EVALUATION OF CIRCUIT PARAMETERS OF MULTISTAGE IMPULSE GENERATOR BY PARTICLE SWARM OPTIMIZATION

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ABSTRACT

Standard impulse waveform have similar characteristics as that of lightning strike and can be used for testing the strength of electrical equipment. For producing high voltage impulses Marx generator is the most popular and is most widely used method. This paper presents a 45KV, 5 stage Marx impulse generator, generates 1.2/50µsec waveform. In this paper, particle swarm optimization technique has been used to access R1 and R2 and best, worst cases has been simulated for both rise and tail time confined to ±30% and ±20% respectively. The case also has been simulated where, parameters of single stage Marx generator can be used to get identical waveform for 5 stage impulse generator in terms of peak voltage, rise and tail time with minimized error.

Keywords— Marx generator; rise time; tail time; particle swarm optimization; R1; R2; multistage impulse generator

I.INTRODUCTION

Electrical equipment must be capable of withstanding overvoltages during operation. Equipments are subjected to withstand tests on which the voltage applied is about twice the normal voltage, but which is less than the breakdown voltage. Impulse generators for high voltage testing has been built up to now almost exclusively in the well known 'Marx circuit'. The basic principle of this circuit operation is rapid charging of capacitors in parallel where by spark gaps are used to make them switched in series for discharging in the waveshape circuit. Lightning voltage can be represented by a doubly exponential curve that rises quickly to the peak and falls comparatively slowly to zero values with respect to time axis. For different waveforms, the value of α and β control the front and tail times of the wave respectively. Value of α is generally less than that of β. An impulse voltage is a unidirectional voltage which, without appreciable oscillations, rises rapidly to a maximum value and falls more or less rapidly to zero Fig.1.

Usually the wave front time is specified as 1.25 times (t4 – t3), where t4 is the time for the wave to reach to its 90% of the peak value and t1 is the time to reach 10% of the peak value.

The nominal wave tail time is measured between the nominal starting point $t0$ and the point, t2 on the wave tail where the voltage is 50% of the peak value i.e. wave tail time is expressed as ($t2 - t0$).

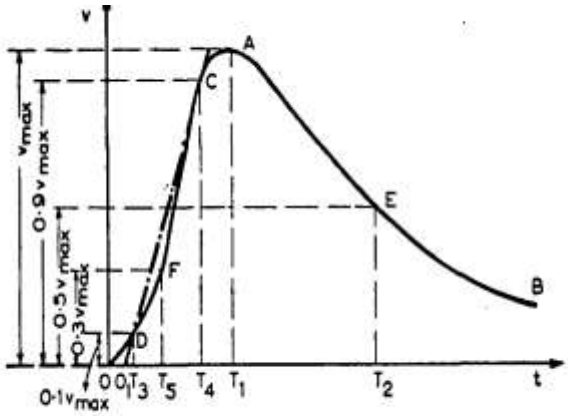

Fig 1. General impulse waveform

A popular standard impulse wave shape is specified as 1.2/50 µ sec. wave i.e. a wave front of 1.2 µsec. and a wave tail of 50 µsec. A tolerance of not more than ±30% on the duration of the wave front and 20% on the time to half value on the wave tail is allowed. The wave is completely specified as 100 kV, 1.2/50 µsec, where 100 kV is the peak voltage value of the wave [6].

Particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO is metaheuristic as it makes few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions.

In this work, parameters of single stage impulse generator i.e. R1 and R2 are optimized and then used in the simulation circuit. Aftermath, a suitable combination of R1 and R2 has been chosen while taking care of the minimized error percentage of rise and tail time.

An economic limit of the charging voltage Vo is, however, a value of about 200 to 250 kV, as too large diameters of the spheres would otherwise be required to avoid excessive inhomogeneous field distributions between the spheres [6]. Expressions are derived without the use of simplifying assumptions that will give the mathematical parameters α and β for any specified double-exponential impulse waveform [10]. One of the major changes in the past was the introduction of reference measuring system in the high voltage measuring technique due to the increasing demand on traceable measuring uncertainty, but finally the recommended method was the comparison between the impulse voltage divider to be calibrated with a reference impulse voltage divider [18]. A substantial decrease in efficiency compared with the standard lightning impulse occurs in the production of very short-tailed lightning impulses by means of the Marx generator. A modification of one of the typical Marx circuit configurations, i.e. the series connection of a sphere gap and an inductance to the tail resistance, is suggested here to overcome this drawback [9]. Voltage multiplication devices, such as the Marx and similar inductance circuits, have been operated at high recurrence frequencies and used as voltage sources for X-ray

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generation. The merits of this arrangement and the problem of obtaining optimum X-ray efficiency are discussed in relation to the design of voltage network and X-ray tube [19]

II.METHODOLOGY

2.1 Circuit Considered

The basic circuit, which is considered in the analysis is 'MARX GENERATOR', which is a series parallel combination of resistors and capacitors. As in this analysis multistage Marx circuit is also taken in account, a single stage of a basic Marx generator has been cascaded. In this work, multistage parameters are also evaluated based on some formulations [13] and standard impulse waveform has been simulated for these values of resistors.

The waveshaping circuit is shown below in fig.2 which is being used in multistage impulse generator. The circuit consists of a charged capacitor, which is discharged into a network of resistor and a test object, consequently an impulse has been got as an outcome.

In this work, C1 and C2 have been taken fixed as 0.1μF and 0.01μF.

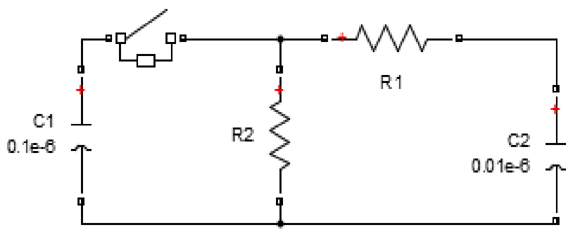

Fig 2. Waveshaping circuit

In this work, capacitor C1 has been charged by an A.C. supply followed by a transformer having turns ratio 1000:1, a diode rectifier, an R-C filter, and capacitor is charged to D.C. voltage which is then discharged into the five cascaded stages of waveshaping circuits. The block diagram of multistage impulse generator being in consideration is shown in below fig. 3.

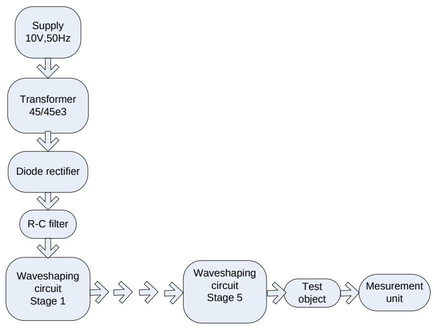

Fig 3. Multistage impulse generator circuit block diagram

2.2 Optimization used

Reiterating, the optimization used in this paper is the particle swarm optimization' in which a code has been run, minimizes the rise and tail time, being calculated in the objective function, gives an outcome, a set of two resistors which are taken globally in the worked algorithm. Here the optimization code simulates the circuit being considered, and compares rise and tail time, generated during simulation to the standard time parameters in the error function itself and minimizes the error function consequently, thus optimization works on. The flowchart for particle swarm optimization has been drawn below in fig 4.

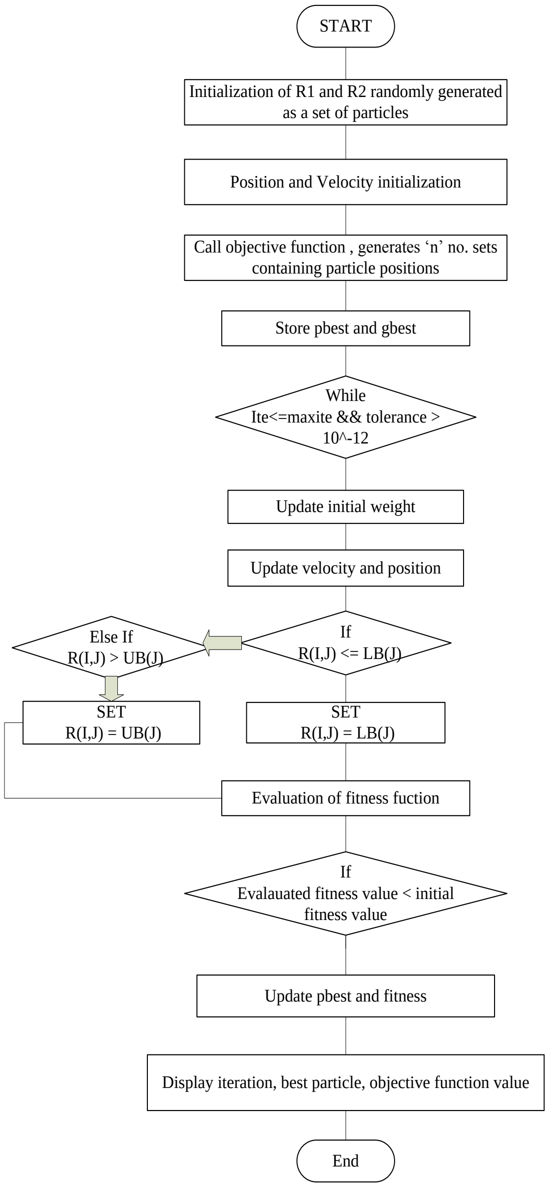

Fig 4. Flowchart for particle swarm optimization

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III.DESIGN AND SIMULATION

In analyzing the circuits, the relationship of the constants is considered also from the point of practical importance. The available capacitance of the generator is frequently a limiting factor both theoretically and economically. In making the tests the relation of the load to the generator capacitance, *C2/C1*, as well as the relation of the series resistance to the shunt resistance, *R1/R2* must be considered if the proper voltage and wave shape are to be applied to the test piece.

In this work, C1/C2 ratio has been taken 10.

3.1 An impulse wave formulation

$$a = \frac{1}{R1.C1.R2.C2} \qquad (1)$$

$$b = \frac{1}{R1.C1} + \frac{1}{R1.C2} + \frac{1}{R2.C1} \qquad (2)$$

$$\alpha 1, \alpha 2 = \frac{b \mp \sqrt{b^2 - 4a}}{2} \qquad (3)$$

$$Vp(t) = \frac{1}{R1.C2.(\alpha 2 - \alpha 1)}.Vo\ [\exp(-\alpha t) - \exp(-\beta t)] \qquad (4)$$

Efficiency, $\eta = V_p/V_o$

Where Vp is the peak output voltage.

Equation(4) is a formulation of an impulse wave, where Vo is the charging voltage. Tail and front time are represented in the wave by α and β which are function of R1, R2, C1, C2 itself.

3.2 How the optimization algorithm works

As the optimization algorithm gives two values of resistors, these values of circuit parameters help simulating the circuit manually thus giving a set of rise and tail time. Optimization algorithm has been run more or less eleven times, during every run the aforesaid process is repeated, thus giving eleven sets of rise and tail times, out of which a best set has been taken for the analysis of multistage Marx generator.

3.3 Calculation of multistage impulse generator parameters

In each case, charging capacitor and test capacitance values has been taken constant, and in the ratio of 10. After getting R1 and R2 with the help of optimization, multistage parameters also have been calculated based on the formulations [13].

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In this work one thing is to be noted that the particular charging voltage value is constant irrespective of the charging capacitance value for both single and multistage Marx generators, and the peak output voltage is constant for a given C1/C2 ratio.

IV.SIMULATION RESULTS AND WAVEFORMS

4.1 At first, single stage Marx generator has been considered, for which total eleven cases have been accessed, these are given in table 1.

TABLE 1. Errors calculated for rise and tail times for both single and multistage impulse generator for each outcome of PSO.

			Single stage		**Multistage**	
No. of runs	**R1**	**R2**	**Error (%) T1**	**Error (%) T2**	**Error (%) T1**	**Error (%) T2**
1.	58.94	501.41	20	17.96	10.83	14.72
2.	58.81	427.50	15	14.32	10	0.36
3.	52.28	416.44	2.5	15.38	-8.4	-3.24
4.	58.60	491.94	0.833	0.26	10.83	13.86
5.	51.50	406.28	1.66	1.7	-8.4	6.08
6.	49.53	419.80	-5	2.4	-10	7.58
7.	47.98	491.94	0	0.26	4.16	4.68
8.	48.32	507.61	0	0	-2.5	7.8
9.	49.54	488.22	1.66	18.82	6.66	7.36
10.	52.14	410.60	0	1.2	1.66	3.42
11.	52.75	424.30	2.5	5.44	1.66	1.08

4.2 Having looked upon table 1, it is observed that although a minimum error has been got for single stage impulse generator on 8th run but at the same time parameters of multistage impulse generator error has not been minimized, so discarding this set we can take 10th run in which error for both single and multi stage Marx generator is minimum.

4.3 The convergence characteristic during 10th run has been shown in below fig 4.

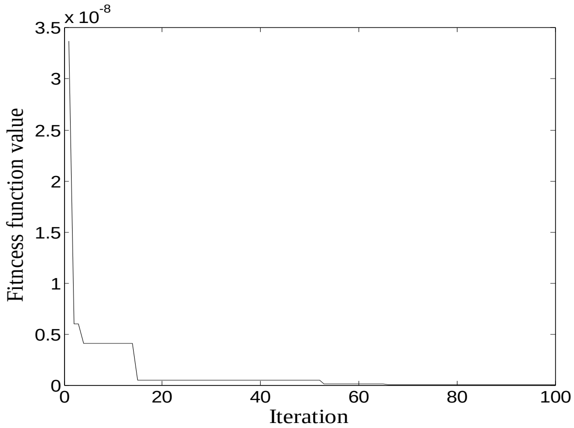

Figure 3. PSO convergence characteristics for the best run

4.4 Best and worst case for getting rise time within limits has been simulated in table 2.

TABLE 2. Simulated cases for rise time

	R1	R2	T1	T2	Error (%),T1
Best case	52.14	410.60	1.20	50.60	0
Worst case	58.94	501.41	1.44	58.98	20

4.5 Best and worst case for getting tail time within limits has been simulated, given in table 3.

TABLE 3. Simulated cases for tail time

	R1	R2	T1	T2	Error(%),T2
Best case	48.32	507.61	1.20	50.01	0
Worst case	49.54	488.22	1.22	59.41	18.82

4.6 The parameters which have been got for optimized error, a set of rise and tail time has been simulated, given in table 4.

TABLE 4. Case comparison of best case for single and multi stage impulse generator

R1	R2	T1(single)	T2(single)	T1(multi)	T2(multi)
52.14	410.60	1.20	50.60	1.18	51.71

4.7 In case of single stage impulse generator values for R1 and R2 has been taken 52.14 ohms and 410.60 ohms respectively. A 1.2/50µsec. waveform has been simulated, shown in below fig.5.

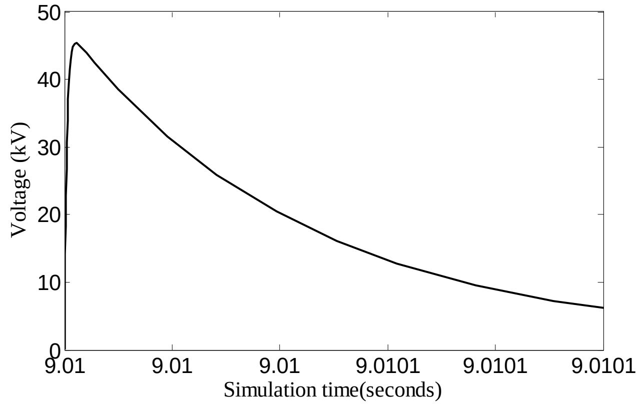

Figure 5. Single stage impulse waveform, 45KV, 1.2/50µsec.

4.8 In case of multistage impulse generaor, parameters are calculated, the charging voltage at the first stage has also been taken care, so that the charging voltage follows the formulations [13], consequently a similar waveform has been simulated having peak voltage as 45 KV, 1.2/50µsec. waveform, shown in below fig.6.

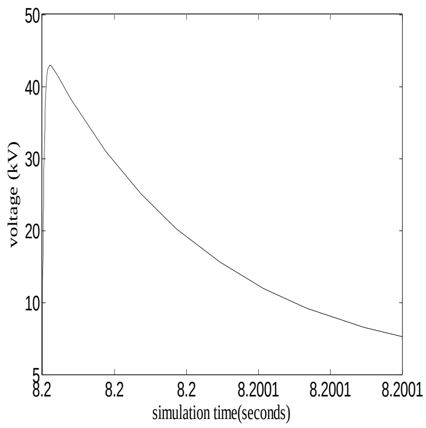

Figure 6. Multistage impulse waveform, 45KV, 1.2/50µsec.

V.CONCLUSIONS

It is attempted to get the circuit parameters with the help of particle swarm optimization. The outcomes of PSO are successfully verified by the MATLAB simulation.

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