APPLICATION NOTE 2.2

Arc furnace transformers
Overvoltage protection
The APPLICATION NOTES (AN) are intended to be used in conjunction with the

APPLICATION GUIDELINES
Overvoltage protection
Metal-oxide surge arresters in medium-voltage systems.

Each APPLICATION NOTE gives in a concentrated form additional and more detailed information for the selection and application of MO surge arresters in general or for a specific equipment.

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Overvoltage protection of arc furnace transformers

Overvoltages due to switching and lightning phenomena require additional MO surge arresters between the phases.

1 Introduction

For general information about MO surge arresters between phases see Application Note AN 1.3.

In special cases, such as in arc furnace installations, switching overvoltages between phases can occur that are insufficiently limited by arresters between phase and earth. Two different arrangements can be used when overvoltage protection between phase-to-earth and phase-to-phase is required, the "six-arrester arrangement", see Figure 1, and the "four-arrester (Neptune) arrangement", sometimes also called "four-legged surge arrester arrangement", see Figure 2.

2 Selection of the MO surge arresters

The MO surge arresters have to be selected as described in the Application Guidelines and the Application Notes AN 1.1 and AN 1.3.

Depending on the expected stresses, electrical and environmental, and the importance of the equipment to be protected it is necessary to decide which characteristics of the MO surge arresters are most important to provide best protection. In this way the type of arrester (arrester class etc.) can be chosen from the beginning.

The examples given below guide through the principle of the selection process step by step.

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Figure 1: Six-arrester arrangement for arc furnace transformer protection.

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Figure 2: Neptune design with four arresters (A1 to A4).
APPLICATION NOTE  ARC FURNACE TRANSFORMERS

Supplied information
• Protection of an arc furnace transformer
• System voltage $U_s = 36$ kV
• High ohmic insulated star point
• Industrial environment

Without further information it is assumed
• $U_m = 36$ kV
• LIWV = 170 kV
• Medium pollution (pollution class c, required medium specific creepage 34.7 mm/kV)
• Continuous operation in case of an earth fault
• Nominal discharge current $I_n = 10$ kA
• Short circuit current of the system $I_s = 20$ kA

In such applications like protection of arc furnace transformers a high energy withstand capability has to be assumed, as well as a low protection level $U_{pl}$ of the MO surge arresters. For this reason a MO surge arrester of class SM (i.e. POLIM-S .. N) is recommended.

The same procedure, equations and assumptions are valid for transformers in delta-connection.

2.1 Six-arrester arrangement
Following the steps given in flow chart AN 1.1 A1, and the equations in AN 1.3, it follows:

Step a) Continuous operating voltage $U_c$
In this case the continuous operating voltage is $U_c \geq 1.05 \times U_s = 1.05 \times 36$ kV = 37.8 kV

Therefore, chosen is according data sheet a POLIM-S .. N with $U_c = 38$ kV

As mentioned above, for such applications a low protection level is recommended. For this reason we don’t add a 10% safety margin for the $U_c$. This would increase the protection level $U_{pl}$ by 10% as well, which is not favorable in this application.

Step b) Rated voltage $U_r$
According data sheet the rated voltage is $U_r = 47.5$ kV

Step c) Nominal discharge current $I_n$
The nominal discharge current is $I_n = 10$ kA

Step d) Charge $Q_{rs}$ and thermal rating $W_{th}$
Based on the decision for POLIM-S .. N (class SM) the
• Repetitive charge transfer rating is $Q_{rs} = 2.0$ C
• Rated thermal energy is $W_{th} = 10$ kJ/kV

Step e) Check lightning impulse protection level $U_{pl}$ and withstand voltage LIWV
Required is: $U_{pl} \leq LIWV / K_s$

With LIWV = 170 kV and $K_s = 1.15$, the maximum allowed voltage at the electrical equipment results in 147.8 kV.
The POLIM-S 38 N has an $U_{pl}$ of 114 kV and meets the demand with a good additional safety margin.

With the steps a) to e) the active part of the MO surge arrester is selected. It follows the selection of the arrester housing and confirmation of mechanical data.

Step f) Creepage distance
With the assumption of medium pollution (pollution class c with 34.7 mm/kV) we have to calculate the required creepage distance. As long as we assume continuous service in case of an earth fault we have to make the calculation based on $1.05 \times U_s$. This results in a required minimum creepage distance of $1.05 \times U_s \times 34.7 = 1312$ mm.

For insulation material like silicone the minimum required creepage distance can be reduced by 20%. This results finally in 1050 mm minimum creepage distance. The POLIM-S 38 N provides according data sheet a creepage distance of 1603 mm and meets the requirement with a good additional safety margin.

Step g) Flashover distance
The minimum necessary withstand values of the empty arrester housing are calculated according to IEC 60099-4, Ed. 3.0 as:

Lightning voltage impulse 1.2/50 µs: $1.3 \times U_{pl} = 1.3 \times 114$ kV = 149 kV

a.c. voltage test 1 min, wet: $1.06 \times U_{ps}$ (switching current impulse 1000 A => $U_{ps} = 95.7$ kV)
It follows $U_{test,pv} = 1.06 \times 95.7$ kV = 102 kV.
This results in $U_{test,pv} = 72$ kV rms, 1 min wet.

The guaranteed withstand values according data sheet are:

Lightning voltage impulse 1.2/50 µs: 359 kV
a.c. voltage test: 102 kV, rms, 1min wet: 102 kV

The housing of the POLIM-S 38 N has higher withstand values than are required by IEC.

Step h) Short circuit current $I_s$
The POLIM-S 38 N was tested with a short circuit current $I_s = 50$ kA and meets easily the assumed 20 kA.
Step i) Mechanical loads
Special requirements for mechanical loads are not given. However, the type POLIM-S 38 N provides very good mechanical withstand values, see data sheet.

It follows: the POLIM-S 38 N is the right arrester from all points of view for this application, and should be installed between the phases and the phases to earth.

2.2 Four-arrester arrangement (Neptune design)
The same provided information and the assumptions made apply for this example as well. We go with a MO surge arrester of type POLIM-S ... N.

2.2.1 Arrangement with four identical arresters

Step a) Continuous operating voltage $U_c$
According Figure 4 in AN 1.3 we calculate the continuous operating voltage to

$$U_c \geq 0.661 \times U_s = 0.661 \times 36 \text{ kV} = 23.8 \text{ kV}$$

It follows from the data sheet with the next higher value a continuous operating voltage of $U_c = 24 \text{ kV}$, and we go for a POLIM-S 24 N. We don’t add a safety margin of 10% to the $U_c$, because we have in the four arrester arrangement in all cases two arresters in series, which results in a total continuous operating voltage between the phases and phases to earth in $U_c = 48 \text{ kV}$, which is far above the system voltage of $U_s = 36 \text{ kV}$.

Step b) Rated voltage $U_r$
The rated voltage is according data sheet $U_r = 30 \text{ kV}$

Step c) Nominal discharge current $I_n$
The nominal discharge current for this type of arrester (class SM) is $I_n = 10 \text{ kA}$

Step d) Charge $Q_{rs}$ and thermal rating $W_{th}$
Based on the decision for POLIM-S ... N (class SM) the

- Repetitive charge transfer rating is $Q_{rs} = 2.0 \text{ C}$
- Rated thermal energy is $W_{th} = 10 \text{ kJ/kV}_{U_c}$

Step e) we have to check the lightning impulse protection level $U_{pl}$ vs the withstand voltage LIWV.
Required is $U_{pl} \leq LIWV / K_s$

The LIWV for the equipment to be protected remains the same. Therefore, we have to consider LIWV = 170 kV. As can be seen from the arrangement in Figure 4 in AN 1.3 we have to make the calculation with two POLIM-S 24 N in series.

This leads us to

$$U_{pl} \leq LIWV / K_s = 170 \text{ kV} / 1.15 = 148 \text{ kV}.$$ 

The two POLIM-S 24 N in series have in total a $U_{pl} = 144 \text{ kV}.$

This value meets the requirement, but provides no additional safety margin.

Step f) Creepage distance
Pollution effects and flashovers occur between the terminals of the MO surge arresters. For this reason, the creepage distance (as well as the flashover distance) has to be calculated for the single POLIM-S 24 N.
We assume pollution class c with 34.7 mm/kV. In the actual case we have to calculate with the continuous operating voltage $U_c = 24 \text{ kV}$. This leads to a minimum recommended creepage distance of $24 \text{ kV} \times 34.7 \text{ mm/kV} = 833 \text{ mm}$. With a 20% reduction due to the silicone insulation we finally come to a value of 667 mm. The POLIM-S 24 N provides a creepage distance of 983 mm and fulfills the requirement with a good margin.

Step g) Flashover distance
The minimum necessary withstand values of the empty arrester housing are calculated according to IEC 60099-4, Ed. 3.0.
Here again we concentrate on the single MO surge arrester POLIM-S 24 N, because the flashover distance and related tests refer to the individual housing, independent of the final arrangement.

Lightning voltage impulse 1.2/50 µs:
$$1.3 \times U_{pl} = 1.3 \times 72 \text{ kV} = 93.6 \text{ kV}$$

a.c. voltage test 1 min, wet:
$$1.06 \times U_{ps} = 1.06 \times 60.5 \text{ kV} = 64.13 \text{ kV}.$$ 

It follows $U_{test, pv} = 1.06 \times 60.5 \text{ kV} = 64.13 \text{ kV}$. This results in $U_{test} = 45.6 \text{ kV rms}, 1 \text{ min wet.}$

The guaranteed withstand values according data sheet are:

Lightning voltage impulse 1.2/50 µs: 239 kV
a.c. voltage test 1 min, wet: 68 kV

The housings of the POLIM-S 24 N have higher withstand values than are required by IEC.

Step h) Short circuit current $I_s$
The POLIM-S 24 N was tested with a short circuit current $I_s = 50 \text{ kA}$ and meets easily the assumed 20 kA.
Step i) Mechanical loads
Special requirements for mechanical loads are not given. However, the type POLIM-S 24 N provides very good mechanical withstand values, see data sheet.

It follows: the POLIM-S 24 N is the right arrester from all points of view for this application.

2.2.2 Arrangement with three identical MO arresters and one with lower U_c
The same provided information and the assumptions made apply for this example as well. We go with a MO surge arrester of type POLIM-S .. N.

Step a) Continuous operating voltage U_c
With the equations under chapter 3.2 in AN 1.3 for a simplified calculation of the continuous operating voltage we come to

\[ U_c \geq \frac{1.05 \times U_s}{\sqrt{3}} \]

\[ = \frac{1.05 \times 36 \text{kV}}{1.732} = 21.82 \text{kV} \]

The next higher value for the continuous operating voltage is according data sheet \( U_c = 22 \text{kV} \).

This leads us to a MO surge arrester POLIM-S 22 N for the MO surge arresters A1 to A3 between phases and neutral.

With \( U_c \geq U_{N,E} = 1.05 \times U_s \times \frac{1.05 \times U_s}{\sqrt{3}} \)

\[ = 1.05 \times 36 \text{kV} - \frac{1.05 \times 36 \text{kV}}{1.732} \]

\[ = 37.8 \text{kV} - 21.82 \text{kV} = 15.96 \text{kV} \]

With the next higher value according data sheet we come to a POLIM-S 16 N for the MO surge arrester A4 between neutral and earth.

Following the same steps a) to i) as in the above examples we get the electrical and mechanical data for the two MO surge arresters POLIM-S 22 N and POLIM-S 16 N as shown in Table 1.

In step e) we have to check the lightning impulse protection level \( U_{pl} \) vs the LIWV. The LIWV is given to 170 kV. Considering the safety factor of 15% we come to 148 kV. We have to consider now two cases, the MO surge arresters between two phases and the MO surge arresters between a phase and the earth.

Between two phases we have in any case two POLIM-S 22 N in series. In this case we have a total lightning impulse protection level of \( U_{pl} = 132 \text{kV} \), which is below the required value.

Between one phase and the earth we have in any case a POLIM-S 22 N and a POLIM-S 16 N in series, which gives a total lightning impulse protection level of \( U_{pl} = 114 \text{kV} \). This is again well below the required value of 148 kV.

It can be concluded that the MO surge arresters POLIM-S 22 N and POLIM-S 16 N fulfill all requirements for the intended application.

<table>
<thead>
<tr>
<th>Table 1: Technical data of the MO surge arresters for example 2.2.2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>POLIM-S 22 N</strong></td>
</tr>
<tr>
<td>( U_c )</td>
</tr>
<tr>
<td>( U_r )</td>
</tr>
<tr>
<td>( I_n )</td>
</tr>
<tr>
<td>( W_{th} )</td>
</tr>
<tr>
<td>( Q_{rs} )</td>
</tr>
</tbody>
</table>

| Creepage distance                                           | 642 mm                                                      | 983 mm                                                      | 465 mm                                                      | 829 mm                                                      |
| Insulation withstand 1.2/50 µs                              | 86 kV                                                       | 239 kV                                                      | 63 kV                                                       | 209 kV                                                      |
| a.c. withstand 1 min, wet                                   | 42 kV                                                       | 68 kV                                                       | 31 kV                                                       | 59 kV                                                       |
| \( I_s \)                                                   | 20 kA                                                       | 50 kA                                                       | 20 kA                                                       | 50 kA                                                       |
| Mechanical loads                                            | no special requirements                                     |                                                             |                                                             |                                                             |
3 Summary

The results of the three possible solutions are summarized in Table 2.

The four-arrester arrangement with identical arresters provides an unfavorable higher protection level $U_{pl}$ of 26% phase-to-phase and phase-to-earth compared to the six-arrester arrangement.

The four-arrester arrangement with three identical arresters and one with lower $U_c$ provides a higher protection level $U_{pl}$ of 16% phase-to-phase and the same $U_{pl}$ phase-to-earth compared to the six-arrester arrangement.

It can be concluded that regarding the overvoltage protection of the equipment the six-arrester arrangement gives the best result.

4 Overvoltage protection of the low-voltage side

For transformers with a delta-connected low-voltage winding, arresters between phases may be necessary on the low-voltage side to limit inductively transferred overvoltages. These arresters can also protect the medium-voltage side of the transformer by absorbing the magnetic energy when switching off transformers.

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Table 2: Continuous operating voltage $U_c$ and protection level $U_{pl}$ for the examples above.

<table>
<thead>
<tr>
<th>Arrester arrangement</th>
<th>six-arrester arrangement</th>
<th>four-arrester arrangement</th>
<th>four-arrester arrangement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All six arresters have identical ratings</td>
<td>All four arresters have identical ratings</td>
<td>Three arresters with identical ratings, one with lower $U_c$</td>
</tr>
<tr>
<td>Equation for $U_c$</td>
<td>$U_c \geq 1.05 \times U_s$</td>
<td>$U_c \geq 0.661 \times U_s$ (total $U_c \geq 1.322 \times U_s$)</td>
<td>$U_c \geq 1.05 \times U_s / \sqrt{3}$, L-N</td>
</tr>
<tr>
<td>Arrester type</td>
<td>POLIM-S 38 N</td>
<td>POLIM-S 24 N</td>
<td>POLIM-S 22 N, L-N, N-E</td>
</tr>
<tr>
<td>Total continuous operating voltage $U_c$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>phase-to-phase</td>
<td>38 kV</td>
<td>48 kV</td>
<td>44 kV</td>
</tr>
<tr>
<td>Total protection level $U_{pl}$ phase-to-phase</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>114 kV</td>
<td>144 kV</td>
<td>132 kV</td>
<td></td>
</tr>
<tr>
<td>Total continuous operating voltage $U_c$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>phase-to-earth</td>
<td>38 kV</td>
<td>48 kV</td>
<td>38 kV</td>
</tr>
<tr>
<td>Total protection level $U_{pl}$ phase-to-earth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>144 kV</td>
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</tbody>
</table>
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