Dispersed Renewable Generation In The Power Supply System Of An Industrial Enterprise: Technical Feasibility And Economic Effectiveness

Sergei V. Podkovalnikov and Marina A. Polomoshina*

Melentiev Energy Systems Institute of Siberian Branch of Russian Academy of Sciences, Irkutsk, Russian Federation

***Abstract* — This paper is concerned with the possibility of using renewable energy sources for power supply to an industrial enterprise (a mechanical plant). We assessed the climatic conditions of the area and explored if it is possible to install renewable energy facilities (solar panels and wind turbines) at this plant. The assessment of climatic conditions in Irkutsk revealed that the use of wind turbines is not reasonable due to the weak wind activity in the city. However, this area has a relatively high potential of solar energy. The paper presents an in-depth analysis of the integration of solar panels into the power supply system of a mechanical plant. Their actual output depending on solar activity was calculated. Based on the area of the buildings roofs, the number of solar modules, inverters and other equipment pieces connected to them was calculated. The payback period of installed equipment was determined to assess the economic effectiveness. According to the assessment results, the economic effectiveness of their use is currently quite low. However, with the expected reduction in the equipment cost and an increase in electricity prices, renewable energy sources will become more cost-effective in the future.**

***Index terms* — Cost-effectiveness, energy potential, integration, power supply systems, renewable energy resources, solar, wind.**

* Corresponding author.
E-mail: polomoshina@isem.irk.ru

http://dx.doi.org/10.25729/esr.2019.01.0002
Received December 18, 2018. Revised March 19, 2019. Accepted March 26, 2019. Available online June 25, 2019.

I. Introduction

In many developed and developing countries of the world, the share of renewable energy sources (RES) in energy balances is quite considerable and further increasing. The transition from conventional energy sources to renewable energy resources is gaining momentum and becoming increasingly global. According to the results of various studies, a gradual transition to renewable energy sources is expected in the near future. Despite the global trends, renewable energy in Russia is still in the early stages of development, although the formation of the renewable energy industry can have a significant positive impact on the Russian economy. For example, RES can foster the creation of new companies and jobs, and provide new opportunities for meeting the consumer loads in off-grid areas [1-4].

This study examines the integration of renewable energy sources into the power supply system of a mechanical plant. According to the project, the plant is located in Irkutsk, and climatic features of the area are taken into account. The input data contain the layout of the plant, including the shops located on the territory of the plant, and a statement of electrical loads of the plant with detailed information about consumers. The renewable energy sources are considered as complementary power sources. The paper describes in detail the integration of renewable energy sources into the power supply system of a mechanical plant, and presents the assessment of their economic effectiveness.

II. Assessement of renewable energy potential in Irkutsk

Many regions in our country (and the Irkutsk region is no exception) are promising in terms of the use of renewable energy, especially the energy of the sun. This is confirmed by the fact that the level of solar radiation in Irkutsk (located at a latitude of 52 degrees north) reaches 1340 kWh/m2, which is a fairly good indicator. The data on

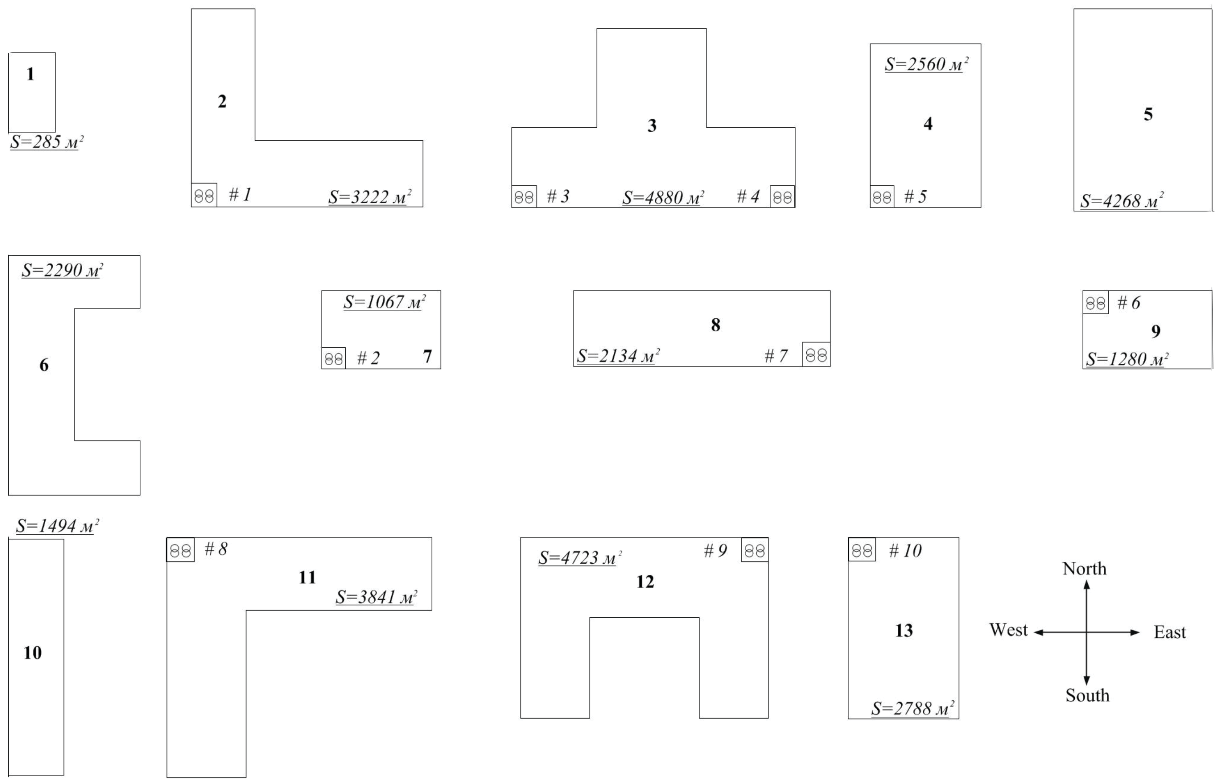

Fig.1. Layout of the mechanical plant shops

the amount of direct solar radiation falling on a horizontal surface under a clear sky in Irkutsk are given in [5]. The highest solar activity is achieved in June at noon in clear weather and it is 2.81 MJ/m2 per hour. The rest of the time, this activity varies depending on the season, weather and time of the day. Thus, the Irkutsk region has a relatively good potential for the development of solar energy, which means that the use of solar panels at the plant is relevant.

In addition, Russia has a huge potential for wind energy. The large territory of the country and a wide climatic diversity foster the development of wind energy. The main indicator of the wind power potential is the annual average wind speed. Despite the wide climatic diversity, the annual average wind speed in most of the Irkutsk region does not exceed 3-4 m/s [6]. When the speed is less than 4 m/s, the use of wind turbines is not advisable, since the speed required for the normal operation of most wind turbines is 10 m/s. Consequently, it was decided not to consider wind turbines in the study.

III. Conditions for the use of solar panels at a mechanical plant

In this section, we analyze the possibilities of using solar panels at a mechanical plant, with the view to meeting demand for electricity by environmentally friendly energy sources.

Solar modules will be mounted only on the roofs of the shops and other buildings because other possible places for their installation in the territory of the plant can be occupied by access routes, warehouses and other facilities. The roofs of the buildings are assumed to be horizontal and, therefore, the roof area will be equal to the area of the building. In addition, placement of solar panels on the ground may be inefficient, since in this case, shadows from fences and shops located nearby may fall on the panels and decrease their effectiveness. Therefore, the installation of solar panels on the roofs of the shops will provide the maximum possible output. Figure 1 shows the layout of the mechanical plant shops, and the area of the buildings.

There are two groups of buildings at this plant:

- energy-intensive production shops with their transformer substation;
- non-production buildings which consume much less power and do not have their own transformer substation.

The solar panels are supposed to be mounted on the entire surface of the roofs of industrial shops. This will allow installing as many solar panels as possible and covering a significant part of the electrical load. At the same time, we need to bear in mind that the power generated by solar panels must not exceed the power load of the shop in order not to feed excess power back into the grid. Daily load curves of the shops are taken into account for this purpose. Such a constraint is imposed not to break the existing relations in the electricity and power market when its participants have a certain established status of electricity consumer or supplier. Moreover, reverse power

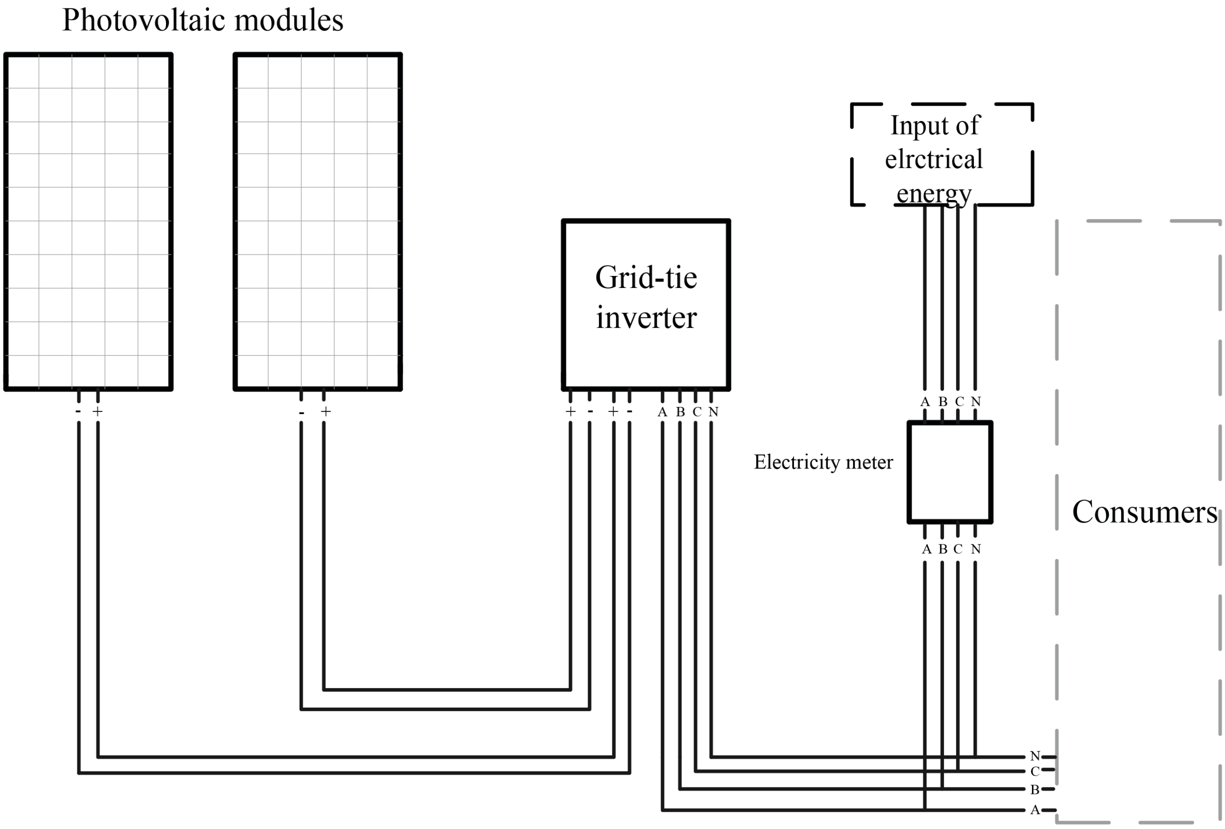

Fig. 2. A scheme of solar panels connection to consumers

Table 1. Actual output of one solar panel depending on the hour of the day and the season in Irkutsk (Wh)

Hours	Month											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
0-1												
1-2												
2-3												
3-4						1.5						
4-5					8.1	14.8	9.6	1.5				
5-6				10.3	30.2	39.8	33.9	19.2	1.5			
6-7			6.6	37.6	58.3	70.1	65.6	43.5	17.0	1.5		
7-8		8.9	30.2	70.1	90.7	104.0	104.0	77.5	50.9	22.9	0.7	
8-9	9.6	37.6	67.9	104.0	126.1	139.4	137.9	115.1	81.1	50.9	14.8	5.2
9-10	28.0	62.0	101.8	135.0	162.3	171.9	166.0	146.8	115.1	78.9	39.8	19.2
10-11	43.5	82.6	124.7	162.3	190.3	194.0	188.8	169.7	141.6	104.0	60.5	33.9
11-12	54.6	94.4	137.9	177.0	203.6	207.3	201.4	179.2	154.9	112.9	70.1	43.5
12-13	54.6	94.4	137.9	177.0	203.6	207.3	201.4	179.2	154.9	112.9	70.1	43.5
13-14	43.5	82.6	124.7	162.3	190.3	196.2	188.8	169.7	141.6	104.0	60.5	33.9
14-15	28.0	62.0	101.8	135.0	162.3	175.6	166.0	146.8	116.5	78.9	39.8	19.2
15-16	9.6	37.6	67.9	104.0	128.3	143.1	137.9	115.1	82.6	50.9	14.8	5.2
16-17		8.9	30.2	70.1	92.2	105.5	104.0	77.5	48.7	22.9	0.7	
17-18			6.6	37.6	60.5	70.1	65.6	43.5	17.0	1.5		
18-19				10.3	31.7	39.8	33.9	19.2	0.7			
19-20					8.1	14.8	9.6	1.5				
20-21						1.5						
21-22												
22-23												
23-24												
Diurnal	271	571	938	1393	1747	1896	1815	1505	1124	742	372	204
Monthly	8409	16007	29063	41750	54143	56872	56282	46619	33710	23014	11138	6344
Yearly	383350.93											

Table 2. The results of calculation of solar panels area

Shop #	S_{shop}, m^2	S, m^2
1	285	312.6
2	3222	3352.18
3	4880	5361.03
4	2560	2813.37
5	4268	4688.95
6	2290	2377.9
7	1067	1172.24
8	2134	2344.47
9	1280	1406.68
10	1494	1641.13
11	3841	3889.34
12	4723	4962.97
13	2788	3063.45

flows may require changes in the relay protection and automation organization in the power supply system of the plant, in the supply substation, and in the grid itself. Thus, the shops with low electricity consumption and non-production buildings should be equipped with a limited number of solar panels to meet the above constraint.

With a decrease in the power supplied from the grid due to the power received from solar panels, the previously selected transformer capacity, cable carrying capacity and switching devices were not revised. This slightly worsened the economic effectiveness of solar panels, however, was necessary because solar energy is unpredictable, it cannot be considered as firm and, therefore, it requires full redundancy. In this case, the grid plays a role of such a backup source. On the other hand, due to the connection of the solar panels to the centralized grid, it was decided not to use electric power storage for solar panels as an additional backup source. This will significantly reduce the cost of solar systems.

To synchronize and connect the solar panels to the power supply system of the plant we use grid-tie inverters. Grid-tie inverters are devices that convert DC voltage from renewable energy sources to AC voltage. They have a distinctive feature – the presence of synchronization of the output voltage and current with a stationary network. Thus, the grid-tie inverter converts direct current from solar panels to alternating current, with the appropriate values of its frequency and voltage phase for the connection with a stationary network. In our study, we use a three-phase inverter. In contrast to single-phase inverters, three-phase inverters evenly distribute energy received from solar panels between phases. In the case of three single-phase inverters, the output power of each inverter will fluctuate depending on the output of the solar panel connected to its input. If the power of solar panels is different and /or each solar panel is oriented or lit differently, then, accordingly, the power supplied by different phases will be different [7].

Figure 2 illustrates the basic principle of connecting solar modules to a grid-tie inverter, and the joint operation of the inverter with a centralized grid.

IV. Calculation of the actual output of solar panel

To perform further calculations, we selected solar panels "Sila Solar" with an installed capacity of 250 W each [8]. These panels has a quite good output at a relatively low price in comparison with the panels of other producers.

The actual power of solar panels averages 75-85% of its rated power. This depends primarily on climatic factors, as well as the angle of inclination (the angle between the horizontal plane and the solar panel) and the orientation of these modules to the south (for the northern hemisphere). Solar panels achieve the highest efficiency when they are directed to the sun and their surface is perpendicular to the sun's rays. Solar panels are located on the roofs of the plant shops in a fixed position; therefore, they are not at a right angle to the sun's rays throughout the day. In this case, the tilt angle of the panels is selected so as to ensure that they are at right angles to the sun's rays during the longest time possible.

The optimum mounting angle of solar panels is chosen depending on the latitude of the area. In the city of Irkutsk, located at a latitude of 52 degrees, the optimum tilt angle is 36 degrees [9].

In this case, the solar panels located on the roofs of the shops are assumed to be south facing. As is seen from Fig. 1, such a geographical location of the panels provides the minimum deviation from the southern direction. With the deviation from the southern direction assumed to be equal to 5 degrees, the power output of solar panels is maximal [10].

To calculate the actual output of one solar panel, we use the formula [10]:

$$E = \frac{I \cdot V \cdot k_o \cdot k}{U}, \quad (1)$$

E – actual output of one solar panel, Wh;

I – amount of solar energy falling on a horizontal surface, kWh/m^2 (it is given in Table 1 with conversion to the specified units);

V – rated power of one solar panel, W (it is given in the technical characteristics of the solar panel "Sila Solar" 250 [6]);

k_o – correction factor depending on the tilt angle of solar panel and the deviation from the southern direction

Table 3. Energy produced by solar panels of shop No.2 (kWh)

	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Diurnal	565	1189	1954	2899	3637	3949	3778	3133	2341	1545	774	424
Monthly	17508	33327	60512	86928	112730	118413	117184	97065	701188	47918	23191	13208
Yearly	798175.78											

Table 4. The calculated data on solar panels of the shops

Substation	Shop	Design power, kW	Number of panels, pcs.	Rated power of solar panels, kW	Generated power, MWh/year
#1	2	1431.08	2082	520.53	798.18
#2	7	1247.313	728	182.02	279.12
#3	3	1266.936	1845	461.13	707.1
#4	3	1248.182	1485	371.33	569.4
#5	4	2764.521	1747	436.86	669.88
#6	9	1147.897	874	218.43	334.94
#7	8	1830.188	1456	364.05	558.23
#8	11	1174.512	2416	603.93	926.08
#9	12	2789.062	3083	770.65	1181.71
#10	13	1737.349	1903	475.69	729.43
−	1	10.84	25	6.25	9.58
−	6	189.36	250	62.5	95.84
−	10	26.74	100	25	38.34
−	5	206.43	490	122.5	187.84
Total			18483	4620.87	7085.65

(it is taken from [9] according to the panel tilt angle and the deviation from the southern direction);

k – loss factor (it is assumed to be equal to 0.94 and includes losses associated with an increase in the panel temperature, with shading and pollution of solar panels, losses during the period of low solar radiation, and losses in shunt diodes);

U – solar radiation intensity at which solar panels are tested, kW/m^2 (it is given in the technical characteristics of the solar panel "Sila Solar" 250 [8]).

Formula (1) is used to calculate the actual output of solar panels. The calculation data are summarized in Table 1.

The calculation results indicate that the highest output of one solar panel will be achieved at 11.00-13.00, in June. The rest of the time, the actual power of one module will decrease in proportion to a decrease in the amount of direct solar radiation.

V. Calculation of energy Parameters of solar panels

The plant layout (Figure 1) indicates the geographical location which is taken into account to make the solar panels face south. Table 2 shows the dimensions of the plant buildings. Since the solar panels are fixed at an angle, their area will increase (comparing to underlying surface of the shop roofs), which will allow mounting more panels than on a horizontal surface.

Table 5. The equipment cost

Equipment	Price, thousand rub.	Quantity, pcs	Cost, thousand rub.
Sofar 11ktl 3- phase photovoltaic grid-tie inverter	120	394	47280
Cable Solarflex PV1-F NTS 10 mm^2	0.19	11820	2246
Solar panels “Sila Solar” 250 W	9.1	18483	168195
Total			217721

The area of solar panels given their tilt angle is calculated by the following formula:

$$S = 0.9\frac{l}{\cos\alpha}\cdot b \tag{2}$$

l – building length, m;

α – solar panel tilt angle equal to 36º;

b – building width, m;

0.9 – coefficient taking into account the area of technical passages for the maintenance of the solar panels.

The calculation data for the shops are summarized in Table 2.

The data from Table 1 are used to calculate the annual output of electricity produced by solar panels. By multiplying the data from the Table by the number of solar panels placed on the roof of the shop, we obtain the power and energy for a particular shop. Further, we calculate the total energy generated by solar panels of the shop for a year. Table 3 demonstrates an example of the calculation of power and energy of solar panels of shop No. 2 depending on the day and time of the year. From this Table we take the total value of the generated energy for the year. This value is necessary to calculate the economic effectiveness of the solar panels. The number of panels for each shop and the rated power of the entire solar system for the shop are also calculated. The calculation results are presented in Table 4.

VI. Selection of auxiliary equipment

The Sofar 11KTL 3-phase solar inverter is used to convert DC to AC and to synchronize solar panels with the power supply system of the mechanical plant [11]. The maximum power of one inverter does not correspond to the power of the connected panels, consequently, it is necessary to calculate the number of inverters required for solar panels for each shop.

The Sofar 11KTL-X grid-tie inverter allows connecting up to 48 solar panels with a capacity of 250 W each [12]. For the production shops, where solar panels occupy almost the entire area of the roofs, the number of solar

Table 6. The calculation of NPV indicator (thousands rubles)

Period (year), T	Capital investment , *CI*	Cash inflows, *CIn*	Cash outflows, *CO*	Cash flows, *CF*	NPV
0	150 227,40				
1	-	20 909.75	6 009.09	14 900.66	-136 430.49
2	-	21 327.95	6 009.09	15 318.86	-123 297.04
3	-	21 754.51	6 009.09	15 745.42	-110 797.82
4	-	22 189.60	6 009.09	16 180.51	-98 904.66
5	-	22 633.39	6 009.09	16 624.30	-87 590.44
6	-	23 086.06	6 009.09	17 076.97	-76 829.06
7	-	23 547.78	6 009.09	17 538.69	-66 595.40
8	-	24 018.73	6 009.09	18 009.64	-56 865.35
9	-	24 499.11	6 009.09	18 490.02	-47 615.74
10	-	24 989.09	6 009.09	18 980.00	-38 824.33
11	-	25 488.87	6 009.09	19 479.78	-30 469.78
12	-	25 998.65	6 009.09	19 989.56	-22 531.65
13	-	26 518.62	6 009.09	20 509.53	-14 990.34
14	-	27 049.00	6 009.09	21 039.91	-7 827.07
15	-	27 589.98	6 009.09	21 580.89	-1 023.88
16	-	28 141.77	6 009.09	22 132.68	5 436.44

panels connected to one inverter is 48. For the rest of the shops, where the panels cover only part of the roof area, for even load distribution we calculated the number of the panels to be connected to one inverter (Table 5).

Knowing the inverter input power and voltage, we calculate the current for the system of solar panels. According to the calculated current, we choose a cable produced by HELUKABEL Company. This is Solar flex PV1-F NTS with a cross section of 10 mm^2 and an ampacity of 40 A [13]. The length of the cable running from the solar panels to the inverter is estimated at 30 meters. The total cable length is calculated by multiplying the number of inverters by the length of the cable from the panels to the inverter. The results of the above calculations are given in Table 5.

VII. Calculation of economic effectiveness of solar systems

Previously, we selected all the necessary equipment for mounting solar panels. In addition to the solar panels, we chose all the necessary auxiliary equipment. Below, Table 5 presents input and calculated data on the cost of this equipment. The cost of mounting is assumed to be 15% of the equipment cost [14]. Thus, the total capital cost of the entire system will be equal to 250379 thousand rubles. According to the calculations made earlier (Table 4), solar panels produce energy equal to 7085.65 MWh per year.

This is 27% of the total plant electricity consumption. This amount of energy is saved owing to dispersed renewable generation system (in other words, the power consumed by the plant from the grid is reduced by this amount).

Considering the fact that the electricity price for industrial enterprises with a power consumption above 10 MW in the Irkutsk region is equal to 2951.22 rubles/MWh, including value added tax (as of August 2018) [15], the cost of electricity saved will be 20911.31 thousand rubles/year.

Preliminary estimates show rather low economic effectiveness of the solar systems. This limits severely investor's activity in financing such projects. However, it should be borne in mind that the price of solar panels has decreased by almost 90% over the past ten years [16] and such dynamics of falling prices will continue. It is predicted that by 2030 the price of solar panels will fall by an average of 40% [17]. Not only the cost of solar panels, but also the cost of inverters and other equipment will be reduced [18].

Apart from the reduction in the equipment cost, another important point is a prospect of an increase in electricity price. Thus, according to the data presented in [15], the cost of electricity for industrial enterprises with power consumption above 10 MW in the Irkutsk region has increased by almost 20% (excluding inflation) over the past ten years, and the annual increase in electricity prices has been about 2%. There is no reason to believe that this trend will not continue in the future. Thus, we calculate the effectiveness of solar panels with a 40% reduction in the cost of equipment, and an increase in the price of electricity by 2 % per year. This will allow us to estimate the potential for the growth of the cost-effectiveness of solar panels.

For the analysis of the effectiveness of this project, we calculate such an indicator as Net Present Value (NPV) according to the formula:

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{\left(1+r\right)^t} - CI \tag{3}$$

$$CF = CIn - CO \tag{4}$$

CF_t - cash flow in time t;

CI - capital investment;

r - discount rate (it is taken to be 8%);

CI_n - cash inflows;

CO - cash outflows.

CI_n is the cost of electricity from the centralized grid substituted by solar panels. CO is the maintenance cost of the panels. CI is the cost of the panels themselves and their installation. The results of calculations according to the above formulas are presented in the Table 6.

NPV was calculated taking into account the reduction in capital costs for equipment and the rise in electricity prices noted above. It reached a positive value in 16 years after the implementation of the project, which is much more cost-effective than the implementation under current conditions.

The achievement of more favorable conditions for such integration is real in the coming decades, as the dynamics of rising electricity prices from traditional energy sources and the reduction in the cost of solar panels themselves, due to the emergence of new technologies, contribute to this.

VIII. Conclusion

The paper is concerned with the possibility of using renewable energy sources to partially replace the electric power received by a mechanical plant from a centralized grid. For this purpose, we considered the possibility of using solar panels and wind turbines. The assessment of the climatic conditions shows that the use of wind turbines is not reasonable due to the low annual average wind speeds, consequently, their installation is not considered. At the same time, with the increased solar activity in the studied region, the use of solar panels for power supply to the plant is relevant. The specific feature of the shop buildings design enables a sufficient number of solar panels to be mounted on the roofs, which will make it possible to cover a significant part of the shop load during the daytime.

The total number of solar panels and the amount of energy generated by them were calculated. To exclude the possibility of feeding surplus electricity back to the grid, the number of solar panels on the roofs of non-production buildings was reduced.

The expected growth in the price of electricity and further steady decline in the cost of equipment for solar systems will significantly increase their economic attractiveness. Moreover, it will stimulate the integration of solar panels into the power supply systems of consumers in Russia.

Acknowledgement

The study has been conducted in the framework of the Research project of Siberian Branch of the Russian Academy of Sciences № AAAA-A17-117030310447-3.

References

[1] V.A. Barinova and T.A. Lanshina, “Development of renewable energy sources in Russia and in the world,” *Russian Journal of Entrepreneurship*, vol.17, no.2, pp. 259-270, Feb. 2016. DOI 10.18334/rp.17.2.2214. (in Russian)

[2] O.V. Marchenko and S.V. Solomin, “An analysis of economic effectiveness of renewable energy sources in decentralized energy systems,” *International scientific journal for alternative energy and ecology*, no.5, pp. 78-84, 2009. (in Russian)

[3] I.Yu. Ivanova, E.P. Maysyuk and T.F. Tuguzova, “Environmental assessment of renewable energy sources and local fuel types for energy supply to consumers living in the coastal zone of lake Baikal,” *Environmental, industrial and energy security*, pp. 335-337, 2017. (in Russian.)

[4] I.Y. Ivanova, D.D. Nogovitsyn, T.F. Tuguzova, Z.M. Sheina, and L.P. Sergeyeva, “An Analysis of Solar Power Plants Operation in the Off-Grid Area of the Republic of Sakha (Yakutia),” *Alternative Energy and Ecology (ISJAEE)*, no.10-12, pp.12-22, 2018. DOI: 10.15518/isjaee.2018.10-12.012-022

[5] L.V. Kopel, Scientific and applied reference USSR. Irkutsk region and western part of Buryat ASSR, Saint-Petersburg: Gidrometeoizdat, 605p., 1991 (in Russian.)

[6] A.R.Batuev, A.V. Belov and B.A. Bogoyavlensky, The Atlas of Irkutsk Region: ecological development conditions, Irkutsk: Institute of Geography SB RAS, 132p., 2004 (in Russian.)

[7] Solar home. Features of three-phase photovoltaic network inverters operation. [Online] Available: http://www.solarhome.ru/solar/pv/3-1-phase-grid-tie-inverter.htm (in Russian.)

[8] Technoline. The solar panel “Sila Solar”. Available: https://e-solarpower.ru/solar/solarpanels/poli-panel/solnechnaya-panel-sila-250vt/ (in Russian)

[9] Ural energy company “Varma”. The orientation of solar panels. Available: http://uekvarma.ru/article/orientatsiya-solnechnyih-paneley (in Russian.)

[10] Solar Soul. The calculation of solar panel average output. Available: http://solarsoul.net/raschet-solnechnoj-batarei (in Russian)

[11] Solar home. SOFAR 11KTL three-phase photo-voltaic inverter. Available: http://shop.solarhome.ru/sofar-11ktl-3-faznij-fotojelektricheskij-invertor.html (in Russian.)

[12] Solar home. Selection of modules for a grid-tie inverters. Available: http://www.solarhome.ru/equipment/inverter/podbor-modulej-dlya-setevyh-invertorov.htm (in Russian)

[13] Stroytorg. HELUKABEL Solarflex PV1-F NTS cable for solar batteries. Available: http://stroitorg.com/products/helukabel-solarflex-pv1 (in Russian.)

[14] Green energy. Installation of solar panels. Available: http://solar-batarei.ru/ustanovka-solnechnih-batarei-cena.html (in Russian.)

[15] Irkutsk power sales company. Maximum unregulated prices in the retail market. Available: https://sbyt.irkutskenergo.ru/qa/2103.html (in Russian.)

[16] AfterShock. The prices of solar batteries have reduced

by 87% for 10 years. Available: https://aftershock.news/?q=node/642261&full (in Russian.)

[17] KIC InnoEnergy. Cost of solar power could come down by as much as half by 2030. Available: http://www.innoenergy.com/wp-content/uploads/2014/03/Cost-of-solar-power-could-come-down-by-as-much-as-half-by-2030.pdf

[18] High-tech. By 2022 the price of solar energy in the world will have decreased. Available: https://hightech.fm/2017/06/28/solar-price (in Russian.)

Sergei V. Podkovalnikov, Ph.D., Head of Laboratory at Melentiev Energy Systems Institute SB RAS. His research interests are the effectiveness of interstate electric ties and interconnected power systems, electric power industry development, liberalization and organizational structures in the electric power industry, mod-eling of electric power systems and markets.

Marina A. Polomoshina graduated from Irkutsk Tech-nical University. She is a master student in electric power systems and researcher at Melentiev Energy Sys-tem Institute SB RAS. Her research interests are re-newable energy sources, power industry development and interstate electric ties.