Determination of Transient Overvoltages in Medium Voltage Networks at Single Phase Faults

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Abstract - The paper presents the influences of the factors which determine the transient overvoltages within electric substations and also experiments carried out to determine the transient overvoltages and homopolar currents in an 110/24 kV network from Romania at net and intermittent ground of one phase the neutral being connected by transformer and compensation coil parallel with three-phase coil having commutable neutral point earthring during short-circuit test. Also the paper presents the preventive measures for limiting overvoltages in order to protect the electrical equipment in network substations.

Keywords - MV network, overvoltages, protection

I. INTRODUCTION

Sometimes, single-phase faults due to intermittent arc phase grounding occur in medium voltage networks. These single-phase short-circuits occur due to cable insulation damaging (LES) at distribution networks or to one line breakage and its contact with the ground at aerial networks.

For cable distribution networks, network insulation weakening in one point may remain even after electric has disappeared because fault voltage has a value high enough and after a certain time electric arc ignition can appear, the phenomenon repeating cyclically [1, 2, 3, 4, 5].

Intermittent arc appearance is associated to some high transient overvoltages having an important part in insulation coordination.

Internal transient overvoltages propagate themselves during the whole fault existence time, on all network branches connected to the faulty circuit and are dangerous due to their amplitude and appearance rate as well.

These considerations were checked experimentally both by simulation and by experimental tests rendering evident the maximum stresses in direct connection with fault kind and with neutral point earthing made for medium voltage networks.

Starting from the observation that the resistances entered into the oscillating circuit have an influence on overvoltage damping in order to reduce overvoltage level a resistive element was series or parallel connected to the electric arc.

In three-phase networks it was efficient to connect a resistance or an inductivity (arc suppression coil) between earth and source neutral. Both neutral point earthing modes delay or exclude voltage increase at capacitor terminals.

For networks with neutral earthed by means of a coil its tuning mode is decisive for withdrawing electric arc reignition. At aerial networks (LEA) the arc induced at the first insulation breakdown is quenching in the air due to current resonance which makes that at the fault place only active current component [2] to exist. At underground networks (LES) the arc voltage can recover after each quenching, making possible arc re-ignition when fault cause has not been removed.

II. THE INFLUENCES OF THE FACTORS WHICH DETERMINE THE TRANSIENT OVERVOLTAGES IN THE ELECTRIC SUBSTATIONS

The overvoltages occur on the unaffected phases of the network on which a monophased fault has occurred. In order to evaluate the overvoltages we will use the overvoltage factor:

\[ k = \frac{U_{\text{max}}}{U_f} = \frac{\ddot{V}_{\text{max}}}{\ddot{V}_f} \]

\[ \ddot{V}_{\text{max}} \] – peak value of the transient overvoltage on the unaffected phase;

\[ \ddot{V}_f \] – peak value of the steady state transient overvoltage on the unaffected phase.

The overvoltages amplitude, therefore the overvoltage factor is determined by the network parameters, including the earthing elements of the network.

The relationship between the overvoltages factors and the network elements is analyzed by graphic method on diagram basis traced on models with transient regime analyzers.

Next it is presented the calculation results for overvoltages coefficient on 24 kV networks with neutral treating by resistance and compensation coil in case of single-phase fault.

• In case of subnetwork with neutral earthing point through resistance, the characteristics are: capacitive current \( I_c = 139 \) A, voltage \( U = 20000 \sqrt{3} = 11560 \) V, resistance \( R = 58 \) \( \Omega \), short-circuit apparent power \( S = 200 \) MVA, line capacitance \( C_0 = 9 \) \( \mu F \). It is calculated the capacitive \( (X_C) \) and inductive \( (X_L) \) reactance, and on graphic [2] basis and ratio \( X_C / X_L = 144 \). It is obtained the value \( k_e = 2.3 \).

So, in the case of underground networks, the capacitive powers, particularly when are extensive, the treating resistance must have lower values, both for fault current limiting and for an efficient protection [2].

• In case of subnetwork with neutral earthing point through compensation coil, the characteristics are: capacitive current \( I_c = 89 \) A, voltage \( U = 11560 \) V, short-circuit apparent power \( S = 168 \) MVA, line capacitance \( C_0 = 6 \) \( \mu F \).
It is calculated the capacitive ($X_{C0}$) and inductive ($X_L$) reactance, and on graphic [2] basis and ratio $X_{C0}/X_L=157$ $k_c=f(X_{C0}/X_L)$. It is obtained the value $k_c=2.7$. A reducing of compensation coil reactance determines a decreasing of overvoltage factor.

By computing, it has been observed that the transient overvoltages produced in the medium voltage networks have lower values in the case of resistance treating than the compensation coil treating.

Analyzing the obtained data by calculating these diagrams it has been observed the following:
- the overvoltage factors, and transient overvoltages respectively are the higher so as the current limiting resistance or coil reactance are higher and vary inversely proportional to increasing of triphased short-circuit power;
- transient overvoltages depend to network type aerial (LEA) or underground (LES) and its stretch;
- the way of treating of the network neutral with resistance, compensation coil or mixed influences the transient overvoltage limiting.

III. EXPERIMENTS TO DETERMINE TRANSIENT OVERVOLTAGES AT SINGLE-PHASE FAULTS

To determine transient overvoltage level at an intermittent grounding of one-phase experiments were carried out in an 110kV/24kV network from Romania [7,8] (Figure 1).

The experiments has been performed on a network with neutral point earthing through resistance (method 1), compensation coil (method 2) (Figure 2) and mixed (method 3) (Figure 3).

In a first stage experiments in the MV network neutral were compensated with compensation coil BS (method 2) and transformer and compensation coil parallel with three-phase coil having commutable neutral point earthing (BS+TS+BS) parallel BPNC (method 3).

At tests from 110kV/20kV station were measured and recorded: applied voltages, connecting and disconnecting transient overvoltages, homopolar current and network voltage reference using a numeric measuring system (Figure 1), composed of: current transformer, capacitive dividers, galvanic insulators, Notebook computer with data acquisition card type National Instruments.

In the first stage on an LEA/LES section a phase T was grounded by means of a short-circuit device at one of the LEA suspension towers (LEA - overload line, LES - cable line, LEA+LES - hybrid line) [7].

In the second stage the intermittent grounding was carried out by means of a 0.1mm fuse connected on a 24kV fusible holder [7].

In the third stage on an LEA section a phase T was grounded (broke phase simulation) by means of a cable of 20m length.

For all duties LEA/LES was:
- overcompensated by 10%
- resonance compensated
- undercompensated by 10%.

In all three cases compensation was performed by means of transformer and compensation coil (BS method 2) and compensation coil parallel with three-phase coil having commutable neutral point earthing (TS+BS) parallel BPNC (method 3).

Tests consisted of (LEA+LES) connecting operations with 24kV/1250A minimum-oil circuit-breaker (4I, 5I), followed of 24kV/1250A Sf6 circuit breaker (3I) connecting on BPNC neutral during the grounding fault and disconnecting operations of (LEA+LES) performed with minimum-oil 24kV/1250A circuit-breaker (Figure 3).

Connection and disconnection operations were performed by means of a small oil circuit breaker synchronously controlled from an automatic programmer.

The tests consisted of three disconnections watching the reference voltage applied to the network, (at $0, 45^\circ, 90^\circ$) recording the applied voltages, recovery voltages, transient overvoltages and fault currents.

The data obtained are shown in Table 1 [2, 3, 4, 6, 7].

For mixed networks (LEA + LES) the capacitive current was 75A and the fault current was 327A; for subterranean networks (LES) the fault current was 400 A (see oscillogram from Figure 5).

Over experimental results obtained by treating the neutral of Romanian network with transformer and compensation coil and compensation coil parallel with three-phase coil having commutable neutral point earthing and resistor are presented in Table 1.
Figure 1 – 110 kV/20 kV Electrical Substation

Figure 2 – Test circuit for method 2

- $I_1$ - circuit-breaker 24kV/630A
- $S_r$ - switching disconnector
- $TC$ - voltage transformer
- $TT_i$ - current transformer
- $TS$ - lightning arresters
- $BS_i$ - power transformer
- $BS_1$ - arc suppression coil
- $Du$ - voltage divider
- $O$ - oscillograph or data acquisition system
- $CLP$ - earthing switches
Figure 3 – Test circuit for method 3

- Capacitive divider: 24 kV/40V; 366.6 pF/0.2 µF
- Coaxial cable: $Z = 75 \, \Omega; L = 50 \, m$
- Hewlett Packard amplifier: $k_A = x_2; f=1MHz$
- Galvanic insulator: 1.5 kV; 10 kHz
- Notebook computer equipped with data acquisition card

Figure 4 – Transient overvoltages measuring and recording diagram using numeric system.
TABLE 1

<table>
<thead>
<tr>
<th>Neutral pointing earthing mode</th>
<th>Single-phase fault</th>
<th>Overvoltage factor $[k_e]$</th>
<th>Network type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Resistor method (1)</td>
<td>BS method (2)</td>
</tr>
<tr>
<td>Over-compensated coil by 10%</td>
<td>net earthing</td>
<td>-</td>
<td>2.81</td>
</tr>
<tr>
<td></td>
<td>intermittent</td>
<td></td>
<td>2.83</td>
</tr>
<tr>
<td>Resonance compensated coil</td>
<td>net earthing</td>
<td>-</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>intermittent broke</td>
<td>-</td>
<td>3.15</td>
</tr>
<tr>
<td></td>
<td>phase</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Under-compensated by 10%</td>
<td>net earthing</td>
<td>-</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>intermittent</td>
<td></td>
<td>2.88</td>
</tr>
<tr>
<td>Resistor</td>
<td>connected</td>
<td>2.25</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>broke phase</td>
<td>1.95</td>
<td>-</td>
</tr>
</tbody>
</table>

IV. CONCLUSIONS

A. Conclusions on the experiments

1) For network (LEA and LES) with neutral earthing point through compensation group (TS+BS) and group (TS+BS) parallel BPNC it results:
   - transient overvoltages experimental determined are greater than the theoretical determined ones, because of the simplified hypothesis of the network model;
   - dielectric stress are greater on unaffected phase for net and earthed phase short-circuit and on affected phase for intermittent short-circuit;
   - it is possible to open poli-phased faults in other points of the network.

2) For network (LEA and LES) with neutral point earthing through a compensation coil parallel connected with the neutral point three phase coil (TS+BS) parallel BPNC result:
   - operating with the neutral point earthed through the compensation coil, at a simple grounding a high percentage of these faults disappear and therefore line disconnection is no more necessary, this being a great advantage taking into account the occurrence frequency of these faults;
     - if the fault does not disappear within about 0.6 s in parallel with BS it is connected BPNC which cause earthing current rise and faultless phase voltage decrease. This leads to a decrease of the probability that the simple earthing to become a double earthing;
     - earthing current rise enables faulty line rapid determination by means of current homopolar protection allowing selective disconnection of the faulty line in a very short while (Figure 6);
     - for a fault like a conductor interrupted and fallen down to the ground the current through BPNC is higher than the homopolar current of the faulty line. Therefore controlling this current such a fault can be found even at transfer resistances to the fault place of hundreds of ohms;
     - from the price viewpoint this neutral point earthing mode is cheaper than the one when the group BPNC+R is parallel connected to the compensation coil. On the other hand this solution is more reliable because a circuit element, namely the resistor, is removed.
3) For network (LES) with neutral point earthing treating through resistance, it results a transient overvoltage lower with 10-20 %.

B. Conclusions after experiments and calculation

Overvoltages determined by calculation were close to the experimental ones, like bellow:
- for network with neutral point earthing through compensation coil, the calculated factor was $k_c=2.7$ and the experimental one was $k_e=2.81$.
- for network with neutral point earthing through resistance the calculated factor was $k_c=2.3$ and the experimental one was $k_e=2.25$.

C. Conclusions on preventive measures of overvoltages limiting and selective protection

It is necessary to mount metal-oxide (ZnO) varistors and to co-ordinate the level of overvoltages of electric equipment from network station.

It is necessary to introduce a new protection system to control homopolar current that desynchronize the functional phases.

V. REFERENCES