# Determination of the Value of the Capacitive Earth-Fault Current in Distribution Networks Operated with Isolated Neutral Point

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*Abstract* — **The new indirect method of measurement and calculation of the phase-earth capacity in networks with isolated neutral point is based on creation of a short-term phase capacity asymmetry in the network. The value of the phase earth capacity in the network can be determined using the voltage ratio in the network and the capacity value of the connected capacitor. When expanded, the method can be also used for the leakage current estimation. Furthermore, this method can be applied to periodic controls of the earth capacitive current value. For the evaluation of the phase earth capacity, a single-purpose automation can be used and thus the whole process of measurement and evaluation is conducted at a defined period (at a given hour, day, month…) or on operator's command.**

*Keywords — isolated neutral point, capacitive earth-fault current, measuring and calculation of phase earth capacity value*

## I. INTRODUCTION

In distribution networks operated with isolated neutral point the capacitive earth-fault current flows through the point of fault in case of a single-phase-to-earth fault. The magnitude of the current depends on the used type of line and scope of network. There are many reasons for determining values of the capacitive earth-fault current. One of the most important reasons is the distribution networks operation safety. During a single phase earth fault, it is necessary to adhere to the allowed values of the touch voltage.

Safety was one of the main reasons which lie behind this research to find an easy and easily applicable method for determination of the capacitive earth-fault current in distribution networks with isolated neutral point. Another reason was a frequently submitted request of the network operator for a change in the manner of the neutral point earthing when the operator requested conversion to networks with the capacitive earth-fault currents compensation. To comply with the aforementioned request, it was necessary to determine the required capacity of the arc-suppression coil. So far, the measurement of the capacitive earth-fault current has been executed by the creation of an artificial earth connection. This, however, has brought the risk of the occurrence of a multi-phase earth fault.

## II. CALCULATION BASED ON THE NODE-VOLTAGE ANALYSIS

For the verification purpose of the artificial increase of the phase-to-earth capacitive asymmetry to determine the value of the capacitive earth-fault current, first the node-voltage analysis was applied. For the calculation, a simple circuit which is provided in Fig. 1 was used.

The leakage admittances can be described by the equation using the average admittance and the deviation from the average value.

$$\vec{Y}_i = G_i + j\omega C_i \tag{1}$$

$$\vec{Y}_i = \vec{Y} + \Delta\vec{Y}_i = G + j\omega C + \Delta G_i + \Delta j\omega C_i \tag{2}$$

In the network with isolated neutral point, the sum of currents flowing through the shunt admittances was expressed using the node-voltage analysis.

$$E(\vec{Y}_1 + \vec{a}\vec{Y}_2 + \vec{a}^2\vec{Y}_3) = \vec{U}_0(\vec{Y}_1 + \vec{Y}_2 + \vec{Y}_3) \tag{3}$$

Where

E refers to the phase voltage value

$U_0$ refers to the network node-to-earth voltage

Y refers to the network phase shunt admittance

a, $a^2$ refers to the complex operator

$$\vec{a} = -\frac{1}{2} + j\frac{\sqrt{3}}{2} \qquad \vec{a}^2 = -\frac{1}{2} - j\frac{\sqrt{3}}{2}$$

In addition, the shunt admittance description based on the equation (2) in the equation (3) was substituted to express the voltage zero-sequence component.

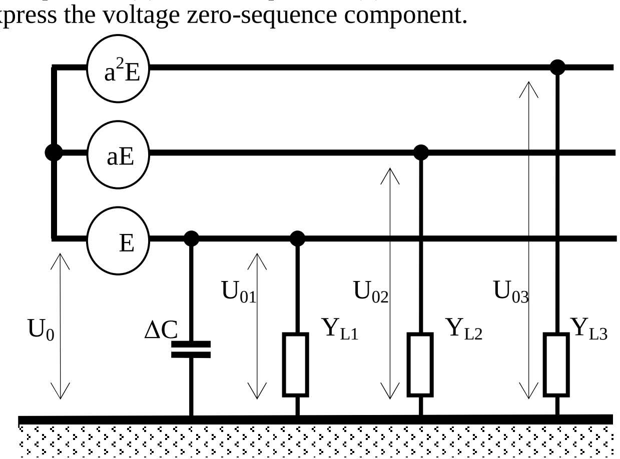


Fig. 1.: Simple circuit for the calculation

Next, the equation (4) based on the equations expressing the sum of the complex operators (5) and on condition that the sum of all deviations from the average value is zero equation (6) was solved.

$$\vec{U}_0 = E\frac{(\Delta\vec{Y}_1+\vec{a}\Delta\vec{Y}_2+\vec{a}^2\Delta\vec{Y}_3)}{3\vec{Y}+\Delta\vec{Y}_1+\Delta\vec{Y}_2+\Delta\vec{Y}_3}$$

$$\vec{U}_0 = E\frac{\vec{Y}(1+\vec{a}+\vec{a}^2)+(\Delta\vec{Y}_1+\vec{a}\Delta\vec{Y}_2+\vec{a}^2\Delta\vec{Y}_3)}{3\vec{Y}+\Delta\vec{Y}_1+\Delta\vec{Y}_2+\Delta\vec{Y}_3} \quad (4)$$

$$1+\vec{a}+\vec{a}^2=0 \quad (5)$$

$$\Delta Y_1+\Delta Y_2+\Delta Y_3=0 \quad (6)$$

The equation (4) can be further reduced based on the aforementioned conditions.

The networks operated in our region are relatively symmetric. The deviation of the phase-to-earth capacities is usually, in particular in the case of three-phase cable lines, lower than 0.2 % of the network total phase-to-earth capacity. We can neglect the deviation for the calculation purpose and the equation (7) will have approximately zero value of the voltage zero-sequence component. If we create a significant phase-to-earth capacity in the network by connecting some capacity between one of the phases and earth, the voltage zero-sequence component will increase. The increase of the residual voltage value induces change of the voltage values and change in the vector rotation of phase voltages in the network (Fig. 2).

$$\vec{U}_0 = E\frac{(\Delta\vec{Y}_1+a\Delta\vec{Y}_2+a^2\Delta\vec{Y}_3)}{3\vec{Y}} \quad (7)$$

The previous equation (7) can be solved by neglecting the leakage in the equation (2) and by adding ΔC phase-to-earth capacity to $L_1$ phase. The value of the leakage is negligible compared to the phase-to-earth susceptance and usually equals a few percent.

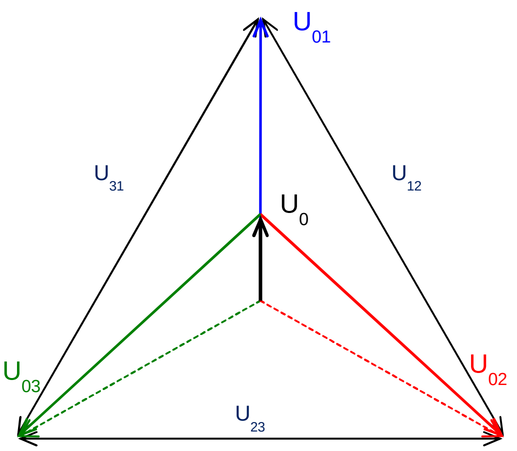


Fig. 2 The vectors of phase voltage and the zero voltage vector

The average value of the shunt admittance can be expressed as follows:

$$\bar{Y} = j\omega C + \frac{j\omega\Delta C}{3}$$

$$\Delta\vec{Y}_1 = \vec{Y} + j\omega\Delta C - \bar{Y}$$

$$\Delta\vec{Y}_1 = \vec{Y} + j\omega\Delta C - \vec{Y} - \frac{j\omega\Delta C}{3} = +\frac{2j\omega\Delta C}{3}$$

$$\Delta\vec{Y}_2 = \vec{Y} - \bar{Y} = \vec{Y} - \vec{Y} - \frac{j\omega\Delta C}{3} = -\frac{j\omega\Delta C}{3}$$

$$\Delta\vec{Y}_3 = \vec{Y} - \bar{Y} = \vec{Y} - \vec{Y} - \frac{j\omega\Delta C}{3} = -\frac{j\omega\Delta C}{3} \quad (8)$$

The equation (8) can be substituted for the equation (4).

$$\vec{U}_0 = E\frac{\frac{2j\omega\Delta C}{3} - a\frac{j\omega\Delta C}{3} - a^2\frac{j\omega\Delta C}{3}}{3\bar{Y} + j\omega\Delta C}$$

$$\vec{U}_0 = E\frac{j\omega\Delta C}{3\bar{Y} + j\omega\Delta C} \quad (9)$$

Now the shunt admittance Y is expressed as

$$\vec{Y} = \frac{j\omega\Delta C}{3}\left(\frac{E}{U_0}-1\right) \quad (10)$$

The equation (10) can be broken down to get the following form:

$$j\omega C_0 = \frac{j\omega\Delta C}{3}\left(\frac{E}{U_0}-1\right)$$

$$C_0 = \frac{\Delta C}{3}\left(\frac{E}{U_0}-1\right) \quad (11)$$

Based on a trivial derivation it is obvious that this analysis can be applied to determine the value of the capacitive earth-fault currents in networks with isolated neutral point. This analysis has already been applied and verified in practice several times. For practical application it is important to determine the magnitude of the connected capacity ΔC. It is important that a measurable change in the magnitude of the voltage zero-sequence component occurred after the connection of the test capacity ΔC. The most accurate results are obtained if the value of the phase earth capacity of the network is higher than 0.2 times the amount of the connected test capacity ΔC up to the value of 8 times the amount of ΔC. In practice, the capacitive earth-fault currents in 6 kV networks are most frequently determined using the connected capacity ΔC = 2 μF. The measured values of the capacitive earth-fault currents ranged between 1.3 A to 50 A.

Within the framework of application in practice, there were networks where it was not possible to measure the voltage zero-sequence component with sufficient accuracy or where the existing connection of the voltage transformer prevented measurement thereof. In the course of the measurement processing it was then impossible to substitute the value of the voltage zero-sequence component $U_0$. For this reason, the equation (11) was modified to allow the substitution of the phase voltage values. For easier application of this method, the necessary software was created, which is based on the situation of the phase voltages prior to and after the additional capacity connection. From the change in the voltages it is possible to calculate the value of phase earth capacity of the network, including approximate determination of the network leakage current value.

This method has extended the possibilities of determination of the capacitive earth-fault current value in networks with isolated neutral point. This method is an indirect method when it is not necessary to create an artificial phase-to-earth connection. With simultaneous measurements of all three phases, e.g. using the transient network analyzer, even a short-time measurement period is sufficient. Usually a connection of the additional capacity for a few seconds is enough. Satisfactory results were also obtained under standard operation when the measured voltages were read from the commonly available portable voltmeter with gradual measurements of voltage in individual phases on the secondary sides of voltage transformers.

After the installation of the automatic measurement system or after the implementation of the method in the control system, it is possible to execute the entire process of measurement of the capacitive earth-fault current automatically. This enables periodic monitoring of the value of the capacitive earth-fault current in networks with isolated neutral point. The automatic processing of the measured data brings a higher accuracy and speed of the measurement. In addition, the automatic measurement system enables to assess the magnitude of the leakage current in the network. Detection of a higher value of the leakage current in the network can alert us to an impaired insulating capacity of the network in a timely manner. The entire system can therefore contribute to the improvement of safety of the operation of the network with isolated neutral point.

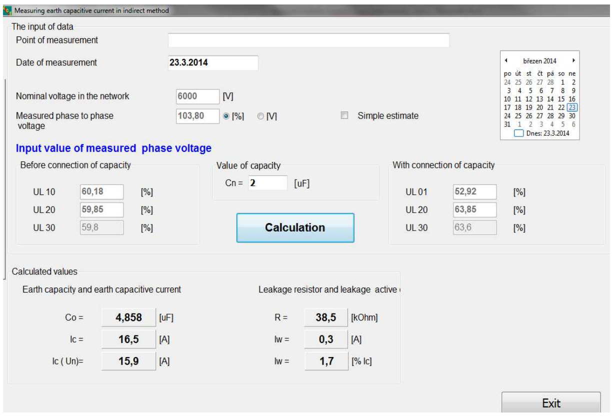


Fig. 3 An example of calculation screen in the software for the indirect method.

## III. Conclusions

This article has been written based on own knowledge and long-time experience acquired by the processing of measurements in the distribution network. These measurements and the conclusions resulting from them are included in the measurement reports and are not publicly available. The described method has been verified in real operation and based on the results, a special-purpose automatic system for the measurement of the capacitive earth-fault current in a network with isolated neutral point has been developed.

## Acknowledgment

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## References

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