Pulse generator of a polygonal design with a high rate of voltage

A Bystrov* and D Lantsev
Peter the Great St. Petersburg Polytechnic University, 195251 St. Petersburg, Russia

* E-mail: stalex81@yandex.ru

Abstract. The paper discusses the results of experimental studies of pulsed generators based on a drift diode with a sharp recovery (DSRD) and inductive energy storage of standard and polygonal structures. For the first time the generator of a polygonal design is presented. It is shown that when the generators are working on an active-capacitive load, the rate of voltage rise on it at the generator of a standard construction is lower. The generator of a polygonal design has high characteristics for the rate of increase of voltage and its amplitude. This article will discuss the effect of capacitive load on the rate of voltage rise and the way to increase it.

1. Introduction

The Modern pulsed power is not an alternative to conventional power with alternating or direct current. The tasks of modern traditional energy are well represented in various scientific publications [1-5]. However, pulsed power is designed to solve other tasks, it works on fundamentally different loads, which are described below. The development of conventional energy is accompanied by the creation of well-known devices, which are presented in articles [6-8]. The development of pulsed power required the creation of all elements that have analogues in conventional power engineering, such as pulse generators, switches, transformers, power transmission lines, systems for pulse shape conversions, etc. On the other hand, the further development of traditional energy is carried out using digital devices [9, 10]. The use of digital devices in pulsed power engineering is problematic, and sometimes not possible. Mathematical analysis of processes in traditional power engineering is carried out in well-known software products, MATLAB and SIMULINK, COMSOL Multiphysics, etc. [11-14]. Modeling processes in pulsed power engineering based on the above listed software products is in most cases not possible. The fact is that the time scale of these software products is not coordinated with the processes of the nano- and subnanosecond range.

Today, nanosecond pulse generators required in pulsed power engineering for the study of electrophysical processes, in medicine, obtaining materials with new, predetermined properties and shock electromagnetic waves to power pulsed lasers, accelerators, water and air purification devices [15].

For the generation of powerful nano- and subnanosecond voltage pulses, two main methods are used, differing in the type of storage device and switch. In the first case, the accumulation of energy occurs in capacitive drives, with its subsequent transfer by means of the closing switch (discharger) to the load. In the second case, the energy is stored in an inductive storage device, and a opening switch (current interrupter) is used to transfer energy to the load. Basic schemes, designs of pulsed generators and their variety have been repeatedly described by various authors [15].
The basic scheme of a pulse generator based on the inductive energy storage device DSRD is presented in Figure 1.

![Figure 1. The basic scheme of a pulse generator based on the inductive energy storage device DSRD.](image)

The main load of the pulse generator is the discharge chamber of the plasma-chemical reactor. The discharge chamber of the plasma-chemical reactor made of metal has an electrical capacity \([16]\). This electrical capacity depends on the design of the discharge chamber and is proportional to its size. The value of this capacity can reach several thousand pF. The rate of voltage rise at the load before the breakdown of the discharge chamber depends on the size of its electrical capacitance and the value of the cumulative inductance. In an impulse generator created on the basis of the circuit shown in figure 1, the cumulative inductance is the leakage inductance of the secondary winding of the saturable transformer.

The rate of voltage rise \((RVR)\) at the load before the breakdown is calculated by equation (1), if you solve this part by sinusoidal.

\[
RVR = \frac{U_a \cos \left( \frac{t}{2\pi\sqrt{LC}} \right)}{2\pi\sqrt{LC}}
\]

where \(U_a\) – peak voltage at the load without breakdown, \(L\) – accumulative inductance value, \(C\) – load electrical capacitance.

We cannot change the electrical capacity of the discharge chamber in a large range, since it is related to its size, but there is a method of significantly reducing the cumulative inductance. This method will be discussed below.

2. Methods

The purpose of this work is to investigate the effect of various structures, standard and polygonal, a pulse generator, the value of the cumulative inductance and, as a result, on the rate of voltage rise on the load.

The method of research involves obtaining the output characteristics of the instrumental method, standard and polygonal structures of nanosecond generators, made of identical components and the same number of basic elements. The measurement results will be compared by the main indicators, the value of the cumulative inductance and the rate of voltage rise on the load.
For experimental studies, two generators of the standard construction in Figure 2 were created, its diagram is shown in Figure 3, and its polygonal construction is shown in Figure 4, of identical components.

Figure 2. Standard nanosecond generator design.

Figure 3. Diagram of a standard nanosecond generator.

Figure 4 show, that the cumulative inductance used in a standard construction, it is divided into n equal parts, called gons, in a polygonal construction. In our paper, n is 4. The beginning of each gon is connected to the end of the subsequent gon through compensating capacitance that were used in the standard design.
Figure 4. The nanosecond generator of the polygonal design.

All gons and capacitance are identical exact size. The inductance of each gon is 300 nH, and the capacitance is 10 nF. With such gon inductance, the cumulative inductance in a standard construction will be greater in $n^2$, i.e. 4.8 μH. According to equation (1) the rate of increase on the load will be lower. The load of the generator of each design has a resistance of 43 Ohms and a capacity of 1200 pF.

Figure 5. Test result of oscillographic probe for Tektronix TDS3054B.

The main parameters are the frequency band 500 MHz, the number of samples 5GS/s, the number of channels 4. The oscilloscope was connected to the measured circuit via a probe with a transmission coefficient of 1:1000. For reliable recording of signals with a rise time of a few nanoseconds, the rise time of the probe should be less than 1 nsec. Probes with such parameters are difficult to access, so such a probe would be made by yourself according to the recommendations [17]. The result of the probe test is shown in Figure 5.
To protect the oscilloscope from external interference, it was placed in a shielded box manufactured according to recommendations [17], and the probe provided with an additional shielding coating.

When carrying out measurements for the generator of a polygonal design, there are additional requirements. In addition to the identity of the gons, their work must occur simultaneously. The primary part of the generator must be galvanically disconnected from the secondary part. Synchronous operation of the gons is carried out when the core of the transformer is saturated.

3. Results and Discussion
In the experiments, several time diagrams were obtained for different designs of nanosecond generators. Using these diagrams, one can estimate the parameters of the generators under study. In this paper, the task of obtaining high characteristics of the studied generators was not posed. The purpose of this work, as mentioned above, is to compare the parameters of the generators of the standard and polygonal structures under equal conditions.

The timing diagram shown in figure 6 refers to a generator of conventional standard design. The measured rise time of the voltage on the load is 17 ns at an amplitude voltage of 2 kV.

![Figure 6. Timing diagram of the generator standard design.](image)

![Figure 7. Timing diagram of a polygonal structure generator.](image)
The generator of a polygonal design in equal conditions provides the best characteristics, the rise time of the voltage on the load is less than 12 ns with an amplitude voltage of more than 3 kV.

At the end of this work, a nanosecond generator was created based on a polygonal industrial scale design. Its timing diagram is shown in figure 8. This generator had excellent characteristics of the voltage rise time at a load of 50 Ohms and 200 pF 5ns at an amplitude voltage of 30 kV.

![Timing diagram of a polygonal industrial scale generator.](image)

**Figure 8.** Timing diagram of a polygonal industrial scale generator.

### 4. Summary
Polygon based generators DSRD reliable and maintenance free. The generators can work with unmatched and / or non-linear loads, including open or short load. They have an amplitude of the output pulse and a pulse constant repeat mode, overheating protection scheme. In this dissertation, solid state pulsed power systems will be discussed in system, device and topology levels and several application-specific nanosecond high voltage pulse generators are presented. Uniform and stable discharges in coaxial reactors with observed without a quartz barrier supplied by nanosecond pulses. The best energy consumption is per g produced ozone. This efficiency is achieved with a pilot installation using ambient flow of moist air at the entrance to the reactor. For comparison specific energy consumption in the best industrial ozonizers served by dry and cooled oxygen. Experiments on cleaning air polluted methyl mercaptan demonstrates a new promising approach for design of gas cleaning systems based on high-voltage nanoseconds pulse generators. Short pulse front duration and very high voltage rise rate ensure significant overvoltage on the reactor which is important for uniform and stable discharge.

### 5. References

[1] Korotkov A and Frolov V 2016 Methods of determination the electrical load schedules on areas in urban distributive power grids *IEEE NW Russia Young Researchers in Electrical and Electronic Engineering Conference (EIConRusNW)* 601–3

[2] Korotkov A and Frolov V 2016 Calculation methods for determination of electrical load schedules of residential *Acta Technica CSAV* 61(1) 73–9

[3] Korotkov A and Frolov V 2015 Experimental studies of electrical load schedules of residential electricity consumers in urban distributive power grids *Acta Technica CSAV* 60(4) 337–46

[4] Zamyatin E O and. Shklyarskiy Y E 2016 Concept for electric power quality indicators evaluation and monitoring stationary intellectual system development *Int. J. Appl. Eng. Res.* 11(6) 4270–4

[5] Shklyarskiy Y E and Skamyin A N 2016 Compensation of the reactive power in the presence of higher voltage harmonics at coke plants *Coke Chem.* 59(4) 163–8
[6] Frolov V and Ivanov D 2018 Calculation of a plasma composition and its thermophysical properties in cases of maintaining or quenching of electric arcs *Journal of Physics Conference Series* **1058**(1)

[7] Frolov V, Ivanov D and Toropchin A 2014 Analysis of processes in DC arc plasma torches for spraying that use air as plasma forming gas *Journal of Physics Conference Series* **550**(1)

[8] Frolov V, Ivanov D, Smirnova E and Yushin B 2009 Induction hardening of air-plasma coatings *18th Symposium on Physics of Switching Arc* 158–61

[9] Frolov V, Bystrov A and Neelov A 2017 Imitating model of a microprocessor trip unit of a circuit breaker *IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)* 838–40

[10] Frolov V, Neelov A, Zhiligotov R and Bystrov A 2018 Identification of the protection parameters of the local electrical network taking into account the detuning of the inrush current *IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)* 626–8

[11] Frolov V, Ivanov D, Podporkin G and Sivaev A 2017 Development of mathematical model of processes in multi-chamber arrester for identification of criteria of arc extinction *International Symposium on Lightning Protection* 240–3

[12] Obraztsov N and Frolov V 2018 A two-dimensional axisymmetric model of an AC arc *IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)* 430–2

[13] Frolov V, Ivanov D and Shibaev M 2014 Modeling the plasmachemical synthesis of nanopowdered materials using a combined plasmatron *Technical Physics Letters* **40**(8) 676–9

[14] Frolov V, Ivanov D and Shibaev 2013 Mathematical modeling of plasma process of nanopowder production using a combined plasma torch *20th Symposium on Physics of Switching Arc* 147–50

[15] Mesyats G 2004 *Pulsed power and electronics* (New York: Springer US)

[16] Frolov V, Ivanov D and Belsky R 2017 Increasing of operation security and of breaking capacity of surge arresters *IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)* 1520–3

[17] Schwab A 1972 *High-voltage measurement techniques* (Cambridge: M.I.T. Press)