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NEUTRAL VOLTAGE AND CURRENT DEPENDENCY ON FAULT IMPEDANCE VALUE IN MEDIUM VOLTAGE NETWORKS

Franković, D.; Marušić, A.

Abstract: *Medium voltage (MV) networks, by their nature, are located between transmission lines and distribution - low voltage lines. Typically, MV networks were held unearthed i.e. isolated due to the superiority of isolated networks in terms of availability. Nevertheless, with the increase of underground cables share in the overall MV network's length, the capacitive earth-fault currents exceed permissive thresholds imposed by national regulations, therefore earthing of networks becomes imperative. Measurement of neutral to earth voltage and neutral current is of crucial importance for correct relay protection operation during transient and stable earth-faults. Special attention will be given to the neutral to earth voltage dependence on fault impedance value.*

Key words: *fault impedance, neutral voltage, earthing, medium voltage networks*

1. INTRODUCTION

Medium voltage networks, located between transmission lines and customers at low voltage, need to be as available as possible and as simple as possible to maintain. A vast number of public utilities adopted the concept of isolated network operation i.e. the neutral points of all transformers and eventual generators were held isolated from earth. Measurement of neutral voltage and current is of vital importance for correct relay protection operation. Along with the rise of neutral to earth voltage due to ground capacitance unbalance of the sound network (Nahman, 1980), rise of the neutral to earth voltage can be the consequence of high voltage (HV) system unbalance, Therefore, neutral to earth voltage can rise from zero value to a considerable value (Leitloff et al. 1994). In this paper accent will be given to isolated networks i.e. neutral voltage dependency on different, normal operation, conditions as well as fault conditions. Special attention will be given to neutral to earth voltage dependence on fault impedance value.

2. ISOLATED NETWORKS

Isolated networks have no intentional connection with earth, i.e. all neutral points of all transformers or generators are isolated from earth, see Fig. 1. Single phase faults are by far the most frequent type of faults on overhead lines (Hanninen, 2001). Isolated networks are "immune" to such faults and continuity of operation is maintained.

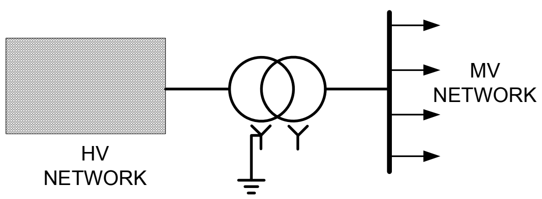

Fig. 1. Medium voltage network with isolated neutral point

2.1 Neutral voltage in normal operation

Neutral voltage of MV isolated network strongly depends on the network structure i.e. the share of overhead lines due to their ground capacitance phase unbalance. The magnitude and phase of neutral voltage can be calculated through the general expression (Nahman, 1980):

$$\overline{V}_N = -\frac{\sum_{i=1}^{3} \overline{Y}_i \overline{E}_i}{\sum_{i=1}^{3} \overline{Y}_i + \overline{Y}_n} \quad (1)$$

With:

$\overline{E}_i$ - phasor of steady state voltage,

$\overline{Y}_i$ - phase shunt admittance,

$\overline{Y}_n$ - admittance connected in neutral point.

The expression (1) can be alternatively formulated as:

$$\overline{V}_N = \overline{K}_e \cdot \overline{V}_{in} \quad (2)$$

Where:

$$\overline{V}_{iN} = \frac{\sum_{i=1}^{3} \overline{Y}_i \overline{E}_i}{\sum_{i=1}^{3} \overline{Y}_i} \quad (3)$$

$$\overline{K}_e = \frac{\sum_{i=1}^{3} \overline{Y}_i}{\sum_{i=1}^{3} \overline{Y}_i + \overline{Y}_n} \quad (4)$$

The term K_e accounts for the earthing method adopted, and for isolated networks K_e equals 1. Neutral voltage dependence on voltage magnitude and phase unbalance, on transformer's HV side, is depicted in Fig. 2 and Fig. 3. respectively.

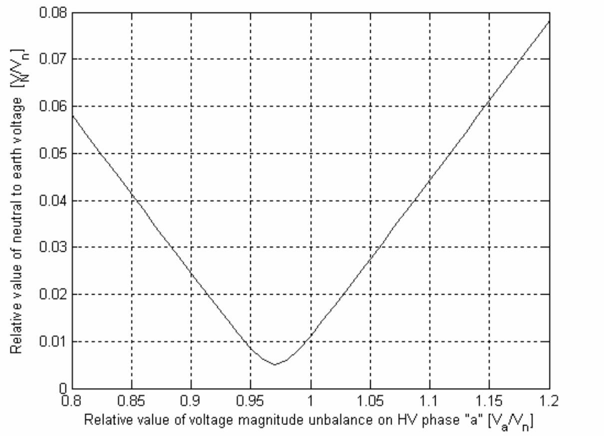

Fig. 2. Neutral voltage dependence on HV magnitude unbalance

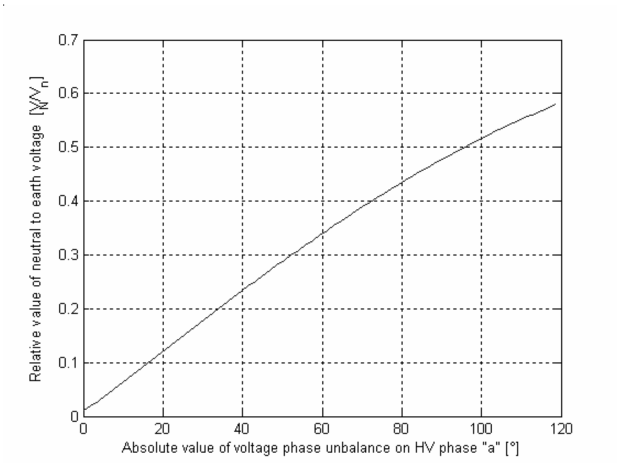

Fig. 3. Neutral voltage dependence on HV phase unbalance

2.2 Earth-fault current value

The value of the earth-fault current does not depend on fault location and is determined solely by the overall galvanically connected MV network's earth capacitance and leakage. The earth-fault current consists of a relatively large capacitive component I_c and a relatively small active component I_g (Druml et al., 2001). The value of the earth-fault current is determined by the general equation (Anderson, 1995):

$$\overline{I}_f = \frac{3 \cdot \overline{V}_n}{2 \cdot \overline{Z}_\alpha + \overline{Z}_0} \tag{5}$$

With:
$\overline{V}_n$ - phasor of steady state phase voltage,
$\overline{Z}_\alpha$ - equivalent impedance of the α-sequence system,
$\overline{Z}_0$ - equivalent impedance of the 0-sequence system.
Neglecting small terms of equation (5) and following further simplification, equation (5) yields:

$$\overline{I}_f = 3 \cdot \overline{V}_n \left(G_0 + j\omega \cdot C_0\right) \tag{6}$$

With:
G_0- earth leakage per phase,
C_0- earth capacitance per phase,
ω- angular frequency.
The earth-fault current alters in accordance to the value of fault impedance at fault location. Therefore equation (5) must account for the value of fault impedance and changes to:

$$\overline{I}_f = \frac{3 \cdot \overline{V}_n}{2 \cdot \overline{Z}_\alpha + \overline{Z}_0 + 3 \cdot R_f} \tag{7}$$

Following the same approximations and simplifications, along with further simplifications for high impedance faults ($R_f \geq 50\text{k}\Omega$), equation (7) simplifies to:

$$\overline{I}_f = \frac{\overline{V}_n}{R_f} \tag{8}$$

Low-ohmic faults are characterized by a fault impedance of a few ohms at fault location. Therefore, equation (7) for low-ohmic faults reduces to:

$$\overline{I}_f = 3 \cdot \overline{V}_n \cdot \omega \cdot C_0 \cdot \left(3 \cdot R_f \cdot \omega \cdot C_0 + j \cdot 1\right) \tag{9}$$

On basis of the afore-mentioned, high-ohmic faults are typically of ohmic type, while low-ohmic faults are characterized by a clear distinction of active and capacitive component within fault current. Which of the two components will be higher depends on the value of fault impedance and the value of network's earth capacitance.

2.3 Neutral voltage during earth-fault

The neutral to earth voltage of the MV winding of the HV/MV transformer strongly depends on the fault impedance at the fault location, and is defined by (Hanninen, 2001):

$$\frac{\left|\overline{V}_N\right|}{\left|\overline{V}_n\right|} = \frac{1}{\sqrt{1 + (3\omega C_0 R_f)^2}} \tag{10}$$

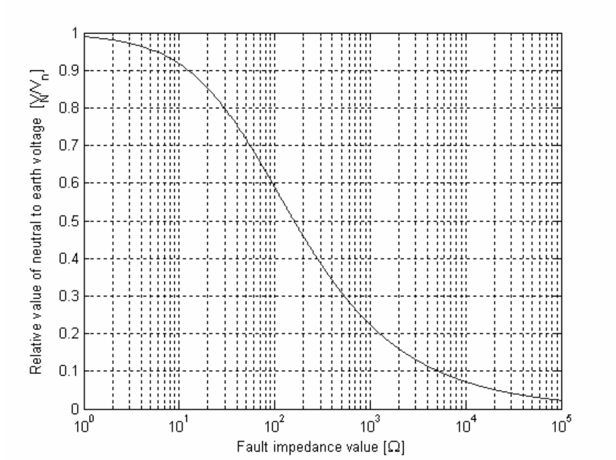

Fig. 4. Neutral voltage dependence on fault impedance value

According to Fig. 4., the absolute value of voltage at the neutral point of the main HV/MV transformer can be used as clear indication of earth-fault conditions if the value of fault impedance lies between 0Ω and approximately 1200Ω. For larger values of fault impedance the relay protection cannot, with reliability, distinguish earth-fault conditions from normal operating conditions.

3. CONCLUSION

In this paper isolated MV networks have been analyzed, especially, dependency of neutral to earth voltage, at the main HV/MV transformer, on voltage magnitude and phase unbalance at HV side. On basis of the general expression for fault current calculation, equations for high and low-ohmic faults have been derived. Further more, dependency of neutral point voltage on the value of fault impedance at fault location has been presented.
Further research shall be focused on capacitance and leakage unbalance influence on neutral point voltage and the possibility to distinguish normal operation unbalances from high-ohmic fault conditions.

4. REFERENCES

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