Open Phase Failure on the HV-Side of Power Plants Requires New Protection Solutions

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Power system structure and open phase failure situation

Two main topics

Influence on the generator

Broken connection to the CB

Byron Failure

Influence on the auxiliary power supply

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Influence on generator (one open phase failure)
Grounded transformer neutral point

After a short transient period there are stable conditions
(depending on the load and settings overcurrent protection can pickup in one phase)

Measurable negative sequence voltage

A higher negative sequence current flows. Thermal negative sequence protection trips after seconds
($I_2^2 \times t = 5 \text{ s} \rightarrow\text{trip after 55,5s}$)
Influence on generator (one open phase failure)
Isolated transformer neutral point

The generator becomes instable and after few seconds an asynchronous condition occurs.

High negative sequence voltage, but the voltage swings (a chattering of a $U_2$-function is possible).

High negative sequence current; he swings synchronous with the positive sequence current ($I_2$-protection trips too late).
Influence on generator (one open phase failure) isolated transformer neutral point

The generator falls out of step (out of synchronism) and this event stresses the turbine and generator.

Impedance trajectory

Asynchronous power swing
(red = active power \( P \); blue = reactive power \( Q \))

Synchronous swing

Asynchronous swing
Proposed solution
Additional characteristic for the out of step protection (ANSI 78)

Possible device: **7UM85**
- More zones are possible (U₂ release via CFC)
- Sensitive and accurate measurement of a low negative sequence voltages (U₂)
- Additional U₂ alarm is possible or U₂ protection function
Power system structure and open phase failure situation

Influence on the auxiliary power supply

Two main topics

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Influence on the auxiliary power supply
Thermal limits of induction (asynchronous) motors

In the technical data of the induction motor no limits for the negative sequence currents are given. Therefore some tests on motors are done and they showed the robustness of motors.

Results from a test in the Lab:
• 5% $U_2/U_1$ (app. 25%$I_2$)
• Motor operation 130min
• Winding temperature increased by 12 K

• 50%$U_2/U_1$ (app. 150%$I_2$)
• Motor operation 60 sec
• Winding temperature increased by 120 K

Conclusion
The limits coming more from the protection due to the selected settings

Given curve from an induction motor:
$U_N = 10$ kV, $I_N = 108$ A; Thermal class: F/B

25% $I_2/I_N \rightarrow$ allowed time 5 min (300s)
One open phase failure on the HV-side of the unit transformer

Summarization of the test results

<table>
<thead>
<tr>
<th>Simulation cases</th>
<th>Negative sequence voltage (U₂)</th>
<th>Positive sequence voltage (U₁)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grounded unit transformer neutral point; generator in operation</td>
<td>3% to 14% U₂ (higher value at higher generator load) Synchronous power swing at high load possible</td>
<td>95% to 100% U₁</td>
</tr>
<tr>
<td>Grounded unit transformer neutral point; generator not in operation</td>
<td>1% to 3% U₂ (higher value at higher transformer load) → values are close to the operation conditions</td>
<td>approx. 100% U₁</td>
</tr>
<tr>
<td>Ungrounded unit transformer neutral point; generator in operation</td>
<td><strong>High values of U₂</strong> (and I₂), see Figure 11 and 5) Asynchronous operation of the generator is possible</td>
<td>U₁ value fluctuates (see Figure 11)</td>
</tr>
<tr>
<td>Ungrounded unit transformer neutral point; generator not in operation</td>
<td><strong>15% to 25% U₂</strong> (normal to high motor load) <strong>8% to 15% U₂</strong> (weak motor load)</td>
<td>80% to 95% U₁</td>
</tr>
</tbody>
</table>
One open phase failure on the HV-side of the external supply transformer
Summarization of the test results

<table>
<thead>
<tr>
<th>Simulation cases</th>
<th>Negative sequence voltage (U₂)</th>
<th>Positive sequence voltage (U₁)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grounded external supply transformer neutral point;</td>
<td>1% to 6% U₂ (higher value at higher load)</td>
<td>95% to 100% U₁</td>
</tr>
<tr>
<td>motor load</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grounded external supply</td>
<td>&lt; 1% U₂ (not measurable)</td>
<td>Approx. 100% U₁</td>
</tr>
<tr>
<td>transformer neutral point; no load</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ungrounded external supply</td>
<td>15% to 25% U₂ (normal to high motor load)</td>
<td>80% to 95% U₁</td>
</tr>
<tr>
<td>transformer neutral point; motor load</td>
<td>8% to 15% U₂ (weak motor load)</td>
<td></td>
</tr>
<tr>
<td>Ungrounded external supply</td>
<td>30% to 70% U₂ (determined via the coupling, winding capacitances) additional the phase to phase</td>
<td>40% to 60% U₁</td>
</tr>
<tr>
<td>transformer neutral point; no load</td>
<td>voltages becomes asymmetrical (lower)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Proposed solution
Supervision of negative sequence voltage

- Additional safety criterion is the supervision of the phase to phase undervoltage (setting must be lower than the reduced voltage during motor start; time grading according max. $U_2$-time (3s))
- At high motor load $I_2 >$ stage can be used additional (short time grading, lowest $U_2$ time)

![Diagram of protection logic]

**German two stage approach**

**Note:** Plants select individual the settings (3.5% $U_3 (3s, 4s)$ and 8.7% (1.5s, 1.7s))

**Scaling of $U_2$:**

$U_2/% := \frac{U_2}{(U_N/\sqrt{3})} \times 100\%$
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