CONCERNING THE NO LOAD HIGH VOLTAGE TRANSFORMERS DISCONNECTING

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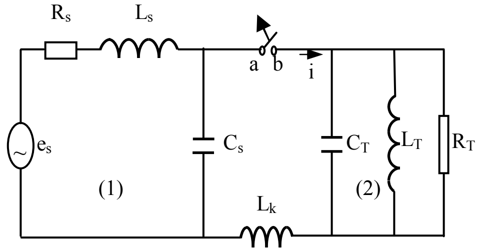
ABSTRACT

The computation program of the transient recovery voltages that appears across the terminals of a circuit breaker, after the low inductive current has been interrupted at the disconnecting no load high voltage transformers, using the routines set developed in Matlab is presented. The computation algorithm is based on the peculiarities of operation of the transformer. The computation program has been applied for transformers from the high voltage electric stations ST North Craiova and ST Urechesti. The computed level of the overvoltage amplitude allows the proper selection of the rated insulation level of the electrical equipment from the electric stations.

INTRODUCTION

The breaking of a low inductive current (around the 100 A value) causes overvoltages. The selection of the circuit breaker will be made so that the overvoltages that occurring do not damage the insulation of the consumers such as transformer or motors. The computation of the overvoltages that appear at the disconnection of a no load transformer (the current interrupted is the transformer magnetizing current) is deeply developed in the literature (Dragan et all, 1975). The evaluation methods of the overvoltages are also well developed, starting from analytical ones, based on a mathematical model of the system obtained using a simplified diagram and ending with the direct methods, based on direct test on the system. By the analytical methods, the integral transformation method and the Laplace transformation respectively, are most common. In this paper an automatic computation algorithm of the overvoltages due to the no load transformers disconnection, when appearing the cutting phenomena of the inductive current, is presented. The low inductive current cutting phenomena appears due to the electric arc instability.

From analysis of the experimental results (Gusa 2002), for the high voltage transformer having a large range of rated current, the value of the cutting current is approximately constant and depends mainly on the characteristics of power circuit breaker and less on the characteristics of the disconnected transformer. The computation of the overvoltages is made by means of the monophase equivalent diagram, Figure 1, neglecting of the electrical resistances of the electrical connections between high voltage source and transformer.



Figures 1: The monophase equivalent diagram of the low inductive current disconnecting

where: L_S is the equivalent inductivity, C_S is the equivalent capacity and R_S is the equivalent electric resistance of the high voltage source; L_T is the transformer magnetizing inductivity, C_T is the transformer equivalent capacity and R_T is the resistance corresponding to the core losses of the transformer; L_k is the inductivity of the electrical connection between voltage source and transformer. At the time when the circuit breaker contacts are opening, the electric current continues to pass through the electric arc formed between the contacts. Due to the intensive deionization, the quenching arc occurs before natural zero inductive current switching. Due to the energy stored in these two circuits, they begin to oscillate independently. The oscillations amplitude from the circuit (1) depends on the stored energy in the L_S inductivity. Therefore, after disconnection, the high frequency oscillations occur, having the small amplitude that overlap with the source voltage so that it may be considered that in the circuit (1) remains the sinusoidal voltage. Meanwhile, in the disconnected circuit (2) the oscillations pulsation ω_T is less than the oscillations pulsation ω_S and higher then industrial pulsation ω: $\omega_T = 1/\sqrt{L_T \cdot C_T}$, but the amplitude overvoltage is greater. The amplitude of the overvoltage in the disconnected circuit (2) is determined using the equation of the energy balance, taking into account the energy loss on the resistance circuit by introducing a subunit factor η (η=0,3÷0,5). If I_t is the current through the L_T inductivity and U_0 is the voltage over the C_T capacity at the time moment of the inductive

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current cutting, the equation of the energy balance is obtained:

$$\eta \cdot \left(\frac{L_T \cdot I_t^2}{2} + \frac{C_T \cdot U_0^2}{2} \right) = \frac{C_T \cdot U_{2\max}^2}{2} \tag{1}$$

where U_{2max} is the amplitude value of the overvoltage. Neglecting the current through the R_T resistance the U_{2max} can be obtained:

$$U_{2\max} = \sqrt{\eta \cdot \left(U_{\max}^2 \cdot \cos^2 \alpha + \frac{L_T}{C_T} \cdot \frac{U_{\max}^2}{\omega^2 \cdot L_T^2} \cdot \sin^2 \alpha \right)} \tag{2}$$

Where U_{max} is the amplitude of the voltage source *u(t)* and α is the current cutting angle $I_t = I_{o\max} \cdot \sin \alpha$. Considering the expressions of the pulsations it is obtained:

$$U_{2\max} = \sqrt{\eta} \cdot U_{\max} \cdot \sqrt{\left(\cos^2 \alpha + \left(\frac{f_T}{f} \right)^2 \cdot \sin^2 \alpha \right)} \tag{3}$$

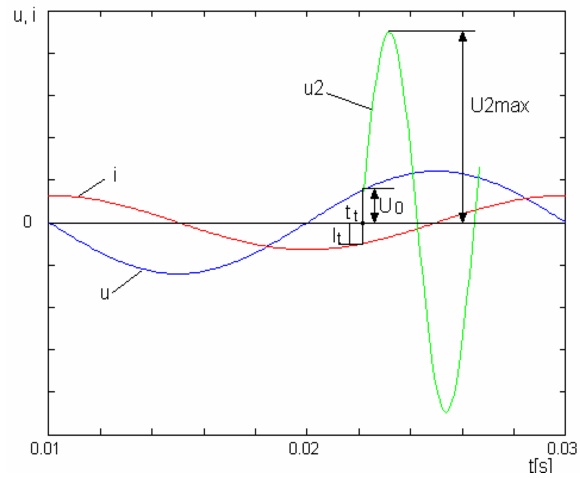
In Figure 2 the variations of the voltage source *u(t)*, the inductive current of the transformer *i(t)* and the recovery voltage $u_2(t)$ across the circuit breaker terminals at the moment of current cutting are shown.
Using the above presented formulas, the amplitude factor of the overvoltage can be computed:

$$\gamma = \frac{U_{2\max}}{U_{\max}} = \sqrt{\eta} \cdot \sqrt{\cos^2 \alpha + \left(\frac{f_T}{f} \right)^2 \cdot \sin^2 \alpha} \tag{4}$$

Analyzing the last formula, can be observed that the worst disconnected case occurs when the cutting angle has the value $\alpha = \pi / 2$, that means the cutting current reaches the maximum value of the inductive current and the maximum value of the amplitude factor is obtained:

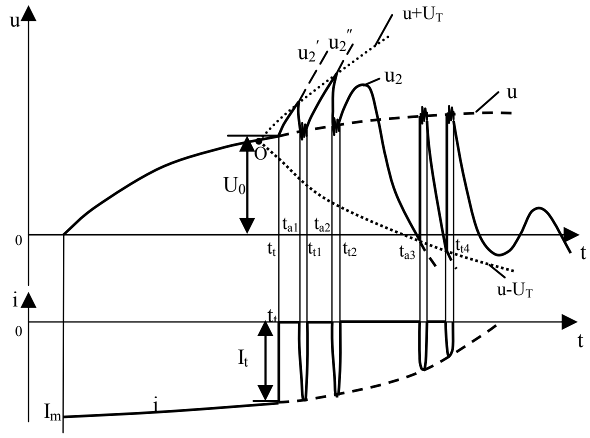
$$\gamma = \sqrt{\eta} \cdot \frac{f_T}{f} \tag{5}$$

The variations of the source voltage, inductive current and transient recovery voltage $u(t), i(t), u_2(t)$ are shown in Figure 2.
From formula (5) it is noted that maximum value of the overvoltage depends on the ratio between the frequency of the overvoltage oscillations from the disconnected circuit (2) and the industrial frequency oscillations. Theoretically, this ratio can reach higher values (4 or 5, even more).



Figures 2: The variation of the $u(t), i(t), u_2(t)$

In reality, the phenomenon is influenced by the appearance of the arc reignition between contacts *a–b* of the circuit breaker. Taking into account the successive reignitions the variations of the $u(t), i(t), u_2(t)$ are shown in Figure 3.



Figures 3: The variation in time of the *u(t)*, *i(t)* and $u_2(t)$ succesive reignitions

If the withstand voltage of the quenching medium of the circuit breaker is exceeded by the transient recovery voltage, then it happens that arc to reignite.
In the figure 3 are displayed the variation of the voltages and the current through the analyzed circuit, considering the successive reignitions of the arc between the contacts a-b of the circuit breakers.
The appearance of the successive reignitions leading to reduction of the transient recovery voltage.

THE COMPUTATION PROGRAM

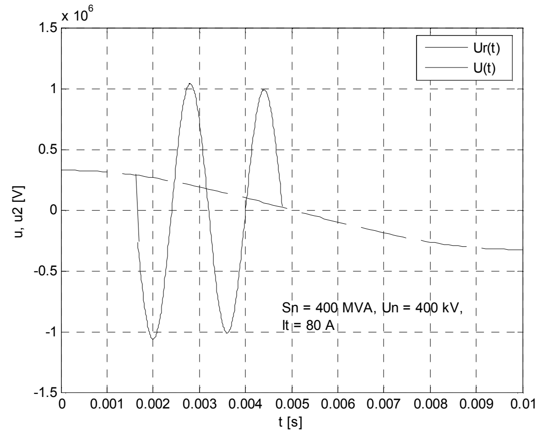
The Matlab application has been developed in order to compute the electrical overvoltages which appear at the disconnection of the no load high voltage transformers from the high voltage electrical stations of the Oltenia district network, named ST North Craiova and ST

Urechesti. The parameters of the AT1 transformer from ST North Craiova are: rated power $S_n = 200MVA$, rated voltage $U_n = 220\,kV$, no load current $I_o = 3\%$, the capacity at the input terminals of the transformer $C_T = 10^{-9}F$. The parameters of the AT2 transformer from ST Urechesti are: rated power $S_n = 400MVA$, rated voltage $U_n = 400\,kV$, no load current $I_o = 19{,}6\%$, the capacity at the input terminals of the transformer $C_T = 10^{-9}F$. The program was developed in an interactive manner which allows the selection of the high voltage network (Brojboiu 2005). The main program runs routines that allow: the calculus of the parameters of the transient overvoltage for the selected transformer (the amplitude of the overvoltage, the amplitude factor and the frequency), the graphical analysis of the influence of cutting angle of the magnetization current on the transient overvoltage; graphical analysis of the influence of the source's power and voltage. The routines can run within the main program or independently. In Table 1 are presented the computed parameters applying the designed program, for electrical stations ST North Craiova and ST Urechesti.

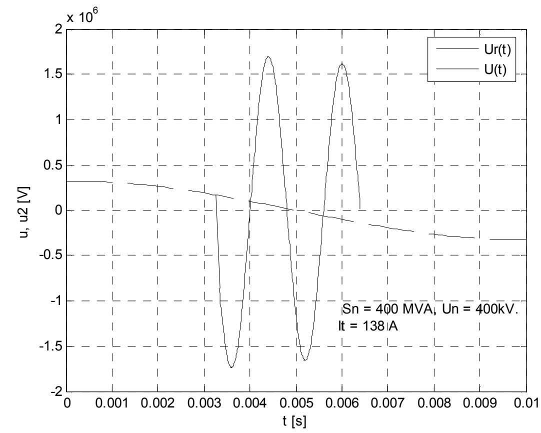
Table 1 The Computed Parameters

Station	I_{omax} [A]	α [rad]	It [A]	U_{2max} [kV]	*k*
ST North Craiova AT1 Sn=200 MVA Un= 220 kV	22	π/6	11,5	320,70	1,58
		π/3	19	477,20	2,65
		π/2	22	498,50	2,77
ST Urechesti AT2 Sn=400 MVA Un= 400 kV	160	π/6	80	1061,7	3,25
		π/3	138	1738,8	5,32
		π/2	160	1911,5	5,82

The Matlab program has been applied to graphically observe the influence of cutting angle on the overvoltages values. By analyzing the computed data, was observed the increasing of the recovery transient overvoltage amplitude as well as the amplitude factor value, as the cutting angle of the inductive current increases. The graphical variations of the source voltage and the recovery transient voltage for the AT2 transformer from ST Urechesti, considering the different cutting angles of the inductive current are presented in Figure 4 ($\alpha = pi/6$) and Figure 5 ($\alpha = pi/2$).

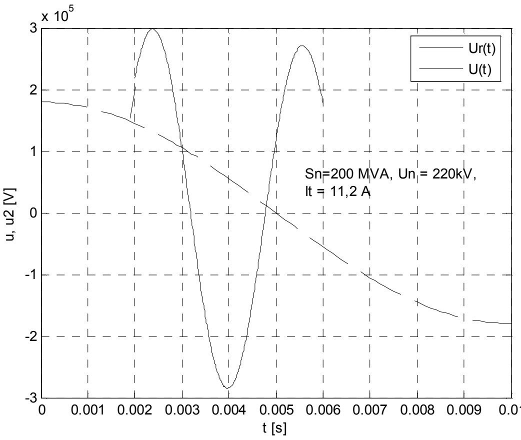


Figures 4: The recovery transient voltage variation $u_2(t)$ Sn=400MVA, Un=400kV, α=pi/6

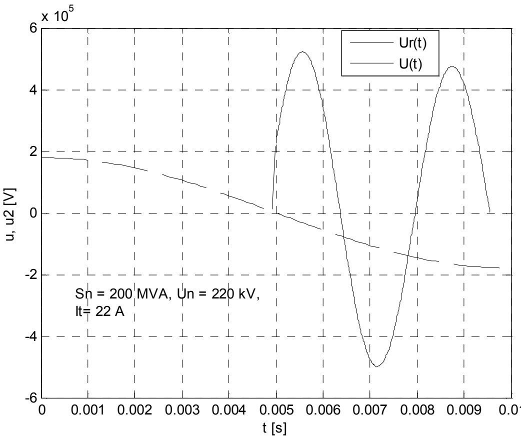


Figures 5: The recovery transient voltage variation $u_2(t)$ Sn=400MVA, Un=400kV, α=pi/3

From the mentioned figures can be noticed the increasing of the overvoltage amplitude value, as the cutting angle increases. The frequency of the overvoltage variation is constant $f_T=624Hz$, because the transformer parameters are constant, $C_T = 10^{-9}F$, $L_T = 6{,}49\,H$. The graphical variations of the source voltage and the recovery transient voltage for the AT1 transformer from ST North Craiova, considering the different cutting angles of the inductive current are presented in Figure 6 ($\alpha = pi/6$) and Figure 7 ($\alpha = pi/2$).



Figures 6: The recovery transient voltage variation Sn=200MVA, Un=220kV,α=pi/6



Figures 7: The recovery transient voltage variation Sn=200MVA, Un=220kV, α=pi/2

The frequency of the overvoltage oscillations is constant $f_T = 362Hz$, because the transformer parameters are constant, $C_T = 10^{-8}F$, $L_T = 25{,}7H$. Regarding the influence of the ratio $I_t / I_{o\max}$ on the amplitude factor for different values of the ratio, the graphical variations are shown in Figure 8.

As expected, the maximum values of the amplitude factor are obtained for the maximum value of the ratio, as result from (5) formula. In the same time, for the same value of the ratio, the amplitude factor increases as the cutting value of the inductive current increases; consequently, the cutting of the current at one value near the maximum value led to the higher value of the recovery transient overvoltage.

In the Figure 9, the variations of the amplitude factor depending on the cutting angle, as parameter are shown. From this figure, the same conclusion can be drown: the amplitude factor value increases as the cutting angle value increases for the same value of the ratio.

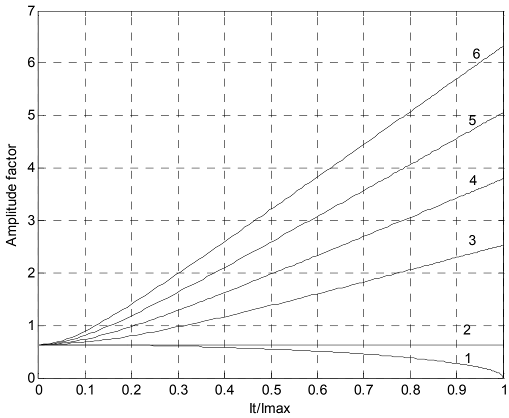


Figure 8 The variation of the amplitude factor vs $I_t / I_{o\max}$ ratio, ω_T / ω as parameter: 1 - $\omega_T / \omega = 0$, 2 - $\omega_T / \omega = 1$, 3 - $\omega_T / \omega = 4$, 4 - $\omega_T / \omega = 6$, 5- $\omega_T / \omega = 8$, 6 - $\omega_T / \omega = 10$

In the Figure 9, the variations of the amplitude factor depending on the cutting angle, as parameter are shown. From this figure, the same conclusion can be drown: the amplitude factor value increases as the cutting angle value increases for the same value of the ratio.

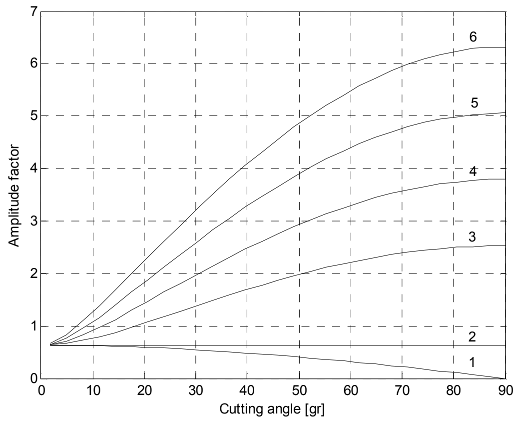


Figure 9 The variation of the amplitude factor vs cutting angle, ω_T / ω as parameter: 1 - $\omega_T / \omega = 0$, 2 - $\omega_T / \omega = 1$, 3 - $\omega_T / \omega = 4$, 4 - $\omega_T / \omega = 6$, 5- $\omega_T / \omega = 8$, 6 - $\omega_T / \omega = 10$

The maximum values of the recovery transient voltage have been computed without taking into account the limiting influence of the withstand voltage of the circuit breaker due to the speed of the recovery of the quenching dielectric medium rigidity (oil or SF_6). The diminishing of the overvoltage level can be also obtained by increasing of the input capacity of the transformer. The limiting of the dielectric stresses of the equipment can be done through the proper selection of the surge arresters parameters.

CONCLUSIONS

The Matlab computation program presented in this paper allows the evaluation of the maximum values of the recovery transient voltages appearing at the no-load high voltage transformer disconnecting. The influence of the cutting angle values of the inductive current on the overvoltage amplitude as well as the influence of the ratio ω_T / ω has been also studied. The program has been applied for the case of the high voltage transformers from ST North Craiova and ST Urechesti, for which the rated parameters are known. The computed level of the overvoltages can be compared with the withstand performances of the switching equipments within the stations. The analysis [Brojboiu, M., 2005] emphases the correctness of the chosen equipments of the station.

REFERENCES

Dragan, G. et all, 1975. *Switching surges in power systems*. Technical Ed., Bucureşti.

Gusa, M., 2002, *The transient regime of the network,* Gheorghe Asachi Ed, Iasi

Brojboiu, M., 2005. "*The computation of the electrical stresses in the high voltage network from the ST Craiova*". Research Report nr.35./2005, Beneficiary – Transelectrica SA Craiova.

Brojboiu, M.; Ivanov, V.; Leoveanu, M.S., 2005. "*Computation program for short-circuit current from Craiova substation*", Buletinul Institutului Politehnic Iaşi Tom 1 (LIV), Fasc. 5, Seria Electrotehnică, Energetică, Electronică.

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