Differential Protection for Converter Transformers

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Abstract

This paper will present differential protection schemes used for special Converter Transformers. These transformers are typically used to feed MV drives, power electronic or FACTS devises. Converter transformers are industrial power transformers which may have phase angle shift different from standard 30° or a multiple of 30°. Typical example is 24-pulse converter transformer with additional phase angle shift $\Theta$ of ±7.5°. Such special industrial transformers typically have three windings, but sometimes even up to five windings. The converter transformer additional phase angle shift $\Theta$ is typically obtained by special connections of its HV winding (e.g. extended-delta or zig-zag).

However, if numerical differential protection for standard three-phase power transformers is directly applied for differential protection of such converter transformer, it will not be possible to compensate for additional, non-standard phase angle shift $\Theta$ caused by special winding connections. As result a permanent false differential current would appear. For the worst case when $\Theta=15^\circ$ the false differential current of up to 26% of the through-load current will appear. Thus, the minimum pickup of the differential protection must be increased to at least double of this value and as a consequence differential relay will not be sensitive for the low level internal faults within the protected converter transformer. Therefore a special differential protection solution is often required. The paper will provide information how to design such differential schemes and present current waveforms from DRs captured in actual installations.

1 Introduction

The converter transformers are often used to feed MV drives, SVCs, large rectifiers, static frequency converters, etc. Most of applications shown in this paper come from the actual installations of MV variable speed drives. Typical MV drive structure is shown in Figure 1.

<table>
<thead>
<tr>
<th>Pulse No</th>
<th>No of transformer LV windings</th>
<th>Phase shift between LV windings</th>
<th>Example for converter transformer vector group</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>1</td>
<td>-</td>
<td>Yy0</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>30° (60min)</td>
<td>Dy11d0</td>
</tr>
<tr>
<td>18</td>
<td>3</td>
<td>20° (40min)</td>
<td>Dd11:20d0d0:40</td>
</tr>
<tr>
<td>24*</td>
<td>4</td>
<td>15° (30min)</td>
<td>Dd0:25d11:25 Dd11:75d0:75</td>
</tr>
<tr>
<td>30*</td>
<td>5</td>
<td>12° (24min)</td>
<td>-</td>
</tr>
<tr>
<td>36*</td>
<td>6</td>
<td>10° (20min)</td>
<td>Yd10:20d11d11:40 Dd11:20d0d0:40</td>
</tr>
<tr>
<td>42*</td>
<td>7</td>
<td>8.57° (17min)</td>
<td>-</td>
</tr>
<tr>
<td>48*</td>
<td>8</td>
<td>7.5° (15min)</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1: Properties of Converter Transformers and corresponding pulse number

* Often built as two or more transformers connected in parallel on the HV side (see Figure 3 and Figure 4)
The main role of the converter transformers in such MV drive application is to:

- Adapt the network supply voltage to the power electronics input voltage
- Isolate the power electronics from the supply network
- Restrict short-circuit currents to the power electronics
- Relieve the motor and/or network from common mode voltages
- Reduce radio interference (EMC) from drive to the network (special screen between windings)
- Protect the MV drive from voltage transients from the feeding network
- Reduce harmonics penetration into the feeding network (transformer impedance and special multi-pulse connections)

Note that converter transformers have been manufactured for applications with rating in excess of 155MVA and are connected to the supply network of up to 400kV.

2 Diff Protection for Converter Transformers

The main problems for differential relay (i.e. 87T) application on a converter transformer are:

- How to compensate for the non-standard phase angle shift
- Cover required number of CT inputs into the differential relay

The theoretical explanation how to apply a numerical differential protection designed for standard, three-phase, power transformer onto a converter transformer is given in references [5, 6, 7]. In this paper only practical installations of a standard transformer differential protection IED, see reference [8], for converter transformer applications will be presented.

2.1 Diff Protection for 18-pulse converter transformer

Differential protection installation on the 18-pulse drive for the oil industry is given in Figure 2. Interposing CTs are used to put the converter transformer vector group to Dd0d0d0 towards the differential relay.

Due to limited space only one recording captured during the differential protection commissioning is presented in Figure 6. It is captured during primary stability test when converter transformer was supplied on the HV side from a three-phase, 400V source while the three-phase short-circuits were made outside of the protected zone on all three LV windings. The following traces captured by the differential relay are shown in this figure:

- HV delta winding CT secondary currents
- LV d(+20°) winding CT secondary currents after the interposing CT
- LV d0 winding CT secondary currents
- LV d(-20°) winding CT secondary currents after the interposing CT
- Differential and bias currents within the differential relay (note that they are given in converter transformer primary amperes on the HV side as calculated by this particular 87T relay [8])

This record clearly indicates that all three differential currents are practically equal to zero, while the bias current is high. Thus the 87T differential relay was fully stable during this test. At the same time it can be noted that phase L1 currents from all four windings are in phase. This is possible due to existence of the interposing CTs within the differential protection scheme, which insure that two LV windings with non-standard ±20° phase shift are brought in phase with the other two converter transformer windings. This ensures the stability of the standard transformer differential relay which is actually set to protect the power transformer having standard Dd0 vector group.

2.2 Diff Protection for 24-pulse converter transformer

Differential protection installation on the 24-pulse drive for the oil industry is given in Figure 3. Note that in this installation two separate transformers (i.e. T1 and T2) are used to build the converter transformer. Interposing CTs are again used to put the converter transformer overall vector group to Dd0d0 towards the differential relay.

Due to limited space only one recording captured by external disturbance recorder is presented in Figure 7. It was captured when the MV drive was fully loaded. The following traces are presented in this figure:
From this record it can be clearly seen that currents from all four LV windings are of a “square nature” and consequently reach in harmonics. However, the HV winding currents are already much closer to the “standard sine waveform shape” typically expected in the three-phase power system. Finally, the sum of the two HV winding currents will be even closer to the ideal sine shape and thus the overall harmonic content from this MV drive towards the 13,8kV supply network will be substantially reduced.

2.3 Diff Protection for 36-pulse converter transformer

Differential protection application on the 36-pulse drive is given in Figure 4. Here as well two separate transformers are used to build the converter transformer. Interposing CTs are again used to put the overall transformer vector group to Yd11y0 for the differential relay. This differential protection scheme is still not in service.

2.4 Diff Protection for a for Cyclo-Converter Drive

MV drive installation based on the cyclo-converter principle is shown in Figure 5. Such installations are typical for mine and cement industries where low speed, high-power MV drives are required. For this application standard three-winding transformers are used as converter transformers because the twelve-pulse rectifiers are used (see Table 1). Particular thing here is that there are three such transformers (i.e. one per phase) are connected in parallel on the HV side in order to provide an AC, three-phase, variable low-frequency supply to the synchronous motor.
4 Conclusion

As shown in this paper, standard numerical differential protection IED [8] can be used for the differential protection of converter transformers. The only pre-request is that interposing CTs are used to adjust the actual non-standard vector group of the protected converter transformer to the closest standard vector group as defined for the standard, three-phase, power transformers. In addition the used differential relay must be capable to handle quite a few number of three-phase CT inputs (e.g. seven).

Practical experience for such 87T applications has been good irrespective of the converter transformer pulse type and number of LV windings. Some of the presented 87T protection schemes are in full commercial operation for several years without any problems. Thus, this standardized way to provide differential protection for converter transformers has been successfully proven in practical installations.

References

[1] ABB Leaflet 1LAB 000 019, "Industrial Transformers", ABB Transformers AG, Bad Honnef, Germany

[2] ABB Leaflet 1LDE000115 12, “Transformers for variable speed drive applications” ABB Switzerland


Figure 6: Currents captured in 18-pulse drive installation during primary testing
Figure 7: Load currents captured in 24-pulse drive installation

Figure 8: Load currents captured in cyclo-converter drive installation