SWITCHING TRANSIENT PHENOMENA AT THE 380 KV UNLOADED LINE SWITCHING

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Abstract- In point of news, in this paper it is modelling and simulated the three-phase unloaded line switching effect in Power System, using PSCAD Program and MathCAD Program. It was obtained the transient recovery voltages (TRV) and the overcurrents (OC) in the 380 kV network and the electrical field (EF), in according with the overvoltages (OV) at 380 kV. After it is make the comparatively analysing of results.

Keywords: switching transient phenomena, power systems, disturbances, circuit breakers.

I. Introduction

THE voltage stress in the switching devices depend on the network configuration [1-7]. Usually, the electromagnetic transient simulations are performed considering the unload line switching, also capacitor bank switching on the middle voltage part, using the circuit breakers [8-17]. 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 waves 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 following of the unload line switching for different lengths of line. In this way were assumed seven different length values for the unload line.

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II. Analytical Approach

The analysis of transient phenomena at the unload line switching can be made analytically by using the following mono-phase schematic circuit proposed by [6, 7] (fig. 1).

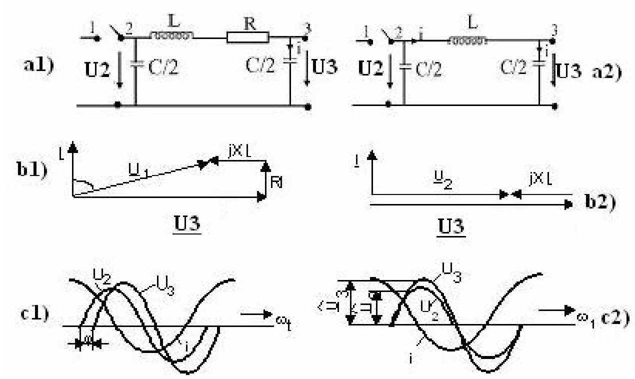


Fig.1 Disconnecting of the unload line

a_1) Model-equivalent a_2) Resistance neglected

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 unload line can be expressed by figure 2 and following equations [6, 7]:

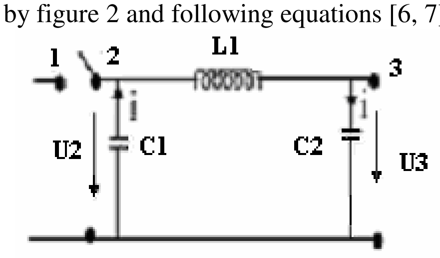


Fig.2.Electrical Model of unload line

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

(2)

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

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

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:

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

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

Result:

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

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

or

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

The maximum value is:

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

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

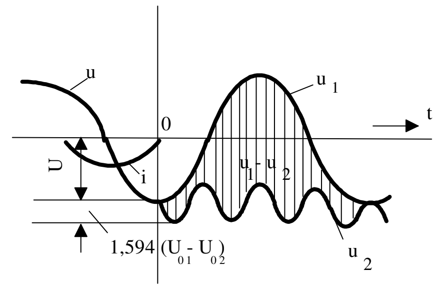


Fig.3. Transient Recovery Voltage

The maximum of the Transient Recovery Voltages will be:

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

(3)

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].

III. APPLICATION EXAMPLE

In order to analyse the transient overvoltages at disconnecting of an unload line in a 380 kV Electric Power System; it was studied by model from figure 4. 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 switching of line and for switching of the capacitor bank. The transient phenomena were simulated with the circuit breaker on first position it was closed, following 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.

(5)

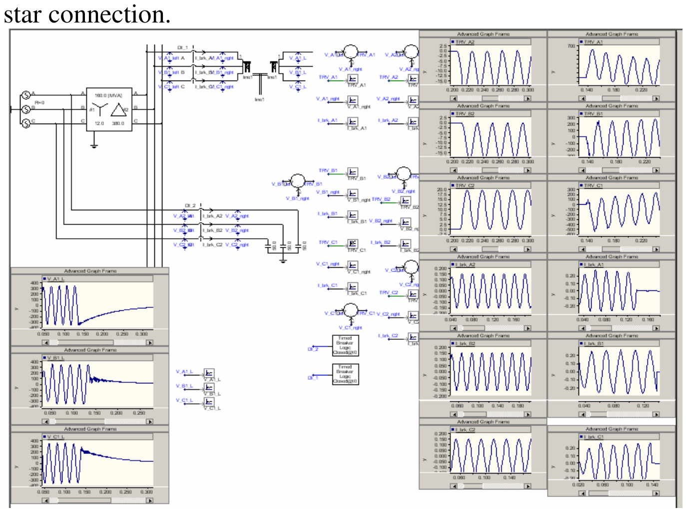


Fig.4. Modelling and simulation of the switching transient phenomena using PSCAD Program

IV. RESULTS

The results are presented in the following tables and figures:

TABLE 1. TRANSIENT RECOVERY VOLTAGES DUE TO SWITCHING TRANSIENT PHENOMENA

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 unload line disconnecting.

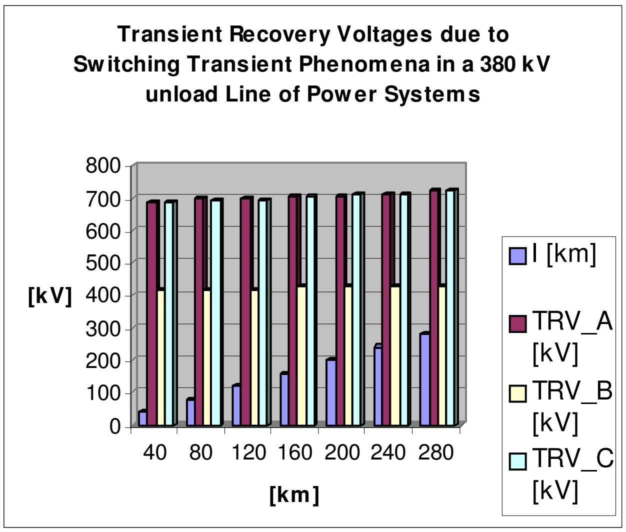


Figure 5. Transient Recovery Voltages

TABLE 2. PHASE VOLTAGES DUE TO SWITCHING TRANSIENT PHENOMENA IN A 380 KV UNLOAD 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 are presented the phase voltages for different lengths of line.

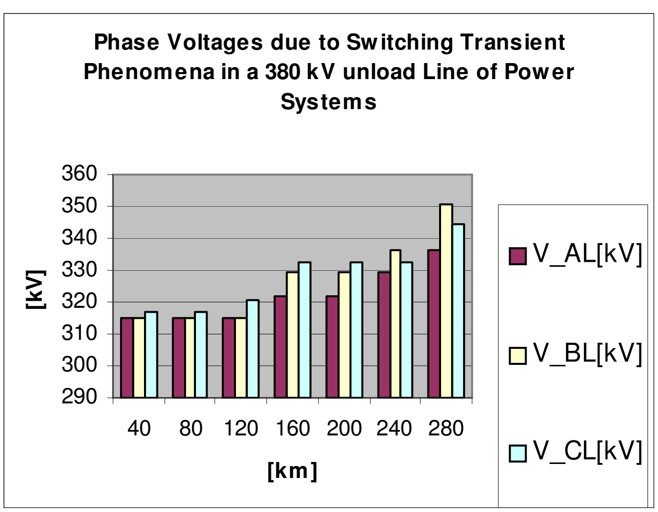


Figure 6. The phase voltages for different lengths of line

TABLE 3. TRANSIENT RECOVERY VOLTAGES AND THE PHASE VOLTAGES

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 unload line of power systems.

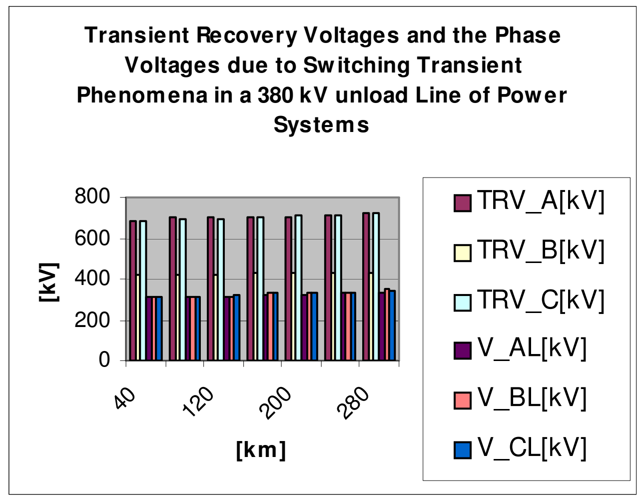


Figure 7. The Transient Recovery Voltages and the Phase Voltages

TABLE 4. THE PHASE VOLTAGES AND THE ELECTRICAL FIELD UNDER 380 KV LINE

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.

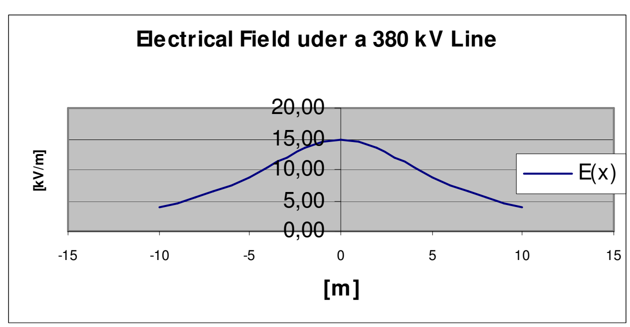


Figure 8. The Electrical Field under 380 kV Line

TABLE 5.ELECTRICAL FIELD UNDER 380 KV LINE

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.

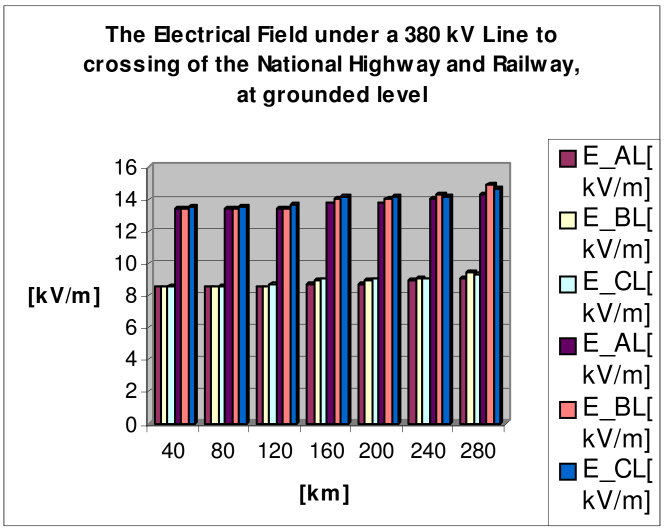
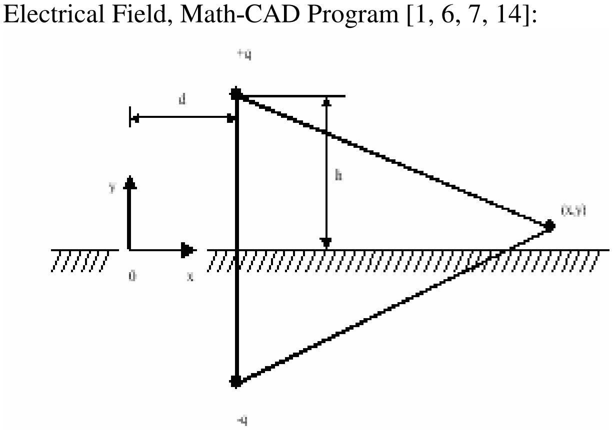


Figure 9. The Electrical Field under 380 kV Line

The tables 1,2,3,4 and 5 show the influence of line length at unload switching about the Transient Recovery Voltages, Phase Voltages and Electrical Fields. It observes that values obtained are very high. These can generate danger influences about Electrical Equipment, Environment and Life. It is necessary to improve the maintenance of Lines of Power Systems and of Circuit Breakers switching for to limit the maximum values of the switching Transient Phenomena.

Figure10:

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



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

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

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

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

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

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

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

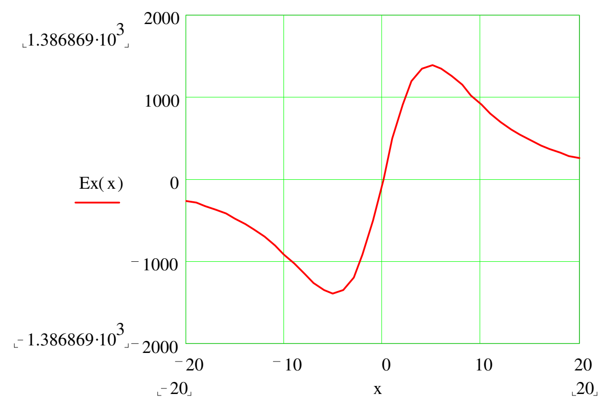


Figure 11: The Ex electrical field component for: d=0m, x=5m and y=2m.

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

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

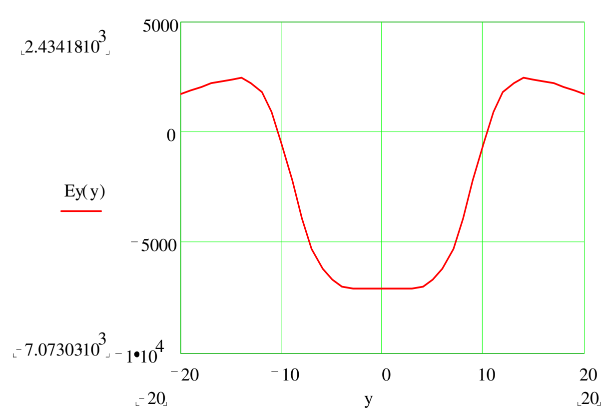


Figure 12. The Ey electrical field component for: d=0m, x=5m and y=2m.

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

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

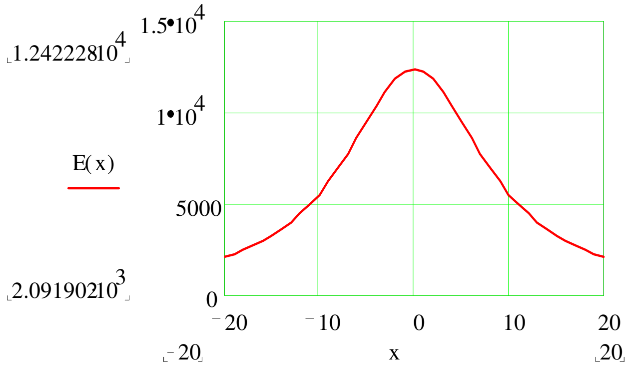


Figure 13. The electrical field at ground level.

Analysing the results obtained concerning of the intensity of electrical field, it observes 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 not appear the significant different.

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

IV. Conclusions

From the above results the following conclusions can be extracted:

- As following of the switching transients phenomena in Electrical Power Systems appear very danger disturbances for electrical equipment and for around environmental. Of these, the electrical fields, in last days, are in the preoccupations of the many specialists, thanks to their negative effect about equipment, environment and life [1, 6, 7, and 16].
- As following the unload line switching appear in Power Systems the big overvoltages (transient recovery voltages, 3.28 [p.u.]; phase overvoltages, 1.59 [p.u.], 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 unload 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.

V. Acknowledgment

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