2002년도 대한전기학회 하계학술대회 논문집 2002.7.10-12

저압측 서지에 의한 주상변압기 고압권선 동특성 해석

정종욱[U], 송일근, 김상준, 장덕근*, 곽희로*
전력연구원, *숭실대학교

Dynamic Behavior Analysis of Pole Transformer Primary by Secondary Surge

Jong-Wook Jung[U], Il-Keun Song, Sang-Joon Kim, Duck-Geun Jang*, Hee-Ro Kwak*
KEPRI, *Soongsil university

Abstract - This paper describes the effect of secondary surges entering low voltage side on the primary winding of pole transformers.

After having connected the secondary winding by 4 different methods, surge voltages were applied to the low voltage side, and voltage waveforms were measured at a surge applied point and a high voltage bushing terminal. The measured voltages were compared by the waveform, magnitude and damping characteristics with each connection.

As a result, the voltage waveforms induced by the secondary surges were different one another with each connection, especially, the conventional connecting method for 2 voltage sources was far different from the present method supplying only 1 voltage source in shape of the voltage waveform.

1. Introduction

Pole transformers were mounted closest to the customers, which directly governs the reliability of power supply. Despite of the fact, many of them has been damaged by various causes and replaced. Out of the causes, the failure due to surges were very difficult to verify the exact developing mechanisms to the failures, therefore, proper countermeasures have not been devised. When it comes to the surge, pole transformer failure cause generally known is mainly due to the imperfect protection of the lightning arrestors. It has been known so far that the surge via high voltage bushing terminal breaks the primary windings and high voltage bushings, while the surge via grounding system, so called "secondary surge or low-side surge", has not been recognized in this country. The secondary surge penetrates through low voltage side of the pole transformers and affects the primary windings. However, according to the results of failure cause analysis carried out by KEPRI, dielectric breakdown between layers was observed at the medium and inner layers of the primary windings with no special causes, and the possibility of secondary surges could not be entirely excluded. In fact, the secondary surge can induce very high voltage, proportional to the turn ratio, in the primary winding, by which the primary conductors can be broken by the electrical breakdown between turns and layers.

Therefore, this paper aims for showing the voltage induced in the primary winding by the secondary surge via low voltage side connected differently.

2. Experimental

2.1 Experimental setup

A pole transformer specially manufactured was used to measure the voltage induced in the primary winding by the surge applied to low voltage side. The specification of the transformer is shown in Table 1.

Table 1 Specification of transformer

rated capacity	rated voltage / current	% impedance
30 kVA	1,320 V / 22.72 A	3.78 % / 75 ℃

The approximate turn ratio of commercial pole transformers is 60:1. When surge voltage is applied to the low voltage side of the commercial pole transformers, the voltage induced in the primary winding will exceed the measurable range of the high voltage probe. Therefore, the turn ratio had to be reduced as shown in the table above. The transformer used in this experiment was single phase and shell type, and the secondary windings were completely separated to get 2 voltage sources.

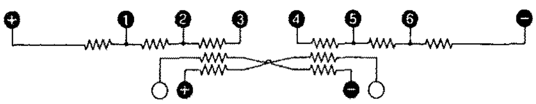

Fig.1 Schematic of internal winding connection of pole transformer for experiment

An impulse current generator(Tozz technology) was used to apply the surge with relatively low peak of 1[kV]. In addition, high voltage probes(Tektronix model:P6015A) with 1,000:1 derating were used to measure the voltage waveforms at high/low voltage windings.

3.2 Experimental procedure

The secondary connection is shown in Fig. 2.

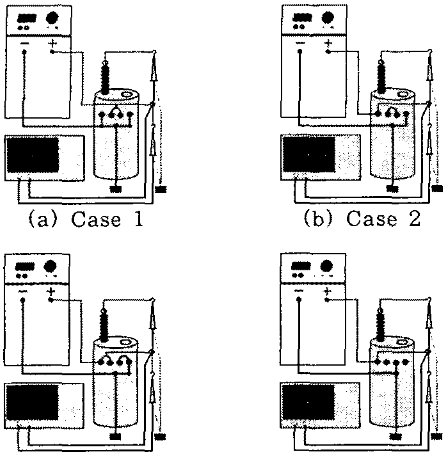

Fig. 2 Secondary connection

As shown in Fig. 2, the secondary windings were connected by 4 different methods prior to the application of surge. Case 1 is past connecting method, to get 2 voltage sources, not employed anymore in distribution lines and to simulate the surge penetrating through the neutral conductor grounded. Case 2 is one of the connecting methods and uses the existing pole transformers even after raising the voltage class to 220[V], with changing only their secondary connection. This case is to simulate the surge penetrating through one secondary terminal connected to the tank also grounded. Case 3 is to simulate the transformer supplying only 220[V]. Case 4 is basically similar to case 3, hardly used in the field. However, this connection was simulated to understand the effect of the change in secondary impedance on the primary voltage waveform.

After connecting the secondary windings by 4 different methods, surge of 1[kV_{peak}] was applied to the low voltage side of each connection, and the applied voltage and the voltage at the primary winding was measured.

4. Results and discussion

The voltage waveforms were measured after applying surge to the secondary winding, and the result is shown in Fig. 3.

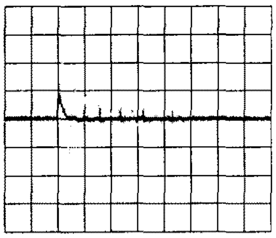

Fig. 3 Voltage waveform at primary winding subjected to secondary surge : case 1
(black : waveform applied to secondary, gray : waveform measured at primary, 20[$\mu s/div_x$], 2[kV/div_y])

As shown in Fig. 3, the applied voltage waveform abruptly increased and decreased when surge was applied to the secondary winding with the connection of case 1. Considering the winding structure of the secondary windings, 2 strands of the secondary conductor is connected in parallel and wound in same direction. Therefore, in case of Fig. 2(a), ⊕ and ● are connected together, which cancels out the secondary voltage as shown in Fig. 3. However, it takes a little time to completely cancel out the secondary voltage because the surge reaches the end of each winding with time difference with distance of the conductors since surge is considered traveling wave. This cancel out is, however, considered difficult to take place in real lines because of the effect of load.

By the way, the voltage induced in the primary winding canceled out in 10[μs] after increasing up to about 4[kV_{peak}]. This is considered damping down due to L and C of the windings when taking the voltage waveforms into account. In real lines, it is assumed that the voltage induced in the primary winding is affected by the unstable secondary voltage different from the waveform shown in Fig. 3, therefore, very high voltage can arise in the primary winding.

The connection is changed to Fig. 2(b), and the voltage waveform was measured after applying the surge to one of the secondary terminals. Fig. 4 shows the result.

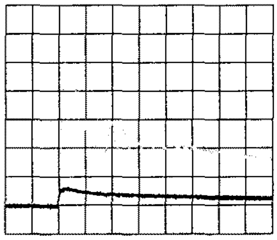

Fig. 4 Voltage waveform at primary winding subjected to secondary surge : case 2
(black : waveform applied to secondary, gray : waveform measured at primary, 20[$\mu s/div_x$], 2[kV/div_y])

As shown in Fig. 4, the voltage induced in the primary winding was more than 10[kV] when the secondary winding was connected as Fig. 2(b), and the peaks exponentially decreased. This is considered due to the L and C of the primary winding as case 1. This case can give the insulating materials of the primary windings the most dielectric stress since the power is supplied by the connection of case 2 if the existing pole transformers are continuously used.

Fig. 5 shows the voltage waveform at the primary winding after applying surge to low voltage side with the connection shown in Fig. 2(c).

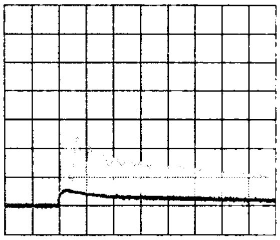

Fig. 5 Voltage waveform at primary winding subjected to secondary surge : case 3
(black : waveform applied to secondary, gray : waveform measured at primary, 20[μs/div$_x$], 2[kV/div$_y$])

As shown in Fig. 5, the voltage induced in the primary winding was more than 6[kV] when the secondary winding was connected as Fig. 2(c), and the peaks exponentially decreased as shown in case 2. In addition, it was found that the voltage of the pole transformer was governed by rather voltage dividing principle due to *R*, *L* and *C* of the windings than voltage transforming principle proportional to the turn ratio when surge entered the pole transformers since the peaks of case 3 was less than those of case 2. Therefore, it was considered that the primary voltage waveforms could be affected by the *LC* resonance. For this, the primary voltage can abruptly increase more than the original voltage applied because of the resonance, as the case may be. It may produce the most severe problem when the resonance is affected by the reflection wave due to grounding. The *L* and *C* of the conductor will depend on its cross sectional area and length if the voltage peaks are related to the circuit constant of the windings. Therefore, in case of the commercial pole transformers, the results are independent of the turn ratio, but in this experiment, the cross sectional area of the primary and secondary conductors are same, thus, the L and C of the conductors depend only on the length of the conductor.

Lastly, Fig. 6 shows the voltage waveform at the primary winding after applying surge to low voltage side with the connection shown in Fig. 2(d).

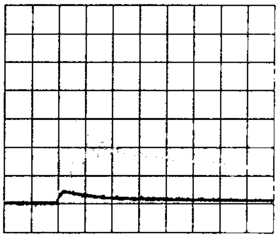

Fig. 6 Voltage waveform at primary winding subjected to secondary surge : case 4
(black : waveform applied to secondary, gray : waveform measured at primary, 20[μs/div$_x$], 2[kV/div$_y$])

As shown in Fig. 6, the voltage induced in the primary winding was about 6[kV] when the secondary winding was connected as Fig. 2(d), and the peaks exponentially decreased as shown in case 2 and case 3. In addition, considering the peaks, they were somewhat less than case 3, and this is considered because the capacitance of the secondary winding of case 4 increased more than case 3 in which the 2 strands of secondary winding was connected in parallel.

5. Conclusions

The voltage induced in the primary winding was measured after connecting the secondary winding by 4 different methods, to understand the dynamic behavior of the primary winding by the secondary surge. The conclusions are as follows:

In case of the connection previously employed for 2 voltage sources, the voltage measured at secondary side canceled out as soon as the surge was applied to the neutral conductor of secondary side, which makes the primary voltage not high. However, in real lines, the secondary voltage can be very high depending on the load, which gives the insulating system of the primary winding much more electrical stresses. In addition, the primary voltage induced by presently employed connection supplying only 1 voltage source is governed by rather the voltage dividing principle due to *L* and *C* of the windings than the transforming principle proportional to the turn ratio of the windings. Considering that the transient voltage can break the insulation of the windings, proper countermeasures have to be devised even though the transient voltage phenomenon shortly disappears.

[References]

[1] H. Asai et al., Electrical Insulating Oil Handbook, Japan Petroleum Institute, February 1987.