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Design and development of prototype model of long duration impulse current generator

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Abstract

The aim of the research is to design and develop a prototype model of long duration impulse current generator. The standard impulse current duration is 4/10 micro seconds and 8/20 micro seconds. Hence an attempt has been made to increase the duration from micro seconds to milliseconds. To achieve this, four different configurations [Equal values of L and C, L and C in ascending order, L and C in descending order, L and C with random values] of impulse current generator were simulated in EMTP/ATP(Electromagnetic Transient Program / Alternative Transient Program) software. Among these four different configurations, the equal values configuration has been identified as an efficient configuration. Then the prototype of the efficient configuration of long duration impulse current generator has been developed.

Keywords: *Impulse current generator, Long duration,*

1. Introduction

An impulse generator is an electrical apparatus which produces very short high voltage or high-current surges. Such devices can be classified as impulse voltage generators and impulse current generators. High impulse voltages are used to test the strength of electric power equipment against lightning and switching surges. High impulse currents are needed to test lightning arresters, fuses, lasers, thermo nuclear fusion and plasma devices.

The surge arrester is a device which is used to protect electrical equipment from over-voltage transients caused by external (lightning) or internal (switching) events. The surge arrester is subjected to the relatively long-lasting currents in the event of discharges from high voltage lines. The surge arrester may be deteriorated in this circumstance. Therefore, the appropriate thermal types tests are introduced to prove thermal stress withstand capability. To perform thermal tests, the long duration impulse current is applied to the arrester [1, 3].

The objectives of the research are to design the long duration impulse current generator circuit. Also four different configurations [Equal values of L and C, L and C in ascending order, L and C in descending order, L and C with random values] of the above designed circuit have been simulated in EMTP/ATP software. After analyzing the output waveforms, equal value configuration has been identified as efficient one and prototype was made.

2. Long duration impulse current

The wave shape should be nominally rectangular in shape. The rectangular waves generally have durations of the order of 0.5 to 5ms, with rise and fall times of the waves being less than ±10% of their total duration. The tolerance allowed on the peak value is ±20% and 0% (the peak value may be more than the specified value but not less). The duration of the wave is defined as the total time of the wave during which the current is at least 10% of its peak value [1]. Figures 1 and 2 illustrate the waveform and circuit diagram of long duration impulse current generator.

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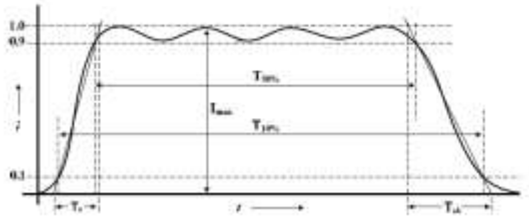
Fig. 1 Waveform of long duration impulse current

Parameters:
Current peak (Ip),
Duration time at 90% of current peak (T_{90}%)
Duration time at 10% of current peak (T_{10}%).

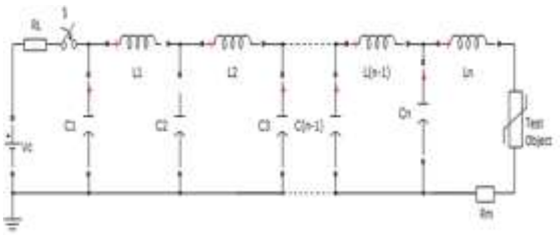
Fig. 2 Long duration impulse current generator

where V_C= *Charging DC voltage source*
R_L = *Current limiting resistor*
C_i = *ith charging capacitor*
L_i = *ith inductor*
R_m= *Matching resistor*

For producing impulse currents of large value, a bank of capacitors connected in parallel are charged to a specified voltage and are discharged through a series RL circuit. Generation of rectangular current pulses of high magnitudes (few hundred amperes and duration up to 5 ms) can be done by charging a number of capacitors in parallel over a relatively long period of time then releasing the stored energy in a short period of time. Usually, 6 to 9 L-C sections will be sufficient to give good rectangular waves [2, 4, 6]. The figure 3 depicts the block diagram of impulse current generator.

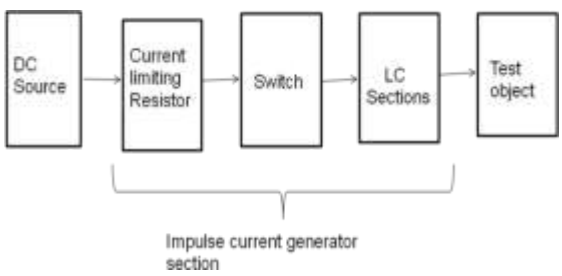

Fig. 3 Block diagram of impulse current generator

3. Mathematical modeling and design

The duration of 90% of a current peak ($T_{90\%}$) can be approximated by the following equation,
$T_{90\%} = 2\ (n-1/\ n)\ \sqrt{LC}$ ----(1)
Where L =total inductances of the generator circuit
C= total capacitances of the generator circuit
n = number of LC circuit sections.
The current peak (I_P) can be approximated by the following equation
$I_P=V_{ch}\ /(2R_m)$ ------(2)
$R_m = \sqrt{L/C}$ ---- (3)
Where V_{ch} is the charging voltage
R_m is the surge impedance of the generator circuit

3.1Equal values configuration

L1 to L12=12mH; C1 to C12=12uF; Number of stages (n)=12
Total Inductance L = 144 mH
Total Capacitance C = 144 uF
$T_{90\%} = 2(n-1/\ n)\ \sqrt{LC}$
$= 2\ \ (11/12)\ \sqrt{(144x10^{-3}\ )\ (144x10^{-6})}$
$=(1.833)(144)(0.000031623)$
$= 0.008347$
$T_{90\%} = 8.347\ mS$
Charging voltage $V_{ch} = 20\ kV$
Surge impedance $R_m = \sqrt{LC}$
$=\sqrt{(144X144)10^{-9}}$
$R_m = 31.622\ \Omega$
Peak current $I_P = V_{ch}\ /(2R_m)$
$= 20x10^3\ /(2\ 31.622)$
$I_P = 316.23\ A$

4. Software Implementation

This section explains the simulated circuits and waveforms for four different configurations. The impulse current generator circuit is simulated using EMTP/ATP software. Figures 4 and 5 illustrate the circuit diagram and waveform for equal values of impulse current generator for the input voltage of 20 kV. Figure 6,7 and 8 illustrates the waveform for equal values of impulse current generator for the input voltage of 10 kV, 1 kV and 200V.

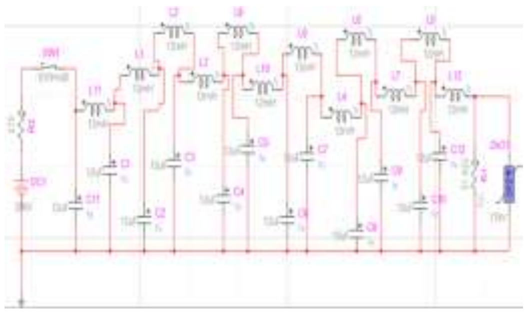
Fig. 4 Circuit diagram for equal values of impulse current generator

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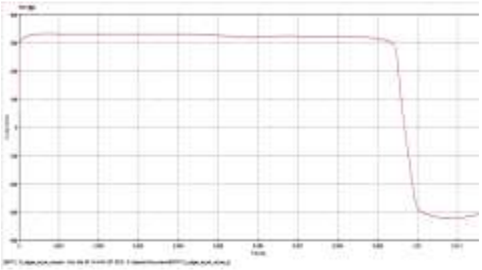

Fig. 5 Waveform for equal values of impulse current generator for the input voltage of 20 kV

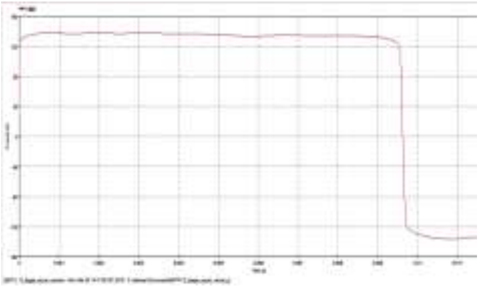

Fig. 6 Waveform for equal values of impulse current generator for the input voltage of 10 kV

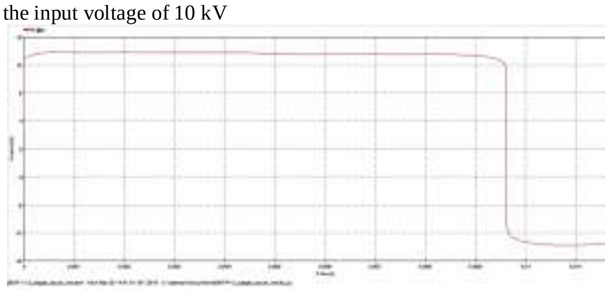

Fig. 7 Waveform for equal values of impulse current generator for the input voltage of 1 kV

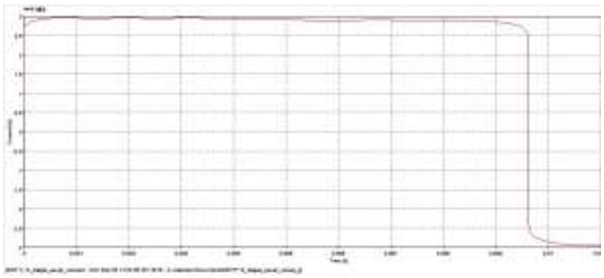

Fig. 8 Waveform for equal values of impulse current generator for the input voltage of 200 V

5. Results

Table 1 give details about the comparison of four different configurations of long duration impulse current generator.

Table 1 Comparison of four different configurations of long duration impulse current generator

Configurations	**Input Voltage (kV)**	**Peak current (A)**		**Impulse current Duration (ms)**	
		Simulated	**Theoretical**	**Simulated**	**Theoretical**
Equal values $L=12mH;C=12uF$	20	310	316.23.	**9.5**	8.347
	10	140	158.11	**9.5**	8.347
	1	14	15.8	**9.5**	8.347
	0.2	3	3.16	**9.5**	8.347
Ascending values L_1 to L_{12}=1mH,2mH….. 12mH; $C_1$to C_{12}=1uF, 2uF…. 12uf	20	320	316.23	5.2	4.52
	10	130	158.12	5.2	4.52
	1	13	15.81	5.2	4.52
	0.2	3	3.16	5.2	4.52
Descending values L_1 to L_{12}=15mH,13mH …..4mH; $C_1$to C_{12}=15uF, 14uF….4uF	20	320	316.23	7.5	6.608
	10	130	158.12	7.5	6.608
	1	13	15.81	7.5	6.608
	0.2	3	3.16	7.5	6.608
Random values L_1=1mH;L_2=1.2mH;L_3 to L_6=6.5mH;L_7 to L_9=7.8mH; L_{10}=13mH; C=0.5uF	20	90	86.81	1.4	1.26
	10	38	43.4	1.4	1.26
	1	3.9	4.3	1.4	1.26
	0.5	0.8	0.868	1.4	1.26

6. Discussion

From the table 1, it is inferred that L and C sections affects the duration of impulse current where as the input voltage affects the amplitude of the impulse current(Ip). Also it is observed that the equal values (configuration 1) is found to have longer duration of 9.5 ms. Hence it is identified as an efficient configuration for long duration impulse current generator.

7. Hardware Implementation

7.1 Diode bridge rectifier

The diode bridge rectifier circuit is shown in Figure 9. The input AC from variac is given to the diode bridge. After rectification of the AC voltage, the DC voltage output is given to the LC sections.

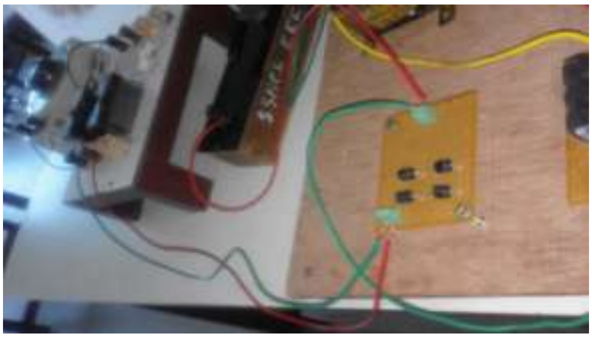

Fig. 9 Diode bridge rectifier circuit

7.2 LC SECTIONS

The LC sections circuit is shown in Figure 10 . The output DC voltage from rectifier circuit is given to six stages LC sections.

Fig. 10 LC sections circuit

7.3 Overall circuit

The overall circuit of long duration impulse current generator is shown in Figure 11. A resistor is connected across the last LC section. A CRO is connected across this resistor to get the output waveform.

Fig. 11 Overall circuit of long duration impulse current generator

7.4 Output waveforms of prototype model of long duration impulse current generator

Case : 1 Un-energized circuit [Ground Line]

The figure 12 depicts the waveform of ground line obtained in the CRO for the un-energized impulse current generator circuit. Even then it is observed that there is some distortion in the ground line of CRO due to the stored charges in the capacitor.

Fig. 12 Waveform of an un-energized circuit

Case : 2 Energized circuit [Charging Capacitor with closed switch]

The waveform of the energized impulse generator circuit with different input voltages is shown in figures 13(a), 13(b) and 13(c). It is observed from the CRO, that the duration of the impulse current waveform is 11ms for all the inputs.

Fig. 13(a) Waveform of an energized circuit with 10 V input

Fig. 13(b) Waveform of an energized circuit with 20 V input

Fig. 13(c) Waveform of energized circuit with 30 V input

Case: 3 De-energized circuit [Discharging Capacitor with open switch]

The waveform of de-energized circuit is shown in figure 14. It is obtained at the instant of opening the SPST switch. There is a slight increase in the amplitude of the waveform has been noticed from CRO.

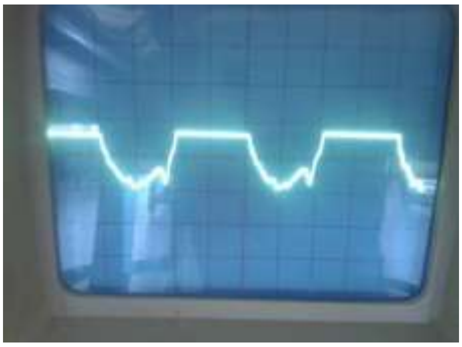

Fig. 14 Waveform of a de-energized circuit

Thus the long duration impulse current waveform for a duration of 11 ms is obtained for the 6 stages of equal values configuration .

8. Conclusions

A long duration impulse current generator circuit is simulated for four different configurations [Equal values, ascending, descending, and random] in EMTP/ATP software. Among these four configurations, equal values configuration is identified as efficient one. And a prototype model of the efficient configuration (Equal values) with six stages is designed and developed. Thus the developed long duration impulse current is used to evaluate test object like surge arrester in aero planes, wind generators (whole system or blades), transmission lines, telephone lines and substations where the surge arrester has to withstand a high voltage.

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