PROTECTION AGAINST IMPULSE SURGE VOLTAGES IN DISSOCIATED SECONDARIES OF 110 KV NOMINAL VOLTAGE TRANSFORMERS

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Abstract : We consider the impulse surge voltages in the dissociated secondary of 110 kV nominal voltage transformers operating either with insulated neutral or with grounded neutral and protection of the secondary. The surge voltages in the primary of transformers depend only on the operating mode of its neutral. The secondary connecting scheme and the operating modes of the two neutrals have a notable influence on the surge voltages as well as on the voltage differences in the secondary. Transformers with Y_0 /Δ, Y /Y_0 and Y_0 /Y_0 connecting schemes can operate without any arrester on the low voltage (LV) -side. As for other transformer types, installation of arresters on the LV-side is unavoidable. In order to ensure the protection of secondary operating free of load (temporarily not in use) we can ground the secondary neutral (in case of a Y scheme), or one of the triangle vertices (in case of a Δ scheme), after having disconnected it from the other elements of the network.

Keywords: transformer surge voltage, protection, arrester, voltage differences.

1 – INTRODUCTION:

In transformers the secondary may be subject to impulse surge voltage waves which mainly come from the primary where they occur due to the manufacturing techniques of these windings and to the operating modes of their neutrals. We observe that the surge voltages crossing to the secondary are greater when the primary neutral is insulated from the ground than when grounded. At this stage it is important to notice that there is a considerable crossing of surge voltages by electric effect via the neutral in transformers operating with the primary neutral insulated from the ground. This situation is observed in 110 kV nominal voltage transformers that are designed to operate either with grounded neutral or not.

The protection of the primary against the constraints of impulse surge voltage waves is achieved by adding arresters at the input of the transformer and a complementary arrester on the insulated neutral [1].

As for the protection of the secondary it must be noticed that first, this winding does not undergo the direct actions of the impulse surge voltage waves. These latter can take place in this winding only after having crossed the primary and we observe that if a surge voltage in the primary does not present any danger to this winding it cannot present a fortiori any danger to the secondary. Secondly the secondary of transformers are always connected to the low voltages buses of the stations and the elements present on these buses reduce the surge voltages in the secondary. Nevertheless, some protection measures are taken for the secondary of transformers, particularly, when it is disconnected from the rest of the elements of the electrical network [2]. This situation occurs, for instance, in a scheme of transformers with dissociated secondary. In such a scheme if a part of a station connected to the dissociated secondary is stopped for a long time (because of maintenance operations or of its disconnection in the minimal load mode), this winding remains open. The existence of windings temporarily not in use is also applied to transformers with three windings and to auto-transformers. In order to reduce the voltages induced in the secondary we can ground their neutrals (in case of a Y scheme), or one vertex of the triangle (in case of a Δ scheme) when disconnecting them from the other elements of the electric network so as to evacuate the induced charges to the ground.

The arrangement of the arresters on the secondary seems to be the most efficient protection measure. However, the experience shows that arresters are destroyed due to important currents that cross them.

The protection of the secondary requires an estimation of the surge voltages crossing from the primary to the secondary of the transformers. If necessary we have to perform adequate corrections on their protection schemes.

This work is dedicated to the determination of the surge voltages in the primary and the secondary of the transformer having dissociated secondary. The exploitation conditions are is taken into account during actions of impulse surge voltage waves on one, two or three phases of the HV winding, with different connecting schemes of the LV winding phases and different operating modes of the primary and secondary neutrals.

This problem is studied by means of computations based on the transformer of type ТРDЦН-125000/110 (a Russian product). This transformer has a dissociated secondary with a nominal voltage equal to 10.5 kV. These computations are achieved using the traditional equivalent scheme of the transformer and its protection scheme taking into account the influences of the station elements [4,5]. In order to obtain results corresponding to the most severe requirements for the insulation, we selected an impulse test voltage characterised by a complete wave 1,2/50 μs. The magnitude of this wave was taken equal to the discharge voltage of the insulation of the 110 kV nominal voltage line.

The computations are performed with the Pspice software and the results are tabulated in tables 1 and 2, and also presented on figures 1 to 4.

II – ANALYSIS OF THE RESULTS

The surge voltage waves reaching the transformer on the HV side are limited by the arrester arranged on this side. The residual voltage and the current values in the arrester are respectively 235 kV (figure 1, curve 1), and 3.478 kA (figure 2). These values correspond to its Volt-Amp characteristic curve.

The voltages at the HV input of the transformer vary from 401 kV to 415 kV (figure 1, curve 2), with respect to the operating mode of the primary neutral and to the connecting scheme of the secondary. These values do not overshoot the surge voltage admissible value which is 470 kV (see table 1).

However, the maximum voltage of the insulated neutral of the HV winding is equal to 481 kV and it overshoots this limit. The installation of a matching arrester on the primary neutral brings the voltage at this point down 183 kV (figure 1, curve 3) and the protection of this winding becomes effective.

The results obtained for the secondary are represented on the tables 1 and 2 and on figure 3 which shows the voltages at the terminals (U_a , U_b , U_c) of this winding. The secondary voltages depend strongly on the connecting scheme of the secondary phases, on the operating mode of the neutral of this winding, and also on the operating mode of the primary neutral.

The maximum secondary voltage which is equal to 42,792 kV (fig.3 a) takes place in the case where the windings are connected in a Y scheme together with insulated neutrals. This is due to the passage of considerable surge voltages through capacitive path on the side of the HV neutral. This value is more than seven times greater than the secondary phase voltage. The grounding of the primary neutral and the secondary neutral achieved separately reduces this voltage down to 28,771 kV et 25,558 kV respectively. In the case where both neutrals are grounded simultaneously we also obtain a secondary voltage that is equal to 25.465 kV. It can be easily noticed that the grounding of the neutral of this winding is very important for reducing the secondary voltage. In this case the reduction is about 40 %. In the use of the connecting scheme Y/Δ the secondary voltage is equal to 38.404 kV and the grounding of the primary neutral, this time, brings the secondary voltage down almost to its half(see table 1).

The conformity of the high values of surge voltages in the operating mode of insulated primary neutral shows that, on the side of the neutral of the HV winding there is a considerable crossing of surge voltages towards the secondary. The operation of the arrester on the primary neutral also reduces the secondary surge voltages. However, this reduction is not important (about 7 kV). The variation of the two-neutrals operating mode and the secondary connecting scheme cause the secondary voltage to vary in a fairly wide interval- from 19.333 kV obtained from the Y_0 /Δ scheme to 42.792 kV – of the Y/Y scheme.

In order to evaluate the surge voltages in the secondary it is necessary to take into account both the operating voltage and the fact that the resistance of windings of high power transformers are very small. Therefore the duration of the oscillations is longer (it can reach some mS). Taking into account the operating voltage, the surge voltages in this winding can reach the value 42.791 + 10.5 *1.41 / 1.73 = 51.349 kV. This latter value is less than the surge voltage admissible value in the 10.5 kV nominal voltage winding, that is 82 kV. But since this surge voltage value is at least 8 times greater than the nominal phase voltage, and due to the too long duration of the oscillations, such surge voltage value can present risks to this winding.

The installation of arresters across the secondary terminals limits the secondary surge voltages to the level 24.481 kV (figure 3 b). We observe in table 1 in the case of Y_0 /Δ, Y/Y_0 and Y_0 /Y_0 connecting schemes that the secondary surge voltages (25.558 kV) are nearly equal to the residual voltage of the arrester with 10.5 kV-nominal voltage. Hence, the use of arresters to protect the secondary of transformers with their windings connected in these types of schemes is no longer necessary. This conclusion means that in order to ensure the protection of the temporarily unused secondary it suffices only to ground the neutral of this winding (if the connecting scheme is the of the Y type with insulated neutral) or one vertex of the triangle (if the connecting scheme is the of the Δ) after having disconnected this winding from the other elements of the electric network. The grounding of one vertex of the triangle reduces the secondary surge voltages down to 17.161 kV.

As for the currents of the arresters installed across the secondary their maximal value is not greater than 330 A. This value corresponds to the Y/Y connecting scheme of the windings.

The actions of the surge voltage waves on one or two phases have been studied for the Y/Y and Y/Δ connecting schemes of the windings. The corresponding results are represented in table 2. With the Y/Y connecting scheme, the secondary surge voltages are greater than those with the Y/Δ scheme. In the case of actions of the surge voltage waves by one or by two phases the secondary surge voltages are respectively equal to 26.010 kV and 33.692 kV. The latter surge voltage value shows that, even during the actions of surge voltage waves by two phases, the surge voltages on the side of the secondary windings can reach dangerous values to their insulation.

The voltage differences between the adjacent elements of the HV and LV windings are represented on figure 4. Figure 4a corresponds to the HV winding. From this figure it may be deduced that only the primary neutral operating modes have an influence on the voltage differences in this winding. The grounding of the primary neutral causes an increase in the voltage differences in the section 0.6–1 of this winding. On the section 0–0.6 such an increase in voltage differences is practically inexistent. When the arrester on the primary neutral operates then the voltage differences in the section 0.4–0.9 of this winding are reduced.

The primary neutral operating modes have almost no influence on the voltage differences in the secondary when connected in a Δ scheme (Figure 4 b, curve 4). When the arrester on the side of the LV winding is in operation it slightly reduces the voltage differences in this winding (Figure 4 b, curve 3). The influence of the primary and secondary neutrals operating modes occurs when the Y scheme is used for the LV winding. The grounding of the primary and secondary neutrals reduces the voltage differences in this winding. In the case where the arresters on the LV side are in operation, the secondary voltage differences are minimal.

III - CONCLUSION :

1. The impulse surge voltages in the primary and secondary windings of 110 kV nominal voltage transformers which can operate either with insulated neutral or with grounded neutral has been considered in the cases of different operating modes of two neutrals and different connecting schemes of the secondary, taking into account the exploitation conditions.

2. The surge voltages in the transformer's primary depend principally on the operating mode of this winding neutral. The influence of the connecting scheme of the secondary and the operating mode of this winding neutral on the surge voltages in the primary are insignificant.

3. The surge voltages in the secondary depend considerably on the connecting scheme of this winding and on the operating modes of the transformer's two neutrals (if the secondary is also connected in Y scheme). The maximal values of the surge voltages in the secondary correspond to the transformer connecting schemes Y/Y and Y/Δ. This is due to the considerable passage by capacitive way on the side of HV neutral. The grounding of the primary neutral as well as of the secondary neutral reduces considerably the secondary surge. As for the transformers which are connected in Y_0 /Δ, Y/Y_0 and Y_0 /Y_0 schemes, the installation of arresters on the LV side is not important. The arresters on the LV side for these types of transformers can be installed only because of the internal surge voltages. As for the transformers which have a secondary connecting scheme inY_0 /Δ, Y/Y_0 et Y_0 /Y_0 , the installation of arresters by the LV side is necessary.

4. The protection of the secondary operating without load (temporarily not used) can be realised by grounding secondary neutral (in case of a Y scheme) or one vertex of the triangle (in case of a Δ scheme) after that this winding has been disconnected from the other elements of the electric network.

5. The greatest value of current of the secondary arrester is equal to 330 A. This value corresponds to the Y/Y connection scheme of the windings.

6. The connecting scheme of the secondary and the operating modes of the primary and secondary neutrals have also influence on the voltage differences of the LV winding. In the case where the connection scheme of the secondary is a Δ scheme the influence of the operating mode of the primary on the voltage differences of this windings is almost inexistent..

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110 kV-luq TRANSFORMATORLARIN BÖLÜNMÜŞ İKİNCİ DOLAĞININ İMPULS İFRAT GƏRGİNLİKLƏRDƏN MÜHAFİZƏSİ

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İkinci dolağı bölünmüş transformatorlarda minimal yük və ya dolaqlardan birinin bağlandığı yarımstansiya hissəsində təmir işləri aparılan zaman uyğun dolaq açıq qalmış olur. Bu dolaqda yaranan impuls ifrat gərginlikləri və bu gərginliklərdən mühafizə metodları tədqiq olunur.

ЗАЩИТА ОТ ИМПУЛЬСНЫХ ПЕРЕНАПРЯЖЕНИЙ ВТОРИЧНЫХ РАЩЕПЛЕННЫХ ОБМОТОК ТРАНСФОРМАТОРОВ 110 кВ

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В трансформаторах с расщепленными вторичными обмотками при малых нагрузках и при ремонтных работах на части подстанции, подключенной к одной из этих обмоток, соответствующая обмотка остается в холостом режиме. В работе рассматривается возникновение импульсных перенапряжений в холостой расщепленной обмотке трансформатора и методы ее защиты от этих перенапряжений.

Table 1

Winding connex.	Actions of surge voltage waves by	HV winding				LV winding				
		U_A	U_B	U_C	U_N	U_a	U_b	U_c	U_n	$I_{P\,LV}$
		kV	kV	kV	kV	kV	kV	kV	kV	A
Y/Δ	Without LV arrester	415	415	415	469	38,404	38,404	38,404	—	—
	With LV arrest.	414	414	414	461	24,465	24,465	24,465	—	305,05
	Arrester HV neutral	415	415	415	183	29,260	29,260	29,260	—	213,85
	b is grounded	413	412	413	474	17,161	0	7,161	—	—
Y_0 / Δ	Without LV arr.	415	415	415	—	19,471	19,471	19,471	—	—
	With LV arrest.	415	415	415	—	19,333	19,333	19,333	—	—
	b is grounded	408	406	408	—	15,751	0	15,751	—	—
Y/Y	Without LV arr.	406	406	406	468	42,791	42,791	42,791	42,864	—
	With LV arrest.	412	412	412	463	24,481	24,481	24,481	24,371	329,49
	Arrest.HV neut.	406	406	406	183	37,277	37,277	37,277	31,436	327,48
Y/Y_0	Without LV arr.	405	405	405	481	25,558	25,558	25,558	—	—
	With LV arrest.	412	412	412	480	24,444	24,444	24,444	—	273,29
	Arrest.HV neut.	405	405	405	183	33,559	33,559	33,559	—	273,23
Y_0 /Y	Without LV arr.	402	402	402	—	28,771	28,771	28,771	21,373	—
	With LV arrest.	412	412	412	—	24,454	24,454	24,454	17,396	288,63
Y_0 /Y_0	Without LV arr.	404	404	404	—	25,465	25,465	25,465	—	—
	With LV arrest.	412	412	412	—	24,429	24,429	24,429	—	249,60

Table 2

Winding connexion	Actions of surge voltage waves by	Winding HV				Winding LV				
		U_A	U_B	U_C	U_N	U_a	U_b	U_c	U_n	$I_{P\,BT}$
		KV	kV	kV	kV	kV	kV	kV	kV	A
Y/Δ	2 phases	414	414	127	317	27,465	29,688	28,692	—	159,72
	1 phase	414	72	72	163	18,309	15,209	16,672	—	—
Y/Y	2 phases	412	412	126	317	33,692	33,692	34,698	9,710	300,70
	1 phase	411	72	72	163	26,010	18,905	18,905	5,555	—

Fig.1. Surge Voltages in the HV Winding.

Curve # 1 – Voltage across the Arrester on the HV Side.

Curve # 2 Voltage across the HV Winding Arrester on the HV Side.

Curve # 3 Voltage on the Neutral of the HV Winding with Neutral Arrester in operation

Fig.2. Current of HV Arrester.

Fig3. Surge Voltages in the LV Winding: (a) in case of absence of LV Arrester .
(b) in case of presence of LV Arrester .

Fig4. Voltage Differences between Adjacent Elements of (a) HV Winding:
(b) LV Winding

Curve # 1 – Connecting Scheme of Windings is Y / Δ

Curve # 2 – ″---------------- ″ --------- ″ Y / Δ , LV Arrester in operation

Curve #3 - ″---------------- ″ --------- ″ Y / Δ , HV Neutral- Arrester in operation

Curve #4 - ″---------------- ″---------- ″ Y_0 / Δ ;

Curve #5 - ″---------------- ″ ------- -- ″ Y / Y_0 ;

Curve #6 - ″---------------- ″ ---------- ″ Y_0 /Y.