Interface construction for the computation of the optimum installation position of metal oxide surge arresters in medium voltage substations

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Abstract: Lightning and switching overvoltages is main factor of failures in electric power systems. In order to protect the electric network and improve its lightning performance, apart from overhead ground wires, surge arresters are installed on the lines and/or the transformers. Especially, in substation the distance in between arresters and the transformer to be protected plays important role for the efficient protection of the equipment. In the current work, an interface is created for the study of the optimum placement of metal oxide surge arresters in medium voltage substations.

Key-Words: Substation; surge arresters; placement; protective zone; interface.

1. Introduction

Internal and external overvoltages are main cause of faults and interruptions in transmission and distribution electrical systems, reducing the reliability of the power network. Lightning strikes and switching actions have as a result shielding failures and backflashovers in lines and damages of critical equipment of the system, such as transformers. The protection of power systems against overvoltages consists of overhead ground wires, insulators and surge arresters. The Hellenic Public Power Corporation S.A. uses ground wires and insulators for the protection of the transmission lines and installs metal oxide surge arresters only on the substations, in order to avoid damage of the transformers. Surge arresters’ protection effectiveness depends on: the electrical characteristics of the arresters, the proximity of the stroke from the arresters, the installation position of the arrester, the system configuration and the statistical data of the lightning current waveform.

In the current work, an interface is created for the study of the optimum placement of metal oxide surge arresters in high voltage substations [1-4].

2. Surge arresters’ characteristics

Surge arresters are installed between phase and earth and lead the current of the overvoltage to the ground. In normal operation of the electric network they present high resistance (MΩ) and during overvoltages they behave like conductors. Surge arresters can be classified as gapped, which contain gap in series with SiC nonlinear resistance, and metal-oxide (MO) gapless, which are composed of ZnO nonlinear resistance. ZnO gapless surge arresters present highly nonlinearity to their voltage-current characteristic and faster response times, and they are nowadays the most used type of arresters. The basic parts of a MO surge arresters are the cylindrical metal-oxide resistor blocks, the insulating housing and the electrodes. Between the varistor column and the polymeric housing there is a glassfibre structure, that either completely encloses the resistor blocks or exerts sufficient force on the ends of the stack to hold the MO blocks firmly together.

The main electric characteristics of a ZnO surge arrester are [4-6]:

a) Continuous operating voltage: the maximum permissible rms power frequency voltage that may be applied continuously between the arrester terminals.

b) Rated voltage: the maximum permissible rms value of power frequency voltage between arrester terminals at which is designed to operate correctly under temporary overvoltages.

c) Residual voltage: the peak value of the voltage that appears between the terminals of an arrester during the passage of the discharge current through it.
d) Energy withstand capability: the maximum level of energy injected into the arrester at which it can still cool back down to its normal operating temperature.

When a lightning current strikes a phase conductor of a distribution line, an overvoltage on the line, propagated along the conductor is created, equal to \( Z_i(t) \), in case that the impact point is at the end of the line, and \( Z_i(t)/2 \), in case that the lightning strikes is in the middle of the line (\( Z \) is the wave impedance of the conductor). When the overvoltage exceeds the insulation level of the line, a lightning failure occurs.

In lines equipped with surge arresters, a part of the lightning current will pass through the arrester to the ground. The magnitude of the current through the arrester depends on the grounding resistance, the arresters installation interval and the electrical characteristics of the arresters. The remaining lightning current will travel along the line as a travelling wave and may cause overvoltages on the next pole. To prevent this, it is necessary to allow a current flow to the ground via a low impedance path, like surge arrester [7].

3. Protection zone of surge arresters

An arrester usually has a limited protective zone of only a few meters to up to several meters, where the protective zone is defined as the maximum separation distance for which the insulation coordination requirements are fulfilled for a given arrester protective level and coordination withstand voltage. Arresters therefore should be installed as close as possible to the device to be protected. Since fast-front overvoltages spread out over the line in the form of traveling waves, the voltage at the terminals of the device to be protected can be considerably higher than the residual voltage of the assigned arrester. The arrester is effective only after a time interval, which depends on the propagation rate of the traveling wave and the distance that is the propagation time between the arrester and the device to be protected. The steepness of the overvoltage has also decisive effect. Generally, the protective level and the location of the arrester must be coordinated in such a way that the coordination withstand voltage of the device to be protected is not exceeded. The protective zone of an arrester, for the simple arrangement of a transformer connected to the end of a single feeder, can be estimated with the use of the following formula:

\[
x_s = \frac{1.15 \cdot u_p}{2s} \cdot v
\]

where:
- \( x_s \) is the protective zone in m,
- \( u_w \) is the standard lightning impulse withstand voltage of the device to be protected in kV,
- \( u_p \) is the lightning impulse protective level of the arrester in kV,
- \( s \) is the front steepness of the lightning overvoltage in kV/\( \mu \)s and
- \( v \) is the propagation speed of a traveling wave in m/\( \mu \)s [6].

4. Surge arresters installation on a transformer: an example

Equipment in the 420 kV system normally has a standard lightning impulse withstand voltage of 1425 kV. This value however is not allowed to be attained in practice. The highest occurring voltage in the case of a non-self-restoring insulation in operation should stay below this value by a factor of 1.15, that is, not exceeds 1239 kV. Nevertheless, the lightning impulse protective level of 823 kV of the sample arrester seems at first to offer more than enough protection. It should be noted that this value represents a voltage across the arrester terminals, caused by the flow of an ideal standardized test current at the same level as the arrester’s nominal discharge current. A significant cause that can allow the voltage at the terminals of the equipment to be protected to take on a considerably higher value are the traveling wave processes, i.e., rapidly increasing overvoltages spread in the form of traveling waves on the line. In those places where the surge impedance of the line changes, refraction and reflection occur. Especially, a voltage wave will be totally positively reflected when reaching an unterminated end of the line. The voltage level at every instant and at every point on the line results from the sum of the different instantaneous values of each individual voltage wave. Thus, at the terminated end this value will be doubled. A connected transformer appears similar to an unterminated end since its winding inductivity for rapid functions exhibits a great resistance compared with the surge impedance.

Fig. 1 shows a surge arrester installed on the input of a transformer. An overvoltage surge with a front steepness of 1000 kV/\( \mu \)s runs towards a transformer. The propagation of such a surge on an
overhead line occurs at the speed of light (300 m/µs). It is assumed that the arrester is an ideal one, which behaves like an insulator up to a voltage level of 823 kV, while higher overvoltages are limited to exactly 823 kV. The overvoltage surge first passes by the arrester and reaches the transformer 0.1 µs later, which is the propagation time on the 30 m long stretch between the arrester and the transformer. At this time the voltage at the arrester has reached a value of 1000 kV/µs x 0.1 µs = 100 kV. Thus the arrester is still behaving like an insulator. At the transformer the arriving surge is reflected. That is why an additional voltage surge, with the same shape and polarity, runs back from there. The superimposition of both surges causes the voltage at the transformer to increase at double the speed, thus at 2000 kV/µs. Another 0.1 µs means a voltage of 200 kV. At the same time the reflected surge has reached the arrester, whose voltage up to the point in time has increased at the original rate of rise and, therefore, in the meantime, has also reached a voltage level of 200 kV. From now on the original and the reflected surges are superimposed on the arrester and the voltage increases at a steepness of 2000 kV/µs not only at the transformer, but also here. The situation at the arrester does not change until the voltage at its terminals has reached the limiting value of 823 kV. In accordance with the starting assumption a higher voltage cannot be on. According to the rules of traveling wave processes, this can only be reached if negative voltage surge with a steepness of 2000 kV/µs spreads out the both sides from the arrester. The superimposition of the original surge on that which was reflected from the transformer, and which is now again reflected from the arrester, causes the voltage at the arresters to maintain a constant value of 823 kV. Another 0.1 µs passes before the negative surge reflected from the arrester reaches the transformer. During this time, however, the voltage there has increased by 200 kV. Therefore, it already has a value of 1023 kV. Only now the arrester is noticeable at the transformer and reduces the attained voltage. The example shows that the voltage at the equipment to be protected can be considerably higher than that found at the arrester. Exactly how high is, depends mostly upon the distance between the arrester and the device to be protected, and on the front steepness of the voltage surge [6].

5. Interface creation

Fig.2 shows the configuration of a typical medium voltage substation.

MATLAB, Simulink and GUI were used, where the transmission lines were represented by a distributed parameter line model, which is based on the Bergeron’s traveling wave method [8] used by EMTP [9] and represents wave propagation phenomena and line end reflection efficiently.

The entry data of the interface, as Fig. 3 shows, are: \(L_1\) the distance between the lightning striking point and the transformer, \(L_2\) the distance between the arrester and the transformer, \(R_g\) the grounding resistance, Peak Current of the lightning, Time Crest of the lightning, Tail Time of the lightning and Protection Voltage of the arrester.

The interface has outputs: the residual voltage of the arrester, the current that passes through the arrester and the transformer’s voltage.
6. Conclusions

A useful interface has been constructed in order to compute the arrester’s voltage and current and the transformer’s voltage of a medium voltage substation in case of a lightning stroke. Inputs were the arrester’s protection voltage, the lightning current characteristics, the grounding resistance and the distances between striking point-transformer and between arrester-transformer.

References:


Vitae:

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