Volume 2, Issue 11, November 2024 **ISSN (E):** 2938-3757

TO THE STUDY OF THE PROCESSES OF CHARGING AND DISCHARGING A CAPACITOR

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Abstract
This article is devoted to the theory of the processes of charging and discharging capacitors, using it as laboratory work, you can experimentally determine the capacitance of the capacitor.

Keywords: charge, discharge, quasi-stationary current, differential equation, asymptotics, exponential law, RC circuit, initial state.

Introduction

The process of transition from one state to another in an electrical circuit is called transition processes. The processes of charging and discharging the capacitor can be added to the same process. The laws of direct current can also be applied to alternating current if its change is slow enough. Because in such cases, the instantaneous value of the current can be considered the same on all cross-sectional surfaces of the electrical circuit. Such a flow and its area can be considered quasi-stationary. As such a circuit, we can take circuits with opening and connecting, capacitors or inductive coils; in such a process, the current can be considered quasi-stationary.

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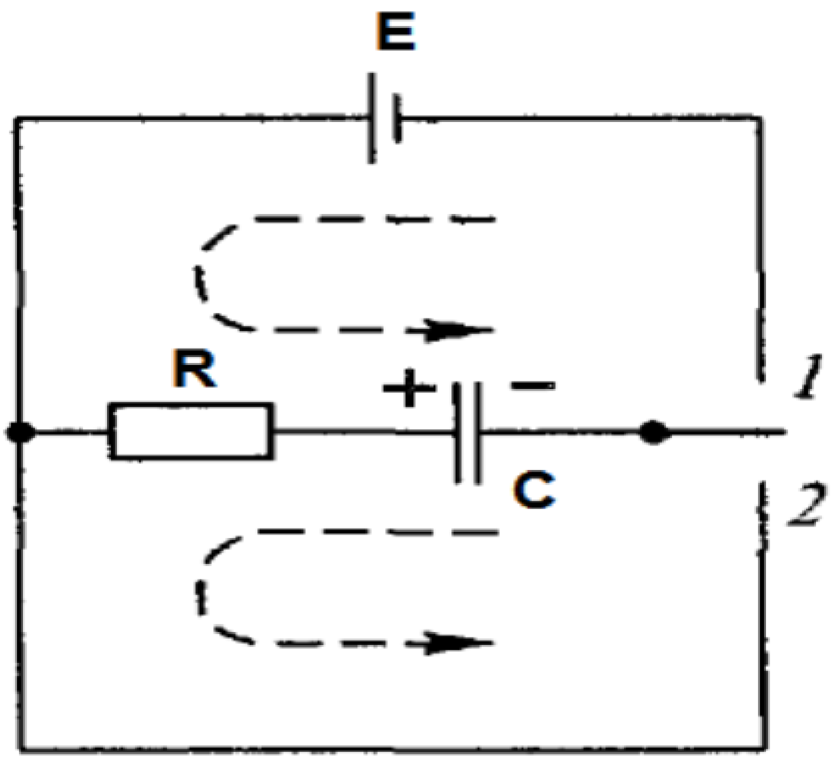
$$RI + U = E$$

where I is the instantaneous value of the current and the instantaneous value of the voltage U on the capacitor, and they can be written as follows:

$$U = \frac{q}{C}, \qquad I = \frac{dq}{dt}$$

By eliminating two of the three variables in the three resulting equations, we can obtain the following equation for only one of them:

$$\frac{dU}{dt} + \frac{U}{RC} - \frac{E}{RC} = 0$$



1-fig. Charging and discharging a capacitor.

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Thus, we have obtained a first order differential equation defining U. Now let's introduce a new variable: u=U-E, then

$$\frac{du}{dt} + \frac{u}{RC} = 0$$

Integrating we get:

$$u = Aexp\left(-\frac{t}{RC}\right)$$

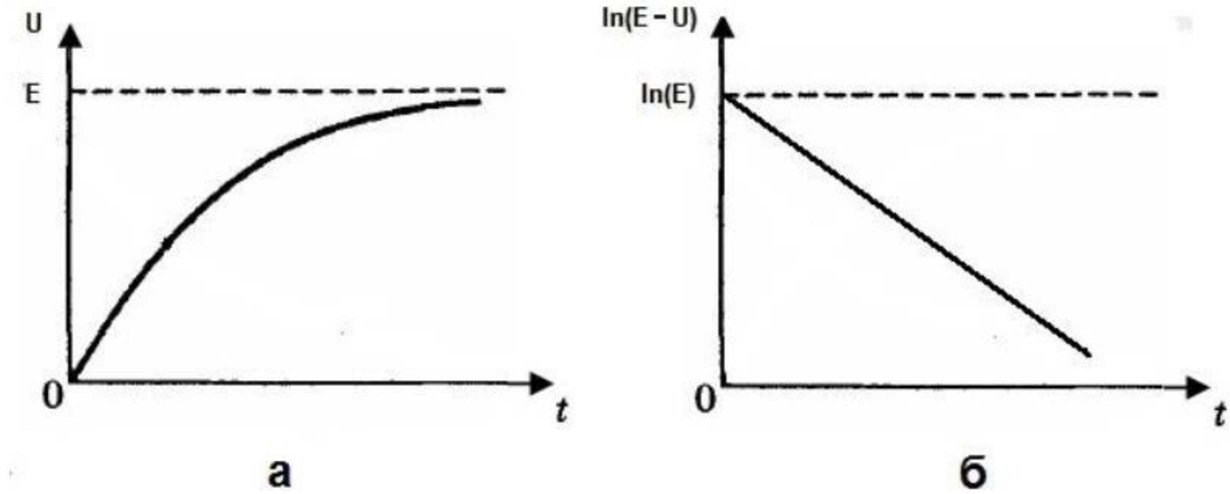
The A-integral constant is found based on the initial conditions. Let's take this time to be the time we connected the chain. Then the initial condition:

$$t = 0, U = 0, u = 0$$

Substituting this into the last solution, we get: A=-E. Returning to the previous variable, i.e. U, we get the following for it:

$$U = E\left[1 - exp\left(-\frac{t}{RC}\right)\right] \qquad (1)$$

This gives U=0 based on the initial conditions at t=0. Over time, the voltage increases and asymptotically approaches the EMF of the current source E (Fig. 2a).



2-fig. Dependence of voltage on the capacitor on time during charging

The expression for charging current as a function of time is as follows:

$$I = \frac{-U+E}{R} = \frac{E}{R} exp\left(-\frac{t}{RC}\right) \quad (2)$$

The current is initially maximum, decreases with time and asymptotically tends to zero.
The initial equations for the discharge process will be:

$$RI = U, U = \frac{q}{C}, I = -dq/dt$$

now, unlike before, expression I includes a minus sign, since the positive direction of the current we have chosen corresponds to a decrease in the charge of the capacitor. Eliminating q and I from the expressions written above, we get:

$$\frac{dU}{dt} + \frac{U}{RC} = 0 \text{ bundan } U = Bexp\left(-\frac{t}{RC}\right)$$

If the start time of the discharge corresponds to the beginning of the calculation, then the initial conditions will be as follows: t=0,U=E. From here we find B=E. Using this to express voltage versus time we get the following:

$$U = Eexp\left(-\frac{t}{RC}\right) \quad (3)$$

When the capacitor is discharged, the voltage decreases over time and asymptotically tends to zero (Fig. 3a).

Web of Technology: Multidimensional Research Journal
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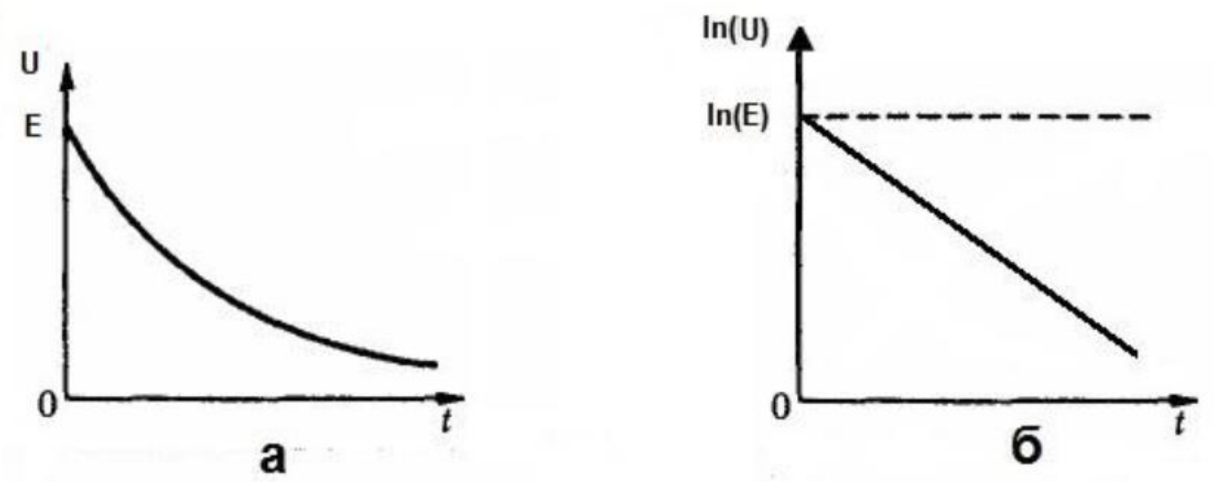
 ISSN (E): 2938-3757



3-fig. Graphs of voltage versus time during capacitor discharge.

The results obtained show that the charging and discharging processes do not occur simultaneously, that is, they last for a certain time. In a circuit consisting of a capacitor and a resistor, the time to restore electrical balance depends on RC. We denote this as T=RC. In fact, the unit of this multiplication gives the unit of time. To change it, you need to change the contour parameters, i.e. R or C. This time constant for a particular circuit shows that the voltage of the capacitor or the field strength within it decreases by a factor of ε = 2.71. If we take R and C in the SI system, then the unit of time is also seconds.

We can take a logarithm to move from an exponential voltage law as a function of time to a linear relationship if we obtain expression (1):

$$U = E\left[1 - exp\left(-\frac{t}{RC}\right)\right]$$

After logarithm we get:

$$\ln(E - U) = lnE - \frac{t}{RC} \tag{4}$$

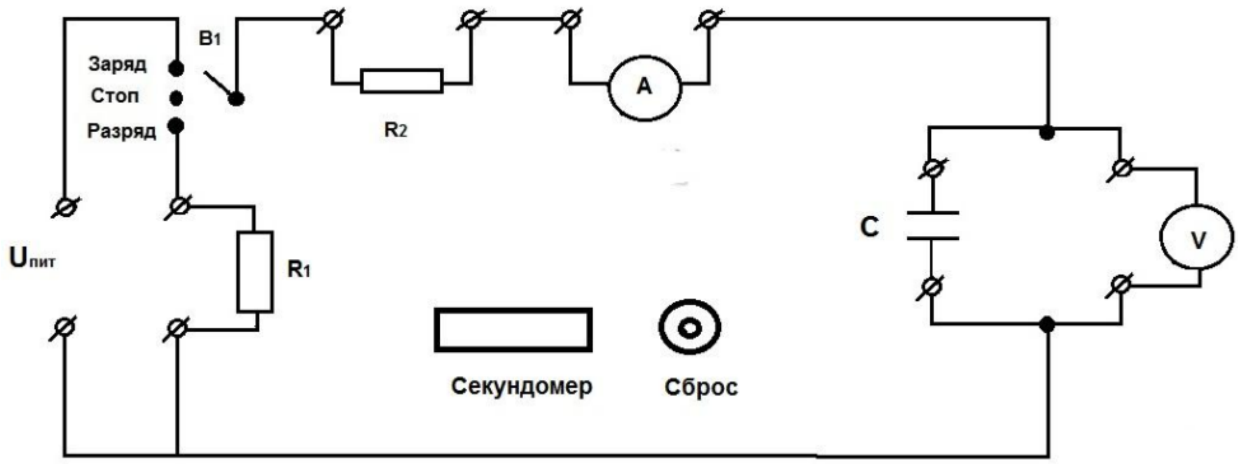
The graph of the function ln(E-U)=f(t) is a straight line (Fig. 2b). The tangent of the angle formed by the resulting straight line with the x-axis gives the constant inverse to RC. Now we logarithm (3):

$$lnU = lnE - \frac{t}{RC} \tag{5}$$

In this case, i.e. in discharge, lnU=f(t) gives a straight line, while the slope gives a constant opposite to RC (Fig. 3b).

There, expressions (4) and (5) make it possible to experimentally test the exponential nature of the transient process and determine the capacitance of the capacitor. The same theory can be investigated experimentally and used as laboratory work. The following scheme is used for this:

The experimental device consists of a current source and a measuring circuit (Fig. 4).



4-fig. Diagram of a device for studying transient processes in an RC circuit, terminals for connecting the Upit-current source, switch for changing the charge-discharge modes of the capacitor B1, R1, R2 - resistors, A - ammeter, B - voltmeter, C - capacitor, stopwatch - digital stopwatch scale, reset button Reset stopwatch.

The Upit terminals are supplied with voltage from the current source. Switch connector B1 has three positions. In the "charge" state, voltage is supplied to the capacitor through resistor R2. and in the "discharge" state, the capacitor is disconnected from the current source and discharged through R1 and R2. The stop position is the neutral position.

Ammeter A measures current in charge and discharge states. A voltmeter measures the voltage between the capacitor plates.

Charge-discharge time is measured with a digital stopwatch. In the "Stop" position, press "reset" to reset the stopwatch. When B1 is charging and discharging, the stopwatch will connect automatically.

In this case, first of all, for the charging process, a graph of the increase in voltage in the capacitor over time is obtained, after which, after the discharge, a graph of the voltage in the capacitor is again obtained. Formula (4) is used to calculate the capacitance from the voltage graph during charging. To do this, first fill out the following table:

t,s							
U, V							
E-U							
ln(E-U)							
RC, s							
C, F							

The graph of the function ln(E-U)=f(t) is constructed by drawing a straight line through the experimental points on the graph, RC is found from the tangent of the angle formed by this straight line with the abscissa axis, and the capacitance of the capacitor C will be found.

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