Circuit Breakers: Past, Present and Future

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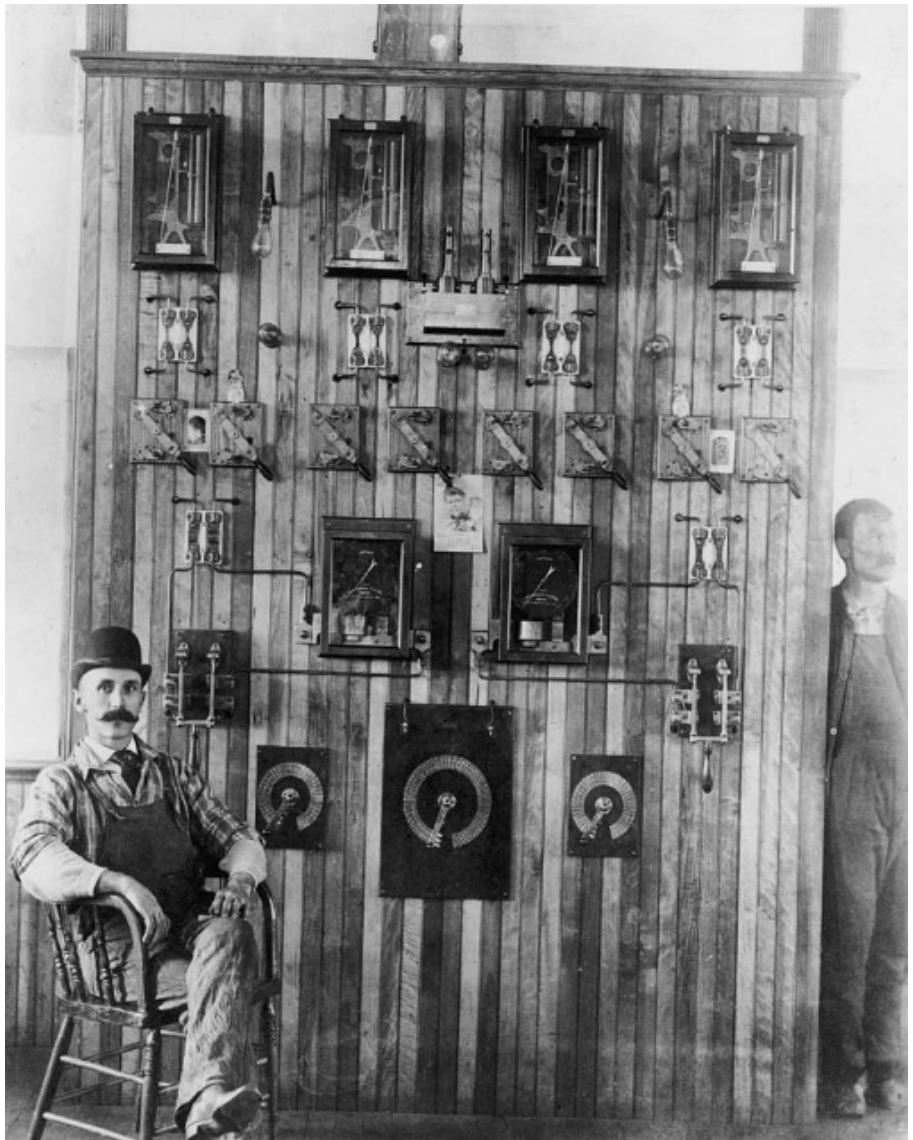
Circuit Breakers: Past, Present and Future

- Pre 1900's Bowler Hat
  - September 4, 1882
  - Used at the Inception of Power Distribution
  - Early DC Interruption
  - 100 Vdc
  - Open Air
  - Mounted on Wood
  - Human Mechanisms/Stick Operated
  - Bowler Arc interruption



Circuit Breakers: Past, Present and Future

- Past 1900's - 1996
  - Oil Circuit Breakers
    - Bulk Oil Circuit Breakers
    - Produced from 1900 - 1996
    - One Tank with all 3 phases
    - One tank per phase
    - 5 kV to 230 kV (245 kV)
    - Pneumatic Mechanisms
    - Pneu-dralic Mechanism
    - Hydraulic Mechanism
    - Not economical at Larger kV
    - Dead Tank Design
    - Ganged Operated

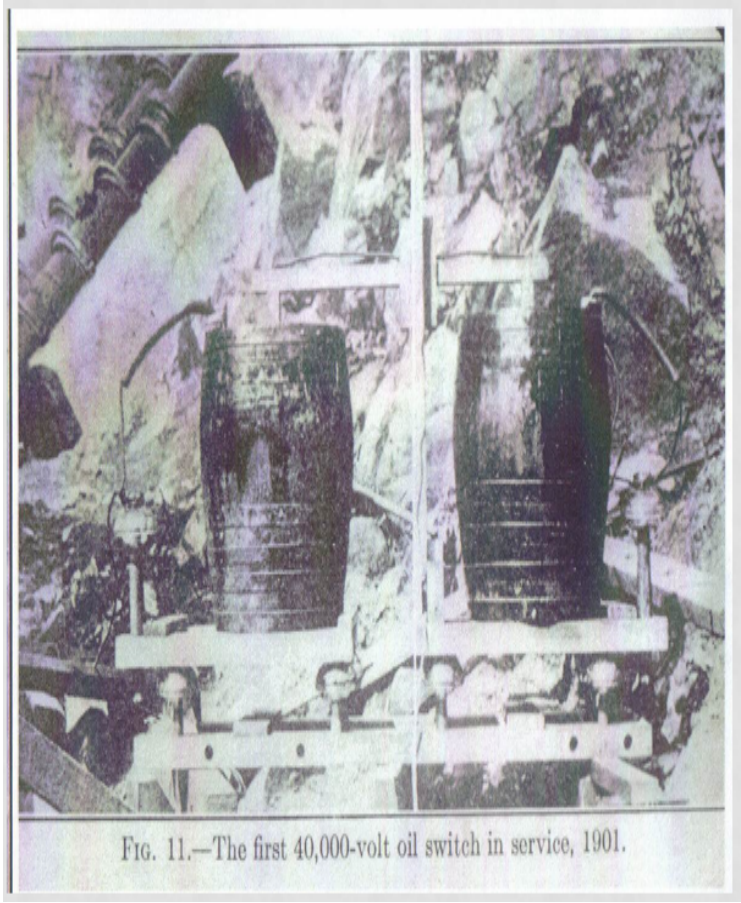
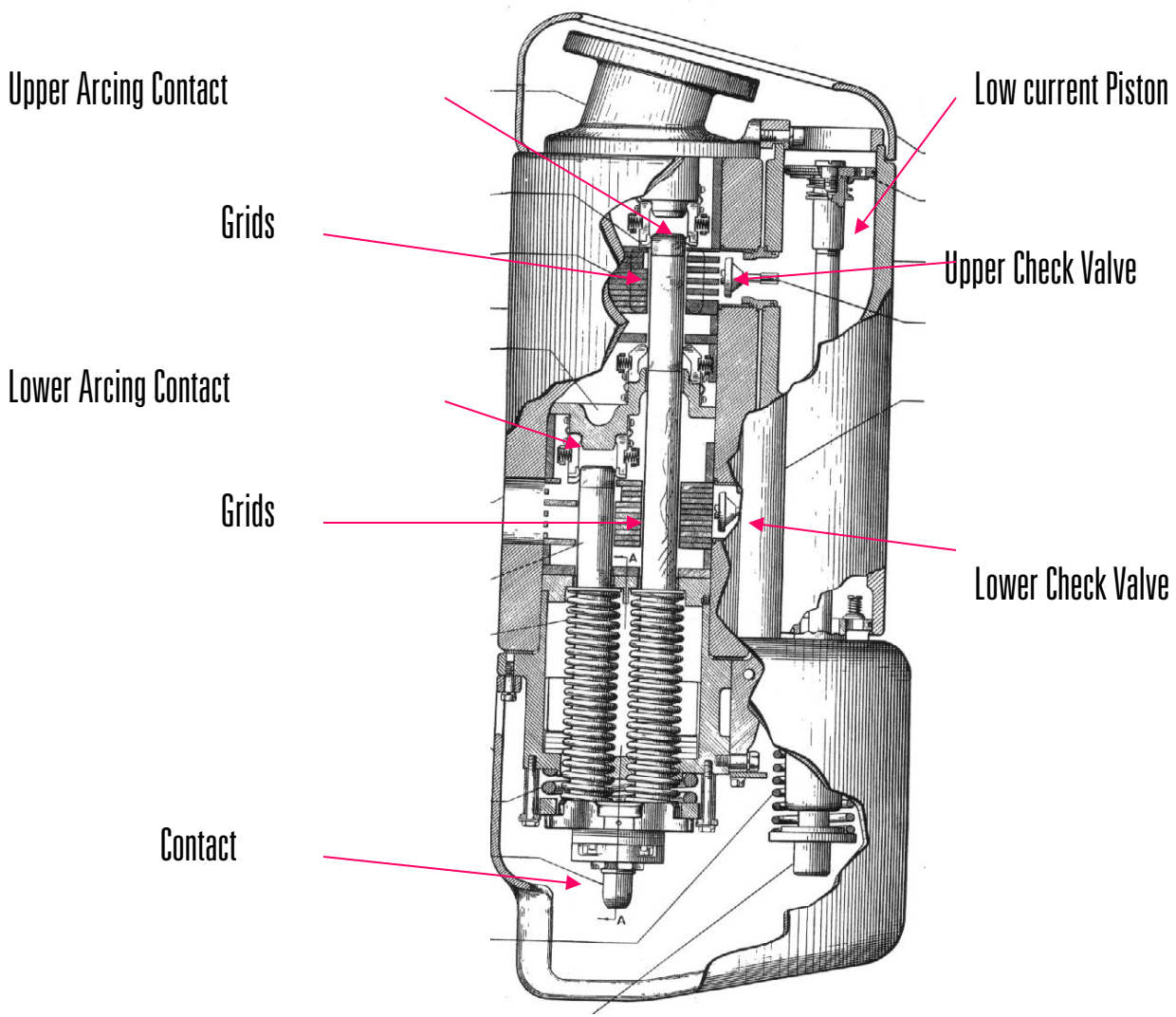


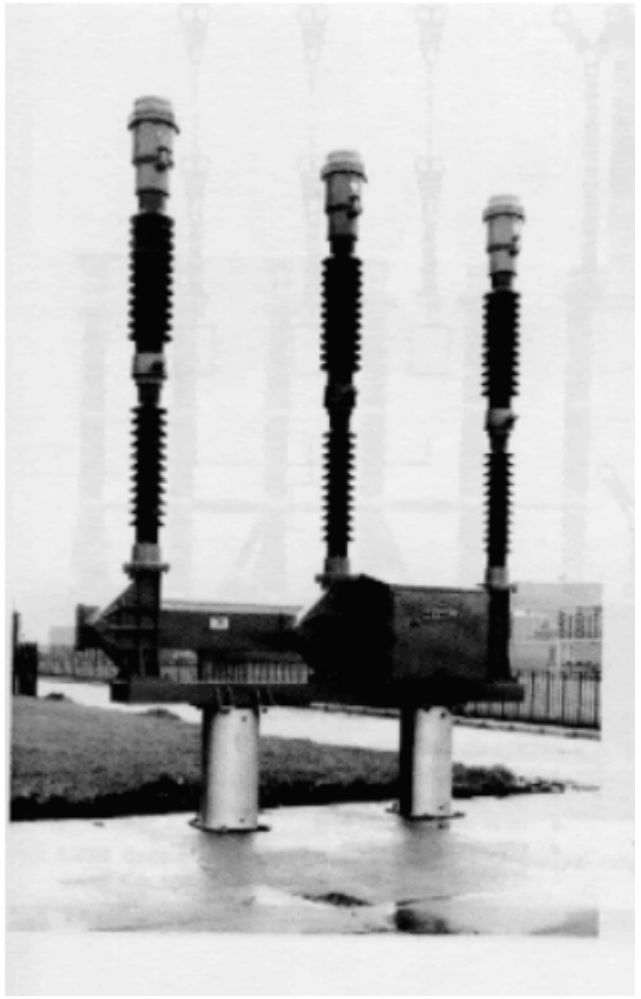
FIG. 11.—The first 40,000-volt oil switch in service, 1901.

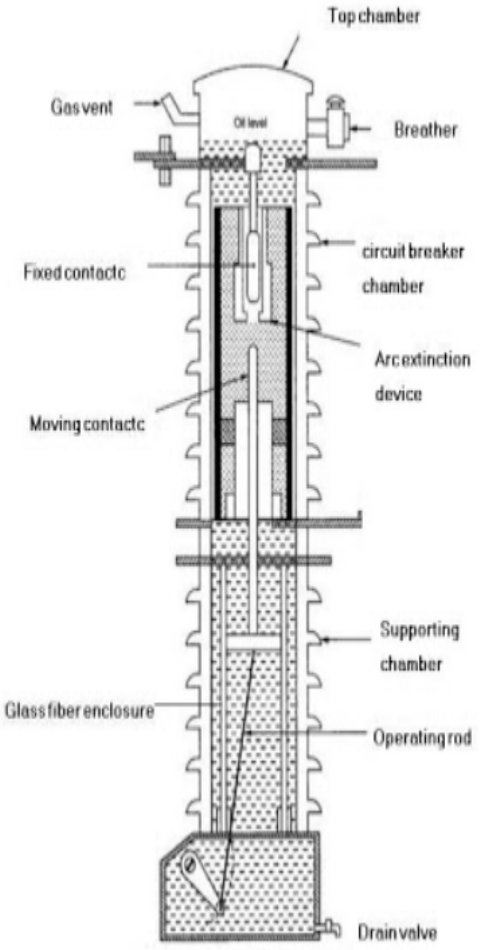
Oil Circuit Breaker Interrupter



Circuit Breakers: Past, Present and Future

- Past 1900's - 1996
  - Minimum Oil Circuit Breakers
    - 138 kV ,245 kV and 345 kV
    - Pneumatic Mechanisms
    - Hydraulic Mechanism
    - One tank per phase
    - ~ 10 % to 15 % of the oil volume of a Bulk Oil Circuit Breaker
    - Much Smaller and compact than Bulk Oil Circuit Breaker
    - Not economical at 500 kV
    - Live Tank Design
    - Ganged Operated





Circuit Breakers: Past, Present and Future

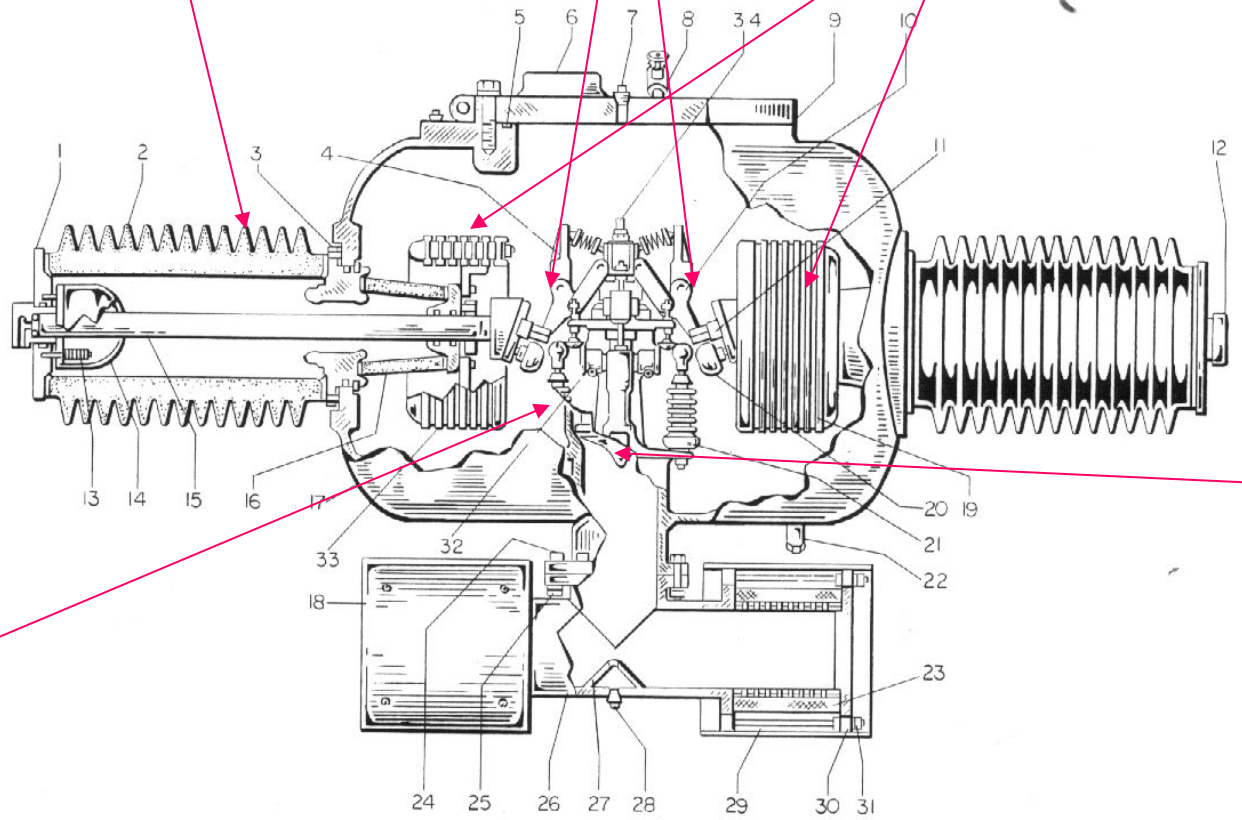
- Past 1900's - 1996
  - Air Blast Breakers
    - Produced from mid 1950'S /1960's to mid to late 1980s
    - 115 kV to 550 kV
    - Extreme high pressures
    - High Pressure Air Plants
    - Fast interruption times 2 cycles
    - One tank per phase
    - Multiple breaks per phase
    - High pressure air-blast as an arc quenching medium
    - No Oil
    - Mostly Live Tank Design
    - Ganged Operated and IPO

Circuit Breakers: Past, Present and Future

Entrance Bushing

Contacts

Closing Resistors

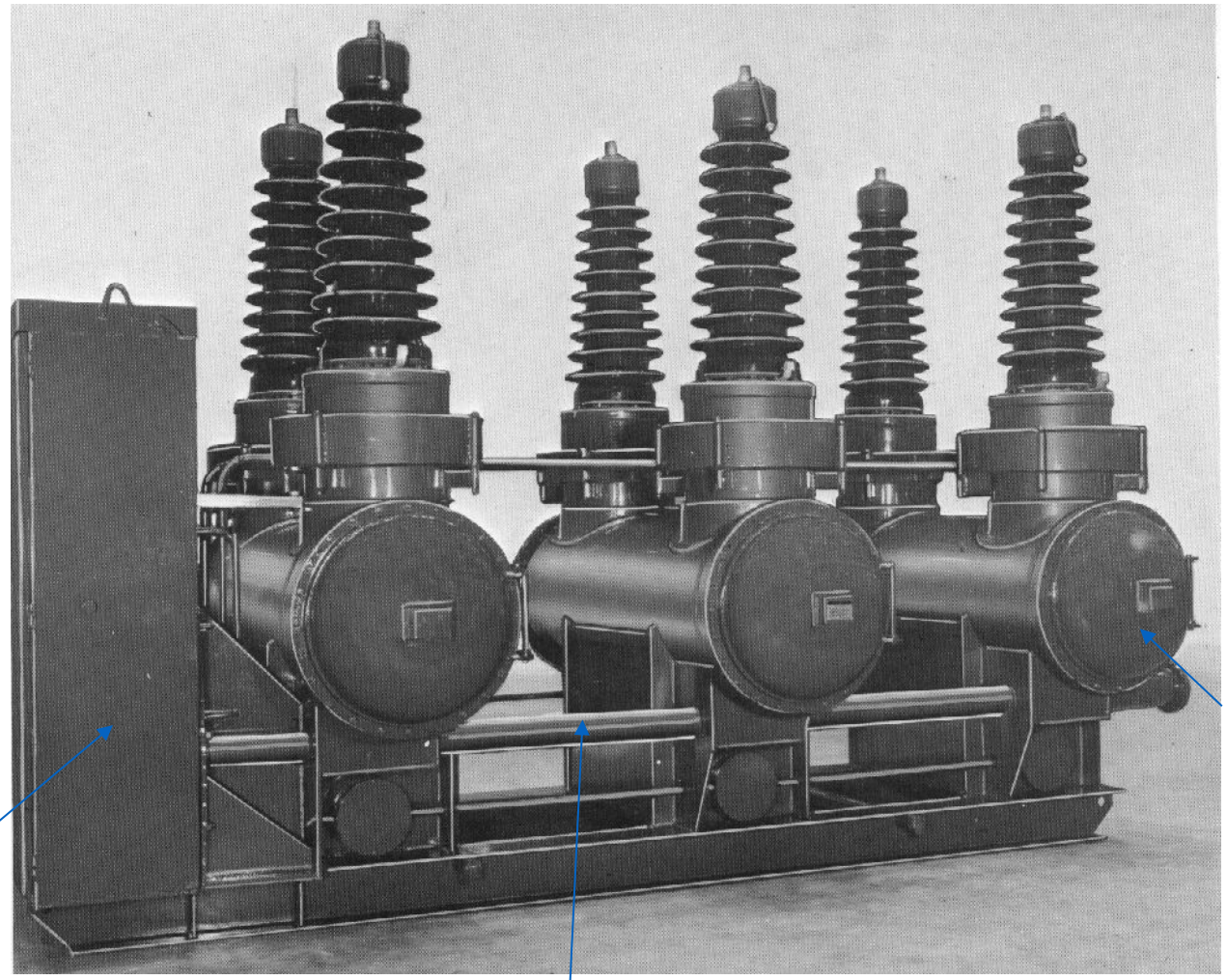


Blast Valve Assembly

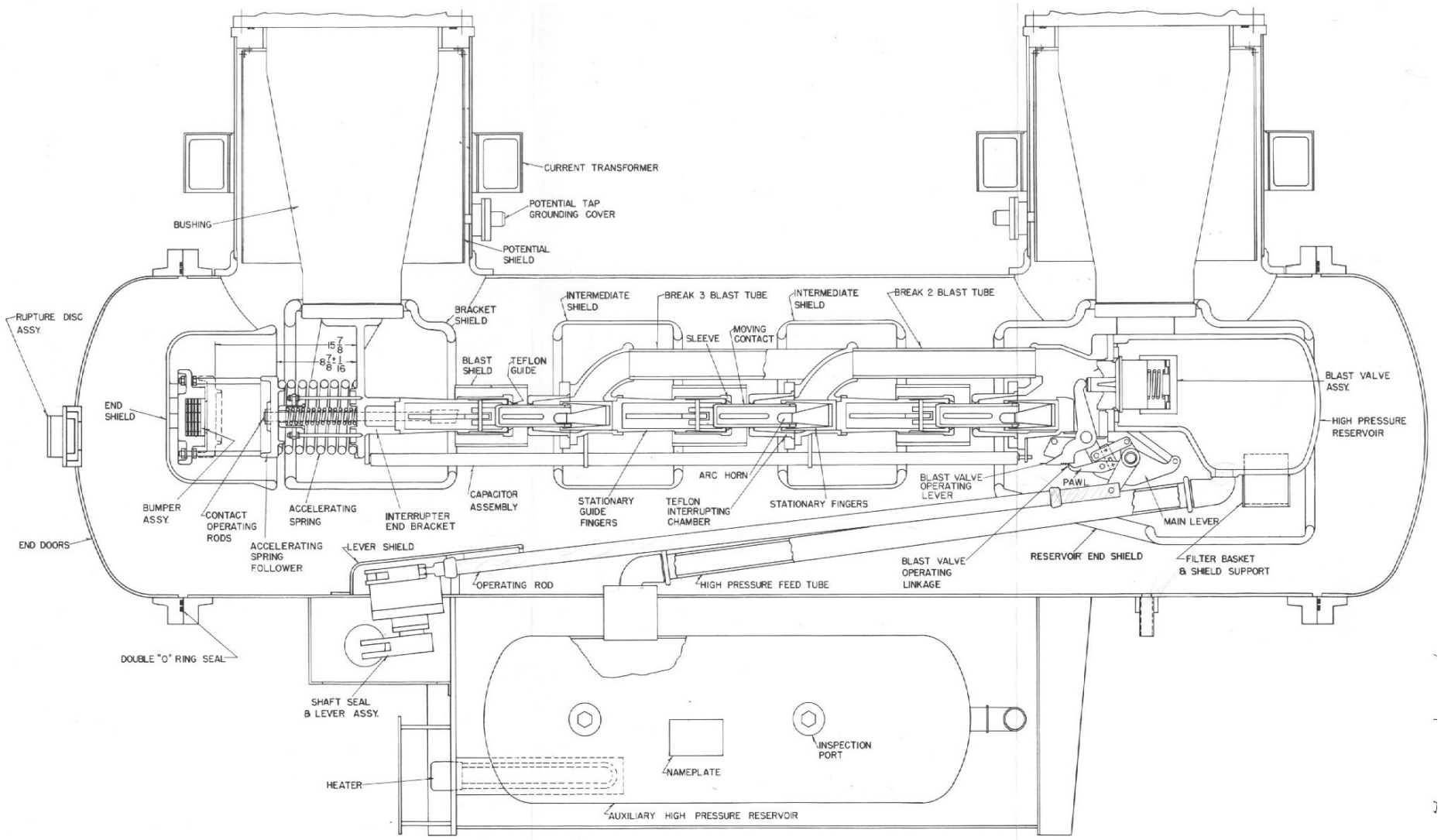
Mechanism Valve (Behind Contact Assembly)

Circuit Breakers: Past, Present and Future

- Past 1900's - 1996
  - Two Pressure SF_6 Breakers
    - First SF_6 Breakers for high voltage application
    - Produced from late 1950's to late 1980s
    - 145kV to 242 kV
    - High Current Interruption 50/63 KA
    - High SF_6 Pressure system
    - Low SF_6 Pressure system
    - One tank per phase
    - Multiple breaks per phase
    - Live and Dead Tank designs
    - Ganged Operated and IPO



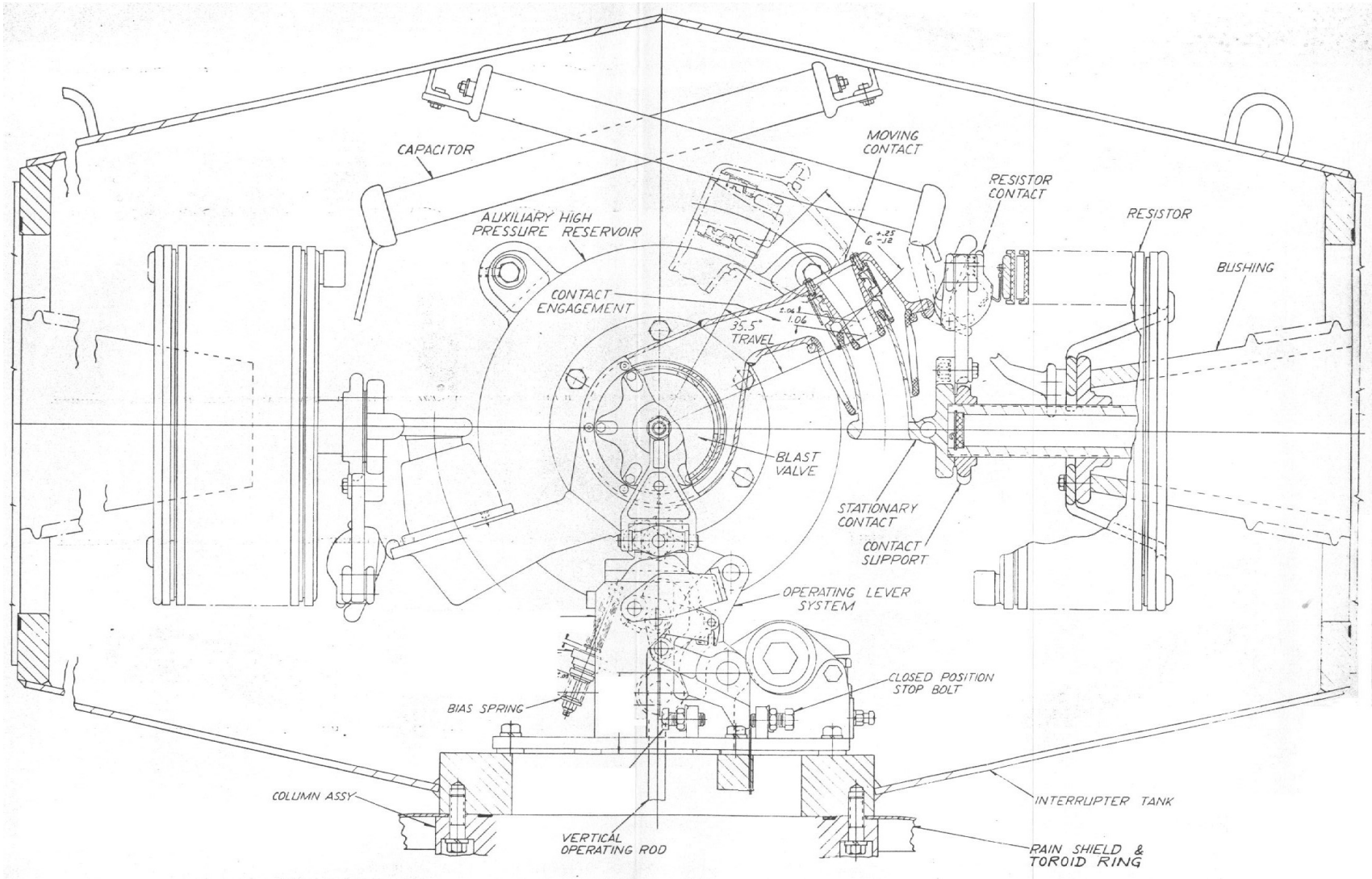
Circuit Breakers: Past, Present and Future



Circuit Breakers: Past, Present and Future

- Past 1900's - 1996
  - Two Pressure SF_6 Breakers
    - First SF_6 Breakers for high voltage application
    - Produced from mid 1960'S to mid to late 1980s
    - 242 kV to 550 kV
    - High Current Interruption 50/63 KA
    - High SF_6 Pressure system
    - Low SF_6 Pressure system
    - One tank per phase
    - Multiple breaks per phase
    - Live and Dead Tank designs
    - Ganged Operated and IPO

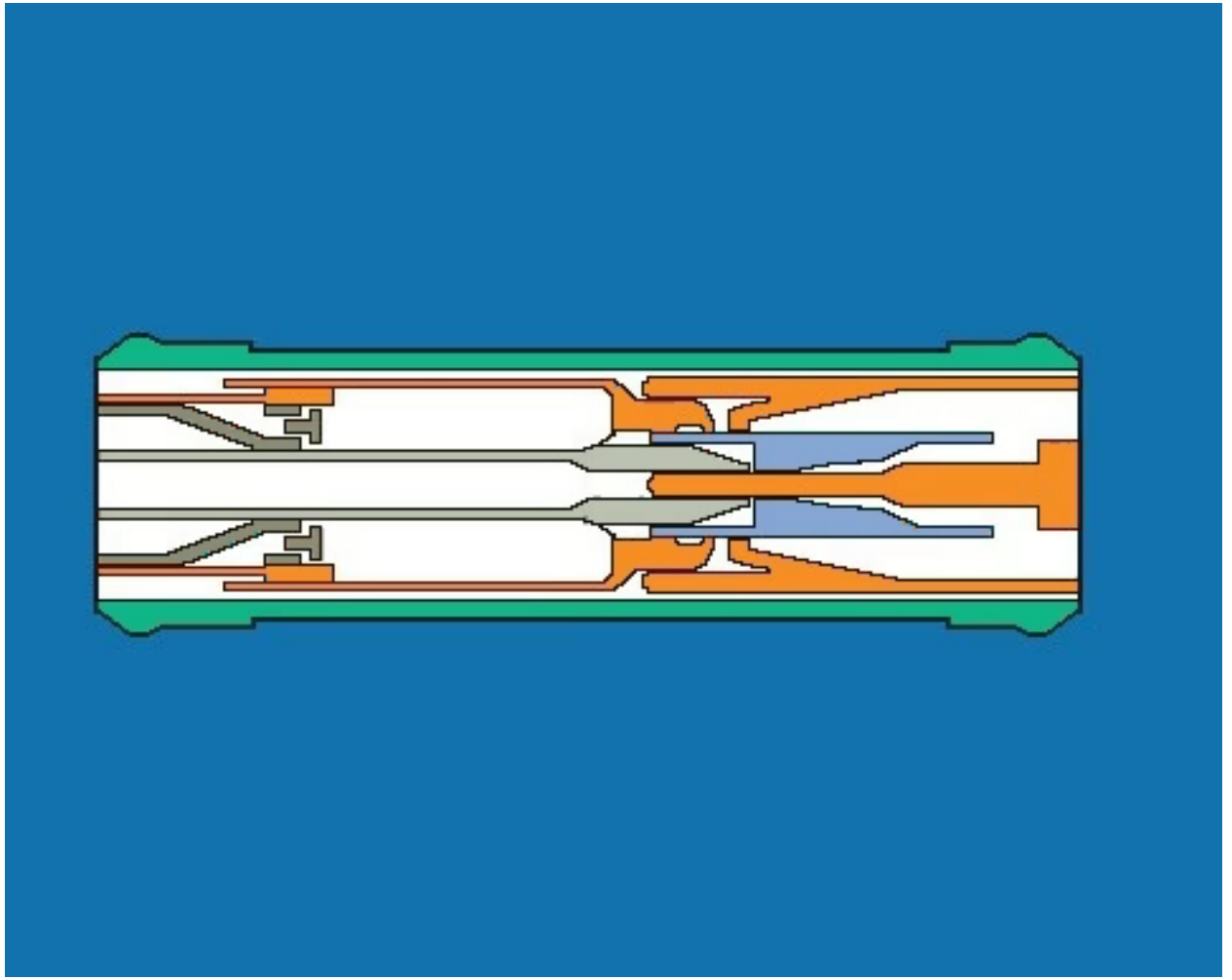
Circuit Breakers: Past, Present and Future



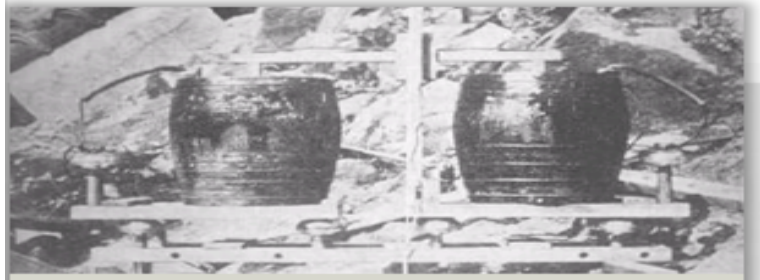
Circuit Breakers: Past, Present and Future

- Present – Late 1980s to Present Day
  - Single SF_6 Pressure breakers
    - Pneumatic Mechanisms
    - Pneu-draulic Mechanisms
    - Hydraulic/Spring
    - Spring/Spring
    - High Current interruption
    - Fast clearing Times 2 cycles
    - High Current Application
    - 15 kV to 765 kV
    - All phases in one tank or One tank per phase
    - Single or Multiple breaks per phase
    - Live and Dead Tank designs
    - Puffer technology used to extinguish arc
    - Arc assist extinction of arc

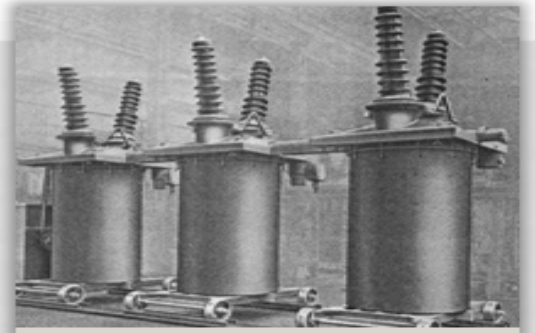
Circuit Breakers: Past, Present and Future



Circuit Breakers: Past, Present and Future

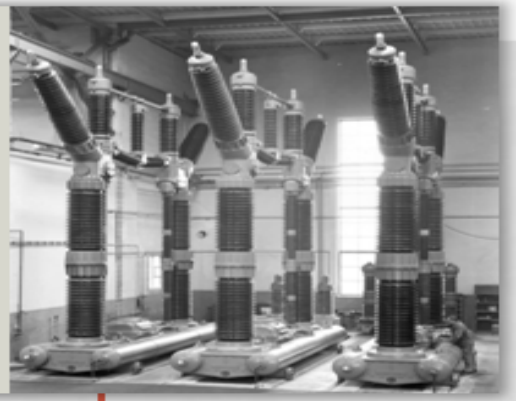


1897: This CB was designed in the US, consisting of two barrels, originally filled with cucumbers, now filled with oil, each with a fixed and a moving contact with ropes forming the breaker



1920: 3-pole oil breaker R49, 100 kV, pneumatic drive

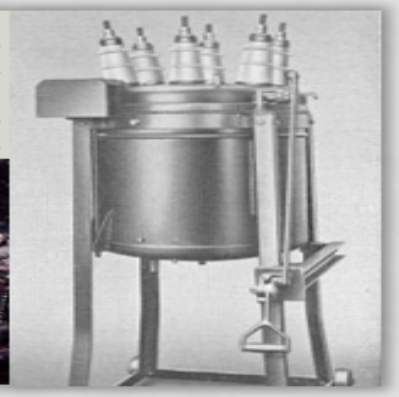
1952: 3 poles of the minimum oil breaker H 646u, 380 kV, 1000 A, 12000 MVA



1897 | **1910** | **1920** | **1941** | **1952**

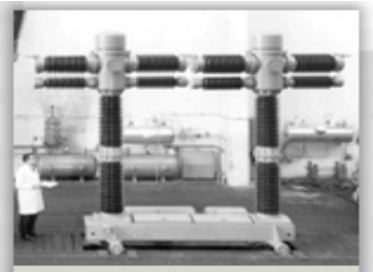
1910: 3-pole oil breaker R40, up to 40 kV, manual drive

Start of CB manufacturing in Berlin, Germany



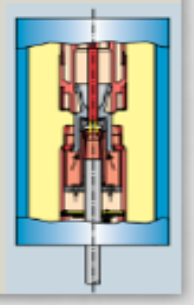
1941: Expansion minimum oil breaker R 620, 110 kV, pneumatic/ spring drive

Circuit Breakers: Past, Present and Future



1964: Delivery of the first SF_6 dual pressure breaker for 220 kV (H 904, 1 pole)

1973: Development of the patented self-compression prin-ciple



1996: Delivery of the first circuit breaker with self compression arcing chamber

2009: Delivery of the first 3AP DCB Disconnecting Circuit Breaker

2012: 2 cycle DT breakers for 245 kV and 362 kV

We are working for the future for over 100 years

1964 1972 1973 1982 1996 2007 2009 2010 2012 2013

1972: LT breaker 3AS2, 220 kV, hydraulic drive

1982: Delivery of the first 800 kV CB (3AT)

2007: Delivery of the first 3AP1 DTC 145 kV compact switchgear

2010: Pilot installation of first vacuum breaker prototypes 3AV 72.5 kV

2013: Pilot installation of ultra high voltage breaker 3AP5 DT 1200 kV

Circuit Breakers: Past, Present and Future

- Changes From Oil to SF_6 Opportunities
  - Overall size of Equipment reduced more 50 %
  - Eliminated dielectric medium (Oil) being replaced
  - Less arcing time
  - Fewer internal inspections and Shorter maintenance outages
  - More efficient interruption of arc
  - Simplified bushing design
  - 50 years to complete the transition

- Changes From Oil to SF_6
- Challenges
  - Industry (Manufactures and Utilities) had to re tool test equipment, maintenance practices, and System procedures.
  - Replaced water and carbon in oil with moisture and purity of SF_6 (Note Measurement units became smaller)
  - All diagnostic equipment was built for laboratory use not for field
  - Impacts of operating and failing equipment on the electrical system very different, Switching Transients, TRV, SLF.

Circuit Breakers: Past, Present and Future

- Changes From Oil to SF_6 Testing and Maintenance
  - Static Contact Resistance
  - Opening/Tripping Time
  - Closing Time
  - Strength and quality of dielectric medium
  - Power Factor
  - First pole to last pole to clearing time
  - CTs required
  - Required mechanism to operate
- Changes From Oil to SF_6
  - Testing and Maintenance
  - Different tools and techniques required for leak detection
  - Different test equipment to test dielectric medium
  - Different processing procedures and equipment
  - Anatomy of interrupters different
  - Specialized PPE required for SF_6
  - Different OSHA and EPA regulations
  - IPO operation
  - Technical Challenges

Circuit Breakers: Past, Present and Future

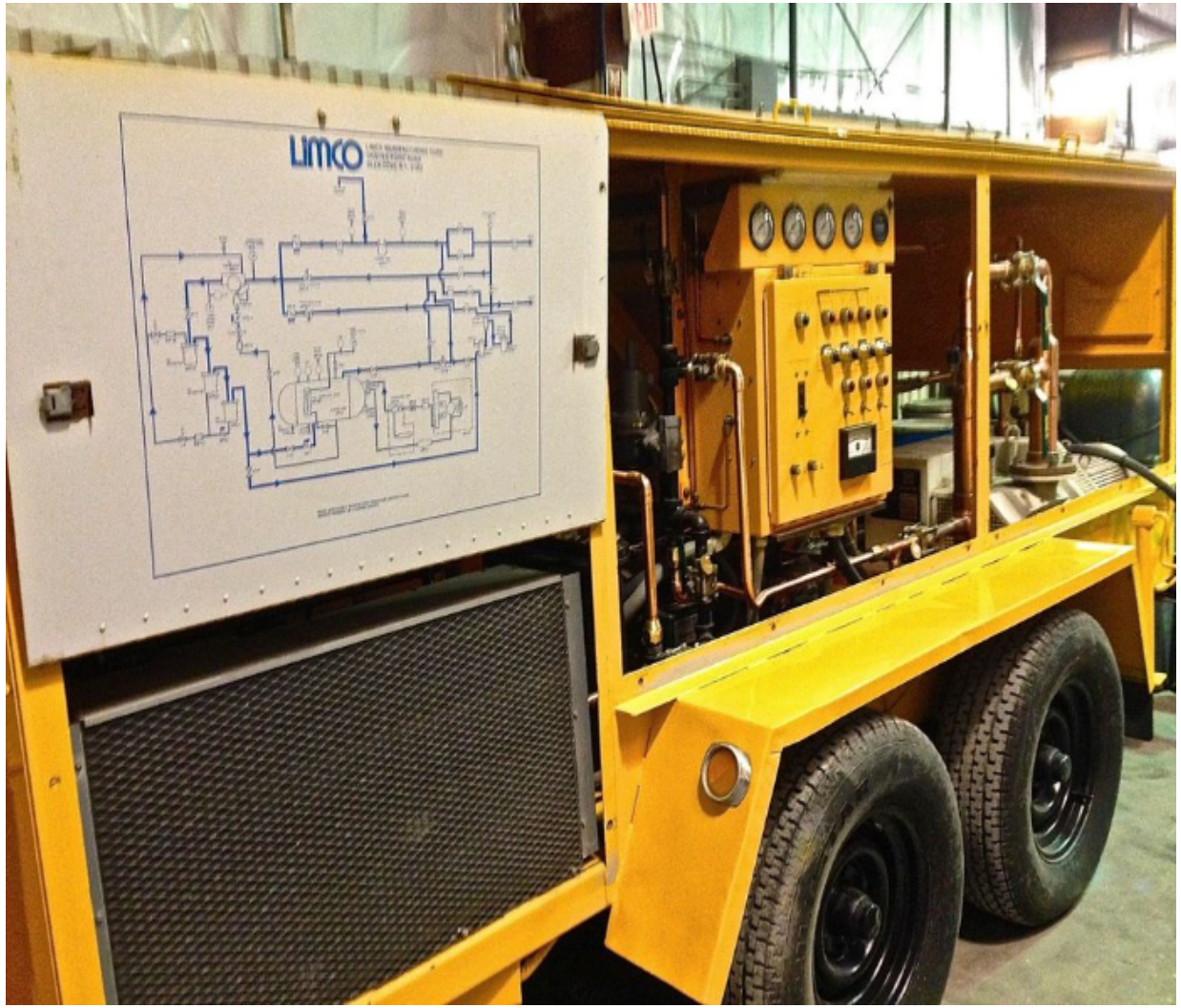
- Early SF_6 Processing Equipment

  Some of the first SF_6 processing equipment was LIMCO in the late 1980's and 1990's

  Manual ball valves operated

  Used liquid SF_6 to cool compressor and equipment

  Required more SF_6 than needed for breaker



Circuit Breakers: Past, Present and Future

- Early SF_6 Processing

Difficult to operated

Manual functions

Refrigeration compressors used that put oil residue in the SF_6. This was acceptable practice for Two pressure breakers.

Technology adopted from refrigeration/chiller industry

SF_6 Test Equipment: Early Years

SF_6 Test Equipment: Improved Equipment

SF_6 Test Equipment: Modern Equipment

SF_6 Test Equipment: Modern Equipment

Maintenance Procedures and Best Practices for SF_6

- Industry SF_6 Procedures, Process, Training, Compliance, Safety, and Guidance
  - Over 5 decades in the making
  - Evolved over time with equipment
  - SF_6 equipment worldwide has improved to current standards
  - Technology used and test equipment improved as the demand increased
  - SF_6 Stewardship in the industry at a high
  - Many performance issues with SF_6 technology improved
  - SF_6 Safety has improved over time
  - SF_6 identified as a Greenhouse gas
  - SF_6 Equipment has reduced maintenance and improved performance

Maintenance Procedures and Best Practices for SF_6

- Industry has standard and recognize Best Practices and guides for the safe handling of SF_6
  - IEEE, IEC, CIGRE, Breaker Manufactures, Utilities, etc.
- Compliance Regulations
  - EPA, CARB, DOT, FMC, etc.
- Safety and Health Standards
  - OSHA, NIOSH, Medical Community, etc
- Developed and proven Training in regards to SF_6
  - Testing
  - Storing/Inventory
  - Transportation
  - Purchasing
  - Re using/Recycling/scrubing

Maintenance Procedures and Best Practices for SF_6

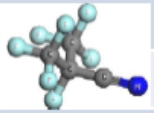
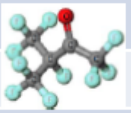
- Why replace SF_6?
  - 100 % Environmental
    - SF_6 has been Identified as a Greenhouse Gas
    - 1 kg of this SF_6 gas is equivalent to 22,800 kg or 22.8 tons of CO_2 Emissions
    - Sulfur hexafluoride (SF_6) is also extremely long-lived, is inert in the troposphere and stratosphere and has an estimated atmospheric lifetime of 800—3200 years.
  - Not Health or Equipment Performance related

Circuit Breakers: Present and Future

- Technology Change : Alternate (Non SF_6) SF_6 Free Technology
  - Vacuum (38 kV and less)
  - Clean Air Vacuum (Vacuum Interrupter in CO_2, Dry Air, Nitrogen Atmosphere)
    - 245 kV and less
    - One vacuum Interrupter per phase
  - 3M™ Novec™ 4710 Insulating Gas (GE) based technology
    - Similar Interrtpter and operating as SF_6 counterpart
  - 3M™ Novec™ 5110 Insulating Gas (ABB) based technology
    - Similar Interrtpter and operating as SF_6 counterpart

Circuit Breakers : Present and Future

Properties of SF_6 and NON SF_6 Alternative Gases

	SF_6	Clean Air	Fluornitrile	C5-Fluorketone
Chemical formular	SF_6 	$N_2 + O_2$ (79,5%/20,5%) 	$(CF_3)_2CFCN$ 	$(CF_3)_2CFC(O)CF_3$ 
CO_2-equivalent	22.800	0	2.100	1
Boiling point (°Celsius)	-64°	< -183°	-4,7°	+26,9°
Gas mixture				
Carrier gas	Pur or mixed with N_2, CF_4	-	96% for GIL 94% CO_2 for GIS	83% CO_2 / 11% O_2
CO_2-equivalent	≤ 22.800	**0**	327…462	**< 1**
Boiling point (°Celsius)	<- 64° (variable)	**< -183°**	-30°…-25°C	~ 0°
Dielectric strength (at same pressure)	**1** (normiert)	~ 0,43	0,7…0,75 for GIL > 0,75 for GIS	~ 0,7 [8] mixed with air
Arcing impact				
Dissociation/decomposition	**~ 2000 K (reversib.)**	**~ 7000 K** (N2 reversib.)	> 920 K (irreversib.)	~ 970 K (irreversib.)
Decomposition products	HF, SO_2, sulphur compounds	**None** under normal operating conditions (VIU) If failure: ozone, NOx	F-Nitrile : HF, CO, COF_2, CF_3CN, C_2F_5CN, C_2F_6 C5-K. : HF, CF_4, C_2F_6, $C_5F_{10}O$, C_3F_8, C_4F_{10},C_3HF_7 C_4F_8, C_4F_6, C_3F_6, C_2F_3N, C_2N_2 in MV GIS with air	

Circuit Breakers : Present and Future

Properties of SF6 and NON SF6 Alternative Gases

Chemical Compound	Chemical Formula	Negative Side Effects
Hydrogen Fluoride	HF	Hydrogen fluoride is a highly dangerous gas, forming corrosive and penetrating hydrofluoric acid upon contact with moisture. The gas can also cause blindness by rapid destruction of the corneas. Because of the ability of hydrofluoric acid to penetrate tissue, poisoning can occur readily through exposure of skin or eyes, or when inhaled or swallowed. Once absorbed into blood through the skin, it reacts with blood calcium and may cause cardiac arrest. Burns with areas larger than 25 square inches have the potential to cause serious systemic toxicity from interference with blood and tissue calcium levels.
Carbon Monoxide	CO	Carbon monoxide is colorless, odorless, and tasteless, but highly toxic. Concentrations as low as 667 ppm may cause up to 50% of the body's hemoglobin to convert to carboxyhemoglobin. A level of 50% carboxyhemoglobin may result in seizure, coma, and fatality. In the United States, the OSHA limits long-term workplace exposure levels above 50 ppm.
Carbonyl Fluoride	COF_2	Carbonyl Fluoride is colourless and highly toxic. Carbonyl fluoride is toxic with a recommended exposure limit of 2 ppm as an 8-hour time weighted average and a 5 ppm as a short-term exposure.

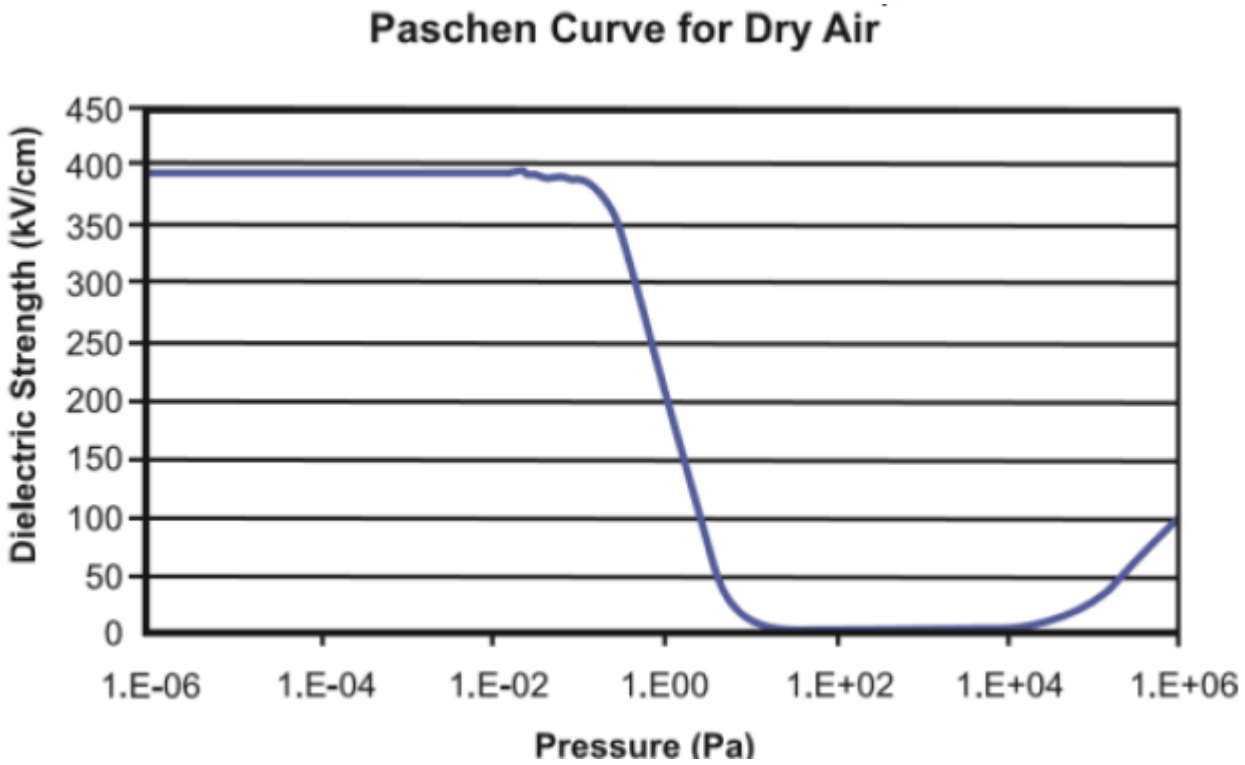
Technology Change : Alternate (Non SF6) SF6 Free Technology

Vacuum Technology

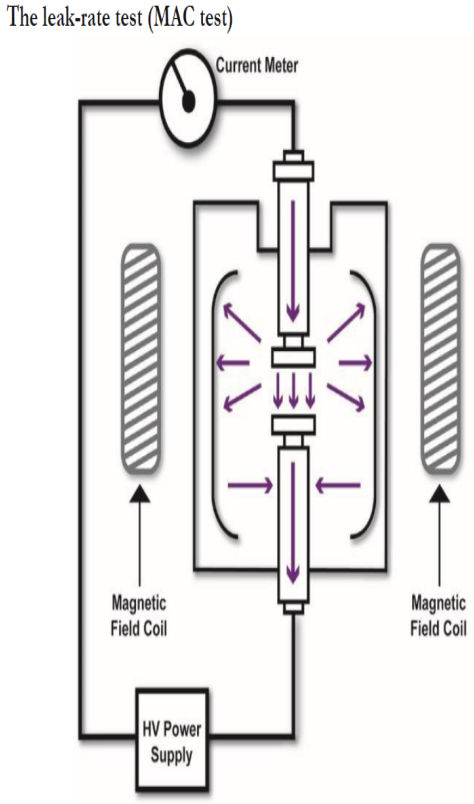
- No F Gas, Out of the scope of any regulations
- Presently available and being manufactured
- Current best practices, guidance, recommendation, maintenance, test equipment, safety requirements and standards already exist
- Vacuum interrupter life is dependent upon 10^{-2} Pa or greater vacuum integrity being maintained inside the vacuum interrupter. Typically 20 to 30 years
- Vacuum equipment have small footprints
- Proven technology over the last 4 decades

Technology Change : Alternate (Non SF6) SF6 Free Technology

Vacuum Technology Principles

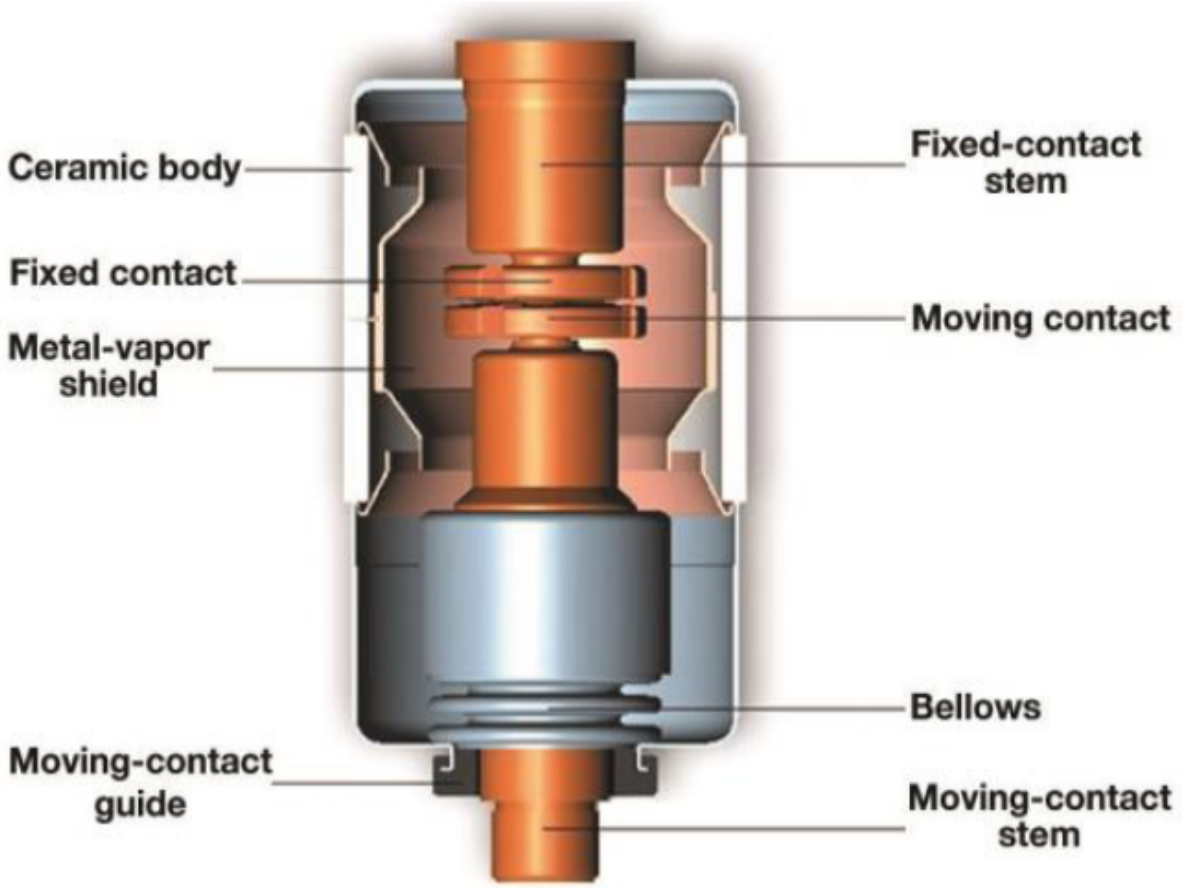


Vacuum level test using the Penning Discharge Principle



Technology Change : Alternate (Non SF6) SF6 Free Technology

Vacuum Technology



Technology Change : Alternate (Non SF6) SF6 Free Technology

Clean Air Vacuum Technology

- No F Gas, Out of the scope of any regulations
- Few manufactures presently have product available and being manufactured 72.5 kV at 40 kA and 145 kV at 40 kA
- Current best practices, guidance, recommendation, maintenance, test equipment, safety requirements and standards already exist
- Vacuum interrupter life is dependent upon 10^{-2} Pa or greater vacuum integrity being maintained inside the vacuum interrupter. Typically 20 to 30 years
- Clean Air Vacuum equipment have similar and slightly larger footprints and dimensions.

Technology Change : Alternate (Non SF6) SF6 Free Technology

Clean Air Vacuum Technology

- Arc interruption occurs inside a vacuum interrupter
- Clean Air gas ensures dry atmosphere and dielectric stability outside the vacuum interrupter, bushing conductor, and connections to vacuum interrupter
- Clean air gas pressure supervised by pressure switch
- Application for capacitive and inductive currents
- Overhead and underground line application
- Only requires regulator and hose to pressurize system
- Clean Air Gas Mixture can be released to atmosphere

Technology Change : Alternate (Non SF6) SF6 Free Technology

Clean Air Vacuum Technology

- Arc interruption occurs inside a vacuum interrupter
- Clean Air gas ensures dry atmosphere and dielectric stability outside the vacuum interrupter, bushing conductor, and connections to vacuum interrupter
- Clean air gas pressure supervised by pressure switch
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- Overhead and underground line application

Technology Change : Alternate (Non SF6) SF6 Free Technology

Clean Air Vacuum Technology

Technology Change : Alternate (Non SF6) SF6 Free Technology

- **3M™ Novec™ 4710 Insulating Gas (GE) based technology**

- An SF_6 alternative designed to reduce greenhouse gas impact by up to 99.99
- When used in a gas mixture, the greenhouse gas impact can be dramatically reduced by up to 99% compared with SF_6 Arc interruption occurs inside a vacuum interrupter
- Compatible with a wide range of equipment components
- Specifically developed to be a sustainable alternative to SF_6
- Non ozone depleting
- Non Flammable
- High dielectric strength

Technology Change : Alternate (Non SF6) SF6 Free Technology

- **3M™ Novec™ 4710 Insulating Gas (GE) based technology**

- (CF3)2CFCN
  - 2,3,3,3-tetrafluoro-2-(trifluoromethyl)-propanenitrile

- An SF_6 alternative designed to reduce greenhouse gas impact by up to 99.99
- When used in a gas mixture, the greenhouse gas impact can be dramatically reduced by up to 99% compared with SF_6 Arc interruption occurs inside a vacuum interrupter
- GE has produced transmission class equipment 72.5 kV and 145 kV with 3M™ Novec™ 4710 Insulating Gas
- GE (Alstom) has pilot equipment in service in Europe

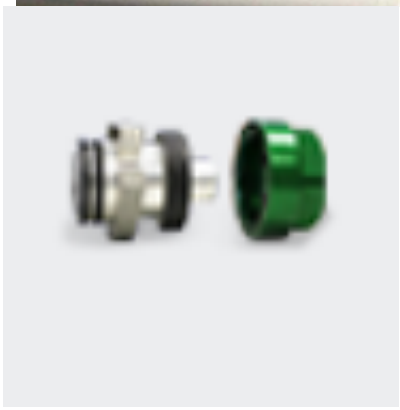
Technology Change : Alternate (Non SF6) SF6 Free Technology

- **3M™ Novec™ 4710 Insulating Gas (GE) based technology**

- Will require specialized test equipment, processing and handling equipment, and applied diagnostics and parameters
- Will require specialized PPE similar to that required for SF_6
- Will require evaluation of current operation philosophy
- Require modifications to training for labor force
- Will require additional operator certifications
- Will require utilities using technology
- Technology will need to grow to meet the wide variation of applications of circuit breakers in the industry

Technology Change : Alternate (Non SF6) SF6 Free Technology

- 3M™ Novec™ 4710 Insulating Gas (GE) based technology



Technology Change : Alternate (Non SF6) SF6 Free Technology

- **3M™ Novec™ 5110 Insulating Gas (ABB)**
  - Characteristics and Properties:
    - CF3C(O)CF(CF3)2
    - 1,1,1,3,4,4,4-heptafluoro-3-(trifluoromethyl)- 2-butanone
    - Global Warming Potential (100-yr ITH, IPCC 2013 method) = < 1
    - Atmospheric Lifetime = .04 Years
    - Ozone Depletion Potential = 0

Technology Change : Alternate (Non SF6) SF6 Free Technology

- **3M™ Novec™ 5110 Insulating Gas (ABB)**

- Characteristics and Properties:
- Greenhouse gas impact can be dramatically reduced by up to 99.99% compared with SF6.

- Mix with inert gases for electric power industry applications

- Fluorinated nitrile designed to be a lower GWP alternative to sulfur hexafluoride (SF_6)

- Excellent dielectric properties for medium and high voltage applications

Technology Change : Alternate (Non SF6) SF6 Free Technology

- **3M™ Novec™ 5110 Insulating Gas (ABB)**
- Will require specialized test equipment, processing and handling equipment, and applied diagnostics and parameters
- Will require specialized PPE similar to that required for SF_6 Will require evaluation of current operation philosophy
- Require modifications to training for labor force
- Will require additional operator certifications
- Will require utilities to use and apply the technology
- Technology will need to grow to meet the wide variation of applications of circuit breakers in the industry

Technology Change : Alternate (Non SF6) SF6 Free Technology

- **3M™ Novec™ 5110 Insulating Gas (ABB)**

Technology Change : Alternate (Non SF6) SF6 Free Technology

- **Challenges and Opportunity with 3M™ Novec™ 4710 and 5110 Insulating Gas**
  - Thermally degrades
    - The hotter the arc the more degradation occurs
  - Limited Life in Breakers, Circuit Switchers, FID where arc extinguishing is required.
  - Not a direct replacement for SF_6 in SF_6 equipment
  - Requires Special (different than SF_6) Testing Equipment Currently No Test Equipment available for each 3M™ Novec™ gas.
  - Requires Special (different than SF_6) processing Equipment for each 3M™ Novec™ gas .

Technology Change : Alternate (Non SF6) SF6 Free Technology

- Challenges and Opportunity with 3M™ Novec™ 4710 and 5110 Insulating Gas
  - 3M™ Novec™ gases are not mixable with each other
  - Limited suppliers of 3M™ Novec™ gases
  - Limited Equipment in production of Circuit Breaker using 3M™ Novec™ gases
  - Limited designs available
  - Limited Applications

Technology Change : Alternate (Non SF6) SF6 Free Technology

- Challenges and Opportunity with 3M™ Novec™ 4710 and 5110 Insulating Gas
  - Requires New Training
  - **SF_6 and SF_6 free Equipment look similar, HP Issues**
  - Limited expertise and subject matter experts
  - Non SF_6 Technology to be correctly, not rushed
  - Utilities are Slow to adopt new technologies

Circuit Breakers: Past, Present and Future

When the Unexpected Happens and When Things Go Wrong . . . .What do you do?

Technology Change: Alternate (Non SF6) SF6 Free Technology

- The Future : Challenges and Opportunity with 3M™ Novec™ 4710 and 5110 Insulating Gas
  - Safety of Employees at the fore front
  - Being able to safely isolate and operated the equipment when things go wrong
  - Equipment operating as designed and excepted
  - Equipment being reliable
  - Having a mixed fleet of technology
  - Identify the Non SF_6 equipment from the SF_6 equipment physically and operationally
  - All working around SF_6 and Non SF_6 equipment need to be aware of the risks and dangers of pure and contaminated gas of the different technologies.
  - Need to have procedures in place in the event of incident
  - Need to have personnel trained
  - Need to have PPE available

Circuit Breakers: Past, Present and Future

- QUESTIONS???

- COMMENTS

Circuit Breakers: Past, Present and Future

- Please take time to meet as many of the DILO Team members, Presenters, and Attendees as you can.
- You never know when a peer or colleague can provide some assistance.
- Take some time to enjoy the sights, sounds, and views of Tampa!

Circuit Breakers: Past, Present and Future

- We would like to Thank the Dilo 4 TH Annual SF6 Gas Management Seminar Team
  - Billy Lao
  - Corey Ratza
  - Lina Probst Encinias
  - All The DILO Employees that made the event possible

- We would also like to Thank the following:
  - Teammates, Attendees , Sponsors , and Friends in attendance !

  - This Presentation By TEAM AWESOME!

Team Awesome

Thank You

And

Have a Breaker Of A Day!

#HABOAD!