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Reducing the Costs for Consumed Electricity through the Solar Energy Utilization

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ABSTRACT

The priority development direction of the Rostov region as the largest agricultural producer of Russia is the creation of modern, competitive processing industries. Since the beginning of 2015, despite record harvests of cereals, the wheat flour cost has been steadily increasing and now exceeds the peak values for the previous period from 2008 to 2015. This caused by the high share of payment for consumed electricity in the production costs, which is approximately 30%, and significant increase in tariffs for it in the last 10-12 years due to unjustifiably high costs of equipment maintenance and operation in grid companies, liquidation of cross-subsidizing prices, as well as rising gas prices. Under conditions of the existing high solar energy potential in the territory of the South of the country, the implementation of technologies for its transformation into electricity will reduce energy costs and, consequently, reduce the costs of produced goods and services. The purpose of the presented research was to determine the composition and parameters of the equipment of a solar electrical power plant that provides energy to the lighting system of the flour milling section No. 1 and No. 2 of the processing plant Ltd. "Rostovremagroprom" in Zernograd of the Rostov Region, taking into account the assessment of the solar radiation intensity during the year, the structural features of the building roof and features of the company's load graph. Full solar energy potential (1246.87 kWh/m²) is possible to realize at the facility partly due to the existing technical limitations imposed by the building roof construction. The design and implementation of economically feasible additional power supply system for the lighting system of the flour-milling departments of the enterprise excludes the usage of accumulating devices, allowing to reduce the annual costs for the payment of consumed electricity by approximately 45 thousand rubles by decreasing the cost of each 1 kilowatt-hour of consumed electricity from 8.1 rubles/kWh to 3.6 rubles/kWh during the period of intense activity of the Sun.

Keywords: Solar Energy Potential, Inclination Angle of the Receiving Surface, The Layout of the Solar Power Plant

JEL Classifications: O13, O44

1. INTRODUCTION

In recent years the agro-industrial complex and its state have determined not only the effective functioning of the economy, but also are a priority and an important line for its intensive, dynamic development. At the same time, one of the main tasks in the food production and food security in the country is the creation of modern competitive business enterprises and technologies for processing agricultural products. One of the largest agricultural regions of the Russian Federation is the

Rostov Region, in which one third of the population works in agriculture and at the same time, of a total of 8.2 million hectares of agricultural land, 5.8 million hectares are tillage land and about 100 kinds of crops are cultivated on it. 50% of tillage land is used for crop rotation of cereals and the winter wheat is the main crop (The site of the Ministry of Agriculture...). Therefore, food and processing industry have the first place among productions according to the volume of shipped goods and its contribution to the total regional industrial production is about 28%.

According to preliminary estimates in all sectors of the agro-industrial complex of the region for the first quarter of 2016, twice as many investments were attracted as compared to the same period of 2015, which is 4.7 billion rubles. According to statistical research, regional agricultural production increased by 53.4% over the period from 2011 to 2015, and by 2.3 times from 2006 to 2015 (Territorial Body of the Federal State...).

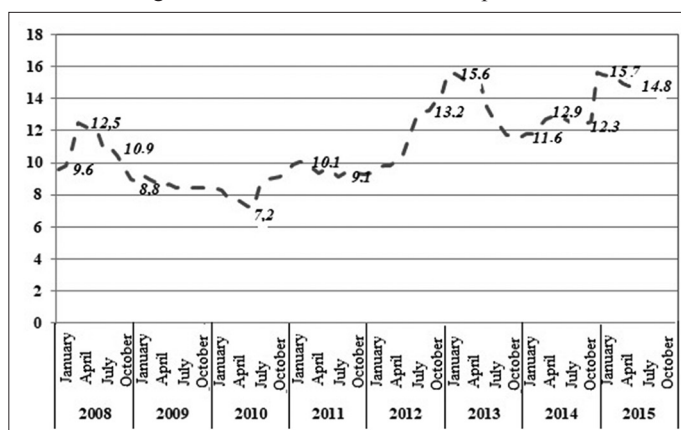
The entrance of agricultural products produced in the Rostov region to the international export markets, the largest exporter of food products and raw materials in the south of Russia, is possible only if high-quality agricultural products are produced at competitive prices. Figure 1 shows the dynamics of average wholesale-selling prices for wheat flour for large and medium flour mills for the period 2008–2015.

Analysis of the data in Figure 1 shows that in the period from mid-2008 to the end of 2010, the wheat flour price was reduced to a minimum of 7.2 rubles per kilo, followed by a rapid increase to 15.6 rubles per kilo in January 2013. Until the end of 2014, such a leap was leveled to 11.6–12.3 rubles per kilo, but since the beginning of 2015 the flour cost has been steadily growing and exceeds the peaks of the previous period from 2008 to 2015.

The cost of production increases primarily due to the fact that over the past 10–12 years in Russia has been an intensive growth tariffs for electricity. The reasons of it are excessively high costs for operation and upkeep of power equipment in grid companies, elimination of cross-subsidization of prices and gas prices growth. In spending pattern for processing grain crops the share of costs for payment for consumed electric energy is about 30% at the moment.

Due to high potential of available solar energy in the south application of technologies of its converting into electricity will allow reducing the amount of payment for consumed electricity by agricultural enterprises, and consequently, will reduce the cost of products and services. Despite the obvious advantages of photovoltaics, the area of its use in the Russian Federation is now limited due to a lack of state support and still high capital costs (Gautam et al., 2015; Belenov et al., 2016; Rabat et al., 2018).

Figure 1: Dynamics of average wholesale-selling prices for wheat flour for large and medium flour mills for the period 2008–2015



The available experience in applying the technology of converting solar energy into electric energy is diverse (Wittenberg and Matthies, 2016; Hernández et al., 2018). It shows the most important in designing such systems is parametrization of solar generating power plant elements. Such significant factors as geographic location, the level of solar radiation during the year, consumption patterns, including the installation and maintenance of the system throughout its lifetime should be taken into account.

Despite the fact that a lot of work has been devoted to the choice of the optimal spatial orientation of photovoltaic panels, locations to avoid shading of their surfaces, most often the complete utilization of the available solar potential of the territory is limited (Martinez-Rubio et al., 2015). Most researchers suggest that there is no barrier between the Sun and the receiving surface from sunrise to sunset. In fact, mutual shading, partial shading from neighboring buildings and structural elements of the roof itself can significantly reduce the efficiency of the solar module (Moghadam and Deymeh, 2015). In addition, the initial approach is valid with flat roof and the spatial orientation of the battery is due to the angle of inclination and the orientation of the roof slope along the sides of the light (Gautam et al., 2015; Belenov et al., 2016; Kapitonov and Voloshin, 2017).

Thus, for each specific object on which it is intended to use solar array electrical power, it is necessary to prepare a separate study of the roof sections. It allows to provide the maximum insolation flux or it is necessary to select the parameters of the solar generating power plant that would allow to organize the required level of energy consumption.

The purpose of the study is to determine the structure, composition and general equipment parameters of a solar generating power plant to provide electricity to the lighting system of the flour mill section No. 1 and No. 2 of the processing enterprise LLC Rostovremagroprom in the city of Zernograd in the Rostov Region. The intensity of solar radiation during the year, the structural features of the roof building and load schedule features should be taken into account.

2. METHODOLOGY

The proposed approach to the search for the parameters of a solar power plant that makes it possible to provide economically feasible electric energy generation includes tentative decision of searching for the number of photovoltaic panels taking into account their spatial orientation, the potential of the solar energy of the area, and the size of the placement field. The criterion here is the minimum value of the cost of the generated electric energy:

$$\sum_{i=1}^L \left(\frac{K}{T_s} \right) / \sum_{n=1}^{362} \sum_{t=t_1}^{t_2} \left[Rsum_{\beta\gamma}(t, n) \cdot N \cdot S_{\phi n} \cdot \eta_{\phi n} \right] \rightarrow \min \quad (1)$$

where $Rsum_{\beta\gamma}(t, n)$ are hourly sums of total solar radiation for a geographic point with coordinates (ϕ, n, λ, E) for the time instant t in day n ; N , $S_{\phi n}$, $\eta_{\phi n}$ are the quantity (pieces), the surface area (m^2) and the coefficient of efficiency (pu) of the photovoltaic panel, respectively; t_1 and t_2 are the beginning and the end of the

day; K , T_e are the cost and lifetime of the i -th element of the solar photoelectric power station, respectively.

There are limitations in the process of solving this optimization problem:

1. The value of the angle of inclination of the collecting surface with relative to the horizon lies in the range $0^\circ \dots 90^\circ$.
2. The value of the orientation angle of the receiving surface along the sides of the light lies in the range $-90^\circ \dots 90^\circ$.
3. Size of the placement field $a \times b$, m.

The solar energy potential for the city of Zernograd in the Rostov region was determined using the express method for estimating the potential of solar energy at a given point in the south of Russia (Camargo et al., 2015; Daus et al., 2016a; Daus and Kharchenko, 2018a; Daus et al., 2018b). It was implemented as a computer program in which the geographic coordinates and spatial orientation of the receiving area are the basic data (Daus et al., 2016b). The search for the optimal angle of inclination of the collecting platform relative to the horizon at a given point in the Southern Federal District was also carried out using a computer program (Daus et al., 2016c).

To assess the reliability of the reached solution, we will select the number of photovoltaic panels based on the required daily amount of electric energy consumed for the 15th day of each month. The estimated operating time of solar batteries was taken from 8.00 to 17.00 (Daus et al., 2018c).

3. RESULTS AND DISCUSSION

For a geographic point with the coordinates of the location of the processing plant, the flux of solar radiation incident on the collecting area at an angle of 10° and 15° was calculated, which matches to the roof slope angle and 30° to the horizon, which equals the optimal slope angle to the insolation surface.

Figure 2 shows the using of the optimal tilt angle that is unregulated during the year makes it possible to utilize the maximum amount of solar radiation per year. But in the period from May to September, when the insolation value is the highest, the receiving area at an angle of 10° and 15° the amount of incident solar radiation.

Using photo-electric monocrystalline batteries of the brand FSM-200 (Okhotkin, 2013), they selected the required number of photovoltaic panels based on the daily demand for electrical energy by the example of the 15th day of each month. The results of calculating the daily output of electrical energy by photoelectric panels selected for July 15 ($n = 196$) are shown in Figure 3.

The dependence of the cost value of the generated electric energy of the solar power plant on the number of photovoltaic panels was also revealed, taking into account the accumulation of excess generation in the traditional layout. That is the southern orientation of the photoelectric panels at the optimum angle to the horizon (Figure 4).

Figure 2: Monthly and annual sums of intensity of solar radiation on differently oriented surfaces for the city of Zernograd

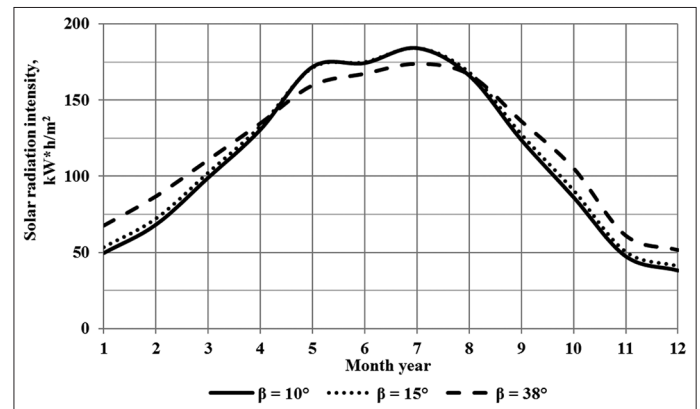


Figure 3: The daily amount of electric energy produced by photovoltaic panels, selected for July 15

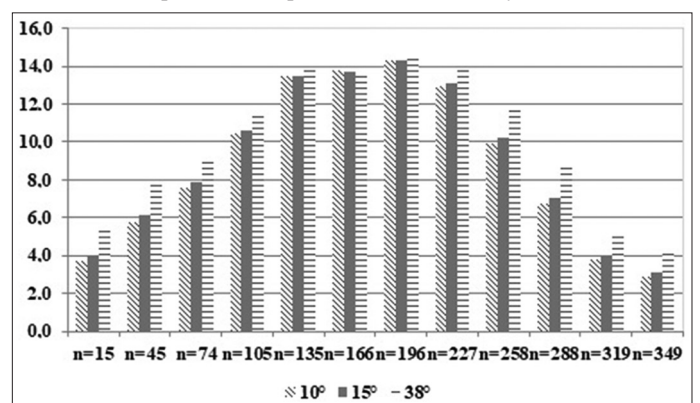
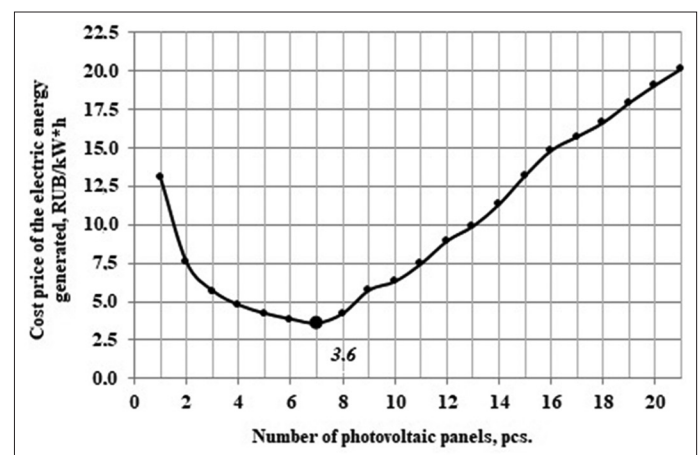


Figure 4: Dependence of the cost price of the electric energy generated by a solar power station depending on the number of photovoltaic panels



The minimum cost value of the electric power generated by the solar power plant corresponds to the number of photovoltaic panels equal to 5. It can be seen that a smaller amount is characterized by an increase in the generation volume prevailing over the increase in the value of the project's capital cost. After the minimum point, a further jump in the cost value is observed (by 42.3%), since from 6 photovoltaic panels an increasing amount of excess electricity is needed to accumulate and the share of costs for equipment storage increases from 14.7% to 67.2%.

However, with the help of the proposed criterion (the minimum cost value of generated electric energy), it is possible to choose such an option for the layout of a solar power plant that will also provide the lowest cost price of the generated electric power. Excess of generated electrical energy can be used for process reorganization or improvement of the conditions of people's housing, office premises (air conditioning, ventilation, hot water, etc.). 30 photovoltaic panels on a flat part of the roof, arranged at an angle of 38° to the horizon in two rows is the solution to this problem. The distance from the front edge of the roof is 18 m and between the rows is 20 m (the maximum amount that can be located on the flat part of the roof, based on the condition of mutual shadowing of rows and from the elements of the roof structure, and also based on the size of photovoltaic panels);

We will analyze the reliability of the gotten result with the help of the proposed criterion taking into account the payback period and for that we consider seven variants with a different number of photovoltaic panels on different parts of the roof (decision under No. 1):

1. 30 photovoltaic panels on a flat part of the roof, located at an angle of 38° to the horizon in two rows; distance from the front edge of the roof is 18 m, between the rows is 20 m.
2. 16 photovoltaic panels on a flat part of the roof, located at an angle of 38° to the horizon in two rows; the distance from the front edge of the roof is 18 m, between the rows is 20 m (this arrangement allows completely to cover the daily amount of electric energy consumed in June and July).
3. 68 photovoltaic panels on the inclined part of the roof, arranged in two rows at an angle of 10° and 15° , respectively (a daily amount of electrical energy is covered).
4. 16 photovoltaic panels on the inclined part of the roof, arranged in a single row at an angle of 15° (this arrangement allows to cover the daily amount of electric energy consumed in the summer period fully).
5. 30 photovoltaic panels on a flat part of the roof, located at an angle of 38° to the horizon in two rows; distance from the front edge of the roof is 18 m, between the rows is 20 m; 25 photovoltaic panels of the inclined part of the roof, arranged in a single row at an angle of 15° (yearly the amount of electric energy is covered).
6. 21 photovoltaic panels on the inclined part of the roof, arranged in two rows at an angle of 10° and 15° , respectively (daily consumption is provided in summer, one spring and autumn month).
7. 32 photovoltaic panels on the inclined part of the roof, arranged in two rows at an angle of 10° and 15° , respectively (daily consumption is provided in summer, two spring and autumn months).

For all presented options for the layout of the solar power plant, the amount of generated electric energy, its shortage or excess in comparison with the annual load, was specified. The results of the calculation are presented in the Table 1.

As a result of the calculation of technical and economic indicators, the payback periods of each variant of the solar power plant layout were determined, with and without additional storage equipment (Figure 5).

It is possible to increase the economic feasibility of using additional power supply from a solar power station by switching to a two-part tariff for electricity, which will reduce the cost of one kw-hour of electricity during the period of solar activity, when the tariff is the highest and receive electricity from the network at a lower tariff at night. As a result, a minimum payback period was obtained for the third variant of the layout of the solar power plant and it's 7.8 years that below the norm for the power industry, while saving money for paying for consumed electricity is more than 45 thousand rubles per year, at a cost price of 3.8 rubles/kW·h. The lower cost value was obtained with the first variant of the arrangement (3.6 rubles/kWh), however, in this case the payback period is longer and it's 8.5 years. But at the same time this option is a priority because it requires less reconstruction and reorganization of the power supply system with the subsequent optimization of its operation mode.

Figure 6 shows the cost of consumed kWh of electrical energy during the day for the selected variant of the layout of the solar power plant (No. 1).

Let's analyze the cost of electricity to provide power supply to the lighting system of the milling sections of the processing plant. It is 8.15 RUB/kW·h (the tariff applicable for the processing plants of the Rostov region in April 2017) the largest one when buying electricity from the electricity grid. With additional power supply from the solar power plant in the period of solar activity (from 700 to 2100) this value is reduced to 4.2 rubles/kWh and it's 44.7% lower than the current tariff. At the same time, the decrease is smooth and reaches a minimum of 13.00, which is the insolation

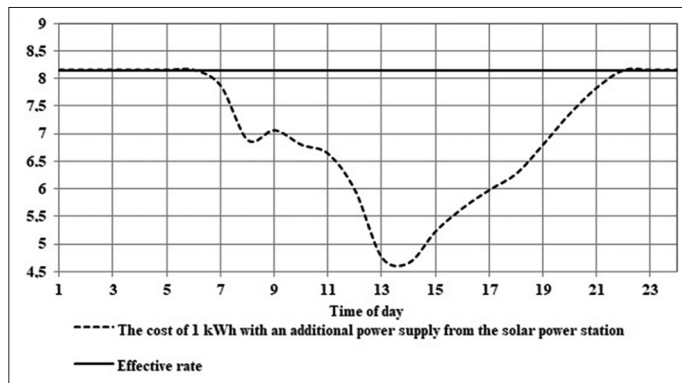
Table 1: Results of electric energy generation for different variants of the layout of a solar power station

Wgen year, kW·h	ΔW_{gen} year, kW·h	The maximum daily relative value of the excess or shortage of the generated electrical energy, % for n=182 (%)
6496.4	1494.0	89.5
3464.7	-1537.7	1.1
14028.8	9026.4	361.4
3300.9	-1701.5	8.6
11241.4	6239.0	245.6
4332.4	-670.0	42.5
6601.8	1599.4	111.7

Figure 5: Terms of payoff of various options for the layout of a solar power plant



Figure 6: Cost of the consumed kWh of electric energy for power supply from the grid and with additional power supply from a solar power station



peak and is due to the nature of the arrival of the solar radiation flux to the collecting surfaces of the southern orientation equally located in space. During the functioning of the solar power plant, the cost of electricity is reduced by 7.9%–14.1% in the morning hours, and by 32.5%–44.7% at high solar activity.

4. CONCLUSIONS

The total potential of solar energy for the Zernograd district of the Rostov region may be partially realized because of the technical limitations imposed by the features of the roof structure (small flat roof parts were taken for design), the conditions of its shading, the fixed angle of its slope.

The organization of an economically feasible additional power supply for the lighting system of flour milling sections of a processing plant excludes the use of accumulating devices and requires the reorganization of the power supply system. Such measures will reduce the annual costs of paying for consumed electricity about 45 thousand rubles at the expense of reducing the cost of each consumed one kw-h of electricity from 8.1 rubles/kWh to 3.6 rubles/kWh during the period of intensity of the activity of the Sun.

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