Turn-to-Turn Fault Detection in Transformers Using Negative Sequence Currents

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Outline

- Traditional Differential Relay
- Proposed Differential Relay Using Negative Sequence Currents
- Results
- Conclusions
Traditional Differential Relay

Drawback of the differential relay - **low sensitivity**

Figure 1 – Percentage Differential Relay of the Transformer

- **Internal fault**
  \[ |i_1 - i_2| > k \frac{|i_1 + i_2|}{2} \]

- **External fault**
  \[ |i_1 - i_2| < k \frac{|i_1 + i_2|}{2} \]
Traditional Percentage Differential

- Difficult to detect low-level turn-to-turn faults.
- Change in transformers terminal current is quite small.
- IEEE C37.91-2000 indicates that ~10% of the transformer winding has to be shorted to cause a detectable change in terminal current.
- Restraint characteristics usually set to about 20%.
Fig. 2 Traditional Differential Relay – Differential and restraining current for various percentages of shorted turns.

10% of turns are shorted

3% of turns are shorted
Other Differential Relaying Schemes

- Sudden Pressure Relays are slow to operate (50-100ms).
- Sachdev, Sidhu (1989) used electromagnetic equations during internal faults (accurate for shorted turns > 5%).
- Gajic et. al from ABB in (2005) presented negative sequence current differential concept.
- Crossley (2004) presented a technique based on increments of flux linkages (accurate for shorted turns > 10%).
- Wavelet transforms (Kunakorn, 2006) & ANN (Li, 2007).
Negative Sequence Current Scheme

- Compared to zero sequence currents, negative sequence current differential provides coverage for phase faults as well as for ground faults.

- Two stages of comparison:
  - Negative sequence magnitudes compared with a pre-set level of 1%.
  - Directional Comparison: $<[0-5 \text{ degrees}]$ then it is an internal fault. If it is 180 degrees then it is an external fault.
  - For $\Delta-Y$ and $Y-\Delta$ the appropriate 30 degree phase shifts could be taken into account.
Relay Logic

Primary currents
\( I_{a1}, I_{b1}, I_{c1} \)

FFT

Neg. seq. current \( I_{NS-P} \)

\( I_{NS-P} > I_{min} \)

No

Yes

If phase shift \( \approx [0 - 5^0] \)

No

Yes

Trip

Secondary currents
\( I_{a2}, I_{b2}, I_{c2} \)

FFT

Neg. seq. current \( I_{NS-S} \)

\( I_{NS-S} > I_{min} \)

No

Yes

Figure 3. Negative sequence current based logic
Figure 4. Direction of negative sequence currents during faults
Simulation Results

- Simulation model developed in PSCAD/EMTDC.
- Three-phase transformer bank constructed using three single phase transformer banks (each 33.3 MVA, 23/132 kV). Mutual coupling taken into account.
- Number of turns on primary: 150. Number of turns on secondary: 866.
- Accurate values of leakage reactance were obtained for different shorted turns.
Figure 5. Negative sequence current magnitudes for various percentages of shorted turns on primary winding (Y-Y).

- **10% of turns are shorted**
- **1% of turns are shorted**
Figure 7. Phase angle comparison between two negative sequence currents for various percentages of shorted turns on primary winding (Y-Y).

10% of turns are shorted

1% of turns are shorted
Figure 8. Response of the proposed scheme during an external B-to-ground fault on the secondary side (Y-Y).
Figure 9. Negative sequence current magnitudes for 3% shorted turns on secondary (Δ-Y)
Figure 10. Phase angle comparison between two negative sequence currents for 3% shorted turns on secondary (Δ-Y) with 30º phase shift
Table 5.7 – Phase currents due to a small unbalance

<table>
<thead>
<tr>
<th>Phase</th>
<th>Load Amps</th>
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<tbody>
<tr>
<td>A</td>
<td>4.1759</td>
</tr>
<tr>
<td>B</td>
<td>4.5976</td>
</tr>
<tr>
<td>C</td>
<td>4.3906</td>
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</tbody>
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Figure 12. Negative sequence current magnitudes due to a small unbalance in the power system
Figure 13. Phase angle between two phasors of negative sequence currents during a small unbalance in the power system.

Figure 14. Output signal from the proposed technique for a small unbalance in the power system.
Figure 15. Negative sequence currents magnitudes during inrush current

Figure 16. Phase angle between two phasors of negative sequence currents during inrush current
Conclusions

• Simple to implement (uses standard sequence current logic).
• successfully detects turn-to-turn fault even when small number of turns are shorted (1-2%).
• accurately discriminates between internal and external faults.
• detection time approximately 12 ms.
• Tested for various operating conditions, inrush currents, unbalanced operation.
• does not require any extra customization compared to the traditional differential relay.