SINGLE-PHASE SHORT-CIRCUIT CURRENT DISTRIBUTION IN MICROHYDROPLANTS

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The design of earth installation for microhydroplants must take into account that in neither of the functioning regimes the admissible values of touch voltage and pace voltage not to be exceeded. These voltage reach maximal values when the currents in earth installation are maximal, such as in single-phase short-circuit. In the paper are considered three cases: short-circuit to earth installation of microhydroplants; short-circuit to earth installation of transformer o,4/20kV; short-circuit to earth installation of low voltage consumer of 0,4kV. The calculation was made starting from a real situation in order to compare the theoretical results with measurements. The method of symmetrical components is used, considering that voltages as well as currents have sinusoidal time variation. The reasonable fit of results shows that the simplifications admitted are technically acceptable.

1. INTRODUCTION

To realize a micro hydro power plant (MHC) respectively a small hydroelectric power plant (CHEMP) it was necessary to review and complete the norms for the station earth dimensioning. The economically dimensioning of the station earth, but taking in consideration the technical conditions, needs the values for the currents, which are close in the most unfavorable regions from the work protection point of view. For the dimensioning of the station earth it is taking in consideration single-phase short-circuit currents because through these installations the currents have maximum values. From the realization mode of the station earth for the substation and the MHC earth electrode or CHEMP earth electrode point of view these are separately realized but these are connected through a steel flat band respectively, through the low voltage network null conductor. It is considerate the case when at the low voltage bar are connected also consumers that are situated far from the MHC or CHEMP, this is the most common case. The calculated results were verified comparing with measured currents. On a real situation it was produced a single-phase short-circuit at the MHC earth electrode, at the substation earth electrode, respectively at the consumers that are connected at the low voltage bar, in an extent station.

2. MATHEMATICAL MODEL FOR THE SINGLE-PHASE SHORT-CIRCUIT CURRENTS CALCULATION

In figure 1 it is presented the single-phase installation scheme on which was calculated the single-phase short-circuit current and the distribution of it on the

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station earth, in the case when the single-phase short-circuit it is at the MHC earth electrode, at the substation earth electrode, respectively at the asynchronous motor carcass. Short-circuit currents and their repartition are determinate experimental too.

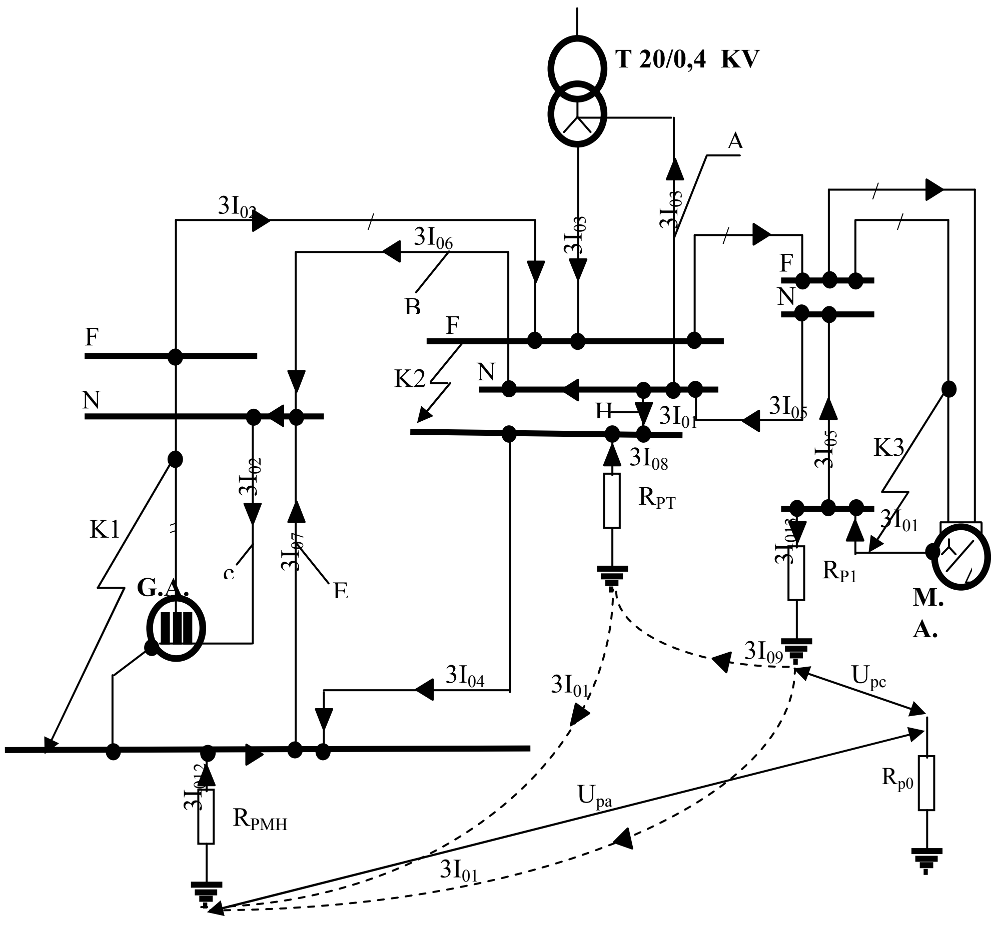

Fig. 1. Single-phase installation scheme and the short-circuit currents

In this figure the notations have the following meaning: T – transformer (20/0.4 kV); H.G.A.- hydro generator realized with an asynchronous generator; M.A. – asynchronous motor feed from MHC or CHEMP; R_{PT} – earth electrode resistance for the substation; R_{MHC} – earth electrode resistance for the MHC; R_{P1} – earth electrode resistance for the consumer; R_{P0} – earth electrode resistance from the point considerate null point; $3I_{01}$ – single-phase short-circuit current; $3I_{02}$ – single-phase short-circuit current put out at the asynchronous generator; $3I_{03}$ – single-phase short-circuit current put out at the system; $3I_{04}$ – current, which is close through the flat band, which connect the MHC, earth electrode with the substation earth electrode; $3I_{05}$ – the current, which is close through the conductor, which connect the substation null with the consumer null; $3I_{06}$ – the current, which is close through the conductor, which connect the substation null with the MHC null; $3I_{07}$ – the current that is close through the cable, which connects the MHC null with the MHC, station earth; $3I_{08}$ – the current which is close through the substation plug; $3I_{09}$ – the current that is close through ground between the consumer plug and the substation; $3I_{010}$ – the current, which is close through ground between the substation plug and MHC; $3I_{011}$ – the current that is close through ground between the consumer plug and MHC; $3I_{012}$ – the current that is close through the MHC plug; $3I_{013}$ – the current, which is close through the consumer, station earth; $3I_{014}$ – the current that is close through the cable, which connect the transformer null with the station earth of the substation.

For the single-phase short-circuit currents calculation it is used symmetrical components method. In figure 2 it is presented the connection mode of the sequence schemes for the three considerate short-circuits.

The impedances which intervene in the sequences scheme have the following meaning: Z_{1T}, Z_{2T}, Z_{0T} – the transformer sequence impedances 20/0.4 kV; Z'_{1L}, Z'_{2L}, Z'_{0L} – the sequence impedances of the electric line from the substation on the MHC bars; Z''_{1T}, Z''_{2T}, Z''_{0T} – the sequence impedances of the electric line from the asynchronous generator terminals on the MHC bars; R_l – the limitation resistance of the single-phase short-circuit current; $X_{\sigma 1}$ – the dispersion reactance of the asynchronous generator stator; $X'_{\sigma 2}$ – the dispersion reactance of the asynchronous generator rotor reduce at the stator; R'_2/S – the rotor resistance of the asynchronous generator rotor reduce at the stator; C – the phase capacity of the condenser battery mount on the MHC bars; Z_{1L}, Z_{2L}, Z_{0L} – sequence impedances of the electric line from the substation bars to the consumer; Z_{NA} – the cable impedance, which is connect to the transformer null 20/0.4 kV like null substation bars; Z_{NB} – the cable impedance, which is connect to the MHC null bars with the substation null bars; Z_{NC}– the cable impedance, which is connect to the asynchronous generator null with the MHC null bars; Z_{ND} – the cable impedance, which is connect to the substation null bars with the consumer null control panel; Z_l – the flat band impedance, which connect the MHC plug with the substation plug; Z'_l – the steel cable flat band, which connect the consumer, control panel null with the earth electrode of the consumer; Z_{N1} – cable impedance, which connect the MHC plug with the MHC null bars; Z_{P1} – the ground impedance between MHC plug and R_{P1} of the consumer; Z_{P2} – the ground impedance between the substation plug and consumer plug; Z_P – the ground impedance between MHC plug and the substation plug; R_{P1} – the dispersion consumer earth electrode resistance; R_{PT} – the resistance to earth of the substation; R_{MHC} - the resistance to earth of the MHC.

In the scheme from figure 2, the relation gives the source voltage:

$$\underline{U}_f = \frac{U_{ff} \frac{1}{j\omega C}}{R + \frac{1}{j\omega C}} ,$$

$$\text{where } \underline{U}_{ff} = \frac{U_{f1}\left(jX_{\sigma 1} + Z'_{1L}\right) + U_{f2}\left(Z_{1T} + Z'_{1L}\right)}{jX_{\sigma 1} + Z_{1T} + 2Z'_{1L}} , \quad (1)$$

$$\text{equvalent impedance is } \underline{Z}_E = \frac{\underline{Z}^* \frac{1}{j\omega C}}{\underline{Z}^* + \frac{1}{j\omega C}} = R_E + jX_E ,$$

$$\text{where } \underline{Z}^* = \frac{\left(jX_{\sigma 1} + Z'_{1L}\right)\left(Z_{1T} + Z_{1L}'\right)}{jX_{\sigma 1} + Z_{1T} + 2Z'_{1L}}$$

$$\underline{Z}_i = \frac{\left(Z_{2T} + Z'_{2L}\right)\left(R_2' + jX_\sigma' + jX_{\sigma 1} + Z''_{2L}\right)\frac{1}{j\omega C}}{Z_{2T} + Z'_{2L} + R_2' + jX_\sigma' + jX_{\sigma 1} + Z''_{2L} + \frac{1}{j\omega C}} = R_2 + jX_2$$

Fig. 2. The sequences scheme connection mode in single-phase short-circuit case at the MHG plug

To calculate the single-phase short-circuit current on each circuit branch presented in fig. 2 it is used the nodes voltage method. Using this method we obtain the following equations, for $V_G = 0$:

$$\begin{aligned}
&\underline{V}_A(\underline{Y}' + \underline{Y}'' + \underline{Y}_E) - \underline{V}_B\underline{Y}'' - \underline{V}_C\underline{Y}' - \underline{V}_F\underline{Y}_E = -\underline{U}_f\,\underline{Y}_E \\
&\underline{V}_B(\underline{Y}'' + \underline{Y}_1 + \underline{Y}_9) - \underline{V}_A\underline{Y}'' - \underline{V}_C\underline{Y}_1 - \underline{V}_F\underline{Y}_9 = 0 \\
&\underline{V}_C(\underline{Y}' + \underline{Y}_1 + \underline{Y}_3 + \underline{Y}_4) - \underline{V}_A\underline{Y}' - \underline{V}_B\underline{Y}_1 - \underline{V}_D\underline{Y}_3 = 0 \\
&\underline{V}_D(\underline{Y}_3 + \underline{Y}_2 + \underline{Y}_5) - \underline{V}_C\underline{Y}_3 - \underline{V}_F\underline{Y}_2 - \underline{V}_E\underline{Y}_5 = 0 \qquad (2) \\
&\underline{V}_E(\underline{Y}_5 + \underline{Y}_6 + \underline{Y}_8) - \underline{V}_D\underline{Y}_5 - \underline{V}_H\underline{Y}_8 = 0 \\
&\underline{V}_F(\underline{Y}_9 + \underline{Y}_2 + \underline{Y}_{10} + \underline{Y}_E) - \underline{V}_B\underline{Y}_9 - \underline{V}_D\underline{Y}_2 - \underline{V}_H\underline{Y}_{10} - \underline{V}_A\underline{Y}_E = \underline{U}_f\,\underline{Y}_E \\
&\underline{V}_H(\underline{Y}_{10} + \underline{Y}_7 + \underline{Y}_8) - \underline{V}_F\underline{Y}_{10} - \underline{V}_E\underline{Y}_8 = 0
\end{aligned}$$

From the (2) equations system result the nodes voltage values. Where the admittances, which intervene, have the following expressions:

$$\underline{Y}' = \frac{1}{3Z_{Na} + Z_{OT} + Z_{OL}'} \quad \underline{Y}'' = \frac{1}{3Z_{Nc} + jX_{\sigma 1} + Z_{OL}''}$$

$$\underline{Y}_E = \frac{1}{R_e + Z_e + R_e + Z_e + R_e} \quad \underline{Y}_1 = \frac{1}{3Z_{Nb}} \quad \underline{Y}_2 = \frac{1}{3Ze} \quad \underline{Y}_3 = \frac{1}{3Z_{Nh}}$$

$$\underline{Y}_4=\frac{1}{3Z_{Nd}+3Z'_e+3R_{p1}}\quad \underline{Y}_5=\frac{1}{3Z_{RPT}}\quad \underline{Y}_6=\frac{1}{3Z_{p2}}\quad \underline{Y}_7=\frac{1}{3Z_{p1}} \tag{3}$$

$$\underline{Y}_8=\frac{1}{3Z_p}\quad \underline{Y}_9=\frac{1}{3Z_{Nc}}\quad \underline{Y}_{10}=\frac{1}{3R_{pMCH}}$$

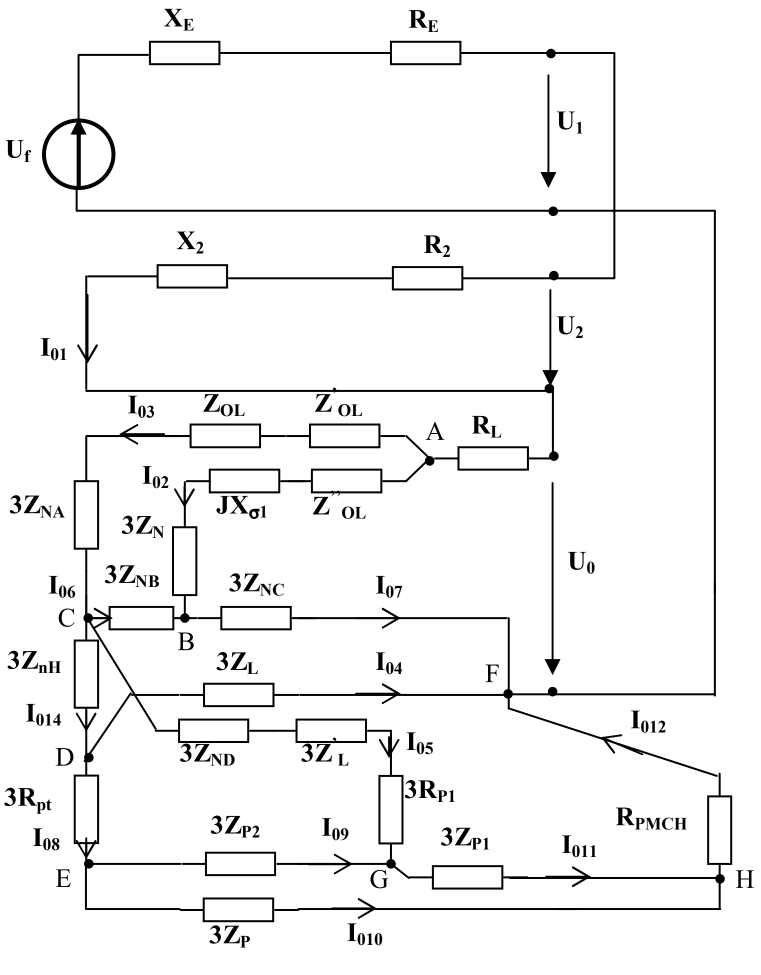

Fig. 2. The sequences scheme connection mode in single-phase short-circuit case at the MHG plug

The branches circuit currents depending on nodes voltage are:

$$
\begin{array}{ll}
I_{01} = (\underline{V}_F - \underline{V}_A)\underline{Y}_E & I_{02} = (\underline{V}_A - \underline{V}_B)\underline{Y}'' \\
I_{03} = (\underline{V}_A - \underline{V}_C)\underline{Y}' & I_{04} = (\underline{V}_D - \underline{V}_F)\underline{Y}_2 \\
I_{05} = (\underline{V}_C - \underline{V}_G)\underline{Y}_4 & I_{06} = (\underline{V}_C - \underline{V}_B)\underline{Y}_1 \\
I_{07} = (\underline{V}_B - \underline{V}_F)\underline{Y}_9 & I_{08} = (\underline{V}_D - \underline{V}_E)\underline{Y}_5 \\
I_{09} = (\underline{V}_E - \underline{V}_G)\underline{Y}_6 & I_{010} = (\underline{V}_E - \underline{V}_H)\underline{Y}_8 \\
I_{011} = (\underline{V}_G - \underline{V}_H)\underline{Y}_7 & I_{012} = (\underline{V}_H - \underline{V}_F)\underline{Y}_{10} \\
I_{014} = (\underline{V}_C - \underline{V}_D)\underline{Y}_3 &
\end{array}
\qquad (4)
$$

3. NUMERICAL AND EXPERIMENTAL RESULTS

For the considerate situation it were determinated the values for the impedances from figure 2. With these values were calculated the nodes voltages (relations 1.1) respectively the currents from the circuit branches (relations 1.3). The values are presented in table 1.

Table 1. Calculated and measured currents values

Short-circuit place	MHC plug			Substation plug			Consumer		
	Calcu-lated	Meas-ured	Error %	Calcu-lated	Meas-ured	Error %	Calcu-lated	Meas-ured	Error %
I_{01} (A)	162	150	8	156,3	142,7	8,7	295	282	4,4
I_{02} (A)	74.2	68,2	8	61,7	54,9	11	102	95	6,9
I_{03} (A)	80.3	76	5	102,1	95,4	6,6	193	185,5	3,9
I_{04} (A)	8.2	6,82	2	10,2	9,3	8,8	16	14	12,5
I_{05} (A)	0,.31	0	-	1,58	1,71	-8,9	251,6	242,3	3,7
I_{06} (A)	71	66	7	56,3	52	7,6	45,4	41,3	9
I_{07} (A)	139.4	134,2	3	10,2	9,3	8,8	61	54	11,5
I_{08} (A)	4.3	3,4	26	0,88	0,65	26	2,1	1,9	9,5
I_{09} (A)	0,21	0	-	0,26	0	-	2,3	1,9	17,4
I_{010} (A)	4,2	3,4	23	0,31	0,38	23	0,5	0,49	2,1
I_{011} (A)	0,25	0		1,84	1,71	7,1	43,1	40,3	6,5
I_{012} (A)	3.9	3,4	14	2,15	1,62	25	43,6	40,8	6,5
I_{013} (A)	0,21	0	-	1,58	1,71	-8,9	43,4	40	7,8
I_{014} (A)	12.1	10.15	19	145,2	136,3	6,1	16,2	14,1	13

In the same table are presented the experimental currents values for the considerated cases, the MHC earth electrode (K1 point), at the substation earth electrode (K2 point), respectively at the consumers that are connected at the low voltage bar (K3 point).

From the table values result that the differences between the calculated currents values and measured currents values are in limits. Taking in consideration the accepted simplifications in the calculation, the deviations are acceptable from technical point of view. These differences are acceptable especially because the determinations possibility to determinate the parameters that appear in the single-phase short circuit current calculation are limited.

4. CONCLUSIONS

In case that exist connections between the substation null and MHC null, a single phase short-circuite at the MHC earth electrode or at the substation earth electrode will not determinate high values currents through the both earth electrode, and the consumer earth electrode doesn't exist current. Because of the low cable impedance which connect the substation null with the MHC null, the single-phase short-circuit current values it's much bigger than the current which is closed through the earth electrode. For this reason it is not necessary to impose special conditions from the MHC earth electrode-dimensioning point of view. The two earth electrode R_{PT} and R_{MHC} are connected through a steel band with Z_l impedance and through the PT null with MHC null, result that the interrupting risk between the earth electrodes is practically zero. In case that the short-circuit is produced at the consumer earth electrode, the current value which is closed through this earth electrode has the approximately value of 120 A, which determinate a 136 V voltage at the earth electrode, dangerous voltage for the work protection. Although the consumer earth electrode current represent only 14,2 % from the single-phase short-circuit current, this value determinate a dangerous earth electrode voltage. For this reason it is necessary to realize a consumer earth electrode with low value and also the connections between the earth electrode must be realized from low impedances cable.

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