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Application of network voltages to insulation monitoring in unearthed AC circuits with rectifiers

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Abstract

Maximum values of possible earth fault currents in low voltage unearthed AC networks supplying DC circuits through diode rectifiers are critical for evaluation of possible electric shock and fire hazards caused by insulation condition deterioration. A method for analytical determination of time functions of earth fault parameters, i.e. wire-to-earth voltages and currents is presented in the paper. Application of two characteristic parameters i.e. the phase voltage mean value and the phase voltages zero sequence component to insulation condition evaluation is discussed. A new method exploiting the phase voltages mean value for insulation resistance monitoring is presented.

Keywords: unearthed AC networks; rectifiers; earth fault voltages and currents; phase voltage mean value, phase voltages zero sequence component.

Wykorzystanie napięć sieci do kontroli izolacji obwodów AC IT z prostownikami

Streszczenie

Maksymalne wartości prądów zwarć z ziemią w sieciach izolowanych AC zasilających obwody DC przez prostowniki diodowe decydują o ewentualnych ryzykach porażenia osób, pożaru i wybuchu. W artykule przedstawiono metodę analitycznego wyznaczania przebiegów czasowych parametrów ziemnozwarciowych tj. napięć i prądów doziemnych; zagadnienie to było dotychczas pomijane w dostępnej literaturze. Wyznaczono zależności dla charakterystycznego parametru układów AC/DC IT, którym jest wartość średnia napięć fazowych strony AC. Omówiono przydatność tej wielkości dla kontroli izolacji tych sieci oraz lokalizacji doziemień. W oparciu o najczęstsze w praktyce przypadki pokazano, że składowa zerowa napięć fazowych spełnia funkcję sygnalizacji pogorszenia stanu izolacji praktycznie jedynie dla strony AC (rys. 4). Przy uszkodzeniach izolacji po stronie DC napięcie tej składowej w nieznacznym stopniu zależy od rezystancji zwarcia doziemnego. Z użyciem wartości zastępczej rezystancji izolacji całego układu AC/DC IT oszacowano maksymalny poziom prądu upływu decydujący o bezpieczeństwie porażeniowym i pożarowym sieci. W artykule zaproponowano nową metodę wyznaczania wartości zastępczej rezystancji izolacji całego układu. Procedura z użyciem dodatkowego rezystora testowego obejmuje pomiary wartości średniej napięć fazowych, na bazie których oblicza się wartość szukanego parametru. Oprócz prostoty i braku wrażliwości na pojemności doziemne metoda wyróżnia się uniwersalnością, gdyż uwzględnia upływności izolacji całej sieci AC/DC IT.

Słowa kluczowe: sieci izolowane AC; prostowniki; napięcia i prądy doziemne; wartość średnia napięcia fazowego; składowa zerowa napięć fazowych.

1. Introduction

Low voltage unearthed (IT) alternating current (AC) networks are electrical systems commonly applied in commercial and industrial objects. Quite often these single- or three-phase networks supply direct current (DC) circuits through diode rectifiers. Rectifiers are used for feeding auxiliary circuits and devices of automation, control, measurements and protections systems. Safe and reliable operation of these "mixed" AC/DC systems requires elimination of possible threats of electric shock to persons, fire hazards and malfunction risks of devices. These dangers exist if short circuit (including earth fault) current levels exceed the admissible values. In order to assess and eliminate the above mentioned risks, it is necessary to know maximum possible levels of earth fault and (earth)leakage currents.

In the "mixed" unearthed networks an AC part of a system is connected with a DC part through rectifying valves. Commutation of the valves causes cyclic variation of configuration of the entire galvanically connected network. A distinct feature of these systems is that voltages between all points of the AC side and earth may have the mean value different from zero, which is not possible in "pure" AC networks. This characteristic parameter i.e. the phase voltage mean value can be used for earth fault signalization and location. A possible application of another characteristic earth fault parameter i.e. the phase voltages zero sequence component (in 3-phase networks) to insulation monitoring should also be considered.

2. Single phase AC/DC IT systems

2.1. Determination of the wire-to-ground voltage mean value

For determination of the mean value of the wire-to-ground (phase) voltage at the AC side of a single – phase AC/DC IT system an equivalent circuit diagram shown in Fig.1 is helpful.

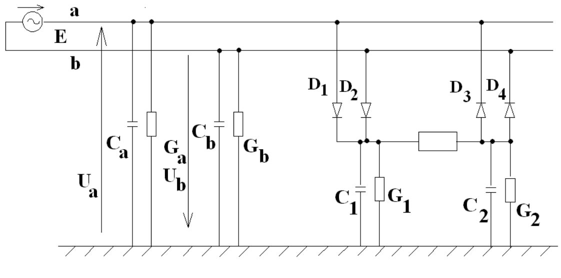

Fig. 1. An equivalent circuit diagram of a single phase AC/DC IT network
Rys. 1. Schemat zastępczy jednofazowej sieci AC/DC IT

Let the source voltage time function be $e(t)=E_m \cdot \sin\omega t$. Within the time interval $0<t<T/2$ diodes D_1 and D_4 conduct. Assuming no voltage drop across the conducting diodes, AC wire a and DC positive pole 1 have the same voltage to earth.

Leakage (to earth) currents balance according to Kirchhoff's 1st law is given by the following equation (for simplicity in the formulas time t variable is omitted i.e. $u_b(t)=e(t)-u_a(t)=e-u_a$).

$$(G_1+G_a)\cdot u_a+(C_1+C_a)\cdot\frac{\mathrm{d}u_a}{\mathrm{d}t}=(G_2+G_b)\cdot(e-u_a)+(C_2+C_b)\cdot\frac{\mathrm{d}(e-u_a)}{\mathrm{d}t} \quad (1)$$

After transformation

$$(G_1+G_2+G_a+G_b)\cdot u_a+(C_1+C_2+C_a+C_b)\cdot\frac{\mathrm{d}u_a}{\mathrm{d}t}=(G_2+G_b)\cdot e+(C_2+C_b)\cdot\frac{\mathrm{d}e}{\mathrm{d}t} \quad (2)$$

Substituting network-to-ground insulation equivalent conductance G_i and capacitance C_i

$$G_1 + G_2 + G_a + G_b = G_i\ ,\quad C_1 + C_2 + C_a + C_b = C_i \tag{3}$$

the following equation is obtained

$$G_i \cdot u_a + C_i \cdot \frac{\mathrm{d}u_a}{\mathrm{d}t} = (G_2 + G_b) \cdot e + (C_2 + C_b) \cdot \frac{\mathrm{d}e}{\mathrm{d}t} \tag{4}$$

For $T/2<t<T$ diodes D_2 and D_3 conduct, thus the positive pole 1 and AC wire b are connected parallel. Leakage currents balance is

$$(G_2 + G_a) \cdot u_a + (C_2 + C_a) \cdot \frac{\mathrm{d}u_a}{\mathrm{d}t} = (G_1 + G_b) \cdot (e - u_a) + (C_1 + C_b) \cdot \frac{\mathrm{d}(e - u_a)}{\mathrm{d}t} \tag{5}$$

which after transformation takes the form

$$G_i \cdot u_a + C_i \cdot \frac{\mathrm{d}u_a}{\mathrm{d}t} = (G_1 + G_b) \cdot e + (C_1 + C_b) \cdot \frac{\mathrm{d}e}{\mathrm{d}t} \tag{6}$$

The mean value of u_a can be calculated by integrating equations (4) and (6) over their respective limits and then adding them. In this way the final formula for $U_{a\text{-}mean}$ is obtained

$$U_{a-mean} = \frac{1}{T} \cdot \int_0^T u_a(t)\mathrm{d}t = \frac{G_2 - G_1}{G_i} \cdot \frac{E_m}{\pi} \tag{7}$$

This formula can be also transformed to the following form

$$U_{a-mean} = \frac{R_1 - R_2}{R_1 + R_2} \cdot \frac{R_{\approx}}{R_{\approx} + R_{=}} \cdot \frac{E_m}{\pi} \tag{8}$$

where $R_{\approx} = \dfrac{R_a \cdot R_b}{R_a + R_b}$ and $R_{=} = \dfrac{R_1 \cdot R_2}{R_1 + R_2}$ are insulation-to-ground equivalent resistances respectively of the AC and DC side of a "mixed" AC/DC IT network.

It follows from the formula (8) that the phase voltage mean value does not depend on network-to-ground capacitances C_a, C_b, C_1, C_2. The second distinctive feature of this parameter is its non-zero value only in case of asymmetry of insulation conductances G_1, G_2 of the respective poles of the DC circuit [1]. Therefore this property can be used for selective location of possible earth faults in "mixed" networks. The maximum value of the mean phase voltage E/π is reached if only one of these two insulation conductances is different from zero and insulation conductances of the AC side are also zero. It should be noted that appearance of the non-zero mean value of the phase voltage exerts influence on operation of insulation monitors utilizing injection of an auxiliary DC test signal e.g. megohmmeters [2].

2.2. Determination of time functions of phase voltages and leakage currents

For some applications an analytical expression for the phase voltage time function may be useful. As shown in the previous section, within the time interval $0<t<T/2$ equation (4) is valid. Its solution is given as

$$u_{a1}(t) = U_{a11} \cdot \sin(\omega t + \alpha) + U_{a12} \cdot e^{-t/\tau} \tag{9}$$

where U_{a11}, U_{a12} and α are unknown values which can be obtained from the following initial conditions (10) and (12)

$$u_{a1}(0) = U_{a11} \cdot \sin\alpha + U_{a12} \tag{10}$$

and $u_{a1}(\frac{T}{2}) = -U_{a11} \cdot \sin\alpha + U_{a12} \cdot e^{-\frac{T}{2\tau}}$ and by substituting general solution (9) $u_{a1}(t)$ into (4).

Within the time interval $T/2<t<T$ equation (6) is valid. Its solution is given as

$$u_{a2}(t) = U_{a21} \cdot \sin[\omega(t - \frac{T}{2}) + \beta] + U_{a22} \cdot e^{-(t-\frac{T}{2})/\tau} \tag{11}$$

where U_{a21}, U_{a22} and β are unknown values which are determined by initial conditions (12) – note that any wire-to-ground voltage is a continuous time function

$$u_{a2}(\frac{T}{2}) = U_{a21} \cdot \sin\beta + U_{a22} = u_{a1}(\frac{T}{2}) \tag{12}$$

and $u_{a2}(T) = -U_{a21} \cdot \sin\beta + U_{a22} \cdot e^{-\frac{T}{2\tau}} = u_{a1}(0)$ and by substituting general solution (11) $u_{a2}(t)$ into (6). In this way all sought parameters are obtained as

$$\tau = C_i / G_i \tag{13}$$

- time constant of the exponentially decaying component

$$U_{a11} = E_m \cdot \sqrt{\frac{\left[(G_b + G_2)^2 + (C_b + C_2)^2 \cdot \omega^2\right]}{G_i^2 + (C_i \cdot \omega)^2}} \tag{14}$$

$$\alpha = -\gamma + \mathrm{arctg}\,\frac{(C_2 + C_b) \cdot \omega}{G_2 + G_b} \tag{15a}$$

$$\cos\gamma = \frac{G_i}{\sqrt{G_i^2 + (\omega \cdot C_i)^2}} \tag{15b}$$

$$U_{a21} = -E_m \cdot \sqrt{\frac{\left[(G_b + G_1)^2 + (C_b + C_1)^2 \cdot \omega^2\right]}{G_i^2 + (C_i \cdot \omega)^2}} \tag{16}$$

$$\beta = -\gamma + \mathrm{arctg}\,\frac{(C_1 + C_b) \cdot \omega}{G_1 + G_b} \tag{17}$$

$$U_{a12} = U_{a22} = -\frac{1 + e^{-\frac{T}{2\tau}}}{1 - e^{-\frac{T}{\tau}}} \cdot (U_{a11} \cdot \sin\alpha + U_{a21} \cdot \sin\beta) \tag{18}$$

Knowledge of the phase a voltage $u_a(t)$ enables calculating the remaining voltages i.e. $u_b(t)$, $u_1(t)$, $u_2(t)$, as well as earth fault or leakage currents through insulation-to-ground admittances. For example the time function of the leakage current from phase a at the AC side is equal to $i_{a\text{-}leak}(t)=G_a \cdot u_a(t)$. However, for assessment of electric shock and fire risks it is more useful to know the maximum possible rms value of the earth fault current. In any case this parameter cannot surpass the level of $I_{ef\,max}=G_i \cdot U_{n\,max}$, where $U_{n\,max}$ is the maximum rms value of any n-th conductor voltage to earth.

3. Three - phase AC/DC IT systems

3.1. Determination of phase voltages

For determination of the mean value of phase voltages at the AC side of a three – phase AC/DC IT system an equivalent circuit diagram shown in Fig.2 is helpful.

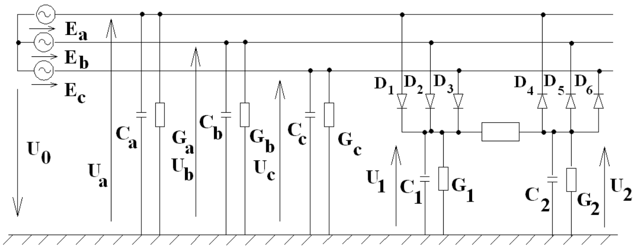

Fig. 2. An equivalent circuit diagram of a three- phase AC/DC IT network
Rys. 2. Schemat zastępczy trójfazowej sieci AC/DC IT

Let the network source voltages be $e_a(t)=E_m\cdot\sin\omega t$, $e_b(t)=E_m\cdot\sin\left[\omega(t-\frac{T}{3})\right]$, $e_c(t)=E_m\cdot\sin\left[\omega(t-\frac{2T}{3})\right]$ and phase voltages $u_a(t)=e_a(t)-u_0(t)$, $u_b(t)=e_b(t)-u_0(t)$, $u_c(t)=e_c(t)-u_0(t)$ where $u_0(t)$ is the so called displacement voltage equal to the zero sequence component of phase voltages taken with a reverse sign.

Within the time interval $T/12<t<3T/12$ diodes D1 and D5 conduct

$$(G_a+G_1)\cdot(e_a-u_0)+(C_a+C_1)\cdot\frac{d(e_a-u_0)}{dt}+(G_b+G_2)\cdot(e_b-u_0)+$$
$$(C_b+C_2)\cdot\frac{d(e_b-u_0)}{dt}+G_c\cdot(e_c-u_0)+C_c\cdot\frac{d(e_c-u_0)}{dt}=0 \tag{19}$$

For the consecutive five time intervals the equations describing the leakage currents according to 1st Kirchhoff's law are written in a similar way.

By adding all theses six equations integrated each one over its specified limits and after transformation, the formula for u_0 mean value is obtained

$$U_{0-mean}=E_m\cdot\frac{3\sqrt{3}}{2\pi}\cdot\frac{G_1-G_2}{G_i} \tag{20}$$

where G_i is insulation-to-ground equivalent (total) conductance $G_i=G_a+G_b+G_c+G_1+G_2$ of the whole „mixed" network. The mean values of u_0 voltage and of each phase voltage are of course equal. In three-phase AC/DC IT networks with rectifiers, the mean value of phase voltages exhibits similar properties as in single-phase systems. It does not depend on network-to-ground capacitances at both sides of rectifier. It also differs from zero only in the case of asymmetry of insulation conductances G_1 , G_2 of single poles of the DC circuit. Therefore this fact can be used for selective detection of earth faults (or even insulation deterioration) in these "mixed" networks.

Time functions of phase voltages $u_a(t)$, $u_b(t)$, $u_c(t)$ can be derived in a similar way as for single-phase "mixed" networks using the six above mentioned equations for respective time intervals. From these equations the expressions for $u_0(t)$ within respective six time intervals are obtained. In the k-th (k=1,..6) time interval $u_{0k}(t)$ function is $u_{0k}(t)=U_{01k}\cdot\sin(\omega t+\alpha_k)+U_{02k}\cdot e^{-(t-\frac{2k-1}{12}T)/\tau}$.

Its coefficients U_{01k}, U_{02k}, α_k are determined by the initial conditions of continuous $u_0(t)$ function. Its time constant τ is equal to C_i/G_i. As in single phase AC/DC IT networks the time function of the leakage current from the n-th conductor is equal to $i_{n\text{-}leak}(t)=G_n\cdot u_n(t)$.

The maximum possible rms value of *a* dead earth fault current $I_{ef\,max}$ in a network with insulation equivalent conductance G_i cannot surpass the level

$$I_{ef\max}=G_i\cdot U_{n\max}\,, \tag{21}$$

where $U_{n\;max}$ is the maximum rms value of any n-th conductor voltage to earth.

3.2. Determination of earth fault parameters at AC and DC sides – an example

The most common case of earth fault occurs at the DC side of a rectifier. For a 3-phase "mixed" network with symmetrical AC side capacitances $C_a=C_b=C_c=C_{ph}$ and negligible remaining insulation admittances, the mean and rms values of u_0 can be calculated in case of the positive pole earthing through $G_f=G_1$ in the following way. As DC side u_1 and u_2 voltages are repeated periodically every $T/3$ (due to symmetry of AC side insulation admittances), it is sufficient to consider the time interval $T/12<t<5T/12$ within which u_0 voltage function fulfills the equation:

$$G_1\cdot(e_a-u_0)+C_a\cdot\frac{\mathrm{d}(e_a-u_0)}{\mathrm{d}t}+C_b\cdot\frac{\mathrm{d}(e_b-u_0)}{\mathrm{d}t}$$
$$+C_c\cdot\frac{\mathrm{d}(e_c-u_0)}{\mathrm{d}t}=0 \tag{22}$$

Its solution is a function

$$u_0(t)=U_{01}\cdot\sin(\omega t+\alpha\;)+U_{02}\cdot e^{-(t-\frac{T}{12})/\tau} \tag{23}$$

which must meet the condition of continuity at limits of the specified time interval $u_0(\frac{T}{12})=u_0(\frac{5T}{12})$. After performing calculations the following formula for $u_0(t)$ voltage is obtained for $T/12<t<5T/12$

$$u_0(t)=\frac{E}{\sqrt{1+\omega^2\cdot\tau^2}}\cdot\sin(\omega t+\alpha)-$$
$$\frac{\sqrt{3}\cdot E\cdot\omega\cdot\tau}{\left(1+\omega^2\cdot\tau^2\right)\cdot\left(e^{-\frac{T}{3\cdot\tau}}-1\right)}\cdot e^{-(t-\frac{T}{12})/\tau} \tag{24}$$

where $\tau=C_i/G_i$ and $\mathrm{tg}\alpha=-\omega\cdot\tau$, giving its dependence on insulation capacitance C_i and earth fault resistance $1/G_1$. Earth fault current $i_{1\text{-}ef}(t)$ through G_1 is given by the formula

$$i_{1-ef}(t)=G_1\cdot u_a(t)=G_1\cdot\left[e_a(t)-u_0(t)\right] \tag{25}$$

For a dead earth fault (i.e. $G_1=\infty$) displacement voltage u_0 is equal respectively to e_a for $T/12<t<5T/12$, e_b for $5T/12<t<9T/12$ and e_c for $9T/12<t<13T/12$. In this case the earth fault current can be determined as a sum of the capacitive currents flowing from unfaulted phases to earth. Within the time interval $T/12<t<5T/12$ the momentary value of the earth fault current flowing from the positive pole 1 is

$$i_{1-ef}(t)=C_b\cdot\frac{\mathrm{d}(e_b-e_a)}{\mathrm{d}t}+C_c\cdot\frac{\mathrm{d}(e_c-e_a)}{\mathrm{d}t}=-3C_{ph}\cdot\frac{\mathrm{d}e_a(t)}{\mathrm{d}t} \tag{26}$$

Its mean value over this time interval is zero. This current waveform is repeated periodically in successive intervals. Therefore its rms value is equal to

$$I_{1-ef-rms}=\sqrt{\frac{3}{T}\cdot\int_{\frac{T}{12}}^{\frac{5T}{12}}[3C_{ph}\cdot\frac{\mathrm{d}e_a(t)}{\mathrm{d}t}]^2\mathrm{d}t}=3\omega C_{ph}\cdot E_m\cdot\sqrt{\frac{3}{T}\cdot\int_{\frac{T}{12}}^{\frac{5T}{12}}[\cos\frac{2\pi}{T}t]^2\,\mathrm{d}t}=$$
$$=3\omega C_{ph}E_m\sqrt{\frac{1}{2}-\frac{3\cdot\sqrt{3}}{8\pi}}\approx 3\omega C_{ph}E_m\cdot 0.54 \tag{27}$$

At any moment displacement voltage u_0 is equal to the faulted phase source voltage. Thus its rms value is given by the formula

$$U_{0-rms} = \sqrt{\frac{1}{T}\cdot 3\cdot \int\limits_{\frac{T}{12}}^{\frac{5T}{12}} \left[u_0(t)\right]^2 \cdot \mathrm{d}t} = \sqrt{\frac{3}{T}\cdot \int\limits_{\frac{T}{12}}^{\frac{5T}{12}} E_m^2 \cdot \left[\sin\left(\frac{2\pi}{T}t\right)\right]^2 \cdot \mathrm{d}t} =$$
$$= E_m \cdot \sqrt{\frac{1}{2}+\frac{3\cdot\sqrt{3}}{8\pi}} \approx 0.84\cdot E_m \tag{28}$$

It seems interesting to compare the above obtained values of $U_{0\text{-}rms}$ and $I_{1\text{-}ef\text{-}rms}$ with the corresponding parameters of a dead earth fault at AC side with negligible insulation admittances at the DC side. For this fault location these characteristic values are given by well-known formulas $U_{0-rms} = \frac{E_m}{\sqrt{2}} \approx 0.71 \cdot E_m$ and $I_{a-ef-rms} = 3\cdot\omega\cdot C_{ph}\cdot\frac{E_m}{\sqrt{2}} \approx 3\cdot\omega\cdot C_{ph}\cdot E_m\cdot 0.71$, respectively. (Dead) earth fault currents at the DC side are therefore few tens of percents smaller than at the AC side. On the contrary, displacement voltage u_0 for earth faults at the DC side is a little higher. Just as in "pure" AC IT networks this voltage could be used as a criterion for detection of insulation-to-ground failures. However, for earth faults at the DC side $u_0(t)$ waveform is not sinusoidal but a roughly constant function (see an example of this waveform in Fig. 3a with a relatively low AC component). Fig. 3b presents the waveform of low–resistance earth fault current $i_{1\text{-}ef}$ at the DC side. In Fig. 4 there are plotted the curves of displacement voltage u_0 as a function of fault resistance R_f for a given value of C_{ph} for earth fault condition at each side of the rectifier.

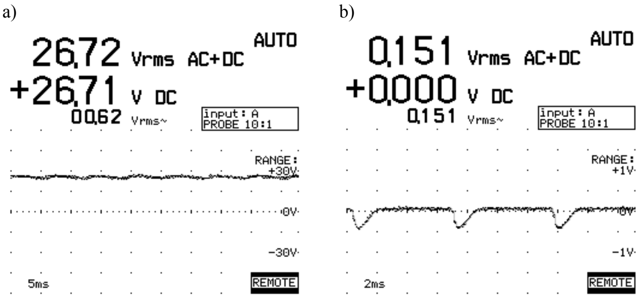

Fig. 3. Waveform of a) u_0 voltage , b) low –resistance earth fault current $i_{1\text{-}ef}$ for earth fault at the DC side positive pole (the current is measured as a voltage across the fault resistance)

Rys. 3. Przebieg a) napięcia u_0 , b) prądu niskooporowego zwarcia bieguna dodatniego prostownika (prąd zmierzono jako napięcie na rezystancji zwarcia)

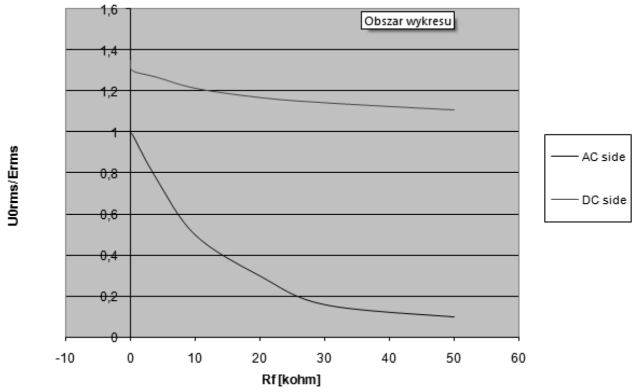

Fig. 4. Displacement voltage u_0 rms value referred to E_{rms} as a function of fault resistance R_f with a given value of $C_{ph} = C_a = C_b = C_c$, G_i=0 for earth fault condition at the AC or DC side of a rectifier

Rys. 4. Napięcie u_0 (wartość skuteczna) odniesiona do E_{rms} jako funkcja rezystancji zwarcia R_f dla danych wartości $C_{ph} = C_a = C_b = C_c$, G_i=0 przy doziemieniu po obu stronach prostownika

4. Insulation monitoring method exploiting the phase voltages mean value

A few methods of insulation monitoring for AC/DC IT networks have been designed and applied so far. These concepts exhibit however some shortcomings e.g. complicated structure with auxiliary test signal injection and/or measurement result dependence on network-to-ground capacitances [1]. A novel, simple method of determination of insulation-to-ground equivalent resistance in "mixed" single or multiphase networks (proposed by the author) is based on the above described characteristic property of these systems. In case of different insulation conductances of both poles at the DC side, the voltages of all points belonging to their AC side may have a non-zero mean value. For 3-phase networks it is given by formula (20). The proposed procedure consists of two steps. The AC side conductor-to-ground mean voltage is measured in two states: (1) $U_{01\text{-}mean}$ in normal working condition, (2) $U_{02\text{-}mean}$ with an additional resistor $R_{add}=1/G_{add}$ connected between any conductor at the AC side and ground. The sought parameter G_i can be calculated from the formula

$$G_i = G_{add}\cdot\frac{U_{02-mean}}{U_{01-mean}-U_{02-mean}} \tag{29}$$

which follows directly from (20).

If the AC side-to-ground voltage has the zero mean value (due to $G_1=G_2$), then one of G_1 or G_2 conductances should be changed by grounding artificially any selected pole through a test conductance G_t. Then both steps of the procedure described above are executed, after which the test conductance G_t should be removed. The sought parameter G_i is given as

$$G_i = G_{add}\cdot\frac{U_{02-mean}}{U_{01-mean}-U_{02-mean}} - G_t \tag{30}$$

5. Conclusions

From the calculations and recordings presented above important conclusions relating to methods of earth fault detection can be drawn. In three-phase AC/DC IT networks the zero sequence component of phase voltages is – in distinction from AC IT systems without rectifiers – a much less useful criterion of earth fault detection [3]. There are few differences concerning application of this parameter to "pure" and "mixed" networks. The non-zero mean value of this voltage is an indicator not only of an earth fault but also of asymmetry of insulation-to-ground resistances of both poles at the DC side. Its rms value exceeds E_{rms} even for a high, but asymmetrical level of insulation resistance at this side e.g. $G_a=G_b=G_c=G_1=0$ and $G_2=G_i$. Thus, this method can produce a false alarm, too. The phase voltages mean value can, however, be exploited for a simple, reliable method for determination of insulation-to-ground equivalent resistance as explained in Section 4. $U_{0\text{-}rms}$ value is also much less influenced by insulation resistances variation at the DC side than at the AC side if asymmetry of G_1 and G_2 is maintained. Therefore sensitive setting of overvoltage relays measuring u_0 voltage rms value is practically impossible when detection of insulation deterioration at both sides is required. A reasonable but only partial solution can be measurement of both AC and DC (mean value) components of u_0 voltage separately.

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