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Current in lighting wire grounded in each tower determination under short circuit to tower or short circuit to earth escape tower

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Abstract. The algorithms for short circuit (SC) currents as well as induced in grounded in each tower lighting wire (LW) currents are presented for the case of SC to overhead transmission line (OTL) tower and to the ground passing the tower.

Introduction

Overhead transmission lines (OTL) are equipeed by lighting wires ontaining fiber optical communication channels (FOLW). FOLW technically are grounded in each OTL tower. OTL damaged phase current magnetic field (MF) as well as short circuit (SC) current in FOLW under SC is created the current, and this current value should not exceed the value permissible by thermal stability. In the report of this workshop 2018 [1,2] Double-circuit 220 kV OTL 46.956 km length without transpositions in tower Itph220-2+5 brand is discussed (Figure 1). There are determined self- and mutual-inductive resistance, earth resistance as well as electromotive force induced in LF under known single-phase SC to the ground for phases and LW by Carson equations [3,4,5] when ρ_3 = 100 Ohm/m ground resistivity and 0.33 km span long. There are calculated induced by SC to the ground MF nearest to the wire C2 phase in LW at 0.5; 1; 2; 3; 4; 5; 7.8 and 10 km from substation 2 for OTL connection to substation 2 with less network resistance and idling (Id) at substation 1 side. Calculations are carried out for following brands LW: FOLW-c-1-24(G.652)-18,7/93, FOLW-c-1-16(G.652)-14,7/61, FOLW-c-1-24(G.652)-13,1/54 and FOLW-ц-1-48(G.652)-12/94. Maximal current value was induced in 6th span under SC at 5 km distance from substation 2 for all FOLW (for FOLW-…-18.7/93 I_{Wmax} = I_{W6} = 5.48 kA). There are determined the currents induced in FOLW for simultanious C1 and C2 phases SC to the ground at 5 km distanse from substation 2 unlikely case. This case for FOLW -…-18.7/93 I_{Wmax} = I_{W6} = 6.296 kA. In [2] there was discussed the case of 220 kV OTL C2 phase (connected to substation 1 and substation 2 and operation without power transmission) SC to the ground at 5 km distance from substation 2, and FOLW-…-18.7/93 I_{Wmax} = I_{W6} = 5.152 kA. SC current and induced in LW current simultaneous determination were carried out for 220 kV OTL idling case at substation 1 (S1) side and C2 phase SC to the ground at 5 km distance from substation 2 [1,2] (Figure 2).

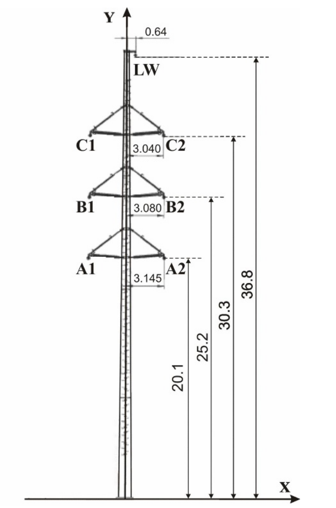

Fig. 1. 220 kV double-circuit OTL on intermediate tower.

Current simultaneous determination method allows taking into account the current in LW affect to SC current as well as SC current flowing into LW. Under case of simultaneous calculation method current greatest value in LW is accounts for first span from substation 2 (S2), and for 220 kV OTL FOLW-…-18.7/93 I_{Wmax} = I_{W1} = 6.876 kA.

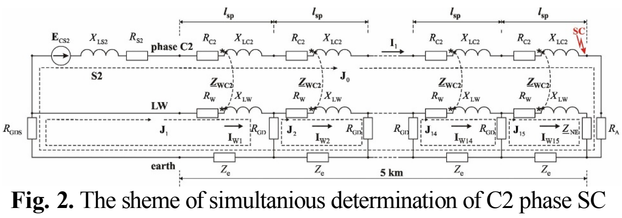

Fig. 2. The sheme of simultanious determination of C2 phase SC current to the ground, and currents induced in LW.

1 Current in LW depend on distance from C2 phase operating in idle regime at S1 side SC to the ground place

For FOLW testing brands let's make a simultaneous determination of SC current and currents in wires under

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C2 phase SC to the ground at the ends of span. The number (No.) of SC span: 1÷5, 8, 10÷15 and 18. Maximal current module value in FOLW for all calculated cases were in first from S2 span, i.e. current I_{W1} has the maximal value.

Figure 3 shows the histogram of current module value of 220 kV OTL with FOLW -…-18.7/93, figure 4 – with FOLW-…-14.7/61 and FOLW-…-13.1/54, and figure 5 – with FOLW-…-12/94.

I_{W1} Greatest current values for:

FOLW-…-18.7/93 under SC span No.=12, I_{LW1}=7.42 kA;
FOLW-…-14.7/61 under SC span No.=11, I_{LW1}=6.86 kA;
FOLW-…-13.1/54 under SC span No.=10, I_{LW1}=6.42 kA;
FOLW-…-12.0/94 under SC span No.=8, I_{LW1}= 4.64 кА.

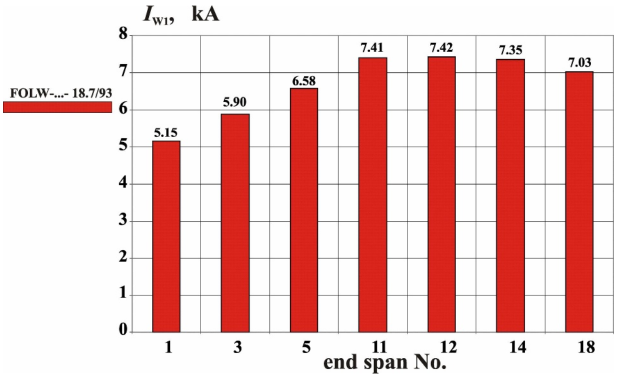

Fig. 3. The histograms of I_{LW1} currents for 220 kV OTL with FOLW-…-18.7/93 under C2 phase SC to the ground at the end of span number: 1, 3, 5, 11, 12, 14 and 18

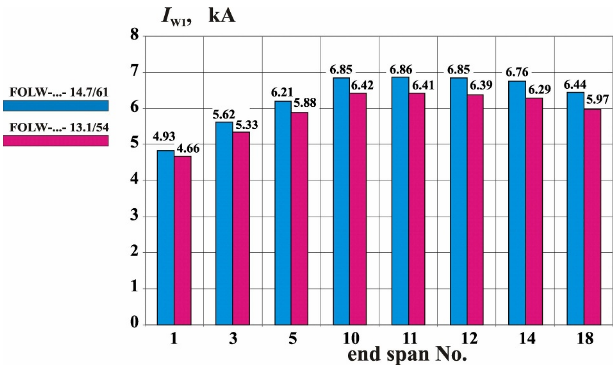

Fig. 4. The histograms of I_{LW1} currents for 220 kV OTL with FOLW-…-14.7/61 and FOLW-…-13.1/54 under C2 phase SC to the ground at the end of span number: 1, 3, 5, 10, 11, 12, 14 and 18

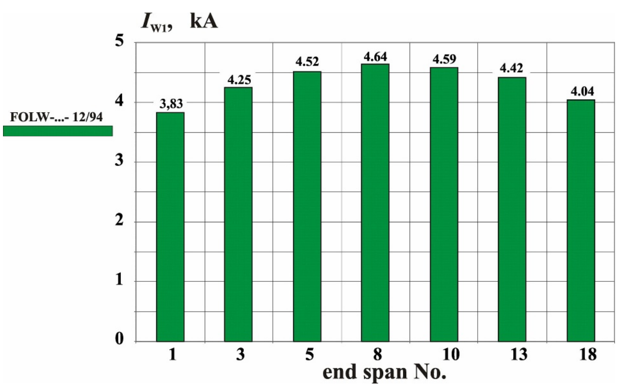

Fig. 5. The histograms of I_{LW1} currents for 220 kV OTL with FOLW-…-12/94 under C2 phase SC to the ground at the end of span numbers:1, 3, 5, 8, 10, 13 и 18

2 Current in LW depending on distance to S2 from C1 and C2 phases 220 kV OTL operating in idle mode at S1 side SC to the ground place

Let's calculate the currents of simultaneous C1 and C2 phases SC to the ground as well as currents in LW. SC is at the end of 15th span from 220 kV S2 operating in idle mode. The sheme of calculation is shown in figure 6.

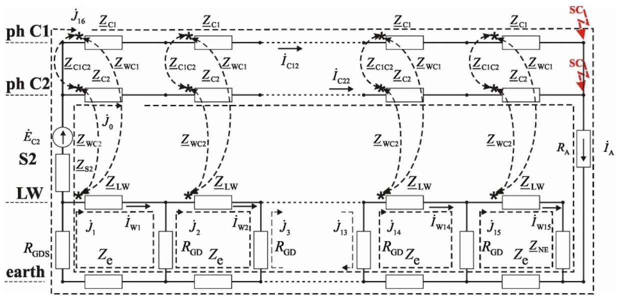

Fig. 6. The scheme of C1 and C2 phases simultanious SC to the ground at the end of 15th span from S2.

Let's analyse 220 kV OTL with FOLW-…-18.7/93. Then for figure 6 sheme: $\underline{Z}_{C1} = R_{C1} + jX_{LC1} = \underline{Z}_{C2} = R_{C2} + jX_{LC2}$ = 0.02433 + j0.23388 Ohm; $\underline{Z}_{LW} = R_W + jX_{LW}$ = 0.0667 + j0.2422 Ohm; Z_e = 0.01533 Ohm; $\underline{Z}_{WC1}$ = 0.0154 + j0.100 Ohm; $\underline{Z}_{WC2}$ = 0.015 + j0.101 Ohm; $\underline{Z}_{C1C2}$ = 0.0155 + j0.1167 Ohm; $\underline{Z}_{S2} = R_{S2} + jX_{LS2}$ = 0.841 + j5.796 Ohm; $\underline{Z}_{NE}$ = 1.257 + j0.816 Ohm; R_{GDS} = 0.5 Ohm; R_{GD} = 10 Ohm; R_A = 0.42 Ohm; $\boldsymbol{E}_{C2}$ = 127017∠120° B.

System of equations by the method of contour currents:

$$\left.\begin{array}{l}
\dot{J}_0(\underline{Z}_{S2}+15\underline{Z}_{C2}+15Z_e+R_A+R_{GDS})+\dot{J}_1(R_{GDS}+Z_e+\underline{Z}_{WC2})+\dot{J}_2(Z_e+\underline{Z}_{WC2})+\ldots \\
\quad \ldots+\dot{J}_{15}(Z_e+\underline{Z}_{WC2})+\dot{J}_{16}(\underline{Z}_{S2}+R_A+15Z_e+R_{GDS}+15\underline{Z}_{C1C2})=\dot{E}_{C2}; \\
\dot{J}_0(R_{GDS}+Z_e+\underline{Z}_{WC2})+\dot{J}_1(\underline{Z}_{LW}+R_{GD}+Z_e+R_{GDS})-\dot{J}_2R_{GD}+ \\
\quad +\dot{J}_{16}(R_{GDS}+Z_e+\underline{Z}_{WC1})=0; \\
\dot{J}_0(Z_e+\underline{Z}_{WC2})-\dot{J}_1R_{GD}+\dot{J}_2(\underline{Z}_{LW}+2R_{GD}+Z_e)-\dot{J}_3R_{GD}+\dot{J}_{16}(Z_e+\underline{Z}_{WC1})=0; \\
-\,- \\
\dot{J}_0(Z_e+\underline{Z}_{WC2})-\dot{J}_{13}R_{GD}+\dot{J}_{14}(\underline{Z}_{LW}+2R_{GD}+Z_e)-\dot{J}_{15}R_{GD}+\dot{J}_{16}(Z_e+\underline{Z}_{WC1})=0; \\
\dot{J}_0(Z_e+\underline{Z}_{WC2})-\dot{J}_{14}R_{GD}+\dot{J}_{15}(\underline{Z}_{LW}+Z_{NE}+Z_e+R_{GD})+\dot{J}_{16}(Z_e+\underline{Z}_{WC1})=0; \\
\dot{J}_0(\underline{Z}_{S2}+15\underline{Z}_{C1}+15Z_e+R_A+R_{GDS})+\dot{J}_1(R_{GDS}+Z_e+\underline{Z}_{WC2})+\dot{J}_2(Z_e+\underline{Z}_{WC1})+ \\
\quad \ldots+\dot{J}_{14}(Z_e+\underline{Z}_{WC1})+\dot{J}_{15}(Z_e+\underline{Z}_{WC1})+ \\
\quad +\dot{J}_{16}(\underline{Z}_{S2}+15\underline{Z}_{C1}+15Z_e+R_A+R_{GDS})=\dot{E}_{C2}.
\end{array}\right\}$$

Solving equations system and considering that $\boldsymbol{I}_{C12} = \boldsymbol{J}_{16}$, $\boldsymbol{I}_{C12} = \boldsymbol{J}_0$, $\boldsymbol{I}_{LW1} = \boldsymbol{J}_1$, $\boldsymbol{I}_{LW15} = \boldsymbol{J}_{15}$, and $\boldsymbol{I}_A = \boldsymbol{J}_0 + \boldsymbol{J}_{16}$, will obtain:

$\boldsymbol{I}_{C12}$ = 7.868 ∠43.5° kA; $\boldsymbol{I}_{C22}$ = 7.822 ∠43.3° kA;
$\boldsymbol{I}_A$ = 15.691 ∠43.4° kA;
$\boldsymbol{I}_{LW1}$ = 8.055 ∠-138.3° kA; $\boldsymbol{I}_{LW2}$ = 7.696 ∠-138.2° kA;
$\boldsymbol{I}_{LW3}$ = 7.357 ∠-137.8° kA; ... ; $\boldsymbol{I}_{LW13}$ = 4.160 ∠-133.0° kA;
$\boldsymbol{I}_{LW14}$ = 3.767 ∠-134.5° kA; $\boldsymbol{I}_{LW16}$ = 3.358 ∠-137.5° kA.

Ток I_{LW1} current has maximal value.

There were carried out simultanious SC current determination as well as currents in LWs under C1 and C2 SC to the ground at the end of span (all analised FOLW brands). No. of span: 1, 3, 5, 8, 10, 11, 12, 13, 14, 18 (Figures 7, 8 and 9).

Maximal current values $\boldsymbol{I}_{LW1}$ for:

FOLW-…-18.7/93 under SC span No.= 13, I_{LW1} = 8.09 kA;
FOLW-…-14.7/61 under SC span No. = 12, I_{LW1} = 7.45 kA;
FOLW-…-13.1/54 under SC span No. = 12, I_{LW1} = 6.96 kA;

FOLW-…-12.0/94 under SC span No. = 8, I_{LW1} = 4.93 kA.

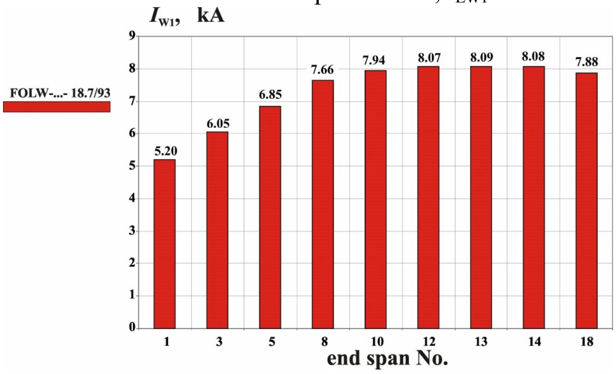

Fig. 7. The histograms of I_{LW1} currents for 220 kV OTL with FOLW-…-18.7/93 under C1 and C2 phase SC to the ground at the end of span number: 1, 3, 5, 8, 10, 12, 13, 14 и 18

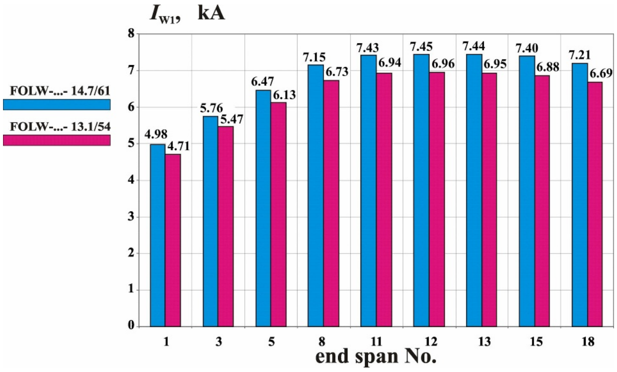

Fig. 8. The histograms of I_{LW1} currents for 220 kV OTL with FOLW -…-14.7/61 and FOLW-…-13.1/54 under C1 and C2 phase SC to the ground at the end of span number: 1, 3, 5, 8, 11, 12, 13, 15 и 18

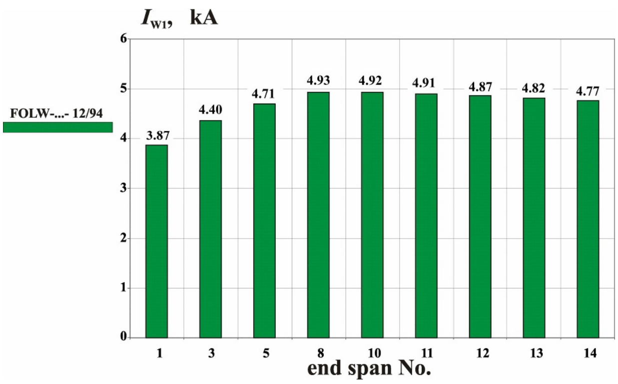

Fig. 9. The histograms of I_{LW1} currents for 220 kV OTL with FOLW -…-12/94 under C1 and C2 phase SC to the ground at the end of span number: = 1, 3, 5, 8, 10, 11, 12, 13 и 14

3 Current in LW depending on the distance from 220 kV OTL (operating in in connected mode, but without power transmission) C2 phase SC to tower place to S2

Currents in LW 220 kV OTL operating in connected to both side mode but without power transmission SC current and and C2 phase SC to tower of first from S2 span current simultanious calculation will make (Figure 10).

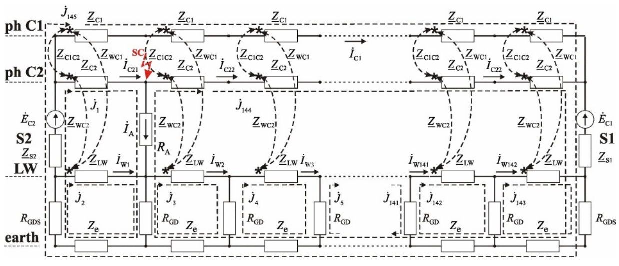

Fig. 10. The scheme of OTL 220 kV operating in both side connection but without power transmission C2 phase SC to tower of 1st from S2 span.

The system of equations by countur current method:

$$
\left.
\begin{aligned}
&\dot{J}_1[\underline{Z}_{S2}+\underline{Z}_{C2}+Z_e+R_A+R_{GD}+R_{GDS}]+\\
&\quad+\dot{J}_2(R_{GDS}+Z_e+R_{GD}+\underline{Z}_{WC2})-\dot{J}_3R_{GD}+0+\ \dots\ +0+\\
&\quad+0-\dot{J}_{144}(R_{GD}+R_A)+\dot{J}_{145}(\underline{Z}_{S2}+R_{GDS}+Z_e+\underline{Z}_{C1C2})=\dot{E}_{C2};\\
&\dot{J}_1(R_{GDS}+Z_e+R_{GD}+\underline{Z}_{WC2})+\dot{J}_2(\underline{Z}_{LW}+R_{GD}+Z_e+R_{GDS})-\dot{J}_3R_{GD}+0+\dots+0-\\
&\quad-\dot{J}_{144}R_{GD}+\dot{J}_{145}(R_{GDS}+Z_e+\underline{Z}_{WC1})=0;\\
&-\dot{J}_1R_{GD}-\dot{J}_2R_{GD}+\dot{J}_3(\underline{Z}_{LW}+2R_{GD}+Z_e)-\dot{J}_4R_{GD}+0+\dots+0+\\
&\quad+0+\dot{J}_{144}(Z_e+R_{GD}+\underline{Z}_{WC2})+\dot{J}_{145}(Z_e+\underline{Z}_{WC1})=0;\\
&-----------------------------------\\
&0+\dots+0-\dot{J}_{142}R_{GD}+\dot{J}_{143}(\underline{Z}_{LW}+R_{GDS}+R_{GD}+Z_e)+\\
&\quad+\dot{J}_{144}(R_{GDS}+Z_e+\underline{Z}_{WC2})+\dot{J}_{145}(R_{GDS}+Z_e+\underline{Z}_{WC1})=0;\\
&-\dot{J}_1(R_{3Y}+R_A)-\dot{J}_2R_{GD}+\dot{J}_3(R_{GD}+Z_e+\underline{Z}_{WC2})+\dot{J}_4(Z_e+\underline{Z}_{WC2})+\\
&\quad+\dot{J}_5(Z_e+\underline{Z}_{WC2})+\dots+\dot{J}_{141}(Z_e+\underline{Z}_{WC2})+\dot{J}_{142}(Z_e+\underline{Z}_{WC2})+\\
&\quad+\dot{J}_{143}(R_{GDS}+Z_e+\underline{Z}_{WC2})+\dot{J}_{144}[\underline{Z}_{S1}+141(\underline{Z}_{C2}+Z_e)+R_A+R_{GD}+R_{GDS}]+\\
&\quad+\dot{J}_{145}(\underline{Z}_{S1}+R_{GDS}+141Z_e+141\underline{Z}_{C1C2})=-\dot{E}_{C1};\\
&\dot{J}_1(\underline{Z}_{S2}+R_{GDS}+Z_e+\underline{Z}_{C1C2})+\dot{J}_2(R_{GDS}+Z_e+\underline{Z}_{WC1})+\dot{J}_3(Z_e+\underline{Z}_{WC1})+\\
&\quad+\dot{J}_4(Z_e+\underline{Z}_{WC1})+\dots+\dot{J}_{141}(Z_e+\underline{Z}_{WC1})+\dot{J}_{142}(Z_e+\underline{Z}_{WC1})+\\
&\quad+\dot{J}_{143}(R_{GDS}+Z_e+\underline{Z}_{WC1})+\dot{J}_{144}(\underline{Z}_{S1}+R_{GDS}+141Z_e+141\underline{Z}_{C1C2})+\\
&\quad+\dot{J}_{145}[\underline{Z}_{S2}+\underline{Z}_{S1}+142(\underline{Z}_{C1}+Z_e)+2R_{GDS}]=\dot{E}_{C2}-\dot{E}_{C1}.
\end{aligned}
\right\}
$$

The solving of eguation system give the values of SC current, currents in LW as well as in C1 and C2 phases. Figure 11 shows the hisogramms of current modules for 220 kV OTL with FOLW-…-18.7/93 ($\underline{Z}_{LW}$ = 0.066 + j0.240 Ohm) and with FOLW-…-12/94 ($\underline{Z}_{LW}$ = 0.368 + j0.249 Ohm), and in figure 12 – with FOLW-…-14.7/61 ($\underline{Z}_{LW}$ = 0.109 + j0.245 Ohm) and with FOLW-…-13.1/54 ($\underline{Z}_{LW}$ = 0.146 + j0.427 Ohm).

Under C2 phase SC to 1st span tower arc current were: for FOLW-…-18.7/93 $\boldsymbol{I}_A$ = 24.74∠43.3° kA, for FOLW-…-12/94 $\boldsymbol{I}_A$ = 24.01∠43.0° kA, for FOLW-…-14.7/61 $\boldsymbol{I}_A$ = 24.65∠44.0° kA, and for FOLW-…-13.1/54 $\boldsymbol{I}_A$ = 24.54∠44.5° kA.

Figure 13 shows the histogram of currents under SC of C2 phase of OTL with FOLW-…-18.7/93 and with FOLW-…-12/94 to 5th tower from substation 2, and figure 14 – to 30th tower from substation 2.

The distance of SC to tower place from substation 2 lead to phase current values as well as current in LW and arc current I_A dicrease. Current higher value in LW is achieved in the span located in the direction of the nearest from the tower on which was SC substation. In our case in the substation 2 direction. The greatest value is current I_{W1} under SC to 1st span tower.

Figure 15 shows the histograms of greatest current module values $I_{W\max}$ in LW under SC to tower of 1÷5th, 10th, 15th, 20th, 30th and 40th span from S2 side for FOLW-c-1-24(G.652)-18.7/93 and FOLW-c-1-48(G.652)-12/94.

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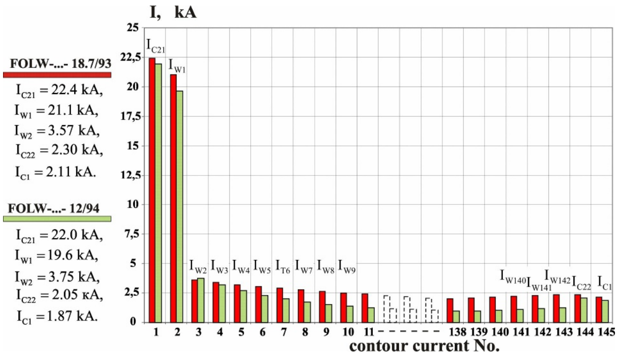

Fig. 11. Current modules under SC of C2 phase SC to 1st span from S2 for FOLW-…-18.7/93 and FOLW-…-12/94.

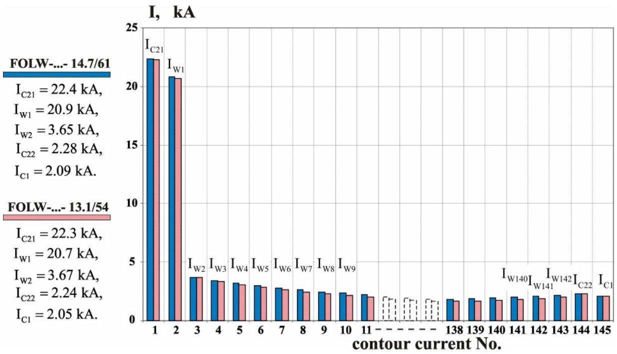

Fig. 12. Current modules under SC of C2 phase SC to 1st span from S2 for FOLW-…-14.7/61 and FOLW-…-13.1/54.

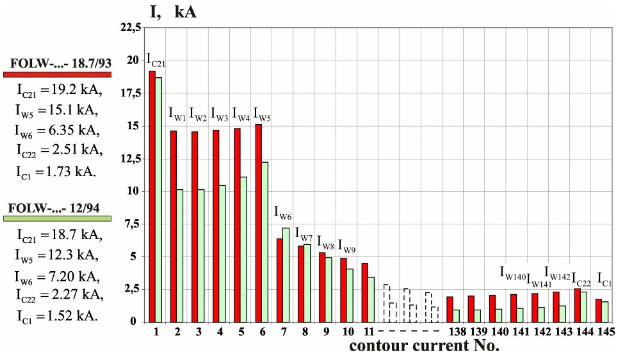

Fig. 13. Current modules under SC of C2 phase SC to 5th span from S2 for FOLW-…-18.7/93 and FOLW-…-12/94.

When OTL is powered from S1 side, idle at S2 side and SC to 1st from S1 tower I_{W1} current has a lower value (Fig. 16), because $\underline{Z}_{N1}$ = 0.93+j8.46 Ohm network resistance at S1 side is more network resistance $\underline{Z}_{N2}$ = 0.84 + j5.00 Ohm at S2 side.

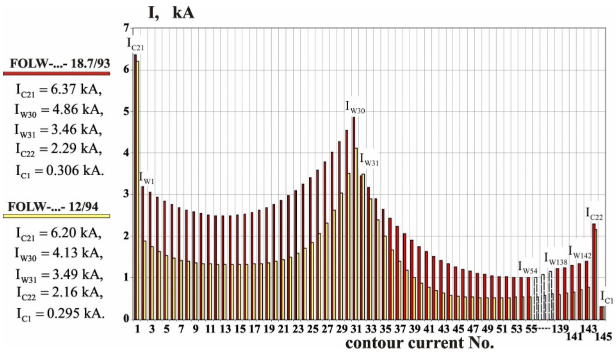

Fig. 14. Current modules under SC of C2 phase SC to 30th span from S2 for FOLW-…-18.7/93 and FOLW-…-12/94.

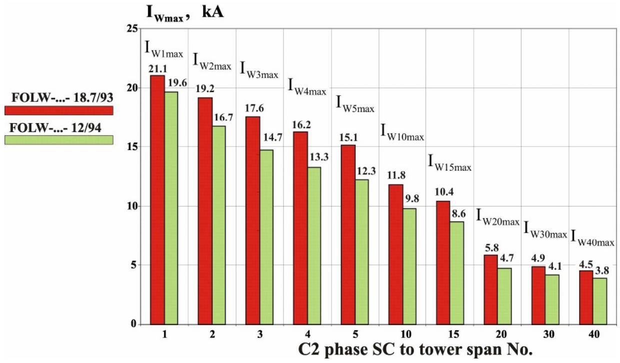

Fig. 15. Current module $I_{W\max}$ change under C2 phase SC to towers in span from S2 side: 1÷5th, 10th, 15th, 20th, 30th and 40th for FOLW-…-18.7/93 and FOLW-…-12/94.

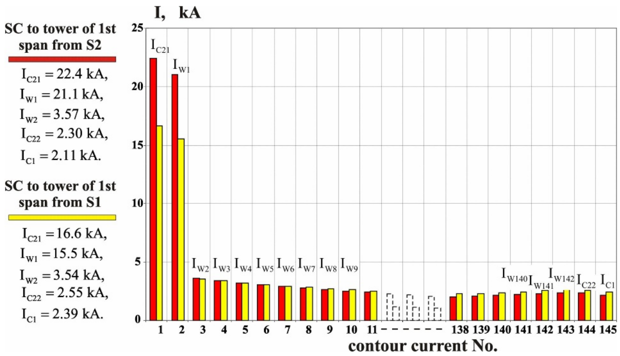

Fig. 16. Current module in LW and 220 OTL phases change under C2 phase SC to 1st from S1 and S2 tower for FOLW-c-1-24(G.652)-18.7/93.

I_{W1} greatest values under SC to 1st from S2 span tower:

- FOLW-…-18.7/93, I_{W1} = 21.1 kA;
- FOLW-…-14.7/61, I_{W1} = 20.9 kA;
- FOLW-…-13.1/54, I_{W1} = 20.7 kA;
- FOLW-…-12.0/94, I_{W1} = 19.6 kA.

4 SC currents as well as currents in LW of 220 kV OTL operating in connected mode but without power transmission under simultanious C1 and C2 SC to first from S2 span tower

Let's simultanious calculate C1 and C2 phases SC to the ground current as well as currents in LW induced by MF of SC to 1st span from S2 current of 220 kV OTL operating in connected mode but without power trznsmission (Fig. 17).

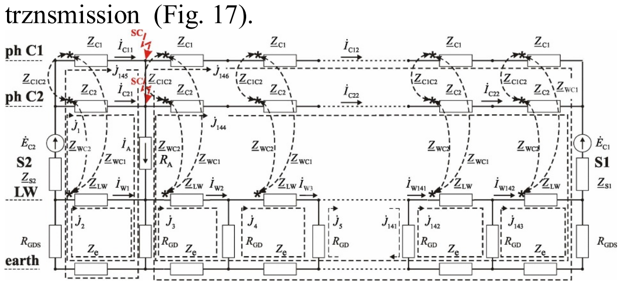

Fig. 17. The scheme of C1 and C2 phases SC to 1st span current determination as well as currents in LW induced by MF of SC currents in 220 kV OTL operating in connected mode but witout power transmission.

Figure 18 shows the histograms of countour current modules in LW spans as well as currents in C1 and C2 under simultanious C1 and C2 phases SC to 1st span tower for LW executed by FOLW-c-1-24(G.652)-18.7/93 and FOLW-c-1-48(G.652)-12/94, and figure 19 - executed by FOLW-c-1-16(G.652)-14.7/61 and FOLW-c-1-24(G.652)-13.1/54.

In case of simultanious C1 and C2 SC to tower of 1st span arc currents were: for FOLW-c-1-24(G.652)-18.7/93 $\boldsymbol{I}_A = 25.01\angle 43.4°$ kA, for FOLW-c-1-48(G.652)-12/94 $\boldsymbol{I}_A = 24.27\angle 46.7°$ kA, for FOLW-c-1-16(G.652)-14.7/61 $\boldsymbol{I}_A = 24.92\angle 44.1°$ kA, and for FOLW-c-1-24(G.652)-13.1/54 $\boldsymbol{I}_A = 24.78\angle 44.6°$ kA.

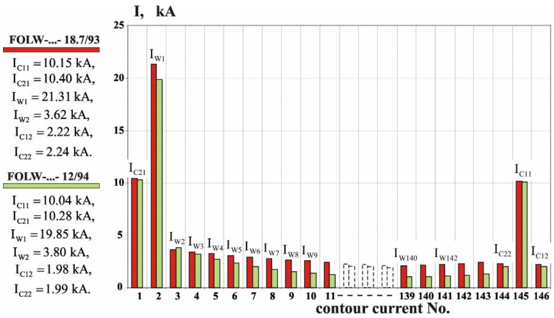

Fig. 18. Current module in LW and 220 kV OTL phases changes under simultaneous C1 and C2 SC to the tower of 1st span for FOLW-c-1-24(G.652)-18.7/93 and FOLW-c-1-48(G.652)-12/94

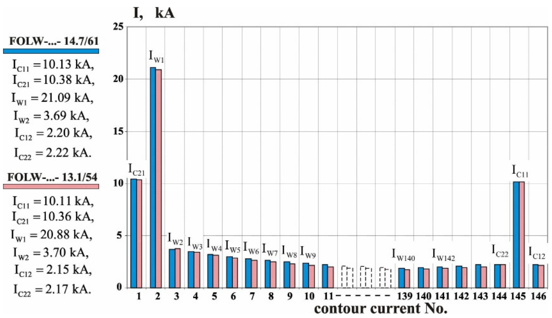

Fig. 19. Current module in LW and 220 kV OTL phases changes under simultaneous C1 and C2 SC to the tower of 1st span for FOLW-c-1-16(G.652)-14.7/61 and FOLW-c-1-24(G.652)-13.1/54.

The greatest I_{W1} current values under C1 and C2 SC to the tower of first from S2 span:

FOLW-…-18.7/93, I_{W1} = 21.31 kA;
FOLW -…-14.7/61, I_{W1} = 21.09 kA;
FOLW -…-13.1/54, I_{W1} = 20.88 kA;
FOLW -…-12.0/94, I_{W1} = 19.85 kA.

Conclusion

Currents created in LW have the greates values under its simultanious determination with currents of joint C1 and C2 SC to the first span from S 2 tower.

Maximal limit time of SC current shutdown ($t_{MIshutd}$) at S2 will find by FOLW thermal stability (ThS, kA^{2}s) and recieved current(I_{W1}) highest value in LW span: $t_{MIshutd}$ = ThS/ I^2_{W1}. Maximal limit time of SC current shutdown $t_{MIshutd}$ at S2 calculation results for analyzed FOLW brands are presented in table.

Table. Maximal limit time of SC current shutdown ($t_{MIshutd}$) at S2

FOLW	18.7/93	14.7/61	13.1/54	12/94	22.5/113
ThS, kA^{2}s	350.2	132.7	78.7	31.2	969.9
I_{W1}, kA	21.31	21.09	20.88	19.85	21.48
$t_{MIshutd}$, s	0.771	0.298	0.164	0.079	2.102

Analyzed FOLW brands have low maximal limit time of SC current and shutdown ($t_{MIshutd}$) (less than 1s). So FOLW-c-1-24(G.652)-22.5/113 with 22.5 mm diameter, 0.12 Ohm/km resisitivity and ThS = 969.9 kA^2·s thermal stability was chosen. This FOLW has under C1 and C2 phases SC to the 1st span from S2 tower I_{W1} = 21.48 kA, I_{C11} = 10.16 kA, I_{C21} = 10.42 kA, I_{C12} = 2.24 kA, I_{C22} = 2.26 kA and $t_{MIshutd}$ = 2.1 s.

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