PARAMETRIC ANALYSES ON SINGLE-STAGE IMPULSE CURRENT GENERATOR AND SURGE ARRESTER FOR VIRTUAL HIGH VOLTAGE LABORATORY ENVIRONMENT

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Abstract: This paper presents the development work done for virtualization of a typical high voltage laboratory. The main objective of the paper is to develop an understanding of an impulse current generator's circuit parameters' effect on output current waveforms. The most significant part includes analyses of various internal constraints which cannot be estimated in a high voltage laboratory. Parametric analyses are carried out on the effects of different parameters for impulse current generator along with desired outputs. Application of an impulse current generator for standard tests on metal-oxide surge arresters in the lower range of distribution voltage is examined.

1 INTRODUCTION

Computer simulation plays an important role in engineering course teaching. Nowadays, a variety of softwares like MATLAB, AutoCAD, and PSCAD are available to simulate electrical circuits; but fail to provide the actual feel of a physical laboratory. Also, most of these softwares come with commercial license at a high price, thus restricting their availability. Virtual high voltage laboratory (VHVL) is a web based [1-3] application which not only serves as a good tool for teaching but also enables a student to understand the influence of the circuit parameters on the output of the various experiments. VHVL can also act as a guide for the testing engineer to arrive at the values of the desired parameters to get a standard output waveform as listed in Table 1 [4]. Also, VHVL prompts user to achieve the standard Impulse Current parameters by providing facility to vary the circuit parameters through graphical user interface (GUI).

Table 1: Time parameters with tolerances for some standard impulse current waveforms

Type of Impulse	Front Time T_f (µs)	Tail Time T_t (µs)
Impulse Current	4.0 ± 10%	10.0 ± 10%
Impulse Current	8.0 ± 10%	20.0 ± 10%

Figure 1 presents the scheme of VHVL which constitutes home page links for various experiments. By selecting a particular experiment from the list, GUI prompts input values. After submitting the input values mathematical analyses (algorithm for impulse current generator (ICG) circuit in this particular case) is run and displays output waveform with the help of JAVA programming. So, present paper deals with the parametric analyses of impulse current generator (ICG) and impulse testing on metal-oxide surge arrester (MOSA).

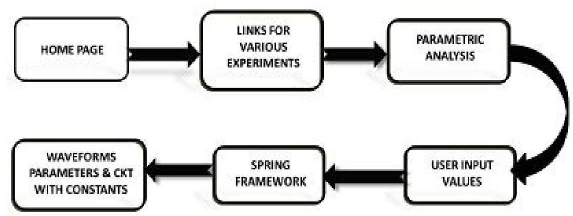

Figure 1: Proposed Scheme of VHVL

2 IMPULSE CURRENT GENERATION

The basic circuit for ICG [5] with capacitive storage is shown in Figure 2. (R, L) are wave-shaping resistance and inductance, (R_l, L_l) are resistance and inductance of the test object. The wave-shape of impulse current is adjusted by adjusting the

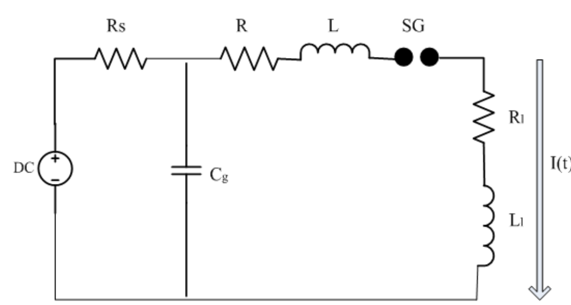

Figure 2: Typical circuit for generation of impulse current

value of R and L. The output impulse current waveform can be un-damped or under-damped sinusoidal in nature and has a front time (4µs or 8 µs) and tail time (10 µs or 20 µs) which depends on the circuit parameters. The output impulse waveform depends on the magnitude of the total resistance ($R+R_l$). If the magnitude of the resistor is large, energy is lost as heat and thus a decrease in the magnitude of the output pulse is achieved. Damping is a way to reduce oscillation in a circuit which depends on the degree of damping coefficient (discriminant, D). Now, Laplace transformed equation for the circuit shown in Figure 2 is:

$$s^2 + \left(\frac{R'}{L'}\right)s + \frac{1}{L' \times C_g} \quad (1)$$

The relation between circuit parameters for producing the above mentioned oscillations are:

i) for undamped oscillations (for D>0),

$$\frac{R'^2}{L'} > \frac{4}{C_g} \quad (2)$$

Solution for this case is given as

$$I(t) = I_0[e^{-\alpha t} - e^{-\beta t}] \quad (3)$$

here,

$$I_0 = \frac{V}{p \times L'} \quad (4)$$

$$p = (\alpha - \beta) \quad (5)$$

α and β are the roots of Eqn. 1.

ii) for underdamped oscillations (for D<0),

$$\frac{R'^2}{L'} < \frac{4}{C_g} \quad (6)$$

Solution for this case is given as

$$I(t) = I_0 \times e^{-\alpha t} \times Sin\left(\frac{\sqrt{-D}}{2}t\right) \quad (7)$$

here,

$$I_0 = \frac{V}{q \times L'} \quad (8)$$

$$q = \frac{\sqrt{-D}}{2} \quad (9)$$

$$\alpha = \frac{R'}{2L'} \quad (10)$$

$$D = \frac{R'^2}{L'^2} - \frac{4}{L' \times C_g} \quad (11)$$

where: I(t) = output current (kA)
C_g = generator capacitance (μF)
I_0 = peak current (kA)
R' = $R+R_l$
L' = $L+L_l$

It is basically a series R-L-C circuit. Damping is a way to reduce oscillations in a circuit. It depends on the degree of damping coefficient. From Figure 3, it is evident that, when there are no oscillations, the circuit is said to produce over damped oscillations. On the other hand, when the oscillations persist and gradually fade out, the circuit is said to produce underdamped oscillations. The relation between circuit parameters for producing the above mentioned oscillations are given in Equations 2 and 6.

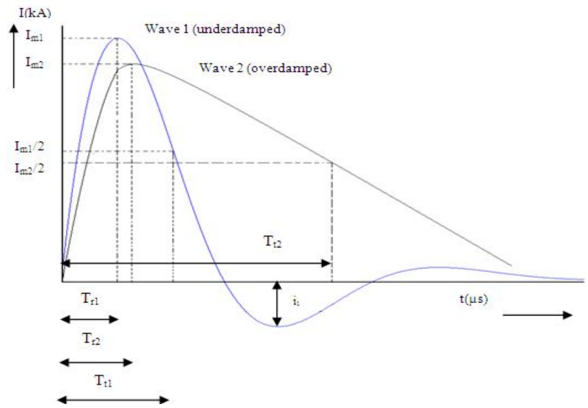

Figure 3: Standard waveform of impulse current generator

where: T_{r1} and T_{r2} = time-to-rise, T_{t1} and T_{t2} = time-to-fall (or time to 50% of peak current) and i_1-undershoot (u.s.).

2.1 Algorithm - impulse current generation

The analysis in previous section allows understanding on how to obtain the impulse current waveform, if the circuit parameters are provided. An algorithm for the implementation of this on VHVL is developed [10]. The flowchart shown in Figure 4 explains the algorithm of parametric analyses for impulse current generation. The first task is to track peak current of waveform, which is accomplished by comparing present and previous sampled values, which are continuously stored. At an instant when previous value is greater than the present value, the sample data of previous value is stored as the value of peak current. After tracking peak current, rise time to peak current (front time, T_f) and time to 50% of peak current (tail time, T_t) are determined. This provides waveform parameters listed in Table 1. Finally, a plot between current vs. time with front and tail time value is displayed with the help of JAVA programming.

Development of VHVL requires detailed mathematical analyses of the involved electrical apparatus in order to arrive at algorithms to be implemented in a web based software module. Proceeding in this direction, mathematical analyses are followed by design of algorithms. These algorithms are implemented in Java to enable web based access to the Virtual High Voltage Laboratory [10].

3 IMPULSE CURRENT GENERATOR APPLICATION

MOSAs are equipments used in power systems protection against several kinds of surges. In this way, they effectively contribute for increasing the

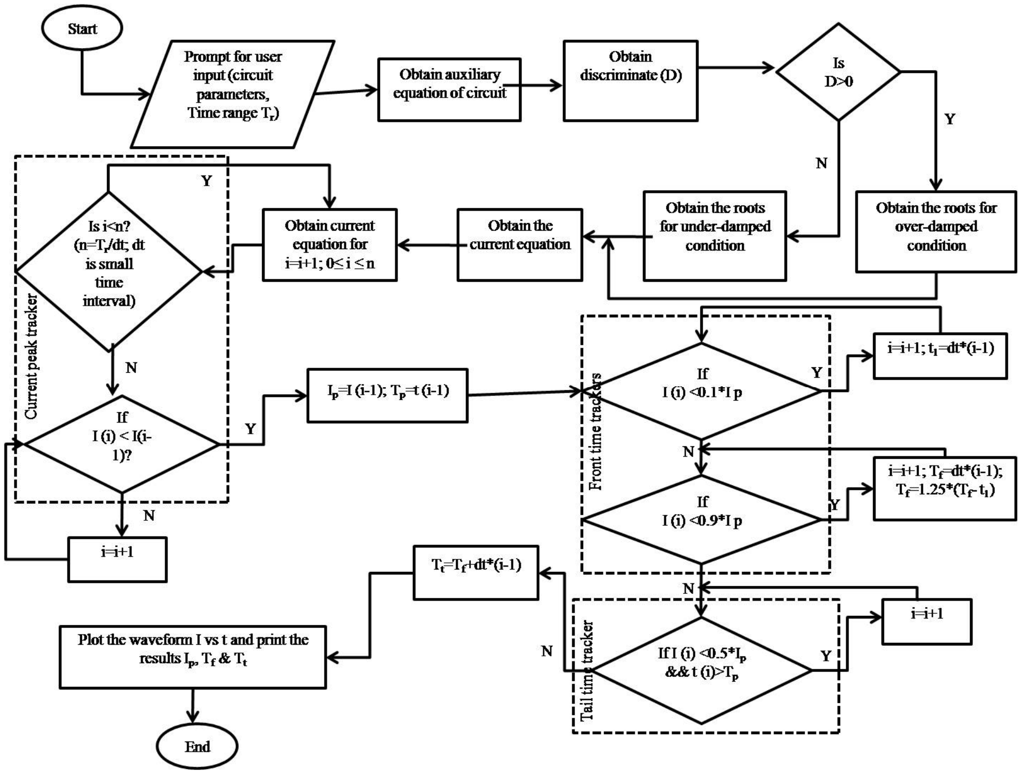

Figure 4: Algorithm for generation and parametric analyses of impulse current generation [Y = Yes, N = No]

reliability, economy and continuity of system protected by them. Due to the importance of MOSA for the electrical systems and the need of accurate representation, several models have been proposed with the aim to provide tools for studies involving: insulation coordination, and energy absorption capability.

Insulation coordination in electric power systems requires knowledge of the voltage stress waveshapes. MOSA are useful tools for impulse voltage stress limitation. The evaluation of these residual voltages is necessary when accurate insulation coordination is wanted. In this paper simulation method is adopted for obtaining circuit models of MOSA evaluating their performances with several impulse front times, as shown in [6].

3.1 Surge Arrester equivalent model

IEEE working group 3.4.11 on MOSA modelling [7] has reviewed a number of ways to model MOSA (The simulation tests are carried out on two samples of two types of zinc oxide varistors (type A and type B) with different physical and electrical characteristics, as explained in [6].) A typical model

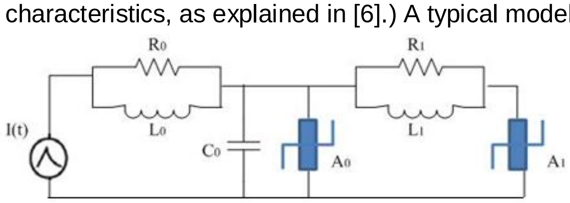

Figure 5: Model of a Typical Surge Arrester

is shown in Figure 5, which gives an appropriate voltage response for a current surge which has a time-to-crest anywhere in the range of 0.5µs to 45 µs. It is based on the fitting of the rated residual voltages obtained from the MOSA models, to kA standard lightning current impulses.

Present work is carried out for the ICG testing analyses of residual voltage for IEEE MOSA model [8], which is composed of two sections of nonlinear resistance, usually designated by A_0 and A_1, which are separated by a R-L filter as shown in Figure 5. An inductance L_0, which represents the inductance associated with the magnetic field in the arrester. The capacitor C_0 represents the capacitance between the arrester terminals. The elements R_1 and L_1 compose the R-L filter that represents the dynamic behaviour of the MOSA. The empirical formulae which are given by IEEE working group for identification of SA parameters given in [6] are as follows:

$$C_0 = 100 \times \left(\frac{n}{d}\right) \tag{12}$$

$$L_0 = 0.2 \times \left(\frac{d}{n}\right) \tag{13}$$

$$L_1 = 15 \times \left(\frac{d}{n}\right) \tag{14}$$

$$R_0 = 100 \times \left(\frac{d}{n}\right) \tag{15}$$

$$R_1 = 65 \times \left(\frac{d}{n}\right) \tag{16}$$

where n = number of parallel columns of metal oxide in SA, d = estimated height of SA.

4 RESULTS AND DISCUSSION

4.1 Impulse current generation

The task is to get a standard Impulse Current waveform of 4/10 μs and 8/20 μs. An analysis is done with variation of R and typical result is shown in Figure 6. As R increases front time and peak current decrease but tail time also increases slightly. For the same parameters undershoot is more and peak current is also high to get an 8/20 μs pulse but low for a 4/10 μs pulse which is seen in Figure 6. This is because of loop inductance provided by the circuit as summarised in Table 2.

Another analysis is carried out by changing the inductance L from 1 μH to 5 μH; the output parameters front and tail time is increased but current decreases with higher undershoot as shown in Figure 7. This is because, increase in inductor value does not allow current to increase but provides increment in front and tail time. But in a slight increment in generator capacitance produces a waveform nearly equivalent to standard waveform of 8/20 μs with increment in peak current and less undershoot. Table 3 summarizes the waveforms for Impulse Current variation with inductor L.

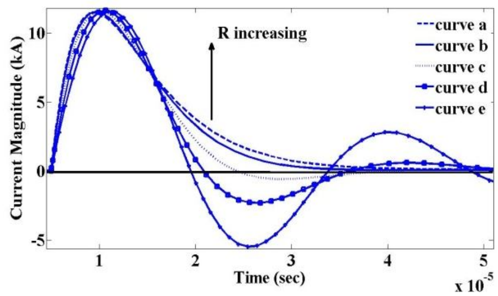

Figure 6: Variation of impulse current waveform with R

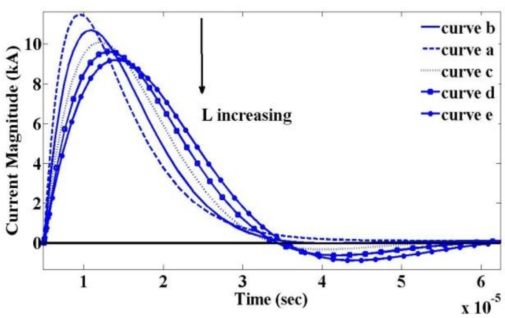

Figure 7: Variation of impulse current waveform with L

where: R = Waveshaping resistance of impulse current generator circuit

L = Waveshaping inductance of impulse current generator circuit

Table 2: Variation of impulse current waveform with R (Charging Voltage, V = 10kV; C_g=10μF, R_l=0.1Ω, L_l=1μH)

Curve	R (Ω)	L (μH)	T_f (μs)	T_t (μs)	I_p (kA)	% o.s.
a	0.8	1	4.32	12.07	11.49	-
b	0.7	1	4.73	11.80	11.53	-
c	0.5	1	4.87	11.40	11.56	5.80
d	0.3	1	5.06	11.25	11.60	15.46
e	0.1	1	6	11.36	11.64	47.36

Table 3: Variation of impulse current waveform with L (Charging Voltage, V=10kV; Cg=10μF, R_l=0.1Ω, L_l=1μH)

Curve	R (Ω)	L (μH)	T_f (μs)	T_t (μs)	I_p (kA)	% o.s.
a	0.8	1	4.32	12.07	11.49	-
b	0.8	2	5.09	14.25	10.70	0.18
c	0.8	3	6.75	16.20	10.09	3.20
d	0.8	4	7.95	18.30	9.62	6.40
e	0.8	5	9.43	19.63	9.20	9.50

4.2 Surge arrester testing analyses

Impulse currents of waveshape 4/10 μs and 8/20 μs are applied to analyze the behaviour of residual voltage and impulse current of SA model. The voltage which appears across SA during discharge current flow is referred as residual voltage. Present paper discusses the residual voltage behaviour for four types of SAs (parameters as shown in Table 4) [6] when impulse current waveform of 7.85/20.93 μs and 4.15/11.34 μs are applied. In Figure 8 waveforms are shown for residual voltage with 7.85/20.93 μs testing impulse current. The output values obtained from the surge arrester parameters are summarised in Table 5. Now high impulse current of 4.15/11.34 μs are applied to the IEEE model of SA with estimated parameters. In Figure 9 waveforms are shown for residual voltage with 4.15/11.34 μs impulse current. The output values obtained from the surge arrester parameters are summarised in Table 6. It is possible to say that, IEEE model can represent the behaviour of the SA for other kind of fast transients too [9].

Table 4: Estimated parameters of Surge Arrester for IEEE model

Arrester	R_0 (Ω)	L_0 (μH)	R_1 (Ω)	L_1 (μH)	C_0 (nF)
A_1	0.5	0.173	0.05	0.752	91.72
A_2	0.724	0.263	8.675e-6	0.529	76.74
B_1	0.5	0.366	5.586e-6	5.706	78.41
B_2	0.5	0.474	5.198e-6	5	84.36

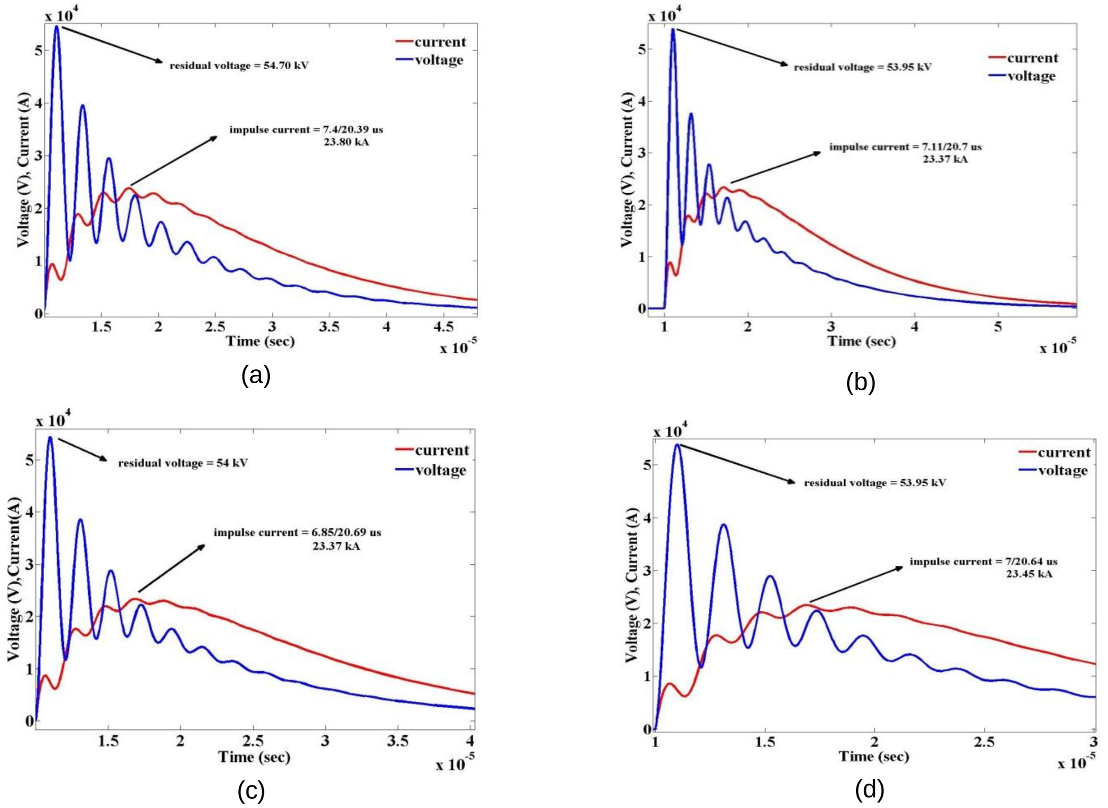

Figure 8: Residual voltage waveforms for a lightning current impulse (7.85/20.93 μs) applied to the (a) arrester A_1 (b) arrester A_2 (c) arrester B_1 (d) arrester B_2

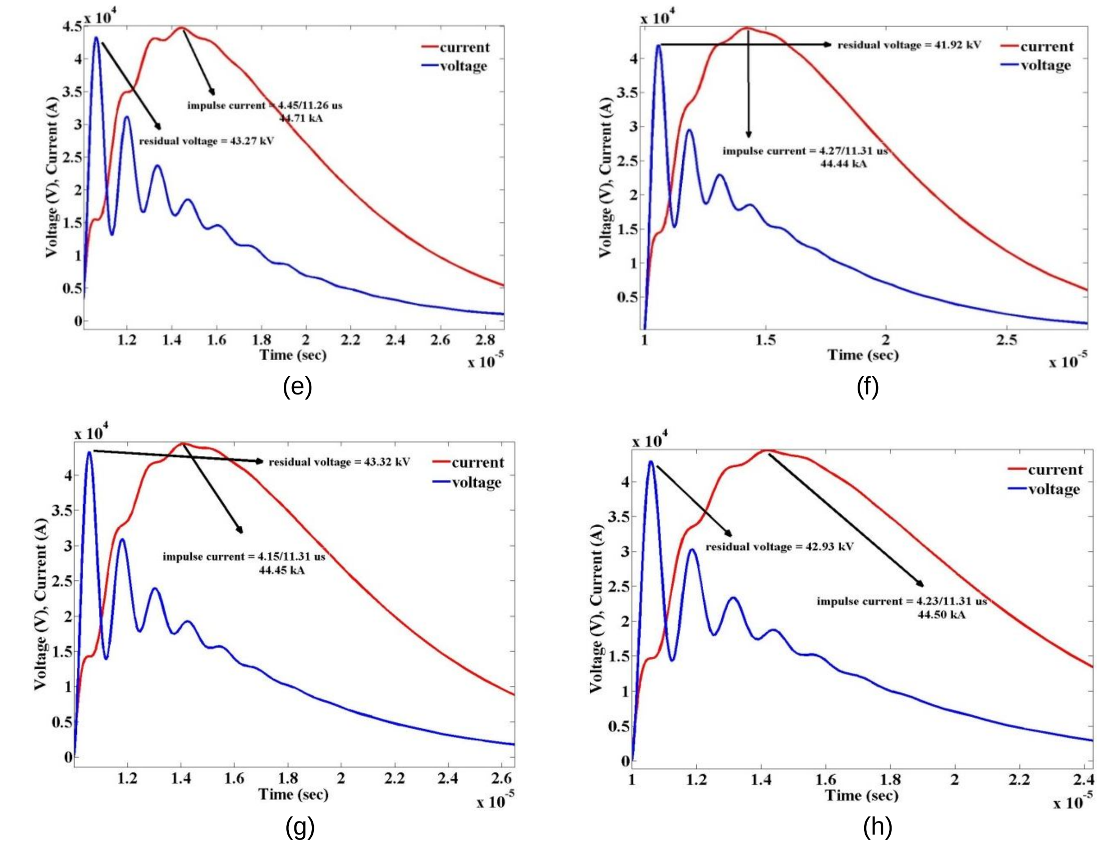

Figure 9: Residual voltage waveforms for a lightning current impulse (4.15/11.34 μs) applied to the (e) arrester A_1 (f) arrester A_2 (g) arrester B_1 (h) arrester B_2

Table 5: Variation in residual voltage (V_r) with arresters for 7.85/20.93 µs Impulse Current

Arrester	$V_{r(peak)}$ (kV)	I_p(kA)	T_f(µs)	T_t(µs)
A_1	54.70	23.80	7.40	20.39
A_2	53.90	23.45	7	20.64
B_1	54	23.37	6.85	20.69
B_2	53.95	23.37	7.11	20.70

Table 6: Variation in residual voltage (V_r) with arresters for 4.15/11.34 µs Impulse Current

Arrester	$V_{r(peak)}$ (kV)	I_p(kA)	T_f(µs)	T_t(µs)
A_1	43.27	44.71	4.45	11.26
A_2	41.92	44.44	4.27	11.31
B_1	43.32	44.45	4.15	11.31
B_2	42.93	44.50	4.23	11.31

V_r = residual voltage, I_p = peak impulse current

5 CONCLUSION

The mutual coordination between present work and VHVL is to provide a remote access of virtual laboratory with accomplished parametric analyses, which is most important for the learning perspective.

This paper outlined and illustrated a MATLAB model to generate standard output impulse current waveforms of 4/10 µs and 8/20 µs using parametric analyses which leads to the simulation analyses on impulse current testing of surge arresters. The focus is placed on studying the change in the waveforms during a simulation test on surge arresters. The waveshapes of residual voltage of the varistors of same type present a similar behaviour. An increment of peak residual voltages with relation to the impulse current is observed. This behaviour is expected and desired for such dynamic SA model.

6 ACKNOWLEDGMENTS

Authors acknowledge the support of this work by Ministry of Human Resource development (MHRD), Government of India (GoI).

REFERENCES

[1] Christof Rohrig and Andreas Jochheim, “The Virtual Lab for Controlling Real Experiments via Internet,” Proceedings of the 1999 IEEE International Symposium on Computer Aided Control System Design Kohala Coast-Island of Hawaii, Hawaii, USA, 1999.

[2] B. Hemalatha, Dipak Kumar Pal and Swati Sinha, “A web based simulator for Impulse Voltage Generation,” First International Conference on Industrial and Information Systems, ICIIS 2006, 8-10 August 2006, Sri Lanka.

[3] Prashant Kr. Agrawal, Chandan and N. K. Kishore, “Development of Virtual Impulse Laboratory,” IEEE Conference on Industrial Electronics and Applications (ICIEA-2006), Singapore.

[4] IS 2071, Indian Standard specifications for “High Voltage Test Techniques,” Bureau of Indian Standards, New Delhi, November 1996.

[5] N.K. Kishore, P. Bhakta and R.K. Sharan, “On the Development of Impulse Current Generator,” International Conference on Electromagnetic Interference and Compatibility, (INCEMIC- 1997:7A-1), Bangalore.

[6] G. R. S. Lira, D. Fernandes Jr. and E. G. Costa, “Parameter Identification Technique for a Dynamic Metal-oxide Surge Arrester Model,” the International Conference on Power Systems Transients (IPST2009) in Kyoto, Japan June 3-6, 2009.

[7] IEEE working group 3.4.11, application of surge protective devices subcommittee surge protective devices committee, “Modelling of Metal Oxide Surge Arresters,” Transaction of Power Delivery, Vol. 7, No. 1, January 1992.

[8] M. Modrusan, “Tests on High Voltage Metal Oxide Surge Arresters with Impulse Current,” 4th International Symposium on High Voltage Engineering, 5-9 September, 1983, Athens-Greece.

[9] A. Bayadi, N. Harid, K. Zehar and S. Belkhiat, “Simulation of Metal Oxide Surge Arrester dynamic behaviour under fast transients,” The International Conference on Power System Transients – IPST 2003 in New Orleans, USA.

[10] Virtual High Voltage Laboratory (VHVL) web site, “http://vlab-ee1.iitkgp.ernet.in/reg.jsp”, last accessed: April 10, 2011.