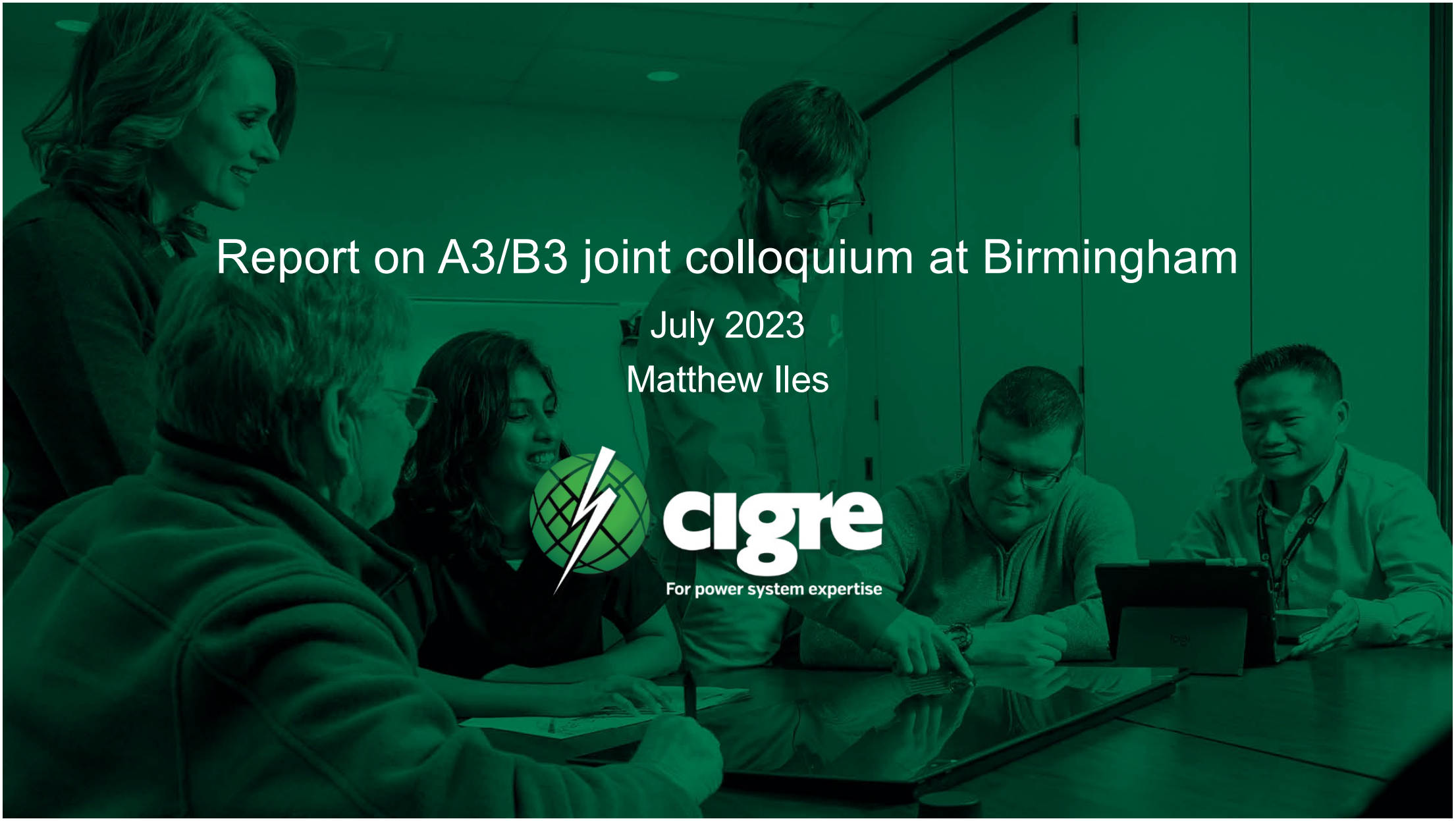


Report on A3/B3 joint colloquium at Birmingham

July 2023

Matthew Iles

cigre

For power system expertise

Overview

- Over 160 attendees from 24 countries across 4 days
- Highlights include:
  - Keynote speech by National Grid Alice Delahunty,
  - Tutorials,
  - Working Group meetings,
  - Paper presentations,
  - Plenary session with panel members from key industry representatives.
  - Evening reception with speeches Mark Waldron (CIGRE UK Chair) and David Wright (National Grid Group Chief Engineer)

WG and other meetings

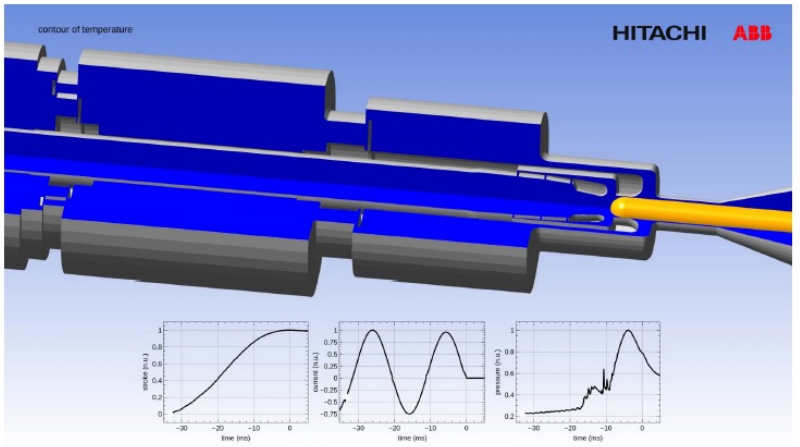
- **WG B3.64** – Guidelines on Optimising Seismic Design of Substations for Power Resiliency
- **WG B3/A3.60** – User guide for non-SF6 gases and gas mixtures in Substations
- **WG B3.61** – Risk and asset health-based decision making in existing substations
- **WG A3.42** – Failure analysis of recent AIS instrument transformer incidents
- **WG A3.48** – 4th CIGRE reliability survey on transmission and distribution equipment
- **WG B3.54** – Earthing System Testing Methods
- **WG A3.46** – Generator Circuit-Breakers: review of application requirements, practices, in-service experience and future trends
- **WG B3.65** – Guidelines for the Selection and Design of escape routes for substations rated above 1kV AC and 1.5 kV DC
- **WG A3.39** – Application and field experience with metal oxide surge arresters
- **Strategic Advisory Group A3**
- **Strategic Advisory Group B3**
- **SC A3 Utility Advisory Board** – Representatives from Utilities to advise on utility issues relating to switchgear topics

Tutorial – Simulation Tools for Electrical Equipment

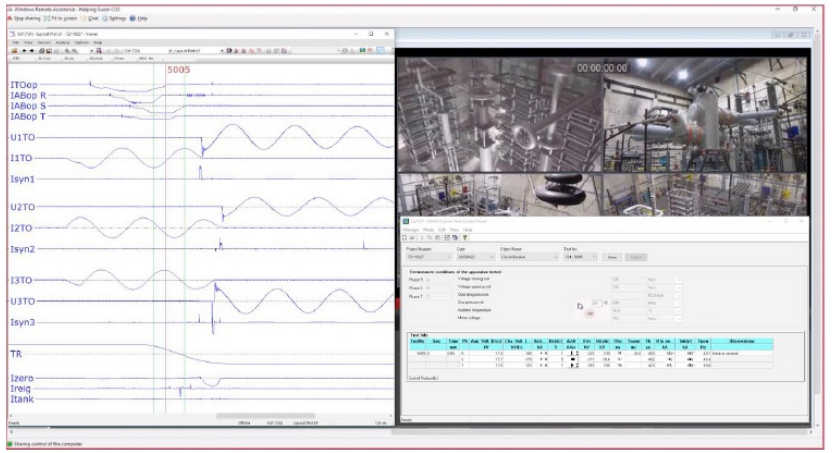
- Use of calculations, simulation and multi-physics-simulation tools for
  - Verification of circuit breaker
  - Interrupter performance,
  - Simulation of internal arc effects
  - Temperature rise.
- Highlights the difference between *calculation* and *simulation*, *verification* and *validation*, and *interpolation* and *extrapolation*.

- Different tools to simulate different aspects.
  - There are numerous simulation tools available, all of which need to be validated through actual test results on aspects such as overpressure, temperature, arc voltage, etc
  - Benchmarking important to compare tools.
- Simulations and calculations are used as verification tools for design and performance assessment.
- Simulation cannot (yet) replace the need for type testing but can reduce time and money in development or for extrapolating results.

Presented by: **Martin Kriegel (CH)**



Simulation

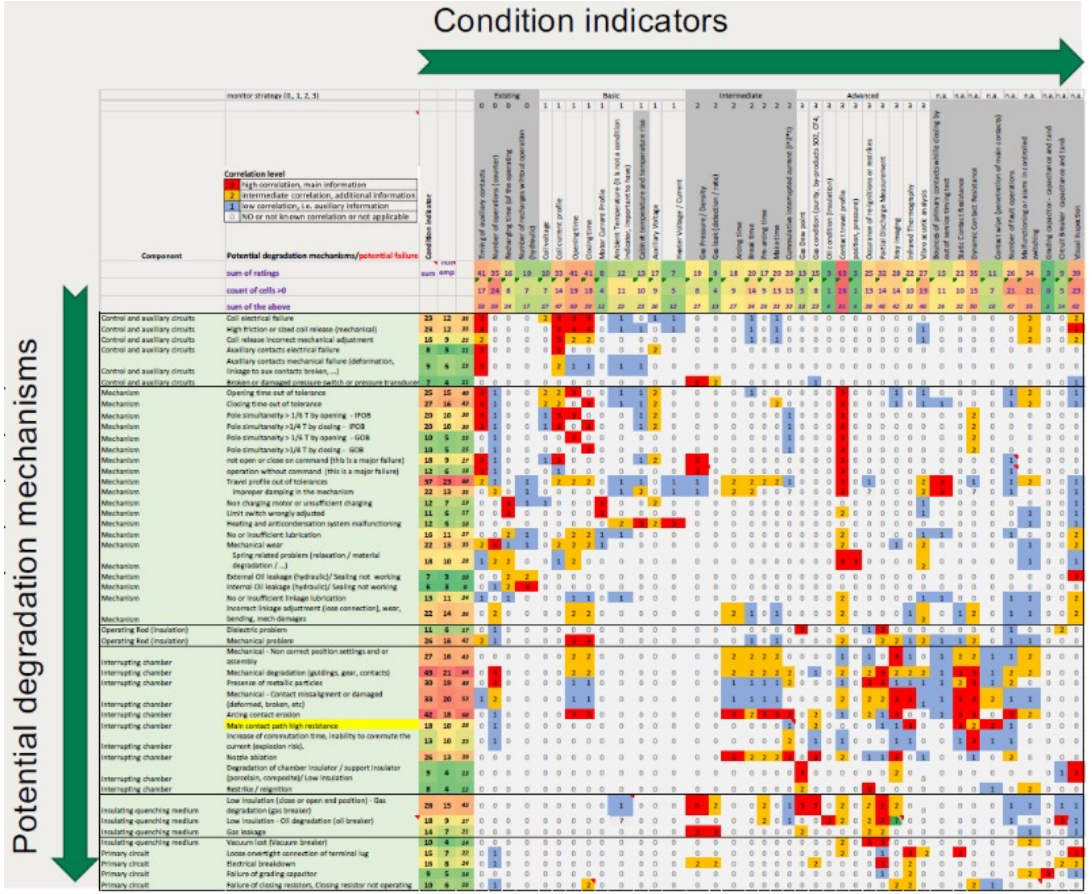


Testing

Tutorial – Tools for Lifecycle Management of T&D Switchgear based on Data from Condition Monitoring Systems

- Looks at the tools available for lifecycle management of transmission and distribution switchgear based on data from condition monitoring systems.
- Explores use of condition indicators (quantitative and qualitative), to determine the condition of one part or function of switchgear.
  - Condition is captured by sensors
  - Output can be interpreted by various diagnostic methods to understand the degradation.
  - Level of monitoring proportional to Health Index

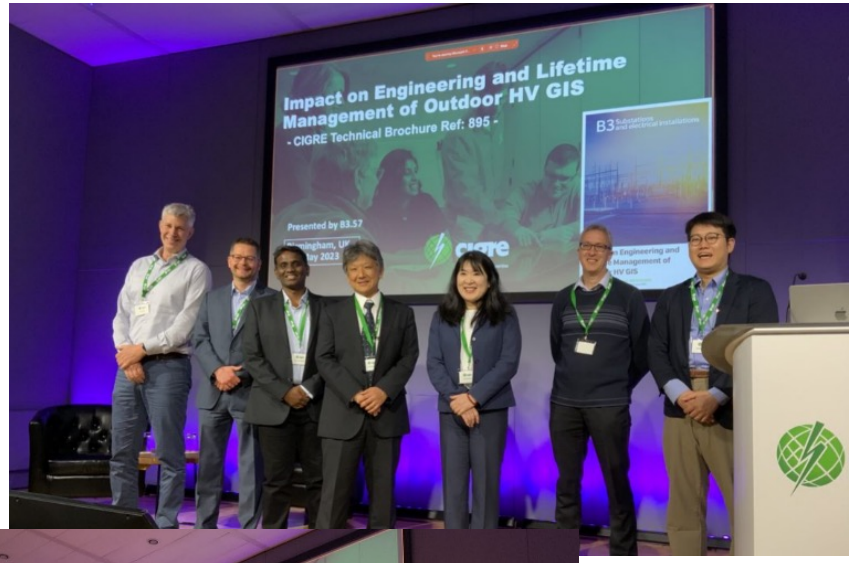
- What are the future needs of condition monitoring systems,
  - Online/Offline
- Future challenges
  - Integration into digital substation,
  - Visualisation,
  - Use of AI to interpret results,
  - Cyber security.



Presented by:
Nicola Gariboldi (CH)

Tutorial – Impact on Engineering and Lifetime management of Outdoor GIS

- Recommendations for HV outdoor GIS taking into consideration
  - Engineering,
  - Design,
  - Procurement,
  - Fabrication,
  - Civil/structural works,
  - Construction,
  - Erection & commissioning,
  - Testing,
  - Maintenance.
- Recommendations facilitate both manufacturers and users to make appropriate capital and operational investment decisions on lifetime management of outdoor GIS.



Presented by:
Toshiyuki Saida (JP)
Tobias Ziesemer (DE)
Ian Johnston (GB)
Dr Santosh Kumar A (IN)
Nobuko OTAKA (JP)

Tutorial – Asset Health Indices for Equipment in existing Substations

- Discusses the different strategies used to define and measure the Asset Health Index (AHI).
  - Covers the proposed eight steps of the generic AHI methodology applicable for all significant asset types.
  - Covers combining individual AHIs into bigger groups like a bay or the whole substation.
- As assets transition from new to aged and develop failure modes users need to have the capability to identify the time frames for the progression of these failure modes.
- Proposes a generic approach to AHI based on current practice on how the health of substation assets should be evaluated.
- Asset health should be the first step towards focused outcomes.
  - To create asset-specific plans for maintenance, refurbishment, and asset replacement.
  - To provide resilience information on a functional basis through a network.
- All assets should have lifetime management plans to meet business objectives.

Presenter – Jan Bednarik
Tutorial session chair – Hugh Cunningham

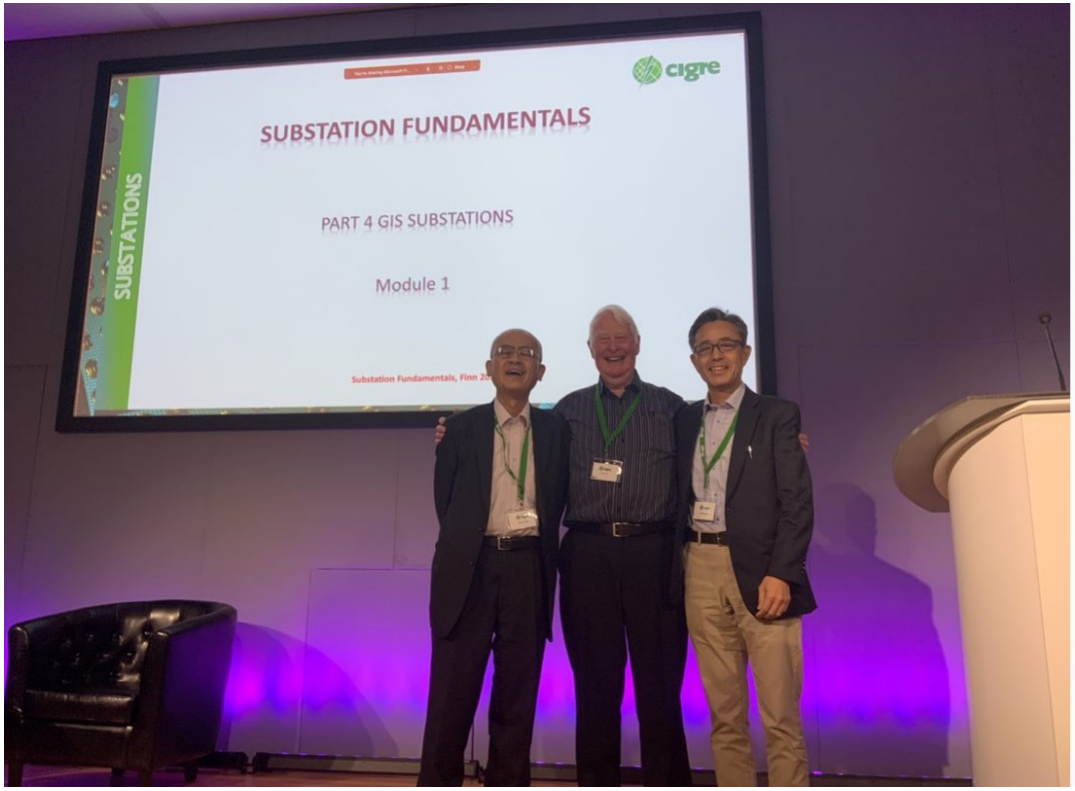
Tutorial – Service Continuity Guide for HV GIS above 52 kV

- Created a definition of service continuity for GIS during maintenance, repair, extension or on-site dielectric test.
- Explanation of the service continuity levels through the MRE Code (Maintenance, Repair, Extension),
  - Definition and guidance on selection of MRE Code
  - Definition of users and manufacturers responsibilities
  - Description of the most important technical aspects including safety issues
  - Description of the technical background of all relevant aspects
  - Recommendations for users and manufacturers
- With the service continuity guide and MRE Code, users and manufacturers can exchange information more effectively.
- Users are provided with a tool that enables more planning reliability for service assignments.

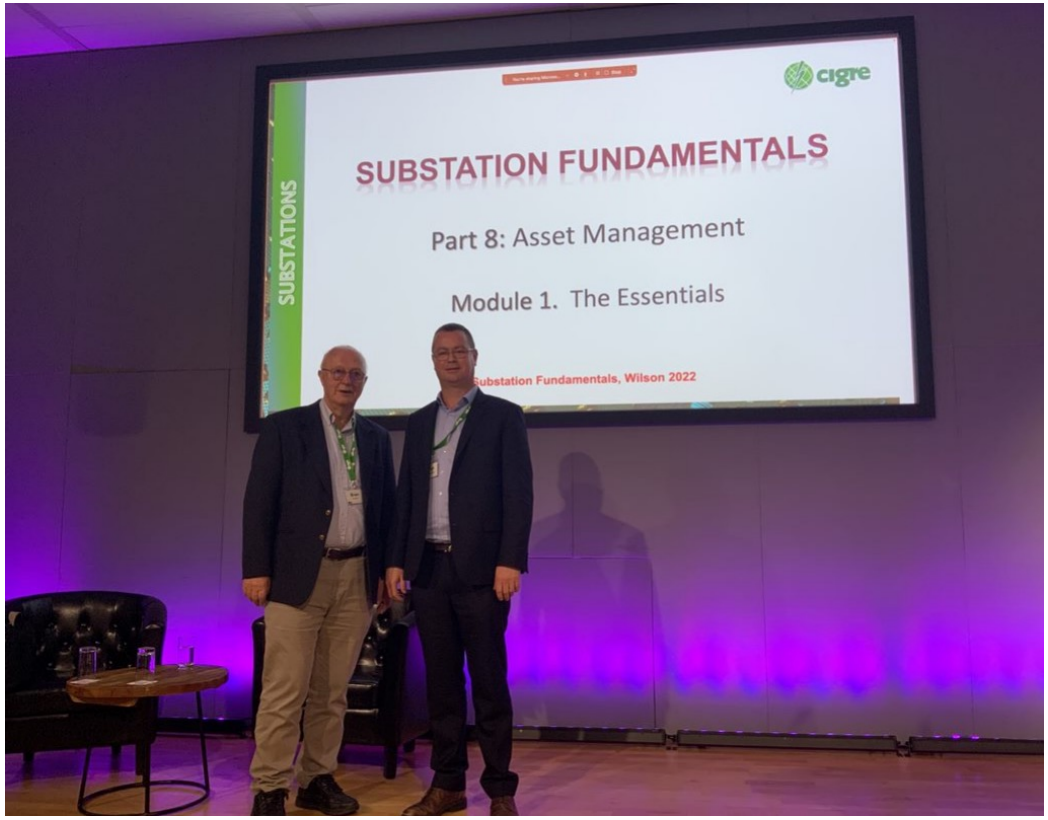
Dr Mark Kuschel

Samuel Pachlatko

Training Course Modules –**Introduction to GIS & Asset Management**



Presented by John Finn (photo with Koji Kawakita, Akira Okada)



Presented by Alan Wilson (photo with Hugh Cunningham)

Keynote Speech

Alice Delahunty with Nenad and Koji, Chairs of study committees A3 and B3

Presented papers Day 1

- Presentation of SF6-free Dead-Tank Circuit Breaker rated 145kV, 63kA
- Update on the development of 420 kV GIS Substations switchgear using environment friendly C4-FN / O2 / CO2 gas mixture
- Performance of High Voltage Circuit-Breakers using C4FN gas mixture on Shunt reactor applications
- 245kV Single Break capability for Air Insulated Switchgear SF6-free Circuit-Breaker
- Type testing of the EconiQ™ 420-kilovolt circuit-breaker based on C4-FN technology
- Dual Gas concept and design compatibility between SF6 & SF6-free GIS products
- Long-term performance and decomposition of Fluoronitrile-containing gas mixtures in gas-insulated systems
- High-Voltage Switchgear Technology Applying CO2/O2 Natural-Origin Gas Mixture as an Alternative Insulating and Interrupting Medium to SF6
- Development of SF6-Free 72/84 kV GIS Using Synthetic Air as an Alternative to SF6
- F-gas-free Natural Origin Gases for MV GIS, to manage a low carbon future
- Zero Emission F-gas-free 420 kV GIS for a Net Zero Carbon Future
- Strategy to select SF6-alternatives and to introduce new technology equipment in the transmission grid of TransnetBW
- Guidelines and tools for end users to estimate, quantify and challenge climate change and ecological impacts of medium- and high-voltage switchgear
- Steps to a CO2 neutral Substation
- Lifetime evaluation of elastomeric seals for high-voltage switchgear using SF6 and its application to synthetic air insulated equipment
- Maximizing the sustainability of day-to-day services for power technology
- Path towards Net-Zero using Life Cycle Assessment

Presented papers Day 2

- CIGRE fourth reliability survey on switching equipment
- Suitability Investigation of a Machine Learning Approach to Evaluate SF6 Alternatives
- Enhancement of Electrical Insulation Performance using FGM Techniques in Air Insulated HV GIS
- Experience with biodegradable liquids in instrument transformers with an emphasis on dielectric testing
- Substation design with compactly developed equipment to reduce carbon footprint
- Pilot projects and ongoing activities in Japan for phasing out SF6 gas
- SF6 gas management in substations
- Analysis of SF6 Leakages Events with Respect to Recommendations for End-of-Life Management of the Substation Equipment
- Transformers and the Circular Economy
- Transformer Fire Safety in the Absence of SF6
- Study on Zero Emission Hydrogen-powered Backup Generator for Substations
- FACTS to enable greater renewables penetration in Ireland – developments and Roadmaps for alternative technologies
- Network & equipment development of FACTS to enable greater renewables penetration in Ireland – developments and Roadmaps for alternative technologies
- Optimisation of Operational Efficiency in Remote Operation
- Expedite Grid Sustainability using IIoT: Kickoff Models & Roadmap

Panel Session Presenters and panel guests

Dr. Nina Støa-Aanensen
Researcher, SINTEF Energy Research
Norwegian representative in SC A3
Editor of TB871 (WG A3.41)
Trondheim, Norway

Matt Barnett
Electrical Plant Subject Matter Expert,
SSEN Transmission
Member of CIGRE JWG B3/A3.60, active in other national and international bodies
Glasgow, Scotland, UK

Dr. Mark Kuschel
Fellow, Siemens Energy at Grid Technologies
Chief Technology Officer Switching Products & Systems
Area Advisor GIS Cigre B3, Vice Chair IEC TC99, Secretary IEC SC17C
Berlin, Germany

Dr. Maik Hyrenbach
Working at ABB AG
Corporate Executive Engineer for MV GIS
Active in CIGRE SC B3 incl. different WGs, T&D Europe, ZVEI, FNN and in IEC and EN standard WGs
Ratingen, Germany

Dr. Tony Lujia Chen
The University of Manchester
Senior Lecturer in HV Engineering
Associate Dean for Research Impact
Secretary for CIGRE JWG B3/A3.59 and member of JWG B3/D1.63
Manchester, UK

Dr. Michael Gatzsche
Hitachi Energy, R&D Principal Engineer
SF_6 Alternatives Technology Development
JWG B3/A3.60
Zurich, Switzerland

Dr. Lisa Schäfer
European Energy Policy Advisor at 50Hertz Transmission
Specialized in EU sustainability & environment policy
Berlin, Germany

Soo Ik Lee
Hyosung Heavy Industries, Korea
Team manager, Gas HV Switchgear Development Team, Power systems PU
Expert of HV CB
Seoul, Republic of Korea

Dr. David Wright
National Grid
Group Chief Engineer
Warwick, UK

Andres Laso
Research engineer at G&W Electric
Member of A3/B3.60 WG
Cigre USNC NGN: Co-chair of Webinars, Chair of Marketing.
Chicago, USA

Nenad Uzelac
G&W Electric
Global Research Manager
Chair of Study Commite A3
Chicago, USA

Koji Kawakita
Fellow, Chubu Electric Power Grid
Chair of Study Committee B3
Nagoya, JAPAN

Dr. Toshiyuki Uchii
Technical Fellow, Grid Solution Division, Toshiba ESS Corp.
Expert of HV CB and GIS.
Member of CIGRE JWG B3/A3.60, B3/A3.59 and B3/D1.63
+ 3 A3&B3 WGs in the past. Member of CZ Club
Kawasaki, Japan

Panel Session Summary – SF6 Alternatives

- **"A lot" has happened the last 10-20 years:**
  - SF6-free vacuum CBs for higher voltages
  - CO2 / O2 circuit breaker technology
  - 2014/2015: C4-FN and C5-FK
  - 2021: C5-FK abandoned for HV applications
  - Cooperation / patent sharing between switchgear manufactures
- **A lot has happened since CIGRE Paris 2022**
  - Many new projects on SF6-free MV and HV ≤145 kV
  - Nov: New SF6-free 420 kV GIS installation announced
  - Nov: New retrofill projects
  - Dec: 3M announces stop in production of NOVEC gases from 2026
  - 2023: EU F-gas regulation update voting
  - Feb: European Chemical Agency with PFAS restriction proposal

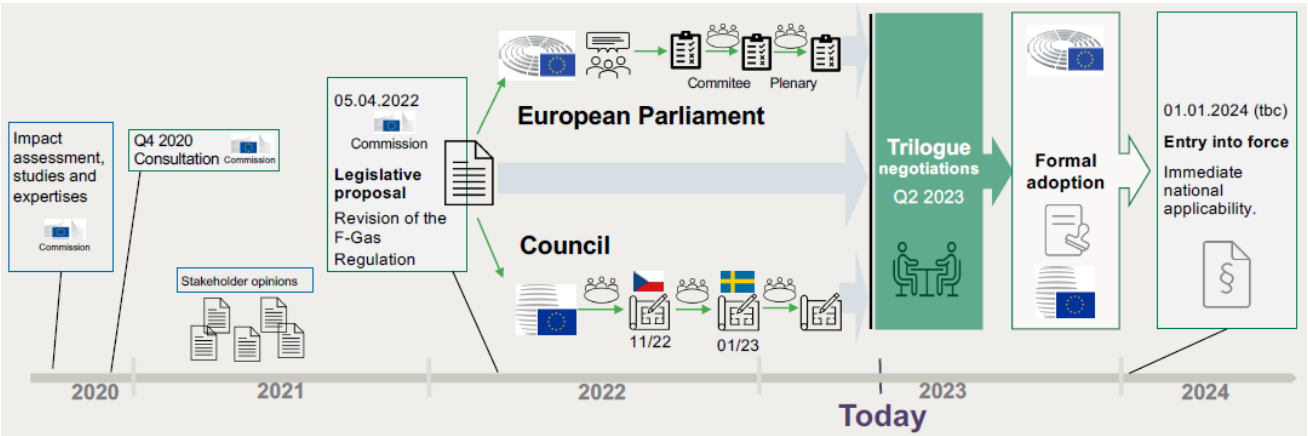
Panel Session Summary – Hot Questions

- Gas switchgear technology:
  - Gas supply in short-term and long-term perspective
  - Updated (and new?) F-gas restrictions (which markets will they affect?)
  - Possible PFAS restrictions (fluoronitrile C4-FN, fluoroketone C5-FK, PTFE, lubricants, sealings): how and for which markets could this affect the transition to SF6-free technology?
- Vacuum switchgear technology (with gas insulation):
  - Scalability for (E)HV applications (is ≥420 kV feasible, and when?)
  - Availability (will the market get sufficiently high units and from multiple suppliers?)
  - What is the required pressure and size if using pressurised air?
  - MV: is size or pressure most important?
- Utility side:
  - Long-term vs short-term challenges (>40 year lifetime vs changing regulations and availability)
  - How to reduce emissions while significantly expanding the grid?
  - Resilience as important as ever!?

Panel Session Summary

- Update from JWG B3/A3.60 – Presented progress on WG aims to develop practical user guidance for non-SF6 gases or mixtures in MV and HV GIS,
  - Definitions
  - On-site gas handling
  - Measurement guide
    - Typical contaminants
    - Measurement equipment
    - Tolerances for mixtures
  - Tightness guide and requirements
  - Environmental, Health and Safety
  - Recycling guide

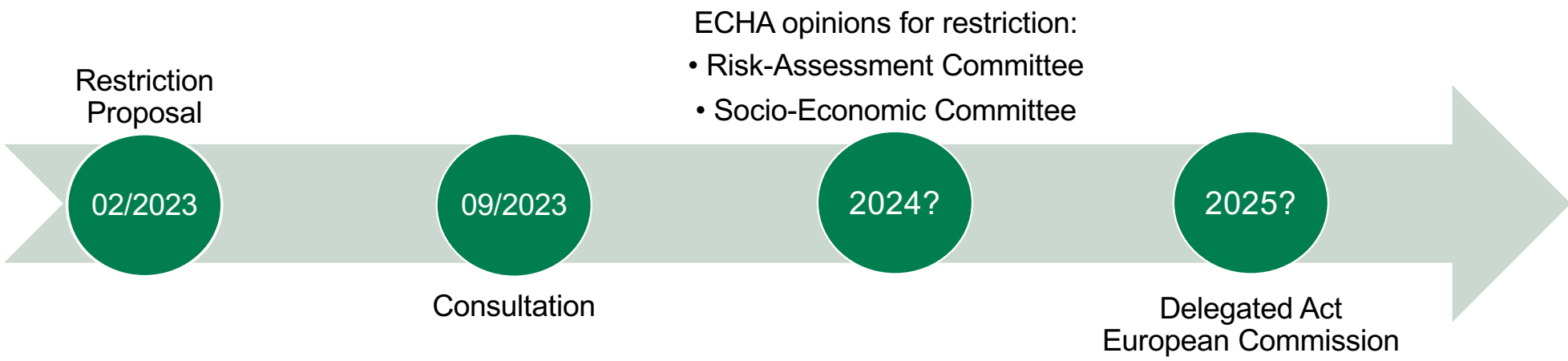
Panel Session Summary – Update on EU F-gas regulations



Strategic Items	European Parliament	Council (EU Member States)
Phase-out date* switchgear 52 < 145 kV	**All F-Gases** from 1 January 2028 *refers to "placing on the market"	**F-Gases with a GWP > 10** from 1 January 2028. *refers to "putting into operation"
Phase-out date* switchgear > 145 kV	**All F-Gases** from 1 January 2031 *refers to "placing on the market"	**F-Gases with a GWP > 10** from 1 January 2032. *refers to "putting into operation"
Exemptions / deviations	**Switchgear with GWP <1000 is allowed if** • no F-Gas-free solution available, *or* • two years after deadlines, only one bid placed for F-Gas-free switchgear.	**Switchgear with GWP <2000 is allowed if** • no switchgear with GWP <10 is available, or • until 2030 and 2034 respectively, only one bid placed for switchgear with GWP <10. **Switchgear with GWP >2000 is allowed if** • no switchgear with GWP <2000 is available.
Spare parts	Spare parts allowed for repairs and maintenance, **not** for extensions of equipment.	Spare parts allowed for repairs and maintenance, **and** for extensions of equipment.
Control of gas use	-	Ban of virgin SF_6 from 2035, exceptions possible on technical grounds.
Leakage checks	Equipment containing F-Gases with > 500 t CO2-equivalent installed from **2017** shall be equipped with a higher sensitivity leakage detection system. This equipment shall be checked every six years.	No additional checks if switchgear is equipped with a density monitoring device (automatic alert). Equipment containing F-Gases with > 500 t CO2-equivalent to be checked every six years.

Panel Session Summary – Update on EU PFAS regulations

- The REACH Regulation governs the management of chemicals in the EU.
- DE, NL, DK, SE, NO have submitted a proposal for a complete ban or "restriction" of PFAS.
- The European Chemicals Agency (ECHA) to provide socio-economic and scientific risk-assessment of PFAS.
- Derogation proposed for switchgear >145 kV for 6,5 years.
- Many heterogeneous stakeholders and sectors involved.
- A restriction seems likely, but the transition period could be extended.
- Question – will the *use* of PFAS in existing switchgear remain allowed?



Panel Session Summary – Update on USA regulations

- EPA currently sets reporting requirements and thresholds for SF6 and PFC's.
- New EPA proposal: to include NF3, Fluoroketones and Fluoronitriles. (June 2022).
- EPA's integrated approach over PFAS is focused on three central directives:
  - **Research** to increase understanding of PFAs exposures and toxicities, human health and ecological effects.
  - **Restrict** PFAS from entering air, land, and water at levels that can adversely impact human health and the environment.
  - **Remediate** to clean up PFAS contamination to protect human health and ecological systems.

SF6 alternatives

July 2023

Explore Reporting Requirements for NF3, Fluoroketones and Fluoronitriles.

PFAS

End 2023

EPA update on proposed guidelines and regulations

2024

Project finalisation

Panel Session Summary – Update on USA regulations

- CARB requires all owners of Gas Insulated Equipment (GIE) to reduce emissions of Greenhouse Gases with GWP>1.
  - Annual emission limit of 1% per year (based on CO2e capacity for all insulating gases)
  - Reduce the emissions starting from 2035 and beyond (5% per year) for ≥10,000MTCO2e
  - All owners must establish and maintain an inventory of GIE (gas capacity, SWP of gas, rating)
  - Set requirements for refilling, measurement, methods, calibration, etc to monitor gas

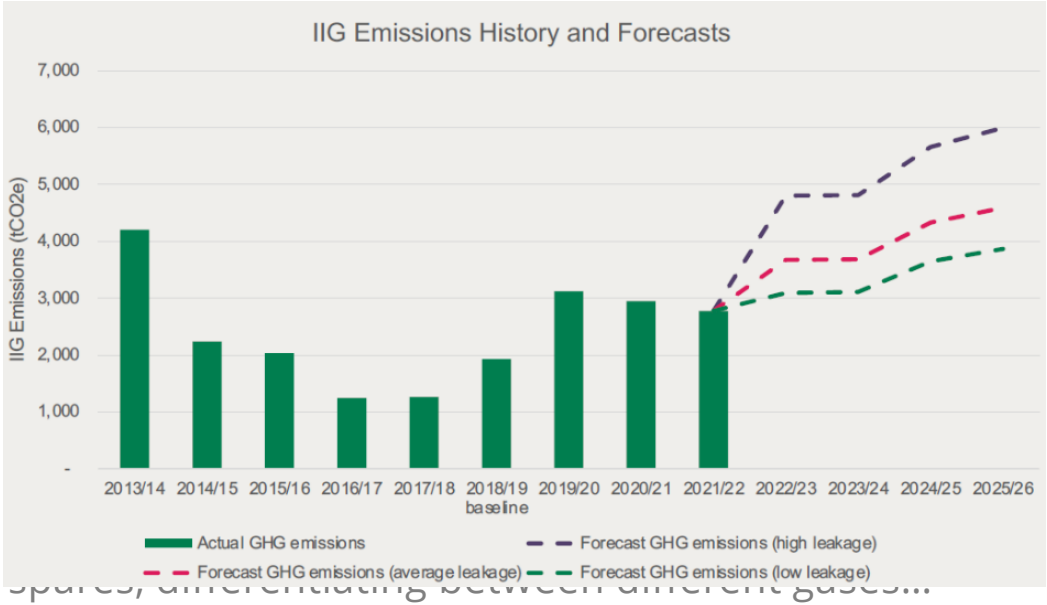
- GIE owners may apply for an exemption for phase out when:
  - No more than 2 suppliers offering SF6 free solutions
  - Available non-SF6 cannot meet size constraint
  - Part replacements or replacement under warranty

Configuration	System Voltage kV	Short Circuit rating kA	SF6 Phase-out Date
MV, Aboveground	Ur < 38	All	2025
	Ur = 38	All	2028
MV, Belowground	Ur ≤ 38	Isc <25	2025
		ISC ≥ 25	2031
HV	38 < Ur ≤ 145	ISC < 63	2025
		ISC ≥ 63	2028
	145 < Ur ≤ 245	ISC < 63	2027
		ISC ≥ 63	2031
	Ur > 245	All	2033

- California currently has numerous regulations restricting PFAS, but do not cover switchgear or power industry.
- Other states issued similar PFAS regulations, generally targeting water, firefighting foams and food
- Maine requires manufacturers to report on the intentional addition of PFAS into their products (01/01/2023)
- Products containing intentional PFAS may not be sold in Maine unless their use is designated unavoidable (01/01/2030)

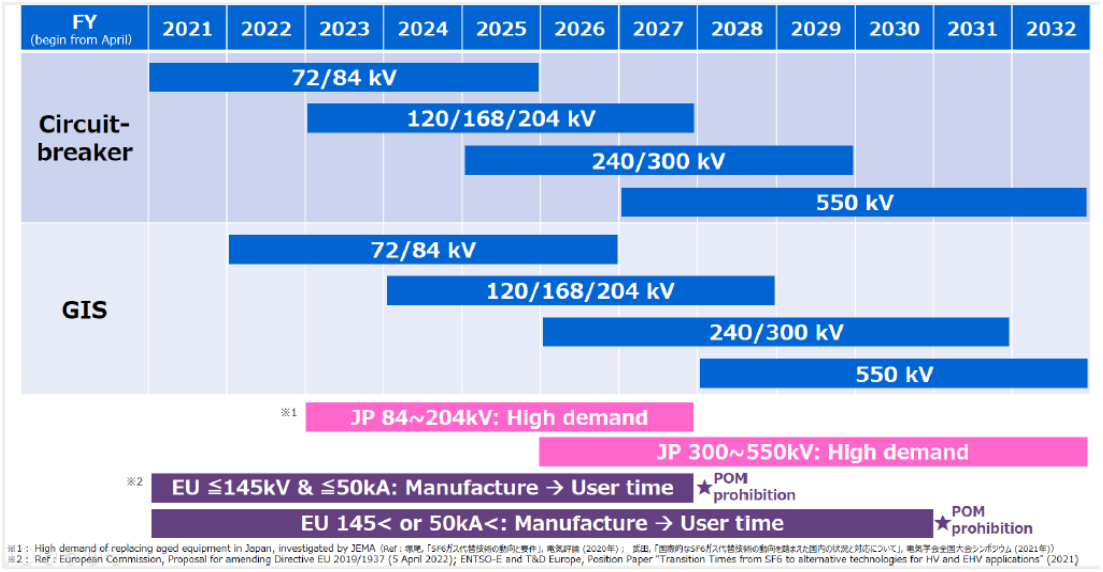
Panel Session Summary – Updates from UK Utilities

- Rapidly growing networks ➡ new substation and switchgear ➡ more gas
- An ever aging fleet of existing SF6 filled switchgear which will may become more leaky over time
- Emissions could be 39-145% higher than 2021/2 by 2025/6
- Priority has to be minimising new SF6
  - 145kV technical air / vacuum AIS CB
  - 145kV technical air Power VT
  - 145 kV C4-FN GIS and AIS CB
  - 420 kV C4-FN GIB
- Many more in Construction / Development
  - 145 kV technical air / vacuum GIS
  - 420 kV technical air GIB
  - 420 kV C4-FN GIS
- Challenges facing utilities include:
  - Product availability
  - Product reliability
    - Operation – handling equipment, training, spares, differentiating between different gases…
    - Asset management – condition assessment, maintenance…
  - Regulators / other stakeholders
- Retrofill options are also being explored – these have technical limitations such as pressure limits and material compatibility.



Panel Session Summary – Updates from other Utilities

- South Korea have agreed to reduce greenhouse gases by 40% by 2030.
  - KEPCO purchase rate of eco-friendly power equipment to be 50% by 2030, then 100% by 2040.
  - Currently planning to continue using C4-FN despite 3M ceasing production, actively seeking alternative gas supplier.
- Japan currently have no restrictive regulation on SF6, however in 2017 a collaboration of Utilities, domestic suppliers and academia agreed to a unified policy called the “7 requirements” to evaluate emerging technologies.
  - Large number of GIS substation will reach end of life within the next 10 years.
- Elia group are aiming to achieve 100% renewable generation by 2032 and reduce the installation of new SF6 by 50% by 2030.



※1：High demand of replacing aged equipment in Japan, investigated by JEMA（Ref：電気「SF6ガス代替技術の動向と要件」, 電気評論（2020年）； 坂田「国際的なSF6ガス代替技術の動向を踏まえた国内の状況と対応について」, 電気学会全国大会シンポジウム（2021年））
※2：Ref：European Commission, Proposal for amending Directive EU 2019/1937 (5 April 2022); ENTSO-E and T&D Europe, Position Paper "Transition Times from SF6 to alternative technologies for HV and EHV applications" (2021)

Panel Session Summary – Updates from Suppliers

- ABB developing a range of “dry air” switchgear up to 12kV. Originally planning to use C5-FK for higher voltages (up to MV) however, regulation changes has meant ABB are changing their strategy to offer only PFAS-free insulation with products aiming to be available in line with F-gas regulation timelines
- Korean domestic suppliers currently exploring multiple options, including C4-FN based GIS with gas breakers wig the first orders currently being delivered. Vacuum interrupters with dry air and C4-FN GIS back parts are still under development.
- Toshiba are currently pursuing an F-gas free solution with products currently available for up to 84kV 31.5kA. 420kV GIL is the next milestone, aiming to be launched in at the end of 2024.
- Siemens are currently pursuing the application of N2 + O2 and vacuum interruption as that will meet any future F-gas and PFAS regulations. Current applications include 420kV GIB, 145kV livetank and deadtank circuit breakers and 420kV instrument transformers. The next development targets are 72.5kV deadtank breakers and 420kV GIS backparts (2024) with a 420kV GIS and Livetank circuit breaker by the end of 2026
- Hitachi are pursuing a C4-FN based product line, with a 420kV 63kA GIS products now commercially available. 145kV livetank circuit breakers are also currently available.
- GE are similarly pursuing C4-FN solutions for AIS and GIS solutions with the first 420kV GIS solutions developing under trial.

Summary

- Networks are expanding at a greater rate than ever, introducing more renewables and facilitating a transition to electrification.
  - We cannot keep installing new SF6 equipment if we are to reduce CO2e emissions.
- Suppliers are progressing with 2 main SF6 alternatives.
  - Switchgear utilising Fluoronitriles and Fluoroketones (F-gas) which is becoming available at ever greater voltages and ratings, offering usable solutions now.
    - GWP of these gases are << SF6 but still >1 (for C4-FN mixtures at least).
  - Vacuum (interruption) and “Natural Origin Gas” which is further behind alternative F-gas in terms of availability at higher voltages and ratings.
    - GWP ≤ 1.
  - Both solutions enable utilities to avoid installing new SF6 which helps them to meet emissions targets.
- However… Proposed legislation may stunt growth and development of alternative F-gas technologies.
  - New F-gas legislation may restrict or prevent use of alternative F-gas with GWP more than 100, or even 1 CO2e.
  - PFAS legislation may prevent use of PFTE in circuit breaker nozzles or other insulation components used in switchgear.
    - Research into alternatives is beginning but currently no available alternatives


Thank you
cigre
For power system expertise