TRANSIENTS PHENOMENA AT THE 400 KV NO-LOADED LINES SWITCHING

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Abstract: - In this paper, there are evaluated the power systems transients phenomena which appear at the 380 kV no-loaded line switching. In point of news, the paper presents the modelling and simulation of a no-load three-phase line switching effect in Power System, using PSCAD Program and MathCAD Program. There were obtained the transient recovery voltages (TRV) and the overcurrents (OC) in the 380 kV network and the electrical field (EF), according with the overvoltages (OV) at 380 kV. After that, a comparatively analyze of results is made. The paper presents the Electrical Field values, according to modelled and simulated disturbances. The simulation was performed using the EMTDC/PSCAD software package, in order to obtain the transient overvoltages, the overcurrents and the electrical fields in the transmission line and in the busbars. Also in the paper are presented experiments performed for determination of switching overvoltages at the 400 kV no-load lines switching in a Romanian network. After that, a comparative analysis of results regarding switching overvoltages determined through modelling and experiments is made and conclusions about admissible limits recommended by the CIGRE and IEEE international norms are established.

Keywords: - Power systems, transient phenomena, disturbances, circuit breakers, switching overvoltages, network.

1. INTRODUCTION

The voltage stress in the switching devices depends on the network configuration [1-7]. Usually, the electromagnetic transient simulations are performed considering the no-load line switching, also capacitor bank switching on the middle voltage part, using the circuit breakers [8-18]. The most common approach is to use the T-model (the Frequency-Dependent model), which should be considered in transient studies in order to obtain accurate results. The T-model of line is based on the travelling wave's formulation, with the voltage disturbances reflecting the delay function and the wave-shape attenuation.

This paper is devoted to the evaluation of the transient recovery voltages, the overvoltages on each phases and the electrical field as a result of the no-load line switching for different lengths of line. In this way, seven different length values for the unload line were assumed.

2. ANALYTHICAL APPROACH

The analysis of transient phenomena at the no-load line switching can be made analytically by using the following mono-phase schematic circuit proposed by [6, 7] (fig. 1).

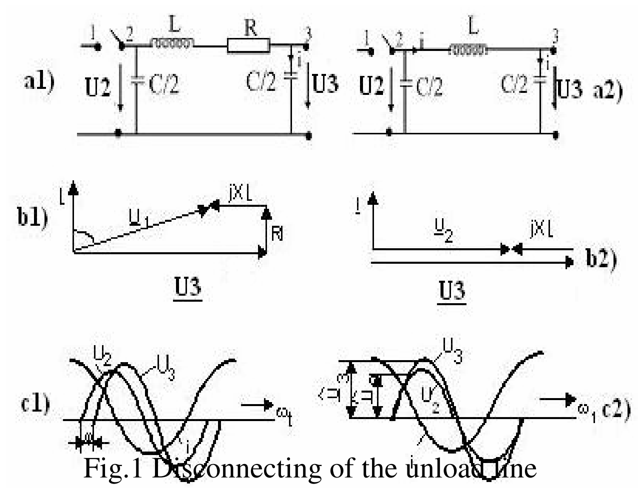


Fig.1 Disconnecting of the unload line

a_1) Model-equivalent a_2) Neglected Resistance
b_1)Phasor-Diagram b_2) Phasor-Diagram
c_1) Instantaneous values c_2) Instantaneous values

Where: both the general network and a reduced network with neglected resistances are held.

Switching transient phenomena of no-load line can be expressed by figure 2 and following equations [6, 7]:

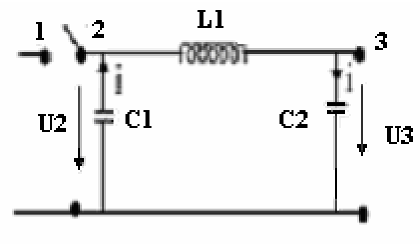


Fig.2.Electrical Model of no-load line

$$\begin{cases} C_1 = \dfrac{2C}{\pi^2} = 0{,}203\,C \\ C_2 = \left(1 - \dfrac{2}{\pi^2}\right) C = 0{,}797\,C \\ L_1 = \dfrac{L}{2\left(1 - \dfrac{2}{\pi^2}\right)} = 0{,}627\,L \end{cases} \tag{1}$$

The voltage u_2 can be calculated by [6-7]:

$$u_2 = u_{02} - \frac{1}{C_1}\int_0^t i\,\mathrm{dt} = \mathrm{L}_1 \frac{di}{dt} + u_{03} + \frac{1}{C_2}\int_0^t i\,\mathrm{dt} \tag{2}$$

where:

u_{02} *and* u_{03} are the voltage values at the 2 and 3 terminals in comparison with ground, in moment of current interrupting.

By Laplace Transform:

$$L[i] = \frac{u_{02} - u_{03}}{p^2 L_1 + \dfrac{C_1 + C_2}{C_1 C_2}} = \frac{u_{02} - u_{03}}{\sqrt{\dfrac{L_1}{C_R}}} \cdot \frac{\dfrac{1}{\sqrt{C_R L_1}}}{p^2 + \dfrac{1}{C_R L_1}} \tag{3}$$

where: $\dfrac{1}{C_R} = \dfrac{C_1 + C_2}{C_1 C_2}$

Result:

$$i = \frac{u_{02} - u_{03}}{\sqrt{\dfrac{L_1}{C_R}}} \sin \frac{t}{\sqrt{C_R L_i}} \tag{4}$$

$$u_2 = u_{02} - \frac{1}{C_1}\int_0^t \frac{u_{02} - u_{03}}{\sqrt{\dfrac{L_1}{C_R}}} \sin\left(\frac{t}{\sqrt{C_R \cdot L_1}}\right) dt \tag{5}$$

or

$$u_2 = u_{02} + \frac{C_R}{C_1}\left(u_{03} - u_{02}\right)\left(1 - \cos \frac{t}{\sqrt{C_R L_1}}\right) \tag{6}$$

The maximum value is:

$$\hat{u}_2 = \hat{u}_{02} + 1{,}594\left(u_{03} - u_{02}\right) \tag{7}$$

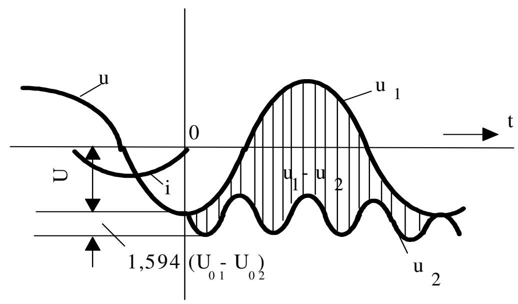


Fig.3. Transient Recovery Voltage

The voltage Diagrams for u_1, u_2 and the Transient Recovery Voltage are illustrated in figure 3.

The maximum of the Transient Recovery Voltages will be:

$$\hat{u}_r = \left(u_1 - u_2\right)\max = 2\hat{U}_2 + 1{,}594\left(\hat{U}_3 - \hat{U}_2\right) \tag{8}$$

The circuit breaker characteristics and the feeding network parameters influence the transient phenomena. The growing speed of dielectric rigidity (U_d = f (t)) and the raise of the transient recovery voltage (U_r = f (t)), play also a very important role in this process [6-7].

3. APPLICATION EXAMPLE

In order to analyse the transient overvoltages at disconnecting of a no-load line in a 380 kV Electric Power System the model from figure 4 has been studied. This model was evaluated using the EMTDC/PSCAD software package. The 380 kV High Voltage Line of the Power Systems (fig.4) presents for analysis: the voltage generators; the transformer; the transmission line modelling by T-Line Model (Frequency-Dependent Model); the busbar, the branch of capacitor bank, connected on generator, the circuit breakers for the line and capacitor bank switching. The transient phenomena were simulated with the circuit breaker on close position, followed by a disconnecting operation. The 1st time was 0.205 [sec] and the 2nd time was 3 [sec]. For capacitor bank it was assumed discrete capacitance values from 30 μF until 150 μF with a step of 20 μF, considering a star connection.

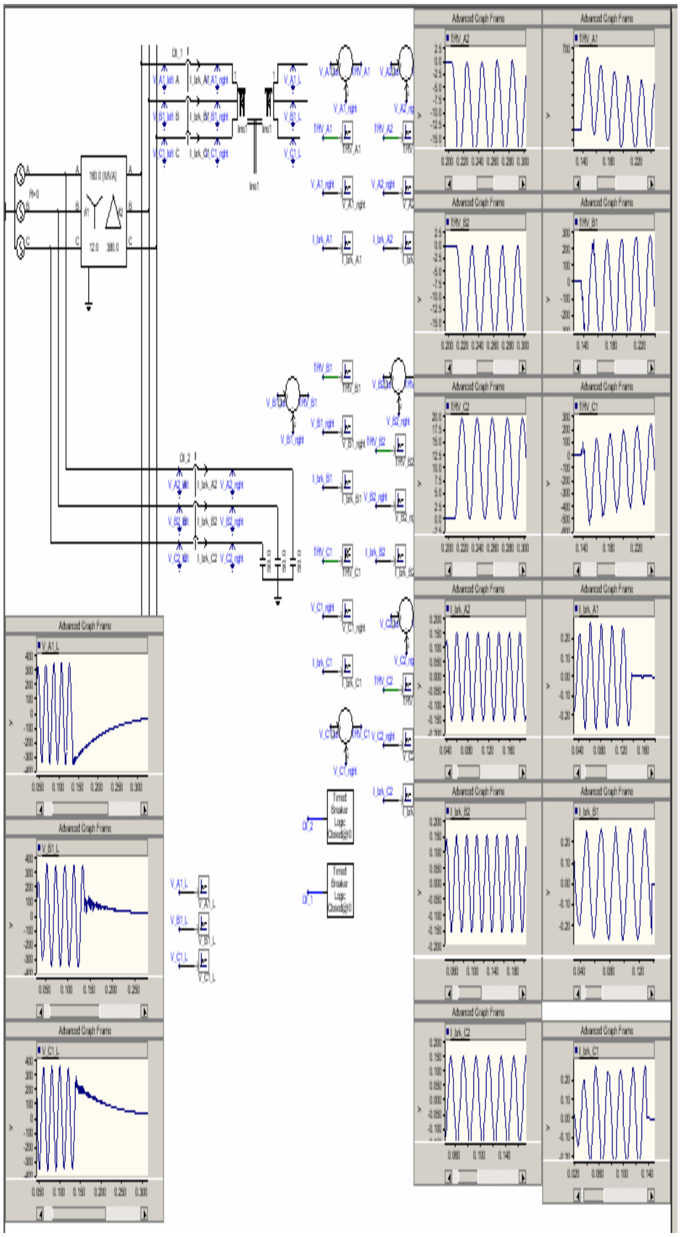


Fig.4.- Modelling and simulation of the switching transient phenomena using PSCAD Program

4. RESULTS

The results are presented in the following tables and figures:

TABLE 1. - TRANSIENT RECOVERY VOLTAGES DUE TO SWITCHING TRANSIENT PHENOMENA IN A 380 KV NO-LOAD LINE OF POWER SYSTEMS

l [km]	40	80	120	160	200	240	280
TRV_A[kV]	687,8	698,2	698,2	702,8	702,85	711,5	720,3
TRV_B[kV]	417,7	417,7	417,7	427,43	427,43	427,43	427,43
TRV_C[kV]	683,19	692,92	692,92	702,65	712,39	712,39	722,12

The table 1 presents the transient recovery voltages for different lengths of no-load line disconnecting.

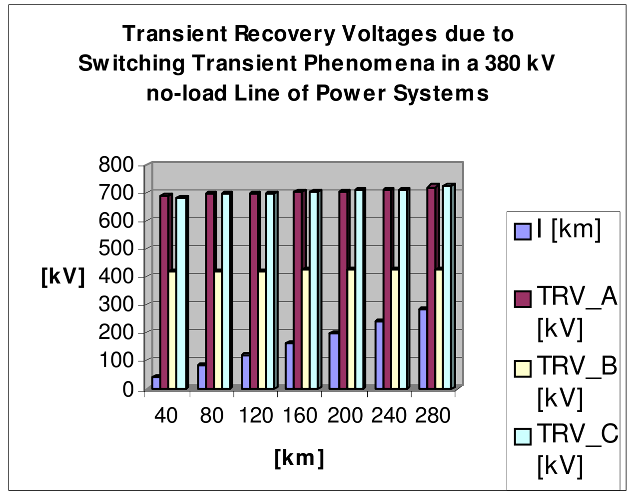


Figure 5. Transient Recovery Voltages at switching of no-load line for different lengths

TABLE 2. - PHASE VOLTAGES DUE TO SWITCHING TRANSIENT PHENOMENA IN A 380 KV NO-LOAD LINE OF POWER SYSTEMS

l [km]	40	80	120	160	200	240	280
V_AL[kV]	315,04	315,04	315,04	322,12	322,12	329,2	336,28
V_BL[kV]	315,04	315,04	315,04	329,2	329,2	336,28	350,4
V_CL[kV]	316,81	316,81	320,35	332,74	332,74	332,74	344,25

In table 2 the phase voltages for different lengths of line are presented.

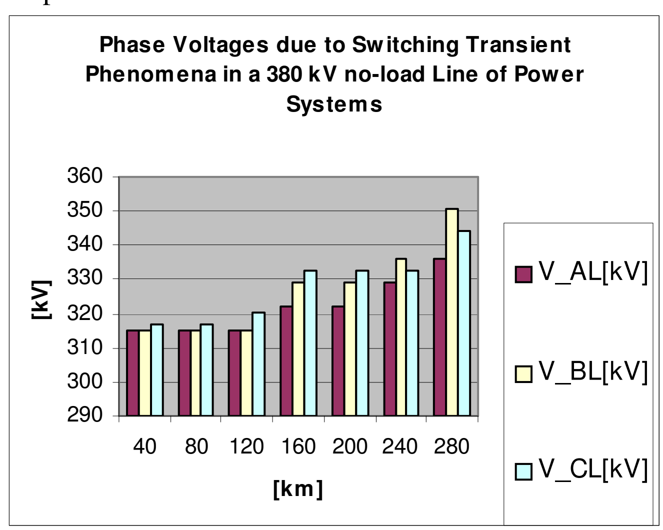


Figure 6. The phase voltages for different lengths of line

TABLE 3. - TRANSIENT RECOVERY VOLTAGES AND THE PHASE VOLTAGES DUE TO SWITCHING TRANSIENT PHENOMENA IN A 380 KV NO-LOAD LINE OF POWER SYSTEMS

l [km]	40	80	120	160	200	240	280
TRV_A[kV]	687,8	698,2	698,2	702,8	702,85	711,5	720,3
TRV_B[kV]	417,7	417,7	417,7	427,43	427,43	427,43	427,43
TRV_C[kV]	683,19	692,92	692,92	702,65	712,39	712,39	722,12
V_AL[kV]	315,04	315,04	315,04	322,12	322,12	329,2	336,28
V_BL[kV]	315,04	315,04	315,04	329,2	329,2	336,28	350,4
V_CL[kV]	316,81	316,81	320,35	332,74	332,74	332,74	344,25

The table 3 presents the transient recovery voltages and the phase voltages due to switching transient phenomena in a 380 kV no-load line of power systems.

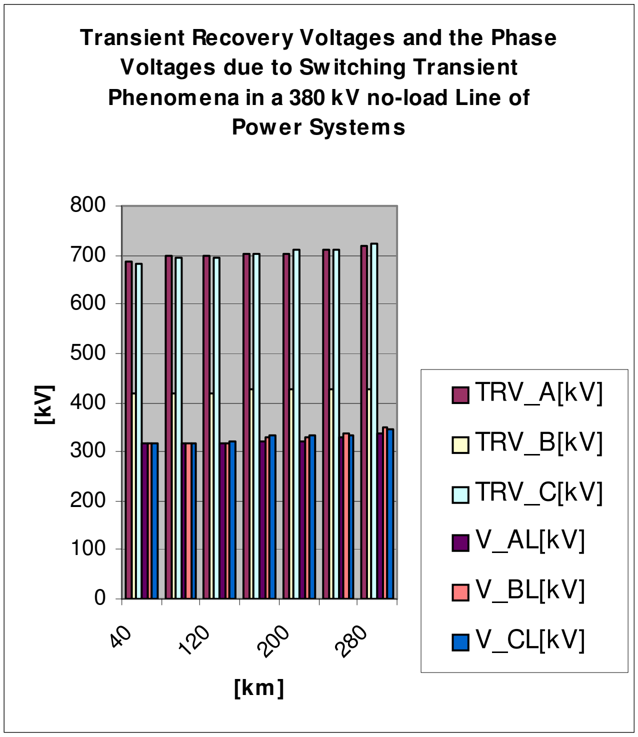


Figure 7. The Transient Recovery Voltages and the Phase Voltages due to Switching Transient Phenomena in a 380 kV no-load Line of Power Systems

TABLE 4. - THE PHASE VOLTAGES AND THE ELECTRICAL FIELD UNDER 380 KV LINE TO THE CROSSING OF THE NATIONAL HIGHWAY AND RAILWAY, AT GROUNDED LEVEL

l [km]	40	80	120	160	200	240	280
V_AL[kV]	315,04	315,04	315,04	322,12	322,12	329,2	336,28
V_BL[kV]	315,04	315,04	315,04	329,2	329,2	336,28	350,4
V_CL[kV]	316,81	316,81	320,35	332,74	332,74	332,74	344,25
E_AL[kV/m]	8,5	8,5	8,5	8,7	8,69	8,88	9,08
E_BL[kV/m]	8,5	8,5	8,5	8,89	8,88	9,08	9,46
E_CL[kV/m]	8,56	8,56	8,65	8,99	8,99	8,99	9,29
E_AL[kV/m]	13,42	13,42	13,42	13,72	13,72	14,02	14,32
E_BL[kV/m]	13,42	13,42	13,42	14,02	14,02	14,32	14,92
E_CL[kV/m]	13,49	13,49	13,64	14,17	14,17	14,17	14,66

In table 4 were presented the Phase Voltages and the Electrical Field under 380 kV Line to the crossing of the National Highway and Railway, at grounded level.

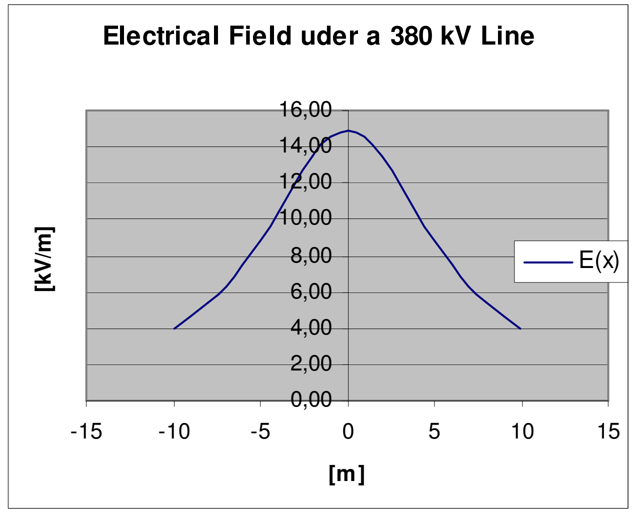


Figure 8. The Electrical Field under 380 kV Line to the crossing of the National Highway and Railway, at grounded level

TABLE 5. - ELECTRICAL FIELD UNDER 380 KV LINE TO THE CROSSING OF THE NATIONAL HIGHWAY AND RAILWAY, AT GROUNDED LEVEL

l [km]	40	80	120	160	200	240	280
E_AL[kV/m]	8,5	8,5	8,5	8,7	8,69	8,88	9,08
E_BL[kV/m]	8,5	8,5	8,5	8,89	8,88		9,46
E_CL[kV/m]	8,56	8,56	8,65	8,99	8,99	8,99	9,29
E_AL[kV/m]	13,42	13,42	13,42	13,72	13,72	14,02	14,32
E_BL[kV/m]	13,42	13,42	13,42	14,02	14,02	14,32	14,92
E_CL[kV/m]	13,49	13,49	13,64	14,17	14,17	14,17	14,66

The table 5 presents the Electrical Field under 380 kV Line to the crossing of the National Highway and Railway, at grounded level, for different lengths of line.

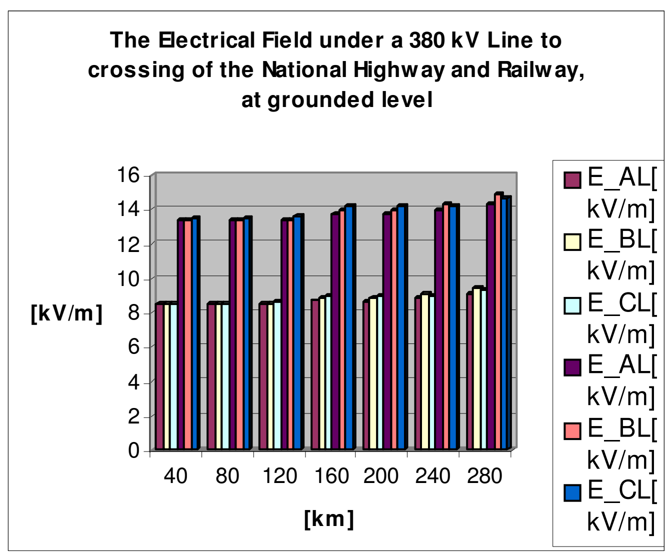
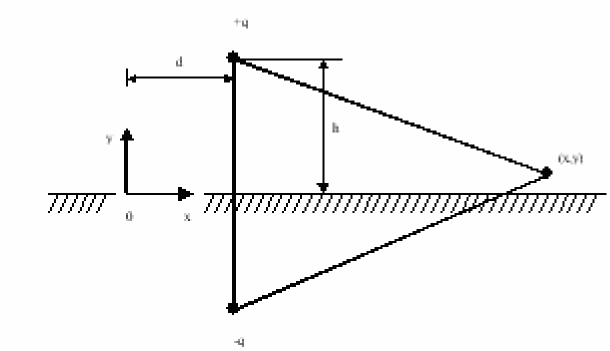


Figure 9. The Electrical Field under 380 kV Line to the crossing of the National Highway and Railway, at grounded level

The tables 1, 2, 3, 4 and 5 show the influence of line length at no-load switching regarding the Transient Recovery Voltages, Phase Voltages and Electrical Fields. There is noticed that values obtained are very high. These can generate dangerous influences on Electrical Equipment, Environment and Life. It is necessary to improve the maintenance of Lines of Power Systems and of Circuit Breakers switching in order to limit the maximum values of the switching Transient Phenomena.

Figure10:
Electrical Field, Math-CAD Program [1, 6, 7, 14]:



$\varepsilon_0 := \frac{1}{36 \cdot \pi \cdot 10^9} \cdot F \cdot m^{-1}$ $\quad Y := 1.376592 \text{ohm} \cdot \text{km}$

$hi := 9 \cdot m$ $\quad \omega := 2 \cdot \pi \cdot f$

$ri := 0.0047873m$ $\quad U := 460.18kV$ $\quad f := 50 \cdot Hz$

$C := \frac{1}{Y \cdot \omega \cdot U}$ $\quad C = 5.025 \cdot 10^{-12} \cdot kg^{-2} \cdot m^{-5} \cdot s^{7} \cdot A^{3}$

$q := C \cdot U$ $\quad q = 2.312 \cdot 10^{-6} \cdot kg^{-1} \cdot m^{-3} \cdot s^{4} \cdot A^{2}$

$$Ex(x) := \left(\frac{q}{2\pi \cdot \varepsilon 0}\right) \cdot \left[\frac{x-d}{(x-d)^2 + (y-hi)^2} - \frac{x-d}{(x-d)^2 + (y+hi)^2}\right]$$

$Ex(x) = 1.387 \cdot 10^{3} \cdot m^{-1}$

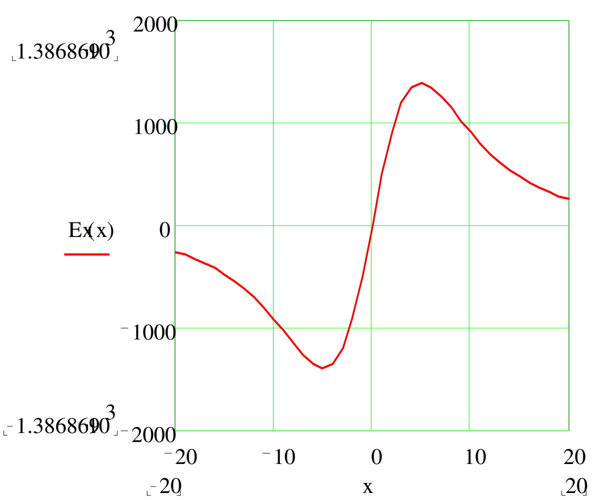


Figure 11: The Ex electrical field component for: d=0m, x=5m and y=2m.

$$Ey(y) := \left(\frac{q}{2\pi \cdot \varepsilon 0}\right) \cdot \left[\frac{y-hi}{(x-d)^2 + (y-hi)^2} - \frac{y+hi}{(x-d)^2 + (y+hi)^2}\right]$$

$Ey(y) = -7.073 \cdot 10^{3} \cdot m^{-1}$

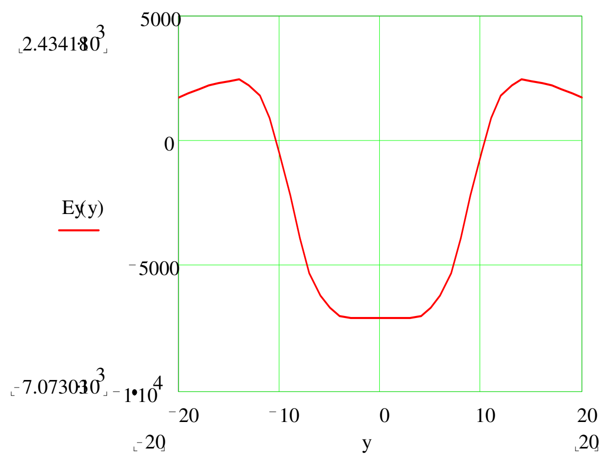


Figure 12. The Ey electrical field component for: d=0m, x=5m and y=2m.

$$E(x) := 2 \cdot \frac{hi}{\left(x^2 + hi^2\right) \cdot \ln\left(2 \cdot \frac{hi}{ri}\right)} \cdot U$$

$E(x) = 1.242 \cdot 10^{4} \cdot kg \cdot m \cdot s^{-3} \cdot A^{-1}$

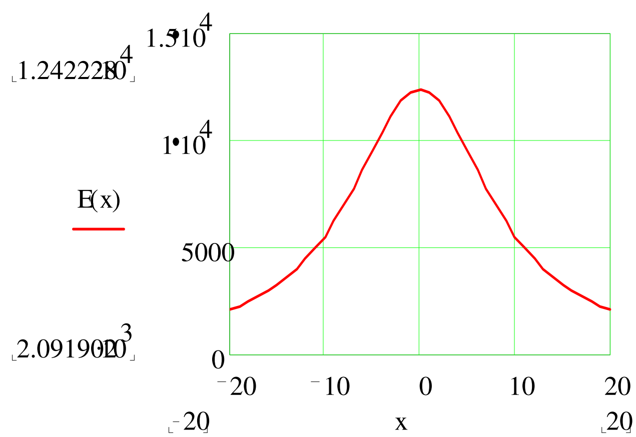


Figure 13. The electrical field at ground level.

Analysing the results obtained concerning the intensity of electrical field, there is noticed that the maximum intensity of electrical field, under the line, at ground level, appears at the maximal line length. These are: 12.42 kV/m for the crossing of the National Highway and 19.6 kV/m at the crossing of the National Railway. Comparative with the limits recommended by the

CIGRE and IEEE International norms [1], these values overtake the admissible limit [1, 17].

Between the results obtained by modelling and simulation in PSCAD and in Math-CAD Programs significant differences don't appear.

Generally, the values obtained for the electrical fields are over the admissible limit, which were recommended of the International Norms [1, 17].

5. EXPERIEMNTS ON A NO-LOAD LINE IN ROMANIAN NETWORK

In a 400 kV substation from Romania were performed tests and measurements for following switching cases [19]:

a) no-load disconnection line with trigger command of the circuit-breaker from substation 1.

b) no-load connection of long line with breaking impulse transmission to the circuit-breaker from substation 2 with remote protection from substation 1

Line characteristics were the following:

- line length: 257.5 km
- steel-aluminium conductor 450/75 mm^2
- 400 kV/1600 A minimum oil circuit-breaker

Tests and measurements were necessary to establish the switching overvoltage level that appears at no-load line connection and disconnection and to check the operating level of the maximal voltage protection due to the voltage growth at the end of the line.

In case a) six tests with trigger command of the 400 kV/1600 A minimum oil circuit-breaker were performed in 400 kV substation 1, the command being given for different moments in the voltage reference curve with respect of the current passing trough zero. In this way a half period was swept simulating the real exploitation conditions.

In order to determine the switching overvoltages that appear in case b) of no-load lines connection, three closing commands of the circuit-breaker in substation 2 with different moments by remote protection with different moments of the current connection were performed.

Principle diagram of measuring and command from Substation 1 is presented in Figure 14.

The following phenomena were recorded: circuit-breaker command current, downstream and upstream voltages of circuit-breaker, switching overvoltages, time base. The error of measuring chain is 3%.

Within established program three connecting operations and three disconnecting operation of the no-load lines were carried out. Determination of switching overvoltages for no-load lines by measurements shown that overvoltage factor is ks=1.81 (p.u) and this is below to that maximally admissible ks=2.3 (p.u) according to CIGRE recommendations.

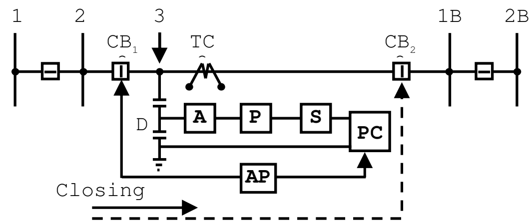


Figure 14 – Test diagram at no-load disconnecting

CB1, CB2 – circuit-breakers
TC – current transformer
D – voltage divider
A – amplifier
S – transducer
AP – programmable automat
PC – personal computer
3 – point for overvoltages measurement

6. CONCLUSIONS

From the above results the following conclusions can be extracted:

- Due to the switching transients phenomena in Electrical Power Systems very dangerous disturbances for electrical equipment and for around environmental appear. Therefore, the electrical fields, in last days, are the concerning for many specialists, thanks to their negative effect about equipment, environment and life [1, 6, 7, and 16].

- Due to the no-load line switching in Power Systems, big overvoltages (transient recovery voltages, 3.28 [p.u.]; phase overvoltages, 1.59 [p.u.] appear, which all generate the electrical fields, with negative impact in Power Systems and around Environment.

- The results obtained for modelling and simulation are in according with theoretical solutions (9.58 %).

- The result obtained for the maximal electrical fields due to a 380 kV no-load line switching in Power Systems from Turkey, under line at grounded level (9.46 kV/m, at the crossing of the National Highway and 14.92 kV/m, at the crossing of the National Railway), show that they overtake the admissible limits recommended by the CIGRE and IEEE International norms [10].

- Therefore it is necessary to make investigations and to impose the limited methods.

- Experiments on a 400 kV no-loaded line in Romanian network shown that the switching overvoltages did not overrun the maximum admissible values so there is not necessary to limit them.

Acknowledgment:
Prof. Petre Tusaliu would like to acknowledge NATO for the fellowship awarded and that allowed him to join the other co-authors in this research.

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