The rationale for the method of powering rail electrified machines

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Abstract. The article presents the rationale for the choice of the method of powering electrical equipment for rail electrified machines used in greenhouses (frame areas). The comparison of two power sources according to the criterion of minimum operating costs is given. The main operating costs of machines with cable and battery power supply methods are highlighted, and cost components are shown. An expression that allows you to make a choice between cable and battery power supply is obtained. The choice of the method of power supply depends on the length of the greenhouse row, which determines the length of the cable line, on the duration of use of the rail mobile electrified machine during the day, on the difference in energy consumption during the direct conversion of electric into mechanical energy and through a battery, on the cost of batteries and cable.

1. Introduction
In greenhouses it is decided to increase the yield by introducing various technologies and tools. The wide implementation of the main development plan is accompanied by measures to save energy and reduce operating costs. In these conditions, not only the application of quickly paying back measures is relevant [1,2], but also the application of fundamental adjustments to multi-production technologies is necessary.

One of the ways to improve production is to optimize time-consuming and long-lasting processes. As a rule, optimization is carried out by the criterion of the lowest costs for a specific period of time and space without a detailed account of the real factors and the life of the process. Taking into account the achievements [3-5], it becomes necessary to check and substantiate the effectiveness of new solutions throughout the entire service life.

In greenhouse production, one of the established processes is the process of harvesting and processing plants using rail electrified machines (REM) [3,4]. In the cost structure of the product, this process using REM is 6-11% [6]. The maximum value of the share of production costs is determined by the productivity of the harvest of ripe crops. Otherwise, with a slow harvest, the ripe harvest begins to deteriorate, which leads to a short production. Using REM is the only way to increase productivity.

Further we will consider the main characteristics of rail electrified machines.

Operating the REM on battery power is associated with a specific implementation of a set of technical procedures: - timely checking the discharge and charge characteristics of the AB; - purchasing the AB charge device; - assembling circuits for parallel connected AB; - provision of dedicated personnel for AB care, etc [7,8]. Considering the various ways of powering an electrified rail machine, a number of difficulties of their application can be identified. For example, the use of cable power requires the...
connection of power points or the use of diesel generators requires the creation of special filling stations, etc. At the same time, a change in the technological process in the greenhouse entails additional production costs. The developments in this field [9, 10] solve particular problems of nutrition methods in related sectors of the national economy. Nevertheless, the problem of evaluating the nutritional options for REM in a greenhouse has not been resolved.

The objective of this study is to substantiate the choice of the method of power supply of a rail electrified machine for the stated service life of a rail vehicle.

2. The object and method of research
The main power sources for such machines are various models of accumulator batteries (AB) [5]. A general view of the machine is shown in Figure 1.

![Figure 1. General view of rail electrified machines: 1 – rechargeable battery; 2 – cabin; 3 – remote control; 4 – electric drive; 5 – trolley frame; 6 – shipping wheels; 7 – drive wheels; 8 – thermal register; 9 – cabin fixing system; 10 – guides.](image)

In general, analyzing the work of REM on AB and short battery life, the operating costs of these machines are too high. And they are associated with the source and method of nutrition. A preliminary estimate of the cost of 1-2 years of operation justifies the use of battery power, and for 5-7 years leads to unjustified expectations and increases operating costs by 4-7 times. The cost of the battery is included in the total cost of the REM. The operational costs of battery maintenance increase every year exponentially. As a result, the frequent discharge-charge mode after 1-2 years of operation leads to the failure of the battery. In these conditions it is necessary to buy additional new batteries. Thus, every 2 years the cost of the purchase increases by 18.0-22.0% of the total cost of the REM [8]. This situation leads to the fact that this method of power becomes too expensive.

3. Results and Discussion
Power can be supplied using a portable generator, cable line, battery, trolls, etc. Based on the technological features of greenhouse production, the supply of power using some methods is difficult to perform. There is a need to change the technological features of greenhouses. Therefore, for consideration, we single out the most feasible power supply methods - AB and cable line (CL). These methods will be considered according to the criterion of minimum operating costs [3,5].

Let us write out the cost components, where in annual operating costs we will separately highlight maintenance costs and electricity costs.

The main costs of the power system of the REM with the battery Z_{AB}, are the costs associated with the purchase of batteries, their mounting, the acquisition of a drive with a DC motor and its control system.
where $E$ – the normative coefficient for bringing investments to 1 year, $E = 0.15$; $K_1$ – the cost of the AB power supply method, rub.; $N_1$ – annual maintenance costs of the AB, rub.; $I_1$ – annual electricity costs, rub.; $O_1$ – the cost of the DC motor and its control system with direct current, rub.; $D_1$ – annual damage from machine downtime, rub.

Let us also consider the cost of the method of power supply from the cable line $Z_{cl}$ on the method of powering the machine from the AC network

$$Z_{cl} = E \cdot K_2 + N_2 + I_2 + E \cdot O_2 + D_2,$$

where $K_2$ – the cost of the method of supply on alternating current, rub.; $N_2$ – the annual cost of servicing the cable line, rub.; $I_2$ – the annual cost of electricity, rub.; $O_2$ – costs for an AC electric motor and its control system, rub.; $D_2$ – annual damage from machine downtime, rub.

Power supply costs include the source itself and its attachment device. For the first method, this is a rechargeable battery and the place of its attachment, and for the second, a cable of the appropriate length, a device for its connection and a device for its attachment (suspension) when moving the machine.

The operation of AC cable on alternating current places demands on the safety of personnel, as well as the technological capability of pulling it for a row length. These components can be included in the price of a double insulated cable and the principle of cable twisting (Figure 2)

![Figure 2. Cable twisting device: 1 – return spring; 2 – drum; 3 – cable.](image)

We will accept the condition under which the use of a cable line as a power source will be beneficial, then

$$Z_{AB} > Z_{cl},$$

or

$$Z_{AB} - Z_{cl} > 0,$$

The scrupulous accounting of all components will lead to the complexity of calculations and, as a result, to the loss of the obvious influence of the main factors, therefore in this calculation we will accept a number of assumptions that will not affect the true dependence of the data.

Assume that the annual damage from machine downtime does not depend on the power supply system and is equal to

$$D_2 = D_1.$$

Modern technologies of production and operation of AB, provide no maintenance of their main component - the electrolyte. Therefore, these chemical power sources are not collapsible, and for such ABs, preventive inspections of the case for integrity and oxidation state of the terminals should be carried out. Modern AB is not serviced (on the passport). However, there is a need to recharge the AB when operating the machine, which can be considered maintenance.

Cable lines (CL) need to be serviced, as frequent unwinding and twisting of the cable on the drum can damage the insulation. If we accept that the annual complexity of the maintenance of the cable line corresponds to the annual complexity of AB maintenance; and these types of work are performed by personnel of the same qualification, then

$$N_1 = N_2.$$

The cost of battery power depends on the price $c_{AB}$ (rub.) of one battery and their number $n_{AB}$. The
AB attachment device is assumed to be equal to zero, since the batteries have a form convenient for installation on any flat surface, then

\[ K_1 = c_{AB} \cdot n_{AB}. \]  \hspace{1cm} (7)

The number of batteries can be determined by the minimum duration of use of the rail machine during the day \( t_d \) from the expression

\[ n_{AB} = \frac{W_{AB}}{P_e \cdot t_d}, \]  \hspace{1cm} (8)

where \( W_{AB} \) - the amount of energy in the battery, kW·h; \( P_e \) - power consumption of the electric motor and its control system, kW.

In turn, the cable method of supply is characterized by costs, which are defined as the product of the price of one meter of cable \( c_{cl} \) (rub./m) for its length \( l \) (m) with the assumption that the cable twisting device is included in cable cost. Then the cost of the power supply from CL will take the following form

\[ K_2 = c_{cl} \cdot l. \]  \hspace{1cm} (9)

Let us consider the annual cost of electricity. Electricity costs for battery mode

\[ I_1 = W_C \cdot c_e, \]  \hspace{1cm} (10)

where \( W_C \) - annual amount of electricity to charge AB, kW·h; \( c_e \) - electricity price, rub./kW·h.

Electricity costs of cable mode power:

\[ I_2 = W \cdot c_e, \]  \hspace{1cm} (11)

where \( W \) - the annual amount of electricity consumed by the control system and the electric motor, kW·h.

The cost of the purchase of electrical equipment used in rail electrified machines consists of the cost of the electric motor and its control system. As a rule, in various sources \([8,9]\) it is noted that the cost of electric motors on alternating current is 1.5-3 times less. In this case, when comparing the methods of power supply by source, let us assume that the cost of sets of electrical equipment with direct and alternating current is

\[ C_{O2} = C_{O1}. \]  \hspace{1cm} (12)

Let us substitute expressions (5 - 12) into expression (4) and after conversion we get

\[ \frac{c_{AB} \cdot W_{AB}}{P_e \cdot t_d} - c_{cl} \cdot l \geq c_e \cdot (W - W_C). \]  \hspace{1cm} (13)

In expression (13), the right-hand side of the inequality indicates the difference in the amount of electricity consumed by the AC electrical equipment and the electrical energy required for recharging the AB, and during the year of operation may be insignificant. Taking the right side of the expression (13) equal to zero, we get

\[ l \leq \frac{c_{AB} \cdot W_{AB}}{c_{cl} \cdot P_e \cdot t_d}. \]  \hspace{1cm} (14)

The resulting expression (14) shows the generalized conditions for the choice of the power supply method REM without taking into account the integral indicators. The graphic presentation of the given inequality is as follows
Figure 3. The boundaries of the choice of the method of powering rail electrified machines.

From the above it follows that with the initial data - the length of the row of the greenhouse is about 65m \((l = 65\, \text{m})\) and the average duration of use of the machine per day is not more than 3 hours \((t_d = 3\, \text{h})\) we find point A in Figure 3, which falls into the region of optimal use of rail electrified machine with cable power supply, if the amount of energy stored in the battery is not more than 720 W·h. If under the same conditions in the battery there is more stored energy \(W_{AB} = 1440\, \text{W·h}\), then in this case the application of the battery power supply will be optimal.

4. Conclusion

Thus, the analysis of the obtained theoretical studies showed that many factors influence the choice of the method of powering electrified rail machines. The main factors are the row length parameter, which determines the length of the power cable \(l\) (m), the duration of use of the rail vehicle during the working day \(t_d\) (h), and also on the amount of stored energy in the battery pack \(W_{AB}\) (W·h), which is determined by the number of rechargeable batteries. With this in mind, it is graphically established that with the cumulative use of REM no more than 1 h it is advisable to use the battery power supply method for any length of the row of the greenhouse. At the same time, it was also established that with a daily occupancy of REM of more than 3.5 h, it is advisable to use the cable method of power supply.

References

[1] Vodyannikov V T 1997 Economic evaluation of means of electrification and automation of agricultural production and the rural energy system (Moscow: MSAU) 180p.

[2] Gimelli A, Mottola F, Muccillo M, Andreotti A, Langella G 2019 Optimal configuration of modular cogeneration plants integrated by a battery energy storage system providing peak shaving service Applied Energy 974–993

[3] Eroshenko G P, Kondratyeva N P 2017 Electrical equipment operation: textbook (Moscow: INFRA) 336 p.

[4] Bojoi R, Armando E, Pastorelli M Lang K 2016 Efficiency and loss mapping of AC motors using advanced testing tools Proceedings 22nd Int. Conf. on Electrical Machines, ICEM 2016 7732654 pp 1043-1049

[5] Ragmani A A, El Omri A, Abhgour N, Moussaid K, Rida M 2018 Novel green service level agreement for cloud computing using fuzzy logic CLOSER Proc. of the 8th Int. Conf. on Cloud Computing and Services Sci. pp. 658–665
[6] Bobryshev A N, Klenov N A 2015 *Methods of calculating the actual cost of production of greenhouses* *Agrarian science, creativity, growth* (Stavropol: The limited liability company Sequoia) pp 18–22

[7] Wang Z, Zhang N, Yu M, Wang S, Qiu J 2019 Boosting redox activity on MXene-induced multifunctional collaborative interface in high Li₂S loading cathode for high-energy Li-S and metallic Li-free rechargeable batteries *J. of Energy Chemistry* 183–191

[8] Amooi R, Moghaddas-Tafreshi S M 2019 Operation of an active distribution network with PV and storage battery and vehicle charge station and modeling of uncertainty with copula model *10th Int. Power Electronics, Drive Systems and Technologies Conf., PEDSTC* 8697757 pp 407–414

[9] Wang C, Zhang T, Luo F, Li P, Yao L 2018 Fault incidence matrix based reliability evaluation method for complex distribution system *IEEE Transactions on Power Systems* 33(6) 6736–6745

[10] Oskin S V, Bogatyrev N I 2016 *Electric drive* (Krasnodar: KubSAU) 490 p