Diagnosing system on the principle of high voltage pulses measurements

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Abstract. The main aspects related to the development of measuring systems working with the high voltage pulses (from 1500 to 6000 V with current reaching $10^5$ A) are presented in the paper. The necessity of screening and noise protection for such systems is explained. The measures to ensure the electrical safety of the operating person while working with the system.

1. Introduction
Choosing parameters to control the functioning of the technological device is always complicated task. And it’s even more complicated when the device is working in pulse mode with high density energy releases. Such devices usually use high power pulse discharges which is related with high amplitude currents and high voltages. One of the ways to control the processes taking place in the system is local measurements of the parameters of plasma radiation [1]. But it’s not always feasible and sometimes can’t provide the adequate data on the processes. It’s especially common in the non-equilibrium systems and systems where plasma might move [2]. So, the main way to control if the electric technological system functioning correctly is still measuring the current and voltage parameters in the system. As an example of such system might be a technological device for production the ultradispersed particles in pulse arc discharge (high voltage (up to 5 kV) short pulses (up to 200 us) at high currents (up to 100 kA)). A detailed description of the device functioning principles can be found in [3].

2. The processes taking place in a device
The following parameters were commonly used in the presented device: power $10^6$–$10^8$ W, maximal current value $10^5$ A, voltage – up to 5 kV, pulse duration 40–200 us (depends on the particular conditions).

Processes taking place in a device are described by massive system of integral-differential equations, including Maxwell equations describing electric and magnetic fields amplitudes, thermal conductivity equations (Stefan problem) describing thermal processes on the electrodes, gas dynamic problem considering inner heat sources and electromagnetic processes taking place in plasma discharge, etc. Moreover, all the processes are complicatedly related to each other and the properties of the mediums at such temperatures and currents are poorly studied. At all causes problems for numerical modeling making it literally impossible.

That’s why such processes should be studied in a combined way, using integral parameters. In terms of this combined method the preparatory experimental researches of voltage dynamics in different technological modes. Comparing received data to the results of numerical modeling the
processes in a matching invariant electric circuit including the elements of the device sepa-rately allowed to distinguish and connect the oscilloscope curve components with the processes taking place in a discharge. As a result, we could figure the particular oscilloscope curves of the voltages on electrodes when the device is functioning “correctly”. They are presented in figure 1.

We used Tektronix TDS 3012c oscilloscope connected to the electrodes through the resistive divider with impedances 12.6 MΩ and 100 kΩ. The input impedance of the oscilloscope was set 100 MΩ. The signal was recorded as 10000 points with the measuring time from 40 to 100 us.

![Figure 1. Voltage dynamics on the main electrodes at different initial voltage in capacitive 500uF battery.](image)

Devices existing nowadays which are capable of measuring such voltages (kilovoltmeter spectral digital “KVC-120”, and digital oscilloscope Tektronix MSO3012) can’t satisfy all the requirements. And the major disadvantage of these devices is their high cost, which makes the whole technological device very expensive. Another disadvantage is the necessity for external computer signal processing. To overcome these difficulties, the system for diagnosing the technological device measuring the voltage pulses and comparing them to the standard signal curves was developed at the laboratory of “Electric Impulse Technologies”.

3. Development of the technological device diagnosing system
The measurements are made through two parallel channels to provide control on two detection points of technological device. The device is controlled via signals sent from PC. The functional diagram is presented in figure 2.

![Figure 2. Functional diagram.](image)

The functioning process of diagnosis system is the following. Measured voltage is sent to the input of matching device (resistive current bridge). The bridge contains metal oxide resistors connected in series (C2-23) 2 W, 300 Ω, 5 %, with total resistance 6 MΩ. The current bridge limits the currents in the system on 1 mA at maximal voltage 6 kV.
The signal from the input is sent to the galvanic splitter being optical isolator. Galvanic isolator divides the device into a number of independent circuits, with electric autonomous signals. After passing the galvanic isolation the signal is amplified and sent to the input of the analog-digital convertor (ADC). ADC sends digital signal to a microcontroller, which records a signal and sends it further to a computer. The circuit diagram is presented in figure 3.

![Electric circuit diagram](image1)

**Figure 3.** Electric circuit diagram.

As the system deals with the voltage pulses from 1500 up to 6000 V at currents up to $10^6$ A, the systems of protection the circuits from noises and short circuit damaging. That’s why for each channel of diagnosis system a galvanic isolation is envisaged. For the isolation HCPL-4504 optocoupler was chosen.

![Optocoupler HCPL-4504](image2)

**Figure 4.** A photograph of the optocoupler HCPL-4504 (a) and functional scheme (b).
The optocouple HCPL-4504 has got high current transfer ratio and low transition latency. The isolating layer between photodiode and photodetector separates galvanically input and output. These optocouples have photodiode bias connectors and the collector of the output transistor figure 4(b). It decreases the capacity between base and collector improving the performance of the optocouples significantly. As the optocouples are semi-conductive devices, they have non-linear transformation characteristic. In order to compensate errors of the transformation two optocouples were used differentially connected to the operational amplifier input. One optocouple was reference and the second – for actual measurements. The circuit diagram of one of the channels is presented at figure 5(a).

![Optocouples commutation diagram](image1)

**Figure 5.** Optocouples commutation diagram (a), diagnosis system appearance (b) DD2 – ADC circuit; DA5, DA7 – optocouples; DA4 – voltage stabilizer; DA8 – operational amplifier.

Such an optocouple commutation principle allows minimizing the nonlinearity of the transformations and significantly decrease the temperature drift caused by currents flow. Another way to decrease transformation errors is to choose the optical isolator breakpoint on the linear part of the current-voltage characteristic. Such a commutation provides a current through refer-once and measuring optocouplers 20 mA current.

A signal comes to the input of the measuring optocouple and adds to the reference current. An appearance of the diagnosis system is presented at figure 5(b). Because both channels are isolated from each other the device contains three independent electric circuits. It required also three channel power supply system. A special power source (figure 6) was developed and constructed for these purposes.

![Power supply](image2)

**Figure 6.** Power supply.

In the electric circuit of each channel the transformer Transled TPG-32 was installed. The voltage from the secondary winding comes to the rectifying bridge. Rectified voltage is further applying to the input of the voltage stabilizer LM317. Using different additive resistive circuits on the stabilizer...
provides creating a number of impedances options on the power source output, making the developed supply more versatile and functional.

Technological device functioning is provided by the pulse discharge. The noise currents appear in the electric circuits of the device and the devices connected to it while processing. Such currents also might appear in the circuits galvanically isolated from each other. Consequently, the diagnosis system has to be screened very carefully. The major type of noises in this case are nanoseconds long. Cancelling their impact is the most factor for device reliability improvement.

The standard IEC 61000-4-4 (GOST R 51317.4.4-99) allows to pick two main components of noise immunity for the device under nanoseconds long noises:
- Inner device grounding.
- Capacitive connections.

When nanoseconds noises pass through the circuit, the potential difference appears between different sections of the ground. And the major effort of the potential difference appearance is brought by the inductive component of the grounding circuit, not resistive one. As such short pulses are steep at their fronts, even minor inductiveness might cause device failure. Such noises are also very hard to capture even using digital recording oscilloscope.

Hence a consistent grounding layer causes the appearance the potential difference when very short noisy pulses pass through a circuit. Potential difference might reach up to couple volts, which might affect the gear.

The main method of protection diagnosis systems from the nanoseconds noises is using optocoules in the measurement links. However, using optical isolator didn’t provide the required level of noise immunity though it increased 1,5–2 times. But this level wasn’t enough to make the system workable. For the further improvements a number of actions like using special wiring layouts on the device board. The example of such hint might be increasing a section of the ground wires on a layout. Empty spaces on the board were covered with grounding polygons on the opposite side of the board. Wiring and tracing the board considered the optimal points of grounding different circuits. The areas with “clear ground” were done.

One of the effective ways of high frequency noises influence decrease in a circuit is adding ferrite filters. Ferrite filters are damping the high frequency components in the conductors. It also provides the nanosecond noises significant reduction.

The dynamics of the voltage on the main electrodes is processed in a special software on a PC. The software interface is presented at figure 7.

![Figure 7. Software interface.](image)

The voltage curve changes show the state of different parts of the technological device and its results. Comparing the voltage dynamics measurements and the pictures of substrates surfaces with sputtered
particles measured with atomic-forced microscopy would help the technological process properties and studying the results of particles production.

4. Conclusions
The developed system of diagnosis of the technological device provides registration the pulses up to 6 kV and beginning with 10 us long. The developed device includes complicated external noise reduction system. Such system includes screening, galvanic isolations and special hints on beard layouts. Moreover, the system includes a protective element for an operating person.

References
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