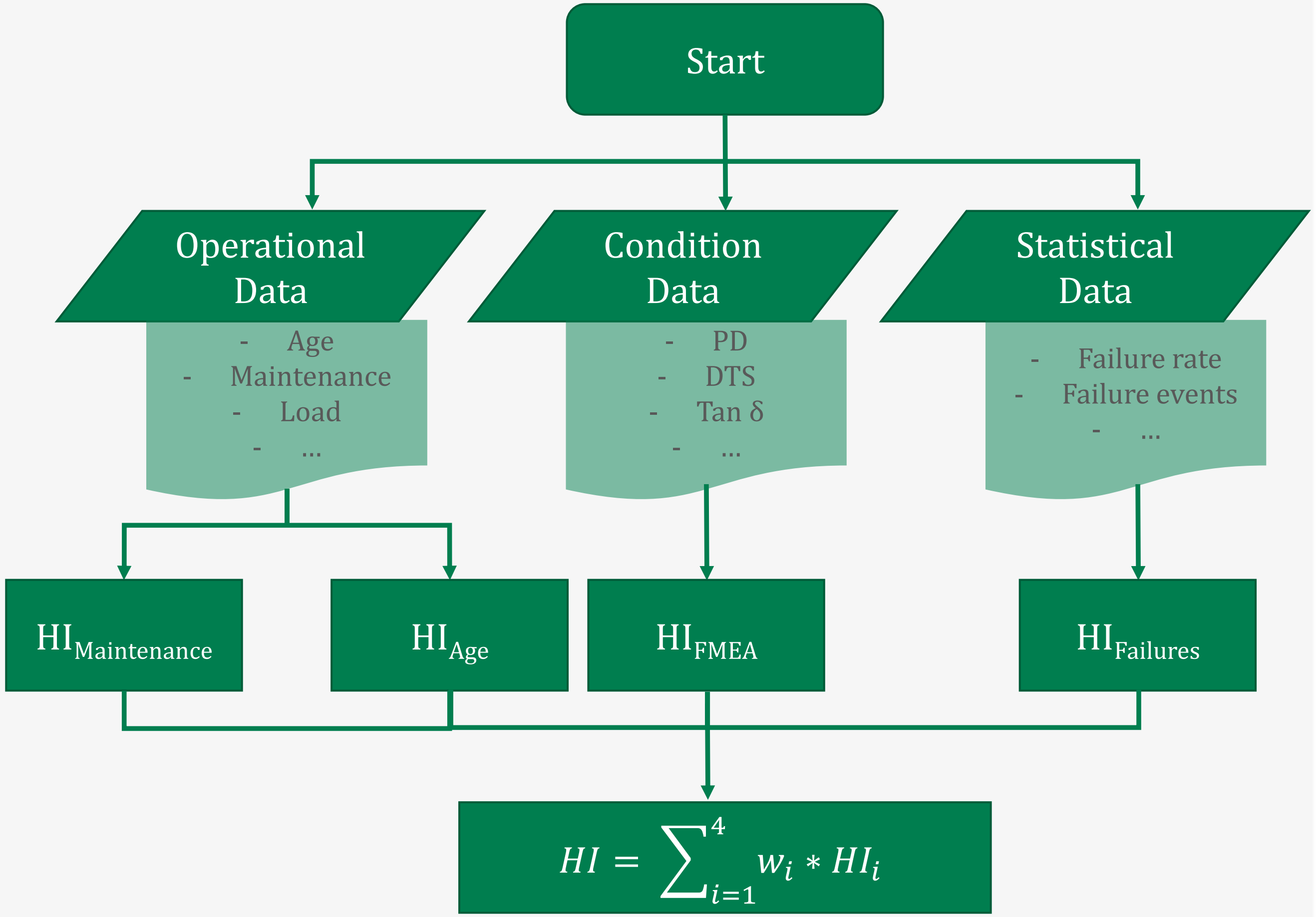
  - Provides **estimate average condition** for similar cable systems.

  - **By adding data (e.g. diagnostic test results)** accuracy can be improved.

Health Index – Introduction
Proposed Method

- Combining several different parameters to gain a **comprehensive indicator** of the asset health.

- The overall Health Index of the cable system is a function of **operational, condition and statistical data.**



Health Index – Scoring

Proposed Method

- A Health Index score from A to E (1 to 5) is assigned to all the individual Health Index categories (Maintenance, Age, FMEA and Failures).
- The final HI calculation results in an overall score between A(1) and E(5) and is linked to the remaining useful life:

A - Very good (1) – Cable in very good condition
(e.g. in excess of 20 years remaining life)

B - Good (2) - Cable in good condition
(e.g. with remaining life between 10 to 20 years)

C - Average (3) - Cable in average condition
(e.g. with remaining life between 4 and 10 years)

D - Poor (4) - Cable in poor condition
(e.g. with remaining life between 1 and 4 years)

E - Very poor (5) - Cable in very poor condition
(e.g. the remaining life could be less than 1 year)

Criticality Index
Proposal of Method

- Assigned to cable system based on the **severity and impact of a failure**

Severity	Moderate	Serious	Severe	Catastrophe
Health & Safety	Mild Accidents – Dangerous Situations – Damage to Goods	Accidents with injured persons	Accidents with injured persons – permanent disabilities	Fatalities and/or permanent disabilities
Loss of Profits	< 1 M€	1 to 10 M€	10 to 100 M€	> 100 M€
Energy Not Supplied	< 100 MWh	100 to 1000 MWh	1000 to 10000 MWh	> 10000 MWh
Laws and Legal Obligations	Noticed by a third party - liability	Criminal liability	New law based on a legal precedent Criminial conviction of a Utility individual staff	Utility legitimacy in question
Environment SF6-Oil-Fire-Endangered Species	Local impact or short-term degradable	Wide impact or middle-term degradable	Long-term degradable Could lead to a loss of ISO 14000 certification	Permanent impact Loss of ISO 14000 certification
Public Image	Local and temporary. Few external parties complaining about Utility or media critics	Regional or National < 3 days. Lots of external parties complaining about Utility with media relays	Regional and National 1 to 2 weeks. Expression of external official actors (politics, state representative...) that target Utility's legitimacy	National and regional > 2 weeks Long-term external association of public actors/representatives that greatly affect Utility's legitimacy
Regulatory context	Regulator asks for information	Regulator asks for a plan of actions	Regulator asks for a change of strategy	Regulator asks for a guardianship of Utility

More examples in:
TB 734
TB 422
TB 541

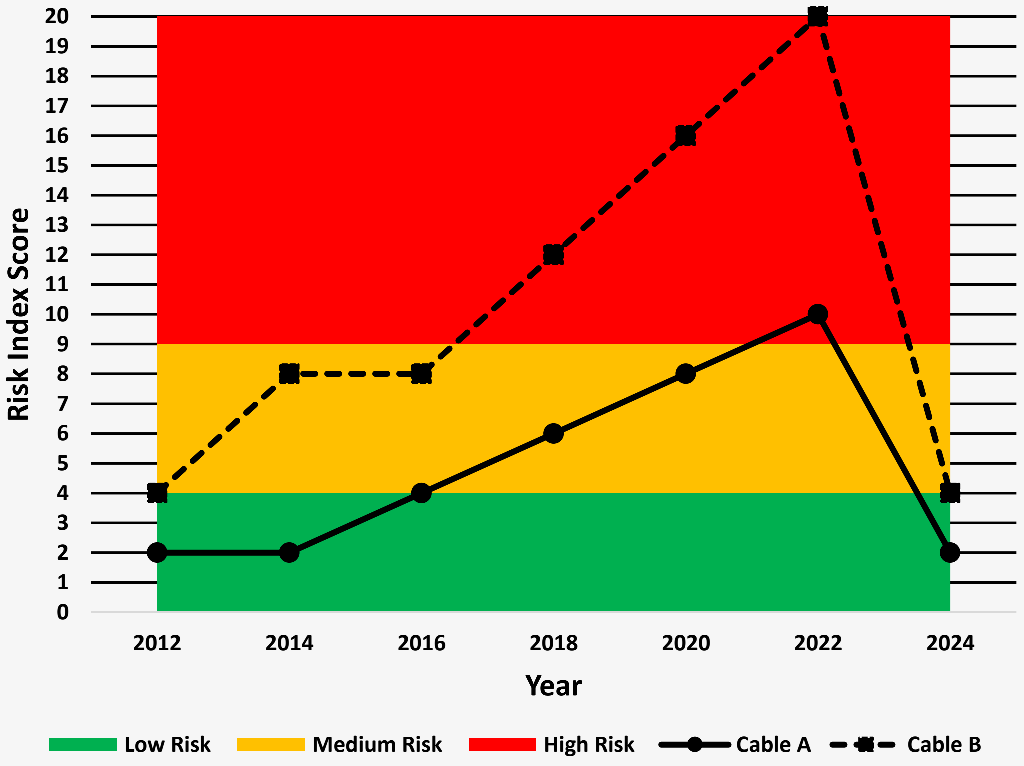
Risk Index (I/II)

Proposal of Method for Condition Assessment and Lifetime Strategy of HV Cable Systems

		Risk Index = HI x CI			
Health Index	E(5)	5	10	15	20
	D(4)	4	8	12	16
	C(3)	3	6	9	12
	B(2)	2	4	6	8
	A(1)	1	2	3	4
		1	**2**	**3**	**4**
		Consequence of failure / criticality			

Risk Index	Risk Level
1 to 4	**Low risk associated with the asset. No action required.**
5 to 9	**Medium risk associated with the asset. Further analysis/observation recommended.**
10 to 20	**High risk associated with the asset. Action recommended.**

- Example of two assets with different, but constant CI
  - ➢ HI determines change in **RI over time**



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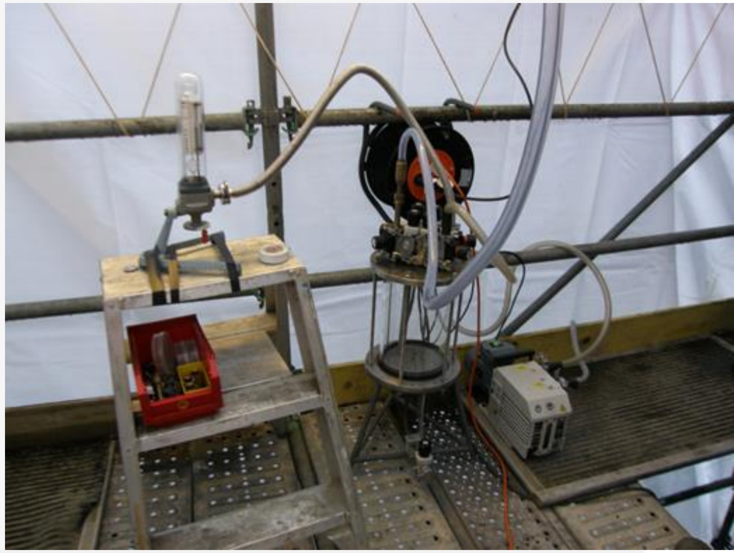
Life extension – practical options

Options for Life Extension and Emergency Strategies

- Practical options for life extension:
  - Implement and follow-up a proper cable maintenance programme
  - Fluid flushing of SCFF system
  - Re-burial of submarine cables
  - Replace selected cable sections/accessories
  - Decreasing mechanical stresses
  - De-rate current or voltage
  - Decrease the hydraulic pressure in SCFF to avoid leaks
  - Re-evaluation of cooling systems
  - Use of on-line sensing techniques
  - Reduced exposure to short-circuits



Emergency strategies

Options for Life Extension and Emergency Strategies

- Understand population of cables & accessories
  - Cable technology, size, compatibility.
  - Accessory type, size, range-taking ability.
  - Include spare part management.

- Risk assessment
  - Feeder criticality.
  - What scenarios should the emergency strategy cover?
    - All or just high risk?
    - Coincident events.

- 80/20 - impractical to cater for 100% of all failure scenarios
  - Primary & backup repair methods (eg transition joints).
  - Recommended to consider accessories first and cables second.

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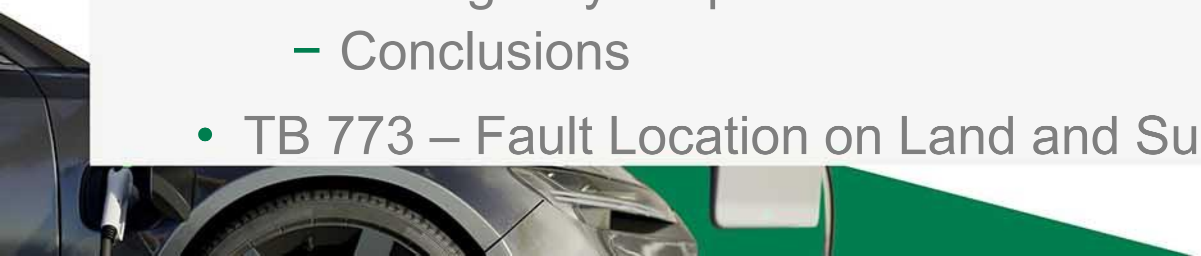

Conclusion (I)

- **Awareness is increasing** on the importance of lifetime strategies
- Trend is **moving towards CBM, RCM and RBM** due to new techniques for condition assessment. Reliable data is crucial.
- Large amounts of data and low failure rates feed into **complexity** of setting up a suitable system
- **Synergies** with data acquired during maintenance activities are not used to their highest potential
- **There is no one-fits-all-solution**, but a proposal should be flexible and adaptable to the respective grid size and structure
- Attention should be given to **RAMS aspects** of new system concepts; Regularly review maintenance strategies since the grid changes

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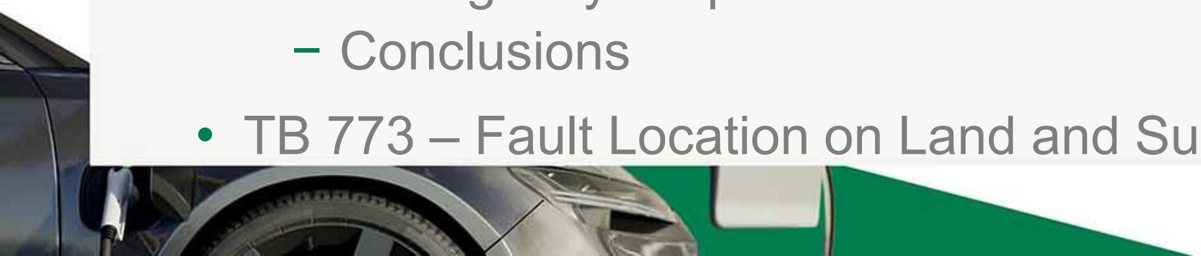


TB 825 - Maintenance of HV cable systems

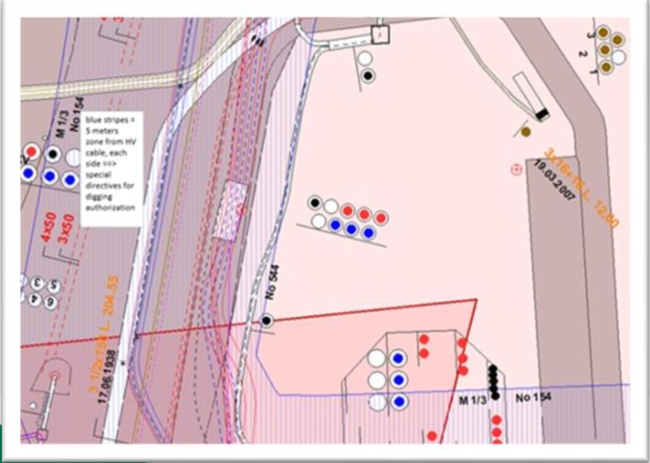
(update of TB 279)

For power system expertise

Underground Cable Systems

- **Third party damage** is a major threat
- Examples of effective measures :

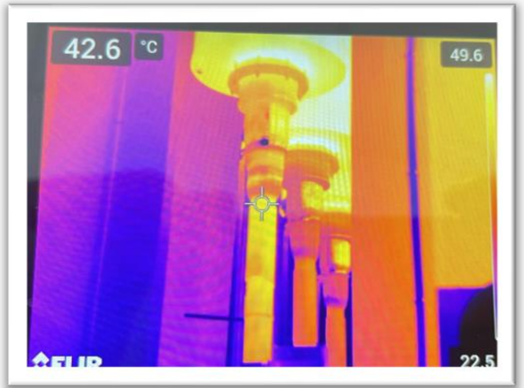
  ✓Route inspections
  ✓Application of marker stones, warning signs, protective covers
  ✓Provision of cable route information to contractors (KLIC)

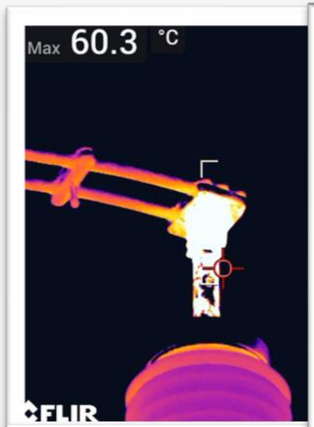


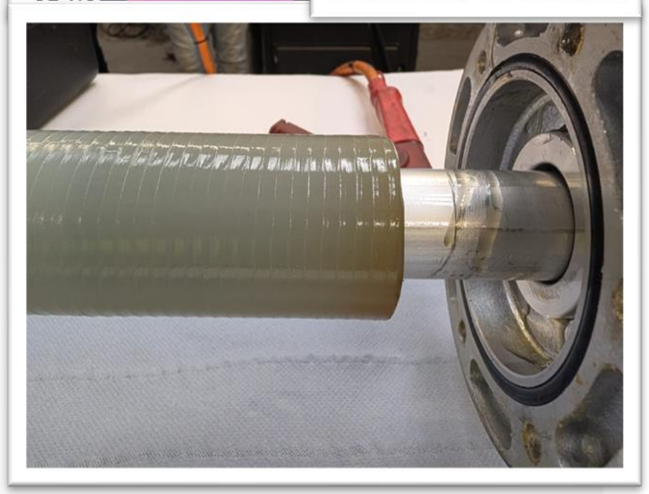
Underground Cable Systems

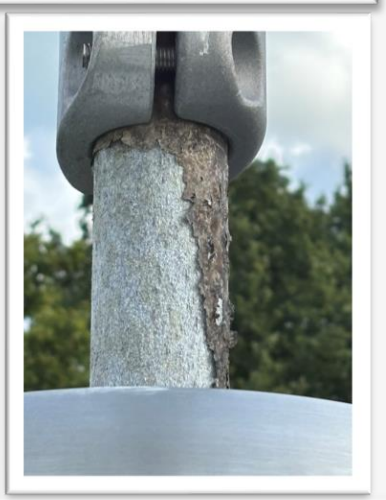
- **Inspections** on accessible parts of the system
  - ✓Cable, Accessories, link boxes, earthing connections
  - ✓Damage / wear/ Defects
  - ✓Corrosion
  - ✓Cable movement
  - ✓Hotspots IR

- High level condition indicators
- Trending possible!



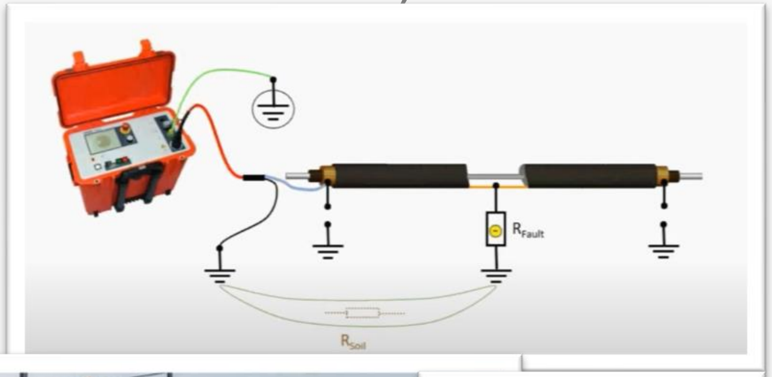


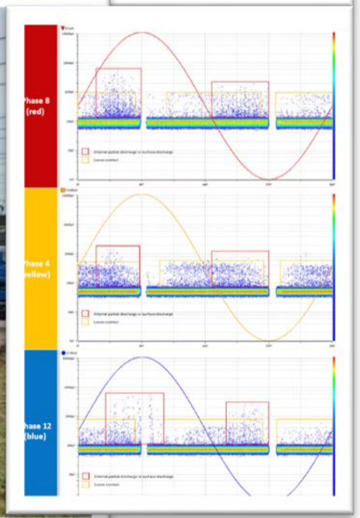


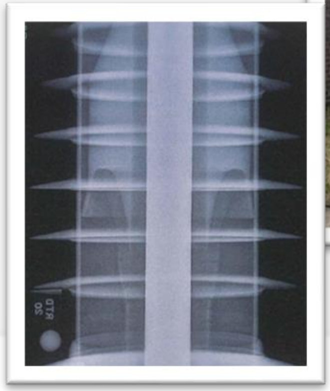


Underground Cable Systems

- **Maintenance diagnostic measurements** (mostly periodic and off-line):
  - ✓Sheath voltage test
  - ✓SVL testing
  - ✓Earth resistance measurement at joint bays
  - ✓Continuity test in earthing cables
  - ✓HV test + PD measurements **
  - ✓PD measurements (on-line) **
  - ✓DTS measurement (on-line)
  - ✓Screen current measurements (on-line)
  - ✓Tan Delta
  - ✓TDR
  - ✓X-Rays (where needed)



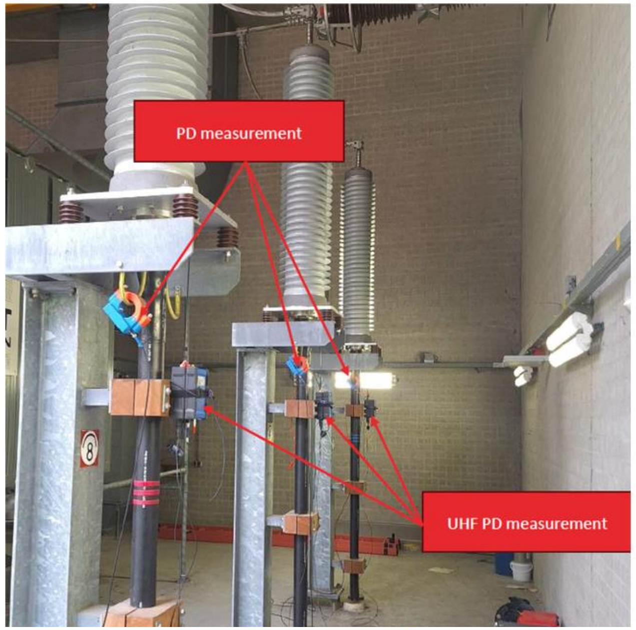


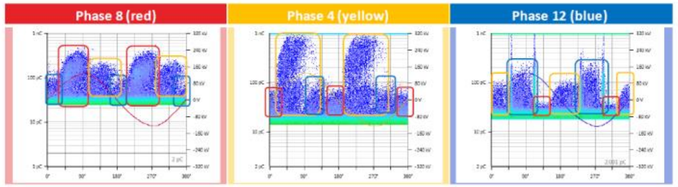


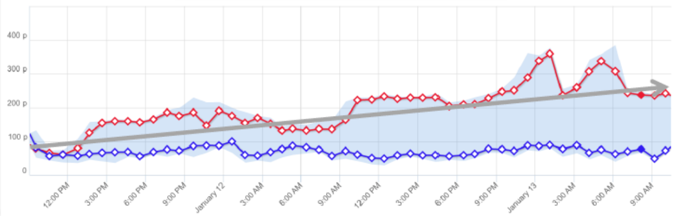
Underground Cable Systems

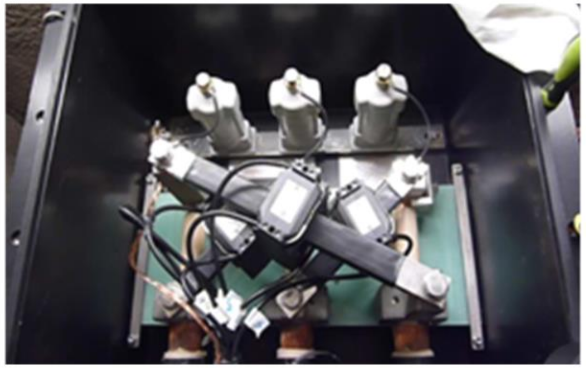
- **On-line monitoring activities**:
  - ✓DTS
  - ✓Partial Discharge
  - ✓Screen currents

- Continuous monitoring or temporary
- Generation of large data









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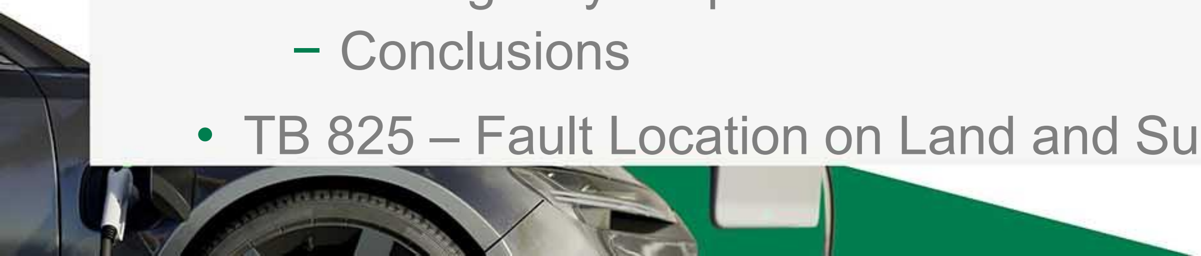


Fluid Filled Cable Systems

Fluid Filled (FF) cable systems: still significant part of transmission network

- Proven reliability
- Some circuits older than 60 years

- Reasons for replacement:
  - Excessive leaks
  - Inadequate ampacity for increasing load

- Challenge: Spare parts

Maintenance on Fluid Filled Cable Systems

Labour intensive maintenance but well defined:

- ✓Inspections of cable accessories such as terminations, joints, fluid pump stations, control systems and backup power supplies
- ✓Fluid pressure readings / monitoring
- ✓Dissolved gas analysis (DGA) of cable fluid
- ✓Dielectric and moisture tests of cable fluid
- Check of cathodic protection systems
- etc.

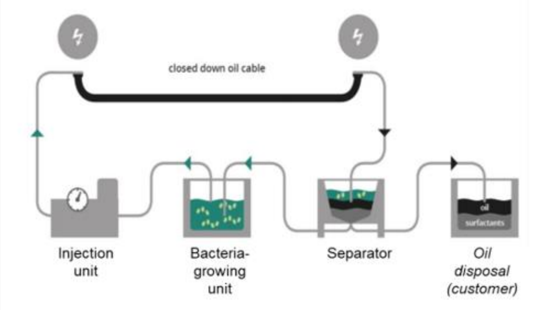
Fluid Filled Cable Systems

Trends on maintenance activities:

- Use of **tracers** in cable fluid to facilitate and speed-up localization of cable fluid leakage

- Online fluid pressure monitoring instead of on the spot pressure readings

- (EoL) Bacteriological removal of oil



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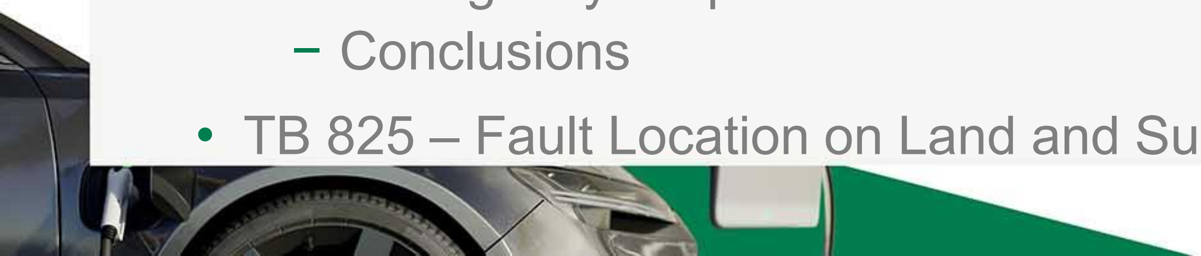
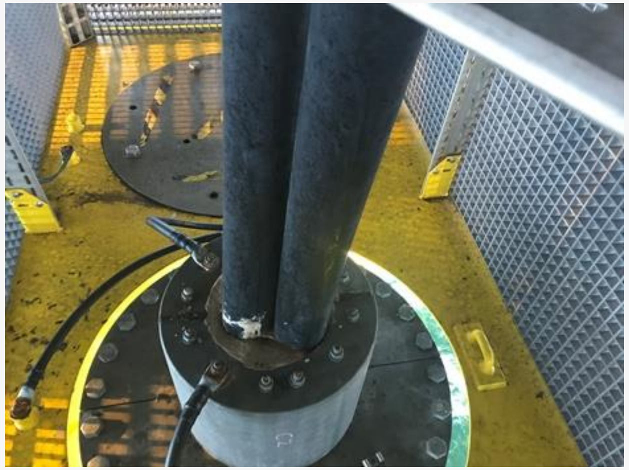


Submarine Cable Systems

- Avoiding third party damage, most effective measures are:
  - ✓ Route inspections
  - ✓ Verifications of burial depth and landfalls
  - ✓ Administrative procedures to provide cable route information, dialogue with local fishermen



Submarine Cable Systems

The cable system is also subject to natural threats such as hydrodynamics, change of seabed morphology, corrosion, earthquake, etc...

- **Activities to control cable protection and health, such as:**

✓Offshore geophysical surveys
✓Inspections at landfalls & offshore platforms
✓Monitoring (DTS; DAS)
✓Additional or remedial protection works

Submarine Cable Systems

Despite all preventive activities, failures can still happen

✓ **Overview of typical activities to perform a repair on a submarine cable**

- Immediate actions after fault occurrence
- Preparation of repair works
- Mobilisation of resources for repair
- Repair works

TB 773 « Fault location on Land and Submarine cables”

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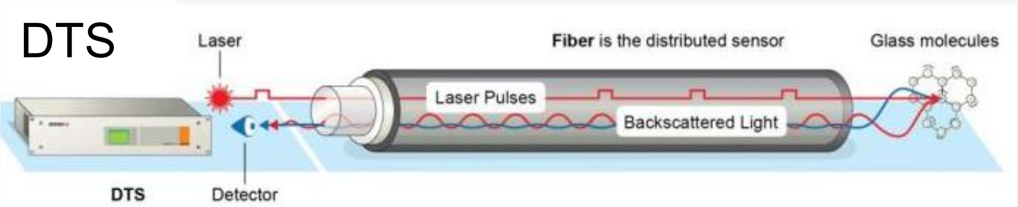
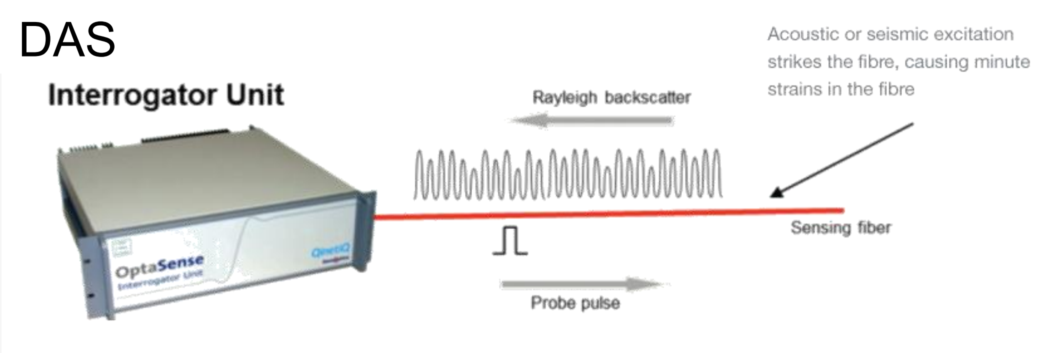
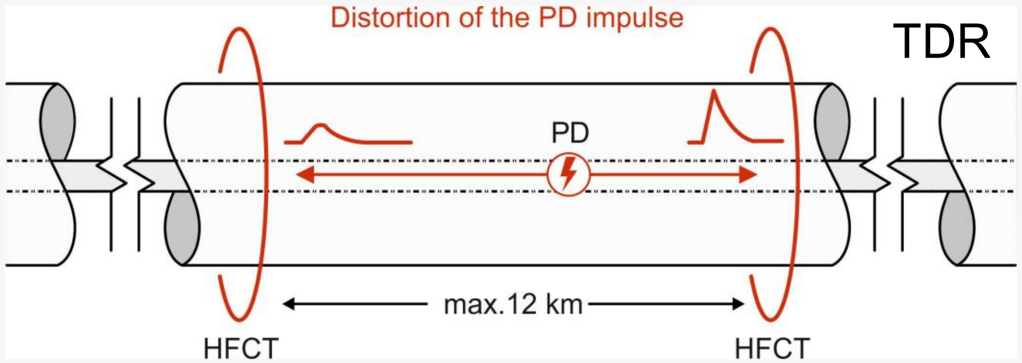
Cable Monitoring (Optical Fiber)

- Congestion Monitoring and higher cable utilization
  - DTS (Distributed Temperature Sensing)
- Health Monitoring
  - DTS
  - DAS (Distributed Accoustic Sensing) / Vibration Monitoring
  - Seabed Laying Depth Evaluation
- Failure Monitoring
  - DAS
  - On-Offline Monitoring (TDR based)







Monitoring is becoming an essential / crucial part for security of supply

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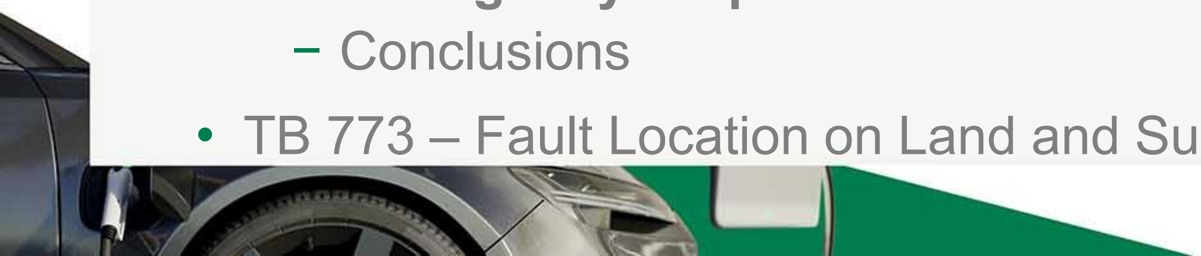
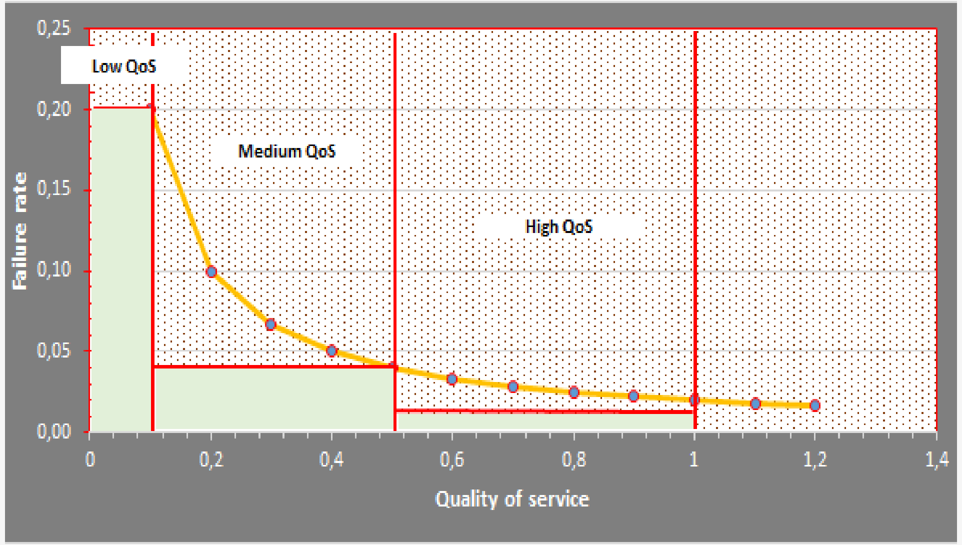


Spare Parts Management

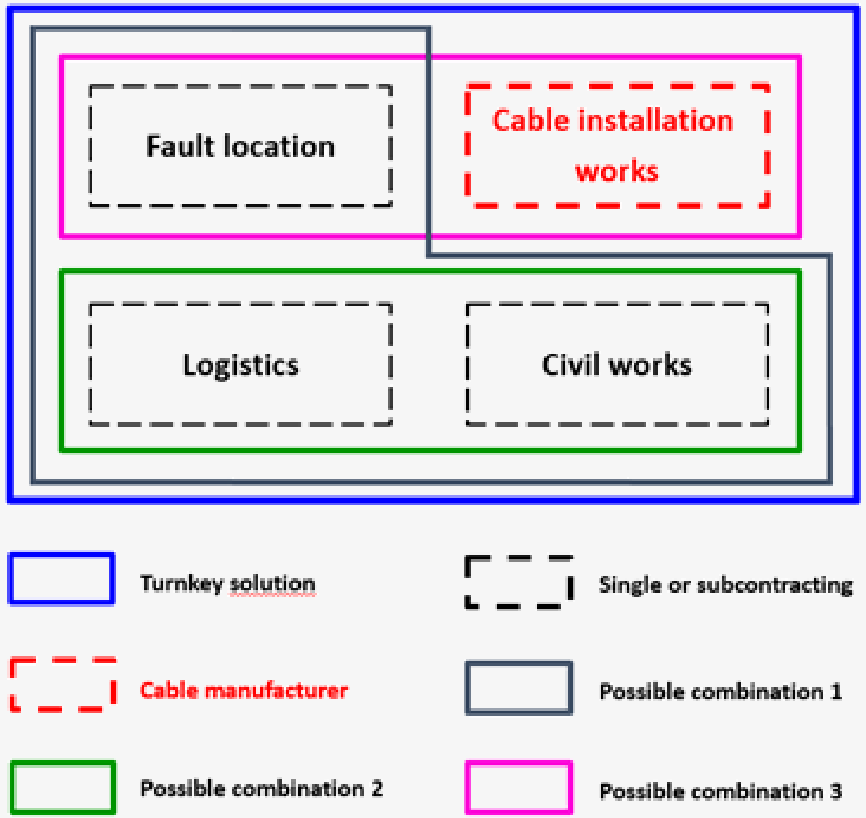
- Spare parts management will decrease the downtime of cable systems in emergency situations.
- Spares need to be checked, stored and maintained accordingly.

- What affects the amount of spares?
  - Component failure rate
  - Impact on the Quality of Service
  - Delivery times
- Provision of spare parts; Inter-compatibility of spares; Spare parts storage; Shelf life



Emergency/Repair Preparedness Plan

- E/RPP should guide through complete repair process for different repair scenarios
- Methodology, processes, agreements with service providers (Service Level Agreement)
- Questions that cable owner may face upon a cable failure
- Contracting strategies



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Future Developments

TBM → CBM;RCM

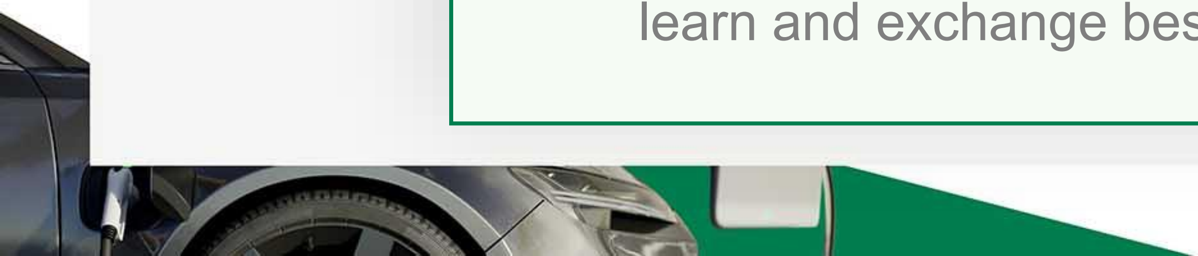
New methods for Condition Assessment

Data storage

Data quality / accessibility

Conclusion

- Clear trend towards more **diagnostics measurements and on-line monitoring** techniques
- Data quality and availability is key for proper implementation of CBM & RCM
- All cable systems require an optimized maintenance plan, which is **not the same** for all cable systems, therefore need to perform maintenance:
  - ✓ based on a clear strategy
  - ✓ based upon statistical analysis of occurred events (FMECA)
  - ✓ include monitoring and diagnostics <u>when this gives added value</u>
  - ✓ Keep informed on new developments;
    learn and exchange best practices (Cigre)



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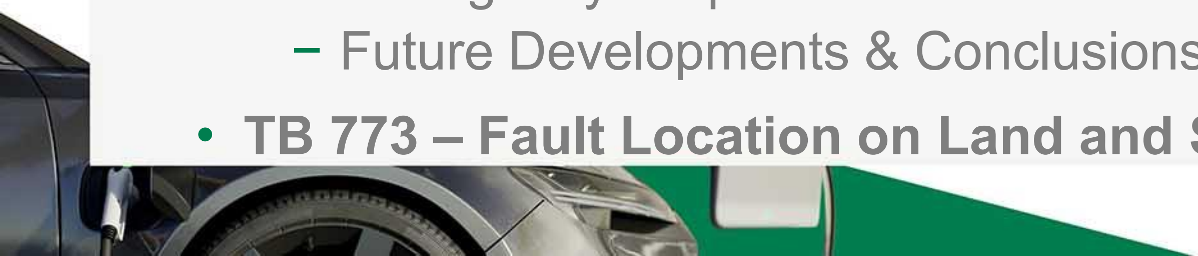


Fault Location on Land and Submarine Links (AC & DC), TB 773

cigre
For power system expertise

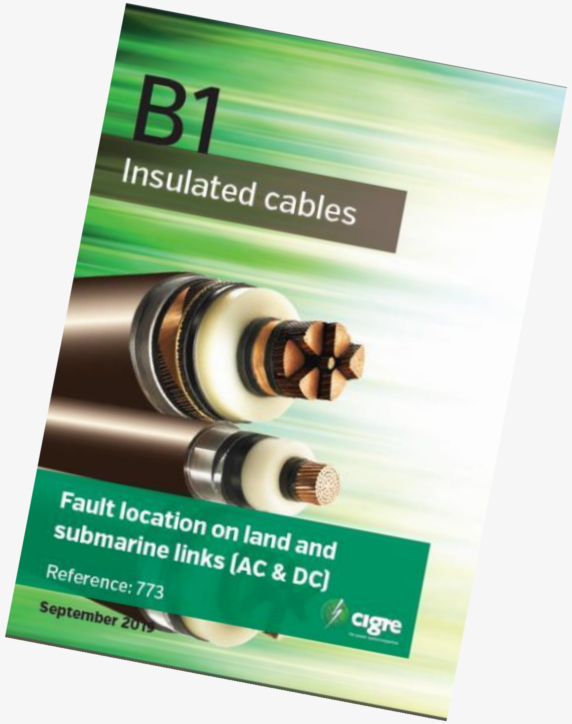
Master Version

Fault localization

- The **increasing number of land and submarine cable assets** globally has created a focus on cable fault location capability
- There are many **well established cable fault location techniques**, particularly for buried underground cables
- Successful cable fault location depends to a great extent on applying the **appropriate technique or combination of techniques**
- Methods for locating cable faults require **competent engineers and service providers**
- **Guidance** is required for engineers on the **correct application of the various techniques** available

Information in the TB773

- Overview of Pre-location & pinpointing methods - accuracy / suitability
- Fault Location Flowchart → Practical application
- Design factors affecting fault location capability, in case of:
  - Cross bonding,
  - Long cable lengths,
  - Cables in ducts and tunnels,
  - Submarine cables
- Marine vessel & support for submarine cable faults
- Case studies of fault location experiences
- Applicability of on-line methods of fault location
- Safety and training considerations
- New and innovative techniques & future developments (Optical Fiber Based)



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