Possibility of Using Alternative Electric Power Industry for Power Supply of Autonomous Infocommunication Complexes

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Abstract. This article analyzes the possibility of using non-traditional – solar and wind power engineering to ensure the autonomous functioning of infocommunication facilities operating without the constant presence of personnel. The technical characteristics of the main functional elements and the conditions for their interaction in the power supply system of the communication object are given. The main results obtained during the operation of the experimental scheme of autonomous power supply are shown.

1. Introduction
One of the urgent problems on difficult terrain suburban routes, remote and inaccessible settlements located far from large cities is the complete absence of radio communication. One of the possible options for solving this problem in such territories is the use of small earth stations for satellite communication (SESSC) for organizing a communication channel, and the provision of communication services can be provided by a standard base station of cellular communication [1-2].

To implement this communication scheme, a reliable autonomous power supply source with the required set of parameters is required. The use of traditional autonomous sources of electricity is costly and difficult due to the need for regular maintenance and constant renewal of the fuel supply. With a significant distance or the absence of a repair and operational base, the use of alternative electric power becomes a real alternative.

The article shows the results of calculating the parameters of solar and wind energy to provide communication with a complex relief suburban route of the Khabarovsk Territory. A static analysis was carried out on the basis of the data of the National Aeronautics and Space Administration - NASA department [3] for the Khabarovsk Territory. The technical characteristics of the main functional elements and the conditions for their interaction in the power supply system of the communication object are given. The main theoretical results of the potential of solar and wind energy are shown, as well as those obtained during the operation of an experimental scheme of autonomous power supply, which is applied and is used to supply power to GSM base stations on the Lidoga-Vanino highway in the Khabarovsk Territory.

2. Calculation of solar and wind energy parameters
Alternative electric power – sources of electricity that are not related to a unified system of electrical power supply: wind power generators, solar power panels, isotopic electrical elements, etc. [4-6]. The initial data for the development of the design of an autonomous power supply source can be
considered the need to provide for the operation of SESSC a standard alternating sinusoidal voltage of 220 V, a frequency of 50 Hz with a load power of about 300 W, and for the operation of cellular equipment – a constant voltage of 48 V with a load power of about 600 W.

It is proposed to use commercially available solar electric panels and wind generators as alternative sources of electricity [7-9].

To use solar energy wisely and with the greatest benefit, the first task is to determine the gross potential. The gross potential of solar energy is the average long-term total energy of solar radiation falling on the area of the region during one year $W_g$, kW·h/y [10-12]. Its value is determined based on the data on solar insolation of the selected area. The analysis of solar insolation of the Khabarovsk Territory is carried out on the basis of the data of the National Aeronautics and Space Administration – NASA department [3]. The values obtained according to the NASA website from 2000 ... 2019 are summarized in a table and based on them a graph of the distribution of the average value of daily insolation during the year on a horizontal platform with an area of 1m² is built, which is shown in Fig. 1. Due to the large number of values, only the graph is shown.

Based on the obtained values, the lowest average insolation value is 0.7 kW·h/m², while the highest average value is 6.3 kW·h/m². Thus, it can be seen that the value of solar radiation varies greatly throughout the year.

The annual insolation, based on the found daily average values for the selected season, is determined by the formula: $E = \sum_{i=1}^{n} E_i$, where, $n$ – the number of days in a year excluding leap years and is equal to 365; $E_i$ – specific insolation on the i-th day of the year [3]. Considering all the daily average values, it turns out $E= 1361.4$ kW·h/m². Gross solar energy potential per year: $W_{gse} = E \cdot S_{khn}$. where $S_{khn}$ – area of the Khabarovsk Territory, $S_{khn} = 788600 \cdot 10^6$ m². $W_{gse} = 1361.4 \cdot 788600000000 = 1073,60$ TW·h.

The technical potential of the region's solar energy is the average long-term total energy that can be obtained in the region from solar radiation within one year. The value of the technical potential depends on the angle of installation of photovoltaic modules (PVM) relative to the horizon; dimensions of the PVM used; temperature coefficient of the panel; solar module power [13].

The installation angle of the PVM should be selected based on efficiency in both summer and winter seasons. In this case, the choice of this angle depends on the latitude of the area, and can also be changed, depending on what kind of optimization in energy production needs to be achieved. There
is a simplified method for calculating the optimal installation angle, which allows the extraction of solar energy with the greatest efficiency throughout the year.

If the solar installation is located at a latitude less than 25°: \( \alpha_{op} = 0.87L \), where \( L \) – the numerical value of the latitude of the area where the PVM is planned to be installed. In the case of a solar installation at latitude 25-50°: \( \alpha_{op} = 0.76L + 3.1 \). Based on the location of the object, we find the optimal installation angle of solar modules, using the formula for the second case: \( \alpha_{op} = 0.76 \cdot 49.18 + 3.1 = 41° \).

The obtained value of the optimal tilt angle makes it possible to determine the value of insolation for a solar installation. The calculation of the average value of insolation for the slope is carried out according to the following formula: \( E_D = \frac{E_i}{\cos\alpha_{op}} = \frac{0.93}{\cos 41°} = 1.22 \text{ kW} \cdot \text{h/m}^2 \).

Then a calculation is performed to determine the average insolation per m² for all days of the year, the calculation results are shown in Fig. 2.

**Figure 2.** The graph of the distribution of the average value of solar insolation on an inclined surface at an angle of 41° throughout the year for 2000 .. 2019.

It can be seen from the graph that the optimization of generation due to the inclined PVM installation increases the maximum insolation from 6.3 to 8.5 kW·h/m², and the minimum from 0.65 to 1.3 kW·h/m².

Next, you need to select a solar panel. The solar panels available today have different weight and size parameters. SILA Solar polycrystalline solar batteries with the following parameters height (h) - 1640mm were selected for the proposed power supply system; width (b) - 992 mm. The technical characteristics of the solar battery are given in the documentation [14]. Then the area of the solar panel with such parameters will be equal to: \( S_{PVM} = h \cdot b = 1640 \cdot 992 = 1626880 \text{ mm}^2 = 1.63 \text{ m}^2 \). Then the solar insolation is recalculated in accordance with the calculated value of the area of incidence of solar radiation for each day of the year: \( E_s = E_D \cdot S_{PVM} = 1.22 \cdot 1.63 = 2 \text{ kW} \cdot \text{h/m}^2 \).

Based on the calculated data, the graph shown in Fig. 3.
Figure 3. The graph of the distribution of the average value of solar insolation on the inclined surface of the PVM area throughout the year for 2000 ... 2019.

The temperature of the environment in which the solar panel operates plays an important role in the efficiency. As a rule, the manufacturer of solar panels indicates the technical parameters of the battery at 25°C. The deviation of the temperature from the temperature of normal conditions has a significant effect on the output power of the solar converter. In this regard, when determining the technical potential, it is necessary to take into account the temperature at which the panel operates. According to the NASA database, the average annual temperature for the Khabarovsk Territory is \( t_a = 2^\circ\text{C} \). The deviation of the average temperature value is determined from the temperature value under normal conditions: \( t_{\text{dev}} = t_{\text{nc}} - t_a = 25 - 2 = 23^\circ\text{C} \).

According to the NASA database, the average radiation value for the year is found: \( E_s = 3.64 \text{ kW} \cdot \text{h} \).

The value of the incoming energy at a given temperature deviation is \( E_f = t_{\text{dev}} K_t = 23 \cdot (-0.50) = -11.5\% \), where \( K_t \) – temperature coefficient.

As a percentage of the nominal coefficient of efficiency, the value: \( \eta_{\text{portion}} = \frac{(\eta_{\text{nom}} E_f)}{100} = \frac{(15.46 \cdot 11.5)}{100} = 1.8\% \). Coefficient of efficiency is found as follows: \( H_r = \eta_{\text{nom}} - (-\eta_{\text{portion}}) = 15.46 + 1.8 = 17.3\% \). Then the actual average value is found taking into account the temperature deviation: \( E_{\text{mod}} = \frac{(\eta_r E_s)}{100} = \frac{(17.3 \cdot 3.64)}{100} = 0.63 \text{ kW} \cdot \text{h} \).

This method was used to calculate the average values of the actual energy generated by the solar module for the batteries located on the Lidoga-Vanino highway. The distribution schedule for production on each of 365 days a year is shown in Fig. 4.
Figure 4. The graph of the distribution of the average production value on each of 365 days a year, taking into account the average insolation for the last 19 years.

The graph shows that the maximum daily output will be 1.9 kW·h, and the minimum – 0.21 kW·h. At the same time, the total annual technical potential that can be obtained from one PVM: $W_{T,PVM} = 426.2$ kW·h.

Determining the wind speed is an important step for the correct assessment of the wind energy potential. The calculation of the wind speed for a given height of the wind generator is carried out according to the formula: $V_h = V_f \cdot \left(\frac{h}{h_f}\right)^m$, where $V_h$ – on high $h=25$ m; $V_f$ – speed at vane height; $h_f$ – weather vane height, 10 m; $m$ – coefficient depending on the average speed at the height of the weather vane. To calculate the average value of the wind speed, the data collected by NASA for a given geo-point for 2000-2019 are used, and for this case $m=0.17$. $V_h = 3.9 \cdot \left(\frac{25}{10}\right)^{0.17} = 4.6$ m/s. The graph of the distribution of velocities at the selected altitude is shown in Fig. 5.

Figure 5. The graph of the distribution of the average wind speed at a height of 25 m for each day of the year during 2000-2019.

An important parameter is the repeatability of wind speed according to actual data. The selected observation period is 19 years. The essence of this method is to determine the prevailing wind speeds in a given region. The resulting range of average speeds according to the method was divided into intervals from 0 to the maximum calculated value. The number of hits of the found velocities in a certain interval is determined by the formula $t_i = \frac{r_i}{R} \cdot 100\%$, where $r_i$ – certain interval; $R$ – total number of wind speed values. In accordance with the given formula, a graph of the frequency of wind speeds is built, which is shown in Fig. 6.
Thus, we can say that the speed in the range 4...6 m/s is predominant and amounts to 90%. In this case, the probability of winds in the range from 6 to 8 m/s, as well as from 2 to 4 m/s is much less, but it takes place in comparison with the other considered intervals. The speed repeatability graph is a characteristic that strongly affects the theoretical wind potential, since it affects the average annual wind speed.

It is necessary to determine the specific density of air by the formula:

$$\rho = \rho_0 \frac{288}{(T_{en} + 273)} = 1,244 \cdot \frac{288}{(17 + 273)} = 1,235 \text{ kg/m}^3,$$

where $\rho_0$ is the nominal air density at a temperature of 15 °C; $\rho_0 = 1,226$ kg/m$^3$; $T_{en}$ – ambient temperature, °C.

Taking into account the probability of recurrence of velocities and air density, the average specific power for one day in a year is determined by the formula:

$$P_{sp} = \frac{1}{2} \cdot \rho \cdot (V_i)^3 \cdot t_i = \frac{1}{2} \cdot 1,235 \cdot 4,6^3 \cdot 0,82 = 74,2 \text{ W/m}^2.$$

Then, for each day of the year, the average specific power is determined and the graph shown in Fig. 7.

The gross potential of wind energy is determined by the following formula:

$$W_{gwe} = 0.025 \rho T S \sum_{i=1}^{n} V_i^3 t_i = 112410 \text{ TW},$$

where $\rho$ – air density, kg/m$^3$; $T = 8760$ – number of hours per year; $S$ – the area of the land, m$^2$; $V$ – mean annual wind speed in the range i; $t$ – the probability of finding the speed in the range i.

The technical resource of wind energy in a region (country) is a part of the gross potential of wind energy, which can be used at the current level of development of technical means and compliance with
environmental standards [15-18]. Wind energy technical resource: \[ W_{tp} = W_{gwe} \cdot C_p \cdot \eta_g \cdot \eta_r \cdot \frac{S_{tw}}{S_{khv}} \] where \( C_p \) - wind utilization factor which has a complex dependence on wind speed. Maximum achieved value for wind turbines with a horizontal axis of rotation 0,4…0,45. We accept \( C_p = 0,4 \), \( \eta_g, \eta_r \) - the coefficients of efficiency of the generator and the gearbox of the wind turbine, respectively, the values of which most often take 0,9. \( S_{tw} \) - territory that may be suitable for placing wind turbines on it. For the territory of interest to us, we will take 1% of the area of the region, that is \( S_{tw} = 7886 \times 10^4 \text{m}^2 \). \( W_{tp} = 112410 \cdot 10^{12} \cdot 0,4 \cdot 0,9 \cdot \frac{78860000000}{78860000000} = 404,676 \text{TW}. \)

The share of technical potential in gross potential is determined:\n\[
\frac{W_{tp}}{W_{gwe}} = \frac{404,676}{112410} = 0,0036 \text{ or } 0,36\%.
\]

3. **Alternative power supply system**

The generation of electricity by alternative sources is highly dependent on weather conditions, and therefore the characteristics of the electricity they produce are highly unstable. Consequently, the system of autonomous power supply of a communication facility based on alternative sources of electricity must contain: primary sources of electricity; block of accumulation of generated electricity (batteries); unit for converting electricity to the required parameters with its further transfer to technological communication equipment.

For the autonomous operation of the base station, a power supply system is proposed that allows it to work around the clock and continuously. The system consists of a wind turbine and solar panels. The units operate in parallel and have their own controllers, to which a battery bank is connected to save energy and load, i.e. all base station equipment. The controllers regulate the battery charge, limiting the maximum permissible current, convert the alternating current supplied from the wind generator into direct current, and stabilize the output voltage of 220 volts. The solar energy supplied to the batteries is converted into DC electrical current, which is then fed to the inverter and converted at the output to 220 volts AC to power all equipment. The general structure of the power supply of telecommunication equipment is shown in Fig. 8.

![Figure 8. General structure of power supply of telecommunication equipment.](image-url)
The device can also be connected to batteries with a voltage of 48 volts, so during operation, part of the solar energy will go directly to the load, and the rest to charge the batteries. In addition, the hybrid specification of the inverter allows an external power source to be connected to it, such as a generator or a 220 V network, if any. Solar panels are connected in series in groups of three. Considering that the operating voltage of one panel is 30.9 volts, when connected in series, the total voltage will be 91.8 volts, which corresponds to the operating voltage range supported by the charge controller (60 - 115 V). Parallel connection of three such groups with an operating current of 8.1 A gives a total current in the circuit up to 24.3 A, which significantly reduces the battery charging time. The total power of nine such panels is 2.25 kW. However, the declared power will be issued only during the hours of maximum solar activity, when the sun's rays will fall at almost right angles. Under poor atmospheric conditions (cloudy, rain, etc.), the efficiency of solar panels decreases. As an additional source of energy, a wind generator is used, which converts wind energy into electric current and also provides battery charging through the controller. The batteries are connected in groups of four in series, which makes it possible to obtain 48 volts at the output using standard 12-volt batteries. This supply voltage is standard for telecommunications equipment. The power supply system also includes a voltage converter from 220 volts at the controller output to a 48 volt DC voltage consumed by telecommunications equipment. Depending on the location of the base station, priority is given to either solar panels or a wind generator. Based on the need to provide round-the-clock power to the base station, it is necessary to calculate the characteristics of the power supply system and select the devices that are suitable for the parameters. Since the system must supply power to the base station even during peak loads, the maximum power consumption of the equipment must be taken into account for the calculation. Table 1 shows the indicators of the maximum power consumption of the equipment of the base station of cellular communication.

### Table 1. The values of the maximum power consumption of the base station equipment.

| Equipment                  | Maximum power consumption $P_{\text{max}}$, W |
|----------------------------|----------------------------------------------|
| BBU3900                    | 60                                           |
| RRU3908                    | $2 \times 250$                               |
| Router MikroTik RB750      | 6                                            |
| Satellite Hughes modem     | 60                                           |
| HT1100                     | 60                                           |
| Inverter SILA5000M         | 50                                           |
| Heating / cooling system   | 600                                          |

The total power consumption can be found as: $P_{\text{total}} = P_1 + P_2 + \cdots + P_n$. Substituting the values, we get $P_{\text{total}} = 60 + 250 + 250 + 6 + 60 + 50 + 600 = 1276$ W.

Taking into account 20% of the stock, the total consumption of the BS will be: $P_{\text{total}} = 1276 \cdot 1.2 = 1531.2$ W.

The worst-case scenario for such a power system would be the winter solstice, when the daylight hours are the shortest and there is no wind. For the Far East, daylight hours at this time are about 8 hours. Thus, the maximum required battery life for this system from sunset to sunrise is about 16 hours.

The SILA 5000M inverter supports 48-volt battery connection. The technical characteristics of the SILA 5000M inverter are presented at reference [19]. The efficiency of the inverter is 0.93. The battery discharge current for our load is calculated by the formula: $I = \frac{W}{V_a K}$, where $I$ – battery
discharge current; \( W \) – total power consumption; \( V_a \) – battery voltage; \( K \) – Inverter efficiency.

\[ I = \frac{1531.2}{48.93} = 34.3 \text{ A} \]

The capacity of the storage battery is found by the formula: \( E = I \cdot T \), where \( T \) – required battery life \( E = 34.3 \cdot 16 = 548.8 \text{ A} \cdot \text{h} \).

Batteries should not be discharged more than 80%, therefore, taking into account this margin, the capacity of the batteries should be: \( E = 548.8 \cdot 1.2 = 658.56 \text{ A} \cdot \text{h} \).

By using twelve-volt batteries connected in series in groups of 4, the 48 V output voltage required for connection to the inverter can be obtained.

It is suggested to use accumulators of the firm SunStonePower MLG12-200 with a capacity 200 A\cdot h. The technical parameters of the SunStonePower MLG12-200 battery are presented at the link [20]. When using three groups of batteries, the total capacity of the batteries will be 600 A\cdot h.

Then the amount of energy in fully charged batteries is calculated: \( W = 600 \cdot 48 = 28800 \text{ W} \).

Thus, in case of incomplete discharge of the batteries (80%), to fully charge them, it is necessary: \( W = 28800 \cdot 0.8 = 23040 \text{ W} \).

Considering that the minimum daylight hours lasts 8 hours, in one hour to fully charge the batteries, you need to get: \( W = 28800/8 = 2880 \text{ W} / \text{h} \).

Considering the power consumed by the system, we obtain: \( W_{\text{total,cons}} = 2880 + 1531.2 = 4411.2 \text{ W} / \text{h} \).

The solar inverter used allows the connection of solar panels with a power of up to 4000 W with an operating voltage of 60 - 115 V. The SILA solar panels recommended for this inverter have different output powers. Let's consider the most suitable ones - 200, 250 and 300 W.

All of them have an operating voltage of about 30 V, so it is most convenient to connect panels in groups of three, connected in series. The result is a suitable total voltage from the panels at the input of the inverter. To increase the power, we can use several such groups.

When using solar panels with a power of 250 W, three groups of solar panels are enough, i.e. 9 batteries in total. The total power in this case will be 2,25 kW. Then a wind generator with a capacity of 2.5 kW will be enough to fully charge the batteries.

The proposed technology for constructing a power supply system for communication equipment was used in the construction and further operation of autonomous communication facilities on the sections of the Lidoga-Vanino highway in the Khabarovsk Territory. Operation of the facility in winter in moderate mountain conditions gave the following results. With a useful daylight hours of about 6 hours, at outside temperatures up to minus 40 degrees, there were no failures in the operation of the facility.

On one section of the road, where communication equipment stands on a hill and the wind is constantly blowing, two sources of electricity are installed in parallel: a wind generator with a capacity of up to 3000 W and 9 solar panels of 250 W each (every three are combined into one assembly and connected to each other in series, and three groups of serial assemblies are connected in parallel).

On the second section of the road, where there are no constant winds, another group of electricity sources is installed: 12 solar polycrystalline panels with a capacity of 300 W each (each three are also connected to each other in series in one assembly, and four groups of series assemblies are connected in parallel) and a wind generator with a capacity 2500 W.

With both options, the actual output voltage of the solar panel units ranges from 90 to 118 volts, the amperage on the batteries remains unchanged and at the same time they are guaranteed to be fully charged.
4. Conclusion
Khabarovsk Krai has significant potential for using renewable energy sources. The calculation of the technical and gross potential for solar and wind energy was made. According to the results of the calculation, the gross potential was 1073,60 TW·h and technical 426,2 kW·h, which can be obtained from one PVM for solar energy. And for wind energy 112410 TW and 404,676 TW respectively. The share of technical potential in the gross for wind energy is 0.36%.

When solving problems similar to those faced by the authors, it is necessary to take into account the following. During the construction of wireless communication facilities, the task of ensuring maximum radio coverage is often solved with the installation of equipment only according to this criterion. In this case, an indicator appears as one of the main criteria. Characterizing the efficiency of using alternative energy resources. This efficiency will depend directly on the careful determination of the location of solar panels and wind turbines, linked to the location of communication equipment.

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