Considerations on the Disturbances Occurred in the Operation of Medium Voltage Electrical Networks with Neutral Treated by Suppression Coil

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Abstract **– In this paper are analyzed the analytical models of theoretical calculation and analysis of the main consequences of neutral treatment by suppression coil on the operation of medium voltage electrical networks, both in normal regime and especially in single-phase fault regime. The size of stationary and transient overvoltages and fault currents is evaluated for a concrete case study. Also the authors present in this paper the results they obtained after the extension of their research and in the field of harmonic regime produced by the grounding of a power line. This type of fault occurs frequently in the case of medium voltage networks, with neutral treated with suppression coil. Thus, they managed to reconstruct the waveforms of currents and voltages during the fault period (grounding). Then, having these calculation elements available, a comparative analysis of similar incidents (earthing) from a 20 kV network with the neutral treated with classic suppression coil and modern Trench suppression coil, respectively, was made.**

Cuvinte cheie: *rețele electrice de medie tensiune, neutru tratat prin bobină de stingere, supratensiuni staționare și tranzitorii, curent de defect, regim armonic.*

Keywords: *medium voltage electrical networks, neutral treated by suppression coil, stationary and transient overvoltages, fault current, harmonic regime.*

I. INTRODUCTION

In the medium voltage networks in Romania it is most frequently used as "*neutral treatment modes*": neutral grounded by suppression (compensation) coil and respectively by low resistance or inductance.

The neutral treatment mode determines numerous consequences on the operation of the electrical networks both *in normal regime and especially in single-phase fault regime*. These consequences relate to: the size of transient and stationary overvoltages, the size of the fault current, the harmonic current emissions, the possibilities (methods and means) of separating single-phase faults, grounding potentials, transmitted disturbances in network, radiated disturbances in certain domains of standardized frequency, electromagnetic influences on low current lines (e.g. telecommunication lines) etc. [1], [2].

The objectives of this article consist in determining the value of transient and stationary overvoltages, fault current for different scenarios and the harmonic analysis of waveforms of these parameters in a 20 kV medium voltage electric network with the neutral treated through classical/modern suppression coil.

II. ANALYSIS OF THE MAIN CONSEQUENCES OF NEUTRAL TREATMENT BY SUPPRESSION COIL ON THE OPERATION OF MEDIUM VOLTAGE ELECTRICAL NETWORKS. CASE STUDY.

A. *The size of stationary and transient overvoltages*

It is considered as *a case study,* a medium voltage electrical network U_N = 20 kV with compensated neutral for which a series of **initial data** are known: maximum total network length l_{max} = 90 km; network capacities: C_A = 0,00485 μF/km; C_B = 0,0043 μF/km; C_C = 0,00485 μF/km; network (specific) conductance $G = 1/r = 0.5 \cdot 10^{-6}$ S/km; depreciation coefficient of the uncompensated network $d^{'}$ = 34,105 %. The compensation coil used is dimensioned to the entire capacitive current of the network, with an overcompensation of k = 15 % and to the phase voltage U_{f0}, having active losses p = 1.5 %.

In *the normal regime* of operation of the networks treated by the extinguishing coil, between the neutral point and the ground there is a voltage whose size depends on the degree of adjustment of the coil, the asymmetry of the network phase admittances to earth and the asymmetry of the phase voltages of power supply.

Because the authors systematized and customized, in their previous research [3], algorithms for the complete calculation of the parameters necessary for the choice and installation of suppression coils in medium voltage networks, they were able to select those system detailed mathematical models that give maximum values for calculated stresses.

Thus considering that the supply voltages form a direct succession system, that the insulation conductances on the three phases are equal (G) and that on phase A where the single-phase defect takes place, the capacity to earth differs by the coefficient m in relation to the other two phases ($m = C_A/C_B$), is obtained for *the modulus of the degree of neutral displacement* (the ratio between the neutral displacement voltage and the phase voltage), expression (1).

$$|\underline{u}| = \left|\frac{V_N}{U_{f0}}\right| = \frac{m-1}{\sqrt{(3d)^2+(2+m-3k)^2}} \qquad (1)$$

where:
$d = I_a/I_C$ is the depreciation coefficient of the network which operates by compensated neutral.
$k = I_L/I_C$ is the degree of adjustment of the compensation coil.

Thus in Fig. 1 is presented the variation of the modulus of the neutral displacement degree related to the adjustment degree of the compensation coil.

Its size depends on the state of adjustment of the suppression coil, reaching the maximum value (u = 0.119) for k = (2 + m)/3 = 1.043, which corresponds to the perfect compensation of the capacitive current in a network with natural asymmetry of capacities to the ground expressed by the factor m (m = 1.128). In this case the maximum voltage of neutral displacement results V_N = 1374 V.

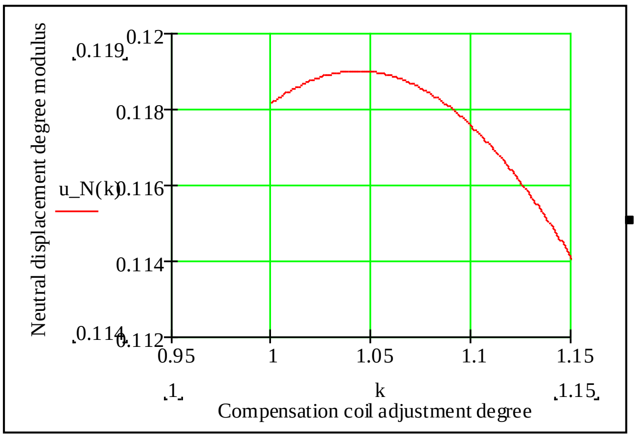

Fig. 1. Degree of displacement of the neutral depending on the degree of adjustment of the compensation coil.

The displacement voltage of the neutral V_N for the network with an overcompensation of k = 15 %, considering the net grounding results according to the graph in Fig. 1, V_N = 1316 V at a degree of neutral displacement of 0.114.

In the case of an artificial earthing, the voltage on the healthy phases with respect to the earth becomes equal to $\sqrt{3}U_{f0} = U_l$, which constitutes *the long-term overvoltage in fault stationary mode*.

In transient mode, the transient grounding overvoltage may be higher, depending on the mode of production of the defect: metallic or by intermittent electric arc. The duration of temporary overvoltages can be limited by the adjustment at resonating of the suppression coil, due to the self-elimination of defects that occur through electric arc [4], [5].

The overvoltage caused by the possible pulsation of the arc is calculated with the approximate relation (2):

$$U_{sup} = U_{f0}\sqrt{k} = 12.38\,\mathrm{kV} \qquad (2)$$

It is found that $U_{sup} = 1.072 \cdot U_{f0} < 2.5 \cdot U_{f0}$ so it is not necessary to mount variable resistance dischargers in parallel with the compensation coil.

Consider the variation of the resetting voltage u in the production range of the electric arc (the total working time of the protection and the protection circuit breakers), according to the expression (3):

$$u(t) = U_N \cdot e^{j(\omega+\phi)}\left[1-e^{\left(-\frac{d}{2}+j\frac{1-k}{2}\right)\omega t}\right] \qquad (3)$$

where:
$U_N = U_{f0}$ - is the rated voltage of the arc production interval, before the defect occurs.
$\varphi = 0^0$ - is the initial phase of the voltage at the time of connection, for which the overvoltage is maximum.

In the hypothesis of a perfect adjustment (1 - k = 0) an exponential dependence of the voltage is obtained that tends towards the value given by the expression (4):

$$u(t) = U_N\left(1-e^{-\frac{\omega d t}{2}}\right) \qquad (4)$$

It can be seen from Fig. 2 that the reset transient voltage (TTR) reaches the maximum value of $U_{TTR\ max}$ = 11.588 kV at t = 0.08398 s, i.e. there is an overvoltage $U_{TTR\ max} = 1.003 \cdot U_{f0}$. The speed of increase of TTR after the current passes through zero is $(\Delta U/\Delta t)_{TTR\ max}$ = 138.579 kV/s which is higher than in the hypothesis of a perfect adjustment when it has the value $(\Delta U/\Delta t)_{TTR\ max\ perfect\ adjustment}$ = 63.312 kV/s (ΔU / Δt).

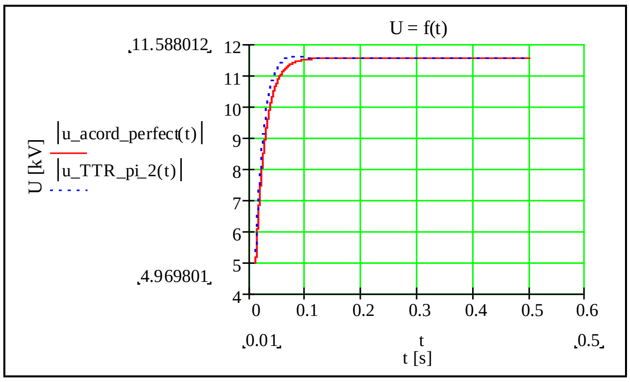

Fig. 2. Variation of the reset voltage in the interval of the electric arc production: for a perfect adjustment (red); TTR (blue).

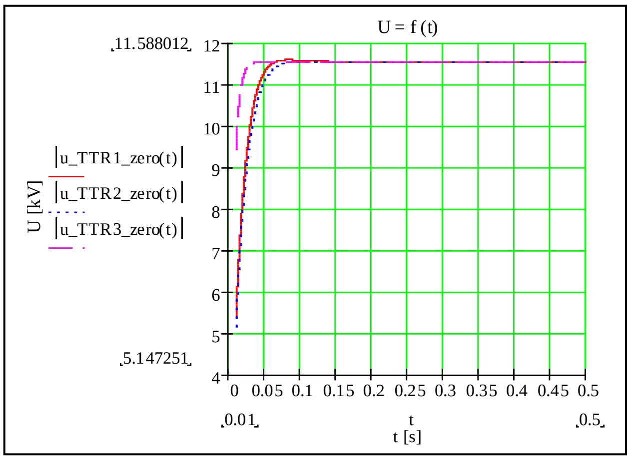

Fig. 3. Variation of the reset voltage in the interval of the electric arc production for different values of the adjustment degree: k1 = 1.15 (red); k2 = 1.1 (blue); k3 = 1.05 (magenta).

Regarding the variation of the reset voltage in the hypothesis of a perfect adjustment (1 - k = 0), it is found that it reaches the maximum amplitude equal to the phase voltage after t = 0.182 s.

From Fig. 3 it is found that the speed of increase of TTR after the current passes through zero, decreases with the decrease of the degree of disagreement and verifies the following inequalities:
$(\Delta U/\Delta t)_{TTR\ max\ k1}$ = 135.405 kV/s > $(\Delta U/\Delta t)_{TTR\ max\ k2}$ = 99.991 kV/s > $(\Delta U/\Delta t)_{TTR\ max\ k3}$ = 99.260 kV/s.

So *the compensation coil* used *ensures the extinction of the electric arc* on the one hand by reducing the grounding current I_{pp}, and on the other hand by reducing the speed of increase of the reset voltage, after the current passes through zero. In this respect, it is indicated that the degree of adjustment does not exceed (5-10) % (k = 1.05...1.1).

B. The size of fault current

The grounding current is calculated by the relation (5).

$$\underline{I}_{pp} = \underline{I}_C \sqrt{(1-k)^2 + d^2} \quad (5)$$

where:
I_C - is the capacitive current of the network which is calculated by the relation (6).

$$\underline{I}_C = 3j\omega C_p \cdot U_{f0} \quad (6)$$

where:
$C_p = l(C_A + C_B + C_C)/3$.
$1 - k$ = - 0.15 is the degree of non-adjustment of the compensation coil.

Consider that the studied network has a variable length l = (10 ... 90) km.

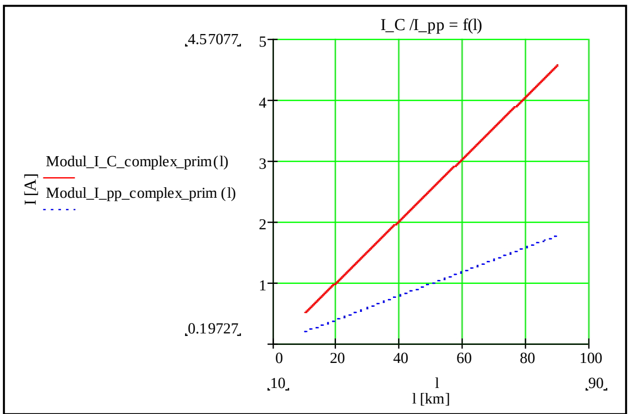

Fig. 4. Variation of the modulus of the grounding capacitive current (red) and of the grounding current (blue) depending on the line length.

From Fig. 4 it is found that, in absolute value, both the capacitive grounding current and the grounding current (at the grounding place), increase proportionally with the length of the line, but with different slopes:

- the capacitive grounding current: $m_{I_C} = \dfrac{C_A + C_B + C_C}{3}\left(3\omega \cdot \dfrac{U_N}{\sqrt{3}}\right) = 0.05\,\text{A/km}$

- the grounding current (at the grounding place) (the right with a lower growth slope): $m_{I_{pp}} \approx 0.02$ A/km.

It is also found that the current at the grounding place represents 0.388 of the capacitive grounding current, i.e. a little more than 1/3 of it and is of course inductive.

When **the grounding takes place through a resistance arc, R_{arc}**, an additional depreciation coefficient denoted *dp* appears, so that the expression of the current passing in this case through the fault location I_{pp} will be:

$$I_{pp} = I_c \frac{\sqrt{(1-k)^2 + d^2}}{\sqrt{1 + \frac{2d}{dp} + \frac{(1-k)^2 + d^2}{dp^2}}} \quad (7)$$

It is found that **the residual grounding current is reduced** if the grounding takes place through a resistance arc R_{arc} = **5 Ω**, by 0.071 % compared to the case if the grounding is net.

III. Harmonic Analysis Of Waveforms Of Grounding Fault Currents And Voltages. Case Studies.

A. Fault in a 20 kV medium voltage electric network with the neutral treated through classical suppression coil without ancillary resistence and digital protections on the 20 kV cell. Case study 1.

The oscillogram of an incident (a ground fault **on the phase "A"**) that was downloaded from a numerical protection relay *SIPROTEC 4 - 7SA6* and viewed with the *SIGRA 4* software [6], [7], shows the evolution of the main analogue and binary quantities supervised by the digital protection relay, in a medium voltage electrical network, on a mixed 20 kV line (**O**ver**h**ead Power **L**ine (LEA) + **U**nder**g**round Power **L**ine (LES)) with neutral treated with + classic **S**uppression **C**oil (BS) without auxiliary resistance and digital protections on 20 kV cell. The yellow cursor is positioned on the oscillogram portion at the moment characterized by 360.5 ms (I circuit breaker connected) and the blue one at the moment characterized by 1384.8 ms (I circuit breaker disconnected).

All sizes that appear in tables or charts are reported at that time. The electrical quantities are displayed in secondary values (U, I, P, and so on). For a better analysis of the amplitude of the defect, it is useful to transform the targeted quantities into primary values.

Within the *SIGRA 4* software, a series of *visualization windows* are available, such as: **Time signals** (visualization of *analogue signals* on the time scale); **Digital signals (binary inputs)**; **Phasor diagrams**; **Viewing the harmonic content** of the circuit breaker disconnection period; **Size tables**. The harmonic content of the measured quantities can be displayed graphically as bars. In the case of the presented defect, the content of harmonics from the switching period of the circuit-breaker can be observed and also, the exact values of these harmonics that can be found in the size table presented in the viewing window from [3].

Regarding **the harmonics content of the currents in the circuit-breaker switching period** in the case of the presented fault, the following observations can be made according to [3], where Ia, Ib, Ic represent the phase currents in [A] secondary values (transformation ratio 200 A / 5 A = 40):

- These have a DC (continuous) component (≈ 52.8 A in primary value, which represents 28.2 % of the fundamental on the „A" phase on which the respective fault appeared (grounding), a value that is also found on the neutral conductor - the null of the network "G" namely ≈ 21.6 A which represents 45.4 % of the fundamental).
- Significant higher harmonics are the 2nd and 3rd order.

In Fig. 5 were graphically represented the fault currents (periodic component), in the same system of coordinate axes, using a calculation program of their own design, developed by the authors in the Mathcad programming environment.

The frequency spectra of the fault currents on the three phases and on the neutral conductor - “G” zero of the network, were synthesized during the switching period of the circuit breaker, knowing the effective values of the components from the size table provided by *SIGRA 4*.

Regarding **the harmonics content of the voltages in the circuit-breaker switching period** in the case of the presented fault, the following observations can be made according to Fig. 6, where Va,Vb,Vc represent the phase voltages in secondary values (transformation ratio 20000 V / 100 V = 200):

- The voltage on the fault phase (A) has a continuous component (≈ 14 V which represents 21.7 % of the fundamental on the phase „A” on which the respective fault appeared (grounding)), while on the healthy phases (B, C) and on the neutral “G” zero of the network, the proportions of the continuous components even if they are small, in absolute values are significant because the values of their fundamentals increase significantly).
- Significant higher harmonics are the 2nd and 3rd order.

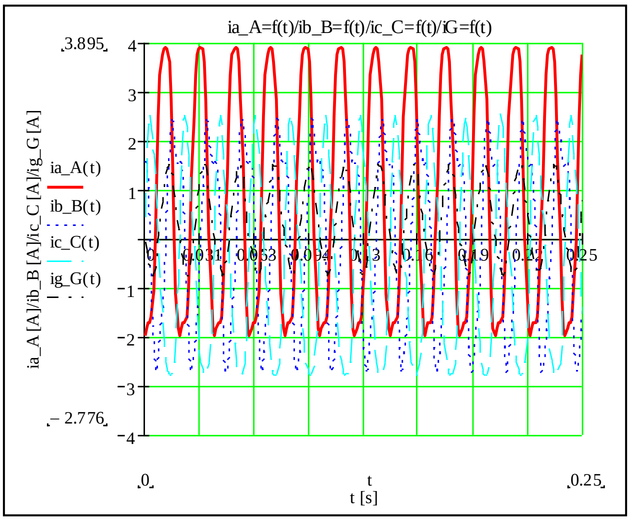

Fig. 5. The time variation of the fault currents on the three phases and on the neutral conductor - the null of the network “G”, in secondary values, in the circuit-breaker switching period.

As in the case of fault currents, in Fig. 6 the fault voltages (the periodic component) were graphically represented in the same system of coordinate axes, using a similar calculation program of their own design, developed by the authors in the Mathcad programming environment.

The frequency spectra of the fault voltages on the three phases and on the neutral conductor - “G” zero of the network, were synthesized during the switching period of the circuit-breaker, knowing the effective values of the components from the size table provided by *SIGRA 4*.

It is noted that the variation of fault currents / voltages has been reconstituted over a time interval of 250 ms which represents the sum of the times required to the triggering circuit breaker of 20 kV (simultaneous opening time of the circuit breaker contacts, indicated in the catalogue, plus the breaking of the electric arc which is approximately 0.15 s for $U_N \leq 35$ kV), as well as of the intermediate relays or of the internal relays of the digital protection equipment.

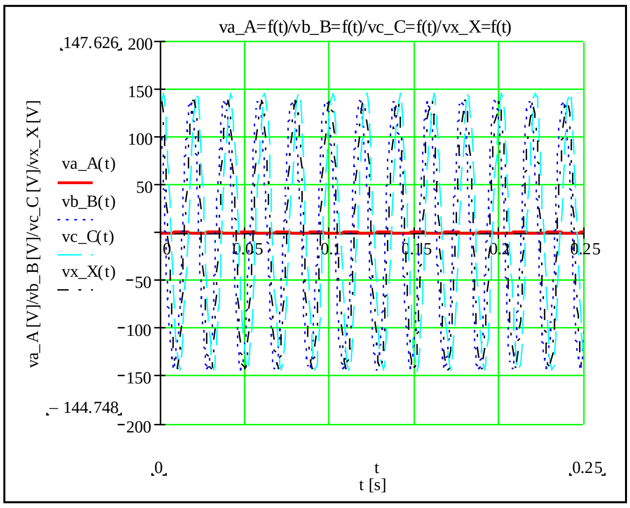

Fig. 6. The time variation of the fault voltages on the three phases and the neutral - the null of the network “G”, in secondary values, in the circuit-breaker switching period.

According to [3], the first component represents the continuous component (average value of the function), then for each complex component *the amplitude - the effective (rms) value* and the argument (which represents *the phase angle (phase shift)*) *of the “k” order harmonics* were identified.

The corresponding Fourier series was written as:

$$y(t) = y_0 + \sum_{k=1}^{k=3} y_k \sin(k\omega t + \varphi_k) \qquad (8)$$

Thus, by making *a harmonic analysis* of the waveforms of the fault currents and voltages on the three phases and the neutral conductor - the “G” zero of the network, **the total harmonic distortion coefficient δ_I [%]** of the injected current in the power system and **the total harmonic distortion coefficient of the voltage δ_V [%]** were calculated, during the switching period of the circuit-breaker, using relation (9), [8], the results being centralized in TABLE I and TABLE II.

$$\delta_Y = \frac{Y_d}{Y_1}100 = \frac{\sqrt{Y_0^2 + \sum_{n=2}^{3} Y_n^2}}{Y_1}100 = \{\sqrt{\frac{1}{10^4}(\gamma_{y0}^2 + \sum_{n=2}^{3}\gamma_{yn}^2)}\}100[\%] \qquad (9)$$

where:

Y_1 - the rms value of the fault current / voltage fundamental harmonic;

Y_d - the rms value of the distortion residue of the current / voltage, obtained by suppressing the fundamental harmonic.

$\gamma_{yn} = Y_n/Y_1[\%]$ - the proportions of the *n*-order harmonics of the fault currents / voltages (the currents / voltages harmonic components on the phases and on the “G” zero of the network) and they are presented in [3].

$\gamma_{y0} = Y_0/Y_1[\%]$ it represents the proportions of the fault currents / voltages continuous components which are also presented in [3].

Regarding the fault currents, it is found that the proportions for the fundamental of the continuous components are great, comparable in order of magnitude, with the proportions from the fundamental of the *n*-order harmonics of the fault currents.

TABLE I.
THE TOTAL HARMONIC DISTORTION COEFFICIENT OF THE CURRENT, COMPUTED ACCORDING OF THE RELATION (9).

	δ_I [%]
Phase A	**40.936**
Phase B	26.698
Phase C	36.387
The average value on the three phases, $\delta_{I\,av}$ [%]	34.673
The neutral conductor (the "G" zero of the network)	46.378

TABLE II.
THE TOTAL HARMONIC DISTORTION COEFFICIENT OF THE VOLTAGE, COMPUTED ACCORDING OF THE RELATION (9).

	δ_V [%]
Phase A	**73.529**
Phase B	3.164
Phase C	4.211
The average value on the three phases, $\delta_{V\,av}$ [%]	26.968
The neutral conductor (the "G" zero of the network)	3.943

Because of this, the harmonic distortion coefficients calculated with relation (9) have large values that also exceed the maximum allowable values imposed today by international standards.

Regarding the fault voltages, it is found that **only in the case of the fault phase (A)** the proportion relative to the fundamental of the continuous component is high, comparable in order of magnitude, with the proportions relative to the fundamental of the *n*-order harmonics of the fault voltages.

Because of this, the harmonic distortion coefficient of voltage on the fault phase A, calculated with relation (9) has a very large value that also exceeds the maximum allowable values imposed today by international standards.

It can be seen that **this fault (grounding of phase A of the 20 kV power line) can be assimilated with a strongly deforming (non-linear) consumer**.

B. Fault in a 20 kV medium voltage electric network with the neutral treated through Trench modern suppression coil and digital protections on the 20 kV cell. Case study 2.

This oscillogram shows the evolution of the main analogue and binary quantities monitored by the digital protection relay, in a medium voltage electrical network, on a 20 kV line (**O**ver**h**ead **P**ower **L**ine) with neutral treated with modern Trench Suppression Coil and digital protections on 20 kV cells, which had a grounding fault **on phase "B"**. This fault produced a grounding current whose maximum instantaneous primary value is approximate 75 A, taking into account that the transformation ratio of the measure current transformers is in this case 300 A / 5 A = 60.

In order to have a clearer view of the exact time when the power line was effectively disconnected, the cursors (sliders) can be moved on the graph at the end and beginning of the period when the current (I) is present, and the difference between the sliders is this time or the pause of RAR (**F**ast **A**utomatic **R**econnect).

Thus the yellow cursor is positioned on the oscillogram portion in the moment characterized by 1327.7 ms (Q0 circuit-breaker disconnected) and the blue one in the moment characterized by 2969.3 ms (Q0 circuit-breaker connected).

In this case, the actual time in which the power line was disconnected would result, resulting from the difference of the C2-C1 sliders calculated by the software, which means that the RAR pause set in the protection relay on this line is 2 seconds, a possible difference coming from of the time required for the switching of the 20 kV circuit-breaker, as well as for the tripping of the intermediate relays or of the internal relays of the digital protection equipment.

The triggering of the 20 kV cell took place through the cell's own protection, but through an external signal from the earthing modules related to the **Trench S**uppression **C**oil cabinet. The 20 kV **O**ver**h**ead Power **L**ine (OHL) is reconnected by RAR (**F**ast **A**utomatic **R**econnect) automation after the RAR break expires.

All data in the oscillogram are similar to those in the previous oscillogram (Section III *A*).

Regarding **the harmonics content of the currents in the circuit-breaker switching period** in the case of the presented fault, the following observations can be made according to harmonics content viewing window for: currents on the three phases - A, B, C; the current on the neutral conductor - the "G" zero of the network, provided by *SIGRA 4*:

- These have a DC (continuous) component (≈ 7.2 A which represents 6.6 % of the fundamental on the „B" phase on which the respective fault appeared (grounding), values that are also found on the neutral conductor - the null of the network "G" namely ≈ 10.2 A which represents 20.6 % of the fundamental).
- Significant higher harmonics are the 2nd and 3rd order.

In Fig. 7 were graphically represented the fault currents (periodic component), in the same system of coordinate axes, using a calculation program of their own design, developed by the authors in the Mathcad programming environment, similar to those mentioned above.

The frequency spectra of the fault currents on the three phases and on the neutral conductor - "G" zero of the network, were synthesized during the switching period of the circuit-breaker, knowing the effective values of the components from the size table presented in a viewing window similar to that presented in [3].

Regarding **the harmonics content of the voltages in the circuit-breaker switching period** in the case of the presented fault, the following observations can be made according to the harmonic content viewing window for:

voltages on the three phases - A, B, C; the voltage (potential) of the neutral conductor - the „Vx" zero of the network, similar to that presented in [3]:

- The voltage on the fault phase (B) has a continuous component in primary value (≈ 2918 V which represents 52.2 % of the fundamental on the phase „B" on which the respective fault appeared (grounding)), comparable in absolute value with the continuous components on the healthy phases (A, C). The continuous component of the neutral potential - the "G" zero of the network in absolute value has the highest value (≈ 5116 V).
- Significant higher harmonics are the 2nd and 3rd order.

In Fig. 8 the fault voltages (the periodic component) were graphically represented in the same system of coordinate axes, using a mentioned similar calculation program of their own design, developed by the authors in the Mathcad programming environment.

The frequency spectra of the fault voltages on the three phases and on the neutral conductor - "G" zero of the network, were synthesized during the switching period of the circuit-breaker, knowing the effective values of the components from the size table presented in a viewing window similar to that presented in [3].

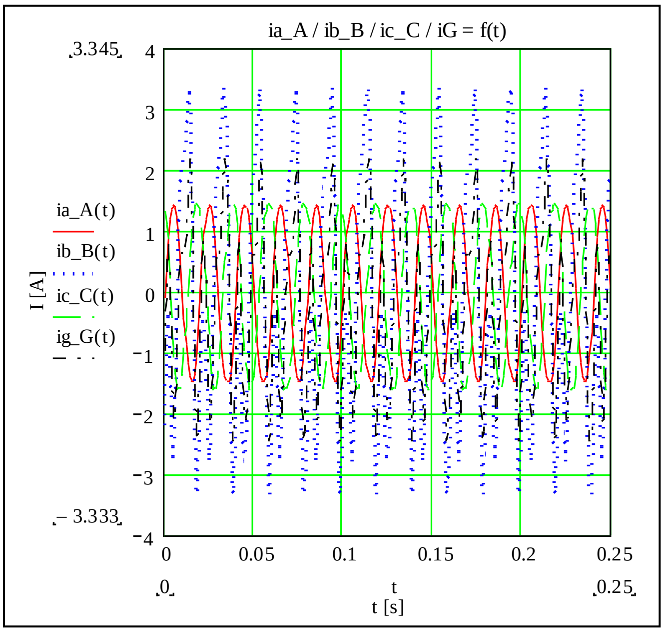

Fig. 7. The time variation of the fault currents on the three phases and on the neutral conductor - the null of the network "G", in secondary values, in the circuit-breaker switching period.

Thus, by making *a harmonic analysis* of the waveforms of the fault currents and voltages on the three phases and the neutral conductor - the "G" zero of the network, **the total harmonic distortion coefficient of the injected current δ_I [%]** in the power system and **the total harmonic distortion coefficient of the voltage δ_V [%]** were calculated, during the switching period of the circuit-breaker, using relation (9), [8], the results being centralized in TABLE III and TABLE IV.

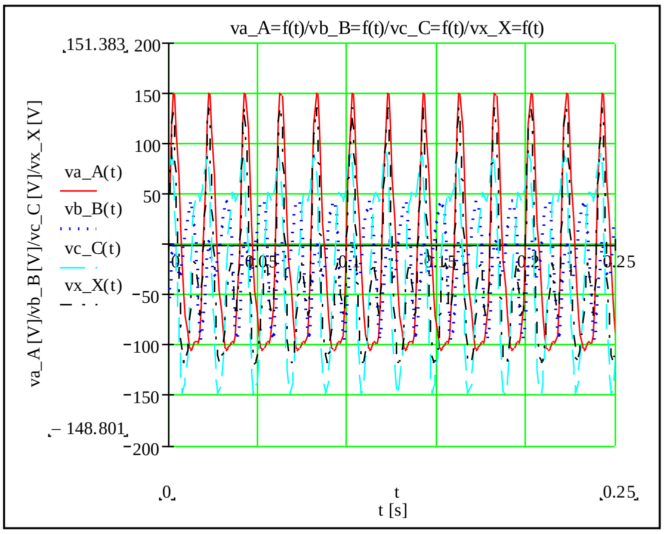

Fig. 8. The time variation of the fault voltages on the three phases and the neutral - the null of the network "G", in secondary values, in the circuit-breaker switching period.

TABLE III.
THE TOTAL HARMONIC DISTORTION COEFFICIENT OF THE CURRENT, COMPUTED ACCORDING OF THE RELATION (9).

	δ_I [%]
Phase A	5.213
Phase B	**68.067**
Phase C	6.22
The average value on the three phases, $\delta_{I\ av}$ [%]	26.5
The neutral conductor (the "G" zero of the network)	139.766

TABLE IV.
THE TOTAL HARMONIC DISTORTION COEFFICIENT OF THE VOLTAGE, COMPUTED ACCORDING OF THE RELATION (9).

	δ_V [%]
Phase A	38.236
Phase B	**115.666**
Phase C	42.508
The average value on the three phases, $\delta_{V\ av}$ [%]	65.47
The neutral conductor (the "G" zero of the network)	101.323

Regarding the fault currents on the phase B (fault) and on the neutral conductor (the "G" zero of the network), it is found that the proportions from the fundamental of the continuous component and these of the fault currents *n*-order harmonics are greater then these on the healthy phases (A, C).

Because of this, the harmonic distortion coefficients calculated with relation (9) **on the phase B (fault)** and on the neutral conductor (the "G" zero of the network) have very large values that exceed the maximum allowable values imposed today by international standards.

Regarding the fault voltages, it is found that **in the case of the fault phase (B)** and of the neutral conductor potential (the “G” zero of the network), the proportion relative to the fundamental of the continuous component is high, comparable in order of magnitude, with the proportions relative to the fundamental of the *n*-order harmonics of the fault voltages.

Because of this, the harmonic distortion coefficient of the voltage on the fault phase B and of the neutral conductor potential (the “G” zero of the network), calculated with relation (9) have a very large value that also exceed the maximum allowable values imposed today by international standards.

IV. CONCLUSIONS

We started from the importance of the way of treating the neutral that determines in certain conditions the appearance of overcurrents or overvoltages.

In this sense, *the authors used programs specially designed by them*, developed in the Mathcad programming environment, which allow the quantitative solution of the problem of neutral displacement, the calculation of grounding currents in the fault place for different scenarios such as net grounding or through an electric arc having a certain resistance.

From the comparative harmonic analysis of the waveforms of the fault currents and voltages from *the two case studies* presented above, namely faults in 20 kV medium voltage electrical networks with neutral treated with *conventional suppression coil without auxiliary resistance or Trench modern suppression coil* and digital protections on the 20 kV cell, the following conclusions can be drawn:

- For the *Case study 1*:

a) The total harmonic distortion coefficient of the fault current, according to TABLE I, records the highest value on the neutral conductor (”G” zero of the network) comparable to the value calculated for the fault phase A (by ≈ 11.7 % higher). The value of this coefficient for the fault phase A is higher than the values calculated for the healthy phases (than in phase B ≈ 1.5 times higher, than in phase C ≈ 1,125 times higher) so comparable to them, but all these values exceed the limits imposed by the specialized standards.

b) The total harmonic distortion coefficient of the fault voltage according to TABLE II, records the highest value on the fault phase A, while the values of this coefficient are at least an order of magnitude smaller for the healthy phases (on phase B - of ≈ 23.24 times lower, on phase C - ≈ 17.46 times lower) and for the neutral conductor (“G” zero of the network) ≈ 18.65 times lower, being just below the limits imposed by the specialized standards.

- For the *Case study 2*:

c) The total harmonic distortion coefficient of the fault current according to TABLE III, records the highest value on the neutral conductor (“G” zero of the network), higher than ≈ 2.05 times than the value calculated for the fault phase B. In the fault phase B the value of this coefficient is one order of magnitude higher than the values calculated for the healthy phases (≈ 13 times higher than in phase A, ≈ 10.9 times higher than in phase C), so that the values calculated for the healthy phases are just below the limits imposed by the specialized standards.

d) The total harmonic distortion coefficient of the fault voltage according to TABLE IV, records the highest value on the fault phase B, comparable to the value calculated for the neutral conductor (“G” zero of the network) - higher by 12.4 %, while the values of this coefficient are by an order of magnitude smaller for the healthy phases (on phase A - ≈ 3 times lower, on phase C - ≈ 2.7 times lower) but being above the limits imposed by the specialized standards.

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