Issues of Rational Energy Supply to Specially Protected Natural Areas and How to Resolve Them with the Example of the Khuvsgul National Park

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***Abstract* — The paper addresses the issues of applying solar plants and solar heating systems for energy supply to the facilities located in specially protected natural areas (SPNA). The findings of the research into the existing energy systems and possible strands of their development, given the installation of reactive power compensators and the adoption of photovoltaic cells (PVCs), are presented. A comparative analysis of the modernized system functioning with the existing power grid is carried out. To this end, a special algorithm for multi-criteria optimization of the locations and generating capacity for solar plants is used, which involves sequentially checking the feasibility of additional capacity to be installed at consumers' of each considered substation. The possibility of using solar heat supply to a specific facility is investigated and economic indicators are calculated for it. A heating system layout has been developed and proposed for the school building, which makes it possible to provide it with thermal energy throughout the year.**

As a case study, the paper considers the problem of electricity and heat supply to consumers in the cross-border recreational area "Baikal-Khuvsgul." At present, power supply to this region is provided from the Central electric power system (CEPS) of Mongolia from the Muren substation along the 35 kV power transmission line (TL) to the substation in the center of the Alag-Erdene sum, and from it, through the 35kV, 15kV and 10 kV distribution networks, further to consumers. At the same time, due to the weak energy infrastructure, significant remoteness and inaccessibility of the area, as well as low population density, the development of this system does not seem effective in most of the territory and does not ensure the conditions for the creation of a reliable fuel and energy supply. According to modern requirements, including the growing loads and the development of ecotourism in the region, it is time to reconsider the concept and approaches to the energy supply and determine the most appropriate ways to implement them. First of all, it is necessary to assess the possibility of using local renewable and other energy resources. The findings of the study on the local energy resources, given the characteristics and environmental vulnerability of protected areas, as well as the seasonal nature of changes in the electrical and thermal loads of most consumers, suggest that the most feasible way is to introduce solar energy.

***Index Terms*: Local energy resources, annual solar radiation, the number of "degree-days" of heating, solar heating, thermal energy storage, solar photovoltaic, local system, backup source, solar power plant, power quality, power supply reliability, multi-criteria optimization.**

I. Introduction

The issue of energy supply in the light of the contemporary energy and environmental problems is resolved by using special, so-called sustainable, methods, technical solutions, and production processes. This strand is essential and decisive, when it comes to power supply to consumers located in specially protected natural areas.

The foregoing seems to be especially relevant for the northwestern zone of the Specially Protected Natural Area (SPNA) of Lake Khuvsgul, which includes the protected areas of Khordil-Sardik, the Darkhad Basin, and the Tsagaan Taiga, where, along with a relative increase in the number of indigenous people in recent years, there is an intensive flow of tourists staying all year-round and seasonally. In this regard, the electricity and heat consumption of the area increases significantly. Study [1] considers the fundamental issues and the current state of power supply to the Baikal-Khuvsgul transboundary territory as prerequisites for research into the possibility of using renewable energy for the purposes of power

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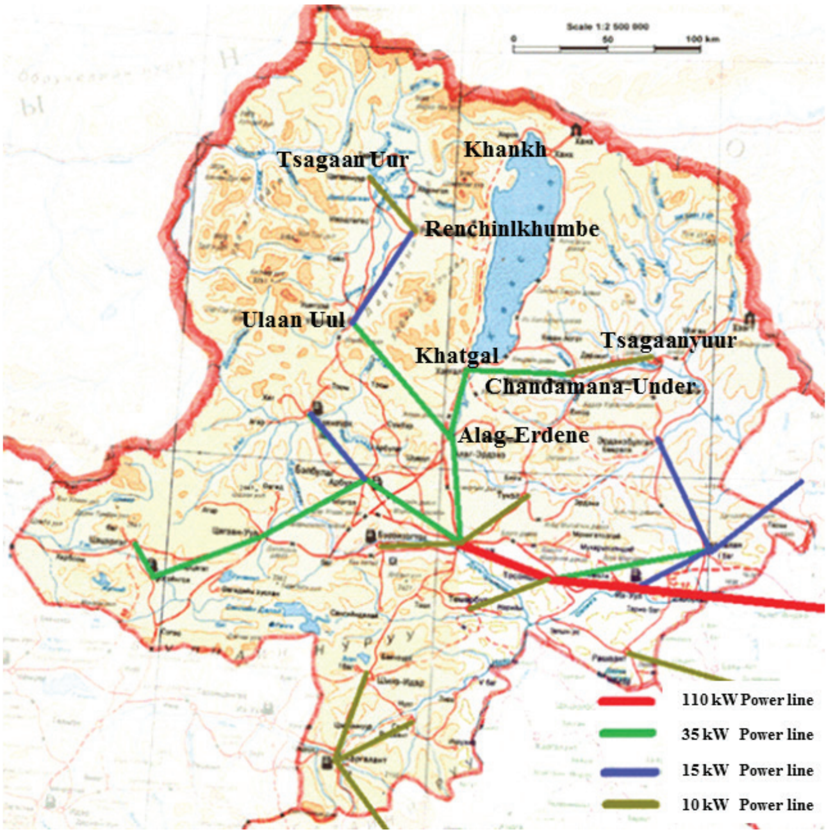

Fig. 1. A scheme of electricity supply to the territory.

supply to consumers. The current power supply system from the EPSs of Mongolia and Russia is analyzed and it is noted that the state of the power supply does not meet the existing controllability and reliability requirements. A further growth in electricity consumption in the region in question exacerbates the situation with energy supply to consumers, as the expansion of electrical networks to cover this territory is complicated due to its remoteness and inaccessibility. Studies by the Russian side to improve the efficiency, quality and reliability of power supply to these areas, including the Khankh sum of Mongolia, show the possibility and sufficient potential to attract distributed generation (DG) through the installation of solar power sources [2].

In Mongolia, the territory located on the right side of Lake Khuvsgul (Fig. 1) is supplied with electricity from the Mongolian CEPS from a substation in the city of Muren through a 35 kV power line of the local power grid through a substation in the center of the Alag-Erdene sum to a substation in the center of the Ulaan-Uul sum, and from it along a 15 kV power line to the center of the Renchinlkhumbe sum and further along a 10 kV power line to the Tsagaan-Uur sum. The left coast of Lake Khuvsgul is also supplied with power from Alag-Erdene via a 35 kV power line through Khatgal to Chandaman-Under and from there via a 15 kV power line to Tsagaan-Uur sum (Fig. 1). Work similar to that presented in [2] was carried out to analyze and assess the efficiency of the local distribution

Table 1. Indicators of population and energy consumption of the area.

Sum	Total population number	Population in the sum	Rural population density,	Annual electrical load,
Tsagaan-Uur	1 950	916/1 034	0.19	341 065
Renchinlkhumbe	4 907	781/4 126	0.49	426 984.33
Ulaan-Uul	4 259	1 400/2 859	0.28	561 083
Tsagaan-Uur	2 650	1 040/1 610	0.18	518 047.8
Chandamana Under	3 058	980/2 078	0.46	545 507.13
Khatgal (city)	3 195	1 195	-	1 810 527.64
Alag-Erdene	3 331	1 001/2 330	0,52	465 989.85
Moron	40 770			33 213 309.42
Khankh	2 783	1 604/1 159	0,21	603 923.44

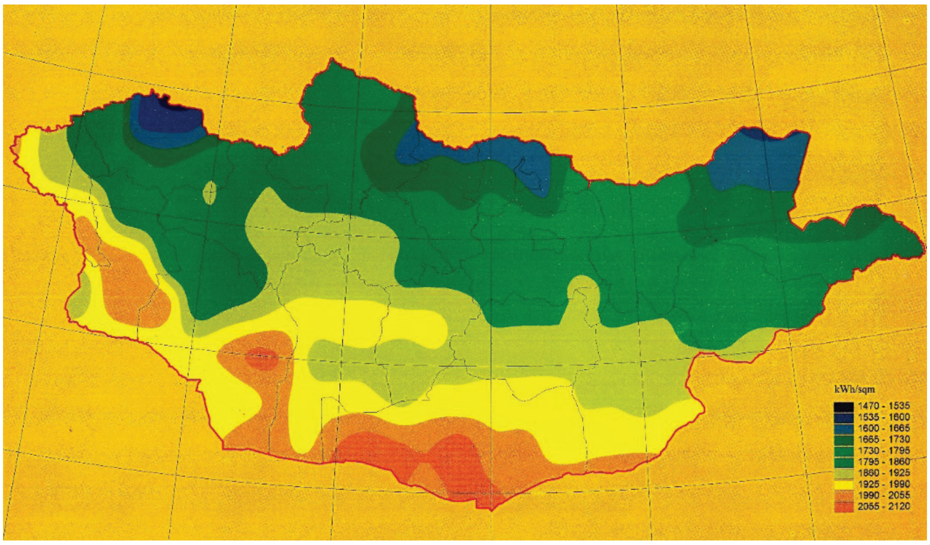

Fig. 2. Annual total solar radiation on a horizontal surface, kWh/m² per year.

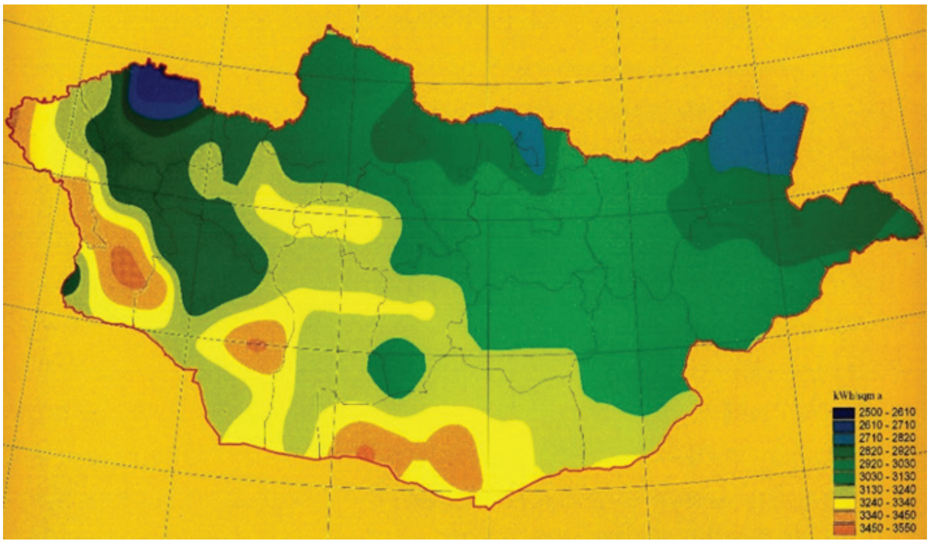

Fig. 3. Annual direct solar radiation on a perpendicular surface, kWh/m²/year.

electrical network operation, and to ensure the quality and reliability of power supply to the sums. The results of the present studies are given below.

When solving the issues of energy supply to consumers in the sums of Khuvsgul aimag, located in remote mountainous taiga regions, it is important to pay attention to population density and types of economic activity developed. The population density in the areas at issue is 0.4–0.7 person/km^2, which is relatively low compared to the average values for both the aimag (1.3 person/km^2) and the country (2.0 person/km^2) [3]. The main economic activities are cattle breeding and tourism. Due to the vast territory and small population of the sums, the density of the rural population in these areas is low (Table 1).

Not all coastal areas of Khuvsgul, except for the centers of sums and some of their settlements and individual consumers, are located within effective distances from the route of power transmission line connected to the country's EPS [1]. Some rural consumers are supplied with electricity from various individual and distributed low power sources (diesel generators and other micro sources). A specific feature of Khuvsgul aimag is the increased number of rural residents living on its territory, 47.2% on average for the aimag. This must be taken into account when addressing the issues of energy supply to the settlements.

When choosing heat supply methods, one should also bear in mind that the majority of centers in the sums have an insignificant heat load. The outcomes of our studies on the heat supply to 23 sums of the Khuvsgul aimag indicate that the heat load of 10 sums is in the range of 0.2–0.4 Gcal/h (232.7–465.2 kW). With such a heat load, given the remote location of consumers across the territory and with respect to one another, the use of a centralized heating system has no competitive advantages over individual heating or the connection of closely located consumers to one heat source (decentralized and group heat supply). Alternative energy

Table 2. Assumed electrical load values.

No.	Substation	Load condition 1		Load condition 2	
		Active power	Reactive power	Active power	Reactive power
		kW	kVar	kW	kVar
	Consumers in the eastern territory of Lake Khuvsgul				
	Substation "Tsagaan-Uur"				
1	Tsagaan-Uur	113.48	23.04	123.48	36.02
	Substation "Chandman-Under"				
2	Chandmana-Under (1)	37.40	7.59	47.40	15.58
3	Khukhkhuu bug (1)	50.00	3.03	65.00	3.94
	Substation "Khatgal"				
4	Khatgal (1)	87.93	5.33	277.93	16.84
	Khatgal ATP-1	67.65	4.10	96.76	5.86
5	Altanmuren goal	45.14	2.74	65.14	3.95
6	BZS "Magniterde"	31.25	1.89	21.25	1.29
7	"Gundalai" holiday center	40.00	2.42	52.00	3.15
8	Alagtsar	50.00	3.03	40.00	2.42
	Consumers in the western territory of Lake Khuvsgul				
	Substation "Tsagaan-Uur"				
9	Tsagaan-Uur	62.86	12.76	72.86	21.25
10	Renchinlkhumbe Substation				
11	Renchinlkhumbe	44.79	2.71	44.79	2.71
	Substation "Ulaan-Uul"				
12	Ulaan-Uul (16)	91.41	5.54	71.41	4.33
	Substation "Alag-Erdene"				
13	Alag-Erdene	66.00	9.40	56.00	7.98
14	Sumber (36)	40.00	2.42	40.00	2.42
	Substation "Muren"				
15	Muren 35-1	200.00	– 28.50	51.00	– 9 613.09
16	Muren 6-1	2 400.00	145.45	1 329.00	80.54
17	Muren 6-2	3 168.00	191.99	2 390.00	144.84

Table 3. Assessments of voltage levels and voltage deviation angles at substation buses.

	Substation	Load condition 1			Load condition 2		
		Ul,	u,	U, angle	Ul,	u,	U, angle
		kV	p.u.	degree	kV	p.u.	degree
	Erdenet 110 kV	114.00	1.01	0	113.00	1.00	0
	Bulgan 110 kV	110.32	0.98	– 4.22	112.06	0.99	– 2.56
	Tosontsengel 110 kV	103.11	0.91	– 19.45	112.81	1.00	– 10.86
1	Muren 110 kV_1	101.61	0.90	– 23.29	112.34	0.99	– 12.64
2	Muren 110 kV_2	101.61	0.90	– 23.29	112.34	0.99	– 12.64
3	Muren 35 kV_1	37.41	1.01	– 33.46	38.62	1.04	– 18.19
4	Muren 35 kV_2	37.41	1.01	– 33.46	38.62	1.04	– 18.19
5	Alag-Erdene 35 kV	36.06	0.97	– 33.84	37.04	1.00	– 18.52
6	Sumber 35 kV	36.06	0.97	– 33.84	37.04	1.00	– 18.52
7	Khatgal	35.79	0.97	– 34.42	37.57	1.02	– 11.87
8	"Gundalai" holiday center 35 kV	35.75	0.97	– 34.46	36.61	0.99	– 19.29
9	Alagtsar 35 kV	35.68	0.96	– 34.54	36.54	0.99	– 19.36
10	Chandamana-Under	35.64	0.96	– 34.58	36.50	0.99	– 19.40
11	Khukhkhuu bag	35.64	0.96	– 34.58	36.50	0.99	– 19.40
12	Ulaan-Uul	35.70	0.96	– 34.26	36.72	0.99	– 18.85

Table 4. Calculated values of load and active power losses for power transmission lines of the electrical network.

	Power transmission line	Load condition 1		Load condition 2	
		Loading	Losses (total)	Loading	Losses (total)
		%	MW	%	MW
	Erdenet-Bulgan	45.82	1.38	26.16	0.44
	Bulgan-Tosontsengel	38.85	3.75	23.99	1.17
	Tosontsengel-Murun	34.98	0.83	17.86	0.21
4-5	Muren-Alag-Erdene	9.22	0.02	10.89	0.02
5-6	Sumber	0.36	0.00	0.32	0.00
5-6	Sumber_a	0.00	–	0.00	–
5-7	Alag-Erdene-Khatgal	3.70	0.00	4.94	0.01
7-8	Khatgal - "Gundalai" holiday center	2.54	0.00	2.57	0.00
8-9	Altantsar - "Gundalai" holiday center	2.21	0.00	2.18	0.00
9-11	Altantsar - Khukhkhuu bag	1.79	0.00	1.89	0.00
10-11	Khukhkhuu bag-Chandamana-Under	0.43	0.00	0.49	0.00
11-10	Khukhkhuu bag-Chandamana-Under_a	1.37	0.00	1.41	0.00
5-12	Alag-Erdene-Ulaan-Uul	1.74	0.00	1.48	0.00

sources can be used in addition to traditional heating boilers for decentralized and individual heating. The main consumers in the centers of sums and small settlements are first-aid posts, hospitals, schools, kindergartens, local administration buildings and houses of culture, which are financed from the local budget. The issue of heat supply to such consumers can be resolved within the framework of the master plan for the development of rural energy using renewable energy sources that do not violate the environmental requirements of specially protected natural areas.

This paper deals with the issues of improving the electricity and heating systems distributed over hard-to-reach mountain-taiga areas in terms of the environmental aspect dictated by the requirements of the special protected areas. The possibility of establishing local systems for electricity and heat supply to consumers by using local renewable energy resources is shown on the example of solar energy.

II. The use of solar energy

Solar energy is one of the most environmentally friendly natural energy resources. Therefore, it can be considered as the primary one for the protected area at issue. Although this area is located in Mongolia's northernmost territory, the solar radiation it receives is not inferior to most of territories in the country [5] and is quite acceptable for the use in energy supply to its consumers. As follows from Fig. 2, the annual incoming total solar radiation of the Khuvsgul region lies in the range of 1600 to 1800 kWh/m^2 per year.

Direct solar radiation on a surface perpendicular to the sun's rays, which is of major importance for the calculation and use of solar power plants (Fig. 3), is in the range of 2800–3000 kWh/m^2 per year. These data are quite consistent with the estimates previously published in [1], corresponding to 1600–1720 kWh/m^2 per year.

III. Transformation and rationalization of power supply

It is obvious that solar energy can be used for both power supply and heat supply to autonomous consumers, agricultural facilities, and settlements. Recently, solar photovoltaic plants have become widespread in Mongolia. Almost all settlements in rural areas use photovoltaic cells for domestic needs. The use of solar photovoltaic cells (PVCs) in power generation is not particularly difficult, except for the need to provide the initial funding of the plants, the cost of which is constantly decreasing. Solar cells seem to be an effective solution for small disparate consumers (households, tourism facilities, schools, hospitals, administrative and public buildings in settlements) in the specially protected area. The solar plants with solar photovoltaic cells constructed in the centers of sums have increased the reliability and improved the operating conditions and voltage stability of 10–35 kV transmission lines in the settlement of Khankh.

The performed computational studies of the power transmission lines operation made it possible to assess the efficiency of the power systems under the existing conditions. To comprehensively present the situational behavior of operating parameters of the substations (Table 1) in this system, the substations of all sums in the Khuvsgul aimag, which are connected via a 110 kV transmission line from the city of Erdenet through the city of Bulgan, were included in the calculated diagrams.

The Power Factory software Toolbox was used to conduct computational studies of the operating conditions of electrical networks. The calculations were performed for two initial conditions, namely, for the winter maximum (load condition 1) and summer minimum loads (load condition 2). Tables 2, 3 and 4 present the assumed values of electrical loads and the results of assessing voltage levels, voltage deviation angles at substation buses, loading and losses of active power in power transmission lines, respectively.

Table 5. Comparison of voltage level and voltage deviation angle for the buses of substations with compensators and with a 5 MW renewable energy source.

Number	Substation	Winter maximum						Summer minimum					
		Load condition 3			Load condition 5			Load condition 4			Load condition 6		
		Ul, kV	u, p.u.	U angle degree	Ul, kV	u, p.u.	U angle degree	Ul, kV	u, p.u.	U angle degree	Ul, kV	u, p.u.	U angle degree
1	Muren110 kV_1, 2	119.51	1.06	– 26.31	123.67	1.09	– 21.89	105,10	0,93	– 11,09	105.97	0.94	– 7.94
2	Muren 35kV_1, 2	36.01	0.97	– 28.25	37.00	1.00	– 23.68	105,10	0,93	– 11,09	37.00	1.00	– 9.69
3	Alag-Erdene 35kV	34.71	0.94	– 29.83	35.61	0.96	– 23.87	35,37	0,96	– 13,39	35.22	0.95	– 10.68
4	Sumber 35kV	34.71	0.94	– 29.83	35.61	0.96	– 23.87	35.37	0.96	– 13.39	35.22	0.95	– 10.68
5	Khatgal	34.59	0.93	– 30.65	35.30	0.95	– 24.43	35.04	0.95	– 14.27	34.89	0.94	– 11.70
6	Gundalay 35kV	34.55	0.93	– 30.70	35.26	0.95	– 24.47	35.00	0.95	– 14.32	34.84	0.94	– 11.75
7	Alagtsar 35kV	34.48	0.93	– 30.78	35.19	0.95	– 24.55	34.92	0.94	– 14.39	34.76	0.94	– 11.84
8	Chandamana-Ulziy	34.43	0.93	– 30.83	35.15	0.95	– 24.6	34.87	0.94	– 14.44	34.71	0.94	– 11.89
9	Khukhkhuu bag	34.43	0.93	– 30.83	35.15	0.95	– 24.6	34.87	0.94	– 1.44	34.70	0.94	– 11.89
10	Ulaan-Uul	34.65	0.94	– 30.82	35.21	0.95	– 24.26	35.08	0.95	– 13.83	34.98	0.95	– 11.29
11	110 kV SPP	–	–	–	123.69	1.09	– 21.87	–	–	–	105.99	0.94	– 7.92
12	35 kV SPP	–	–	–	39.34	1.06	– 20.38	–	–	–	33.70	0.91	– 5.89

The voltage level for the maximum load conditions ranges from 0.90 to 1.01 in per units, and for the minimum load conditions, it varies from 0.99 to 1.04 p.u. The voltage deviation angle at the substation buses reaches 34.58º under the maximum load condition, and 19.40º – under the minimum load condition.

Power losses in power transmission lines are at an acceptable level, and the load of Erdenet-Bulgan transit double-circuit lines reaches up to 45.82% at the winter maximum load and only 26.16% – at the summer minimum load.

The computational studies show that the distribution of active and reactive power, overloads of lines and substations, and voltage levels by node change within the allowable limits outlined by regulatory documents, which confirms the admissibility and feasibility of the planned load conditions. Power quality can be assessed by using the indicators such as the voltage deviation in the network from its nominal values. They must be within acceptable limits. The cost-effectiveness of the load condition can be determined by the values of power and electricity losses in the electrical network. To this end, we identified eight local calculated nodes, for which the following indicators were analyzed:

Minimization of the total voltage deviation on the low side of substations supplying consumers

$$\delta U_{\Sigma} = \sum_{i=1}^{n} \left| \delta U_i \right| , \quad (1)$$

where δU_i is voltage deviation from the nominal value on the low side of the i-th substation, %.

Minimization of total active power losses in the network

$$\Delta P_{\Sigma} = \sum_{j=0}^{k} \left| \Delta P_j \right| , \quad (2)$$

where ΔP_j is active power losses in the j-th component of the electrical network, kW.

Maximization of the power supply reliability index for the consumer, which was estimated by the share of the essential consumers load covered with the help of RES at each substation

$$R = \sum_{k=0}^{n} \frac{1}{n \cdot L_i} \left(\min\left(L_i ; \frac{P_{res}}{n \cdot P_i} \right) \right), \quad (3)$$

where n is the number of substations; L_i is share of the i-th substation load corresponding to essential consumers, p.u.; P_{res} is power of renewable energy source installed at consumers of the i-th substation, kW; P_i is the load of the i-th substation, kW.

To improve the power grid operation with an increase in power consumption in winter and summer, computational studies were conducted for the installation of reactive power compensators and the usability of photovoltaic cells. The analysis of the initial conditions allowed identifying the sites for installing compensators according to the largest deviations of the voltage angle on consumer buses, including 35 kV and 15 kV buses of substations. The substations mentioned above are Khatgal, Tsagaan-Uul, Ulaan-Uul and Muren. The Muren substation was chosen to adopt RES.

For illustration, Table 5 shows the results of a computational study for the winter maximum load conditions in the power grid with compensating devices connected in the above places (Load condition 3) and with a renewable source at the Muren substation (Load condition 5) for all substations that belong to the Khuvsgul sums. Here, for comparison, the calculation results are also given for the summer conditions (Load conditions 4 and 6).

For clarity and comparison of the initial winter conditions (Load condition 1) with the data of the calculated conditions given in Table 5, Figure 4 indicates

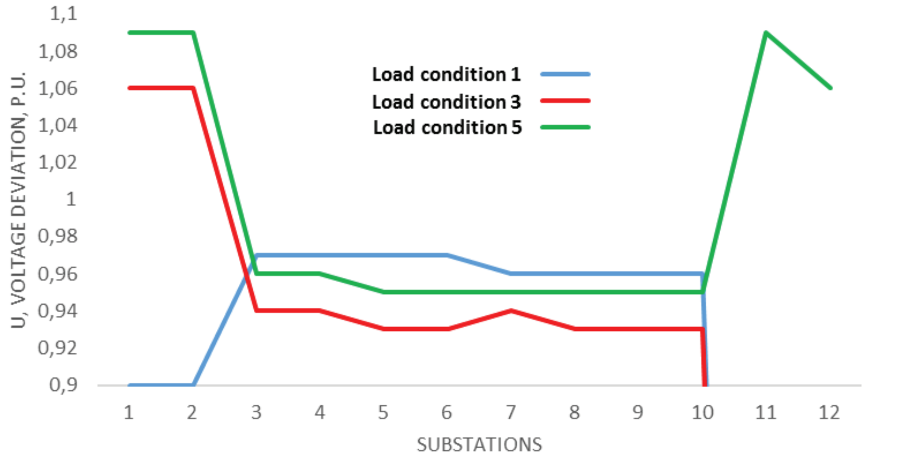

Fig. 4. Voltage deviation (in p.u.) at substations for the winter maximum conditions with respect to steady state with and without compensators and a 5 MW renewable energy source.

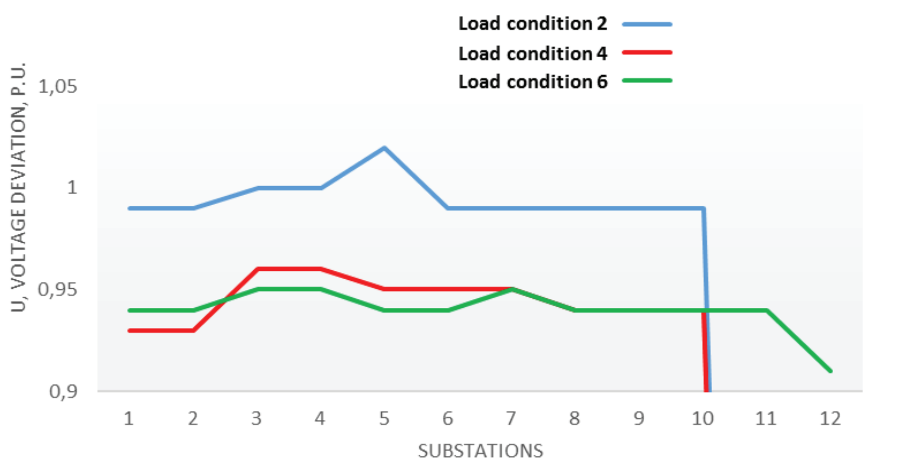

Fig. 5. Voltage deviation (in p.u.) at substations for the summer minimum conditions with respect to steady state with and without compensators and a 5 MW renewable energy source.

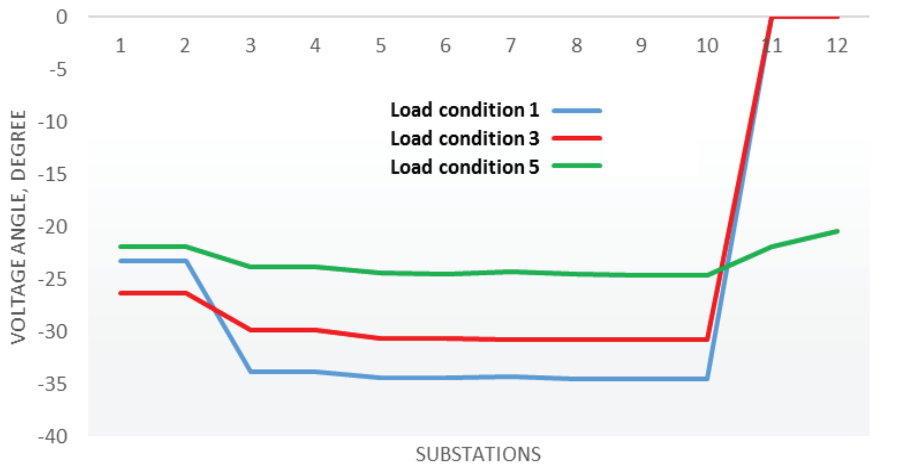

Fig. 6. Voltage angle deviation for the winter maximum at the substations with and without compensators and a 5 MW renewable energy source.

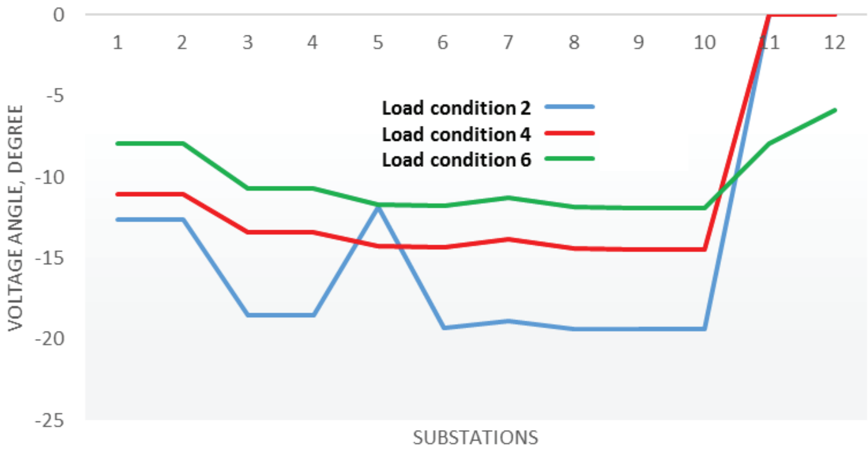

Fig. 7. Voltage angle deviation for the summer minimum at the substations with and without compensators and a 5MW renewable energy source.

Table 6. The assessment results for the loading of power transmission lines and active power losses with compensators and 5 MW solar plants at the Muren substation.

No.	Power transmission line	Winter maximum				Summer minimum			
		Load condition 3		Load condition 5		Load condition 4		Load condition 6	
		Loading	Losses (total)	Loading	Losses (total)	Loading	Losses (total)	Loading	Losses (total)
		%	MW	%	MW	%	MW	%	MW
1	Erdenet-Bulgan I	47.91	1.49	44.13	1.26	25.32	0.42	24.45	0.39
2	Erdenet-Bulgan II	47.91	1.49	44.13	1.26	25.32	0.42	24.45	0.39
3	Bulgan-Tosontsengel	49.23	5.67	43.51	4.22	19.86	0.9	14.1	0.42
4	Tosontsengel-Mörön	41.97	1.16	35.18	0.8	17.12	0.2	12.54	0.1
5	Moron-AlagErdene I	11.69	0.03	10.16	0.02	12.08	0.03	13.52	0.03
6	Sumber	0.37	0	0.36	0	0.33	0	0.36	0
7	Sumber_a	0	–	0	–	0	–	0	–
8	Khatgal-Gundalai amralt	2.63	0	2.58	0	2.69	0	2.98	0
9	Alagtsag-Gundalai	2.28	0	2.24	0	2.29	0	2.53	0
10	AlagErdene-UlaanUul	2.31	0	1.81	0	1.52	0	1.71	0
11	Khukhkhuu bag-Chandmani Undur	0.44	0	0.43	0	0.51	0	0.57	0
12	Khukhkhuu bag-Chandmani Undur_a	1.42	0	1.39	0	1.48	0	1.64	0

their combined graphs constructed to show the distribution of voltage deviations at the substations of the Khuvsgul sums and the Muren substation.

Following the objectives set in this work, all data given in Tables 2–5 and Figures 4 and 5, represent only the findings related to the diagram of the grid supplying power to the Khuvsgul sums that are part of the protected area.

The remoteness from the power generation center and the length of the local power grid significantly affect the values of its operating parameters, especially the voltage level. The reactive power compensators reduce the voltage deviation and, consequently, make corresponding operating conditions of the power grid more stable and resilient. As seen in Tables 2–5, compensators are to be purposefully installed to maintain the required voltage level and other operating parameters.

Detailed studies on the choice of parameters and sites for placement of compensators have shown that the achievement of the desired results can be facilitated through the reasonable use of RES.

The cost-effective energy supply solutions obtained in these studies became possible due to a comprehensive

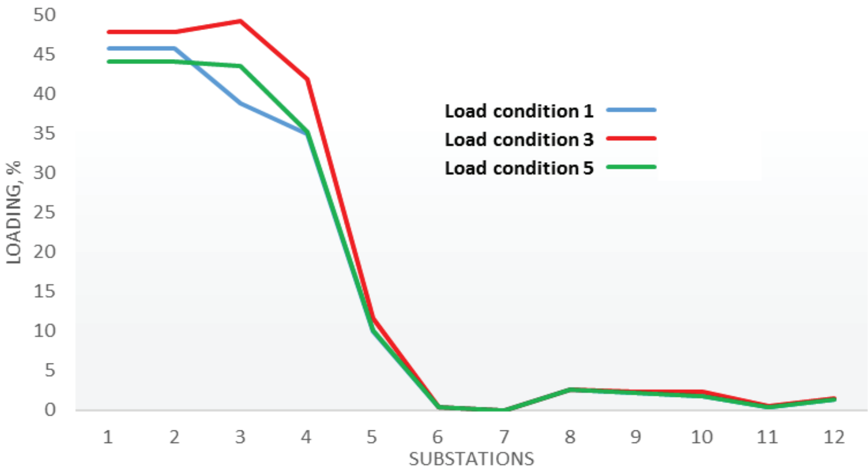

Fig. 8. Change in the level of loading of power lines at maximum loads.

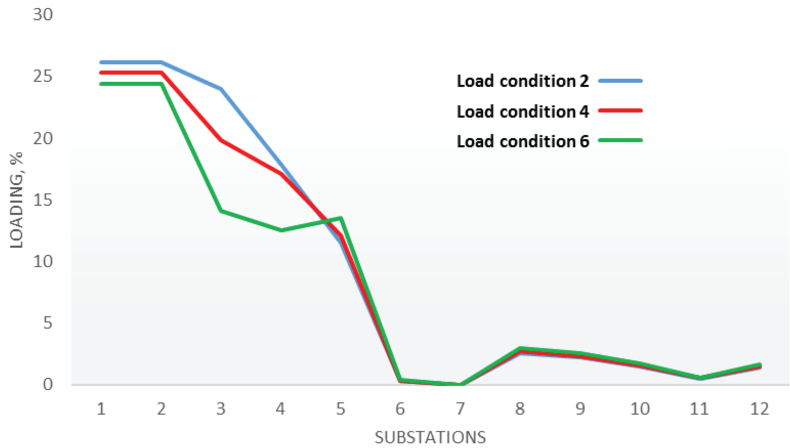

Fig. 9. Change in power loss in power transmission lines for the winter maximum load with compensators (1), without them (3), and with a 5 MW renewable energy source (5).

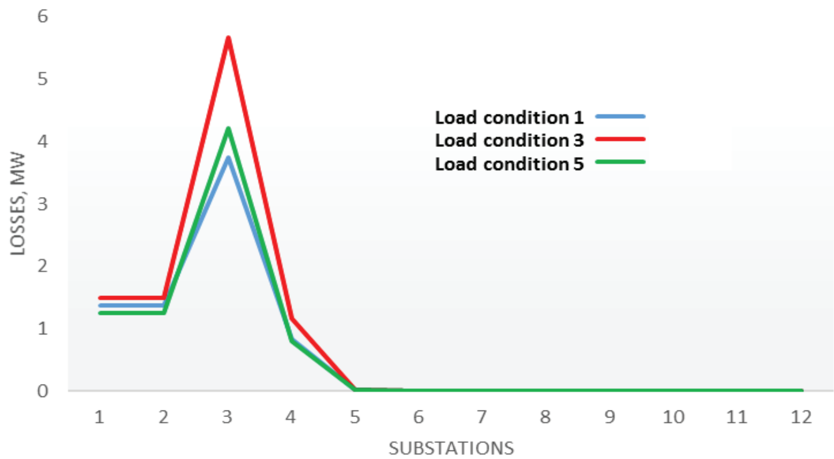

Fig. 10. Change in active power losses in power lines at maximum loads.

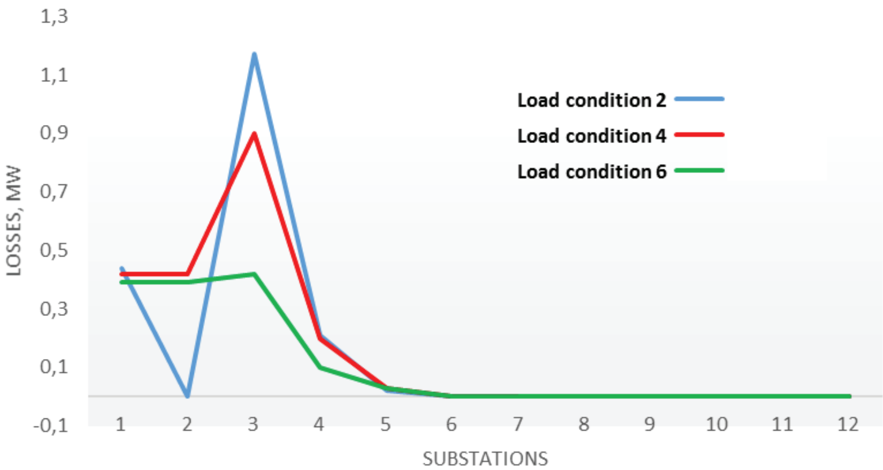

Fig.11. Change in active power losses in transmission lines at minimum loads.

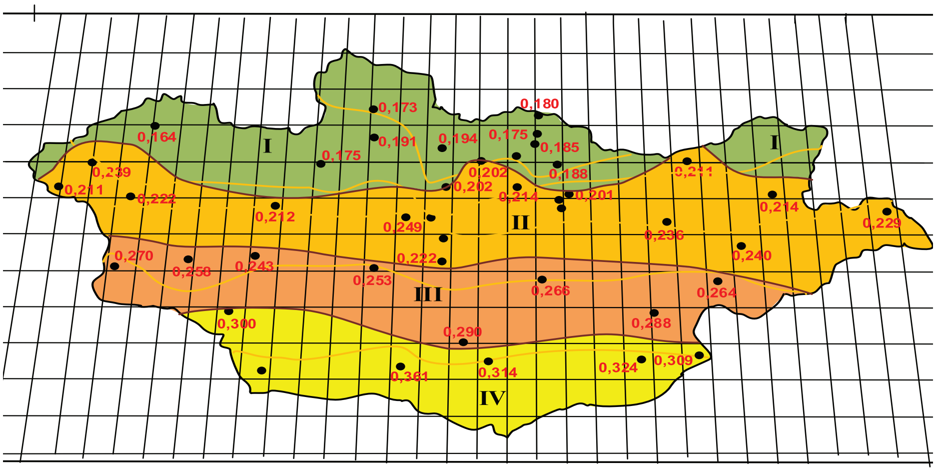

Fig.12. Zoning map of Mongolia's territory for the use of solar energy for heating buildings.

Fig.13. View of the school building for 320 students.

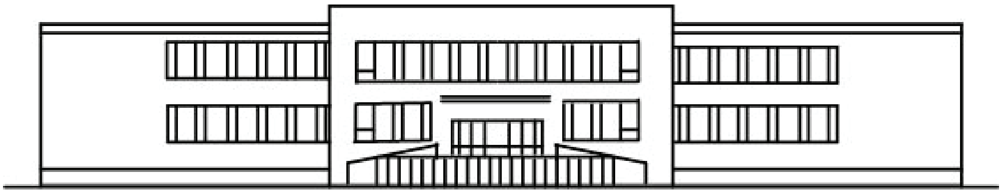

Fig. 14. General view of the building of the secondary school for 320 students.

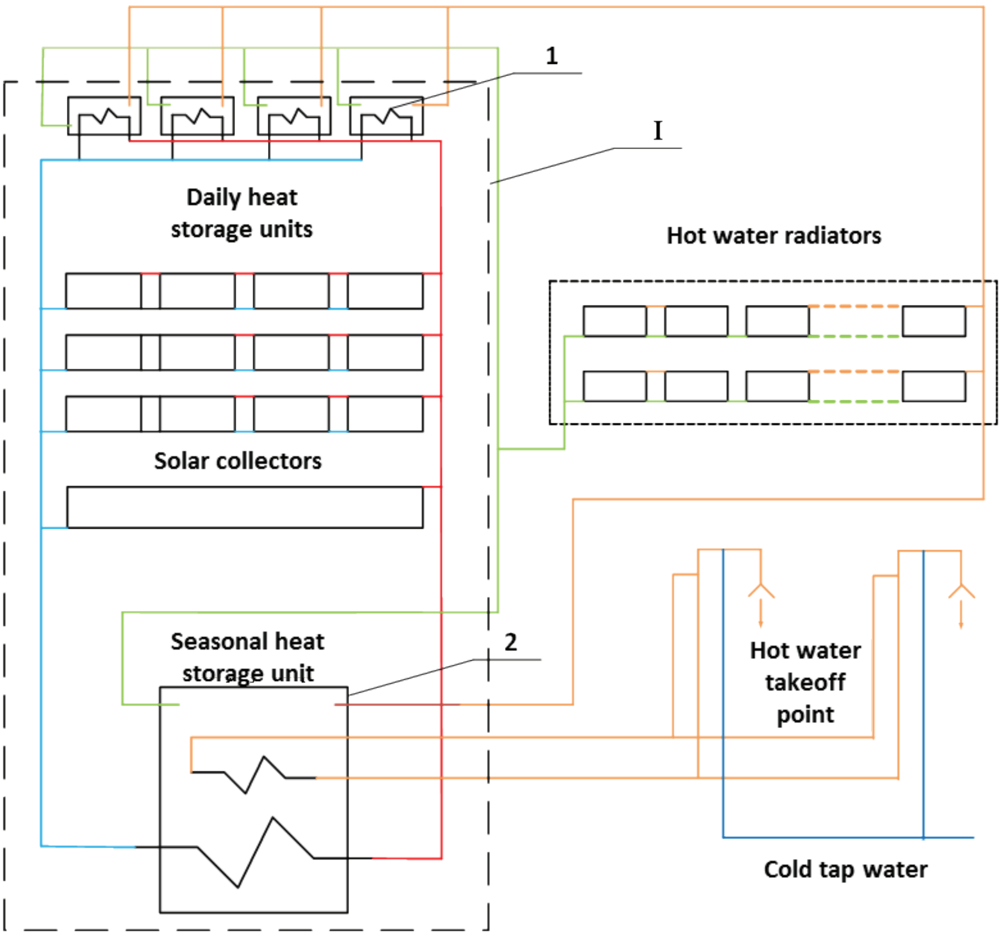

Fig. 15. Diagram of the solar heating system of the building.

consideration of this issue, taking into account the reasonable combination of centralized energy supply and distributed generation with renewable energy sources, as well as the use of advanced power grid equipment. These solutions are shown in Fig. 6 in the form of operation plots for voltage deviation for all substations in the Khuvsgul aimag power grid. Substations and nodes in this Figure are represented by conventional numbers from 1 to 12. According to the initial conditions, the considered power flows correspond to those given above and have the same numbering. The system stability effects obtained for low summer loads were more pronounced (Fig. 7).

In winter, the main 110 kV transit transmission line is loaded up to 45.82% of the installed capacity, and in summer, the load is 26.16% of the installed capacity. The transfer capability decreases with the use of compensators and increases with the introduction of new capacities of renewable energy sources. Power losses in transmission lines go up with the use of compensating devices and go down with the renewable capacities added, which happens due to the reduction of long transmission lines.

Thus, with the compensators, the voltage deviation in relative terms approaches unity. With reactive power compensation at the substations Khatgal (21), Tsagaan-Uul (16), Ulaan-Uul (23) and Muren (8), voltage deviations and active power losses decline, and the reliability of power supply and the stability of the electrical network operation increase.

Calculations confirm that in order to maintain the required voltage level and other operating parameters, compensators should be placed not only on the buses of these substations but also at some other nodes. The calculations also show that compensating devices can minimize the total voltage deviations on the low side of the substations supplying power to consumers. The additional input of RES represented by a solar plant of PV-type proves to be an effective solution to maintain voltage stability in the networks.

The expected addition of new potential electricity consumers may lead to unacceptable voltage deviations on the low side of substations in sums and settlements, as well as to high active power losses in the electrical network. In this regard, for the sustainable socio-economic development of the Baikal-Khuvsgul transboundary recreational area, it is necessary to ensure an environmentally sound and reliable power supply to existing and prospective consumers according to the electricity requirements.

Thus, the calculations show (Figures 8, 9, 10, and 11) that compensators and renewable energy generation can minimize the total voltage deviations on the low side of substations that supply consumers under the growing electrical loads on the territory of Khuvsgul aimag.

IV. Solar heating

The use of solar energy in heat supply (hot water, heating, cooling, and others) faces structural and technological problems arising when it is integrated into existing or newly established systems. Let us dwell on these aspects in more detail.

Previous studies on the use of solar energy for heat supply focused on technological solutions for generating heat [5] and zoning the territory of Mongolia in terms of its efficiency for heating buildings, depending on the climatic conditions of the area [5, 6]. According to the findings of these studies, four solar heating efficiency zones were identified in the direction from north to south of the country. In Fig. 9, they are shaded in different colors. In green zone I, located at the top of Fig. 10, year-round (including the entire heating period) use of solar heating is associated with considerable financial costs, i.e., initial capital investment. This zone includes the Khuvsgul aimag, which is part of the protected area. This is due to the relatively low solar activity.

A thin yellow line on the map of Mongolia (Fig. 10) shows the isolines of total solar radiation on a horizontal surface, dividing the country's territory according to its values of 1200, 1300, 1400, 1500 and 1600 kWh/m^2 per year. They can serve as a basis for assessing the integral indicator of the natural thermal energy coming to the studied area. The heat consumption of a building for its heating under specific climatic conditions of the area can be characterized by its integral indicator, the so-called "heating degree-day" (HDD). It represents the total time of the difference between the standard (normative) room temperature and the outdoor air temperature for the heating season, calculated following its daily variation [6]. The average indoor air temperature value, called the "standard temperature," was assumed to be equal to 18.33°C (65°F) when determining the HDD index. Based on the ratio (θ) of the annual total solar radiation coming on a horizontal surface (ASRHS) and the number of heating degree-days, the country's territory was divided into the above 4 zones. In actuality, when moving from north to south and with a decrease in HDD, the ASRHS rises, which indicates the enhancement of the efficiency of solar heating in buildings. Dots on the map mark the calculated values of θ = ASRHS/HDD [kWh/(m^2·°C·day)].

V. Solar energy for heating school

The design outdoor air temperature for heating in the centers of 23 sums in the territory of Khuvsgul aimag is between – 24.5 and – 43.2°C. The main thermal energy consumers in the centers of sums, along with the population, are a secondary school, a hospital, houses of culture and local administration, as well as trading and public service facilities. The research carried out by IT&IE (Institute of Thermal Engineering and Industrial Ecology at Mongolian State University of Science and Technology, Ulaan Baator, Sukhbaator district.) shows that for the centers of Khuvsgul aimag sums, the annual total heat load ranges from 296.6 Gcal/year (the Erdenebulgan sum) to 2 114.0 Gcal/year (the Tarialan sum) and the maximum hourly loads are 0.103

Table 7. Heat output of the solar system and heat balance of the building (for the months of heating season), kWh.

Month	X	XI	XII	I	II	III	IV
Heat output of the solar system	1 373.3	1 064.7	947.0	1 031.7	1 275.6	1 537.2	2 103.7
Heat consumed by the building for heating	398.5	732.9	968.2	1 030.8	923.6	645.8	356.6
Hot water supply	282.9	282.9	282.9	282.9	282.9	282.9	282.9
Total heat demand of the school	681.4	1 015.8	1 251.1	1 313.7	1 206.5	928.7	639.5
Daily heat balance (+/–)	+691.9	+48.9	–304.1	–282.0	+69.1	+608.5	+1 464
Monthly heat balance (+/–)	+20 797	+1 516	–9 123	–8 742	+2 142	+17 038	+43 920

Gcal/h and 0.743 Gcal/h, respectively [7]. This indicator for the centers of sums considered here ranges from 0.2 to 0.4 Gcal/h. The possibility of using solar heating in these areas (for example, centers of the sums) was assessed on the example of a secondary school for 320 students, which has a standard building design (Fig. 11).

The use of solar energy for heating and hot water supply to housing stock, buildings of educational and public institutions, tourist and health facilities, and holiday homes usually operating in the warm seasons of the year, is a relevant objective, especially in the light of environmental protection measures and development of ecotourism in specially protected areas. The efficiency of these technologies is quite high, despite the rich resources of fuel biomass obtained by cleaning forest areas of the Khuvsgul taiga and the preparation of firewood for household needs. Large solar water heating systems on the beaches of Lake Khuvsgul can be an example of solar plants. High-capacity water heaters designed to provide hot water and water procedures, and meet sanitary needs have been used and have demonstrated successful operation in holiday centers, sanatoriums (Terelzh, Sugnogor and Under-Dov), a summer camp for Selbe school students, at a remote railway siding (52-nd siding of the UBRW), and other facilities of the country.

We will consider the possibilities of using solar heating for consumers of zone I (Fig. 10) in the case of a school building for 320 students. These studies have made it possible to get some general results of a computational experiment on providing year-round heat supply to buildings, which can be extended to other projects [6]. The general view of the building is shown in Fig. 12, and the schematic diagram of the solar heating system adopted for it is demonstrated in Fig. 13. The system includes daily and seasonal heat storage units. According to the standard project, the construction volume of the school building is 16 065 m^3, the total area of all floors is 3 662.1 m^2, the dimensions of the base area in the plan are 48.0 m × 48.0 m (there is a free area in the center of 18.0 m × 18.0 m), and the height of the building is 7.75 m. The building must meet the requirements of energy efficiency. For this reason, annual heat loss is calculated per unit floor area, and has to be reduced to a value of the specific indicator of less than 100 kW/m^2 per year. This should be done by increasing thermal resistance of external enclosing structures through the measures reducing heat losses, for example, by using triple glazing and double-glazed windows and doors of the REHAU type, equipment for the southern facade of the building, which structurally combines a wall fence with flat solar collectors of the FT-FP-2M*1M type, ventilated air heat recovery, and others [8]. Vertical installation of solar collectors on the southern facade of the building is the most effective for solar systems primarily used in the cold seasons in northern latitudes, where the sun's height is low [5].

For the Darkhad basin, where Renchinlkhumbe sum is located, the total annual heat consumption for heating a building under the climatic conditions of the region can be 250 583.0 kWh/year, which corresponds to a specific heat loss indicator of 68.4 kWh/m^2 per year.

The adopted thermal diagram of the solar system includes flat solar collectors located on the front facade of the building and on its roof for heating the non-freezing liquid heat carrier of the first closed loop (I). The system is composed of daily heat storage units in the form of separate tanks (1) and a seasonal heat storage unit in the form of a large concrete tank (2). They are equipped with a heat exchange surface through which the heat carrier heated in solar collectors flows. The system is provided with heating devices (for example, water radiators), hot water takeoff points that have cold tap water mixing lines for temperature control, measuring instruments, and others. For the climatic conditions of the region where the minimum temperature reaches –40°C, the primary loop of the system must have a heat carrier that does not freeze up to a temperature of –50°C, for example, TYFOCOR L, which is an odorless hygroscopic liquid based on propylene glycol, which is not harmful to health. It is actively used as a cooling brine or heat transfer fluid.

Table 7 summarizes the results of a computational study relying on climatic data of the area, indices of the solar system heat output, thermo-engineering characteristics of the building envelope and heat consumption by the school building.

Table 7 shows that in October and April, the solar system produces more heat than required. Consequently, the excess energy is stored in daily storage systems for later use. From November to March, daily output becomes insufficient to meet the building's demand for heat and the lack of heat is replenished from the seasonal storage. The seasonal storage facility accumulates excess heat produced by the solar system throughout the year, primarily during warm periods. This is the basic principle of year-round continuous operation of the solar system, which ensures complete thermal independence of the school. The objective of providing autonomous heat supply can be achieved by choosing an optimal combination of daily and seasonal storage capacities based on mathematical modeling and calculation, and economic criterion. If necessary, a supplementary heat source can be used.

Capital investment in the school building for 320 students, aimed at the measures to reduce heat losses by enclosing structures and equipment of the solar heating system, is about MNT 170 million (at the rate of 2014). This value roughly corresponds to 10% of the capital investment in the school project. The payback period for additional capital investments, associated with a decrease in heat losses relative to the design value and equipment of the solar heating system for the building in question due to savings in fuel costs, is 7.3 years. The discounted payback period is 9 years.

To provide a convincing illustration of the possibility of using local environmentally friendly energy resources to supply energy to consumers in the specially protected areas, we considered the case of solar heat supply to the largest consumer in the sum center – a secondary school. In addition, the choice of solar heating for the school is of paramount importance for the environmental education of children.

In most cases, small consumers can apply simpler methods and schemes of solar heating systems without much difficulty. These systems work reliably on clear days at any time of the year.

Thus, the use of solar energy is an urgent issue that contributes to comfortable living and helps tackle other social and economic problems, primarily for remote regions of Mongolia. At the same time, if buildings are equipped with photovoltaic cells, they become energy-independent eco-facilities that meet the energy supply requirements.

VI. Conclusion

1. The Mongolian-Russian transboundary Baikal-Khuvsgul specially protected natural area is a unique ecosystem, which is of great scientific importance not only for studying natural diversity, but also for exploring the impact of human economic activity on the natural formation. Therefore, special attention should be paid to potential consequences of any activities carried out in this area. Energy supply to local consumers and that related to a sharp increase in touristic activities in the region are no exception.

2. A specific feature of the specially protected natural areas is an underdeveloped system of fuel and energy supply due to the remoteness of settlements and low density of the population. In this situation, the issue of energy supply can be addressed by involving local renewable energy sources. The territory under consideration has a high solar energy potential.

3. Increase in the reliability and continuity of centralized power supply together with improvement in the electricity quality are possible by the use of distributed generation sources (solar photovoltaic cells) at specific local electrical network nodes mainly corresponding to the centers of sums and settlements. The Power Factor Software can be employed to identify and obtain the options for ranking the weak nodes, placement of compensators, the required capacity and location of solar plant, which ensure the permissible voltage deviations for consumers, low total losses of active power, and high reliability of power supply.

4. The centralized system is not advisable for heat supply to the centers of small settlements with their small and often dispersed load. Therefore, the issue of their energy supply can be resolved through an individual and/or group system based on solar or other renewable energy. The real possibility of using a solar heating system (heating and hot water), even for fairly large facilities, is shown by the example of a typical secondary school. Based on modeling and calculation of the school's energy supply, it was determined that additional funds (10% of the total capital investment in the project) would be required. Apart from solar heating to be used in the building, another important strand is the implementation of measures to reduce heat losses to meet the requirements of energy-efficient buildings. It is worth noting that the solar system receivers installed on the southern wall structure reduce heat loss. All the listed measures to enhance energy efficiency made it possible to bring the annual rate of heat loss through the building envelopes (reduced to the floor area) to 60 kWh/m^2 per year.

5. The use of solar plants to provide hot water to meet the domestic needs of the population, the needs of sanitary-resort and tourist facilities, and their heating, as well as the use of solar cells to generate electricity for consumers in remote areas are an effective and advantageous direction of energy supply to the Khuvsgul National Park and specially protected natural areas in general.

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