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DESIRED IMPULSE SHAPE PROXIMITY ENHANCEMENT IN IMPULSE TEST OF POWER TRANSFORMER

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Abstract*- In this paper the demonstration of the high voltage impulse test is performed to testify the withstand capability of power transformer. Then the problems associated in practical wave generation will be stated which are to be improved by the proposed algorithm using PC tools. Then a simulation result will be presented for a practiced equipment range of parameters.*

Keywords: Marx Generator, PSPICE, Laplace Transformation, Impulse Wave shape.

1. INTRODUCTION

The outdoor power transformers are highly at risk to receive heavy voltage surge from lightening. As to design the insulating capability a similar or even severe impulse wave, shaped with a defined rise/front time and tail time is applied in indoor to the leads of it [1]. Now to get the exact scenario, the correct type of wave shape generation is must which seems to be trial and error to get in practice. So a mathematical representation of the instrument with load effect and stray capacitances under concern, a automatic generation of the parameters (R,C, air gap) can be achieved to apply for some predefined wave shapes necessary for different kV level test and get the result in 1st try. For the preceding sections, simulated model and mathematical tools like Laplace have been utilized.

2. PRINCIPLE OF OPERATION OF MARX TYPE IMPULSE GENERATOR (IG)

A Marx-type impulse generator has the schematics like Fig.1 which is commonly applied to the test.[2],[1].

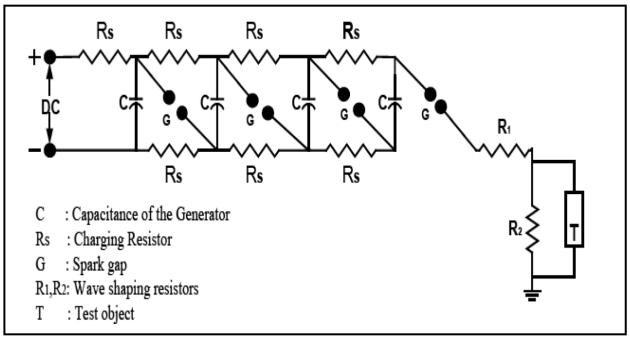

Fig.1: Marx Generator for Impulse Voltage Regulation

The mainly generated impulse voltage waveform represents the following common incidents:
1) Standard lightening impulse waveform
2) Standard switching impulse waveform
3) Other special switching or uncontrolled impulses.

At the beginning of the operation a DC generator is used to charge the staged capacitors to its peak value. Normally the peaks of individual capacitors lie in 20 kV. Now when to test an insulator string (i.e) the air gap is made to break down by triggering the lowest air gap.

The impulse capacitor is charged via a high charging resistance (R_o) to the direct voltage U_o and then discharged by ignition of the switching gap F. During this charging and discharging period, the desired impulse voltage U(t) appears across the load capacitor Cy. As in the Fig.2:

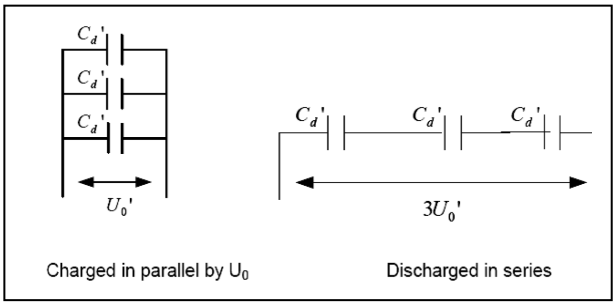

Fig.2: Charging and discharging phase capacitor orientation

The discharging path then made the impulse to be appeared across the test object, as shown in the Fig.3.

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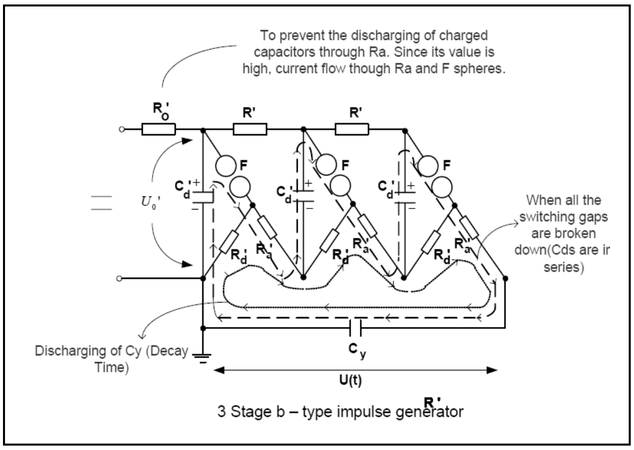

Fig.3: Operational paths of discharging capacitor current

Now the waveform, generated has 3 major components to define before applied to [4]. These are: 1)Amplitude or percentage of amplitude, 2) Wave front time, T_C, 3) Wave trail time, T_S.

An acceptable Impulse [4] which can represent a lightening like waveform has the following shape defined by T_C, T_S & U_{max}:

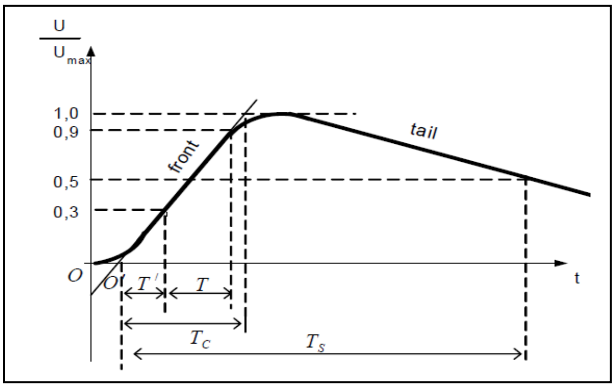

Fig.4: Lightning Impulse Waveform

Now for creating a signal which should be automatically generated with the given parameters of R, C, U_o fulfilling the necessary T_C, T_S & U_{max}. For that coding has been created and simulated it in SPICE in the preceding sections. Then it has been applied in a practical test, to get the real data and to verify its use in 1st time accurate try in impulse test.

3. SIMULATION AND ANALYSIS

In this segment simulation of the IG in Pspice (Fig.5) with no transformer as load has been done.

The simulated waveform for the specific parameters appears as below which has reported dissimilarities with our practical findings. These are demonstrated with the following figures:

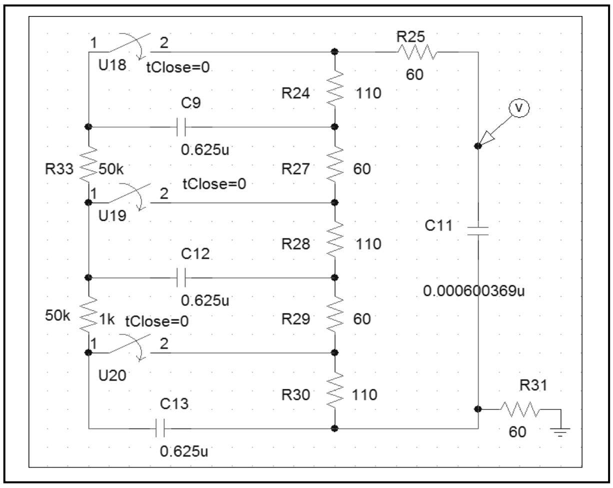

Fig.5: PSPICE circuit of Impulse Generator at no Load

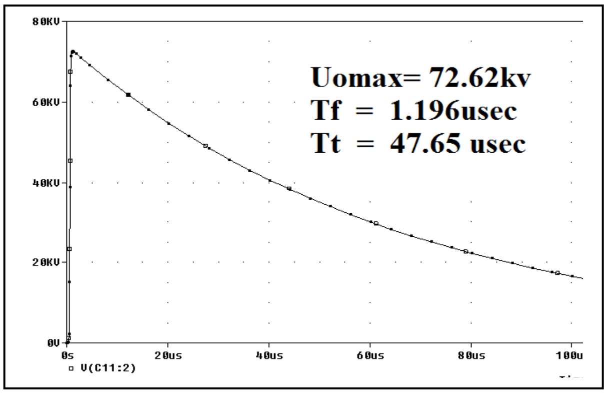

Fig.6: Simulated Waveform of PSPICE circuit at no Load

The practically granted wave shape in Impulse lab (Energypac) appeared as Fig.7 (which is made by trial and error basis): [1],[2],[4]

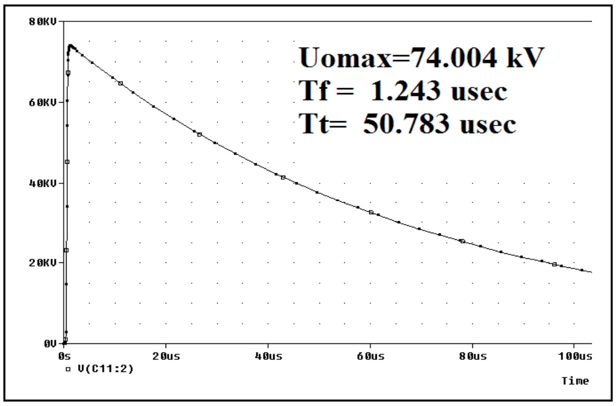

Fig.7: Practical Simulated Waveform of Impulse circuit at no Load

Hence to mathematically represent the system where, for the same value of front and tail resistor a multistage IG can be reduced to a single stage by using Laplace transform and it's inverse [6] As shown, the single stage is like as Fig.8.

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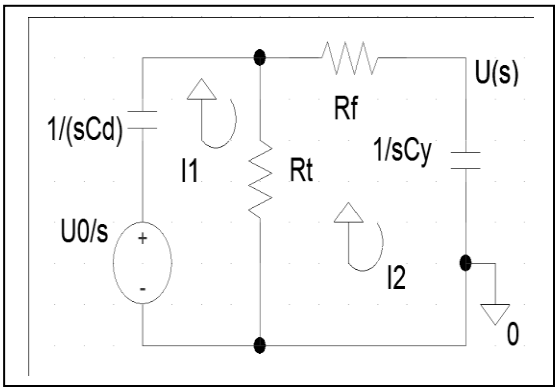


Fig.8: Single Stage Circuit for analysis

Then by using KCL, KVL and inverse Laplace output parameter U(t) [6] is obtained in time domain as:

$U(t) = k\,[e^{s1t} - e^{s2t}]$ ……………………. [1]

Here,

$k = A / (s1-s2)$ $\quad s1, s2 = -b \pm \sqrt{(b2-4ac)}/2a$

a=1,

$$b = \frac{1}{Rf*Cd} + \frac{1}{Rt*Cd} + \frac{1}{Rf*Cy},$$

$$c = \frac{1}{(Rf*Cy*Rt*Cd)}$$

$$A = \frac{Uo}{Rf*Cy}$$

The single staged parameters are defined for multistage as:

U_0 = n* per stage voltage of capacitor
R_f = n* per stage resistance of front resistor
R_t = n * per stage resistance of tail resistor
C_y = capacitance of divider/load capacitor
C_d = (1/n) * per stage capacitance of capacitor

Now, MATLAB coding has been used to plot U(t).In practice iterative process in fixing the suitable resistance and capacitance values for a defined waveform are used. By using the above equations and coding it is possible to bring a more proximate waveform in a quicker and easier way which reduced the time, labor of handling weighty elements and chance to decrease the durability of the transformer insulation.

In this portion the spice model with a capacitive load representing a real equivalent transformer has been tested. But as found the tail time deviates from the practical test data for a 200KVA transformer. Moreover now in the schematics (Fig.9), the stray capacitances have been added which are inherited in the system. This caused a visible improvement in proximity with real test wave shape which is given in part IV of this paper.

The generated wave shape across the capacitor divider is given below (Fig.10) which is showing a definite deviation.

The main sources of this deviation are the non-calculated distributed capacitances that an original transformer winding has. If it is possible to calculate then measurement of loading can be done to use it in the simulation and hence to produce the testable wave shape. [3],[5],[6].

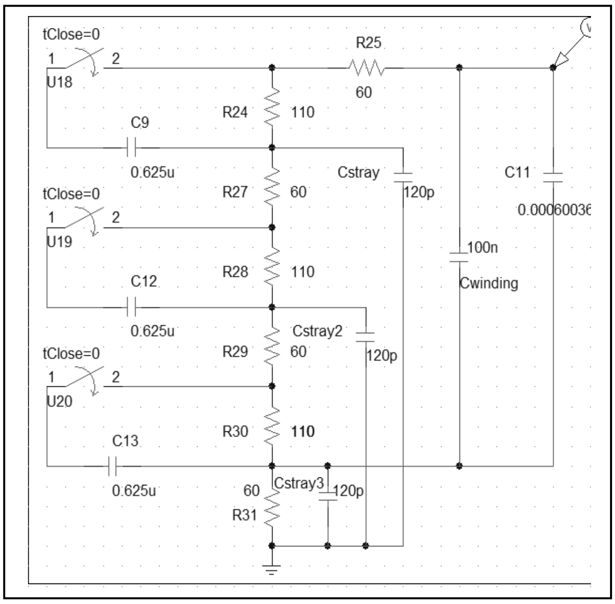


Fig.9: PSPICE circuit with stray capacitance and load

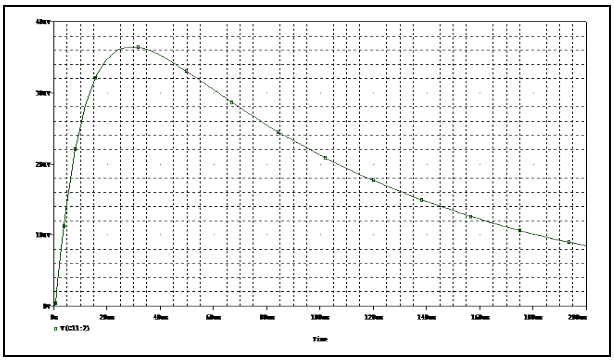
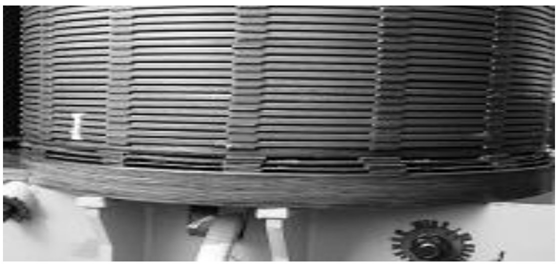


Fig.10: Generated Wave shape with stray capacitance and load

For the exact R_f, R_t and U_o to find, a calculated mathematical model is necessary which can represent a transformer's equivalent capacitance. For the tested circular disk wound transformer development of the total capacitance of a winding. [5],[6],[7] is performed.

$C_{winding} = C_{turn\text{-}turn} + C_{disk\text{-}disk}$
$= C_{tt} + (C_{dd\ due\ to\ key\ spacer} + C_{dd\ due\ to\ insulating\ oil})$

C_{tt} exists as for the turns on a disk have paper insulation in between them and C_{dd} exists as for key spacer in some portion and insulating oil for the rest of the portion in between the disks consisting the turns. As shown in the figure below: (photo courtesy: EnergyPac Ltd, Bangladesh)



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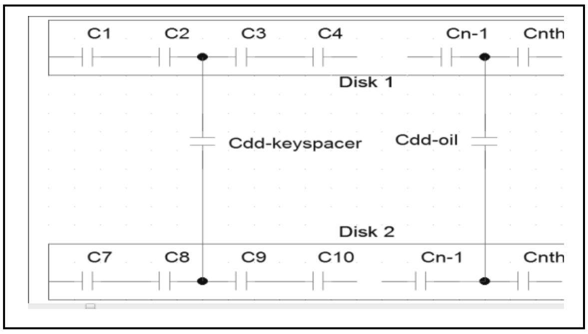

Fig.11: Capacitance between Turns

For the disk type transformer the equations for designed parameter have used. These are: [6], [7].
The turn-turn capacitance C_{tt} :

$$C_{tt} = \varepsilon_0 \varepsilon_p * 2 * \pi * R_{ave} * \frac{(h + 2\tau p)}{\tau p} \quad \ldots\ldots\ldots\ldots\ldots\ldots [2]$$

Where, R_{ave} = Average radius of the disk
h = Bare copper or conductor height
$(h + 2\tau p$ = taking fringing effect into account)
ε_0 =Permittivity of air (vacuum)
ε_p= Relative permittivity of paper
R_{ave} = Avg distance of the ring from center.

Now the disks are positioned one upon one using Key spacer which are paper or plastic type material, in some portion. The rest of the gaps are filled with oil as insulating as well cooling media. So the disk-disk capacitance is expressed as:[6],[7].

$$C_{dd} = \varepsilon_0 \pi * (R_{out}^2 - R_{in}^2) * \left[\frac{fks}{\tau p/\varepsilon p + \tau ks/\varepsilon ks} + \frac{(1 - fks)}{\tau p/\varepsilon p + \tau p/\varepsilon oil} \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots [3]$$

Here, f_{ks} = Key spacer fraction (usually 1/3 in value)
Then the approximate total capacitance of transformer is K where the equation of K is given below: [8]

$$K = \frac{27.8 * D}{N} \left[\frac{\varepsilon p (h + 2\tau p)}{2 * n * \tau p} + \frac{4}{3} * \frac{r + \tau ks}{2\tau p/\varepsilon p + \tau ks/\varepsilon ks} \right] * 10^{-12}\, F \quad \ldots\ldots\ldots\ldots\ldots\ldots [4]$$

Here, K = Approx. total capacitance of transformer. [8]
D = Mean winding diameter
N = No of discs in winding
n = No of turns per disc
τ_p = Thickness of paper insulation
τ_{ks}= Thickness of key spacer
The tabulated data for real life tested 28MVA, 33/11Dyn 11 outdoor type transformer is given in table 1: [1],[4].

Table 1: Parameters of 33/11 Dyn 11, 28MVA Transformer

Parameter	Value	Parameter	Value
R_{out}	453 mm	τ_p , τ_{ks}	0.5 mm,4.2mm
R_{in}	365 mm	h	12.2 mm
f_{ks}	1/3	ε_p	3.5
n	8	ε_{oil} , ε_{ks}	2.2, 4.5

With these data, calculation is performed with the approximate total capacitance of the transformer, K which is found as 33.7×10^{-12} Farad. Then the value is used as $C_{winding}$ to find the desired impulse.

4. REAL TIME INSTRUMENT & EXPERIMENTATION

The application of the stated method is utilized in a practical impulse test. The IG is made by HUAGAO H.V. which has the rated voltage of 1600kv and rated energy storage of 100kJ. The parameters and design data are tabulated and the findings in wave shape in 1st try are compared.

IG wave found at lab for no load using R_f, R_t found from simulation as in Fig.12:

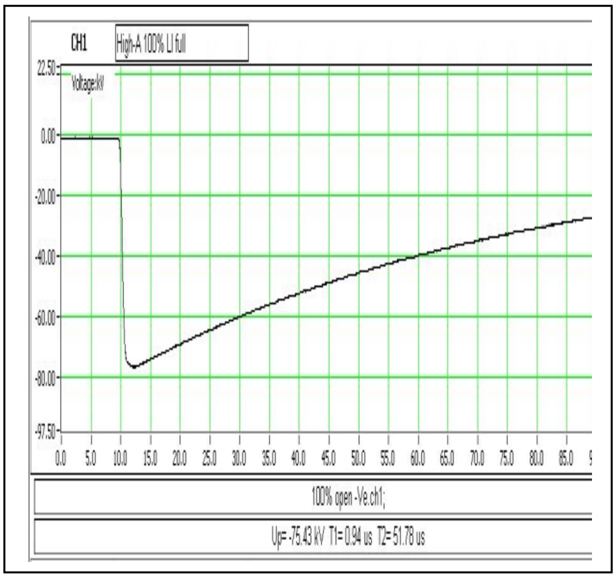

Fig.12: Real Wave shape from Oscilloscope at no load

IG wave found in lab using R_f, R_t obtained from the simulation of both Spice and MATLAB where stray capacitance and transformer winding equivalent model are included as in Fig.13:

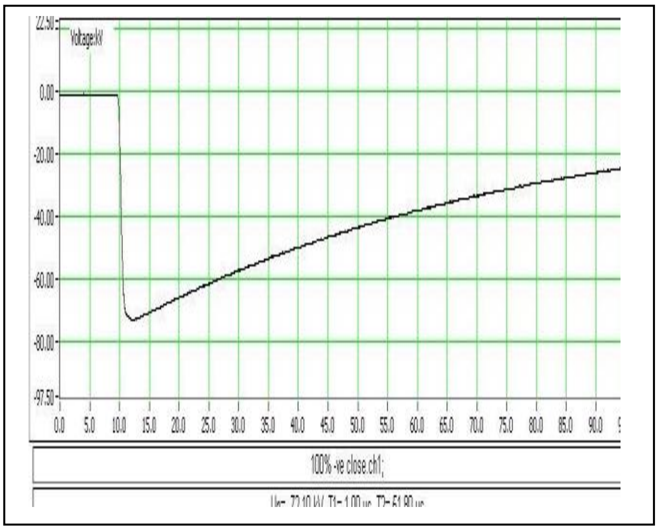

Fig.13: Real Wave shape from Oscilloscope with load and stray capacitance

Table 2: Simulated model parameters with load and stray capacitances included, for comparing the characteristics of impulse wave

Lab found		Determined from simulation		Input parameters found from MatLab coding		Simulation model parameters	
T_f	T_t	T_f	T_t	R_f	R_t	C_{stray}	C_{load}
1.00 usec	51.8 usec	1.26 usec	50.97 usec	59	114	50pf	33.7 pf

So that, here an acceptable wave shape has been found in lab for the test object in first try.[1],[4].

5. CONCLUSION AND FUTURE WORK PLAN

In the present work the authors created a procedure where output obtained from PSPICE software can be utilized for the value needed for the parameters in real test which perform the real life impulse test in a quicker and safer way. This can reduce the error as well the durability of various precious equipments.

In future the authors are going to work on low tension side. At low tension terminal as the voltage level is low, so the inductance plays a big role in creating required wave shape. The resultant wave has overshoots as well some high frequency transients. So the authors are planning to make a detailed model for LT IG test. From which, by means of software they should be able to get the correct wave shape at an instant.

6. ACKOWLEDGEMENT

The authors want to give their gratefulness to Energypac Engineering Ltd. Bangladesh for giving the opportunity for using the Impulse Lab.

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8. NOMENCLATURE

Symbol	Meaning	Unit
R_f	Front Resistor	(Ohm)
R_t	Tail Resistor	(Ohm)
T_f	Front Time	(micro second)
T_t	Tail Time	(micro second)
τ_p	Thickness of paper insulation	(mm)
τ_{ks}	Thickness of key spacer	(mm)

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