Circuit breaker technology made easy
HV and MV distribution
What is a HV/MV Circuit Breaker?
- Definition, function and application

What interrupter insulating mediums are used?
- Air, Oil, vacuum and SF$_6$

What types of HV/MV Circuit Breakers are there?
- Common circuit breaker types
- Live Tank vs. Dead Tank circuit breakers

What are the primary components of HV/MV Circuit Breakers?
- Main components including ct’s and bushings
- Arc interruption (SF$_6$)
- Mechanisms, bushings and ct’s

How are HV/MV Circuit Breakers certified?

Question time.
What is a Circuit Breaker?

Definition

- “A mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short circuit.” – IEC 60050

Light Switch

Common Moulded Case Circuit Breaker
What is a Circuit Breaker?

Primary application

Closed position  ➔ Ideal conductor
  - Carry its rated current and voltage

Open position  ➔ Ideal insulator
  - Withstand its rated voltage

Provides network reliability
  - Load current switching (normal network conditions)
  - Fault current switching (abnormal network conditions)
What is a circuit breaker?
Where used
What is a Circuit Breaker?

Primary applications

Switching and Controlling

- Transmission overhead lines
- Transformers and shunt reactors
- Capacitor banks and harmonic filters
- Generator switching
- Bus tie & transfer switching
- Special applications

Protection

- Fault clearing
- Protection of the utility assets
- Protection of personnel and public

We can meet all customer needs
Interrupter Insulating mediums
Air, oil and vacuum

- Compressed Air (Air Blast):
  - Inefficient at higher voltages
  - Loud or noisy during operation
  - Large physical size and is maintenance intensive
  - Extremely high pressures (>17 Bar)

- Oil:
  - Flammability (ancillary plant and operator safety risks)
  - Poor capacitive switching capability
  - Oil handling issues with maintenance (incl possible environmental issues)
  - Large and expensive designs

- Vacuum:
  - Cost effective
  - Highest number of switching operations (maintenance free)
  - Limited interrupting capabilities
  - Inefficient at higher voltages
Interrupter Insulating Mediums

Characteristics of SF$_6$ gas

- 1$^{st}$ prepared in laboratory in 1900 (Moissou & Lebeau)
- Highest dielectric strength of any known gas (e.g. 10 times higher than N$_2$)
- Excellent arc extinguishing medium
- Approximately five times heavier than air
- Thermally stable
- Regeneration characteristics after arcing
- Excellent heat transfer properties
- Superior arc quenching capabilities
- Excellent sound attenuation properties
- Non-corrosive, non-toxic, non-flammable, colorless and odorless
- Currently the most predominant insulating medium for Live and Dead Tank circuit breakers at ratings $\geq$60 kV
- Green house gas (environmental concerns, GWP 22 000 more than CO$_2$)
Interrupter Insulating Mediums
Breakdown voltage

Breakdown voltage of different insulating media depending on gap distance

<table>
<thead>
<tr>
<th>Rated voltage (rms)</th>
<th>Impulse voltage (peak)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 kV</td>
<td>75 kV</td>
</tr>
<tr>
<td>17.5 kV</td>
<td>95 kV</td>
</tr>
<tr>
<td>24 kV</td>
<td>125 kV</td>
</tr>
<tr>
<td>36 kV</td>
<td>170 kV</td>
</tr>
<tr>
<td>72.5</td>
<td>325 kV</td>
</tr>
<tr>
<td>145</td>
<td>650 kV</td>
</tr>
<tr>
<td>420</td>
<td>1 425 kV</td>
</tr>
<tr>
<td>765</td>
<td>2 100 kV</td>
</tr>
</tbody>
</table>
Interrupter Insulating Mediums
Number of switching operations

Permissible number of switching operations $n$ of circuit-breakers as a function of the breaking current $I_a$

- Vacuum circuit-breaker
  - a) $I_a = 1250$ A, $n = 30,000$
  - b) $I_a = 25$ kA, $n = 100$

- SF$_6$ circuit-breaker

- Minimum-oil circuit-breaker
Types of Circuit Breakers

Circuit breaker development

- **Air Blast**
  - Example: 420 kV
  - ...around 1960’s

- **Oil Minimum**
  - ...around 1970 – 80’s

- **SF₆ Gas**
  - ...today’s technology

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Types of Circuit Breakers
Major & Minor failure rates: Statistics

Figure 2-47: Distribution of CB MiF per component responsible

Figure 2-48: Distribution of CB MaF per component responsible
Types of Circuit Breakers

Examples

362 kV type ATB air blast breakers with three breaks per phase

ITE Type 242GA: Two pressure SF₆ puffer

362 kV Type HPL Live tank breaker: Two breaks per phase

ITE Type 69KSB
Oil filled breaker with two breaks per phase

362 kV type PM Dead Tank, Single pressure SF₆
These are all 230 kV breakers: Bulk Oil, Two pressure SF$_6$ and modern single pressure SF$_6$ designs
Types of Circuit Breakers
Added benefit of SF₆ (continued....)

- Type 800PM 800 kV DTB with 3 breaks per phase
- 1 200 kV SF₆ breaker with 4 breaks per phase
Types of Circuit Breakers
Dead Tank vs Live Tank circuit breakers

Dead Tank (DTB)
- Grounded breaking chamber (ground potential)
- Bushing mounted current transformers
- Popular in the US, Russia, UK, and Latin America

Live Tank (LTB)
- Ungrounded breaking chamber (at line potential) and looks like a “T” or candlestick
- Free standing current transformers
- Popular around the world, specifically Europe
Primary Circuit Breaker Components

**LTB**

1. **Breaking element(s)**
   - Breaking chamber, interrupter chamber, interrupter housing, etc.
   - Contains interrupter, interrupting medium

2. **Support insulator**
   - Line-to-ground insulator
   - Contains insulated pull-rod, insulating medium

3. **Operating mechanism**
   - Stored energy, secondary wiring
Primary Circuit Breaker Components

DTB

- **SF₆ bushing**
  - Line-to-ground insulator
  - Hollow, contains conductor and SF₆ gas

- **Bushing Current Transformers**
  - Transforms high current to a lower, useable output

- **Interrupter(s)**
  - Interrupter chamber, interrupter housing, tank, etc.
  - Tank contains interrupter and SF₆ gas

- **Operating mechanism**
  - Stored energy, secondary wiring
Recovery voltage

The voltage which appears across the terminals of a pole of a switching device after the breaking of the current.

This voltage may be considered in two successive intervals of time, one during which a transient voltage exists known as Transient Recovery Voltage (T.R.V.), followed by a second one during which the power frequency or the steady-state recovery voltage alone exists which is known as the Power Frequency Recovery Voltage.
Primary Circuit Breaker Components
Transient recovery voltage during switching
Primary Circuit Breaker Components
Transient recovery voltage during switching
Primary Circuit Breaker Components

Arc interrupting requirements

- Interrupt at Current Zero
- Meet Thermal Interruption Requirements
- Withstand Dielectric Stresses at Interruption
Primary Circuit Breaker Components
Requirements to withstand the TRV: SF$_6$

- **SF$_6$ Pressure!**
  - SF$_6$ puffer interrupters build up pressure through mechanical compression
  - Higher pressures lead to greater voltage withstand capability

- **SF$_6$ Gas Flow!**
  - Higher gas flow velocities cool the arc more efficiently
  - Efficient gas flow clears the contact region of hot gases, contaminants due to arcing and unstable post-arc conductivity

- **Exhaust!**
  - Hot exhaust gases must be well controlled
Primary Circuit Breaker Components
SF₆ puffer interrupter

The current flows from the upper (fixed) terminal to the moving part through the main contacts.

Circuit breaker in the closed position
Primary Circuit Breaker Components
SF₆ puffer interrupter simulation
The current flows from the upper (fixed) terminal to the moving part through the main contacts.

Circuit breaker in the closed position
Primary Circuit Breaker Components

SF₆ autopuffer quenching technique

- Closed
- Opening of the main contacts
- Opening of the arcing contacts
- Open
Primary Circuit Breaker Components

\( \text{SF}_6 \) autopuffer interrupter simulation

**Auto-puffer: high current**

**Auto-puffer: low current**
Primary Circuit Breaker Components
SF\textsubscript{6} autopuffer interrupter – double motion
Primary Circuit Breaker Components
Factors influencing interrupting ability

- Speed of operation
- Fault levels
- System parameters and characteristics
- Point of switching/interruption
- Type of “energy”
- Insulating medium
- Arc quenching technology employed
- Atmospheric conditions
- Contact separation distances
- Temperature
- Equipment condition and application
Primary Circuit Breaker Components
Drive mechanism

- **Purpose:** To open and close the moving interrupter contact assemblies.
- **Accumulator:** Device that stores the mechanical energy, typically springs or compressed gas.
- **Translator:** Means of conveying mechanical energy from the accumulator to the moving contact assemblies.
- **Charging System:** Means of restoring mechanical energy in the accumulator.
## Primary Circuit Breaker Components

### Drive technologies compared

<table>
<thead>
<tr>
<th>Energy storage</th>
<th>Spring (not temp sensitive)</th>
<th>Hydraulic (Pneumatic) drive</th>
<th>Pneumatic drive</th>
<th>Hydro mechanical spring drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature sensitive</td>
<td><strong>No</strong></td>
<td><strong>Yes</strong></td>
<td><strong>Yes</strong></td>
<td><strong>No</strong></td>
</tr>
<tr>
<td>Operation control</td>
<td>Mechanical latch</td>
<td>Valve</td>
<td>Valve</td>
<td>Valve</td>
</tr>
<tr>
<td>Transmission trough</td>
<td>Linkage</td>
<td>Piston</td>
<td>Piston</td>
<td>Hydraulic piston</td>
</tr>
<tr>
<td>Damper</td>
<td>External hydraulic</td>
<td>Internal hydraulic</td>
<td>Internal gas</td>
<td>Internal hydraulic</td>
</tr>
<tr>
<td>Damper</td>
<td><strong>High</strong></td>
<td><strong>Low</strong></td>
<td><strong>Low</strong></td>
<td><strong>Low</strong></td>
</tr>
<tr>
<td>Maintenance</td>
<td>Some</td>
<td><strong>Frequent</strong></td>
<td><strong>Intensive &amp; frequent</strong></td>
<td>Maintenance free</td>
</tr>
<tr>
<td>Reliability</td>
<td><strong>Good</strong></td>
<td><strong>Low</strong></td>
<td><strong>Least</strong></td>
<td><strong>Highest</strong></td>
</tr>
<tr>
<td>No. of moving parts</td>
<td><strong>High</strong></td>
<td><strong>Low</strong></td>
<td><strong>High</strong></td>
<td><strong>Low</strong></td>
</tr>
<tr>
<td>No. of installed drives</td>
<td>Lower end energy</td>
<td>High end energy</td>
<td>High end energy</td>
<td>Whole energy range</td>
</tr>
<tr>
<td>Main application</td>
<td>Common tech</td>
<td>Phased-out tech</td>
<td>Phased-out tech</td>
<td>State-of-the-art tech</td>
</tr>
<tr>
<td>Technology</td>
<td>Common tech</td>
<td>Phased-out tech</td>
<td>Phased-out tech</td>
<td>State-of-the-art tech</td>
</tr>
</tbody>
</table>
Primary Circuit Breaker Components
Operating mechanism – spring (FSA1)

- Simple Low Energy Design with minimum parts. Tested to M2 duties as per IEC 62271-100 (10000 mech. ops)
- Highest Mechanical reliability with field experience of many years (> 20000 drives worldwide)
- Now improved and adapted to operate new energy efficient Autopuffer breakers for higher voltages as well
  - ED, 52 – 72,5 kV single and three pole operation
  - LTB D, 72,5 – 145 kV single pole operation
  - LTB D, 72,5 – 145 kV three pole operation
Primary Circuit Breaker Components
HMB mechanism operation

Breaker Open

Breaker Closed

Output Shaft

High Pressure Oil

Control Valves

Low Pressure Oil

Disk Springs

Pump

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Primary Circuit Breaker Components
HMB spring operating mechanism simulation

- Operating rod
- Open interlock
- Hydraulic oil reservoir and level indicator
- Disc springs
- Output piston
- Hydraulic pump
- Hydraulic change-over valves

Animation of Operations
1) uncharged in open position
2) charging in open position
3) close operation
4) open operation
5) depressurising in open position

Display mode for: text/pictures
exit program.

Operating mechanism uncharged in open position
Primary Circuit Breaker Components

Bushings: their purpose

- Insulate HV connections from ground to tank
- Provide mechanical support against various mechanical forces
- Hold the power path to the interrupter
- Either porcelain or composite
Primary Circuit Breaker Components
Bushings: main components (SF$_6$)

- Conductor (Thru-rod)
- Line Terminal (Adjustable flat pads or studs)
- Porcelain or Composite Insulator
- Mounting Flange
- Grading Shield
Primary Circuit Breaker Components
Bushings: terminology

- Creepage distance is the distance along the insulator surface between ends expressed in kV/mm

- Strike Distance Definition

Distance between metal ends
Primary Circuit Breaker Components
Bushings: porcelain vs. composite insulators

- Advantages of Porcelain
  - Long operating experience
  - Structural rigidity
  - Lower cost at some ratings

- Advantages of Composites
  - Hydrophobic pollution resistance
  - Reduced weight and seismic moments
  - Impact resistance
  - Shorter lead time and tighter tolerances
  - Lower cost at higher ratings
Composite insulators with silicone rubber
To improve personnel and equipment safety

- Explosion proof
- Non-brittle
- Excellent insulation
- Low weight
- Maintenance free
- Outstanding seismic performance

Easier handling
Lower damage risk →
Lower risks in project execution
Certification of Circuit Breakers

Extensive testing...

...ensures fulfillment of customer needs

Ice load test

Power test

Earthquake test

Dielectrical test

Mechanical test

Special test
Standards define the test requirements circuit breakers must pass

- TRV
- Continuous, and short circuit current
- Impulse voltage
- Mechanical endurance
- Seismic
- Pressure Vessel codes

**IEEE Std C37.09-1999**
(Revision of IEEE Std C37.09-1979)
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Special solutions within Live Tank Breakers

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FACTS
CO₂ breaker
DCB
DCB with FOCS
Circuit Breaker Technology Made Easy
Expect the unexpected

Any questions?

Thank you for your attention
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