SCHEMES OF HIGH-POWER PULSED GENERATORS WITH INDUCTIVE STORAGES ON STEPPED LINES

V.S. Gordeev, V.S. Bossamykin

Russian Federal Nuclear Center, All-Russian Scientific Research Institute of Experimental Physics, 37Mira prosp.,607190 Sarov (Arzamas-16), Nizhni Novgorod region, Russia

Abstract

The paper describes some multistage pulse generator designs based upon homogeneous transmission lines of equal electrical length T_0, their impedance varied stepwise. The energy is initially stored as magnetic field by all the generator stages, while it is also stored by some of them as electrical energy. Upon triggering the switch connecting the high-voltage electrode of charged lines to the grounded generator frame, both magnetic and electrical energies would become wholly concentrated at the generator output due to wave effects. Ideally, for any number of stages, the resistive load connected in parallel to the current opening switch is where a square-shaped voltage pulse of $2T_0$ width would be generated, whose peak value may be considerably higher than the generator charging voltage.

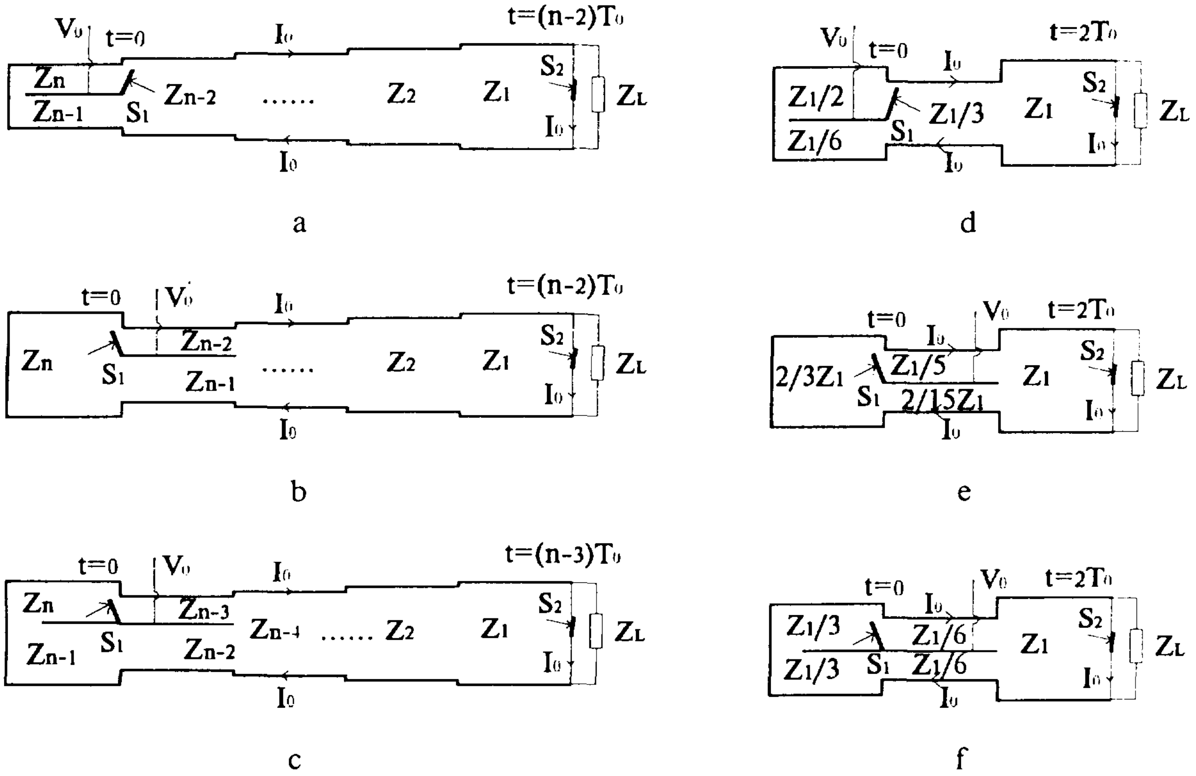
Introduction

Most recently, there have been quite a big variety of design concepts for high-voltage pulse generators considered, which basically use homogeneous transmission lines of one and the same electrical length. These designs have the impedance varied stepwise from stage to stage, therefore we call them stepped-line generators. The energy initially stored by the many stages is to become concentrated at the generator output due to wave effects upon triggering the switch. With the line impedances being in specific proportion, the whole of the energy can be delivered to a matched resistive load with a square-shaped voltage pulse to be generated there. The output pulse width is independent of how many stages and overall dimensions the generator has, but it is only determined by the double electrical length of an individual stage. Simultaneously, there occurs the increase in voltage or current due to wave effects. Some concepts have been suggested which can provide a higher pulse power value. Theoretical and experimental studies on high-voltage nanosecond stepped-line generators carried out by RFNC-VNIIEF are summarized in refs. [1-5].

Like any other transmission - line generator reported, these devices may be two types - generators having initial energy stored capacitively and those with inductive energy storage, depending on whether the initial energy is stored only as magnetic or electrical field. Ref. [1] addresses two generator designs using stepped-line inductive storage with whatever number of stages. The magnetic field energy is made to build up through the generator's length by wave effects occurring upon triggering the input current opening switch. This is followed by significant current increase towards the generator output end. Ref. [3] describes a generator design, in which the stepped-line magnetic energy is brought up to the load as a result of square-shaped voltage pulse being supplied externally from a supplementary source. Wave effects are observed to cause substantial increase in the pulse voltage. This paper addresses just a few of the generator designs with inductive storage considered, the case specifically featured by initial energy being stored in the inner generator volume both magnetically and electrically at a time. Therefore, these devices can be referred to as combined energy storage generators. All the generator circuits are capable of increasing voltage.

Generator configurations

Fig. 1 (a, b, c) shows three stepped-line generator circuits based on combined energy storage. Generally, the generator is formed by "n" homogeneous transmission lines having the same electrical length T_0. The lines are numbered consecutively starting from the generator output, with their impedances Z_1, Z_2, Z_3 . . . , Z_n respectively. The total number of stages, "n", for the a, b and c cases shown may be at least 2, 3 and 4 respectively.



a

b

c

d

e

f

Fig. 1. Generator circuits.

The generators perform as follows. The closed circuit made up by the generator frame and the initially closed switch S_2 has I_0 current produced by the external power supply (not shown in fig. 1), and the energy is stored as magnetic field. Simultaneously, another external supply is to provide pulsed charging up to V_0 voltage of several generator lines with additional energy being stored as electrical field. The first and second cases each have two lines charged, their impedances Z_{n-1}, Z_n and Z_{n-2}, Z_{n-1}, respectively, and the third - four lines with Z_{n-3}, Z_{n-2}, Z_{n-1} and Z_n impedances. Following the initial energy storing process, there occurs triggering of the switch S_1 which is connecting the high-voltage electrode of charged lines to the grounded generator frame. The current I_0 direction and the charging voltage V_0 polarity are specified such that the first electromagnetic wave as it arrives would result in the current increasing at the generator output. Wave processes are what make both magnetic and electrical energies concentrated at the generator output. Along with this, the voltage is observed to achieve a several times higher peak value. The output switch S_2 that connects the resistive load Z_L to the generator output would become opened just when the first electromagnetic wave arrives at it. Ideally, the matched load have a square-shaped voltage pulse of $2T_0$ width generated.

We can show that the following relationships must be satisfied to ensure that electromagnetic energy will be wholly transmitted to the matched load:

- 1st case $$Z_i = Z_1 \frac{\alpha(\alpha+1)}{(\alpha+i-1)(\alpha+i)}, \quad \text{where } i = 1,2,\ldots(n-1),$$

$$Z_n = Z_1 \frac{\alpha(\alpha+1)}{(\alpha+n-1)}, \quad V_0 = I_0 \cdot Z_n;$$

- 2nd case $$Z_i = Z_1 \frac{\alpha(\alpha+1)}{(\alpha+i-1)(\alpha+i)}, \quad \text{where } i = 1,2,\ldots(n-3),$$

$$Z_{n-2} = Z_1 \frac{\alpha(\alpha+1)}{(\alpha+n-3)(2\alpha+2n-5)}, \quad Z_{n-1} = Z_1 \frac{\alpha(\alpha+1)}{(\alpha+n-2)(2\alpha+2n-5)},$$

$$Z_n = Z_1 \frac{\alpha(\alpha+1)}{(\alpha+n-2)}, \quad V_0 = I_0 Z_1 \frac{\alpha(\alpha+1)}{(2\alpha+2n-5)};$$

-3rd case $$Z_i = Z_1 \frac{\alpha(\alpha+1)}{(\alpha+i-1)(\alpha+i)}, \quad \text{where } i = 1,2,\ldots(n-4),$$

$$Z_{n-3} = Z_{n-2} = Z_1 \frac{\alpha(\alpha+1)}{2(\alpha+n-3)(\alpha+n-4)}, \quad Z_{n-1} = Z_n = Z_1 \frac{\alpha(\alpha+1)}{2(\alpha+n-3)},$$

$$V_0 = I_0 \cdot Z_n.$$

We have used here α, the coefficient which is the ratio of electrical to magnetic energy as initially stored by the generator. If the above mentioned relationships are satisfied, the matched load voltage should be $0.5(\alpha+n-1)/\alpha$, $0.5(2\alpha+2n-5)/\alpha$ and $(\alpha+n-3)/\alpha$ times the charging voltage, respectively. Increasing the load voltage as compared with the charging voltage requires adding more stages and/or decreasing α value, i.e. making the electrical energy portion in the total energy input larger. Adding more stages would result in higher maximum-to-minimum impedance ratio of the stepped line, which is normally within 20 for coaxial lines, given the same dielectric material used throughout the generator. Note, that the impedance ratio grows with lower α values when the stages are fixed in number.

The most general case can be used to illustrate that closed inductive storage systems using stepped lines, must have with complete energy extraction the ratio of the matched load current to I_0, the initial current, equal to $(\alpha+1)/2$. Particularly, one may conclude the total energy stored by the generator would be $(\alpha+1)^2$ times the energy stored at the generator output stage as magnetic field.

The output switch opening can be provided by making use of the fact that at the arrival of the first electromagnetic wave the switch current would grow by a factor of $(\alpha+1)$ for all the circuits considered. This is of special importance in making several generators operate simultaneously as part of a multimodular system. It would be reasonable to ensure reliable triggering of the current opening switch by increasing the α value, i. e. the electrical energy portion in the total energy stored.

As an illustration, fig. 1 (d, e, f) gives the most suitable impedance rations for generators having the total electrical length of $3T_0$, given that equal energy values ($\alpha=1$) have been stored initially in electrical and magnetic fields. The first two cases (d, e) are where the generator includes four, and the third (f) case - five transmission lines, and the matched load voltages are 2, 2.5 and 3 times the charging voltage, respectively. With each stage added and the respective impedance and V_0/I_0 variations the voltage can be increased by $0.5V_0$ for the first circuit, and by V_0 for the second and third.

Triggering the switch S_1 produces electromagnetic waves. When the lines have transmitted the wave which is shown by the figures to travel initially to the left of the switch, their voltage becomes equal to zero. When the wave arrives at the point where different line impedances are connected, there occurs a reflected voltage wave. However, just at the same time there is another wave to come up to the same connection, which has been initially traveling to the right of the switch S_1. The generator circuit and line impedances are selected such that the superposition would result in the reflected wave having its net peak value of zero. This requirement is satisfied at any connection between different line impedances. Impedance ratios are selected so as to provide the same current value simultaneously for all the lines the wave in question has traveled through. While this current is the same in magnitude, its direction is opposite to the initial current I_0. Thus, there occurs not only complete lines discharging but also the magnetic field is made zero due to the superposition. Ideally, a square-shaped voltage pulse would be generated in the matched load as it is switched by opening the switch S_2 at the arrival of the first electromagnetic wave.

Conclusions

Some design concepts of multistage generators using stepped-line inductive storage have been discussed. What is distinctive of this approach is that initially the energy is to be stored by all the stages as magnetic field, but at the same time it is stored also as electrical field by some of them. Upon triggering the switch connecting between the high-voltage electrode of charged lines and the grounded generator frame, there are wave effects which make both magnetic and electrical energy concentrate wholly at the generator output. Ideally, given whatever number of stages, there would be a square-shaped pulse of $2T_0$ width generated in the resistive load, whose peak value may be substantially higher than the generator charging voltage.

The concepts discussed can be used as a basis to develop powerful high-voltage pulse generators including those to be incorporated in multimodular systems. Although the data described in this paper have not been tested experimentally, analytical and numerical studies they summarize involved techniques repeatedly verified by experiments on numerous stepped-line generators using capacitive energy storage. Anyway, selection of the generator circuit design and optimal requirements should be made individually for any specific application.

[1] Bossamykin V.S., Gordeev V.S., Pavlovskii A.I.. New schemes for high-voltage pulsed generators based on stepped transmission lines// 9-th International Conference on High-Power Particle Beams, BEAMS-92, Washington, DC, May 25-29, 1992 ; V. 1, PP. 511-516.

[2] Bossamykin V.S., Gordeev V.S., Pavlovskii A.I. et. al. Pulsed power electron accelerator with the forming systems based on stepped transmission lines// 9-th International Conference on High-Power Particle Beams, BEAMS-92, Washington, DC, May 25-29, 1992; V. 1, PP. 505-510.

[3] Bossamykin V.S., Gordeev V.S.. Stepped line conversion of pulsed voltage, current and electric power // 9th IEEE Internat. Pulsed Power Conf., Albuquerque, NM, June 21-23, 1993; V.2. PP. 918-921.

[4] Bossamykin V.S., Gordeev V.S., Pavlovskii A.I. et. al. STRAUS-2 electron pulsed accelerator // 9th IEEE Internat. Pulsed Power Conf., Albuquerque, NM, June 21-23, 1993; V.2. PP. 910-912.

[5] Bossamykin V.S., Gordeev V.S., Pavlovskii A.I. et. al. Linear induction accelerator LIA-10M// 9th IEEE Internat. Pulsed Power Conf., Albuquerque, NM, June 21-23, 1993; V.2. PP. 905-907.