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Evaluation of Impulse Generator Circuit Parameters for Testing of Underground Power Cables using Matlab/Simulink

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Abstract: In this paper the impulse generator circuit is evaluated by taking capacitance of the 6.35/11 kV, 3-core cable as load by using Matlab Simulink. Cable of same voltage rating i.e. 6.35/11 kV but of different size is taken. Attempts are made to evaluate the variation in the front resistance and tail resistance of the impulse generator for different size of cable, in order to get the standard wave front time and wave tail time. Further the efficiency and voltage regulation is calculated for different size of the underground cable and for different values of C_1/C_2.
Keywords: Impulse Generator, Underground cable, Matlab Simulink, Load capacitance, Front resistance, Tail resistance

I. INTRODUCTION

Power cables are an essential part of transmission and distribution network by underground mode. Underground cables are not directly threatened to danger but lightning can induce stress on its insulation. Thus the insulation of these cables must be tested for its dielectric strength with the help of standard lightning impulse wave having a wave front of 1.2 µsec, and a wave tail of 50 µsec, and switching impulse wave having a wave front of 250 µsec, and wave tail of 2500 µsec, as specified by International Electrotechnical Commission (IEC) [1]. The lightning current that cause breakdown of the soil, does not damage the insulation of the cable, rather it depends on the amplitude of the striking current, length of cable, dielectric strength of cable and the configuration of the grounding system [2]. The transient behaviour of the cable is studied, when the standard and non-standard lightning impulse voltage wave is applied. It has been observed that, the higher voltage stress in the cable is caused by the non-standard impulse voltage wave [3] In order to test the insulation strength, generation of these impulse voltages are done in high voltage laboratory. Various methods are there for the generation of these impulse voltage wave and anyone of them can be used. Now a days by using various techniques, very fast high voltage impulse with a rise time of less than 50 nanoseconds is generated [4-5]. In order to get the front and tail resistances, for obtaining the standard double exponential impulse voltage wave, an approximation method is given in [6]. The load capacitor of the impulse generator is itself the part of the wave shaping circuit and according to it, the generator needs to be reconfigured. In [7], with the help of simplex search algorithm, the reconfiguration of impulse generator is done. The output of the impulse generator should follow some standards given by IEC, but there are some deviations due to the generator parameters like the self-inductance of the generator, the wave front resistance and wave tail resistance and may be due to the generator load [8-9]. In this paper, the capacitance of the 6.35/11 kV, 3-core cable is taken as load, and different cases are studied in which the cable size is varied and its effect has been observed on the front and tail resistance, in order to get the standard impulse waveform. Also the efficiency and voltage regulation has been calculated for each case. All these studies are done with the help of model of impulse generator simulated in Simulink, an extension of Matlab.

II. METHODOLOGY

The simulation of impulse generator is carried out by using Matlab/ Simulink. The working of impulse generator is that, it consists of a charging resistor which is charged up to the desired limit and then discharged across the load or the test capacitor with the help of spark gap. If the charging voltage has value less than 200 kV, then single stage impulse generator can be used in an economical manner. After this voltage, there would be lots of issues, like too large capacitor size, requirement of very high DC voltage source, etc. Thus in order to avoid all these problems, an impulse generator having multistage can be used.

Here in this work a three stage impulse generator is used, which is shown in Fig. 1, V_0 is the initial DC charging voltage, R_{ch} represents the charging resistors, C_g represents the charging capacitor, C_l represents the capacitance of the cable which is taken as load, R_a and R_b are the wave shaping resistors. Since in the library of Simulink, sphere gap is not present, thus an ideal switch is used here.

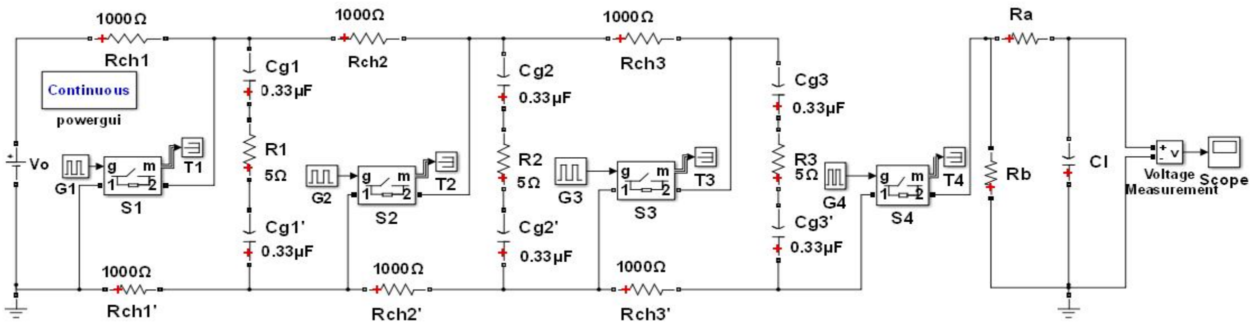

Fig. 1 Simulation model of three stage impulse generator.

III. CASE STUDIES

With the variations in the load capacitance values, different parameters of the impulse voltage generator has also to be varied, in order to get the standard impulse voltage waveform. These variations in the parameters have been accounted in different case studies, by considering the capacitance value of 6.35/11 kV, 3-core cable of different size.

A. Simulation of 3 stage Impulse Voltage Generator with load as capacitance of 6.35/11 kV, 3-core, 35 mm² cable

For 6.35/11 kV the test voltage required is 75kV as per the IEC standards.

V_0= maximum output voltage= 29×3 = 87 kV

C_{g1}= generator capacitance= $\left(\frac{0.33}{2}\right) \times \left(\frac{1}{3}\right)$=0.055μF=55 nF

The IEC standard value of capacitance of cable 6.35/33 kV, 3 core, 35 mm^2= 0.21μF/km [10]

Length of cable= 10m

C_l= the load capacitance for 10m cable=$\left(\frac{0.21}{1000}\right) \times 10$μF = 2.1nF

R_a= Front resistance

R_b= Tail resistance

C_1/C_2= (55/2.1) = 26.19

These values have been used in the 3 stage impulse generator model as shown in Fig. 1 and R_1=120Ω and R_2=3500Ω is acquired to get standard impulse voltage wave as shown in Fig. 2.

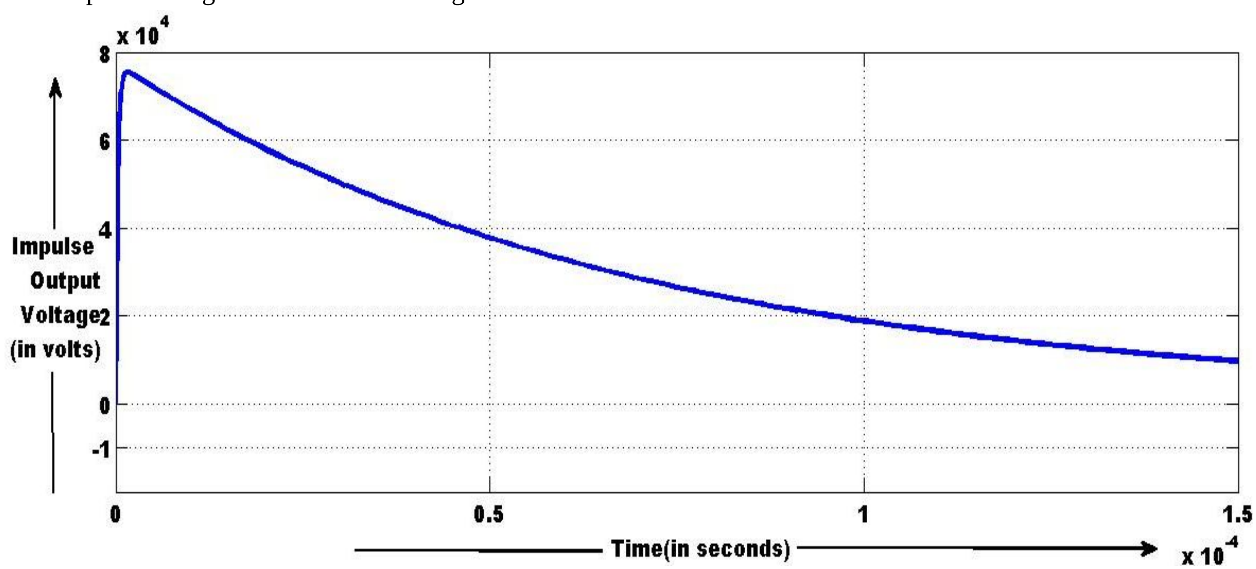

Fig. 2 Impulse output voltage obtained from three stage impulse generator.

The maximum output voltage obtained is V_0= 75.4 kV. The front time is obtained as 1.34 μs and tail time as 50.5 μs.

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B. Simulation of 3 stage Impulse Voltage Generator with load as capacitance of 6.35/11 kV, 3-core, 70 mm² cable

V_0= maximum output voltage= 29×3 = 87 kV

C_{g1}= generator capacitance= $\left(\frac{0.33}{2}\right) \times \left(\frac{1}{3}\right)$=0.055μF= 55nF

The IEC standard value of capacitance of cable 6.35/33 kV, 3 core, 70 mm^2= 0.25μF/km [10]

Length of cable= 10m

C_l= the load capacitance for 10m cable=$\left(\frac{0.25}{1000}\right) \times 10$μF = 2.5nF

R_a= Front resistance

R_b= Tail resistance

C_1/C_2= (55/2.5) = 22

These values have been used in the 3 stage impulse generator model as shown in Fig. 1 and R_1=95Ω and R_2=3500Ω is acquired to get standard impulse voltage wave.

The maximum output voltage obtained is V_0= 74.98 kV. The front time is obtained as 1.3 μs and tail time as 50.33 μs.

C. Simulation of 3 stage Impulse Voltage Generator with load as capacitance of 6.35/11 kV, 3-core, 185 mm² cable

V_0= maximum output voltage= 29×3 = 87 kV

C_{g1}= generator capacitance= $\left(\frac{0.33}{2}\right) \times \left(\frac{1}{3}\right)$=0.055μF= 55 nF

The IEC standard value of capacitance of cable 6.35/33 kV, 3 core, 185 mm^2= 0.36μF/km [10]

Length of cable= 10m

C_l= the load capacitance for 10m cable=$\left(\frac{0.36}{1000}\right) \times 10$μF = 3.6nF

R_a= Front resistance

R_b= Tail resistance

C_1/C_2= (55/3.6) = 15.28

These values have been used in the 3 stage impulse generator model as shown in Fig. 1 and R_1=50Ω and R_2=3500Ω is acquired to get standard impulse voltage wave.

The maximum output voltage obtained is V_0= 75.18 kV. The front time is obtained as 1.33 μs and tail time as 50.88 μs.

D. Simulation of 3 stage Impulse Voltage Generator with load as capacitance of 6.35/11 kV, 3-core, 300 mm² cable

V_0 = maximum output voltage= 29×3 = 87 kV

C_{g1} = generator capacitance= $\left(\frac{0.33}{2}\right) \times \left(\frac{1}{3}\right)$=0.055μF=55 nF

The IEC standard value of capacitance of cable 6.35/33 kV, 3 core, 300 mm^2 = 0.46 μF/km [10]

Length of cable = 10m

C_l = the load capacitance for 10m cable=$\left(\frac{0.46}{1000}\right) \times 10$μF = 4.6 nF

R_a = Front resistance

R_b = Tail resistance

C_1/C_2 = (55/4.6) = 11.96

These values have been used in the 3 stage impulse generator model as shown in Fig. 1 and R_1=35Ω and R_2=3300Ω is acquired to get standard impulse voltage wave.

The maximum output voltage obtained is V_0= 75.22 kV. The front time is obtained as 1.29 μs and tail time as 50.7 μs.

The above case studies have been summarized in Table 1 and the effect of changing the size of cable on the voltage regulation and efficiency has been observed.

1) The efficiency is calculated by using,

$$\text{Efficiency } (\eta) = \frac{\text{output impulse voltage}}{(\text{no of stages} \times \text{input voltage})} \quad (1)$$

2) And the voltage regulation is calculated by,

$$\%VR = \frac{\text{input voltage} - \text{output impulse voltage}}{\text{output impulse voltage}} \times 100 \quad (2)$$

Table I
Comparision Of Impulse Generator Parameters For Different Size Of Cable As Load

S. No	Cable Size (in mm^2)	Load Capacitance (nF)	Front Resistance R_a (in Ω)	Tail Resistance R_b (in Ω)	Front Time (in μs)	Tail Time (in μs)	Output impulse peak(in kV)	C_1/C_2	%VR	Efficiency (%η)
1.	35	2.1	120	3500	1.34	50	75.4	26.19	15.38	86.67
2.	70	2.5	95	3500	1.3	50.33	74.98	22	16.03	86.18
3.	185	3.6	50	3500	1.33	50.88	75.18	15.28	17.71	84.9
4.	300	4.6	35	3300	1.29	50.7	75.22	11.96	19.65	83.58

It can be seen from Table 1 that, as the size of the cable is increasing, the value of load capacitance increases correspondingly. In order to get the standard impulse waveform i.e. the front time of 1.2 μs $\pm$ 30% and tail time of 50 μs $\pm$ 20% according to the IEC standards [1], the front resistance, R_a and tail resistance, R_b has to be varied accordingly. It has been observed from Table 1 that, in order to get the standard waveform, the variation in the value of front resistance is appreciable, but there is very little effect on the value of tail resistance and its value is almost constant for all the four cable sizes i.e. 3500 Ω.

It has also been observed that as the cable size is increasing, then the efficiency decreases accordingly. Voltage regulation has also been calculated for each of different cable size with the help of (2) and it has been observed that the effect of the increase in the cable size is the increment in the voltage regulation. Also with the increase in cable size the value of C_1/C_2 is decreasing and it can be noticed that while the ratio C_1/C_2 decreases, the efficiency increases correspondingly.

IV. CONCLUSIONS

Through Matlab / Simulink software, the study of the three stage impulse generator is done with capacitance of the 6.35/11kV, 3 core cable as load. It can be concluded from the simulated system that, with the increase in the size of the cable, the front resistance varies appreciably, but the tail resistance is almost constant in order to get the standard impulse waveform. It has been observed that when the size of the cable is small, the efficiency is quite high. But as the size increases, then correspondingly the efficiency starts decreasing. Also with the increment in the size of cable, the ratio C_1/C_2 decreases for the same value of generator capacitance and the voltage regulation increases and efficiency decreases accordingly.

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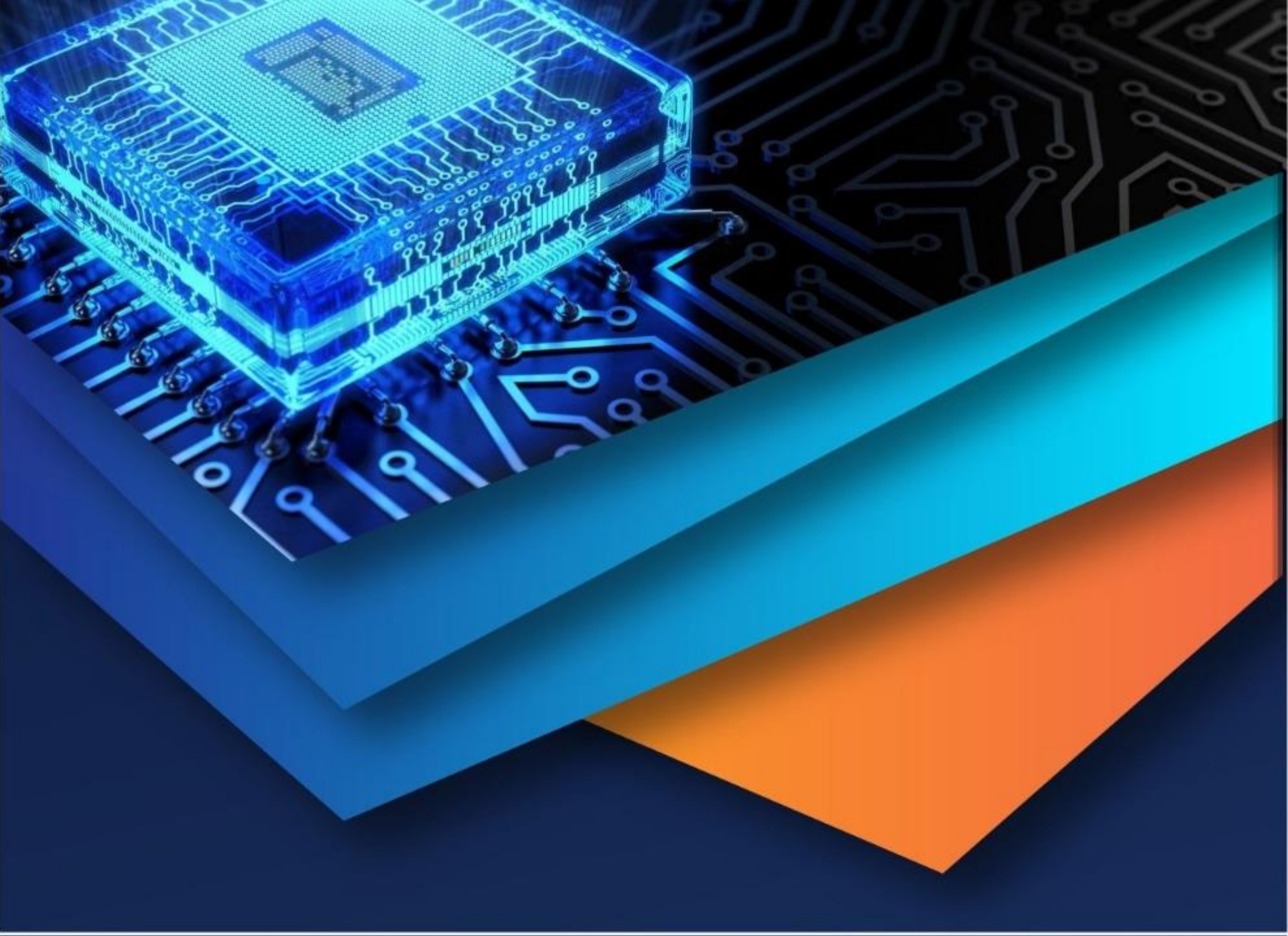

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