Investigation of the application of a high-voltage liquid voltage divider on Multisim software (version 10.0) and SolidWorks

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Abstract. The considered model was investigated according to the main characteristics corresponding to the real process (even the geometrical dimensions and electrophysical parameters coincide). It is known that a prerequisite for physical modeling is a strict geometric similarity of the model and character, as well as the equality of the corresponding similarity criteria in them. The cheapest insulator in the power industry is air. The air environment plays an important role in the design of ball arresters used in pulsed technology. In this case, it is important to measure the high-voltage voltage and obtain the exact shape of the discharge current pulse on the oscillogram. For this purpose, in this work, liquid voltage dividers were studied and the corresponding electronic models were developed. The results obtained in the electronic model are unreliable without experimental verification. The measuring equipment during the experiment gave positive results, indicating the quality of measurements, the correctness of the process of electric pulse treatment of seeds.

1. Introduction

Determining the characteristics of the technical equipment and physical systems used is a complex and time-consuming operation. If this system is not developed or is under development, it will not be possible to conduct research. For research purposes, it is widely used to create a physical model that reproduces the current system on a scaled-down scale. The parameters of this model should be selected so that they correspond to the parameters of the current system.

Models of various physical nature can be created: electrical, mechanical, hydraulic, etc. The simplest and most universal of these models are electrical models. They are widely used. The use of electrical models is suitable for both stationary (stable) and dynamic (transient) processes. The idea behind the simulation is based on the study of electrical circuits. Voltage, current, power and other quantities are taken as the investigated quantities of operating systems. The paper [1] considers the issues of PBD application as a model of the chain of the process of electric treatment of cotton seeds. In the work [2], the issues of measuring the electrical resistance of the components of the cotton seed are considered in detail. Such data can be the basis for physical and electronic modelling.

In the work [3], the discharge processes in electrical networks near power transformers are analyzed and the advantages of the dynamic model are given. Researchers [4] have used new materials for arresters in order to improve the performance of the arrester.
2. Materials and methods

Depending on the gas pressure, its temperature and the distance between the electrodes, electron avalanches develop to the level of a streamer consisting of superconducting plasma. This channel, containing two different charge polarities, grows at a very high speed ($10^8$ cm/sec) towards the opposite electrode (anode). Negative charges flow from the cathode to the volume entering the streamer channel. Due to the high electric field strength, the approach of the streamer head to the anode creates an almost instantaneous bridge due to rapid ionization in the still unfinished space between the streamer and the anode. Through the anode into the streamer channel in the opposite direction to the streamer movement, positive charges tend to accelerate and neutralize the excess negative charges of the streamer. This will be the main discharge. Depending on the parameters of the electrical circuit, the discharge can be spark. In sharply inhomogeneous electric fields, the formation of a discharge usually begins with an electrode of large curvature. Since the formation of an electric discharge depends primarily on the impact ionization of electrons, it is important to know what charge the electrode with the greatest curvature has.

As an example, consider the electric field of the tip interval. In practice, this is the boundary condition for a sharply inhomogeneous field. An anode streamer is formed in a positively charged needle. Due to the intense ionization in the space between the tip and the positive space charge, a very fast plasma is formed and a positive streamer is formed. This streamer grows relatively easily in the direction of the negative plane, which is facilitated by the positive space charge in the leader. A cathode streamer appears on the negatively charged needle. Due to intense ionization, two different signal charges are formed near the tip, as in the previous case. However, electrons fall into the region of low voltages as they move away from the negative tip. Impact ionization is less likely here. Consequently, electrons lose speed and easily form negatively inactive ions with oxygen molecules. They form a negative space charge scattered in space with the electrical component of a small velocity vector directed to the positive plane. Positive ions are attracted to the needle as a compact positive charge. This charge weakens the electric field between itself and the positive plane. This makes it difficult to develop a cathode streamer.

Consequently, the dielectric strength of the gap increases on a negatively charged needle and decreases on a positively charged needle. In the considered gap between the needle and the plane, the dielectric strength in the negative needle will be 2.5 times higher than in the positive one. As the field asymmetry decreases, the polarization effect decreases. A complete calculation of physical processes during the combustion of a spark arc in a gas environment becomes much more complicated.

The above mentioned reasoning refers to the processes in the air gap. Such physical processes occur in lightning phenomena, in protective arresters, ball spark gaps, etc. The electrical strength of the air under normal conditions is approximately $25 \div 30$ kV. The study of discharge processes is always difficult. And at the same time, the use of safe measurement methods is an urgent task.

Let us consider some of the ways and methods related to the use of liquid dividers. Figure 1 shows the elements of the Industrial tank system.
Figure 1. Industrial tank system: a - liquid level e-tape sensor setup inside tank; b - simple voltage divider circuit; c - liquid level system

It is known that [5] industrial tank systems play an important role in industrial applications such as food, pharmaceutical, chemical, water treatment systems and many others. In the work [5], the sensor is used to measure the current temperature of the liquid inside the tank and the system software is written in C, interrupt routines are used to record and process time data to accurately calculate the liquid level. The investigated system measures the water level up to 25 cm and operates in the supply voltage range of 5 V. Above are images that explain the essence of the analyzed work.

In Shanghai, a precision high-voltage voltage divider was developed for the electron beam ion trap. At the same time, the uncertainty caused by the temperature coefficient of resistance (TCR) and the voltage resistance coefficient was studied in detail and was minimized to the level of the ppm range ($10^{-6}$). After TCR matching between the resistors, the precision of the division ratio finally also reached the ppm range. In this work, we measured the divider delay caused by the inserted capacitor in order to minimize the voltage ripple (the divider delay with the inserted capacitor was 2.35 ms). The divider was applied to an experiment to measure the resonance energies of some dielectronic recombination processes for highly charged xenon ions [6]. In the work [7], the characteristics of the temperature rise and the error analysis of the DC voltage divider were studied.

3. Results and Discussion

Below (Table 1) are experimental data for the electrical treatment of wetted seed. Here in the numerator, the breakdown voltage in the interelectrode gap without a seed, in the denominator with a seed subjected to two-fold moistening. These experiments were carried out under the guidance of Professor A. Mukhammadiev [8].
Table 1 Experimental data for the electrical treatment of wetted seed

| Interelectrode distance, mm | Electrode shape | Breakdown voltage (kV) at capacitor capacity, pF |
|----------------------------|-----------------|-----------------------------------------------|
|                            |                 | 220          | 470          | 1000         |
| 6                          | Needle          | 5,9/2,5      | 5,68/2,1     | 5,2/1,8      |
| 9                          | Flat electrode  | 7,27/3,6     | 7,04/3,28    | 6,36/3,18    |
| 12                         |                 | 8,41/5,2     | 7,49/5,0     | 7,04/3,6     |
| 15                         |                 | 9,77/7,27    | 7,95/6,6     | 7,5/5,36     |
| 18                         |                 | 10,04/8,2    | 8,86/7,27    | 7,95/6,8     |

Note: In the numerator, the breakdown voltage in the interelectrode gap without a seed, in the denominator with a seed subjected to two-fold moistening.

The given data in Table 1 were the basis for creating an electronic model of a liquid voltage divider. The essence of the operation of simple dividers on a resistive structure is shown in Fig. 2, image a, on a capacitor structure in image b.

![Figure 2](image)

**Figure 2.** Voltage dividers: a - with resistors; b - with capacitors.

Below are the results of the studies (Figures 3 and 4).

![Figure 3](image)

**Figure 3.** Electronic model of a high-voltage liquid voltage divider on SolidWorks: a - and b - design stages, c - finished form (metal electrodes have plastic caps for electrical safety)

In Figure 4 in picture a the key (air gap) is in the closed state, and in picture b the key (air gap) is in the open state.
4. Conclusion

Liquid voltage dividers were investigated by some scientists from different countries of the world (Russia, China, Ukraine, etc.) in order to identify their temperature characteristics of resistance, measurement errors, etc. However, in the considered works, the possibilities of using liquid voltage dividers to determine the characteristics of oscillography of high-voltage pulsed spark discharges were not investigated. We have developed electronic models using Multisim software (version 10.0) and made the prerequisites for creating a liquid voltage divider developed on the SolidWorks platform and obtained the characteristics of high-voltage spark discharge pulses on an oscilloscope. By changing the parameters of the electronic circuit, it is possible to adjust the parameters of the electrical pulse. The basis for the research was the scientific and practical work carried out by us on the use of electric spark discharges in crop production over the past 30 years under the guidance of Professor A. Mukhammadiev.
| Element designations | Element name          | Element designations | Element name          |
|----------------------|-----------------------|----------------------|-----------------------|
| Multisim software    | Alternating EMF source| TD_SW1 (Time Delay   | Capacitor             |
| (version 10.0)       |                       | Switch)              |                       |
|                      |                       | C1                   |                       |
|                      |                       | 900 mF               |                       |
|                      | Voltage Controlled   | R9                   | Resistance            |
|                      | Switch               | 200mΩ                |                       |
|                      | TS_XFMR1 transformer | Diodes D1 and D2     | Voltage divider       |
|                      |                       | R3                   |                       |
|                      |                       | R4                   |                       |
|                      |                       | R5                   |                       |
|                      |                       | R6                   |                       |
|                      |                       | R7                   |                       |
|                      | Oscilloscope          | XSC1                 |                       |

**Figure 5.** Elements used in the study of liquid voltage dividers on Multisim.

In preparation, we analyzed journal articles on the Scopus information base [9-10].

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