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IMPULSE SURGE VOLTAGES IN TRANSFORMER WINDINGS IN THE USE OF DIFFERENT GROUNDING MEANS OF THE PRIMARY NEUTRAL

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Abstract. We consider in this paper the influence of the grounding element of the transformer neutral on the surge voltages and the voltage differences between the adjacent elements in its windings. As a grounding element we use the linear induction reactance, the non-linear saturable induction and the concrete resistor resistor. The non-linear saturable induction reactances of the different nominal voltages and currents have few influences on the surge voltages and voltage drops in the primary particularly in the surrounding of the neutral. The influence of this reactance on the surge voltages and voltage drops in the secondary is practically absent. The surge voltages in both the primary and secondary do not reach dangerous values if the primary neutral is connected to the primary ground through either a linear induction reactance or a resistance (provided an increase in resistance up to 200 Ω). The choice of the non linear saturable reactance for the grounding of the transformers' primary neutral should be made provided the restriction of the asymmetrical short-circuit currents and the improvement of the disconnecting property of the circuit breakers

Key words: Surge voltage, transformer, arrester, non-linear saturable reactance, concrete resistor
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I - INTRODUCTION

The various means for grounding the neutral of transformers and autotransformers in order to limit the asymmetrical short circuit currents have been proposed by [1, 2, 3, 4]. According to these propositions, the neutral of transformers can be grounded through a linear induction reactance or a non-linear induction reactance or also through a concrete resistor. For instance the Instructions Dirigeants for the limitation of the shot-circuit currents suggests to ground the neutral of transformers and autotransformers through a linear induction reactance [1].

It is well known that the element through which the neutral of the transformer is grounded is located in the loop of the circuit breaker and that it creates an influence on the disconnecting property. Thus, in order to increase the disconnecting property of the circuit breakers it is preferable to replace on the neutral of the transformer the linear induction reactance by the non-linear induction reactance, which is suggested in [2]. The nominal voltage of this non-linear induction reactance should be less than 1 % of the mains operating voltage and of that equipped with the elements used to form the frequency characteristics that ensure the decrease in speed of the short circuit current close to its null value. From this point of view, the application of a non-linear saturable induction reactance is comparatively much more advantageous.

The best results, based on the recovery voltage are obtained in [3], when the grounding of the neutral of the transformers is made through a concrete resistor in the networks in which the nominal voltages are in the range of 110 to 220 kV. Nevertheless, the exploitation of such networks show that the electrical resources of the concrete resistor are not sufficient, because of the permanent existence of the currents in which they find their electrical resources. This makes the use of concrete resistor resistors not very practical.

The change in the operating mode of the neutral due to application of a grounding element ensuring the limitation of the asymmetrical short circuit currents will increase the surge voltages and the surge voltage gradients in the transformers' windings. Usually the insulation level of the grounded neutral of transformers and autotransformers winding has a lower class than that of the remaining part of this winding. Therefore, the change in the operating mode of the neutral requires an evaluation of the surge voltages on the insulation of the transformers windings and -if necessary- the performing of a correction for their protection.

The present work is dedicated to the determination of the surge voltages and the surge voltage gradients in the primary and the secondary of a 220 kV transformer, taking into account the operating conditions and at the occurrence of the action of impulse surge voltage waves on three phases of the HV winding which has different neutral operating modes.

This problem is studied by means of computation according the TDU-125000/220 transformer type (of Russian production), which has a maximal secondary voltage of 13,8 kV. The computations are made using the equivalent representation of the transformer and the station. (fig.1), [5].

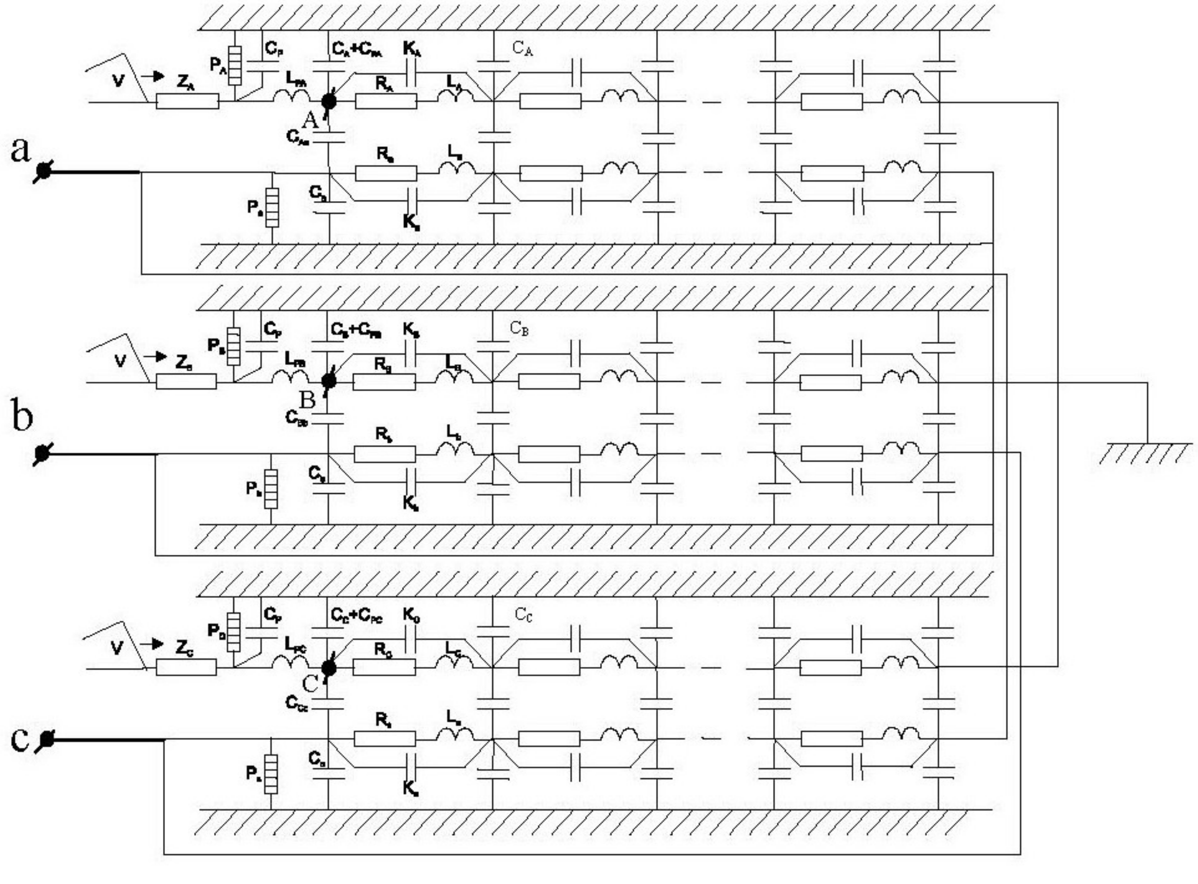


Fig.1.Computing scheme

II - COMPUTATION SCHEME

On the diagram of figure 1 the characteristic impedances of the phases A, B and C on the HV side are noted respectively Z_A, Z_B and Z_C. The distances between the transformer and the arresters P_A , P_B and P_C are introduced in the calculus by means of parameters $L_{P\,A}$-$C_{P\,A}$, $L_{P\,B}$-$C_{P\,B}$ and $L_{P\,C}$- $C_{P\,C}$. On the HV side we take into account the unidirectional station expressed by C_{pHA} , C_{pHB} and C_{pHC} . Each winding is subdivided under certain conditions into six parts shown on figure 1 by six elements connected in series (the software used here does not permit to deal with an electrical diagram having more than 100 nodes). Each element of the diagram represents one ore more constitutive elements of the winding (discs, coils or simply turns, according to 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. $L_r(\Phi)$ represents the saturable non linear induction reactance on the neutral of the transformer HV winding. In the computations we used the non linear induction reactance having a nominal voltage that is equal to 1%, 10% and 20% of the maximum value of the network phase voltage under consideration . For each of these selected nominal voltages we chose the different of the nominal current according to [6]. For the nominal voltage equal to $0.01U_{ph\,m}$ we chose two nominal currents equal to 600 A and 6000 A; For the nominal voltage $0.1U_{ph\,m}$ - 600 A, 6000 A, 12000 A, 20000 A and for the nominal voltage $0.2U_{ph\,m}$ - 12000 A, 20000 A. As for the linear induction reactance, we used the one with the type TOPMT-110-1350-15A.

In order to obtain results corresponding to the most severe solicitations of the insulation, we selected an impulse test voltage characterized by a complete wave 1,2/50 µs. The magnitude of this wave was taken equal to the discharging voltage of the insulation of the 220 kV nominal voltage line.

III – ANALYSIS OF THE RESULTS

The computing tool used here is the Pspice hardware and the yielded results are presented in tables 1 to 4 and on figures 2 to 5. The tables 1 and 2 represent the surge voltages and the surge voltage differences between adjacent elements of the primary and the secondary in the case of a -type connection for the secondary and a Y-type with the neutral insulated from ground. Tables 3 and 4 represent the surge voltages in the case of the Y-type connection for the secondary with the neutral grounded. Tables 5and 6 represent the surge voltages in the case of the primary neutral grounded through a concrete resistor.

The surge voltage waves reaching the transformer on the HV side, undergo a limitation by the arresters arranged on this side at a distance of 120 m from the transformer in accordance with the regulations [7]. The voltage and the current values in the arrester are respectively 465 kV (figure 2, curve 1), and 3.85 kA (figure 3). These values correspond to the Volt-Amp characteristic curve of the arrester. The surge voltages across the transformer are equal to 836 kV (figure 2, curve 2), these latter never overshoot the surge voltage admissible value for the insulations of the nominal voltage 220 kV. Inside the HV winding these surge voltages decrease gradually from the beginning of this winding to its end. The surge voltages on the neutral of the HV winding are very small (se tables 1, 3 and figure 2, curve 3). This shows that when we apply the saturable non linear induction reactance, the operating mode of the neutral is nearly identical to that of the directly grounded neutral. We deduce from observation of tables 1 and 3 that the influence of the saturable non linear induction reactance is noticeable nearly over 30 % of the winding length close to the neutral. Starting from the neutral point towards the beginning of the winding, this influence decreases. Despite this latter mention, this influence is in fact completely insignificant.

Table 1

U_{nr}/U_{nm}	I_{nr}	U_{1H}	U_{2H}	U_{3H}	U_{4H}	U_{5H}	U_{6H}	U_{7H}	ΔU_{1H}	ΔU_{2H}	ΔU_{3H}	ΔU_{4H}	ΔU_{5H}	ΔU_{6H}	I_{LN}
	kA	kV	KV	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	A
0.01	0.6	833	569	408	316	210	127	1.89	264	185	133	121	114	125	683
	6	824	562	411	318	209	126	0.15	261	183	131	122	115	126	642
0.1	0.6	829	566	406	316	219	138	19.3	264	184	131	119	113	124	713
	6	819	559	409	317	210	127	1.67	260	182	130	121	115	126	700
	12	811	553	411	317	210	126	0.82	258	180	129	122	115	126	685
	20	834	569	410	317	210	126	0.51	265	185	132	121	115	126	708
0.2	12	823	562	411	318	209	126	0.82	261	183	131	122	115	126	687
	20	826	564	411	318	209	126	0.49	262	184	132	122	115	125	686
Linear reactan.	1,35	834	583	441	376	290	221	161	250	170	114	106	98	101	536

Table 2

U_{nr}/U_{nm}	I_{nr}	U_{1B}	U_{2B}	U_{3B}	U_{4B}	U_{5B}	U_{6B}	U_{7B}	ΔU_{1B}	ΔU_{2B}	ΔU_{3B}	ΔU_{4B}	ΔU_{5B}	ΔU_{6B}
	kA	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV
0.01	0.6	56,3	51,1	44,1	36,9	36,6	39,2	41,3	5,228	7,148	7,472	6,889	5,303	2,927
	6	55,9	50,7	43,6	36,4	37,0	39,3	41,4	5,191	7,099	7,294	6,909	5,373	2,961
0.1	0.6	56,4	51,2	44,1	36,9	36,5	38,9	41,1	5,207	7,114	7,337	6,753	5,215	2,879
	6	55,4	50,2	43,1	35,9	36,7	39,2	41,3	5,181	7,085	7,271	6,921	5,379	2,959
	12	54,3	49,6	43,2	36,5	36,9	39,2	41,3	4,889	6,681	7,306	6,956	5,407	2,981
	20	54,7	49,9	43,4	36,6	36,9	39,2	41,3	5,099	6,966	7,329	6,968	5,412	2,984
0.2	12	54,3	49,6	43,2	36,5	36,9	39,2	41,3	4,897	6,685	7,273	6,929	5,387	2,969
	20	54,7	49,9	43,4	36,6	37,0	39,3	41,4	5,099	6,966	7,312	6,920	5,380	2,965
Linear reactan.	1,35	60,1	55,7	49,8	44,1	43,6	44,0	44,9	4,419	5,861	6,096	5,494	4,132	2,346

Table3

U_{nr}/U_{nm}	I_{nr}	U_{1H}	U_{2H}	U_{3H}	U_{4H}	U_{5H}	U_{6H}	U_{7H}	ΔU_{1H}	ΔU_{2H}	ΔU_{3H}	ΔU_{4H}	ΔU_{5H}	ΔU_{6H}	I_{LN}
	kA	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	KV	kV	KV	A
0.01	0.6	833	567	415	325	218	131	1.84	266	186	133	121	120	129	638
	6	820	558	417	325	217	130	0.15	261	183	131	122	120	129	622
0.1	0.6	831	566	412	325	227	142	0.018	265	186	133	120	119	127	654
	6	836	569	417	325	218	130	1.511	266	187	134	121	120	129	644
	12	811	553	417	325	217	130	0.753	259	181	130	122	120	129	639
	20	818	558	417	325	217	130	0.452	261	183	131	122	120	129	631
0.2	12	811	553	417	325	217	130	0.753	259	181	130	122	120	129	631
	20	818	567	417	325	217	130	0.452	261	183	131	122	120	129	631
Linear reactan.	1,35	820	570	447	390	303	231	144	250	170	114	104	100	98	548

Table 4

U_{nr}/U_{nm}	I_{nr}	U_{1B}	U_{2B}	U_{3B}	U_{4B}	U_{5B}	U_{6B}	U_{7B}	ΔU_{1B}	ΔU_{2B}	ΔU_{3B}	ΔU_{4B}	ΔU_{5B}	ΔU_{6B}
	kA	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV
0.01	0.6	51,6	45,8	37,4	28,1	18,6	9,48	0,09	5,832	8,392	9,320	9,486	9,367	9,505
	6	51,1	45,3	37,0	27,8	19,2	9,99	0,08	5,772	8,315	9,239	9,385	9,254	10,01
0.1	0.6	51,5	45,7	37,4	28,1	18,6	9,59	0,09	5,797	8,361	9,306	9,472	9,356	9,608
	6	50,6	45,0	36,9	27,8	19,2	9,99	0,08	5,613	8,134	9,119	9,339	9,263	10,01
	12	50,8	45,0	36,8	27,6	19,2	9,99	0,08	5,752	8,279	9,187	9,321	9,241	10,01
	20	51,0	45,3	37,0	27,7	19,3	10,0	0,08	5,768	8,307	9,226	9,369	9,258	10,02
0.2	12	50,8	45,0	36,8	27,6	19,2	9,99	0,08	5,752	8,279	9,187	9,321	9,241	10,01
	20	51,0	45,3	37,0	27,7	19,3	10,0	0,08	5,768	8,307	9,226	9,369	9,258	10,02
Linear reactan.	1,35	53,0	47,5	39,5	30,4	21,0	11,0	0,11	5,556	8,020	9,015	9,450	9,950	10,99

Table 5

R_N	U_{1H}	U_{2H}	U_{3H}	U_{4H}	U_{5H}	U_{6H}	U_{7H}	ΔU_{1H}	ΔU_{2H}	ΔU_{3H}	ΔU_{4H}	ΔU_{5H}	ΔU_{6H}	I_{LN}
Ω	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	KV	A
2	826	564	410	317	209	126	1,38	261,9	183,8	131,6	121,2	114,6	125,4	688
5	836	571	411	317	210	128	3,36	265,1	185,9	133,1	121,4	114,5	125,4	671
10	834	570	408	317	212	129	6,44	264,5	185,4	132,7	120,6	114,1	124,7	664
20	819	559	407	317	215	133	13,2	259,3	181,5	129,7	119,9	113,4	124,0	661
50	825	565	404	317	224	144	31,5	260,3	181,9	129,3	117,8	111,6	122,0	630
100	821	564	403	319	238	162	55,1	256,9	178,6	125,7	115,7	109,2	119,0	551
200	824	568	408	328	264	194	98,1	256,1	177,5	124,0	113,2	105,9	113,3	491

Table 6

R_N	U_{1B}	U_{2B}	U_{3B}	U_{4B}	U_{5B}	U_{6B}	U_{7B}	ΔU_{1B}	ΔU_{2B}	ΔU_{3B}	ΔU_{4B}	ΔU_{5B}	ΔU_{6B}
Ω	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	kV	KV
2	54,7	49,9	43,4	36,6	36,9	39,2	41,3	5,060	6,911	7,346	6,971	5,411	2,983
5	55,9	50,9	44,0	37,0	36,9	39,3	41,4	4,991	6,839	7,279	6,849	5,335	2,939
10	56,3	51,1	44,1	36,9	36,7	39,1	41,3	5,129	7,019	7,310	6,915	5,361	2,956
20	55,9	50,7	43,6	36,4	36,6	39,0	41,2	5,177	7,073	7,212	6,847	5,331	2,939
50	56,5	51,3	44,3	37,2	36,6	39,0	41,1	5,122	6,889	7,112	6,660	5,163	2,846
100	57,0	51,9	45,1	38,2	37,7	39,2	41,4	5,048	6,854	6,932	6,439	4,979	2,739
200	56,8	52,1	45,7	39,3	38,8	39,9	42,1	4,834	6,499	6,731	6,175	4,809	2,659

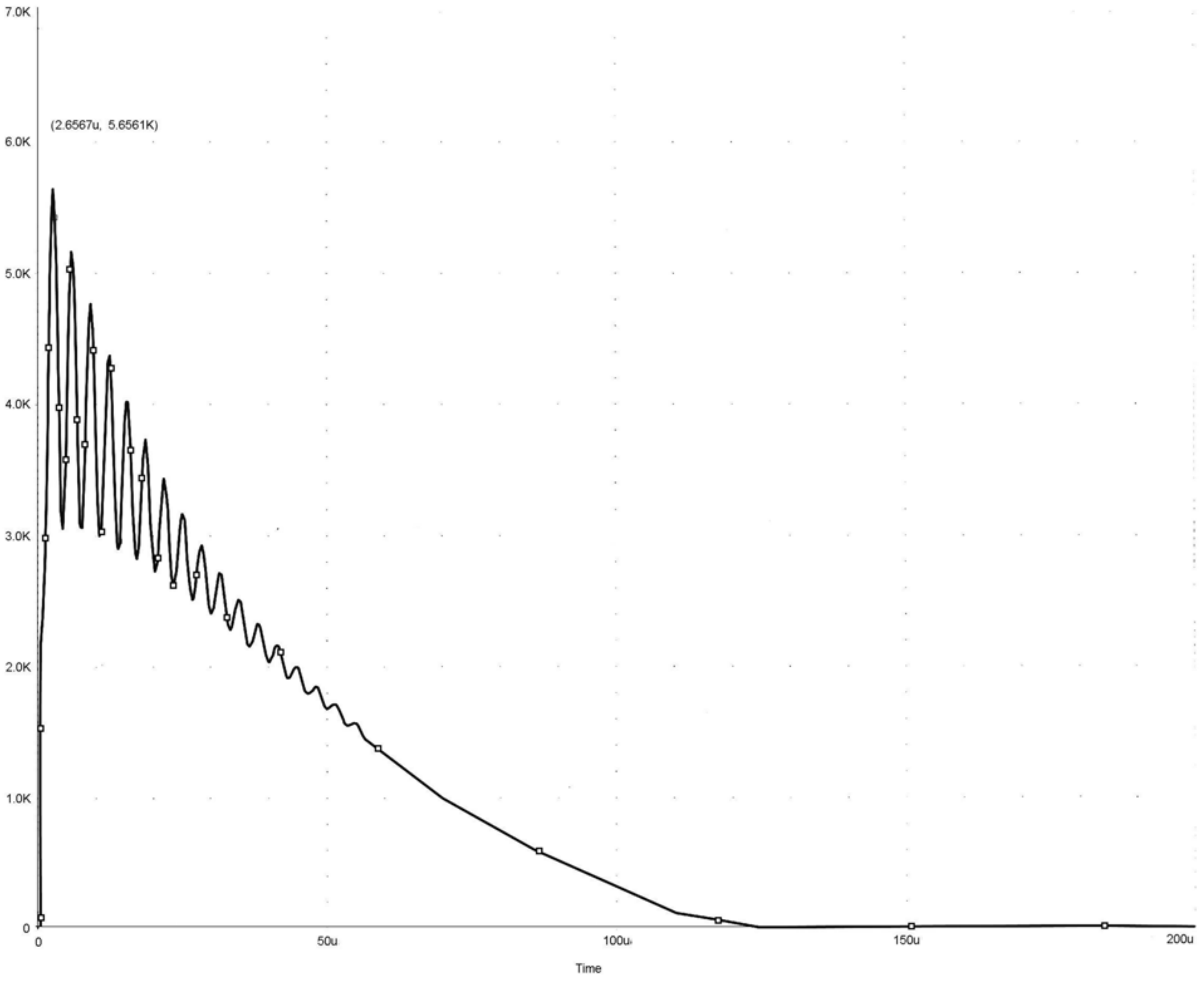
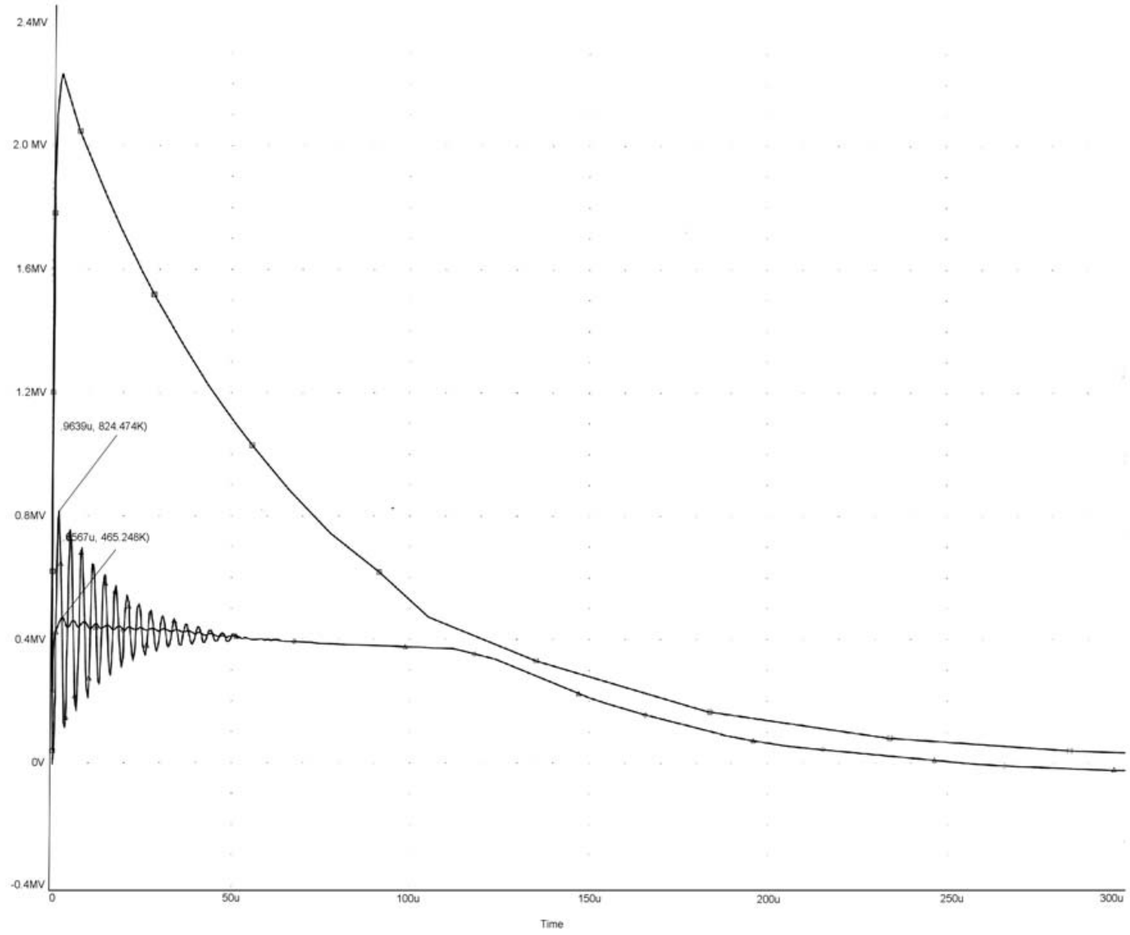
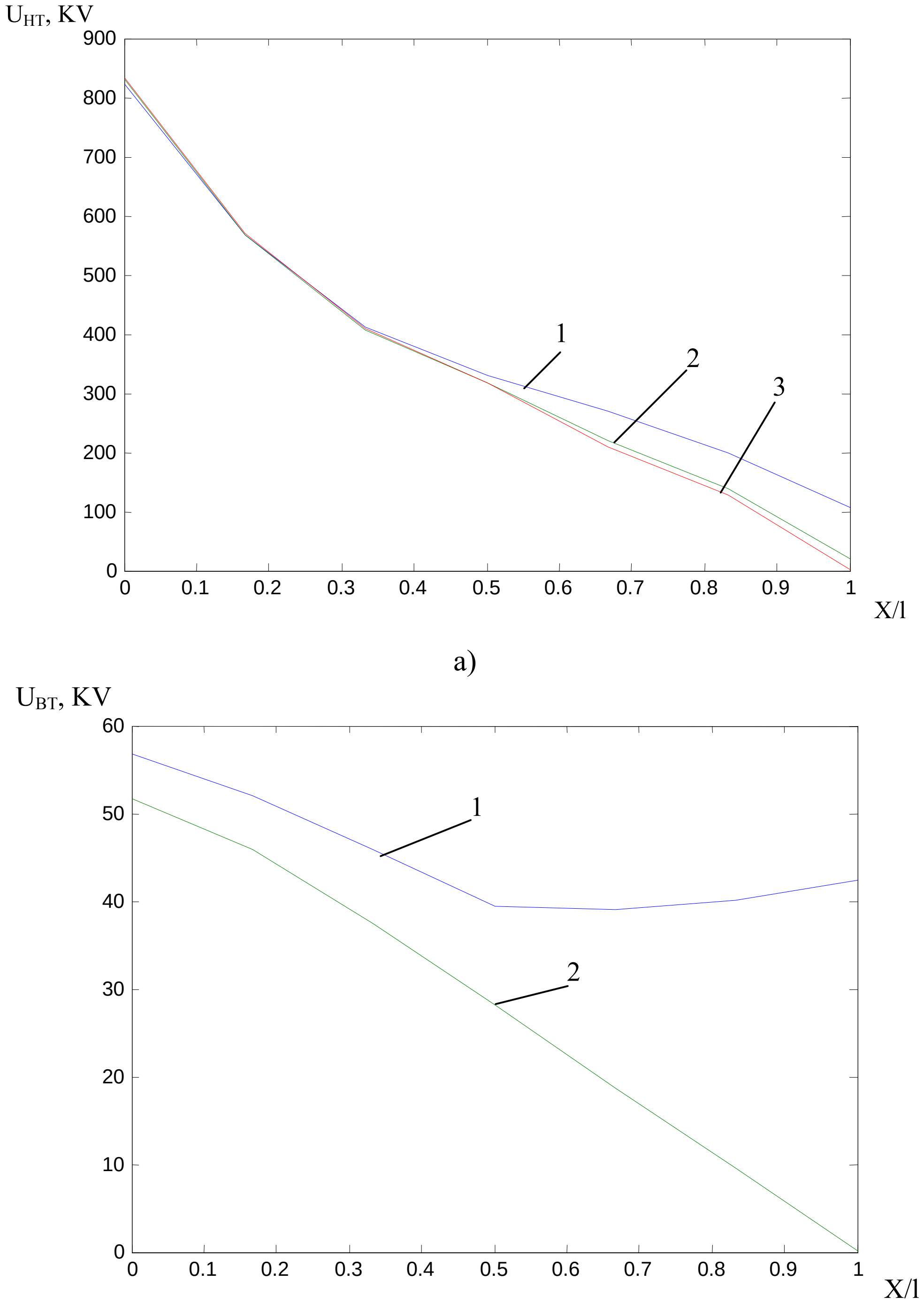

7.0K
6.0K
5.0K
4.0K
3.0K
2.0K
1.0K
0
(2.6567u, 5.6561K)
0
50u
100u
150u
200u
Time

Fig.2



2.4MV
2.0 MV
1.6MV
1.2MV
0.8MV
0.4MV
0V
-0.4MV
.9639u, 824.474K)
567u, 465.248K)
0
50u
100u
150u
200u
250u
300u
Time

fig.3



a)

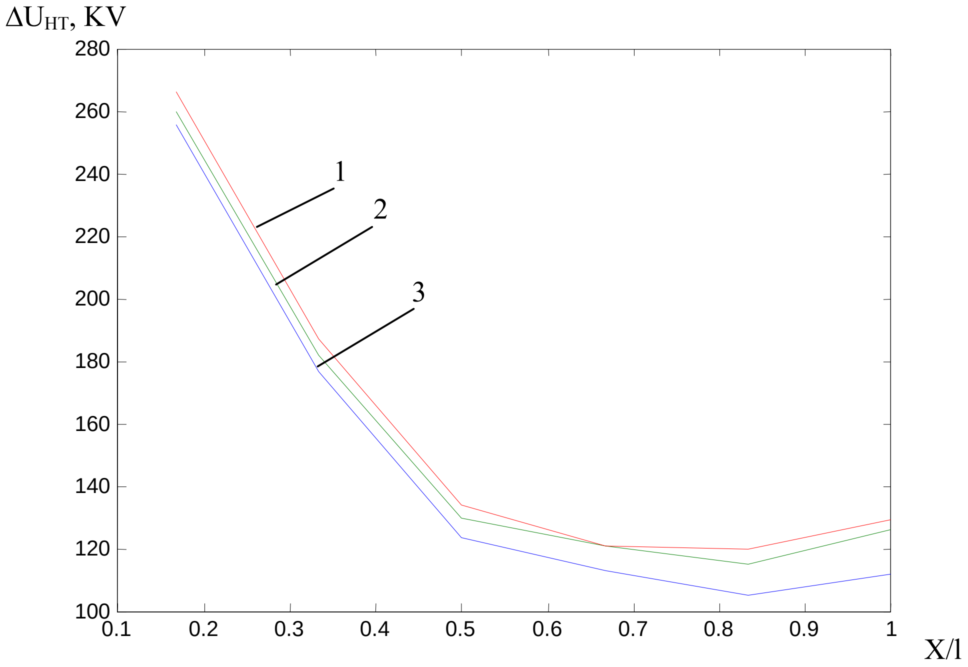
b)

Fig. 4. Surge voltages in the HV and LV windings of the transformer.

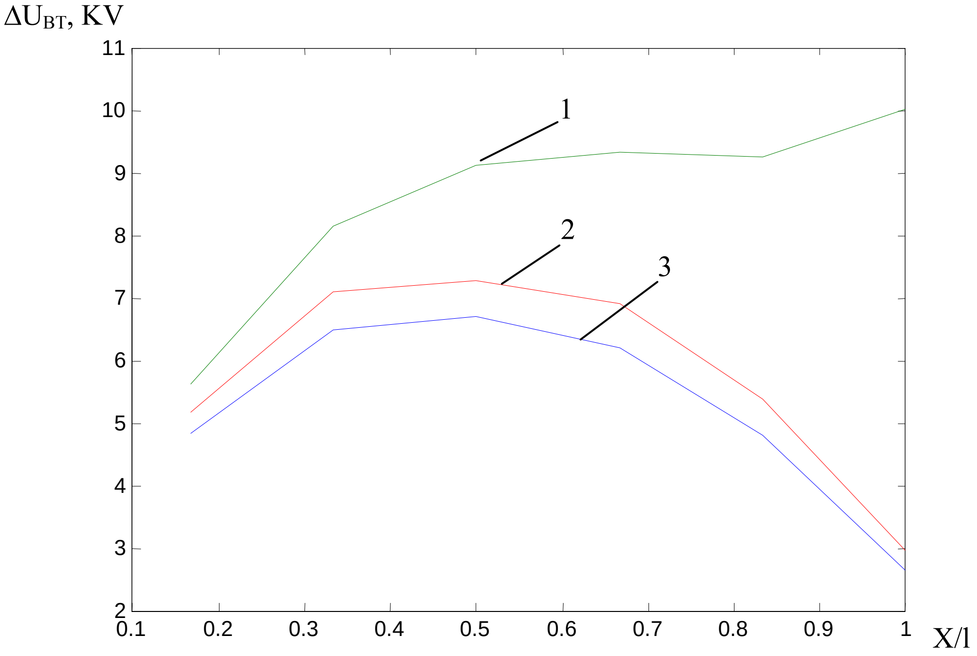
a) curve 1 – the primary neutral is grounded through a resistor of value $R_N = 220\ \Omega$;
curve 2 – the primary neutral is grounded through a nonlinear inductance with
$U_{L\,n} = 0.1\sqrt{2}\, U_{ph\,n}$; $I_{L\,n} = 6000$ A ;

curve 3 – the primary neutral is grounded through a nonlinear inductance with
$U_{L\,n} = 0.01\sqrt{2}\,U_{ph\,n}$; $I_{L\,n} = 600$ A ;

b) curve 1 – the secondary is connected in Δ (or in Y) ;
curve 2 – the secondary is connected in $Y_{\perp}$.



a)



b)

Fig. 5. Voltage différences between adjacent elements in the HV and LV windings of the transformer

a) and b) curves 1 – the primary neutral is grounded through a nonlinear inductance,
the secondary is connected in Δ (or in Y) ;
curves 2 – the primary neutral is grounded through a nonlinear inductance,

the secondary is connected in Y⏚.
curves 3 - the primary neutral is grounded through a résistor of value
$R_N = 220\ \Omega$.

The surge voltage differences in the primary are shown in figure 5a. It can be deduced from this figure that the different neutral operating modes have a quite weak influence on the surge voltages and the surge voltage differences of the primary, close to the neutral of this winding.

The connection scheme of the secondary puts in evidence a very slight influence on the surge voltages and surge voltage differences between adjacent elements of the primary. We notice a very small increase of the surge voltages and surge voltage differences near the neutral of the primary winding (see tables 1, 3 and figures 4a, 5a). This is due to the retroactive influence of the secondary on the primary.

The surge voltages and surge voltage differences between adjacent elements of the secondary are represented in tables 2 and 4, and in figures 4b and 5b. We can deduce from these tables that the saturable non linear induction reactance with different parameters exerts no influence either on surge voltages, or the surge voltage differences of the secondary. The grounding of the secondary neutral reduces the surge voltages and increases the surge voltage differences, particularly in the surrounding of the neutral (figure 4b and 5b).

The impulse current wave in the nonlinear saturable induction reactance is nearly equal to 700 A.

In the case where the primary neutral is grounded through a linear induction reactance there is an increase of the primary surge voltages particularly near the neutral. However, this neutral voltage (161 kV) is much more smaller than the admissible voltage. The increase of the secondary surge voltage is quite small. The surge voltage differences in these two windings are slightly reduced (see tables 1, 2, 3, 4 and the figures 5a and 5b).

The results corresponding to the grounding of the primary neutral through a concrete resistor are shown in the tables 5, 6, and on figures 4, 5. In the computations, the resistance values are taken in the interval 2 to 200 Ω.

The increase in resistance of the neutral leads to an increase of their influence zone in the primary. For instance, in the case of the change of this resistance in the interval 2 to 50 Ω, the influence is observed on points 5, 6 and 7 of the winding. If we increase the resistance up to 200 Ω, the influence is observed also on point 4 of the winding. It is related to the surge voltage differences between the adjacent elements of the HV winding.

The increase in resistance of the neutral up to 200 Ω does not create any dangerous surge voltage on the neutral of this winding. When the resistance is equal to 200 Ω, the surge voltage on the neutral point does not reach even 100 kV, whereas the admissible value of surge voltage for the insulations of the 110 kV nominal voltage is 470 kV.

The influence of the resistance of the primary neutral on the surge voltages in the secondary starts from the value of 200 Ω. It is well known that in the transformer which neutral is insulated from earth by the side of the neutral there is a considerable transfer of the surge voltages to the secondary. Therefore when approaching the operating mode of a neutral insulated from earth, the passage of the surge voltages from the neutral towards the secondary will increase.

CONCLUSION

1. The surge voltages and the surge voltage differences between adjacent elements of the primary and the secondary when grounding the primary through the nonlinear saturable induction reactance-having different nominal voltages and currents- are well defined.

2. The nonlinear saturable induction reactance of the different nominal voltages and currents exert a slight influence on the surge voltages and surge voltage differences of the primary particularly in the vicinity of the neutral. The influence of this reactance on the surge voltages and surge voltage differences of the secondary are practically inexistent.
3. The grounding of the primary neutral through a linear induction reactance induces a small increase of the surge voltages and a small decrease of the surge voltages in the transformer windings comparatively to the case of the primary neutral grounded through a nonlinear saturable induction reactance.
4. The increase in resistance on the primary neutral increases the zone of their influence in the HV winding as well as the surge voltages in this winding. In the secondary, the increase in the surge voltages is observed starting from the value of 200 Ω of this resistance. The grounding of the primary neutral even with a 200 Ω resistance does not create a dangerous surge voltage to the insulations of the primary and of the secondary of the transformer.
5. The selection of the value of the nonlinear saturable reactance for the grounding of the transformer primary neutrals should be realized in the restrictive conditions of the asymmetric short circuit currents and of the improvement of the disconnecting property of the circuit breakers.

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1. Руководящие указания по ограничению токов однофазных коротких замыканий в электрических сетях 110-220 кВ энергосистем.//К.М.Антипов и др., Москва, Союзтехэнерго, 1965, с.19.(Russian).
2. Бейбутов Р.А., Гашимов А.М., Джуварлы Ч.М. Насыщающийся реактор в цепи короткого замыкания //В сборн. “Численные эксперименты при исследованиях переходных и квазиустановившихся процессов в электрических сетях“, Баку, Элм, 1991, с.160-169. (Russian).
3. Джуварлы Ч.М., Дмитриев Е.В.,Гашимов А.М. Исследование влияния параметров сети и заземляющей резисторной установки на амплитуду и скорость восстанавливающихся напряжений при ликвидации коротких замыканий.// В сборн. ”Частичное заземление нейтрали в электрических системах через резистор“.Баку, Елм,1976,с.99-114. (Russian).
4. А.с. 661679. Кл.H02H9100, H02H 7/09. Устройство для заземления нейтрали трансформатора.//А.И.Назаров, опубл.05.05.79., бюлл.№17. (Russian).
5. Mufidzada N.A., Chaibi R., Otman-Cherif T. Effects of impulse surge voltages on alternators. IEEE Power Tech Conference, 2001, Porto, Portugal.
6. Гашимов А.М., Дмитриев Е.В., Рустамов С.А. Моделирование трансформатора с нейтралью, заземленной через нелинейный насыщающийся реактор. //В сборн. “Сборник статей по электрофизике и электроэнергетике”, Баку,Елм,1994, с.136-144. (Russian).
7. Руководящие указания по защите от перенапряжений электрических установок переменного тока 3-500 кВ. Москва,1975. (Russian).

NEYTRALI MÜXTƏLİF ÜSULLARLA YERƏ BAĞLANMIŞ TRANSFORMATORLARIN DOLAQLARINDA İMPULS İFRAT GƏRGİNLİKLƏRİN TƏDQİQİ

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Neytralı xətti, qeyri-xətti reaktiv və xətti aktiv müqavimətlə yerə bağlanmış 220 kV-luq transformatorun dolaqlarında impuls ifrat gərginliklər tədqiq olunur. Neytralın müxtəlif üsullarla yerlə bağlanması hallarında transformatorun dolaqlarında ifrat gərginliklər və dolaqların qonşu elementləri arasındakı gərginliklər fərqli təyin edilmiş olur.

ИССЛЕДОВАНИЕ ПЕРЕНАПРЯЖЕНИЙ В ОБМОТКАХ ТРАНСФОРМАТОРОВ, НЕЙТРАЛИ КОТОРЫХ ЗАЗЕМЛЕНЫ РАЗЛИЧНЫМИ СПОСОБАМИ

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Рассматриваются перенапряжения и градиенты напряжений в обмотках трансформатора с номинальным напряжением 220 кВ, нейтраль которого заземлена либо через линейный реактор, либо через резистор (сопротивление резистора увеличивается до 200 Ом). Выявлены перенапряжения и разности напряжений между соседними элементами обмоток при различных способах заземления нейтрали трансформатора каждого из этих элементов.