STUDY OF THE PASSAGE OF IMPULSE SURGE VOLTAGE WAVES FROM ONE WINDING TO ANOTHER IN TRANSFORMERS

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ABSTRACT : We consider the passage of surge voltage waves from the HV winding to the LV winding. The results of analysis show that this passage depends on the operating conditions of the two neutrals and on the connection type of the LV winding. If the primary neutral is insulated, the passage is quite important and can present risks for the 110 KV nominal voltage transformers, operating with their neutral insulated. The arrester at the LV side should not be distant from the LV winding, because it is situated downstream from this latter with respect to the direction of propagation of the surge voltage wave. The set of the LV arresters in the case of 110 KV transformers must be studied meticulously. The voltage drops between adjacent elements of the HV windings are dependent only on the operating conditions of its neutral. The connection types of the windings and the operating conditions of the two neutrals have a strong influence on the secondary voltage drops.

I. INTRODUCTION

The co-ordination of transformers' insulations is based on the characteristics of the arresters intended to protect them against surge voltages. The standards in effect in electrical engineering prescribe the determination of the insulation level of each winding, from the residual voltage of the arrester of the same voltage class as that of the winding to protect.[1]

This approach of the co-ordination of the insulations does not take into account the over-voltages that can appear in a winding, following the passage of a surge voltage wave in another winding. Thus, the surge voltage phenomenon provoked by other ones that have affected a different winding is generally not mentioned, above all when the direction of HV winding - LV winding is considered. The argument produced to justify such approach comes from the fact that we assume that if a surge voltage in the HV winding does not present any danger for this particular winding, a fortiori it cannot create any danger for the LV winding.

A deeper analysis of the operation of a transformer shows that the passage of a surge voltage wave from the HV winding to the LV winding does not occur in the same conditions depending on the fact that the neutrals are insulated or connected to earth, and also on how the windings are connected: Y-type or Δ-type. One can therefore encounter situations where the passage of a surge voltage wave is of no risk to the LV winding as well as we can encounter other situations where the surge voltage in the winding can reach values which are dangerous to this winding. It is of high interest to note that the danger to the LV winding cannot be suppressed by the arrester of this winding since it is situated beyond this one with respect to the direction of the wave propagation. On the base of the latter notes, it appears necessary to ensure the protection of secondary windings of transformers against the passing surge voltages and to look for an increased precision in the co-ordination of the insulations that takes into account this type of surge voltage.

The representation of the windings with three phases permits to consider the actions of the surge voltage waves coming from one phase, or from two phases or even from three phases. It is clear that the probability of the advent of a surge voltage wave on one or two phases is far greater than that on the three phases. On the base of the global study, and the fact that the requests are weaker when the surge voltages affect only one or two phases rather than three. Therefore, it is necessary to define more precisely the insulation level of the windings

HV and LV transformer windings. In the present paper, we consider the surge voltages that affect the HV and LV transformer windings, taking into account the different operating conditions of the neutrals and the connection types of the windings. The surge voltage waves in consideration come by the HV side on one, two or three phases.

2. COMPUTATION SCHEME

The problem is tackled by the way of computation. The data that are used are those of a TDU – 200000 / 500 type transformer, manufactured in Russia. The secondary maximal voltage is equal to 15.75 KV. The calculus are executed starting from the usual equivalent diagram valid for the study of impulse surge voltages in the transformer (figure 1) and the station [2,3].

In accordance with the regulations [1], 500 KV high voltage transformers are protected by the side of this voltage with two lightning arresters (this aims to decrease the arrester current). The first arrester is directly connected to the terminals of the HV winding, whereas the second one is set at a distance of 120 m from the transformer.

On the diagram of figure 1, the characteristic impedances of phases A, B, and C at the HV side are noted Z_A , Z_B and Z_C respectively. The distances between the arrester pairs are introduced in the calculus by means of the following parameters L_{PA}- C_{PA}, L_{PB}-C_{PB} et L_{PC} - C_{PC} and we take into account the station at the HV side through the input capacitances C_{HPA}, C_{HPB} and C_{HPC}. Each winding is subdivided under certain conditions into six parts shown on figure 1 by six elements connected in series. Each element of the diagram represents one ore more constitutive elements of the winding (discs, coils or simply turns according the design). The resistances, the self and mutual inductances, the transverse capacitances (with respect to the core, to the tank and between the windings) and the longitudinal capacitances are respectively represented by R, L, M, C and K. Taking into account the high frequency of the applied wave and the existence of one winding in transformers that is always connected in Δ type, we neglect the influence of the core (besides, the traditional equivalent diagram does not take the core into account). In order to obtain results corresponding to the most severe requests of the insulation, we have selected an impulse test voltage characterised by a full wave of 1.2 / 50 µs. The wave magnitude is taken equal to the discharge voltage of the 500 KV nominal voltage line insulation.

3. DISCUSSION OF THE RESULTS

The surge voltage entering the transformer by the HV side (figure 2, curve 1) are limited by two arresters and the voltages at the HV terminals of the transformer do not overshoot the limits of the arresters, the values of these voltages are 838 KV (figure 2, curve 2). The arresters currents are represented on figure 3 on which appears the value of the first current, which is equal to 6.5 KA and the value of the second current which is equal to 4.5 KA. The arresters voltages and currents are related through their current-voltage characteristics.

During the acting of the asymmetric voltages (action on one or two phases) the voltage at the terminals of the phases that are not affected by the wave, remains very small (see table 1). The voltage of the insulated HV winding's neutral increases when the surge voltage wave comes simultaneously from the three phases. Our calculus shows that these voltages do not overshoot 1150 KV (figure 2, curve 3). In the case of action by two or by only one phase, the value of this voltage becomes equal to 2/3 and 1/3 times the one obtained with the action on three phases (778 KV and 390 KV) (see table 1).

The comparison between the connection diagram of the Y/Y, Y/Y⏚ and Y⏚/Y, Y⏚/Y shows that the HV winding voltage corresponding to the case when the secondary winding's neutral is insulated, are slightly smaller than those obtained with a secondary neutral connected to earth. This is due to the retroactive influence of the secondary o the primary.

The period of oscillations in the primary depends on the operating conditions of the neutral. When this winding's neutral is connected to earth, this period equals 150 μs whereas if the neutral is insulated the value of this period is equal to 300μs.

The operation of the arresters at the LV side (the values of the denominators in table 1 correspond to the cases where the arrester operate at the LV side) exerts an influence too, weak indeed, on the HV winding's voltages. If the secondary winding is connected in Y type or in Δ type, with insulated neutral, this influence is positive and becomes apparent through a slight increase of the primary voltages. When the secondary is connected in Y type with the neutral connected to earth, we observe the inverted phenomenon that is a negative influence. The operation of the LV arrester makes a link to earth, that increases the secondary current which itself induces an increase of the voltages in the HV winding by retroactive effect.

The obtained results for the LV winding are represented in table 1 and on figures 4 which show the voltages V_a, V_b and V_c . These voltages V_a, V_b and V_c of the winding connected in Δ type in the case of action of three phases and neutral insulated and connected to earth are represented on figure 4 a et 4 b. The existence of the capacitive links between the LV and HV windings brings to sight an initial voltage distribution in this winding, in addition to that that always exists in the HV winding. On the figures 4, these voltage components are well visible and they are greater when the primary neutral is insulated. In this latter case, there is a very important passage through the capacitive link close to the neutral.

After the phase of initial voltage distribution, the LV winding tends towards its final state by its own oscillations. This final state is determined by the electromagnetic influence of the primary. During these transient process, the secondary winding exerts in its turn an influence on the primary winding. This influence is called the retroactive effect.

The secondary voltages depend strongly on the connection type, on the operating conditions of the this winding's neutral, but also on the operating conditions of the primary's neutral. If the connection type is Y/Δ and during the surge voltages coming from the three phases, the secondary voltages at any point of the triangle do not change. The form of these voltages is the same as that of the voltage close to the HV winding's neutral (figure 4 a.). This can be explained by the fact that, as mentioned above, at the side of the HV winding's insulated neutral, there is a very important passage through the capacitive links as well as a passage by the magnetic way. But it is known that in the case of an HV winding with insulated neutral, the self oscillations of this winding are odd oscillations that are they consist in a spatial distribution of odd wave quarters. The magnemotive forces of these oscillations have at each moment the same direction and generate a magnetic flux which induces in its turn an electromotive force of the same period in the secondary.

If the primary neutral is connected to earth, the secondary voltage is diminished of around 25%. The form of this voltage is exactly non periodic (figure 4, curve 2). This is due to the connection of the HV neutral to earth, inducing oscillations made up of half-waves. These half-waves have an antagonistic spatial distribution which prevent them from making a contribution to the general magnetic flux. However, if the neutral of the HV winding is connected to earth, we observe the apparition of an increasing current in this winding, created by the applied voltage. The magnetic flux of this current induces an electromotive force in the LV winding. Just like the current that generates it, this electromotive force is not periodic and this is why the secondary voltage shows a non periodic form as represented in figure 4, curve 2. In the case of actions of the surge voltage waves from two or one phase, the secondary voltage are diminished to equal respectively 77% and 45% of the voltage corresponding to an action taking place in three phases.

In the case of a $Y_{\perp}/\Delta$ configuration, which is widely used in the electrical nets (especially in the transformer-alternator blocks), the secondary voltages do not overshoot 52 KV. In order to evaluate the surge voltages in the secondary windings, it is necessary to take into account the nominal voltage and also the fact that the resistance of this winding is very small and that the duration of the oscillations is greater. In taking into account the nominal voltage, the surge voltages in this winding can rise up to $52+(15.75).\frac{\sqrt{2}}{\sqrt{3}} \approx 65$ KV. This last value is inferior to the voltages limit in the 15.75 nominal voltage winding, equal to 110 KV [1]. However, taking into account an oscillation of great duration, these surge voltages can present risks to this winding.

The use of arresters at the LV side permits to eliminate these risks. The computations results are collected on the figure 4 c and the table 1. By reading this table, we note that if the secondary winding is connected in Δ type or in Y type with the neutral insulated, the voltages in the middle overshoot those existing at the terminals of this winding. This reason leads to set the arresters at the LV side not very far from the transformer, since they are situated before this latter, with respect to the wave's propagation direction. This is more important for hydraulic power station which are situated generally at the bottom of mountainous regions.

The analysis of the Y/Y and $Y_{\perp}$/Y connection types shows that with such connections, the passage of the surge voltage waves from the primary to the secondary is similar to that encountered with Y/Δ and $Y_{\perp}/\Delta$ connection types. In the case of a Y/Y configuration, the secondary voltages are slightly greater than those encountered with a Y/Δ connection type. This is explained by the fact that the current in the Δ has the effect of slightly diminishing these voltages. This phenomenon is also observed when comparing $Y_{\perp}$/Y and $Y_{\perp}/\Delta$ connection types.

The connection of the secondary to earth significantly diminishes the surge voltages in this winding. The secondary voltages decrease in a monotonous way starting from the terminal to the neutral. In general, if the neutral of the secondary is connected to earth, with the arrester at its terminals, the surge voltages at all points of the winding do not overshoot the residual voltage of the arrester [4]. This form of secondary voltage repartition allows to conclude that the insulated neutrals of secondary windings operating whithout load must be earthed. This is very important for the blocks where two alternators are connected to two dissociated secondary windings of a step-up transformer. In the case of alternator under repair of an alternator, or in the case of minimal loads, one of the both alternators is disconnected and the correspondent secondary winding operate whithout load.

As mentioned above, the passage of the surge voltages at the side of the insulated neutral is far more dangerous to the transformers with an insulated neutral. The 110 KV nominal voltage transformers operate either with the neutral connected to earth or with the neutral insulated.

The voltage differences between the adjacent elements of the HV and the LV windings are represented on figures 5.

The curves on figure 5 correspond to the windings' different connection types and to the two neutrals' different operating conditions. The minimal values of the primary voltage differences (figures-5. I and II) correspond to the cases where the connection to earth does not exist (Y/Δ and Y/Y connection types). The connection to earth of the HV winding's neutral increases significantly the voltage differences in this winding. However, the connection to earth of the neutral of the secondary and the operating of the arrester at the LV side almost do not influence these voltage differences. In the case of actions of surge voltage waves by two or by one phase, the voltage differences in the windings of the phases from which the wave does not come are very small.

The windings connection types and the neutrals operating conditions exert great influences on the voltage differences in the secondary winding figure-5. III, IV, V and II. If the surge voltage wave comes from the three phases the connection of the primary's neutral to earth can increase these voltage differences of the secondary up to 20 %, but in the case where the secondary neutral is connected to earth this increase can reach almost 50 %. In this particular case, the voltages differences increase in a monotonous way starting from the beginning of the winding towards its neutral. The maximal values take place in the neutral's zone .

The operation of the arrester at the LV side diminishes these voltage differences and in such cases, the minimal values will take place in the middle of the winding (figure 5.IV and 5.VI). In the case of actions of the surge voltage waves by one or by two phases, the secondary voltage differences decrease.

4. CONCLUSION

The passage of surge voltages waves from the HV winding to the LV winding has been considered in the cases of the two neutrals insulated and connected to earth with all the possible connection types.

The surge voltages in the HV winding depend mostly on the operating condition of this winding's neutral. The influence of the LV winding's operating conditions is non significant.

The surge voltage in the LV winding depend on the connection type of this winding and on the operating conditions of the windings' two neutrals.

The analysis of the Y/Y and $Y_{\perp}$/Y connection types shows that with such connections, the passage of surge voltages from the primary to the secondary is similar with Y/Δ and $Y_{\perp}$/Δ connection types respectively.

The connection to earth of the primary's neutral diminishes the secondary surge voltages nearly of two times. The use of the arrester at the LV side diminishes these surge voltages, this principally in the vicinity of the LV terminals. In these cases, the voltages at the middle of the winding are greater than those at this winding's terminals. This is why the LV arrester should not be remote from this winding's terminals. This is more important for the hydraulic power station which are situated generally at the bottom of mountainous regions.

In the case where the primary's neutral is insulated, the passage of the surge voltages at the side of this neutral is significant. This phenomenon is far more dangerous for the transformers of 110 KV nominal voltage, operating with the neutral insulated.

The connection type, the operating conditions of the secondary neutral and the operation of the LV arrester exert almost no influence on the voltage differences between the adjacent elements of the HV winding. The minimal values of the primary voltage differences correspond to the cases where there is no connection to earth (Y/Δ Y/Y connection types). Connecting this winding's neutral to earth increases significantly the voltage differences in this winding.

The connecting types of the windings and the operating conditions of the two neutrals exert great influences on the secondary winding's voltage differences. Connecting the primary neutral to earth increases the voltage differences up to 20 % whereas connecting the secondary neutral to earth increases these voltage differences up to 50 %. The nature of this increase is monotonous starting from the beginning of the winding towards its neutral. The use of the LV arrester diminishes the voltage differences in this winding.

During the actions of surge voltage waves by two or one phase, the surge voltages and the voltage differences in the LV winding are very small.

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1. Manual on the protection of the electrotechnical equipments in AC- voltage 3-500 KV against the surge voltages. Moscou , 1975.

2. *Heller B. et Veverka A.* Processus impulsionnelles dans les machines électriques. ‘’Energuiya’’, 1973 , Moscou.
3. *Djuvarly Ch..M ; Mufidzada N.A.* How the Working Voltage Influence Overvoltage on Autotranformers for Operation of Valve-Type Arresters. ‘’Electritchestvo ‘’ 1984 , No.7, pp-63-64 , Moscow.
4. *Mufidzada N.A., Otmane-cherif T., Chaibi R.* ‘’Effects of Impulse Surge Voltages on Alternators ‘’.IEEE Power Tech Conferences , Sept 2001 , Vol N°4, Porto ,Portugal.

TRANSFORMATORLARDA İMPULS İFRAT GƏRGİNLİK DALĞALARIN BİR DOLAQDAN DİGƏRİNƏ KEÇMƏSİ

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Məqalədə təyin edilib ki, ikinci dolağda keçən gərginliyin forması və qiyməti əsas etibarilə dolaqların birləşmə sxemindən və hər iki neytralın rejimindən asılı olur. Birinci dolağın izolə edilmiş neytralı tərəfdən ikinci dolağda elektrostatik yolla keçən gərginliklər də qorxulu qiymətlərə çata bilər.

ИССЛЕДОВАНИЕ ПЕРЕХОДА ИМПУЛЬСНЫХ ВОЛН ПЕРЕНАПРЯЖЕНИЙ ИЗ ОДНОЙ ОБМОТКИ В ДРУГУЮ В ТРАНСФОРМАТОРАХ

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В статье определено, что переход импульсных волн перенапряжений из одной обмотки в другую в основном зависит от схемы соединения обмоток и режимов работы обеих нейтралей. Перенапряжения переходящие электростатическим путем со стороны изолированной нейтрали высоковольтной обмотки могут достигать опасных значений.

Table 1a

connection Scheme	Action by	HV winding							LV winding						
		U_{A1}	U_{B1}	U_{C1}	U_{A4}	U_{B4}	U_{C4}	$U_{N\,HT}$	U_{a1}	U_{b1}	U_{c1}	U_{a4}	U_{b4}	U_{c4}	$U_{N\,BT}$
		KV	KV	KV	KV	KV	KV	KV	KV	KV	KV	KV	KV	KV	KV
Y / Δ	3 Phases	837	837	837	985	985	985	1126	74	74	74	74	74	74	-
		837	837	837	989	989	989	1137	39	39	39	49	49	49	-
	2 Phases	837	837	125	805	805	411	763	52	58	60	63	54	60	-
		837	837	105	806	806	413	768	39	39	36	46	45	41	-
	1 Phases	837	69	53	626	209	209	388	44	44	53	53	52	45	-
		837	69	53	625	209	209	388	31	31	36	38	35	31	-
Y⏚ / Δ	3 Phases	837	837	837	448	448	448	0	52	52	52	52	52	52	-
		837	837	837	449	449	444	0	38	38	38	40	40	40	-
	2 Phases	837	837	2,9	450	450	4,4	0	38	48	48	46	39	48	-
		837	837	2,8	450	450	3,9	0	34	38	37	38	32	40	-
	1 Phases	837	1,4	1,4	451	2,4	2,0	0	31	21	32	31	30	23	-
		837	1,4	1,4	451	2,4	2,0	0	30	20	31	29	29	21	-

Table 1b

Connection scheme	Action by	HV winding							LV winding						
		U_{A1}	U_{B1}	U_{C1}	U_{A4}	U_{B4}	U_{C4}	$U_{N\,HT}$	U_{a1}	U_{b1}	U_{c1}	U_{a4}	U_{b4}	U_{c4}	$U_{N\,BT}$
		KV	KV	KV	KV	KV	KV	KV	KV	KV	KV	KV	KV	KV	KV
Y / Y	3 Phases	837	837	837	985	985	985	1126	78	78	78	74	74	74	78
		837	837	837	990	990	990	1138	38	38	38,4	54	54	54	56
	2 Phases	837	837	126	805	805	412	764	61	70	56	53	56	63	53
		837	837	125	806	806	413	768	38	37	47	45	47	40	42
	1 Phases	837	68	69	626	209	209	388	71	57	60	52	51	51	43
		837	67	67	626	209	209	387	38	32	38	35	29	29	27
Y⏚ / Y	3 Phases	838	838	838	448	448	448	0	68	68	68	52	52	52	68
		838	838	838	450	450	450	0	38	38	38	36	36	36	45
	2 Phases	838	838	5	450	450	5,7	0	60	60	45	39	45	58	45
		838	838	3	451	451	4	0	38	37	33	32	33	38	37
	1 Phases	838	2,5	2,5	452	3	3	0	56	40	42	30	29	29	23
		838	1,6	1,6	452	252	2,2	0	38	27	30	2,9	22	22	17

Table 1c

Connection Scheme	Action by	HV winding							LV winding						
		U_{A1} KV	U_{B1} KV	U_{C1} KV	U_{A4} KV	U_{B4} KV	U_{C4} KV	$U_{N\ HT}$ KV	U_{a1} KV	U_{b1} KV	U_{c1} KV	U_{a4} KV	U_{b4} KV	U_{c4} KV	$U_{N\ BT}$ KV
Y / Y	3 Phases	837	837	837	998	999	999	1150	67	67	67	44	44	44	0
		837	837	837	994	994	994	1147	38	38	38	35	35	35	0
	2 Phases	837	837	120	814	814	419	778	62	62	15	42	42	12	0
		837	837	100	813	811	419	776	38	38	15	33	33	12	0
	1 Phases	837	64	64	630	283	213	396	59	2	8	40	6,6	6,6	0
		837	64	64	629	212	212	395	38	1,8	7,8	30	6,6	6,6	0
Y / Y	3 Phases	837	837	837	454	454	459	0	54	54	54	38	38	38	0
		837	837	837	453	453	453	0	38	38	38	27	27	27	0
	2 Phases	837	837	0	455	455	0	0	54	54	3,5	37	37	2,4	0
		837	837	0	453	453	0	0	38	30	1,30	27	27	1	0
	1 Phases	837	0	0	455	0	0	0	54	0,83	0,83	38	0,5	0,5	0
		837	0	0	453	0	0	0	38	0,5	0,5	27	0,3	0,3	0

Table 2 : Signification of the used letters in the graphs and that of the different transformer connections

Letter	Connection	Letter	Connection	Letter	Connection	Letter	Connection
A	Y/Δ	D	Y/Δ	G	Y/Y	J	Y/Y
B	Y/Δ	E	Y/Y	H	Y/Y	K	Y/Y
C	Y/Δ	F	Y/Y	I	Y/Y	L	Y/Y

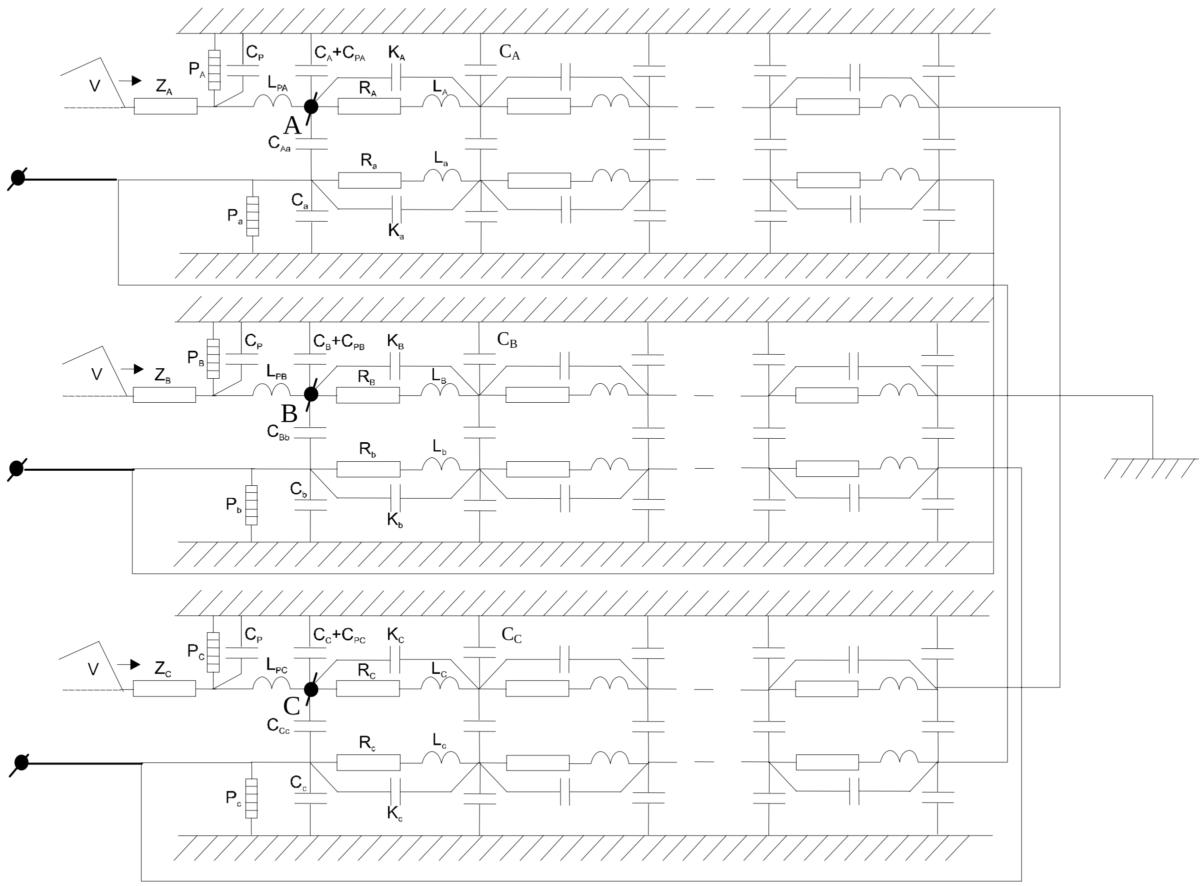


Fig.1 : Computing scheme

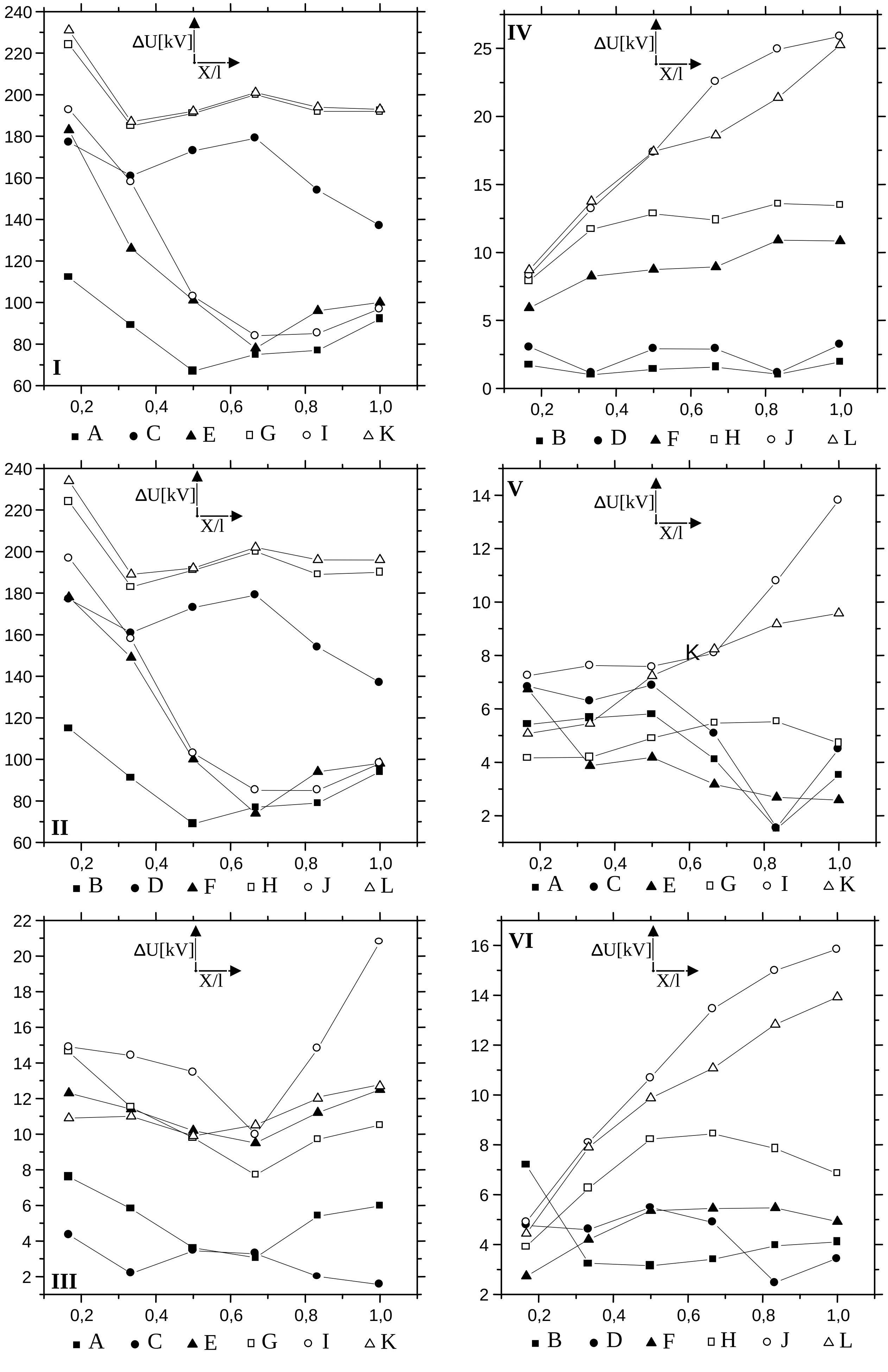


Figure 5 :Potential gradients of the relative distance **. I, III,** et **V** with arresters at the low voltage side **II.IV and VI** with arresters at the low voltage.

Table 2 : Signification of the used letters in the graphs and that of the different transformer connections

Letter	Connection	Letter	Connection	Letter	Connection	Letter	Connection
A	Y/Δ	D	Y/Δ	G	Y⏚/Y	J	Y/Y⏚
B	Y/Δ	E	Y/Y	H	Y⏚/Y	K	Y⏚/Y⏚
C	Y⏚/Δ	F	Y/Y	I	Y/Y⏚	L	Y⏚/Y⏚

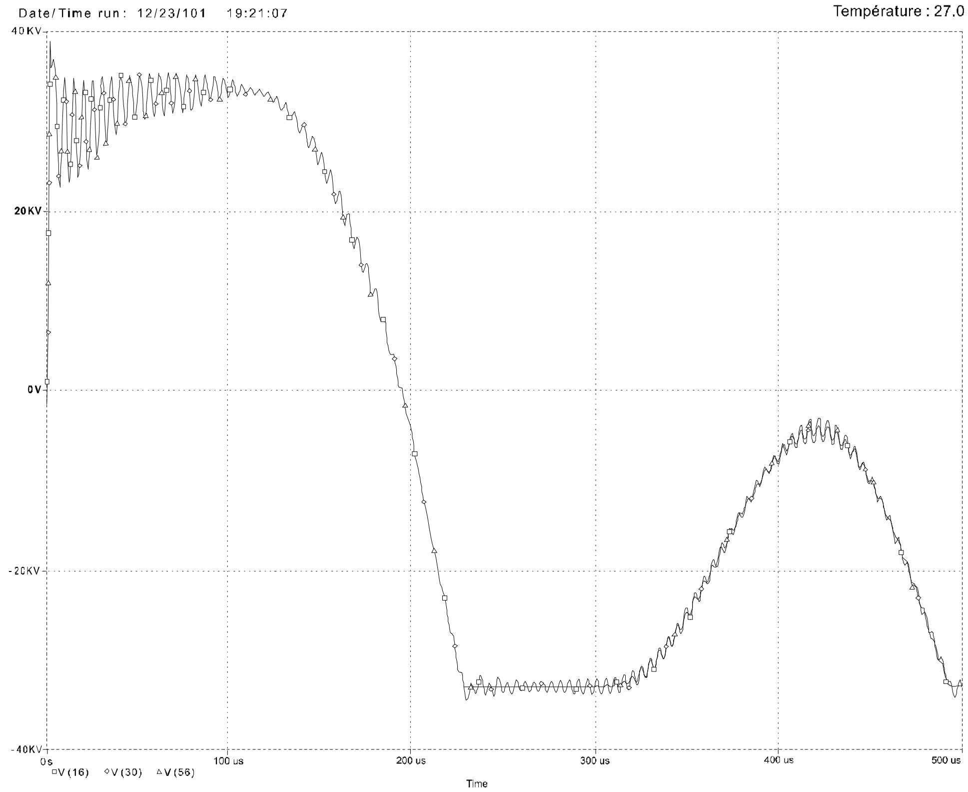


Fig.4c : The primary neutral is earthed with emplacement of the arrester at the N-side

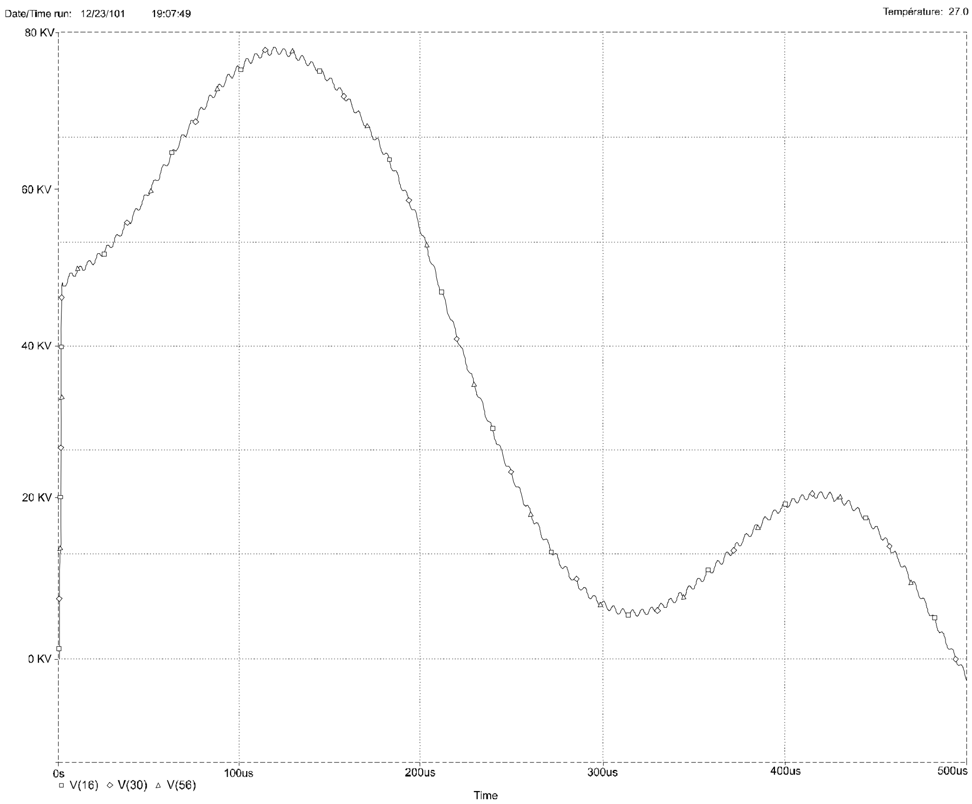


Fig.4 : Surevoltage onthe LVwinding connected in Δ type

a) neutral HV winding is insulated to earth
b) neutral HV winding is connected to earth

the arresters at the LV non fonctionnel

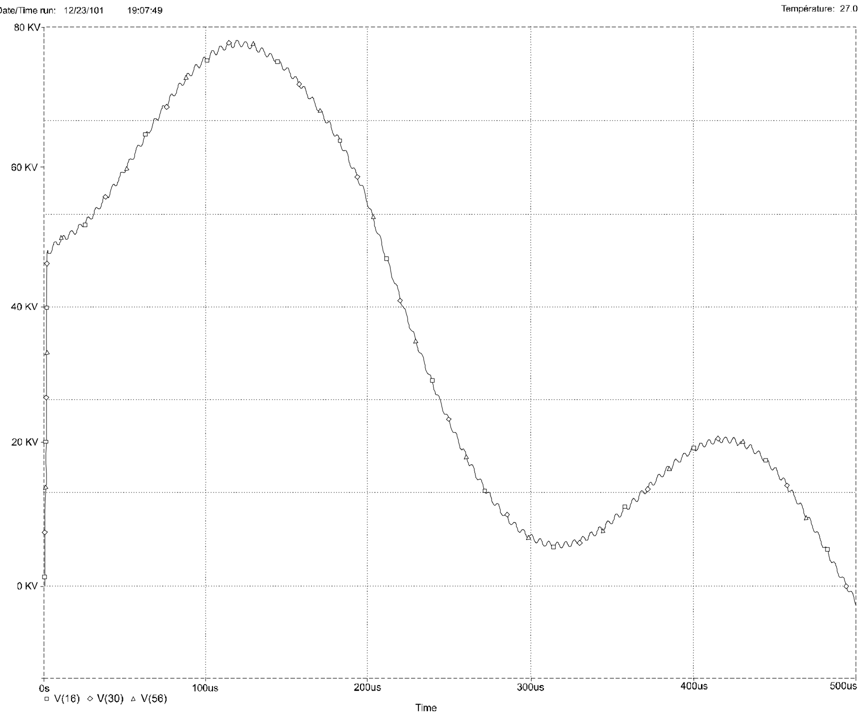


Fig.4 : Surevoltage onthe LVwinding connected in Δ type

a) neutral HV winding is insulated to earth
b) neutral HV winding is connected to earth } the arresters at the LV non fonctionnel

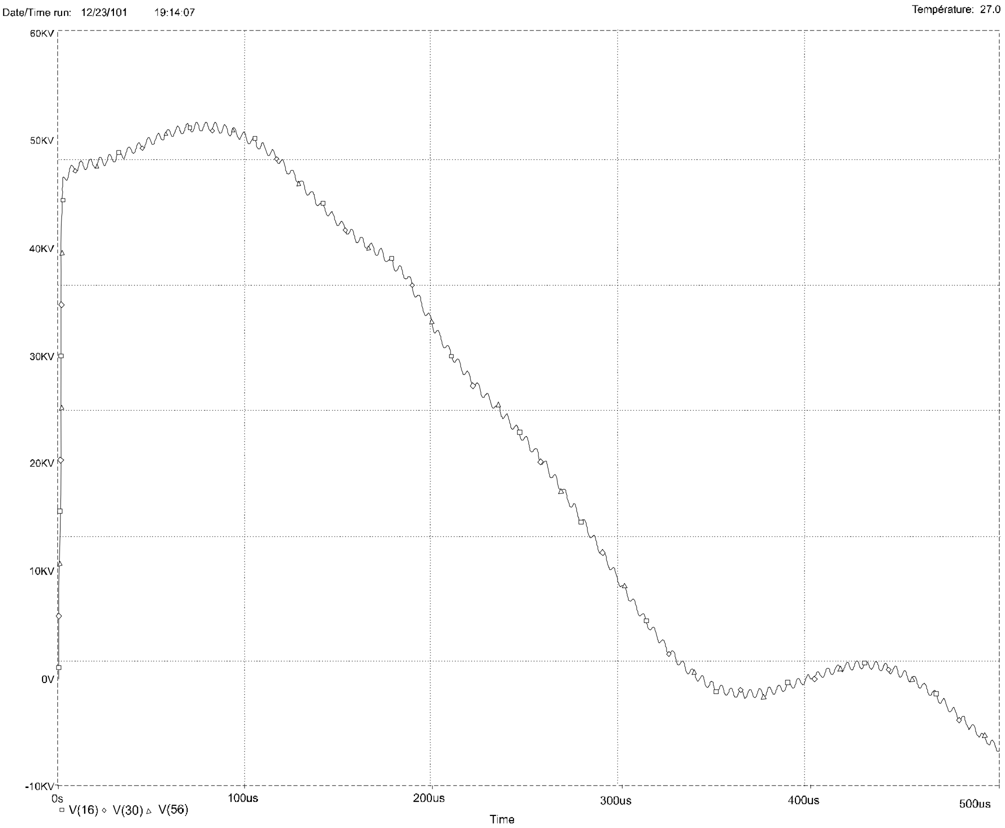


Fig. 4b : The primary neutral is earthed without arresters

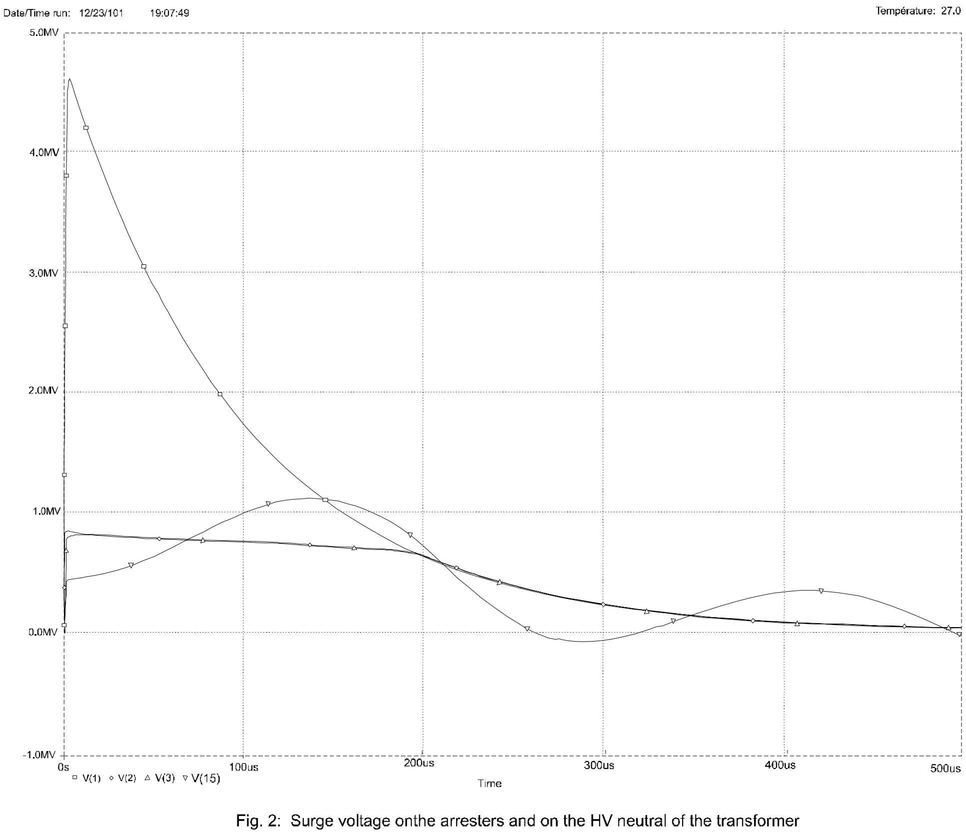


Fig. 2: Surge voltage onthe arresters and on the HV neutral of the transformer

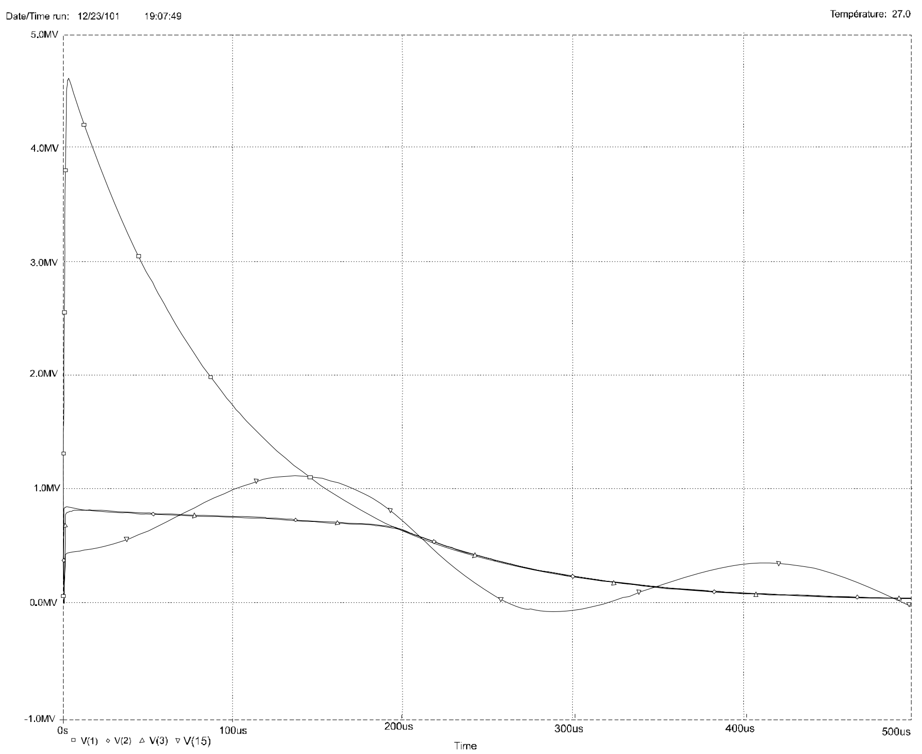
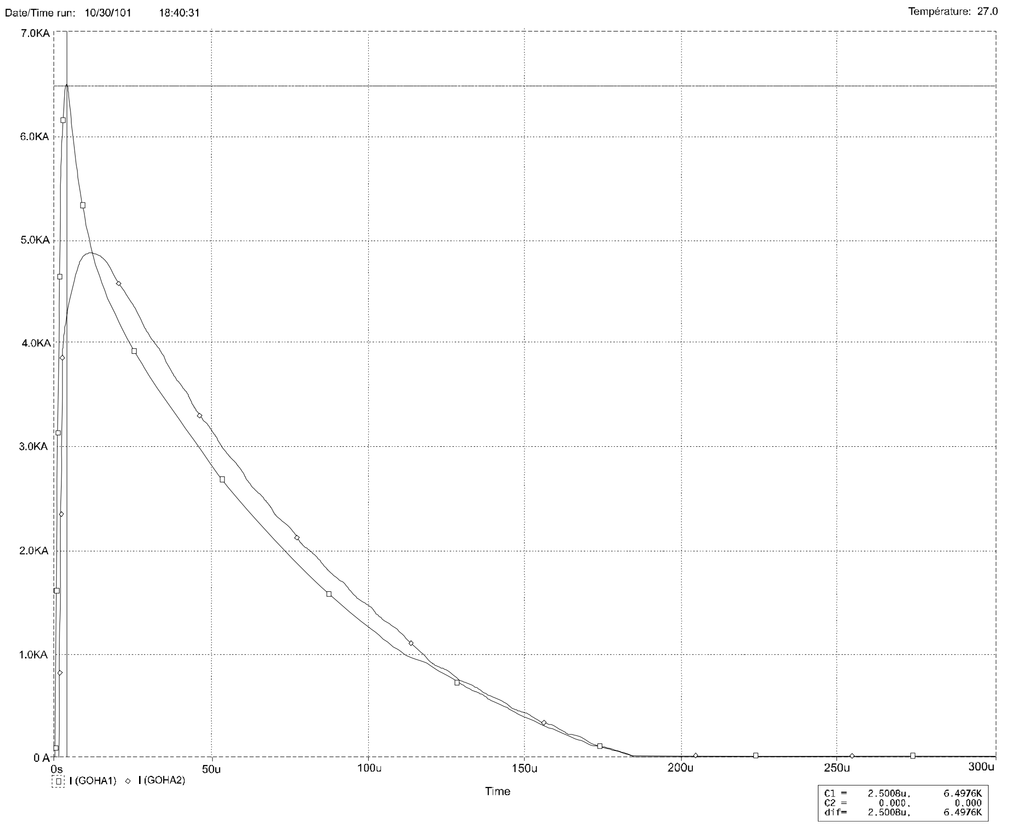


Fig. 2: Surge voltage onthe arresters and on the HV neutral of the transformer



Date/Time run: 10/30/101 18:40:31
Température: 27.0
7.0KA
6.0KA
5.0KA
4.0KA
3.0KA
2.0KA
1.0KA
0 A
0s
50u
100u
150u
200u
250u
300u
I (GOHA1)
I (GOHA2)
Time
C1 = 2.5008u, 6.4976K
C2 = 0.000, 0.000
dif= 2.5008u, 6.4976K