1

A3 session

44 papers presented at e-CIGRE Aug. 26-27, 2020

- HVAC circuit breakers (7)
- SF6 alternatives (11)
- Reliability (9)
- Instrument transformers (5)
- Medium voltage equipment (1)
- Controlled switching (4)
- Testing (3)
- HVDC switchgear(4)

2

HVAC switchgear

- **In Service Diagnosis of Grading Capacitor Dielectric Deterioration – A3.204 UK Elimpus**
  Dielectric health of grading capacitor
  Sensors: RF PD detector system, 50 Hz, trip current pulse
  Location of PD activity in the breaker
  Shows example of PD in old and replaced capacitor during arcing
  Degradation of GIS grading capacitor (holes in the foil)
  In-service, non-invasive, 0.5 day, also for GIS
- **External flashover of a 245kV live tank circuit breaker – A3.222 France EdF**
  Failure case discussed in detail. Replacement of breaker
  breakdown very shortly after fault clearance
  Description of failure investigation following IEC 60815-1
  Pollution investigated in the laboratory (salt deposit)
  Highest peak TRV in out-of-phase condition, but not cause of failure
  Creapage distance was too short given the pollution level
  Lab tests set-up in out-of-phase + pollution condition. Leakage current measured
  Failure can be reproduced in the lab
  Replaced by a 345 kV breaker as a solution.

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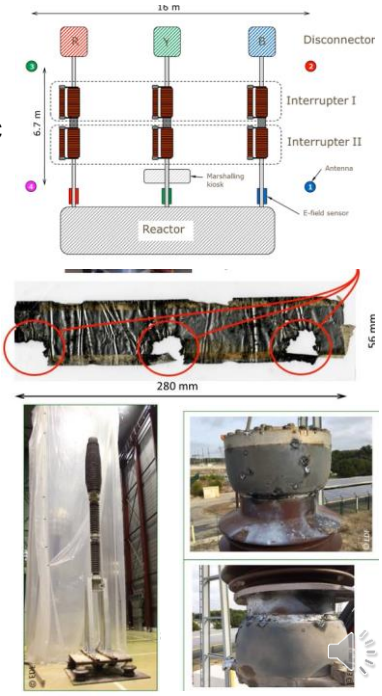

3

HVAC switchgear

- **Circuit Breaker Derating Assessment under High DC Time Constant – A3-205 UK Univ**
  45 ms dc time constant sometimes too small
  No consensus for approach of dealing with higher DC time constant
  Up to now arc energy in last loop is taken as reference CIGRE TB304
  Equations are given for derating factor
  Simplified method in TB304: taking last loop as rectangular
  UK practice UK EREP 89 discussed, polynomial given, comparison with exact calculation is given
  Comparison between various approaches
- **Fault current limiters for electrical grids 220 kV on the base of the fast acting high voltage explosive commutators – A3.107 Russia**
  Explosive switcher (ES), fast acting commutation
  1.5 ms, 1,7 ton, 5 - 15 kA limitation at 220 kV
  Tests performed
  Bus coupling, at renewable gen plant
  Field experience in 500 kV station in Moscow
  Prospective current of 63 kA can be limited to … kA
  Also for HVDC, and to 500 kV AC

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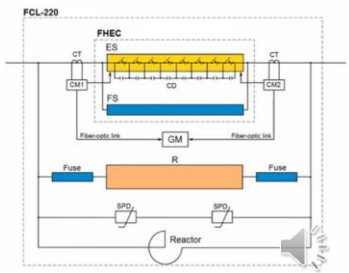


4

HVAC switchgear

- **Development of 362 kV 63 kA 60 Hz SelfBlast Breaker without additional capacitors to prevent ferroresonance by improving the SLF performance – A3.215 Korea LS**
  - 60 Hz more severe than 50 Hz, capacitor may be needed to interrupt
  - This may lead to ferroresonance
  - Designed is aimed to avoid the add-on capacitor, simulation study for pressure
  - Detailed report of internal design process
  - Tested according to IEC

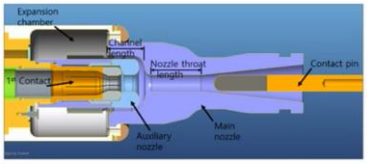
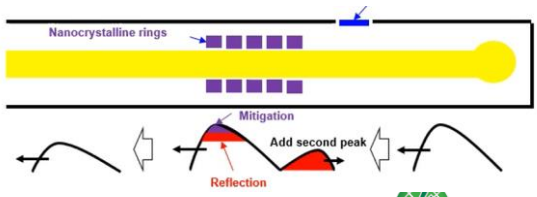


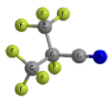
Fig 3. Inner structure of self blast breaker

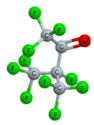
- **Damping Performance of VFTO using Magnetic Rings in 800kV GIS – A3.216 Korea Hyosung**
  - Very Fast Transient Overvoltages necessary
  - Mitigation: Magnetic rings, shunt resistor, RF resonator, surge arrester
  - Full-voltage test set-up in GIS
  - Measurement is an issue, 11 MHz is expected in VFTO
  - 3 types of nano-crystalline magnetic rings with upto 36k magnetic permeability
  - Aim: damping of travelling wave in the GIS
  - Performance 17% reduction of UHF peak
  - More rings (upto 17) more effective, but take up space



5

SF6 alternatives





GAS

- Two commercial available applications
  - g3
  - AirPlus
- Mixtures with small amount of 3M NOVEC gas
- Breaker needs to be redesigned
- NOVEC gas is consumed by arcing
- Decomposition products as with SF6
- Higher pressure, gas composition may vary
- > 20 pilot projects up to 170 kV 50 kA
- CIGRE Technical Brochure 802 + A3.41

g3™	GWP	P_{min} (MPa)	T_{min} (deg)
HV: CO2+O2 + 4-6% C4-PFN	327 .. 690	0.67 .. 0.8	-25 .. -10
MV: N2 + 20-40% C4-PFN	1300 .. 1800	0.13	-25 .. - 20

AirPlus™	GWP	P_{min} (MPa)	T_{min} (deg)
HV: CO2+O2 + 6-12% C5-PFK	1	0.7	-5 .. +5
MV: Air + 7-13% C5-PFK	0.6	0.13	-25 .. -15

VACUUM

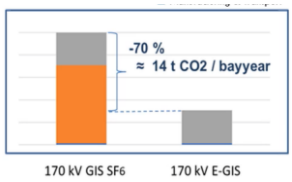
- Up to 170 kV 50 kA single break metal enclosed in clean air insulation

6

SF6 alternatives

- **First 170 kV / 50 kA GIS with Clean Air and Vacuum Interrupter Technology as a Climate neutral Alternative to SF6 – A3.301 Korea Iljin**

  Kepco to reduce SF6 emission -> Eco friendly GIS
  -25 – 40 C requirement, GWP< 500, < 1MPa filling pressure
  Synthetic air as insulation, vacuum for switching
  including disconnection switch, also clean air insulated
  including arresters and current transformer
  70% reduction



- **The First Development of SF6 free 170kV 50kA 60Hz GIS with Fluoronitile (C4F7N) Mixtures A3.114 – Korea LS**

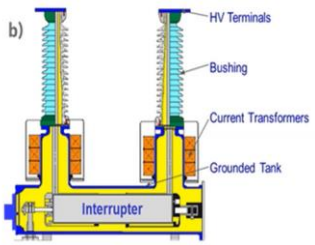
  Based on C4FN, without capacitor
  Simulation based design process
  SF6 design needs to be adapted to new gas after T100 failure
  Capacitive switching (line, cable, bank) C2 class successful
  IEC test-duties passed after modification
  Bus transfer and bus charging performance OK. EM induced longer arcing time than SF6. Making test also included.

7

SF6 alternatives

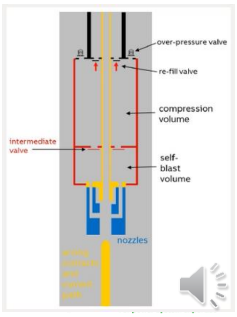
- **Environmental Performance of Dead Tank Circuit Circuit Breakers with SF6 and Alternative Gases – A3.102 USA GE**

  72.5, 4000 A, 40 kA rating
  Four alternatives: SF6, CO2/O2/C4FN, vacuum air 0.5 and 0.6 MPa
  Dielectric performance: air needs very high pressure, difficult for vacuum bellows, has impact on tank dimension. Vacuum/air 1645 -> 2500 kg mass
  LCA aspects of all alternatives
  Climate impact 50-60% reduced, CO2/O2/C4FN lowest impact (lower losses lower mass)



- **C5 fluoroketone based gas mixtures as current interrupting media in high voltage switchgear – A3.118 Switzerland Hitachi ABB**

  C5FK based, GWP < 1, design changes required
  Make proof earthing switch, few 100 A EM ES induced current interrupted add gas flow to make it happen.
  Circuit breaker
  CO2 based only 2/3 performance of SF6. Design needs to be optimized: refill valve
  Increase pressure built up an reduce blow-gas temperature
  CFD simulations were used for design

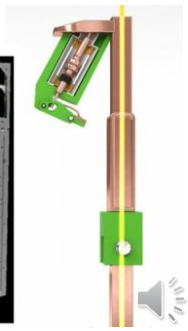


8

SF6 alternatives

- **First CO2 neutral 145 kV and up to 63 kA Dead Tank Circuit Breakers based on Vacuum Switching and Clean Air Insulation Technology – A3.106 Germany Siemens**
  with PG&E, USA
  maintaining SF6 leaks <1% extremely expensive
  comparison of SF6 and alternatives: clean air, C4FN and C5FK mixtures
  Phase out California > 245 kV 2029 > 550 kV by 2031
  Now demonstrated 145 kV 4000 A 40/63 kA in vacuum
  Type test partially completed IEC and IEEE


- **Innovative SF6 Free Load Break Switch with Shunt Vacuum Interruption (SVI) Technology- A3.116 France Schneider**
  MV application
  Pressurized air with vacuum is best alternative, C4FN high toxicity, same as C5FN
  HFO1234zeE with 36 kV products, at lower voltages air instead
  Classical: vacuum + 3 position disconnector (two devices)
  Alternative: vacuum switch operated by the discon mechanism
  Can be used with switch/fuse combination for transformer; pilots running



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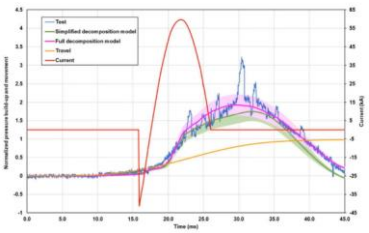
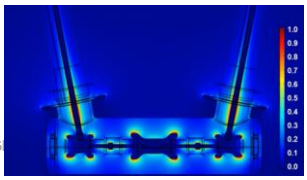
SF6 alternatives

- **Theoretical and Practical Behaviour of EcoFriendly SF6 Alternatives in High Voltage Switchgear – A3.119 Switzerland Hyundai**
  C4FN based
  Goes into thermodynamics and computational fluid dynamics for decomposition
  Decomposition is an issue for all 3M gases, 0.54 mol/MJ, volume dependent
  Decomposition compared with ablation of nozzle
  170 kV 40 kA case treated, every species density calculation used



- **Basic aspects of switching with series connected vacuum interrupter units in high voltage metal enclosed and live tank arrangements – A3.112 Germany Siemens**
  Vacuum and clean air as insulation. Up to 245 kV single break under development
  Up to 550 kV and beyond, multi break needed
  Scale test with two 24 kV vacuum interrupters in series with/without grading caps
  With 825 pF grading even distribution, without 20-80%
  Test with live tank breaker and 500 pF grading and 30% fault current
  Rated voltage 362 kV reached with two gaps rated
  145 kV each
  550 kV maybe possible with 2 x 245 kV

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SF6 alternatives

- **Return of experience of the SF6 free solution by the use of fluoronitrile gas mixture and progress on coverage of full range of transmission equipment – A3.117 France GE**

Based on C4FN/CO2/O2
GIL 420 kV (6 sites); GIS 145 kV (34 bays in service); IT (245 kV -30 C)
No change in gas composition
Now up to 63 kA 60 Hz dead tank with 3.5% C5FN, 13% O2, 83.5% CO2
Impact of O2 content on physical phenomena (carbon/soot removal)
CO reduction at increased O2 content
Electrical endurance check: limit is contact degradation, not the gas
All HV equipment up to 550 kV replaced with alternatives this decade

Reliability 1

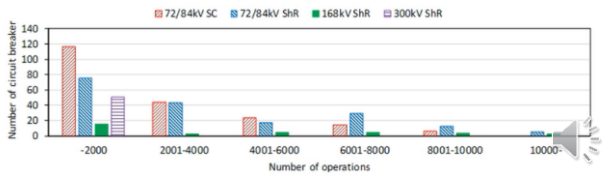
- **CIGRE Reliability Survey on Equipment – A3.201 Japan AG3.01**

International survey, 4th survey reported, 18 utilities, > 520k CB-years
Includes now HV VCB and generator circuit breakers
Slightly lower reliability wrt 3rd survey, but different set of countries
New WG to start end of 2020 for further analysis

Equipment	4 th CIGRE survey		
	Populations	Major failures	Participants
CB	520,235 CB-year	under evaluation	9 counties
DS	1,647,086 DS-year	0.350 %	5 counties
ES	198,076 ES-year	0.0005 %	4 counties
IT	584,932 IT-year	0.1314 %	4 counties
GIS	232,444 CB bay-year	under evaluation	7 counties
MOSA	549,381 SA-year	0.0739 %	6 counties
VCB	2,538,494 CB-year	0.187 %	5 counties

- **Actual use survey and maintenance practice of circuit breakers for frequent switching applications – A3.206 Japan Hitachi**

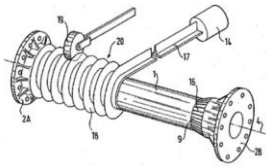
Number of operation is key parameter in wear of breaker
Shunt reactor and capacitor bank have high failure rates
468 breakers 72 - 300kV in 3 JP utilities in frequent operation, max 21k operations, 90 percentile is 10k times
Shunt reactor operation 2x of capacitor banks ops
maintenance: time based every 6 years, condition based on accumulated current
Service life extension: new materials (low erosion nozzle); controlled switching; series reactor in cap bank
Life is 40 years
TBM now, CBM to become more important



Reliability 2

- **A campaign for the ageing evaluation of station hollow core composite insulators after a number of years of service – A3.207 Italy Terna**

Polymeric material much more sensitive to stresses than porcelain
420 kV HTV silicone hollow core insulation current transformer
Survey started 2019, list of research programs
Manufacturing extrusion technology of Reinhausen
Salinity resistance studied in Italian grid up to > 160 g/l salinity
Chemical-physical material tests collected (IR, TGA, DSC, DMM, SEA, etc.)



- **Air core reactor monitoring – not numbered Austria Trench**

Essential quantities: temperature, magnetic field, current, vibration
Issues: high voltage surrounding, strong magnetic field inside
Monitoring system shall be maintenance free, needs to harvest its power from the EM field inside the reactor
Scale tests performed in laboratory HV, EM, EMC
Turn-to-turn short detection, surface tracking to be included

Reliability 3

- **Approach & Experience of IoT Based Predictive Maintenance Technologies in Power Distribution Network – A3.217 India Tata Power**

General causes of failures and mitigation factors
IoT equipment: thermography, ultrasound (tracking, PD activity, not inside busbar)
RFID position sensor on joints
Pilot project 11 kV incoming feeder
Issues: no guidelines, lifetime, reliability, accuracy over time, standards SCAD, ADMS have different protocols, integration into existing infrastructure, limited number of manufacturers

Image. 9 Temperature sensor

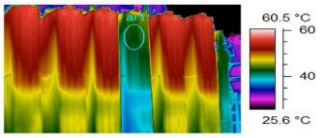
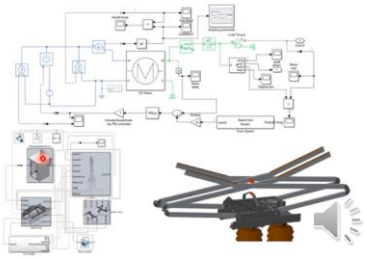


Image.1 Transformers one radiator valve not opened

- **Digital Disconnector and smart sensors: example of integration in the condition base asset management cloud tool – A3.221 France GE**

Overview of maintenance strategies
Digital disconnector with plenty of sensors + electronic control
Temperatures, position, motor current, operation energy, …
Digital twin in the cloud with mechanical, thermal and dielectric model
Digital twin architecture based on MatLab, Ansys behind it
Gives dashboard related to health index 0 - 5
Issues warning when maintenance is required, overload, ageing
To be integrated in AM in the station to predict replacement, maintenance

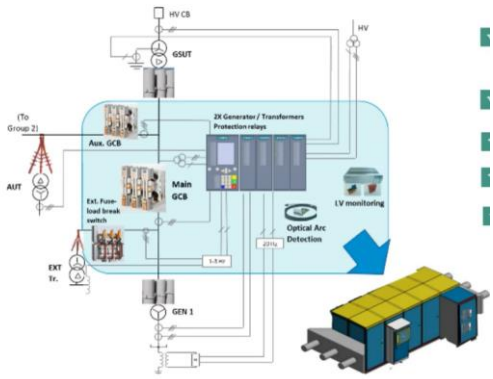


Reliability 4

- Influence of Contact Heating on Main Circuit Resistance Measurement and Dynamic Contact Resistance – A3.211 China GEIRI
- Operational Aged Switchgear With The Age Up To 50 Years Investigations, Testing, Results Considerations For The Design And Operation Of Old and New Switchgear – A3.213 Germany TU Berlin
- Development of Light Asset Models based on Data Mining – A3.225 France GE – no sound

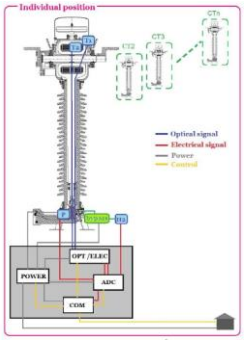
Medium voltage

- **Power plants Modernization by Smart integrated vacuum generator breaker switchgears – A3.109 Germany Siemens**
  - Vacuum switchgear green solution
  - Modernization, new standard common IEC and IEEE
  - Very large fault currents
  - Internal Arc Classification recommended
  - Integrated system presented, including protection, control & LV monitoring
  - LCA discussed



- Two papers not presented:
- Technical Economic Study on Spark Gaps Replacement by Surge Arresters on Pole Mounted MV/LV Transformers A3.218
- Pollution and Humidity Effects on Air Insulated Switchgear (AIS) of MV/LV Substations A3.219

Instrument transformers1



- Studying the characteristics of non-traditional current and voltage converters for digital substations – A3.108 Russia
  Rogowski coil most suitable for relay protection and automation devices (harmonics!)
  self diagnosis: thermal, PD,
  applied down to -40 C
- **Online monitoring of paper oil insulated current transformers – A3.208 Spain Arteche**
  fault evolution up to explosion
  sensors (in blue): temperature, pressure and hydrogen. Requirements discussed
  Integration into protection is main challenge
- Investigation of ferroresonance oscillations in the systems with electromagnetic potential transformers by experimental and calculation methods – A3.214 Russia ElMash
  no standards, this paper gives input
  simulation compared with tests with breaker with grading capacitor
  IVT 126 kV test with real components. Simulation allows much more cases to be investigated

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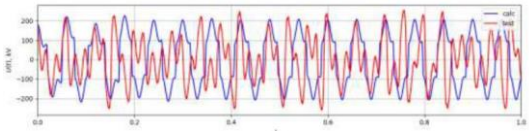

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Instrument transformers 2

- **Monitoring of asymmetric short circuit currents at a hydro power plant using electronic fibre optical current transformers DC offset measurement and zero missings - A3.223 CH Condis**
  < 10 A absolute error 0-2 kA
  comparison with conventional VTs, CTs
  flexible optical fiber transformers (F-EFOCT), wrap around busbar
  proof-of-concept in FATs, interoperability between digital fault recorder and OCT, communication checked
  site acceptance tests in hydro-station + full system verification
  Retrofit is feasible, testability is simple to verify accuracy

- Accuracy study of a combined low power instrument transformer in different climatic and pollution conditions – A3.224 CH Condis
  installed in polluted station at EdF, 2 years with periodic inspections
  F-EFOCT, Electronic voltage transformer, electronic procession unit
  temperature cycles for each in climatic chambers
  after 1 year no ageing, drift of accuracy

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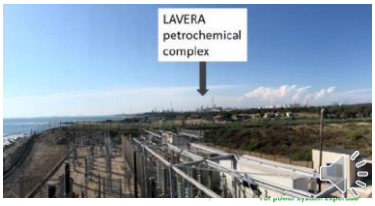

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Testing 1

- Innovative T&D Switching Equipment and Development of its Testing Technology – A3.104 KEMA NL

Increase of ratings
Local generation
Environment & safety
Digitalisation
HVDC switching
Fast drive technology
Resilient equipment







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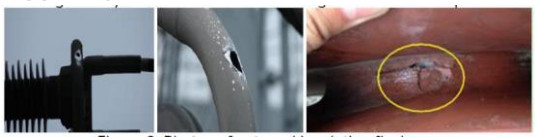
Testing 2

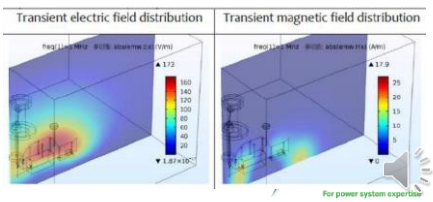
- Experience of Capacitive Current Switching of EHV and UHV AC Circuit Breaker in Power System and Test – A3.111 China Xihari

high rate of incidents in filter bank switching, 400 – 500 switching per day
faults statistics and failure mode
standards not covering this,
new Chinese standard for filterbank switchgear
NSDDs observed in SF6 breakers
Synthetic testing with non-decaying AC recovery voltage is highly recommended



- Research on Simulation Testing Method of System Level's Strong Electromagnetic Disturbance in Substations – A3.212 China

36% failure rate observed in electronic transformers > 110 kV (206 events since 2010)
cause of failure is EM interference
simulation study performed with switching disconnector as source
1- 3 MHz oscillation causing 4-20 kV/m E-field and hundreds A/m B field



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Controlled Switching

- Overvoltages research in switching modes of cable and mixed overhead cable lines, power transformers, shunt reactors and capacitor banks of 110 750 kV and development of a controlled switching device for the above electrical equipment – A3.208 Russia
- Performance tests of circuit breakers for controlled switching –A3.303 Switzerland/India Hitachi ABB
- Case Study – Improving Reliability of Circuit Breaker by using Controlled Switching and removing Pre-Insertion Resistor (PIR) – A3.115 India PG
- Operational Experience, Field Test and EMT Simulation for EHV Shunt Reactor Switching A3.202 Norway Stattnet

HVDC Switchgear

- VARC DC circuit breaker – a versatile concept for nonzero current interruption – A3.103 Sweden SciBreak
- Low loss DC circuit breakers and DC GIS equipment – A3.105 Japan Mitsubishi, Toshiba
- Benchmarking the suitability of a BiStaple Disc Spring as Novel UltraFast Actuation Principle – A3.302 Switzerland ETH
- EDISON: A New Generation DC Circuit Breaker, A3.101 USA Florida Univ

- **Dank voor uw aandacht!**
- **Voor vragen:** **rene.smeets@kema.com**
  andre.lathouwers@tennet.eu
- **CIGRE Nationaal Comité A3: T&D Equipment**

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