Justifying the duration of operation of a solar and battery-powered sprinkler machine

S M Bakirov¹, J V Ivankina¹, Sh Z Ziniev² and S S Eliseev¹
¹Saratov State Agrarian University named after N. I. Vavilov, 1, Theatralnaya Square, Saratov, 410012, Russia
²Grozny State Oil Technical University named after academician M. D. Millionshchikov, 100, H.A. Isaeva ave., Grozny, 364051, Russia
E-mail: bakirovsm@sgau.ru

Abstract. The development of solar energy allows considering a possibility of using solar panels as the main power source for mobile machines. Especially for the machines used in open sunlit spaces, for example, for sprinkler machines. This article discusses a problem of justifying the parameters of a power supply in the form of accumulator batteries charged from solar panels while ensuring the required duration of operation of a sprinkler machine. Studies show that the duration of operation depends on the time of day when a sprinkler machine is started, its accumulator battery parameters, duration of the recovery charge, climatic zone and the area of the solar battery. Dependence of these parameters was found on the duration of operation of the electric drive of the support trolley of one section of the sprinkler machine, and a graphical solution to this problem is provided.

1. Introduction
Use of renewable energy is a modern way to reduce energy costs. The development of solar power and continuous scientific research in the field of the energy potential of solar radiation allows considering a possibility of using solar panels as a source of energy supply for sprinkler machines [1,2]. Alternatively, the renewable energy sources are used in conjunction with accumulator batteries [3,4]. This is due to the peculiarities of energy conversion. For example, a solar panel generates electricity only during the day, and a wind generator-only when there is a sufficient speed of wind flow.

At other times, electricity is released from accumulator batteries that are installed together with a renewable source. Therefore, when considering such a source of energy for a sprinkler machine, first of all, it is necessary to take into account the parameters of the accumulator batteries. When using accumulator power supply with a charging from solar battery, it is necessary to ensure the specified duration of operation of the sprinkler machine. During the operation of the sprinkler machine section, the solar battery can be used as the main source of energy and for charging the accumulator battery. However, unlike accumulator batteries, the solar panel is affected by various factors that affect performance. These factors include cloud cover, dust, resistance of solar cells, ambient air temperature, wind speed, humidity, etc. [5,6].

However, despite the depth of study of the ways of using solar panels, there is a problem of justifying their parameters and parameters of accumulator batteries to ensure the agrotechnical requirements of irrigation and power supply of the sprinkler machine. Therefore, the purpose of this
work is to justify the parameters of the power supply of the sprinkler machine in the form of accumulator batteries with a charge from solar panels.

2. Materials and methods
Let us consider a scheme that includes solar cells, an accumulator battery and a load in the form of control devices for the sprinkler machine section and an electric motor for the mobile support of the sprinkler machine section [7]. The parameters of the solar battery are selected depending on the parameters of the accumulator battery, since the current flowing from the solar battery must provide the required charge current of the accumulator battery. To prevent accumulator battery discharge to the solar battery, a rectifier diode is placed in the accumulator battery charge circuit. Taking into account the voltage drop on the diodes and the loss of current passing through buses of the solar panel and cable lines, it is necessary to consider the number of elements connected in series \( x \) and in parallel series \( j \). The value of the discharge current of the accumulator battery during the operation of the sprinkler machine must correspond to the value of the load current. In an equivalent scheme of power supply from accumulator battery power supply with a charge from solar panels, it is necessary to take into account the variable components that flow in the circuit during transients.

3. Research results
We will study this power supply on the example of a single section of a sprinkler machine. Consider the processes that occur in the solar battery and accumulator batteries under the influence of environmental factors. To describe these processes, we will draw an electrical equivalent circuit in which \( x \) serially-connected and \( j \) parallel-connected solar cells are wired to the accumulator battery.

![Figure 1. Equivalent circuit of the energy supply of one section of the sprinkler machine with an accumulator power supply with a charging from solar battery: \( i_{ph1-4} \) is photocurrent flowing through the solar battery; \( R_{1-4} \) are the internal resistance values of the solar battery; \( VD_{1-4} \) are diodes to prevent the damaging effects of shading solar cells; \( C_{1-4} \) are solar battery capacity values; \( VD_{SB} \) is a diode from solar battery to accumulator battery; \( x \) is the number of series-connected elements; \( j \) is the number of parallel-connected elements; \( R_{ACC0-1} \) are resistance of the accumulator battery; \( C_{ACC0-1} \) are the accumulator battery capacitance values; \( L_{ACC} \) are inductive resistances of the accumulator battery; \( e_{ACC} \) is the electromotive force of the accumulator battery; \( R_{contr} \) is the resistance of the controller, \( L_{contr} \) is the inductive resistance of the controller; \( C_{contr} \) is the capacitive resistance of the controller; \( i_{contr} \) is the controller current; \( R_{device} \) is the resistance of the control device elements; \( C_{device} \) is the capacitive resistance of the control device; \( L_{device} \) is the inductive resistance of the control device; \( R_{m\_motor} \) is the resistance of the electric motor circuit conductors of the sprinkler section; \( L_{m\_motor} \) is the inductive resistance of the electric motor circuit.
conductors of the sprinkler section; $C_{el.motor}$ is the capacitance resistance of the electric motor circuit conductors of the sprinkler section; $R_{el.motor}$ is the internal resistance of the motor elements of the sprinkler section; $L_{el.motor}$ is the inductive resistance of the electric motor elements of the sprinkler section; $C_{el.motor}$ is the capacitance resistance of the electric motor elements of the sprinkler section; $i_{sb}$ is the circuit current of the solar battery; $i_{acc}$ is the accumulator battery circuit current; $i_{el.motor}$ is the electric motor circuit current.

The presented equivalent circuit takes into account dynamic modes, which are not considered in this study. Therefore, for a more visual representation, we depict energy supply equivalent circuit in Figure 2.

Figure 2. Equivalent circuit of the power supply of the sprinkler machine section from accumulator battery with a charge from solar panels, prepared for calculation: $e_{SB}$ is the electromotive force of the solar battery; $R_{SB}$ is the internal resistance of solar cells; $i_{sb}$ is the circuit current of the solar battery; $R_d$ is a diode resistance, $i_d$ is a diode circuit current; $R_{ACC}$ is an internal resistance of accumulator battery cells; $i_{c.device}$ is a control circuit current.

Let us consider resistance $R_{contr}$, $R_{c.device}$, $R_{el.motor}$, for equivalent resistance $R_{eqv}$ or

$$R_{eqv} = R_{contr} + \frac{R_{el.motor} R_{c.device}}{R_{el.motor} + R_{c.device}}. \quad (1)$$

While taking into account (1), let us transform the equivalent circuit of the power supply chain in figure 3 and calculate the resulting circuit according to taking the direction of currents and voltage at the clamps 1,2.

This electric circuit is considered from the point of view of the action of two electromotive forces, taking into account the synchronization conditions, in one circuit, which, according to the principle of superimposition, induce their currents in each branch.

Will calculate the current and the required value of the voltage at the clamps to which the load is connected, using the method of contour currents [8].
Using the theory of electrical circuits [9], the voltage across the clamps $U_{12}$ is described by the following expression

$$U_{12} = \frac{e_{SB}}{(R_{SB} + R_d) + \frac{1}{R_{ACC}}} + \frac{e_{ACC}}{\frac{1}{R_{ACC}} + \frac{1}{R_{eqv}}},$$

or

$$U_{12} = I_{12} R_{12},$$

where $I_{12}$ is the current at the clamps «1-2»; $R_{12}$ is the resistance at the clamps «1-2».

Let us denote the load power at terminals 1-2 as

$$P_{12} = U_{12} I_{12}.$$

In view of (4), equate expressions (2) and (3)

$$P_{12} = \left\{ \frac{e_{SB}}{(R_{SB} + R_d) + \frac{1}{R_{ACC}}} + \frac{e_{ACC}}{\frac{1}{R_{ACC}} + \frac{1}{R_{eqv}}}, \right\} I_{12}. \tag{5}$$

The duration of power use over time shows energy consumption. Therefore, we will multiply both sides of expression (5) by the time interval of operation of the section of the electrified sprinkler machine.

$$P_{12} t = \left\{ \frac{e_{SB}}{(R_{SB} + R_d) + \frac{1}{R_{ACC}}} + \frac{e_{ACC}}{\frac{1}{R_{ACC}} + \frac{1}{R_{eqv}}}, \right\} I_{12} t. \tag{6}$$

We will express resistance $R_{SB}, R_{ACC}, R_d, R_{eqv}$ in (6) as electrical conductivity $g_{SB}, g_{ACC}, g_d, g_{eqv}$.
Let us assume that the electrical conductivity in circuit the solar battery and the diode is equal to the conductivity in the accumulator battery circuit [10]. Let us denote the electrical conductivity in the solar and accumulator battery circuits as \( g \), then we get
\[
g_{SB} + g_d = g_{ACC} = g_{eqv}
\] (8)

Then expression (7) will take the form
\[
P_{12}t = \left( 2 + \frac{g_{eqv}}{g} \right) I_{12}t
\] (9)

The ratio of the equivalent conductivity of the \( g_{eqv} \) to the conductivity in the solar battery and accumulator battery circuits will denote as \( G \)
\[
\frac{g_{eqv}}{g} = G
\] (10)

Then, after reductions and transformations, expression (9) takes the form
\[
P_{12}t = \frac{e_{SB} + e_{ACC}}{2 + G} I_{12}t
\] (11)

Multiply, then the expression
\[
P_{12}t = \frac{e_{SB}I_{12}t + e_{ACC}I_{12}t}{2 + G}
\] (12)

where
\[
e_{SB}I_{12}t = W_{SB}
\] (13)

\( W_{SB} \) is the energy of solar battery
\[
e_{ACC}I_{12}t = W_{ACC}
\] (14)

\( W_{ACC} \) is the energy of accumulator battery.

In view of (13) and (14), expression (12) takes the form
\[
P_{12}t = \frac{W_{SB} + W_{ACC}}{2 + G}
\] (15)

Let us use (15) to express the operating time of the section of the sprinkler machine from battery power with a charge from solar batteries
\[
t = \frac{W_{SB} + W_{ACC}}{P_{12}(2 + G)}
\] (16)

Thus, the duration of operation of the sprinkler machine will depend on the energy reserve of the accumulator battery and the energy received from the solar battery, as well as on the load power and the relative specific electrical conductivity of the intermediate elements of the circuit. Let us plot a graphical solution of this expression in Figure 4.
4. Conclusion

Thus, the theoretical justification and graphical representation of the duration of operation of the electric drive of the support trolley is not limited to just one section and can be applied to the sprinkler machine as a whole. Research shows that a section of the sprinkler machine will work longer with the energy reserve from a solar panel that has a larger area. The graph (Figure 4) shows the duration of operation of the sprinkler machine section at any turn-on time $t_0$. If the sprinkler machine is switched on in the morning or afternoon time interval $t_0$, then the power reserve will increase by the amount of $\Delta t$ from $t_1$ to $t_S1$ for the area of the solar battery $S1$. If the area of the solar battery is twice as large as $S2$, the duration will increase by $2\Delta t$ from $t_1$ to $t_S2$. In cloudy weather, with the area of the solar panel $S1$, the duration of operation of the electric drive will increase, but in proportion to the cloud score, to the value $t_{S1}$. If the operation of the sprinkler machine section starts at night, the solar panel will not be able to provide an additional power reserve and the duration will be $t_1$. The graph also shows the maximum energy reserve and the critical energy reserve, which is determined by the parameters of the accumulator battery.

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