ECE 525

POWER SYSTEM PROTECTION
AND RELAYING

SESSION no.  28
Threshold is set above any possible non-fault condition.

\[ \Rightarrow \text{Determine worst possible inrush} \]

- Some vendors use instantaneous current (CRAW) unfiltered.
- Some use a TRUE RMS.

\[ \Rightarrow \text{Some recommend 12 pu as threshold} \]
\[ \Rightarrow \text{The paper says over 16} \]
D. Differential Element

- Unrestrained

- Fast response to severe internal faults

- Top > 7% of 

- Top > Threshold

- MWAsc = 1000

- 7 A - unrestrained

- 254 mV

- 87
older computer power supply
What if internal fault already present when energize or one occurs during energization - can pose problems with cross blocking.

- Fault resistance

Rf - Fault resistance...
Normal Inrush

$|I_1|$  $|I_2|$  

$t=0$

end of inrush

$\frac{|I_2|}{|I_1|}$

Block Threshold
Back to restrained differential element

Harmonic Blocking

- \( I_{\text{op}} \)
- \( I_{\text{ret} \cdot SLP} \)
- \( I_{\text{op}} \)
- \( I_{\text{omin}} \)

\[ B.C \]

\text{CROSS BLOCKING}

\[ I_{\text{opunfiltered}} \]

Harmonic Blocking CALC

Filters:
- fundamental
- 2nd
- 5th
- other

\[ I_{\text{opraw}} \]

\[ I_{\text{2set}} \]

\( Z \) usually some % of \( \text{fund} \) ~ 15\% of \( |I_1| \)
Internal fault

\[ \frac{I_d}{I_1} \]

Fault occurs

Bigger change with low \( R_f \)

Threshold
Figure 6: C-Phase Inrush Current Obtained from Transformer Modeling

Fundamental Frequency and Second-Harmonic Content of the Inrush Current

Figure 7 shows the fundamental frequency and second-harmonic content of the C-phase inrush current shown in Figure 6. The maximum fundamental frequency current magnitude is 71.9 amps, and the maximum second-harmonic magnitude is 48.0 amps. Both magnitudes decrease as the inrush current diminishes. Figure 7 also shows the second harmonic as percentage of the fundamental frequency current. This percentage is above 60% for this energization condition.

Figure 7: Fundamental Frequency and Second-Harmonic Content of the Inrush Current
Figure 9 shows the A-phase current obtained with the transformer model for the same overvoltage condition. The peak value of the excitation current is approximately 57 amps in the actual current and in the modeled current. The two current waves are similar in magnitude and in shape. To properly simulate the excitation current zero crossings, we modeled the hysteresis loops for this overexcitation condition.

Table 1 shows the odd-harmonic content of the current signal shown in Figure 9. The third and fifth harmonics provide reliable quantities to detect overexcitation conditions. The third harmonic is filtered out with the delta connection compensation of the differential relay or the delta connection of the CTs. A fifth-harmonic level detector can identify overexcitation conditions.

<table>
<thead>
<tr>
<th>Frequency Component</th>
<th>Magnitude (Primary Amps)</th>
<th>Percentage of Fundamental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental</td>
<td>22.5</td>
<td>100.0</td>
</tr>
<tr>
<td>Third</td>
<td>11.1</td>
<td>49.2</td>
</tr>
<tr>
<td>Fifth</td>
<td>4.9</td>
<td>21.7</td>
</tr>
<tr>
<td>Seventh</td>
<td>1.8</td>
<td>8.1</td>
</tr>
</tbody>
</table>

**Current Differential Relay**

The relay consists of three differential elements. Each differential element provides percentage restrained differential protection with harmonic blocking and unrestrained differential protection.

![Diagram of Current Differential Relay](image)

Figure 10 shows the block diagram of the data acquisition and filtering sections for Winding 1 currents. The input currents are the CT secondary currents from Winding 1. The relay reduces the magnitude of these currents and converts them to voltage signals. Low-pass filters remove high-frequency components from the voltage signals. Digital filters extract the fundamental, second-, and fifth-harmonic quantities from the digital signals. The Tap 1 setting scales the signals in magnitude. After signal scaling, the relay removes the zero-sequence component of
Harmonic Restraint

- Adding to the slope during inrush

\[ I_{RT\text{A}} = |I_{\text{ET fundamental}}| \cdot SLP + |I_{R+2}| \cdot k_2 \]

\[ + |I_{R+4}| \cdot k_{2y} \ldots \]

\[ |I_{R4}| + |I_{S4}| \]
<table>
<thead>
<tr>
<th></th>
<th>Harmonic Blocking</th>
<th>Harmonic Restraint</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>External Fault Security</strong></td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Inrush Security</strong></td>
<td>Good *</td>
<td>Good *</td>
</tr>
<tr>
<td></td>
<td>* modern steels w/ lower Iz</td>
<td></td>
</tr>
<tr>
<td><strong>Dependable</strong></td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Response speed internal fault (normal cond)</strong></td>
<td>somewhat faster</td>
<td>fast</td>
</tr>
<tr>
<td><strong>Fault on energization</strong></td>
<td>fast</td>
<td>faster (esp low Rf fault)</td>
</tr>
</tbody>
</table>
- Woods Neal CT
- Node
- Neutral CT
- Neutral
- Neutral (terminal)

Terminal

- Net market current
- Can see high IT
- Current close to neutral
- 3y - 6s side, an inerter

Restricted Earth Fault Protection

3/15
b) Consider the restricted earth fault protection scheme shown below. Determine whether the earth fault is inside or outside the protected zone, give reasons for your answer.

Neutral CT current:

- \( I_N := 1200 \cdot e^{j \cdot 30\text{deg}} \)

\( \text{CTR}_{\text{Neutral}} := \frac{400}{5} \)

LV CT currents (note negative sign due to polarity of CT compared to labelled current)

- \( I_{A,\text{LV}} := -596 \cdot e^{j \cdot 16.8\text{deg}} \)
- \( I_{B,\text{LV}} := -349.2 \cdot e^{j \cdot 22.6\text{deg}} \)
- \( I_{C,\text{LV}} := -346.2 \cdot e^{j \cdot 60.4\text{deg}} \)

\( I_R := I_{A,\text{LV}} + I_{B,\text{LV}} + I_{C,\text{LV}} \)

\[ |I_R| = 1225.161 \quad \text{arg}(I_R) = -150.275\text{-deg} \]

\( I_{R,\text{sec}} := \frac{I_R}{\text{CTR}_{\text{phase}}} \)

\( \text{Torque}_{\text{REF}} = \text{Re}(I_{R,\text{sec}} \cdot I_{R,\text{sec}}) \)

\( \text{Torque}_{\text{REF}} = -229.715 \)

- Negative torque implies fault is out of zone.
\[ \frac{d\phi}{L} = \frac{U_1}{N_1} = \frac{U_2}{N_2} = \frac{V_f}{N_f} \]