CONTROLLED SWITCHING
CIRCUIT BREAKER CONSIDERATIONS

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OUTLINE

- Circuit breaker characteristics
- Interrupter wear
- Life extension, maintenance intervals
- Circuit breaker performance
- Benefits for switched equipment
- Benefits for the power system & equipment
- Conclusions
Circuit Breaker Characteristics

Independent-Pole Operated
Independent-Pole Operated
Circuit Breaker Characteristics

Mechanically-Staggered Linkage
Spring Mechanism
Hydraulic Mechanism
Timing Characteristics

- Effect of idle time
- Influence of ambient temperature on operating time
- Hydraulic pressure - Spring constant
Controlled Closing - RDDS

Voltage across circuit-breaker (absolute value) \([\text{pu}]\)

- \(k_0 - \Delta k\)
- \(k_0 + \Delta k\)
- Maximum making voltage
- Nominal making instant
- \(T_{\text{Target}}\) Target Point
- Nominal instant of contact touch

\(\Delta t_{\text{making}}\)
Live-Tank Circuit Breaker

<table>
<thead>
<tr>
<th>Mark</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Terminal</td>
</tr>
<tr>
<td>2</td>
<td>Fixed contact support</td>
</tr>
<tr>
<td>3</td>
<td>Main contacts</td>
</tr>
<tr>
<td>4</td>
<td>Moving contact</td>
</tr>
<tr>
<td>5</td>
<td>Moving contact support</td>
</tr>
<tr>
<td>6</td>
<td>Envelope</td>
</tr>
<tr>
<td>10</td>
<td>Arcing contacts</td>
</tr>
<tr>
<td>11</td>
<td>Fixed contact rod</td>
</tr>
<tr>
<td>12</td>
<td>Insulating nozzle</td>
</tr>
<tr>
<td>13</td>
<td>Valve</td>
</tr>
</tbody>
</table>
Controlled Closing - RDDS

Field Simulation

15 mm and 4.0 ms from contact touch

$E_{\text{max}}$
Benefits for the Circuit Breaker

- Extension of circuit breaker life,

- Increase in time intervals between interrupter maintenance or retrofit,

- Added value associated with circuit breaker performance enhancement during current interruption in the thermal or in the dielectric region.
Interrupter Wear

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Interrupter Wear

Benefits of controlled switching for the purposes of life extension, reduction of maintenance cost:

- Decrease in magnitude of energization currents.
- Reduce associated interrupter wear.
- Lower probability of occurrence of damaging restrikes.
Interrupter Wear

• Arcing contact wear
  – Source is burning arc across the gap.
  – Loss of material caused by vaporization, melting and burnoff.
  – Consequences are contact shape distortion and increase in surface roughness.
Arcing Contact Wear

- Depends on:
  - contact material composition and micro-structure
  - contact surface porosity
  - initial contact shape
  - manufacturing process
  - arc current duration, amplitude, shape

- Implications
  - erosion, burnoff, vaporization
  - change in shape, surface
Teflon Nozzle Ablation

- Depends on:
  - nozzle geometry
  - material (teflon) and fillers

- Implications:
  - increase in diameter of throat
  - flake-off, erosion, vaporization of inside surface
  - changes to the dynamic gas flow during interruption
  - degradation of breaker performance (thermal region)
Interrupter Wear

- Definition of maintenance interval
- Number of allowable operations between maintenance/refurbishment
- Simple relation between the interrupted current and a maximum number of operations
Improved Assessment of Interrupter Wear

- Separate limits for arcing contact wear and nozzle ablation
- Specific to interrupter design
- Can be implemented together with electronic monitoring

\[
\begin{align*}
\int (i(t) \, dt) &= \int i(t) \, dt \\
\int (i(t)^n \, dt) &= \int i(t)^n \, dt
\end{align*}
\]
Maintenance Intervals and Costs
Circuit Breaker Performance Enhancement

- Improve performance during interruption
  - Thermal region of interruption
  - Dielectric region of interruption

- Increase or decrease arcing time
  - Life extension
  - Unusual system voltages (25 Hz rail system)
  - Higher X/R ratios
  - Further reduce restrike probability for severe TRV applications
Thermal (Energy Balance) Region

- Rate of Rise of Recovery Voltage (RRRV)
- Initial Transient Recovery Voltage (ITRV)
- Reignition if current re-established <1/4 cycle

Successful interruption

Failure (reignition)
Circuit Breaker Performance Enhancement

HGF1015 T100 50kA 15ms
temperature (200 – 1500K)
Dielectric Region

- Peak value of the transient recovery voltage
- **Restrike** if current re-established >1/4 cycle

Schematic of ETRV and Uc = 250kV showing successful interruption and failure (restrike).
Contact Coordination
Voltage Gradients on Interrupter Components

Circuit Breaker Performance Enhancement

Contact coordination HGF1014/63 kA

stationary side -0.5 pu
moving side +0.5 pu

E (%/mm) vs gap (mm)
Circuit Breaker Performance Enhancement
Circuit Breaker Performance Enhancement

HGF1015 cap switch. density (30–50 kg/m³)
Circuit Breaker Performance Enhancement

HGF1015
cap switch
Benefits for Power System and Equipment

DT1-145 F3 Probability of Exceeding an Inrush Current Value
Back-Back Closing 2x25 MVAR banks, 145 kV

- Maximum inrush current: 10.5 kA, f = 9 kHz
- 10 mH inductor: \( I_{\text{inrush}} = 4.3 \text{ kA}, f = 3.7 \text{ kHz} \)
- 20 mH inductor: \( I_{\text{inrush}} = 3.2 \text{ kA}, f = 2.7 \text{ kHz} \)

DT1-145 F3, \( P(I_{\text{inrush}} > I) \)
Benefits for Power System and Equipment

- Technical and economic benefits
  - reduction of stresses on switched equipment leading to life extension,
  - control of local transients in the substation,
  - local surge suppression, reducing possible coupling to the control and protection scheme,
  - decrease in the severity of remote transients and their effects on sensitive loads.
Benefits for Power System and Equipment

[Graph showing magnitude vs. frequency with susceptibility curve, margin, and transient level curve]
Benefits for Power System and Equipment

- **Susceptibility**
  - Compromise of system of equipment function
  - Frequency dependent

- **Mechanism**
  - Coupling
    - conductive, inductive, radiative
  - Modes
    - common mode, differential mode
Benefits of Controlled Switching

- Conclusions
  - Effective means of reducing switching transients and their effects on a power system and equipment
    - life extension
    - reduction of maintenance costs
    - system reliability
    - power quality
  - Enhancement of circuit breaker performance
  - Alternative to tradition means of transient control
Benefits of Controlled Switching

Conclusions

- Assessment depends on conditions:
  - new or existing installation
  - planned or unplanned effects
- Driver may be:
  - desire to acquire experience
  - problem solving
  - preventive or corrective
- Can be used in combination with other means of transient control