Study about Numerical Relay SEL-387 for Overcurrent and Differential Protections of 110/20 kV Transformers

ANGELA IAGĂR\textsuperscript{1}, GABRIEL NICOLAE POPA\textsuperscript{1}, CORINA MARIA DINIŞ\textsuperscript{1}, GHEORGHE MORARU\textsuperscript{2}

\textsuperscript{1}Faculty of Engineering Hunedoara, Politechnica University Timișoara
Str. Revoluției, no 5, Hunedoara, 331128, ROMANIA

\textsuperscript{2}SMART Sibiu
Bd. Corneliu Coposu, no 1-3, Sibiu, 550245, ROMANIA
misu@smartsb.ro

Abstract: - Nowadays, the main problems of the relay protections result from the fact that in the modern electric systems the performances imposed to the protections operation became very severe, enhancing the difficulty in their simultaneous satisfaction. In these conditions, the numerical relays are used more and more for the electrical installations protection. This paper presents a study regarding the establishment of the protection, measuring and automation functions necessary for the numerical relay SEL-387 concerning the protection of the 110/20 kV transformers from the national energetic system (Romania). In this purpose, were calculated the adjustable settings of the protection functions, and after setting, the numerical relay was verified in laboratory conditions.

Key-Words: - Numerical protection relay, Differential protection, Overcurrent protection, Transformer

1 Introduction

In the last decades a strong development of the energetic installations was registered, as regards the quantitative parameters (intense increase of transmission capacity of lines, lines total length etc.), but also the qualitative ones (increasing the installed capacity utilization time, very high voltages for the transmission lines, increasing the grids looping degree, improvement of maintaining the frequency and voltage values, increasing the safety and the continuity of the consumers power supply etc.) [1-3].

However, once with the energetic systems development, maintaining of their stability became more and more difficult.

The condition for maintaining the stability imposed the achievement of some protections with a very reduced pickup time (20-30 ms).

But, within a short interval from the appearance of a fault, the transient components of the electric quantities that supply the protective relays are very large.

Hence, one of the current problems of the relays protection technique consists in elaboration of some measures that should eliminate the influence of the transient components upon the protection operation. Here is framing the achievement of some new types of current and voltage transformers, and introducing of some filters that should allow the relays supply only with sinusoidal quantities (the fundamental harmonics of current and voltage) [4,5].

The second problem in the relays protection technique is related to the increase of faults clearance safeties and preventing their transformation into system failures.

In this respect, a special attention shall be given to the back-up protections. Also, for safety increase, the protection operation is combined with the automations of system [4,6,7].

Another problem in the relays protection technique is related to the necessity of ensuring simultaneously the selectivity and speedily operation for the faults appeared on the entire protected line.

Thus, in the modern electric systems the performances imposed to the protections operation became more severe, enhancing the difficulty in their simultaneous satisfaction.

In these conditions, the numerical relays (relays) are used more and more for the protection of electrical installations [8-10].

The numerical protection relays present important advantages compared with the electromechanical or static relays. Among these, communication in the local dedicated area network...
at bay level and at the substation level, respectively
the human-machine communication interface would be the most important[8-10].

The self-supervision function is extremely important for the optimization of the protections maintenance [9-11].

Integration of multiple protection, control and self-supervision functions, at the same level, provide reduced size of wires in the substation, reducing the probability to appear human mistakes and improving the electromagnetic compatibility [3,9].

One can notice also the possibility of integrating the numerical relays in any application [3,10,11]. However, is imposed the correct setting of the numerical relay and its testing in laboratory conditions.

Further is presented a study concerning the establishment of the protection, measurement and automation functions necessary for the numerical relay SEL-387 concerning the protection of the 110/20 kV transformers from the national energetic system (NES) and its experimental checking.

2 SEL-387 numerical protection relay
SEL-387 is a current differential and overcurrent numerical relay.

The main features of SEL-387 are [12]:
- Two-, Three-, and Four-Winding Current Differential Protection
- Sensitive current differential protection (with programmable single- or dual-slope percentage restraint) is supervised by a choice of second and fourth-harmonic blocking or restraint elements, plus fifth-harmonic and dc blocking elements for secure protection of up to four windings.
- Phase current harmonic blocking is set for either common or independent winding basis.
- Unrestrained high-set differential elements provide fast operation for high-magnitude internal faults.

"Around the clock" phase angle compensation settings and automatic tap calculations simplify settings.
- Individual Winding Overcurrent Protection
- Torque-controllable overcurrent elements, including one instantaneous, one definite-time, and one inverse-time element each for phase, negative-sequence, and residual ground currents, provide comprehensive overcurrent protection on each winding input.

Combined current feature sums current from two CTs for ring-bus and breaker-and-a-half overcurrent applications.

- Through-Fault Recording and Monitoring
  Through-fault duty is recorded and accumulated for use in SELOGIC® control equations or manual monitoring.
- Protection and Control Logic
  Restricted Earth Fault (REF) logic provide a sensitive grounded-wye winding ground fault protection. SELOGIC Control Equations with SELOGIC variables, timers, latch bits, and remote control elements customize advanced protection and control schemes.

  SEL-387 includes local programmable control elements and programmable text display points for advanced local operator interface.
- Metering and Reporting
  Oscillographic event reports (up to seven 60-cycle reports), Sequential Events Recorder (SER) reporting, and accurate metering eliminate or reduce external recorder and metering requirements.
- ACSELERATOR® QuickSet™ Software
  Develop relay settings off-line, program SELOGIC control equations, and analyze post-fault event reports.

  Automatically captures and stores 23 most recent eleven-cycle, oscillographic reports detailing current, voltage, contact I/O, and protection element conditions during events.
- Sequence-of-events recording captures, time-tags, and stores 512 latest state changes of contact inputs, contact outputs, control points, and protection elements.
- SEL-387 relay includes a sophisticated thermal model to monitor temperatures and insulation aging of mineral oil immersed transformers.
- Additional local and remote control switches and binary SER messaging.
- Distributed Network Protocol (DNP) 3 Level 2 Slave communications protocol.
- SEL-387 is certified to a wide range of electrical noise, temperature cycling, and seismic tests.

3 Setting of SEL-387 for a three-phase transformer
The basic data of the transformer that should be protected are:
- \( U_1 = 110 \text{ kV} , U_2 = 20 \text{ kV} , S = 25 \text{ MVA} \);
- vector group of the transformer: YD11.
- Selection of the current transformers (CTs) for the differential protection

Windings 1 and 2 are validated for differential protection, and windings 3 and 4 for overcurrent protection.

Settings will be: \( E87W1 = Y \), \( E87W2 = Y \), \( E87W3 = N \), \( E87W4 = N \).

The setting labels have the following definitions:
- \( E87Wn \) - Enable Winding n in Differential; \( n \) is the number of winding; \( Y \) – Yes; \( N \) – No.
- \( Y1 \) = \( W87E \) = \( Y2 \).
- \( N3 \) = \( W87E \) = \( N4 \).

The setting labels have the following definitions:
- \( WnCT \) - Winding n CT Connection, \( n \) is the number of winding.
- \( CTRn \) - Winding n CT Ratio \( (I_{PR}/I_{SN}) \), \( n \) is the number of winding; \( I_{PR} \) - primary current; \( I_{SN} \) - secondary current.

- The following settings refer to the CTs connection and to the current ratio for each winding:
  - \( W1CT = Y \) ; \( CTR1 = 150 \) (110 kV)
  - \( W2CT = Y \) ; \( CTR2 = 800 \) (20 kV)

The necessary settings for the internal compensation of the current transformers:
- \( W1CTC = 0 \); \( W2CTC = 11 \) (330° around the clock compensation),
where:
- \( W1CTC \) - Winding 1 Connection Compensation;
- \( W2CTC \) - Winding 2 Connection Compensation.
- Relay calculates the Winding n Current Tap (TAPn) based on the following equation:
  \[
  TAPn = \frac{MVA \cdot 1000}{\sqrt{3} \cdot VWDGn \cdot CTRn} \cdot C
  \]
- The CTs are connected in a Wye (Y) configuration.

Further, will be achieved the internal compensation of the current transformers.
Because the windings of the transformer to be protected are wye- (Y) and delta- (D) connected, and the windings of the current transformers are all wye, it should be made an adjustment of the phase angle.

The necessary settings for the internal compensation of the current transformers are:
- \( W1CTC = 0 \); \( W2CTC = 11 \) (330° around the clock compensation),
where:
- \( W1CTC \) - Winding 1 Connection Compensation;
- \( W2CTC \) - Winding 2 Connection Compensation.
- Relay calculates the Winding n Current Tap (TAPn) based on the following equation:
  \[
  TAPn = \frac{MVA \cdot 1000}{\sqrt{3} \cdot VWDGn \cdot CTRn} \cdot C
  \]
where:
- \( C = 1 \), if the CTs are connected in a Wye configuration (\( WnCT = Y \));
- \( MVA \) - is the Maximum Transformer Capacity (Three-Phase MVA);
- \( VWDGn \) - represents Winding n Line-to-Line Voltage, [kV].

With \( MVA = 25 \), \( VWDG1 = 110 \), \( VWDG2 = 20 \), result: \( TAP1 = 0.875 \) A, \( TAP2 = 0.902 \) A .

If \( MVA = \text{OFF}, \) the user must define TAPn.

- \( \text{TAP} \), \( n \), must be less than or equal to 7.5. Otherwise, the numerical relay warns the user upon this.
- Setting of the operating current.
  Operating current is set to a minimum value, but high enough to avoid the operation at a stationary regime error of the current transformers and at the excitement current of the transformer. Is requires: \( O87P_{MIN} \geq 0.1 \cdot I_{TAP} \cdot MVA \).

\[
O87P \geq 0.1 \cdot I_{TAP}
\]
and: \( O87P = 0.1 \cdot I_{TAP} \)

- \( O87P \) - Restrained Element Operating Current Minimum Pickup, per unit of TAP.

- Then, is set the percentage restraint characteristic in order to make the difference between the internal and external faults.

Considering that the CT error is 1%, it can be set:
- \( SLPI = 25 \), \( IRSI = 3 \), \( SLP2 = 55 \).
- \( SLPI \) - represents Restrained Element Slope 1, [%]
- \( SLP2 \) - represents Restrained Element Slope 2, [%]
- \( IRSI \) - Restrained Element Slope 1 Limit.

- \( SLP2 \) improves the sensitivity in the region where the CT error is small and ensures the security at high current in the region where the CT error is big.
- Setting the unrestrained current instantaneous protection.

This protection has the purpose to operate speedily at a very high current, which clearly indicates an internal fault.

- The operation level is set to approximately 10 times \( TAP \):
  \( U87P = 10 \) (TAP multiples)

- \( U87P \) represents Unrestrained Element Operating Current Pickup Level.

- Second-harmonic blocking

Second-harmonic current can be used to identify the inrush currents and to avoid the protection relay misoperation.

- Is set \( PCT2 = 25\% \) (the restrained differential protection is blocked if the second harmonic is higher than 25% from fundamental).
- \( PCT2 \) - Second-Harmonic Blocking Percentage of Fundamental

- Fifth-harmonic blocking

According with the industrial standards (ANSI/IEEE C37.91, C37.102) the overexcitation occur when the ratio between voltage and frequency applied to the transformer increases by 1.05 per completely loaded unit, or by 1.1 per unloaded unit. The transformer overexcitation produces odd harmonics in the exciting current. These produce false differential currents that could cause relay misoperation.

- Is set \( PCT5 = 35\% \) (the operation is blocked if the fifth harmonic is higher than 35% from fundamental) and \( TH5P = \text{OFF} \) (the 5th harmonic alarm is deactivated).
- \( PCT5 \) - Fifth-Harmonic Blocking Percentage of Fundamental
- \( TH5P \) - Fifth-Harmonic Alarm Threshold
Independent Harmonic Blocking
The independent blocking is not activated: IHBL = N (any harmonic blocking element blocks all 87R elements).

4 SEL-387 laboratory tests

4.1 Instantaneous Overcurrent Protection
The connection diagram used for checking the SEL-387 relay in case of the instantaneous overcurrent protection is presented in figure 1.

For checking the SEL-387 relay was used an OMICRON test system (TEST UNIVERSE) (fig.1).

Fig.1. The connection diagram used for checking the instantaneous overcurrent protection

➢ 50P12P – The instantaneous overcurrent protection on winding 1
The adjustable settings of the SEL-387 relay for the instantaneous overcurrent protection on winding 1 are presented in Table 1.

Table 1
Adjustable settings for the instantaneous overcurrent protection on winding 1

<table>
<thead>
<tr>
<th>I, t</th>
<th>Phase</th>
<th>R</th>
<th>S</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>I_{act} [A]</td>
<td>2.8</td>
<td>2.8</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>t_{act} [s]</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
</table>

The experimental results obtained by checking the instantaneous overcurrent protection on winding 1 are shown in figure 2 (a, b, c).

➢ 50P22P – The instantaneous overcurrent protection on winding 2
The adjustable settings of SEL-387 for the instantaneous overcurrent protection on winding 2 are presented in Table 2; the experimental results are shown in figure 3 (a, b, c).

Table 2
Adjustable settings for the instantaneous overcurrent protection on winding 2

<table>
<thead>
<tr>
<th>I, t</th>
<th>Phase</th>
<th>R</th>
<th>S</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>I_{act} [A]</td>
<td>2.8</td>
<td>2.8</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>t_{act} [s]</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
</table>

➢ 50P32P – The instantaneous overcurrent protection on winding 3
The adjustable settings of SEL-387 for the instantaneous overcurrent protection on winding 3 are presented in Table 3. The experimental results are shown in figure 4 (a, b, c).

Table 3
Adjustable settings for the instantaneous overcurrent protection on winding 3

<table>
<thead>
<tr>
<th>I, t</th>
<th>Phase</th>
<th>R</th>
<th>S</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>I_{act} [A]</td>
<td>2.8</td>
<td>2.8</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>t_{act} [s]</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
</table>
Figure 3. Results of checking the instantaneous overcurrent protection on winding 2

Figure 4. Results of checking the instantaneous overcurrent protection on winding 3

Table 4

<table>
<thead>
<tr>
<th>Phase</th>
<th>R</th>
<th>S</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>I_set [A]</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>t_set [s]</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Figure 5. Results of checking the instantaneous overcurrent protection on winding 4

4.2 Differential Protection

The connection diagram used for checking the numerical protective relay SEL-387 in case of the differential protection is presented in figure 6.

For checking the SEL-387 relay was used an OMICRON test system (TEST UNIVERSE) (figure 6). The experimental results are presented in Table 5.

Further the experimental tests was found that the SEL-387 relay corresponds to the norms specified by the manufacturer.
**Fig. 6. The connection diagram used for checking the differential protection**

**Table 5**

<table>
<thead>
<tr>
<th>I₁</th>
<th>I₂</th>
<th>I₃</th>
<th>θ</th>
<th>t</th>
<th>I₁</th>
<th>Iᵢ</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.87</td>
<td>0.9</td>
<td>0.87</td>
<td>48</td>
<td>0.313</td>
<td>0.510</td>
<td>1</td>
</tr>
<tr>
<td>1.741</td>
<td>1.8</td>
<td>1.741</td>
<td>45</td>
<td>0.522</td>
<td>0.0532</td>
<td>2</td>
</tr>
<tr>
<td>2.611</td>
<td>2.7</td>
<td>2.611</td>
<td>45</td>
<td>0.783</td>
<td>0.0544</td>
<td>3</td>
</tr>
<tr>
<td>3.48</td>
<td>3.6</td>
<td>3.48</td>
<td>49</td>
<td>1.321</td>
<td>0.0354</td>
<td>4</td>
</tr>
<tr>
<td>4.351</td>
<td>4.5</td>
<td>4.351</td>
<td>52</td>
<td>1.908</td>
<td>0.0326</td>
<td>5</td>
</tr>
<tr>
<td>5.22</td>
<td>5.4</td>
<td>5.22</td>
<td>54</td>
<td>2.495</td>
<td>0.0526</td>
<td>6</td>
</tr>
<tr>
<td>6.09</td>
<td>6.3</td>
<td>6.09</td>
<td>55</td>
<td>3.031</td>
<td>0.0332</td>
<td>7</td>
</tr>
<tr>
<td>6.96</td>
<td>7.2</td>
<td>6.96</td>
<td>56</td>
<td>3.6</td>
<td>0.0558</td>
<td>8</td>
</tr>
</tbody>
</table>

### 5 Conclusions

SEL-387 numerical relay ensures security for external faults, inrush, and overexcitation conditions and provide dependability for internal faults.

This relay combines harmonic restraint and blocking methods with shape recognition technique. Even harmonics of the differential current provide restraint, while the fifth harmonic and dc component block relay operation.

Further the experimental tests was found that the SEL-387 relay corresponds to the norms specified by the manufacturer and can be used for the protection of 110/20 kV transformers from national energetic system (Romania).

### References:


