Study to Compare Lightning Impulse Waveform Evaluation using IEC 60060-1ED 2 and IEC 60060-1 ED 3

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Abstract — Eventhough the evaluation of lightning impulse has amended according to IEC 60060-1Ed 2 to IEC 60060-1 Ed 3 with K factor fitting, still many test labs and manufacturers use the old IEC evaluation. The study has conclusive evidence to prove that there a deviation in parameters such a Upk, T1, T2 and Overshoot. and K factor fitting in the new IEC provide better evaluation of the lightning impulse waves with oscillation and overshoot. The study also provides an insight to the change in parametric values due to circuit loop inductance and their changes with different evaluation methed.

Keywords: EHV -Extra High Voltage, HVS- High Voltage standard, HiAS- High resolution Impulse Analysis system, HF- High Frequency, IEC- International Elctrotechnical Commissioin, LI- Lightning Impulse, LF- Low Frequency, UHV- Ultra High Voltage

I. INTRODUCTION

The standard for Lightning Impulse waveform has front time T1 as 1.2 uS and Tail Time T2 as 50 uS with tolerance of 30% and 20% respectively [1].The other evaluation parameters such as overshoot, frequency, Td are also part of the evaluation which is defined in the IEC 60060.The recommended IEC for the evaluation for LI testing for various test objects as a part of routine or special test is specified in IEC 60060-1 Ed 3, IEC 61083-2 Ed 1 This was a modification IEC 60060-1 Ed 2,IEC 61083-2 Ed 1 (old). Even though this change came in 2010, still many manufacturers and testing labs are using the IEC 60060-1989 for evaluating lightning impulse test. Study aims to understand the difference between the two versions of the standard and the effect on the results such as T1, T2, Overshoot etc. The study is conducted in 3 stages.

- Stage 1: Theoretical study- to understand the basic difference between the two versions of the IEC.
- Stage 2: Waveform generation and Data collection-To generate the standard lightning waveform with different test object capacitance values.
- Stage 3: Evaluation and Analysis: The collected data will be analysed in using both version of IEC evaluation method and difference in the parametric values will be tabulated with the conclusion based on the evaluation.

Even though the aim of the study is to provide the difference in between the two versions of the IEC for Lightning impulse testing, the study also provide more insight to the changes in the values and limits with respect to the tolerance limit and also the parametric variation due to additional oscillation in the lightning impulse wave occurred due to low inductance of the test object or the increase in loop inductance of the test circuit. It has been observed in various testing situations that the Loop inductance play a bigger role in the front oscillation of the lightning impulse and leading to higher overshoot (β) and relative overshoot (β') evaluated as per HVS.

II. RESEARCH METHODOLOGY

A. Stage 1- Theoretical Study-Difference between the old and the New IEC 60060-1

The main difference in the evaluation between the old and the new IEC 60060 is that introduction of the K Factor for calculation of the Test Voltage. The IEC under the old evaluation was done as per the below curve evaluation method [1]

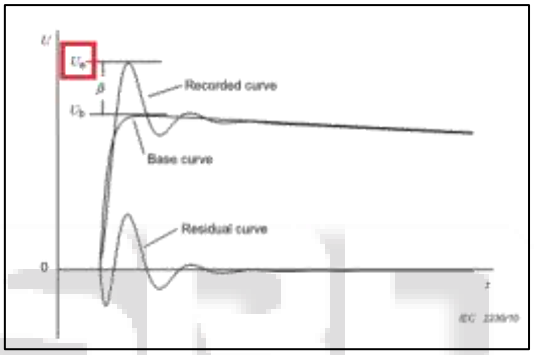

Fig. 1: The upper evaluation shows the recorded curve and base curve overshoot and residual curve, IEC 60060-1 Ed 2, IEC 61083-2 Ed 1 (old)

The calculation formula for the Ubase curve is given by the formula

$$Ubaee\ curve\ (t) = Ub * (e(t - o1)/\tau 1 - e(t - o1)/\tau 2) \quad (1)$$

Former k-factor (1) according to IEC 60060-1 Ed. 2.0 with k-1 for f < 500 kHz and k-2 for f > 500 kHz [2].

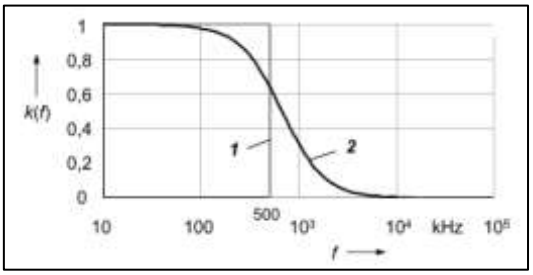

Fig. 2: The upper evaluation shows the recorded curve and base curve overshoot and residual curve, IEC 60060-1 Ed 2, IEC 61083-2 Ed 1 (old)

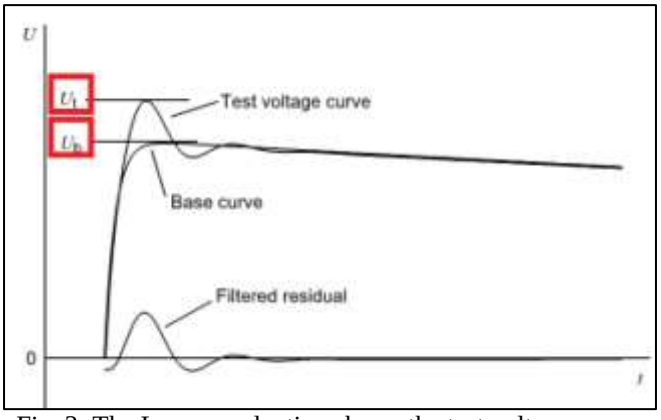

Fig. 3: The Lower evaluation shows the test voltage curve (addition of base curve and filtered residual curve), IEC 60060-1 Ed 3, IEC 61083-2 Ed 2 (New)

The test Voltage Ut is calculated using the formula.

$$Ut = Ub + k(f) * (Ue - Ub) \quad (2)$$

Where: $k(f) = 1/(1 + 2.2\,f2)$

B. Stage 2- Waveform generation and data collection

For the purpose of generating the waveform Haefely AG make recurrent surge generator was used and for data recording and evaluation HiAS 743 was used with analysis software.

The experimental setup is as shown below.

Image 1: Experimental setup

For the study six waveforms were used considering different test object capacitance and loop inductance. The results are as tabulated below in table 1.For evaluation HiAS 743 hardware was used with analysis software version 1.9.1.

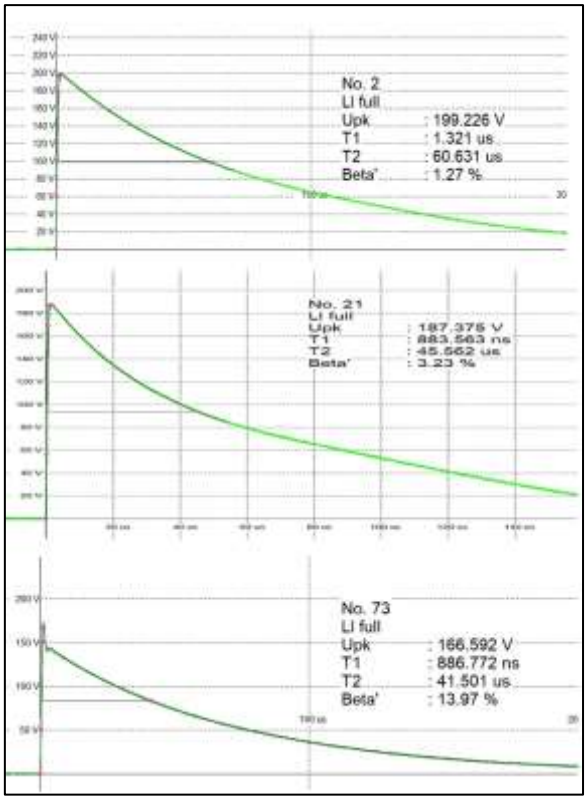

Fig. 5: Waveform evaluation using IEC 60060-1 Ed 3, IEC 61083-2 Ed 2.

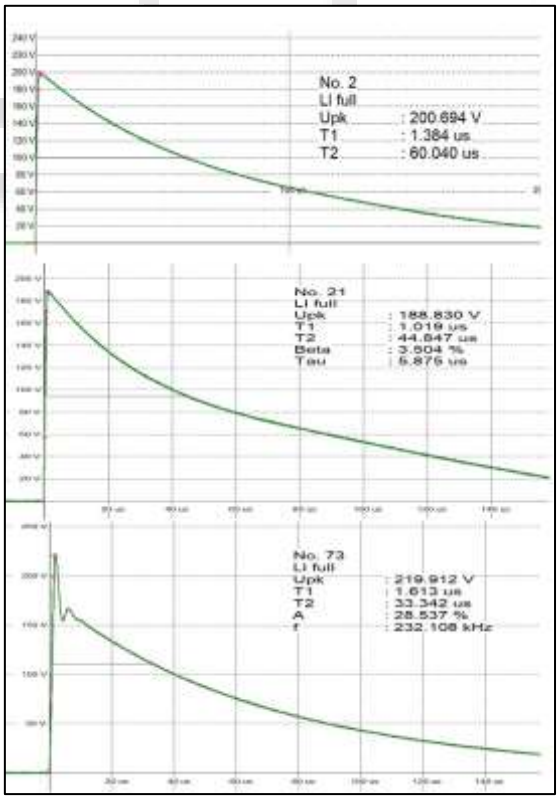

Fig. 6: Waveform evaluation using IEC 60060-1 Ed 2, IEC 61083-2 Ed 1.

SL	LLoop	CS	CB	RS	RP	IEC 60060-1 Ed 3			
						Upk	T1	T2	Beta'
1	10	100nf	1nF	330	680	199.226	1.321	60.631	1.27
2	50	22nF	1nF	330	1.5k	187.375	0.883	45.562	3.23
3	10	1uf	2.2 nF	220	68	201.16	1.536	51.583	0.4
4	10	1uf	3.3nf	150	68	201.748	1.375	51.215	0.37
5	30	1uf	4.7nF	68	68	166.592	0.8867	41.501	13.97
6	10	1uf	10nF	68	68	194.436	1.579	51.549	0.8
SL	LLoop	CS	CB	RS	RP	IEC 60060-1 Ed 2			
						Upk	T1	T2	Beta
1	10	100nf	1nF	330	680	200.694	1.384	60.04	0
2	50	22nF	1nF	330	1.5k	188.83	1.019	44.847	3.504
3	10	1uf	2.2 nF	220	68	201.163	1.569	51.629	
4	10	1uf	3.3nf	150	68	201.896	1.411	51.21	
5	30	1uf	4.7nF	68	68	219.912	1.613	33.342	
6	10	1uf	10nF	68	68	194.405	1.55	51.489	

Table 1: Results With IEC 60060-1 ED 3 and IEC 60060-1 ED 2 Evaluation

[a]LLOOP= Loop Inductance in uH; CS = Sourse capacitance in nF or uF, CB = Test object Capacitance in nF, Rs = Series resistance in Ohms; Rp = Parallel resistance, Upk = Peak Voltage inV, T1 = Front time in uS, T2 = Tail Time in uS, Beta = Overshoot in %, Beta' = Relative overshoot in %

All the test except test no two and test no five is done with LLOOP as 10uH. For test No 2. 50uH and test No 5. 30uH is used. The test was conducted for various test object capacitance varying from 1nf till 10nF.The waveform generated were selected to cover the β' value from 0.4% till 14% approximately. The difference and the deviation in the test results for each setup was calculated and tabulated in table 2.

DEVIATION BETWEEN IEC 60060-1 Ed 2 and IEC 60060-1 Ed 3 EVALUATION RESULTS		
Upk (%)	T1 (%)	T2 (%)
-0.737	-4.769	0.975
-0.777	-15.402	1.569
-0.001	-2.148	-0.089
-0.073	-2.618	0.010
-32.006	-81.910	19.660
0.016	1.837	0.116

Table 2: Difference in Evaluation Results

C. Stage 3- Evaluation and Analysis

From table 1 the following observations are made.

1) Increase in loop Inductance LLOOP will increase the oscillation in the impulse waveform.
2) Increase in loop Inductance with increase in test object capacitance CB will also increase the oscillation and overshoot. This has more effect than the latter.
3) Upk calculation with overshoot calculation as per IEC 60060-1 ED 2 is gives bigger error in comparison to the IEC 60060-1 ED 3.
4) T1 and T2 parameters are functions of the test voltage and since the test voltage function is changing the T1 and T2 parameters are also changed when evaluated between the two amended IEC standards.

From table 2 the following observations are made.

1) The Upk value has less than 1% deviation when the waveform is not having any oscillation.
2) The waveform with oscillation with LF (frequency less than 500kHz) evaluated with IEC 60060-1 Ed 2 has larger impact with Upk, T1 and T 2 Values.
3) The waveform with oscillation with HF (frequency above 500kHz) evaluated with IEC 60060-1 Ed 2 has less impact with Upk, T1 and T 2 Values.
4) Higher the loop inductance more oscillation the wave front will be leading to higher deviation.
5) Deviation in T1 Values are beyond acceptable limit when overshoot is higher in nature leading to calculation error.

III. Result

From the study the new k-factor evaluation of the Lightning impulse voltages according to the IEC 60060-1 Ed3 varies from the results of the IEC 60060-1 Ed 2. Especially with the waveform with higher overshoot or oscillations. The difference in the values shows that a wrong calculation and application of wrong wave for the testing can happen if the user choses to use the older version of the IEC for the evaluation purpose. The new standard k factor allows a reproducible evaluation of test voltage which has influence on the superimposed oscillation which is dependent on the frequency. The Loop inductance and the test object capacitance plays a big role in the oscillation and overshoot in lightning impulse test for UHV and EHV class equipments.

IV. Conclusion

The study provide conclusive evidence for the deviation in parameters of Upk,T1,T2 and Beta (overshoot) in comparison between the IEC standard 60060-1 ED 3 and IEC 60060-1 Ed 2.These deviations are more evident and larger in the lightning impulse waves with high oscillation or overshoot. The K factor fitting method used in the IEC 60060-1 Ed 3 is more suitable for the evaluation of lightning impulse wave with higher oscillation. The Loop inductance in the test circuit play an important role in the oscillation of the lightning impulse wave during testing. The evaluation of test objects such as transformers with low inductance winding on the low voltage side causing high oscillation can be more consultable with less calculation error with this k factor fitting. The test lab users should adopt the new IEC standard 60060-1 Ed 3 evaluation software for the testing of electrical apparatus to comply with the standard.

V. Future Scope of Study

Due to limitation on time and budget a full extensive study on the topic was not possible and have a future scope of improvement. The study can be extended to identify the effect of the Loop inductance in comparison with the IEC standard 60060-1 Ed 2 and IEC 60060-1 Ed3.

Acknowledgment

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