TRANSFORMER PROTECTION
PHILOSOPHY, SETTING & PERFORMANCE

ANUCHIT SOMJUNTR
Control and Protection System Division
Electricity Generating Authority of Thailand
TYPE OF TRANSFORMER IN EGAT TRANSMISSION SYSTEM

1. LOADING TRANSFORMER
   (115kV/22kV, 33kV)
   DY1, YYd1

2. TIE TRANSFORMER
   (500kV/230kV, 230kV/115kV, 69kV)
   YYd1
<table>
<thead>
<tr>
<th>Fault Type</th>
<th>Protection Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary winding Phase-phase fault</td>
<td>Differential; Overcurrent</td>
</tr>
<tr>
<td>Primary winding Phase-earth fault</td>
<td>Differential; Overcurrent</td>
</tr>
<tr>
<td>Secondary winding Phase-phase fault</td>
<td>Differential</td>
</tr>
<tr>
<td>Secondary winding Phase-earth fault</td>
<td>Differential; Restricted Earth Fault</td>
</tr>
<tr>
<td>Interturn Fault</td>
<td>Differential; Buchholz</td>
</tr>
<tr>
<td>Core Fault</td>
<td>Differential; Buchholz</td>
</tr>
<tr>
<td>Tank Fault</td>
<td>Differential; Buchholz; Tank-Earth</td>
</tr>
<tr>
<td>Overfluxing</td>
<td>Overfluxing</td>
</tr>
<tr>
<td>Overheating</td>
<td>Thermal</td>
</tr>
</tbody>
</table>
PROTECTION FOR LOADING TRANSFORMER

87K = Transformer Differential relay
51T = High Side Phase OC relay
51 = Low Side Phase OC relay
51G = Low Side Ground OC relay
PROTECTION FOR 230/115 KV TIE TRANSFORMER

87B = Bus Differential relay  
87K = Transformer Differential relay  
51T = High Side Phase OC relay  
51TG = High Side Ground OC relay  
51 = Low Side Phase OC relay  
51G = Low Side Ground OC relay  
51GB1,2 = Ground Backup OC relay
PROTECTION FOR 500/230 KV TIE TRANSFORMER

87B = Bus Differential relay
87K-S = Sec. Transformer Diff. relay
87K-P = Pri. Transformer Diff. relay
51T = High Side Phase OC relay
51TG = High Side Ground OC relay
51 = Low Side Phase OC relay
51G = Low Side Ground OC relay
51GB1,2 = Ground Backup OC relay
24T = Overfluxing Relay
RELAY SETTING CRITERIA

1. Transformer Differential Relay

- **Considerations**
  - Phase correction
  - Filtering of zero sequence currents
  - Ratio correction
  - The effect of magnetizing inrush during initial energization
RELAY SETTING CRITERIA

1. Transformer Differential Relay

- **CT. Ratio**
  - Main CT ratio = 150% FOA rating of transformer
  - 20 times of primary current of the selected CT ratio must higher than maximum busbar fault current
  - Secondary current must lower than relay rating current
1. Transformer Differential Relay

- Check CT performance

- CT must not be saturated when a maximum external fault occurs

\[
V_k = \frac{IF_{\text{max}} \times (RCT + 2RL + RT)}{N}
\]

Where:

- \(V_k\) = Required CT Knee point voltage (volts)
- \(IF_{\text{max}}\) = Maximum value of fault current (A)
- \(RCT\) = CT secondary winding resistance (Ohms)
- \(RL\) = Single lead resistance from CT to relay (Ohms)
- \(RT\) = Effective impedance of interposing CT
- \(N\) = CT turn ratio
1. Transformer Differential Relay

- **Phase correction**

  *Without interposing CT*

  - Use star connected CT on delta windings of the transformer
  - Use appropriated delta connected CT on star windings of the transformer to ensure that the transformer primary and secondary currents, as measured by the relay, are in phase
RELAY SETTING CRITERIA

1. Transformer Differential Relay
   
   - **Phase correction**

   *Without interposing CT*
RELAY SETTING CRITERIA

1. Transformer Differential Relay

   • Phase correction

   *Without interposing CT*
RELAY SETTING CRITERIA

1. Transformer Differential Relay

   - Phase correction

   Without interposing CT
RELAY SETTING CRITERIA

1. Transformer Differential Relay

- **Phase correction**

  *With interposing CT*

  - Use star connected CT on all windings of the transformer
  - Compensate for the winding phase shift by interposing CT
  - Use star/star connected interposing CT on delta windings of the transformer
  - Use star/delta connected interposing CT on star windings of the transformer
RELAY SETTING CRITERIA

1. Transformer Differential Relay
   - Phase correction

   *With interposing CT*
1. Transformer Differential Relay

- Phase correction

*With interposing CT*
RELAY SETTING CRITERIA

1. Transformer Differential Relay
   • **Phase correction**
     
     *With interposing CT*
RELAY SETTING CRITERIA

1. Transformer Differential Relay

   • Phase correction

   Numerical and Digital relay

   - Use star connected CT on all windings of the transformer
   - Compensate for the winding phase shift by software
1. Transformer Differential Relay

- **Phase correction**

*Numerical and Digital relay*
RELAY SETTING CRITERIA

1. Transformer Differential Relay

- **Ratio correction**
  - Calculate interposing CT ratio at normal tap of transformer
  - Percent mismatch of CT must be lower than 5 %
  - Percent mismatch of CT can be calculated from

\[
\text{Percent mismatch} = \frac{[I_{\text{to relay (HS)}} - I_{\text{to relay (LS)}}]}{[I_{\text{to relay (HS)}} + I_{\text{to relay (LS)}}]} \times 100 \% \\
\frac{[I_{\text{to relay (HS)}} + I_{\text{to relay (LS)}}]}{2}
\]
RELAY SETTING CRITERIA

1. Transformer Differential Relay

- **Differential current setting (I_{\text{diff}} > )**
  - I_{\text{diff}} > must be greater than
    - CT mismatch + CT error + % Tap change

- **Percent slope setting**
  - Set as the relay manufacturer’s recommendation
  - Consider that relay will not operate when a maximum external fault occurs
  - Generally lower slope = 20-30% , upper slope = 70-80%
1. Transformer Differential Relay

- **High-Set Differential current setting (I diff >>)**
  - I diff >> must be greater than maximum inrush current
    (about 15 time transformer rating current)

- **Harmonic stabilization**
  - Inrush restraint ratio (2\textsuperscript{nd} harmonic) = 12\% \( \frac{I_{2fN}}{I_{IN}} \)
  - Activate cross-block function
RELAY SETTING CRITERIA

1. Transformer Differential Relay

![Graph showing tripping characteristic of Transformer differential relay]

Tripping characteristic of Transformer differential relay
RELAY SETTING CRITERIA

2. Phase and Ground Overcurrent Relay

- **CT. Ratio**
  - Main CT ratio = 150% FOA rating of transformer

- **Minimum Pick up Current**
  - Phase overcurrent relay = 150% FOA rating of transformer
  - Ground overcurrent relay = 30% FOA rating of transformer
RELAY SETTING CRITERIA

2. Phase and Ground Overcurrent Relay

- **Time Characteristic Curve**
  - 115/22KV Loading transformer = Normal inverse
  - 230/115kV Tie transformer = Normal inverse
  - 500/230kV Tie transformer = Very inverse

- **Operating Time**
  - Co-ordination time interval between low side and high side overcurrent = 0.5 sec at maximum fault
RELAY SETTING CRITERIA

2. Phase and Ground Overcurrent Relay

- **Operating Time**

  *115/22kv Loading and 230/115kV Tie Transformer*

  - High side phase overcurrent (51T) = 2.0 sec at Maximum 3 Ph. Fault Current Contributed to Low Side Busbar

  - High side ground overcurrent* (51TG) = 2.0 sec at Maximum SLG Fault Current Contributed to Low Side Busbar

*Note* * High side ground overcurrent for Tie Transformer only
RELAY SETTING CRITERIA

2. Phase and Ground Overcurrent Relay

- **Operating Time**

  *115/22kv Loading and 230/115kV Tie Transformer*

  - Low side phase overcurrent (51) = 1.5 sec at Maximum 3 Ph. Fault Current Contributed to Low Side Busbar

  - Low side ground overcurrent (51G) = 1.5 sec at Maximum SLG Fault Current Contributed to Low Side Busbar
2. Phase and Ground Overcurrent Relay

- **Operating Time**

*500/230kV Tie Transformer*

- High side phase overcurrent (51T) = 1.5 sec at Maximum 3 Ph. Fault Current Contributed to Low Side Busbar
- High side ground overcurrent (51TG) = 1.5 sec at Maximum SLG Fault Current Contributed to Low Side Busbar
RELAY SETTING CRITERIA

2. Phase and Ground Overcurrent Relay

- **Operating Time**

  **500/230kV Tie Transformer**

  - Low side phase overcurrent (51) = 1.0 sec at Maximum 3 Ph. Fault Current Contributed to Low Side Busbar
  
  - Low side ground overcurrent (51G) = 1.0 sec at Maximum SLG Fault Current Contributed to Low Side Busbar

- **Instantaneous Unit**

  - Block
Overcurrent Relay Time Curve
3. Overcurrent Ground Back-up Relay (Tertiary winding)

- **CT. Ratio**
  
  - CT ratio = Use maximum ratio in tertiary winding
  
  - Connect all 3 phases in parallel to relay
3. Overcurrent Ground Back-up Relay (Tertiary winding)

- Minimum Pick up Current

  - Overcurrent Ground Back-up Relay No.1 = 100% OA rating of tertiary winding

  - Overcurrent Ground Back-up Relay No.2 = 200-300% OA rating of tertiary winding

Note – The value will be multiply by 3 because of the three CT in tertiary winding connected in parallel
RELAY SETTING CRITERIA

3. Overcurrent Ground Back-up Relay (Tertiary winding)
   • Time Characteristic Curve
     - Overcurrent Ground Back-up Relay No.1 = Long time inverse
     - Overcurrent Ground Back-up Relay No.2 = Very inverse
RELAY SETTING CRITERIA

3. Overcurrent Ground Back-up Relay (Tertiary winding)

• **Operating Time**
  
  - Time characteristic curves of both relay must be lower than transformer thermal damage curve

  - Operating Time = 1.5 sec. at maximum circulating current \((3I_{ot})\) in tertiary winding when SLG fault occurs at low voltage side of the transformer

• **Instantaneous Unit**

  - Block
RELAY SETTING CRITERIA

3. Overcurrent Ground Back-up Relay (Tertiary winding)

Overcurrent Ground Back-up Relay Time Characteristic Curve
RELAY SETTING CRITERIA

4. Overfluxing Relay for 500/230kV Tie Transformer

- Set time characteristic curves of overfluxing relay so that relays always operate before transformers reach the overfluxing limit

- Time margin = 1-2 sec.
4. Overfluxing Relay for 500/230kV Tie Transformer

RELAY SETTING CRITERIA

Overfluxing Relay Time Curve

Transformer Overfluxing limit Curve

Overfluxing Relay for 500/230kV Tie Transformer
## PERFORMANCE OF DIFFERENTIAL RELAY

<table>
<thead>
<tr>
<th>YEAR</th>
<th>CORRECT OPERATION</th>
<th>UNNECESSARY OPERATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tie</td>
<td>Loading</td>
</tr>
<tr>
<td>2001</td>
<td>4</td>
<td>43</td>
</tr>
<tr>
<td>2002</td>
<td>4</td>
<td>44</td>
</tr>
<tr>
<td>2003</td>
<td>6</td>
<td>37</td>
</tr>
<tr>
<td>2004</td>
<td>6</td>
<td>34</td>
</tr>
<tr>
<td>2005</td>
<td>6</td>
<td>34</td>
</tr>
</tbody>
</table>

Total Number of Transformer = 588 Units (Tie = 36%, Loading = 64%)

Correct / Unnecessary Operation Of Transformer Differential Relay

- **Old relays (age > 15 years)**
- **New relay maloperation**
PERFORMANCE OF DIFFERENTIAL RELAY

230/69kV Transformer KT6A at NB sub. Date 19/06/2004
B-C fault (Short turn) Clearing time = 96 ms. Relay type MBCH (GEC)
PERFORMANCE OF DIFFERENTIAL RELAY

230/115kV Transformer KT3A at SR2 sub. Date 14/09/2005
C-G fault (Low side bushing explode) Clearing time = 90 ms. Relay type HU (ABB)
PERFORMANCE OF DIFFERENTIAL RELAY

230/115kV Transformer KT2A at LPR sub. Date 16/09/2005
A-B-C-G fault (Flash over at LA 22kV) Clearing time = 108 ms. Relay type D202 (BBC)
PERFORMANCE OF DIFFERENTIAL RELAY

230/115kV Transformer KT4A at HY2 sub. Date 10/11/2005
B-G fault (High side bushing flashover) Clearing time = 64 ms. Relay type MBCH (GEC)
THANK YOU