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Researching Parameters Selection, Testing Circuit Configuration in Lightning Impulse Test for 500kV Single Phase Power Transformer Produced in Vietnam

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Abstract

This article presents the result of researching in parameters selection in testing circuit configuration for the lightning impulse (LI) 1.2 /50 µs power transformers which was produced in Viet Nam. This test was performed at The National Key Laboratory for High Voltage Techniques (HVLAB) - Institute of Energy, the unique laboratory in Vietnam where this test can be perform. In order to research the lightning impluse parameters and determine the endurance of high-voltage and ultra-high electrical equipment insulation in general and particularly for 500kV power transformer, it is necessary to set a simulation voltage of standard lightning impulse at 1.2 /50 µs. These results will allow evaluating the quality of the insulation system in 500kV power transformer, the withstand ability of atmospheric overvoltage or operation overvoltage according to IEC60076-3,-4: 2000, TCVN6306- 3: 2006; IEC60060-1: 1989, in order to obtain safety power transformer operation in gridline.

Keywords: Lightning Impulse (LI); Switching Impulse (SI); International Electrotechnical Commission (IEC).

1. Introduction

Along the power grid operation, the overvoltage occurs frequently will make the main cause of damaging the insulation in electrical equipment. In particular, the overvoltage due to directly lightning stroke or spread lightning will have the highest overvoltage value and potentially cause discharge in the insulation system. Besides, the switching process also make overvoltage with the relatively high voltage value which may endanger the insulation system. The breakdown caused by atmospheric overvoltage or operation overvoltage took a large proportion. Therefore, the insulation parameters against LI or SI is the key value when reasearching for insulation system. To research these parameters and determine the endurance of equipment insulation, it is necessary to set a simulation voltage of standard LI and SI. The transformer test method will follow to standards IEC 60076-3, TCVN(ISO) 6306-3 and measurement method will follow to IEC 60060-1. [1, 2].

2. Theory

2.1. Testing voltage value (U_{Test}): with the non-oscillated LI, the testing voltage value will be the peak value (U_p). [1, 2].

2.2. Full LI: is defined as the LI which is not interrupted by any flashover. (Fig. 1). [1].

2.3. Chopped LI: is defined as the LI in which the flashover causes voltage breakdown promptly, ultimately the voltage back to zero. This breackdown can occur at raise time (*front*), at *peak* or end time (*tail*) of the impulse. The chopped LI can be created by spark-gap or by discharging inside insulation system or by external insulation system. (Fig. 2). [1, 2].

2.4. The front time T_1 : The front time T1 is the time between the virtual origin O1 and the point of intersection of the straight line through A and B with the peak line :

$$T_1 = 1.67 \times T_{AB},$$

wherein T_{AB} is the time interval between the points A at 0.3 U_p and B at 0.9 U_p on the front of the impulse voltage. [1, 2].

2.5. Virtual origin O_1: Starting point for the determination of the time parameters is the virtual origin. It is fixed as that point of time which precedes the point A of the impulse by the time $0.3 \times T_1$ (Figure. 2). With the linear measurement, O_1 is obtained as the point of intersection of the straight line through the points A and B with the time line at the front time. [1].

2.6. The time to half-value T_2 : is the interval time between the virtual origin O_1 and the point when the voltage reduce to 0.5 U_p on the tail of the impulse. [2].

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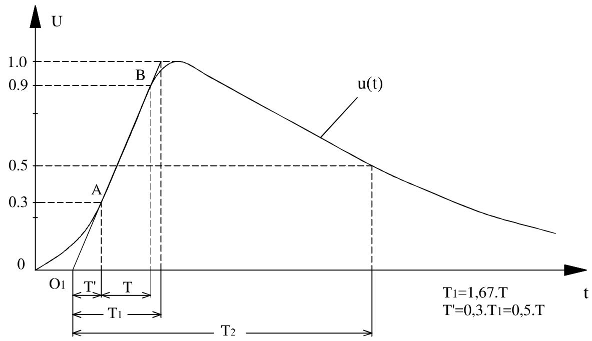

Fig. 1. Standard full lightning impluse.

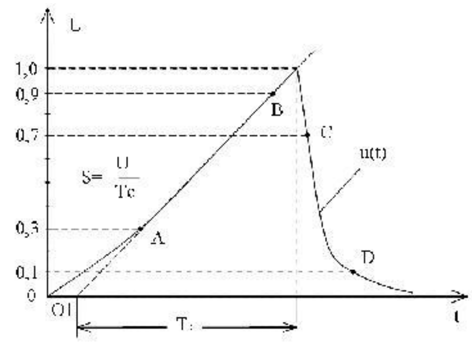

Fig. 2. Front chopped lightning impulse

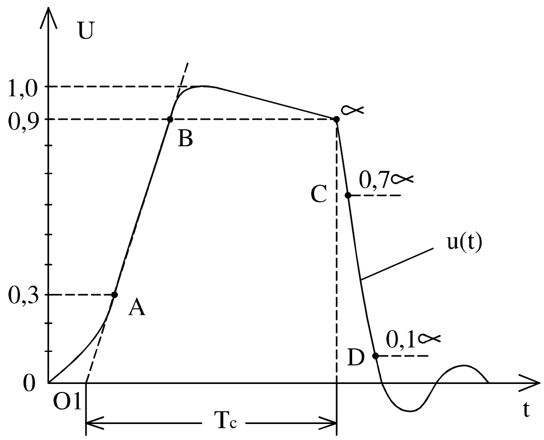

Fig. 3. Tail chopped lightning impulse

2.7. Chopping point : is the point when the voltage starting reduce instanly, it will be the beginning of the choping process. The voltage at this point will be U_c. [1, 2].

2.8. The time to chopping T_c : is the time interval between the virtual origin O_1 and the chopping point. [1, 2].

2.9. Characteristic related to instant reduction of voltage at chopping: is defined by two points C and D located at 70% and 10% chopping voltage (Figure 3). The period of rapid collapse voltage is 1.67 times the interval between C and D. The slope of rapid dropping voltage is the ratio of chopping voltage to the start dropping rapidly voltage interval time. [1, 2].

2.10. Linear wavefront of chopped impulse:

A voltage increased with nearly constant slope until it was cut due to breakdown discharge, will be called a chopped impulse with the. To define, we outlined the most appropriate line in the first front of the wave between 30% and 90% of peak amplitude, the intersection of this line with the amplitude of 30% and 90% respectively defined by the points A and B.

A chopped impulse is determined by:

- Peak voltage U_P;

-Wavefront interval time T_c;

- Conventional slope $S=U/T_c$

This is the slope of the line through the points A and B, represented by kV/µs.

This chopped impulse is considered to be nearly linear if in wavefront, from the 30% of amplitude to chopping point, perfectly located between two straight parallel lines to the line AB, but the time is shifted by ± 0.05 T_1. According to IEC 60060-1, the standard LI is the 1.2/50 µs impulse with the value T_1 = 1.2µs (±30%) and T_2 = 50µs (± 20%), the peak value: ± 5 %. [2].

3. LI test for 500kV single phase transformer

Transformer is a costly equipment, in order to prevent it from damage, a spark-gap bridge must be used as the peripheral protected device. The conductor wire will be connected from the high-voltage electrode of the test device through the spark-gap to the transformer's electrodes. The spark withstand voltage will greater not more than 10% U_{Test} in accordance with IEC. While testing transfomer, the cover, the base frame and all others electrode must be grounded into the common earthing system of the lightning test device. [4, 5].

3.1. The required measurement parameters

- Neutral current (with the stars or Z-shape connected windings, a neutral could be grounded);
- Widding current (with all others coil neutral when a neutral not be grounded);
- Cover leackage current;
- Voltage of the widding which is not be tested.

The LI test procedure for transformer will be:

- The LI withstand overvoltage for each testing voltage level;
- The minimum distance for each testing voltage level;

- The grounding diagram equivalent to each widding type.

An important notice for oil insulated transformer, the LI should be the negative impulse to prevent the insulator system from being flashover(IEC 60076-3). [4].

3.2. Lightning impulse cycle test:

With the full LI, the test process will invole:

1 impulse at 50% or 75% and 3 impulses at 100% of the LI withstand voltage;

If the discharge occurs or the measuring device provide an improper waveform, the test object will not PASS, the test will be stopped and other appropriate test will be perform. With the chopped LI, the test process will invole :

- 1 full impulse at the reduced voltage;
- 1 full impulse at the withstand voltage
- 1 or more chopped impulse at the reduced votage;
- 2 chopped impulses at testing voltage;
- 2 full impulses at testing voltage.

The results were compared to the standard impulse to determine the damage in the insulator system, the definition is refered to IEC 70076-3, -4. The chopped impulse amplitude does not exceed 1.1 times the maximum voltage withstand. T_c must be in range of 2÷6 µs. [5]

4. The measurement equipment system

The impulse generator is based on the theory of MARX generator. It is composed of many capacitors layer, loaded with the same voltage and discharge in series through spark-gap. (Figure 4 in HVLAB). [3].

Fig. 4. The LI test system GTN 18-10

Table 1. The LI test system parameters

Voltage impulse generator	GTN 18-10
Maximum loaded voltage	3600 kV
Maximum energy	180 kJ
Layers/Capacitors per layer	18/2
DC generator Maximum voltage Maximum current Polarity change	 200 kV-DC 100 mA Automatic
Maximum LI voltage	3420 kV
Capacitance/Voltage per layer	0,5 µF/200 kV
Power input	400V–50 Hz
Pneumatic pressure	6 bar max – 4 bar min
Ambient condition Temprature Humidity	 -5 ÷ + 45 °C 20 ÷ 95 %

4.1. Test circuit configuration

One atfer another impulse voltage are injected in each transformer terminal. The winding with neutral point, this point should be grounded directly or through measuring shunt resistor. The cover also be grounded directly. With the three-windings transformer, not testing terminals of the coil will need to be grounded directly or through an inductance. With an auto transformer, the received impulse may not properly follow the standard when the remaining winding is grounded directly or through measuring resistors. In this case, the widing will be allowed grounding with R<400Ω. [4]. In case of testing low inductance windings, due to difficulties in obtaining standard followed waveform, the remaining windings can be grounded through the resistor. In the above case, the voltage at ground winding may not exceed 75% with the star connection and 50% with triangular connection.

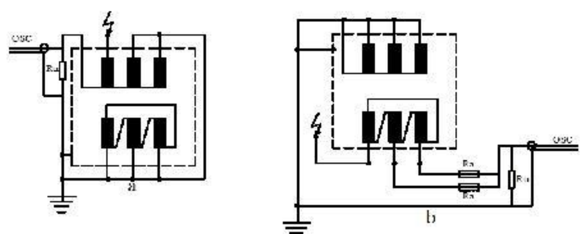

Fig. 5: Single phase testing circuit

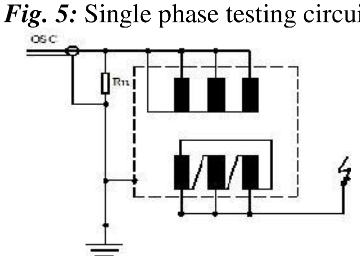

Fig. 6. Three phase testing circuit, triangular connection

With triangular connection winding, combining two pole and three-pole test, the impulse will be injected on both terminal at the same time while the other terminal will be grounded (Two poles testing, Figure 7). In this case, the two phases are tesitng simultaneously. [4].

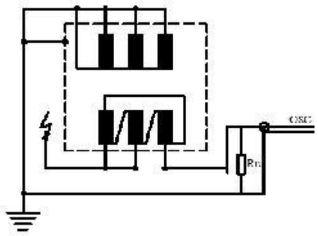

Fig. 7: Two poles testing circuit

4.2. Parameters researching, circuit configuration selecting for LI test

Main configuration for single phase 500kV-150MVA, C ≅ 6000nF transformer testing will be : 9 parallel x 2 serial. The value of Resistor will be: R_{Out} = 20 Ω ; R_{Front} = 20 // 20 // 30 Ω = 7,5 Ω and R_{Tail} = 150 Ω

4.2.1. The 500 kV winding LI test

Generator				Transformer	
Configuration GTN 18-10	R_{Front} (Ω)	R_{Tail} (Ω)	R_{Out} (Ω)	S (MVA)	$U_{\%}$
9x2	7,5 20//20//30	150	20 (60//30)	>125	10

4.2.2. The 220 kV winding LI test

Generator				Transformer	
Configuration GTN 18-10	R_{Front} (Ω)	R_{Tail} (Ω)	R_{Out} (Ω)	S (MVA)	$U_{\%}$
18x1	20	150	90	60-125	6-10
18x1	30	150	90	< 60	6
9x2	20	150//150	30	60-125	6-10
9x2	30//30	150//150	90	60-125	6-10

4.2.3. The 123 kV winding LI test

Generator				Transformer	
Configuration GTN 18-10	R_{Front} (Ω)	R_{Tail} (Ω)	R_{Out} (Ω)	S (MVA)	$U_{\%}$
18x1	20	150	90	< 125	6-10
18x1	30	150	90	< 125	6
9x2	20	150//150	30	< 125	6-10
9x2	30//30	150//150	90	< 125	6-10
6x3	30	150	90	< 125	10

5. Results and analysis

- The LI test process will record the oscillation of voltage or current in the tested winding.

- The testing transformer will be considered meet the standard if waveform achieved a standard 1.2/50 μs waveform, with tolerances as follows:

+ Peak value: ± 5%;

+ Front time T_1 ± 30 % ;

+ Time to half T_2 ± 20%

- When there is any breakdown , even a very small oscillating point of the wave shape is skewed, it will be noticed as an insulator damage. From there we will detect insulator breakdown, especially between two windings of transformer.
- If the test occur breakdown, the test voltage will be reduced to 2 levels (normal level lower than test voltage of 60, 75 and 90%). The reduced voltage will apply for 3 impulse, and if breakdown occurs continously, the test will be stopped. In the other hand, test for 3 next impulse 3 with higher voltage level until achieving a breakdown.
- If the breakdown is not repeated in breakdown voltage level, it will not allow to raise a higher voltage to avoid breakdown in the other level. If the test records have two or more breakdown, the test must be stopped.
- The breakdown windings need to unload partial or all to find the reason and repair or replace the other winding.

Before and during the test, HVLAB staff calibreated the 18-10 GTN System. [3].

The results from table 2, 3 and 4 show:

- With the 500kV winding, the peak voltages (U_{peak}) : - 1570kV, - 1580kV and - 1590 kV are all greater than the standard voltage - 1550kV with the respectively tolerance (%): + 1.3, + 1.93 and + 2.58;

- With the 220kV winding, the U_{peak}: -795kV, -1060kV are all greater than the standard voltage - 787.5kV and -1050kV with the respectively tolerance (%) : + 0.9 and + 0.95;

- With the 110kV winding, the U_{peak}: - 412kV, - 555kV are all greater than the standard voltage - 400kV and -550kV with the respectively tolerance (%) : + 3.0 and + 0.9;

- The front time (T_1) and time to half (T_2) are all have the waveform as the 1.2/50 μs standard waveform, with the tolerances from - 13.3% to + 7.5%.

Table 2. LI 1.2/50μs test for 500kV winding

Test voltage set	U_p (kV)	T_1 (μs)	T_2 (μs)
U_{Test1} = - 500kV	-495	1.11	45.6
Tolerance (%)	-1.0	- 8	- 8.8
U_{Test2} = - 1000kV	-1060	1.10	45.4
Tolerance (%)	+4.0	-8.3	-9
U_{Test3} = - 1550kV	-1570	1.15	45.2
Tolerance (%)	+1.3	-4.16	-9.6
U_{Test4} = - 1550kV	-1580	1.17	45.9
Tolerance (%)	+1.93	-2.5	-8.2
U_{Test5} = - 1550kV	-1590	1.08	46.1
Tolerance (%)	+2.58	-10	-7.8

Fig. 8. The 500 kV winding LI test result.

Table 3. LI 1.2/50µs test for 220kV winding

Test voltage set	U_p (kV)	T_1 (µs)	T_2 (µs)
U_{Test1} = - 550kV	-577	1.14	46.6
Tolerance (%)	+ 5.0	- 5.0	-6.8
U_{Test2} = - 787.5kV	-795	1.04	45.9
Tolerance (%)	+ 0.9	-13.3	-8.2
U_{Test3} = - 1050kV	-1060	1.07	46.8
Tolerance (%)	+ 0.95	-0.8	-6.4

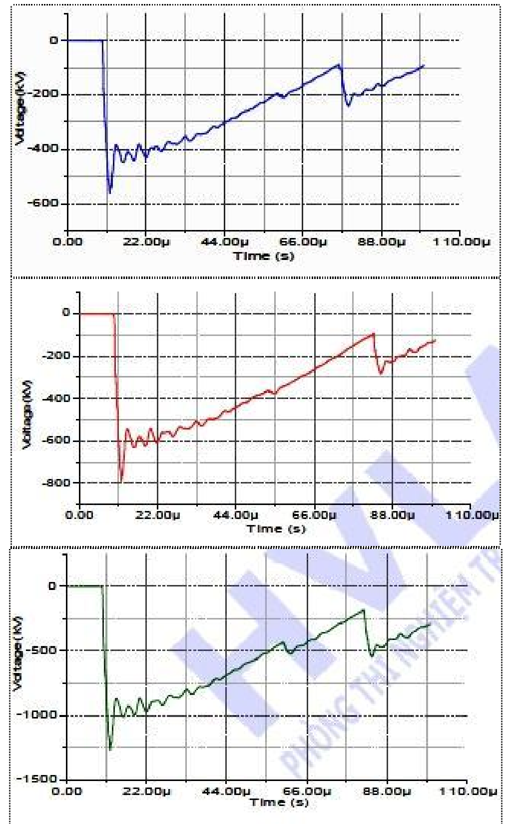

Fig. 9. The 220 kV winding LI test result.

Table 4. LI 1.2/50µs test for 123kV winding

Test voltage set	U_p (kV)	T_1 (µs)	T_2 (µs)
U_{Test1} = - 400kV	- 412	1.27	46.1
Tolerance (%)	+ 3.0	+ 5.8	- 7.8
U_{Test2} = - 550kV	-555	1.29	46.3
Tolerance (%)	+ 0.9	+ 7.5	- 7.4

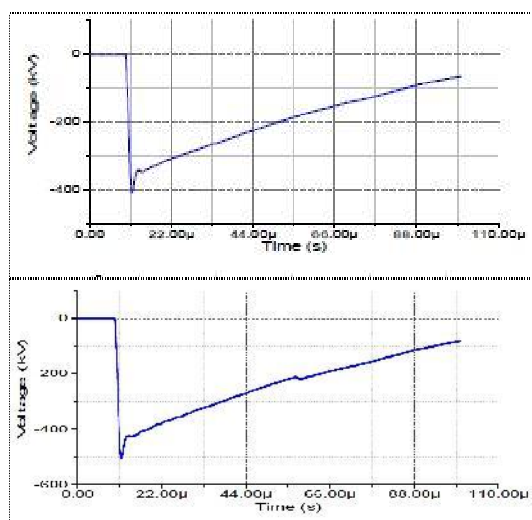

Fig. 10. The 123 kV winding LI test result.

6. Conclusion

From the test results above, we can have these conclusion:

- When overvoltage occurs, the voltage put on 500kV winding insulation will have the maximum value at -1590kV. The parameters T_1= 1.08µs, (- 10%) and T_2= 46.1µs, (- 7.8%). With the 220kV winding, the maximum voltage is - 1060kV, the parameters are T_1= 1.07µs, (- 0.8%) and T_2 = 46.8µs, (- 6.4%). And with 123kV winding, the maximum voltage is - 555kV the parameters are T_1= 1.29µs, (+ 7.5%) and T_2= 46.3µs, (-7.4%).

- The tested transformer has met the technical standards. During the test, the unexpected raising value of testing current did not occur, the testing voltage did not decline, the wave form did not have deviation and it did not have the ignition sound inside the transformer.

- In the past, due to the lack of compatiable test device, most high voltage equipment has not taken this important test in VietNam.

- In order to obtain safety transformer operation to ensure power grid supply reliability and to ensure the high quality, testing produce have HVLAB has researched the testing standards IEC60076-3:2000; TCVN(ISO)6306-3:2006 table 1, section 7.1, in which states: for transformer with high-voltage windings U_m> 72.5kV, the LI test is a regular test for all transformer windings. Thus we recommend Ministry of Industry and Trade to create a legal framework to insert the LI test for high voltage, ultra high voltage equipment and especially for transformer into National Regulations on Electrical Engineering, in order to meet the technical requirements in current Vietnam conditions, as well as to fully promote the effectiveness of this testing system which was invested by goverment resources.

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