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# STUDY ON THE PROTECTION TO EARTHINGS IN HIGH VOLTAGE INSTALLATIONS WITH GROUND-ISOLATED NEUTRAL POINT

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**ABSTRACT.** In high voltage electrical networks which operate with ground-isolated neutral point the state of the insulation resistance to earth has to be permanently tested because of the following reasons: i) Single-pole earthings do not lead to short-circuits so that they will not be disconnected from the protections using over relays from the rigging of high voltage cells; ii) Single-pole earthings as well as phases insulation faults to earth lead to the occurrence of leakage currents (sneak currents) which may lead to spontaneous detonation of electrical detonators which can cause electrocutions, fires and explosions that often have catastrophic effects. The paperwork presents the methods for insulation resistance testing and the means of protection to earthings in high power electrical networks.

**Key words:** insulation resistance, high voltage, protection to earthings, zero-sequence component.

### ИЗСЛЕДВАНЕ НА ЗАЩИТА ОТ ЗАЗЕМЯВАНЕ ПРИ СЪОРЪЖЕНИЯ С ВИСОКО НАПРЕЖЕНИЕ ЧРЕЗ ЗАЗЕМЕНА НЕУТРАЛНА ТОЧКА

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РЕЗЮМЕ: При електрически мрежи с високо напрежение, които работят чрез заземени неутрални точки, състоянието на изолационното съпротивление трябва да се проверява периодично поради следните причини: 1) заземяването в една точка не води до къси съединения , така че то няма да доведе до изключването му от защитите, когато се използват максимални релета при монтирането на клетки с високо напрежение; 2) заземяването в една точка, както и фазовото съединение към земята, водят до появата на токови загуби от утечки, които от своя страна могат да доведат до спонтанни детонации на електрическите детонатори , което може да породи токов удар, пожар или експлозия с често катастрофални последствия. Докладът разглежда методите за тестване на изолационното съпротивление и начините за защита на заземяването в електрически мрежи с високо напрежение.

**Ключови думи:** изолационно съпротивление, високо нпарежение, защита на заземяването, компонент с нулева последователност

## Introduction

In high voltage electrical networks there has to exist a permanent control of the insulation resistance state, as well as a protection to earthing. In high voltage electrical networks this thing is achieved based on two principles:
- The asymmetry of phase voltages
- The occurrence of voltage and current zero-sequence components.

## Asymmetry of phase voltages

The asymmetries of phase voltages represent an indicator of insulation faults as well as of earthings.

By using three voltage over-relays (U>) which permanently control the phase voltage, the following protection scheme presented in Figure 1 is achieved.

The voltage over relays U > are supplied from the secondary of the measurement transformer. The three relays control the phase voltage of the three-phase system.

The normally open contacts of the voltage over-relays are parallel connected. In the absence of insulation faults or of earthings, the three-phase voltage system is symmetric and balanced and the protection does not operate. In case of a fault or of an earthing, the three-phase voltage system unbalances and the voltage over relay (or relays) will action, and the disconnecting command of the general switch G.S. will be transmitted, command which removes the network from the voltage supply.

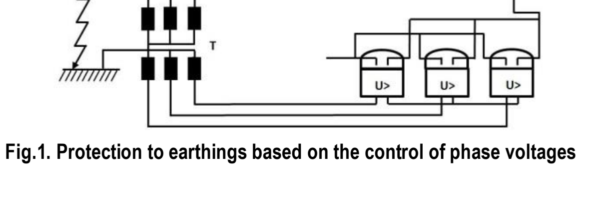



**Fig.1. Protection to earthings based on the control of phase voltages**

If one of the phases is earthed, the voltage on that phase will be zero, on the other two damaged phases the voltage will increase $\sqrt{3}$ times, the voltage over relays disconnect the G.S. which removes the network from the voltage supply.

The voltage transformer T is not an ordinary transformer because in case of a single pole earthing, like the one presented in Figure 1, the magnetic flow from the undamaged phases will induce an electromotive voltage in the short connected circuit, this one will generate very high currents which through thermal and electro dynamical effects may destroy the transformer T.

$$e = -\frac{d\phi}{dt} \qquad \phi = \frac{F}{\Re} \tag{1}$$

## Occurrence of voltage and current zero-sequence components

At the occurrence of insulation faults or of earthings, the three-phase voltages and currents network becomes asymmetric. It is known that every voltage or current asymmetric regime can be decomposed in three components:
- The positive sequence component;
- The negative sequence component;
- The zero-sequence component.

The zero-sequence component of the voltage is given by the following equation:

$$\vec{U}_0 = \frac{\vec{U}_1 + \vec{U}_2 + \vec{U}_3}{3} \tag{2}$$

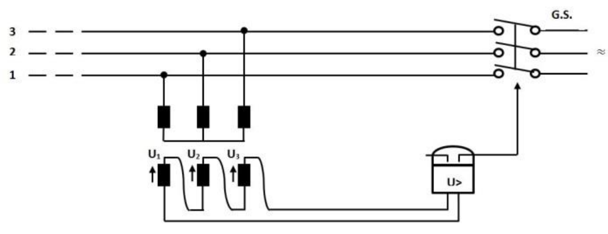
The zero-sequence component of the current is given by the following equation:

$$\vec{I}_0 = \frac{\vec{I}_1 + \vec{I}_2 + \vec{I}_3}{3} \tag{3}$$

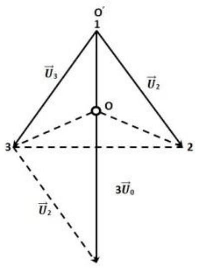
In the absence of insulation faults or of earthings, the zero-sequence voltage or current components are null. At the occurrence of insulation faults, the zero-sequence components of the voltage and of the current will be non-zero. Based on the occurrence of zero-sequence voltage components the following protection scheme (Figure 2) can be achieved:

The three secondaries of the transformer T are serial connected. In this way the voltage over-relay (U >) controls a voltage which is proportional with the value of the zero-sequence component ($U_0$) of the voltage. In operating conditions, so in the absence of insulation faults or earthings, the zero-sequence component of the voltage is null and the protection does not operate.

In case of the occurrence of an insulation fault or of an earthing, the zero-sequence component of the voltage ($U_0$) will be non-zero and through its normally open contact which closes, it transmits the disconnection command of the general switch G.S. which removes the network from the voltage supply.




a)




b)

**Fig.2. Protection to earthings based on the zero-sequence voltage component**

If one phase of the three-phase system is earthed, the zero-sequence component of the voltage becomes equal to the phase voltage, as observed from the following vector diagram (Figure 3) and from the related geometrical demonstration:

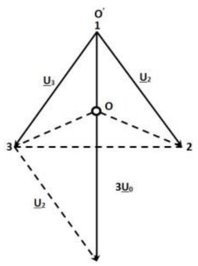
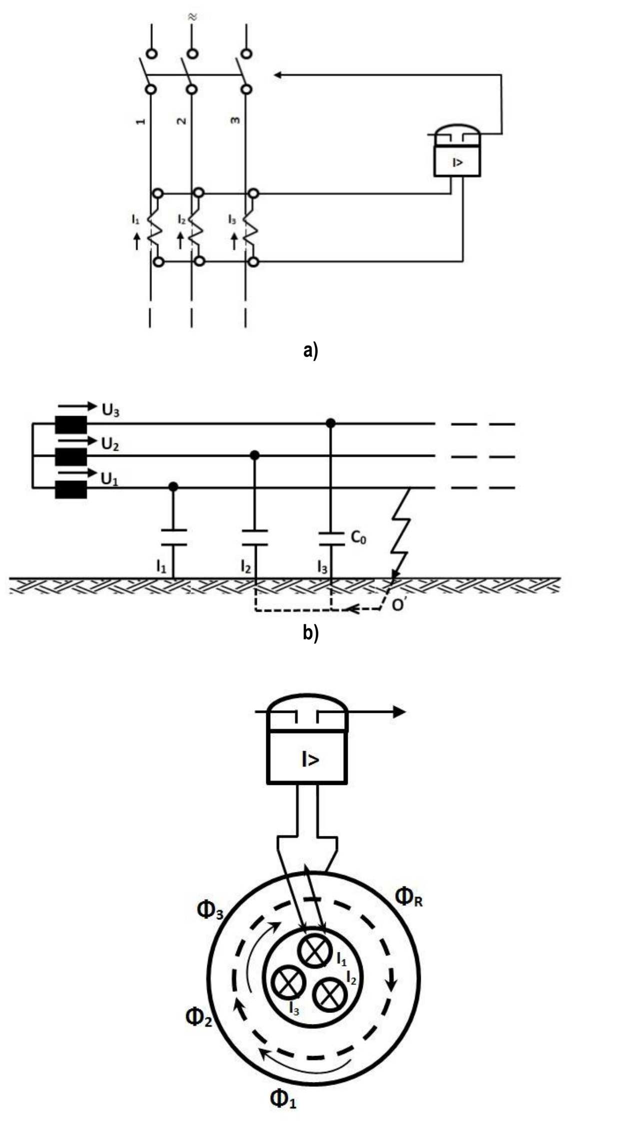



**Fig.3. Vector diagram (Zero-sequence component of the voltage equal to the phase voltage)**

For example, if phase 1 of the system is earthed, the neutral point of the system moves to point 1. In this way the voltages on the undamaged phases ($U_2$, $U_3$) increase $\sqrt{3}$ times and become line voltages. Equation 2 turns into:

$$\begin{aligned}
\vec{U}_0 &= \frac{\vec{U}_2 + \vec{U}_3}{3} \\
3 \cdot \vec{U}_0 &= \vec{U}_2 + \vec{U}_3 \\
3 \cdot U_0 &= 2 \cdot U_l \cdot \cos 30^\circ = 2 \cdot \sqrt{3} \cdot U_f \cdot \frac{\sqrt{3}}{2} = 3 \cdot U_f \\
U_0 &= U_f
\end{aligned} \tag{4}$$

There exist protection schemes which are based on the occurrence of the zero-sequence component of the currents. Such a scheme is presented in Figure 4 a:




c)

**Fig.4. Protection to earthing based on the zero-sequence component of currents**

The scheme uses three current transformers, and from their secondary the coil of the current over-relay I > is being supplied. The following notations are performed: $I_1$, $I_2$, $I_3$ represent the values of the currents that circulate through the secondaries of the current transformers. According to Kirchhoff's first law, through the coil of the current over-relay (I >) circulates a current which is proportional with the value of the zero-sequence component of the current $I_0$.

In the absence of insulation faults or of earthings, the zero-sequence component of the current is null and does not operate. When an insulation fault or an earthing occurs, the zero-sequence component of the current becomes non-zero $I_0 \neq 0$, the current over-relay I > will power up and through the normally open contact which closes, it sends the disconnection command of the G.S. which removes the network in which the insulation fault occurred from voltage supply.

Basically, based on this principle there are achieved relays for controlling the insulation resistances and for protection to earthings, relays that use a toroidal transformers which in the specialized literature is named Ferranti transformer. The basic diagram is presented in Figure 4c.

The Ferranti transformer uses a toroidal magnetic circuit M.C. of ring form. The three phases whose insulation resistance is controlled represent the primary of the Ferranti transformer and they are travelled by the currents: $I_1$, $I_2$, and $I_3$, whose directions are indicated in the diagram. The currents $I_1$, $I_2$, $I_3$ produce in the magnetic circuit M.C. the flows: $\Phi_1$, $\Phi_2$, $\Phi_3$ whose directions are obtained by using the drilling rule. The three flows $\Phi_1$, $\Phi_2$, $\Phi_3$ produce in the magnetic circuit a resulted flow Φ, which is given by the following relation:

$$\vec{\Phi} = \vec{\Phi}_1 + \vec{\Phi}_3 + \vec{\Phi}_3 \qquad (5)$$

All Ferranti transformers comprise a single spiral (w=1) from which the coil of the over relay of current I > is supplied. Keeping into account the magnetic circuit law:

$$\vec{\Phi} = \frac{\vec{F}}{R} \qquad (6)$$

F – magneto-motive voltage;
R – magnetic circuit reluctance.

We can write:

$$\vec{\Phi} = \frac{\vec{F}_1}{\Re} + \frac{\vec{F}_2}{\Re} + \frac{\vec{F}_3}{\Re} = \frac{\vec{I}_1 \cdot w}{\Re} + \frac{\vec{I}_2 \cdot w}{\Re} + \frac{\vec{I}_3 \cdot w}{\Re} =$$
$$= \frac{\vec{I}_1 \cdot 1 + \vec{I}_2 \cdot 1 + \vec{I}_3 \cdot 1}{\Re} = \frac{3 \cdot \vec{I}_0}{\Re}$$
$$\vec{\Phi} = \frac{3 \cdot \vec{I}_0}{\Re} \qquad (1.7)$$

In operating conditions or in absence of earthings the zero-sequence component of the current is null, in the secondary of the current transformer there is not induced any current and the protection does not operate. In case of an insulation fault or of an earthing, the zero-sequence component of the current is non-zero ($\vec{I}_0 \neq 0$), the resultant flow is non-zero ($\Phi \neq 0$) and in accordance with the electromagnetic induction law $\left( e = -\frac{d\Phi}{dt} \right)$ a current is induced in the secondary of transformer. The current over-relay (I >) will power and through its normally open contact which closes it transmits the disconnection command to the general switch I.G. which removes the network from the application of voltage.

## Conclusions

Both presented solutions have as purpose to increase the reluctance of the magnetic circuit ($\Re$), decrease the magnetic flow (Φ) and therefore decrease the electromotive voltage induced in the short connected circuit (e) as well as of the currents that will occur.

Based on the zero-sequence component of the current, in practice are achieved the relays for insulation resistance control and for protection against earthings, named leakage relays. This one usually equips high voltage cells. For example the ZSG relays which equip the the Polish made ROK-6 cell or the ASP ones (different versions) which equip the Romanian made CAA – 7.2 kV cell.

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