Modeling of high power pulse generator based on the non-linear elements of pulsed facilities

G P Averyanov, V V Dmitrieva and A V Kobylyatskiy
National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia
E-mail: gpaveryanov@mephi.ru, vvdmitrieva@mephi.ru, avkobylyatskiy@mephi.ru

Abstract. The article considered the software implementation mathematical model of the voltage pulse generator with a hard switch. The interactive object-oriented software interface provides the choice of generator parameters and the type of its load, as well as pulses parameters analysis on the load at the generator switching.

1. Introduction
High-power pulse generators of microsecond range are widely used in pulsed radiolocation, coded data transmission systems and in the nuclear physics research, particularly, in accelerator facilities. These devices can also be used in other electronic systems in various fields of science and industry. This work is devoted to the description of the specialized software, designed to simulate high-power pulse generators. The computer modeling features of the high-power pulsed devices, the mathematical model of a high-power pulse generator with a hard switch and the main elements of the software GENH GUI are described. The lamp generator model (lamp modulator) includes parasitic elements, which present in the real devices, and non-linear characteristics of the lamp.

![Figure 1. The lamp modulator circuit.](image-url)
The most widely used devices in electrophysical facilities are the ones with a hard switch. They are used to produce high-power high-voltage pulses and based on the electronic vacuum lamps (figure 1). The main challenge during the development of such devices with a choice of circuit elements is to provide the requirements in pulses parameters and to take into account the characteristics of switches. If the lamp is a high-frequency one, this device is often called a modulator. Thus it is necessary to take into account the output device that is introduced into the circuit. When designing modulators of this type it should be also taken into account the forming device of initial pulse applied to the input.

Now consider the operation of such a modulator. During the pause between the pulses when the lamp is locked by the voltage offset on the first grid $U_{c1}$, the storage capacitor $C_1$ through the charging resistance $R_3$ is charged from the power supply. By applying a positive pulse to the control grid the storage capacitance $C_1$ is partially discharged through the open lamp. The discharge current flows through the load and the charging resistance $R_3$. Of course, the voltage drop on the lamp should be minimal, as the lamp is connected in series with the load. Power loss on the lamp reduces the efficiency of the modulator.

The shunt inductance $L$ can reduce the fall time value of the pulse. After locking the lamp (between the pulses) in the circuit with inductance and parasitic capacitances $C_P$ harmonic damped oscillations occur. To damp these oscillations, which can lead to re-activation of the load or breakdown the lamp, the inductance is connected in parallel with the diode $D$. At the end of the pulse forming the diode shunts $L_{C_P}$ and damps parasitic oscillations. Reducing the inductance $L$ leads to a shortening of the falling edge with an increase of its peak recession.

2. **Generator mathematical model**

The practical use of pulsed power devices at the modulator output leads to the need to study the most typical operating modes, viz. undervoltage and overvoltage modes.

![Diagram](image)

**Figure 2.** Pulsed anodic characteristics of the lamp.

To study the process use the anode pulse characteristic, shown in figure 2. This characteristic feature is that it can be presented in the form of two linear sections that correspond to the undervoltage mode ($r_i$) and overvoltage mode($R_i$).
In undervoltage mode, the internal resistance of the lamp is defined as:

\[ r_i = \frac{U_a}{I_a} \]  

(1)

In overvoltage mode the bulb operates as a current source \( I_A \) and has an internal resistance, which can be defined as:

\[ R_i = \frac{U_a - U_{a,sw}}{I_a - I_A} \]  

(2)

One must also consider the third mode of operation lamp-lamp in a locked condition. In this mode, the lamp can be represented as an open circuit. For the modulator with load \( R_l \) in undervoltage mode is valid the next expressions:

\[
\begin{align*}
\frac{I_A}{p} + \dot{i}_2 + \dot{i}_1 &= 0 \\
\dot{i}_2 R_l - \dot{i}_1 \left( R_n + \frac{1}{pC_1} \right) &= \frac{U_a}{p}
\end{align*}
\]  

(3)

where \( p \) – Laplace operator and \( I_A = \frac{U_{a,sw}}{R_l} \) and in overvoltage mode:

\[ I_s \left( r_i + R_l + \frac{1}{pC_1} \right) + \frac{U_a}{p} = 0 \]  

(4)

When switching between modes you need to know the state of inertia contour elements

3. Lamp modulator simulator interface

![Simulator GENH interface. Block “Lamp modulator”](image) 

**Figure 3.** Simulator GENH interface. Block “Lamp modulator”.
When you run the simulator GENH of lamp modulator GUI window appears (figure 3). At the top right is the generator circuit, and below – its equivalent circuit. The generator load type can be changed using the buttons "type of load", located under the equivalent circuit. Possible types of load are (left to right):

- resistance
- parallel $RC$-circuit
- parallel $RL$-circuit
- parallel $RLC$-circuit
- $RLC$-circuit in parallel with the diode

The parameters of the generator and load can be changed using the input textfields in the lower left corner of the window. The parameter names match with ones in the equivalent circuit. In the left column are the generator parameters:

1. $U_0$ – voltage on the capacitor $C_1$
2. $T$ – pulse time (switch K is closed at $t = 0$ and opens at $t = T$)
3. $C_1$ – capacitance of capacitor $C_1$
4. $R_i$ – the value of the internal resistance of the lamp.
5. $I_n$ the right column – load parameters:
6. $R_l$ – load resistance
7. $C_l$ – load capacitance (textfield is disabled when load type is “resistance” and “$RL$-loop”)
8. $L_l$ – load inductance (textfield is disabled when load type is “resistance” and “$RC$-circuit”)
9. $R_P$ – DC resistance of the diode (textfield is enabled only when the load type is “$RLC$-circuit in parallel with the diode”)

To change one of the parameters press the left mouse button on the appropriate textfield and enter the desired number from the keyboard. Input is terminated by pressing "Enter" and the new calculation with the new parameters will be produced immediately. When you mouse on the signal image its coordinates in t and V are displayed directly below the image. The scale is also showed there. To change the scale the buttons of zoom in and out in the upper right corner of the signal image are used. If you move the mouse cursor while holding the left mouse button, the waveform will move with the cursor, allowing you to see areas of the diagram out of the window.

Figure 4. The time diagram in BMP format.
The result (the voltage pulse shape on the load) will be displayed in the upper left corner of the window or in its own window. The main part of the oscilloscope block window takes a scaled image of the studied signal. At the top is time values in microseconds, and on the right – the voltages in volts. Using the control elements you can set the initial position of the signal, change the scale and the image position relatively to its vertical and horizontal axes. You can save the waveform to disk in BMP format. At the same time one of the two saving options you can select: color picture (the same as on the screen), or black-and-white (for the printing) of the form in figure 4.

4. Conclusion
The High-power pulse generators can be represented as the electrical circuits containing conventional elements with lumped parameters and elements with distributed parameters, such as transmission line with variable distributed electrical parameters. This software interfaces is purpose for initial study of high-power pulsed generators. Task is to understand the working principles and the influence of the elements of the device on its work so it is much easier than interfaces of CAD.

5. References
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