

# Economic Feasibility of Using a Renewable Energy Source for a Remote Industrial Enterprise

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## ABSTRACT

The article deals with the problem of economic feasibility of choosing the type of power supply for a remote industrial facility. A comparative analysis of the use of two options for Autonomous renewable and centralized power supply is carried out. The methods described in the article allow us to take into account the distance of an industrial enterprise from a centralized power grid.

**Keywords:** *power supply, industrial enterprise, photovoltaic module, economic feasibility*

## 1. INTRODUCTION

This article deals with a comparative analysis of the economic feasibility of using various electricity sources. Technological advances of today allow companies to select centralized or autonomous power supply systems.

Decentralized autonomous power supply provides for the supply of electric energy to the consumer from a source that is not connected with the energy system. In the field of autonomous power supply, hydrocarbon-based electric generators are most widely used. These installations often use gasoline or diesel generators.

An alternative to fossil fuels is renewable energy (RES). RES - energy sources generated on the basis of constantly existing or periodically occurring processes in nature. Improving the energy efficiency of plants using renewable energy sources is a very urgent problem.

In solving this problem, the following areas have been outlined, both improving the technical and economic characteristics of the power equipment itself, and optimizing its energy balances and modes, taking into account the changing load and energy of the renewable source [2].

Intensive work to improve the technical and economic characteristics of renewable energy-based power plants in many countries has shown positive dynamics in reducing the cost of producing green electricity.

The Russian industry has a huge potential for energy conservation, including in energy-intensive industries. On average, energy costs account for 10% of all production costs. In energy-intensive industries, such as steel, chemical or pharmaceutical industries, this figure is even higher - up to 40% [14].

The most dynamically developing energy sector at present is solar photovoltaics - an area of energy production associated with the direct conversion of solar energy into electrical energy based on the photoelectric effect.

Photovoltaic modules are proposed to be used as the latter. This problem is not only relevant for the companies located in hotter and sunnier regions, but also in the areas with the moderate climate.

Contemporary developments feature such high efficiency that it is possible to produce enough electricity even with a few sunny days. That being said, the problem of economic feasibility with the consideration of capital and current costs remains open. This is especially important for remote industrial enterprises.

The comparative analysis of the assessment necessity for conventional and alternative power sources in the South Urals

Stiff economic environment in contemporary markets leads industrial companies to investigate and employ energy-saving technologies. This trend is especially notable in companies, with facilities located relatively far from the centralized power grids.

Improving the energy efficiency of plants using renewable energy sources is an urgent problem. The problem can be solved in different ways, providing for both improving the technical and economic characteristics of energy equipment and optimizing its energy balances and modes taking into account the changing load and energy of a renewable source.

Intensive work to improve the technical and economic characteristics of power plants and complexes based on renewable energy, carried out in many countries, contributed to the positive dynamics of reducing the cost of producing "green" electricity.

Nowadays, the production sites are being built several kilometers away from large settlements due to both industry-specific factors (as in cases of mining, oil prospecting, and agriculture) and the concerns of environmental security of the local populace.

When a decision to set up a remote unit is taken, its electric supply becomes a pressing problem. There are two ways to solve this problem [18]. Firstly, the power grid can be extended.

Secondly, an autonomous power supply system can be installed. In the second case, it is preferable to use such renewable energy sources as water and sunlight. The company may look into such options as building a minor hydroelectric power plant or a solar power farm.

In both cases, the economic feasibility of the action must be calculated. A number of articles deal with the possibility of employing solar modules in the climate of Siberia [6].

The measurements of voltage and current show that the increase of the surface temperature of the module leads to the decrease of the power output. It is yet another evidence of the possibility and indeed of better efficiency of solar modules operating at low temperatures [11].

When using photovoltaic modules, the generation and consumption of energy occur in the same place, which avoids the loss of electricity in transmission lines and creates additional savings, which is 10% - 15% of the supply of electricity to the network.

Thus, the design and creation of modern autonomous photovoltaic power plants should solve the problem of developing photoconverters with high efficiency, as well as systemic issues of designing photovoltaic systems and power plants with high energy efficiency.

A team of scientists from Tomsk State University of Control Systems and Radioelectronics (TUSUR) has developed an autonomous power plant with an extreme power control system (ERM) for solar batteries (the accuracy of controlling the extremum of solar power is at least 98%).

This installation uses continuous automatic tracking of photovoltaic panels for the sun. It is proved that the use of extreme regulators is more effective in the spring, autumn and winter periods with lower temperatures [11].

## **2. THE DESCRIPTION OF FACTORS CONSIDERED DURING THE EVALUATION OF ECONOMIC FEASIBILITY WHEN SELECTING A POWER SOURCE**

Contemporary technical advances allow producing solar modules [8] that can produce electricity even in the areas where there are not many sunny days, for example in the South Urals.

Besides, the existing devices can transform solar energy on the spot and supply it directly to the field bus, bypassing storage elements. It significantly reduced the company's costs incurred due to both the losses during additional power transmission [15] (to the battery and from it) and the purchase of the storage elements (possibly through decreasing their number).

When developing a modern business model of energy supply for the enterprise, a full analysis is carried out, including the determination of reactive power, calculation of short circuit currents, a probabilistic reliability analysis, as well as the calculation of dynamic stability and coordination of protection [16].

An autonomous photoelectric power station, in addition to solar panels, usually contains batteries and a charge-discharge controller [5]. . If it is necessary to power consumers requiring a standard voltage of 220 / 380V AC, an inverter must be included in the photoelectric power station.

The parameters of the elements of a photovoltaic plant [10] (type and number of photovoltaic panels, battery capacity, inverter power), and accordingly its cost, depend on many factors: the composition of the electrical load, the

average daily power consumption and the average monthly solar radiation value.

It is necessary to take into account the number of consecutive days without sun at the place of installation of the photovoltaic modules and the orientation system of solar panels on the Sun.

The regions with fewer sunny days per year have longer daylight hours, which can be compensatory [11].

When solving the problem of energy saving and improving the power supply costs of an industrial enterprise, it is necessary to calculate the economic feasibility of employing a centralized or an autonomous power source [4]. A number of positive and negative aspects must be taken into consideration and compared in order to define the more economical power source.

First of all, capital costs. In order to use a centralized power source, power lines must be built and all the necessary auxiliary devices installed, including, for example, input and output meters, additional automated power metering systems to eliminate useless losses [7]. An autonomous power plant (e.g. a solar farm) requires the purchase and installation of photovoltaic modules.

It must be noted, that in the former case, there is an environmental threat (trees must be cut down near the line, pylons mounted, animals and people are at risk if the line breaks, etc) [14]. With the autonomous option, modules can be installed on company buildings' roofs and thus the environment will be saved.

According to calculations, the surface area of solar elements sufficient to supply power to a medium-size industrial establishment is one thousand square meters [9]. An industrial enterprise consumes about 2 MW of power [1]. One solar module of 1 square meter in area produces 20 kW.

Thus, 1000 modules will be enough to supply power to the establishment. The required area of the power plant shall be, as mentioned above, one thousand square meters [20]. This figure corresponds to the surface area of roofs for the production buildings of a medium-sized industrial company.

Secondly, some power is lost during transmission. When using a centralized source, the losses are significantly greater due to the length of power lines. The companies using this type of electricity source also face a risk of greater losses due to the power supply breakdowns leading to pauses in production process. The amount of losses was calculated in [19].

## **3. THE ECONOMIC IMPACT SIMULATION FOR THE SELECTION OF A RENEWABLE ENERGY SOURCE FOR A REMOTE INDUSTRIAL ENTERPRISE**

The capital costs of installing high-voltage lines include the following, according to [3]:

- the cost of installing 1 km of the power line, depending on the power load and pylon material;
- the cost of stationary structures (3.3%);
- the cost of other works (5%);
- the costs of maintaining the administration of the property developer (2.8%);

- the cost of design and survey works (7.5%);  
 - unforeseen expenditures (3.0%).  
 Thus, the total cost of installing a power line increases by 21.6%.

We must also consider the costs of cleanup activities, such as preparing forest corridors, building corduroy roads, as well as the increase factor for such works due to the location features (for the Southern Urals, a mountainous region, this factor is 1.04).

When using the power line, a remote consumer shall incur costs associated with the maintenance of their line and energy losses. The current costs for power grid maintenance and repair amounts to 4.9% according to [4]. The current costs for power line maintenance and supply breach elimination can be calculated using the following formulae:

Aerial and cable lines, load losses:

$$\Delta W_l = \frac{W_a^2}{U_{av}^2} * \frac{R_0 * L}{T} * 10^{-3},$$

Here,  $W_a^2$  is the active component of the electric power consumed in the considered period in kWh;

$U_{av}$  is the average line voltage for the considered period in kW;

$R_0$  is the active impedance in 1 km of cable at the average temperature in ohm per meter;

$L$  is the line length in km;

$T$  is the line operation duration in the considered period in hours.

Idling losses in transformer:

$$\Delta W_{xx} = \Delta P_{xx} * T_0,$$

Here,  $\Delta P_{xx}$  is the idling losses in the transformer in kW;

$T_0$  is the transformer idle time within the considered period in hours.

Supply transformer, load loss calculation:

$$\Delta W_{pow.l} = 1.101 * \Delta P_{sc} * T,$$

Here,  $\Delta P_{sc}$  is the short-circuit losses in kW;

$T$  is the line operation duration in the considered period in hours.

Current transformers, power losses:

$$\Delta W_{T_r} = \frac{50 * N}{n} * T,$$

Here,  $N$  is the number of current transformers in pcs.;

$n$  is the yearly time fund in hours;

$T$  is the line operation duration in the considered period in hours.

If capital expenditures for the construction of a cable line are accepted as  $K_{cab}$ . Then the formula for the reduced costs when using a centralized energy source will take the form:

$$K_{red.cab.} = E_{en} * K_{cab} + (0,049 * K_{cab} + (\Delta W_l + \Delta W_{xx} + \Delta W_{pow.l} + \Delta W_{T_r}) * T_{en})$$

Here,  $K_{cab}$ . is capital expenditures for cable line construction;

$\Delta W_L$  is aerial cable lines, load losses;

$\Delta W_{xx}$  is idling losses in transformer;

$\Delta W_{pow.l}$  is load losses of the power transformer;

$\Delta W_{T_r}$  is current transformers, power losses.

These costs for using a renewable energy source (photovoltaic power plant) can be written as follows:

$$K_{red.aut.} = (M * P * 1.3 + A) * E_{en} + \Delta W_{T_r} * T_{en}$$

Here,  $M$  is the necessary number of solar modules in pcs. defined by the company power consumption and a single module output;

$P$  is the price of a solar module in rubles;

$A$  is the costs of batteries in rubles defined by the operational conditions, production load and climate within the considered period

$\Delta W_{T_r}$  is current transformers, power losses.

The next stage of our study is to determine the length of the line over which Autonomous renewable energy sources should be used, and if the value is lower, it is more profitable to connect to centralized sources.

At the same time, the capital costs for the construction of high-voltage power lines, which we previously presented as the total amount of  $K_{cab}$ , must be painted with the allocation of the length of the line and, accordingly, the costs of its acquisition and construction.

$$K_{cab} = L * K_{cab.1},$$

Here,  $K_{cab.1}$  is the total cost of creating a cable line unit;

$L$  is the line length in km.

To simplify the calculations, we will introduce another symbol, all losses associated with transformers will be taken as:

$$\Delta W_{transf} = \Delta W_{xx} + \Delta W_{pow.l} + \Delta W_{T_r},$$

Here,  $\Delta W_{xx}$  is idling losses in transformer;

$\Delta W_{pow.l}$  is load losses of the power transformer;

$\Delta W_{T_r}$  is current transformers, power losses.

Then the formula for the reduced costs when using a centralized energy source will take the form:

$$K_{red.cab.} = E_{en} * K_{cab} + (0,049 * K_{cab} + (\Delta W_L + \Delta W_{transf}) * T_{en})$$

Here,  $K_{cab}$ . is capital expenditures for cable line construction;

$\Delta W_L$  is aerial cable lines, load losses;

$\Delta W_{transf}$  is all losses related to transformers.

Load losses are represented by the formula:

$$\Delta W_L = \frac{W_a^2}{U_{av}^2} * \frac{R_0 * L}{T} * 10^{-3},$$

Here,  $W_a^2$  is the active component of the electric power consumed in the considered period in kWh;

$U_{av}$  is the average line voltage for the considered period in kW;

$R_0$  is the active impedance in 1 km of cable at the average temperature in ohm per meter;  
 $L$  is the line length in km;  
 $T$  is the line operation duration in the considered period in hours.  
 Length of electric transmission line:

$$\Delta W_L = L * \Delta W_{L1} * 10^{-3},$$

Here,  $\Delta W_{L1}$  is load losses per unit of high-voltage cable line;  
 $L$  is the line length in km.  
 Equating the formulas for the reduced costs, we Express the value of the line length:

$$L = \frac{K_{red.aut}}{(E_{en} + 0,049) * K_{cab.1} + (\Delta W_{L1} * 10^{-3} + \Delta W_{transf}) * T_{en}}$$

Here,  $\Delta W_{L1}$  is load losses per unit of high-voltage cable line;  
 $\Delta W_{transf}$  is all losses related to transformers;  
 $K_{cab.1}$  is the total cost of creating a cable line unit;  
 $K_{red.aut}$  is reduced costs for using a renewable energy source (photovoltaic power plant).

The resulting line length value is a threshold value. If the distance of the enterprise exceeds the result obtained, it is most appropriate to use an Autonomous source of renewable energy.

If we consider the capital costs for cable line construction to be  $K_{cab.}$ , the full reduced costs formula for centralized power source will look as follows:

$$K_{full.red.cab} = \sum_{t=1}^n \frac{K_{cab.} + (0,049K_{cab.} + (\Delta W_L + \Delta W_{xx} + \Delta W_{pow.l} + \Delta W_{Tt}) * T_{en})_t}{(1+r)^t}$$

Here,  $\Delta W_L$  is aerial cable lines, load losses;  
 $\Delta W_{xx}$  is idling losses in transformer;  
 $\Delta W_{pow.l}$  is load losses of the power transformer;  
 $\Delta W_{Tt}$  is current transformers, power losses  
 The full reduced costs when using a renewable power source (solar farm) can be written down as follows [17]:

$$K_{full.red.aut} = \sum_{t=1}^n \frac{(M * P * 1.3 + A)_t + \Delta W_{Tt} * T_{ent}}{(1+r)^t},$$

Here,  $M$  is the necessary number of solar modules in pcs. defined by the company power consumption and a single module output;  
 $P$  is the price of a solar module in rubles;  
 $A$  is the costs of batteries in rubles defined by the operational conditions, production load and climate within the considered period;  
 $\Delta W_{Tt}$  is current transformers, power losses.

As we see from the relationships given above, the use of autonomous power sources lacks the current costs associated with load losses in the transformer, as well as the idling losses and load losses of cable and aerial lines [12].  
 When using the full cost reduction formula, the discount rate must take into account, among other things, the

various risks associated with the power supply of a remote industrial enterprise.  
 The expert assessment method was used to assess the risk. The result is presented as a table.

**Table 1** Calculation of the level of allowances for various types of risks for remote industrial enterprises of the Ural mining zone.

The amount of the premium to the discount rate by type of risk	Selected power supply source	
	Centralized	Autonomous renewable
Equipment reliability	0,033	0,028
Impact of natural conditions	0,048	0,030
Human factor	0,037	0,027
Cost of repairs	0,05	0,034
Possibility of increasing the volume of electrical supply	0,052	0,048
Value general risky allowances	0,22	0,167

After calculating the given level of reduced costs, taking into account the degree of risk, you can make a choice about the most profitable option for supplying electricity to a remote industrial enterprise.

Environmental damage assessments from power plants using renewable energy sources show that large facilities can have a significant environmental impact. Installations of small capacity can be considered environmentally friendly, the predicted environmental effect of their operation will be relatively higher than their possible environmental damage.

The use of photovoltaic systems does not have any impact on the environment [13]. Environmental problems may arise during the production of photovoltaic cells and as a result of their improper disposal.

#### 4. CONCLUSION

The development of economic and mathematical models and algorithms for optimizing investments in energy conservation is an urgent problem.

The comparison of full reduced costs for both centralized and autonomous power sources, a more efficient power supply type can be selected for a remote enterprise. In each case, it is necessary to justify assessment methods and determine the degree of risk in the implementation of energy-saving projects.

Our methods will help provide industrial establishments with the most efficient and reliable power supply and avoid losses associated with the use of lengthy power lines.

The absence of adverse environmental effects, such as deforestation, animal death, harmful emissions due to the conventional energy production, are among the most important benefits of using renewable power sources. Improving the feasibility study of energy-saving projects using renewable energy resources requires a quantitative assessment of environmental benefits.

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