Electricity Systems Resilience by Design

Influence and interaction from Transmission and Distribution equipment

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For power system expertise

What is Resilience?

- “The ability of people or things to recover quickly after something unpleasant, such as shock, injury, etc”.

- The ability to recover from a fault, failure or other event

- There are many ways for a grid operator or owner to be resilient, many of them are interdependent.

Using a car as an example…..

- Check your tyres regularly
- TPMS or other pressure monitoring
- Change tyres at appropriate intervals (condition, operating conditions or age)
- Car has run flat tyres
- Spare wheel in your car (or repair kit)
- Membership with a recovery company
- Use public transport/taxis/walking instead

✓Manual Monitoring
✓Automated Monitoring
✓Maintenance

✓Specification (Preventative)
✓Specification (Recovery)
✓Recovery
✓Avoidance/Alternative

- There are lots of different mechanisms to achieve resilience.

Asset Management

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Grid Design
- Circuit redundancy
- Circuit capabilities
- Bypass or re-routing arrangements
- Protection arrangements, duplication and diversity

Grid Operation
- managing circuit capacities depending on power flows and anticipated demand
- maintaining operating margins for voltage, frequency, currents, fault levels, etc
- outage availability and management
- Equipment availability

Market Mechanisms
- having different generation sources and generation flexibility
- services like “spinning reserve”, fast response, and frequency response
- voltage control services
- Generation capacity

Equipment design and specification
- ratings and compliance with relevant standards and test requirements
- circuit or component redundancy
- component obsolescence
- component susceptibility to cyber vulnerability

Installation design and specification
- How to install equipment to enable quick turn around or replacement
- Clearances to mitigate collateral damage

Inspection and Maintenance policies
- maintenance activities and frequencies
- maintenance dependence on condition

Condition Monitoring
- techniques used for monitoring (active and passive, in service and out of service conditions)
- ability to collate and interpret condition data

(Strategic) Spares
- new or recovered key components
- new or recovered complete assemblies
- arrangements with OEMs or other parties to pool spares

Replacement policies
- design diversification
- age and condition for replacement. Asset management maturity (asset health indices)
- obsolescence management (sub-components and complete assemblies, especially integrated electronics)

Supply Line resilience
- supplier diversification
- local vs international suppliers (geographical location)

Emergency response and recovery capability
- Personnel
- processes and management structures for emergency response
- Testing of response to simulated incidents

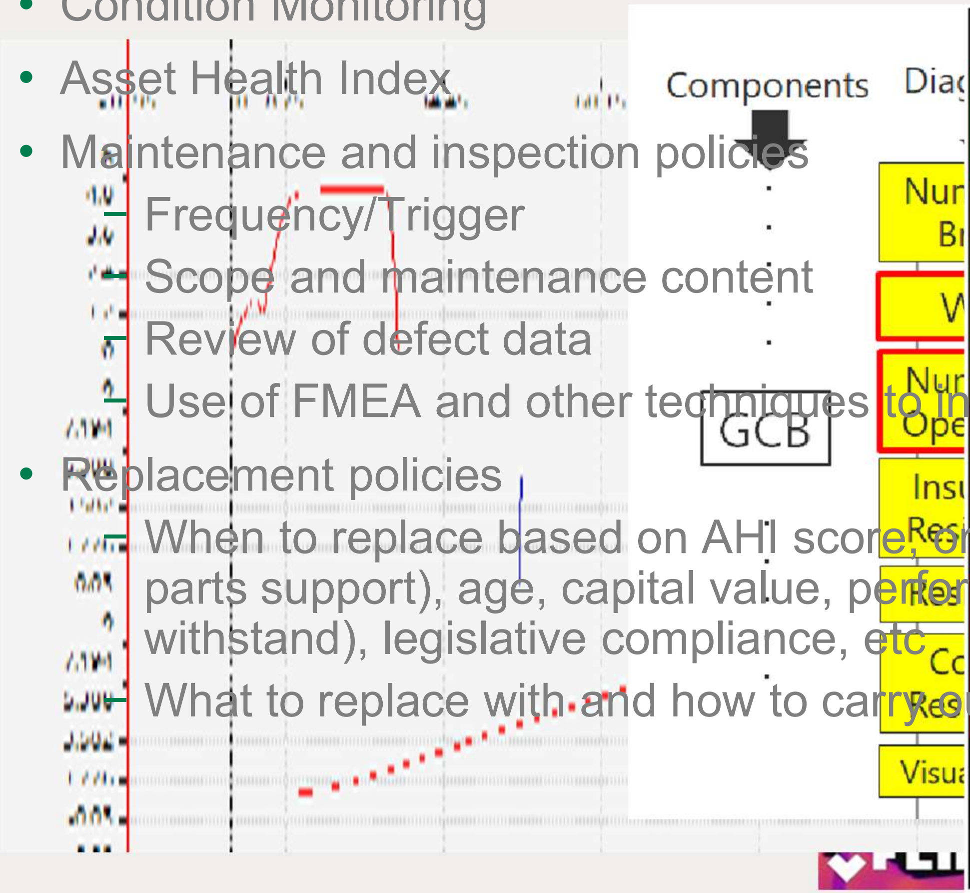
Equipment design and specification

- IEC standards
  - Standard requirements
  - Specific or optional requirements

- Customer standards and specifications
  - Recognition of your systems parameters or future parameters
  - Current and future environmental operating conditions, including environment class
  - Built in redundancy
  - Embedded monitoring
  - Maintenance requirements/contracts
  - Component/Operational (cyber) security
  - Longevity/life expectancy/support of components

Condition Monitoring, Maintenance and Replacement (Asset Management)

- Condition Monitoring
- Asset Health Index
- Maintenance and inspection policies
  - Frequency/Trigger
  - Scope and maintenance content
  - Review of defect data
  - Use of FMEA and other techniques to influence policy
- Replacement policies
  - When to replace based on AHI score, or other criteria such as obsolescence (OEM and parts support), age, capital value, performance and other capability measures (fault withstand), legislative compliance, etc
  - What to replace with and how to carry out that replacement with minimal disruption



AHI	CONDITION	DEFINITION	ACTIONS	TIME SCALES
1	Very good	Very low likelihood of failure over many years. This would be in the original factory condition or after extensive refurbishment.	Continue with inspect and test schedule.	**More than 10 years** likely before additional maintenance and refurbishment is undertaken. Timing of interventions is asset specific and indicated by the inspection and test results.
2	Good	Low likelihood of failure over a long period. General deterioration is consistent with its time in service.	Continue with inspect and test schedule.	**5-10 years** likely before additional maintenance and refurbishment is undertaken. Timing of interventions is asset specific and indicated by the inspection and test results. Subcategory bands can be introduced based upon failure mode and rate of change in diagnostics. The impact of any life-limiting irreversible deterioration is expected to be beyond this time frame. If not, introduce extra column with 5-year replacement bands.
3	Fair	Low risk defect or life-limiting deterioration has been detected. Performance may be adversely affected long term unless remedial action is carried out.	Investigate the issue and plan any intervention. Continue with a revised inspect and test schedule. Revise life expectancy planning into likely 5-year bands.	**2-5 years** before interventions. Timing and scope are indicated by investigations, together with changes in inspect and test results. Subcategories introduced in yearly bands based upon failure mode and rate of change in diagnostics.
4	Poor	Progressive deterioration has been detected, with high likelihood of failure in the short term. The unit can remain in service, but short-term reliability is likely to be reduced. Subcategories are useful to define urgency of repair or replacement timeframes.	Remedial action to be carried out and/or increased condition monitoring implemented. De-rating and risk management zones may be needed.	**3-24 months** before interventions. Planning the action and its timing is determined by failure mode analysis and operational practicalities. This is managed using increased surveillance.
5	Critical	High likelihood of immediate failure exists and the unit should not remain in service.	Any exception would require intensive risk management actions. If returned to service decision points and time frames need to be defined.	**0-3 months** determined by risk assessment.

Spares

- Common or foreseeable spare parts or consumables
  - Primary contacts
  - Operating coils
  - Contactors, relays, fuses
  - Short life items
  - Gas or fluid seals
- Complete new assemblies
- Recovered/certified reused equipment

- Held by user, or
- In collaboration with other users, or
- Held by the OEM, or
- A combination of these

- Require suitable knowledge and skills to repair or install full or partial replacement

Current Cigre working groups (just in A3)

- **WG A3.42** Failure analysis of recent AIS instrument transformer incidents
- **JWG A3.43 /CIRED** Tools for lifecycle management of T&D switchgear based on data from condition monitoring systems – TB 953 published in 2025
- **WG JWG A3/A2/ A1/B1.44** Limitations in Operation of High Voltage Equipment Resulting of Frequent Temporary Overvoltages
- **A3.47** Lifetime Management of Medium Voltage Indoor Switchgear
- **WG A3.48** 4th CIGRE reliability survey on transmission and distribution equipment
- **WG A3.49** Aging effects on accuracy class of Instrument Transformers
- **WG A3.51** Requirements for HV T&D Equipment operating under Abnormal Weather Conditions

The future?

- Could AI be used to optimise maintenance and replacement policies?
- What information could digital twins bring us in future?
- What new switching duties may arise from future grid developments?
- How will SF6 alternatives affect equipment reliability?
- How do users manage the increasing pace of obsolescence?