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Renewable energy sources and storage batteries for electrification of Russian decentralized power supply systems

D Karamov¹, I Volkova², Suslov¹, and I Dolmatov²

¹ Irkutsk National Research Technical University, 83, Lermontov Street, Irkutsk, Russia

² National Research University Higher School of Economics, 20 Myasnitskaya Street, Moscow, Russia

E-mail: souslov@istu.edu

Abstract. The use of renewable energy sources (RES) and storage batteries (SB) in decentralized power systems is a cost-effective way to supply power to consumers. In this case, storage batteries are one of the most important system components. The significance of storage batteries is conditioned by a stabilizing effect obtained at generation from RES that are defined by stochastic oscillating functions. However, it is worth noting that storage batteries also improve the cost-effectiveness of such systems by reducing consumption of diesel fuel. This is particularly noticeable at night when load is the least and the use of diesel generators is inefficient. One of the most important points is the determination of potential internal processes of aging and breakdowns that occur in storage batteries during operation. The use of a tested model for categorization of storage batteries according to the operating conditions makes it possible to take account of these factors at the stage of a system design. The paper presents a detailed analysis of decentralized power supply system Verkhnyaya Amga. The focus is made on the cost-effectiveness of a combined use of RES with storage batteries, annual saving of diesel fuel, operating parameters. The research reveals hidden problems that represent various uncertainties that affect greatly the economic and operation parameters of the system.

1. Introduction

Modern energy policy in various countries is oriented to an increase in the share of renewable energy sources in the total generation [1-3]. The accelerated transition to carbon-free energy was dictated by signing the historic Paris Agreement on the climate that suggested a reduction in the greenhouse gases into the atmosphere. The Kyoto Protocol and 20 years later Paris Agreement are the fundamental mechanisms of a transition to the environmentally friendly energy in the world [4].

It is worth noting that RES are an important link in the electrification of rural areas in the developing countries [5-6]. It contributes to the improvement in social and economic, environmental indices that characterize the level of living conditions of people and reduces the migration from rural areas to large-scale cities [5-8].

Integration of storage batteries into the power supply systems involving RES makes it possible to considerably increase the efficiency of the generated power utilization [9-10]. The main problems that arise from the use of RES jointly with storage batteries have an optimization character [9-14]. Normally the main goal of the optimization is to determine installed capacity of equipment, which the levelized cost of electricity (LCOE) has the minimum values [15-17]. The emissions and fossil fuel consumption can also be used as objective functions.



Currently there are some software packages intended for the optimization of decentralized power supply systems involving RES and SB. These software packages are known both scientifically and practically. Some of them are: HOMER – Hybrid optimization modeling software [18-20], HOGA – Hybrid optimization by genesis algorithm [13,21-22] and HYPORA – Hybrid power optimized for rural/remote areas [23]. The presented software allows us to solve the optimization problems with the use of hourly characteristics of wind speed, solar radiation, consumer load, economic environment indices, etc. However, it is also necessary to take into account various kinds of uncertainties. For example, the uncertainty of fuel prices, consumer load, system expansion, which can considerably affect the unit commitment and operating parameters of the system [46-47].

These processes are rather complex and require additional studies [5,7,45-47]. Their complexity lies in the fact that in these uncertainties there is an overlap of economic, political, demographical and other constituents which are difficult to take into account for a long period of time [45].

The paper demonstrates the efficiency of involving RES and SB in the decentralized power supply systems in the Far East. The research presents cost-effectiveness, reduction in diesel fuel consumption, and operating parameters. Also some hidden problems (caused by uncertainties) are discussed, which were identified from the data on operation of such systems. The obtained results are compared with the conclusions and hypotheses of other researchers.

2. Decentralized power supply systems in Russia.

There is a great amount of decentralized power supply systems in Russia. For example in the Far East alone there are above 250 decentralized power supply systems, including 130 in the Republic of Sakha (Yakutia) [24].

The main generating equipment in these systems is represented by diesel generators with varying installed capacity. Electricity generated by the diesel power plants is very expensive. This is conditioned by high costs of diesel fuel transportation to consumers as well as by specific consumption of diesel fuel. Fuel transportation is performed in two stages [25]. The first stage involves transportation by river to the primary stock point in summer-autumn period. The second stage includes automobile transportation in winter. Such a complex scheme of delivery is caused by poorly developed logistics in the region [26]. Moreover, many populated areas are literally isolated from the external world due to impassible huge swamps and endless taiga. Such areas can be accessed only by helicopter or in winter when swamps and rivers are frozen. Such roads are called ice roads.

To reduce diesel fuel consumption the company “RAO Energy Systems of the East” devised a program for the development of decentralized power supply systems in the Far East. This program is aimed at using renewable energy sources and storage batteries in decentralized power supply systems. According to the official data it is planned to place into service about 150 MW of installed capacities using RES and SB in the Far East by 2020 [27].

Now there have been installed 14 PV power plants and 3 wind power plants. These projects make it possible to save up to 1590 tons of diesel fuel annually.

It is worth noting that only 3 of the system use SB which are represented by lead-acid, lithium-ion, and lead-carbon. The use of SB in decentralized power supply systems with RES considerably saves fuel and allows disconnection of diesel generators at night, thus preserving their technical resource [11]. These conditions are important for decentralized power supply systems in the Far East. The practice, however, shows that the use of RES and SB within decentralized power supply systems has hidden problems which should be paid special attention to.

3. Decentralized power supply systems in Russia.

The theory of graphs is applied to describe the structure of a decentralized power supply system. Geometry of any system including decentralized power supply system can be represented by a digraph in which all segments are marked with numbers. In this case we determine n segments of the circuit (electric ties), m nodes of the circuit (components of generation, storage, etc.), and the number of linearly independent loops which are shown with the Roman numbers in Figure 1.

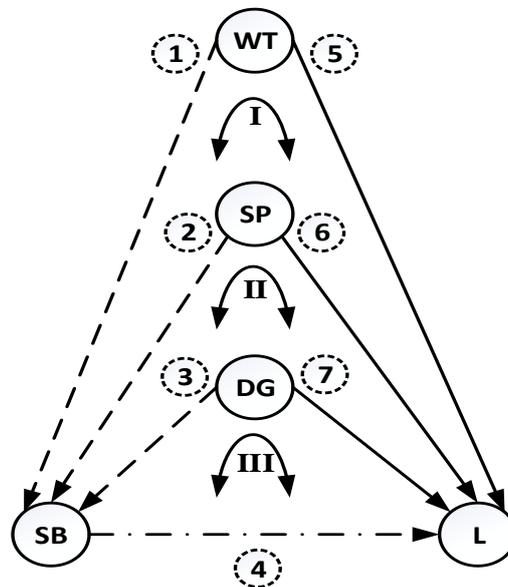


Fig.1 A digraph of decentralized power supply system with RES and SB

The digraph of decentralized power supply system has 5 main nodes which are represented by the components of generation (WT, PV, DG), loads (L), and SB. Moreover, on the basis of (1) the digraph of decentralized power supply system has 7 electric ties and 3 linearly independent loops.

Then two matrices are constructed: $A - a \cdot (m - 1) \cdot n$ matrix of couplings of linearly independent nodes and segments of the highlighted digraph and $B - a \cdot (c \cdot n)$ matrix of linearly independent loops and segments of circuit. These matrices are necessary to determine a stabilizing component of the system [28].

It follows from the digraph that the known parameters of the system are the values of power at nodes of the circuit, i.e. vector function [29] of scalar argument (t).

$$P_{WT}(t) = \begin{matrix} \zeta_{WT} \\ \xi_n \end{matrix} \left\{ \begin{matrix} P_{WT}^{ins}, \eta_{WT}, V_w^{min}, V_w^{max} \\ V_w(t), \rho_a(t), p_a(t), T_a(t) \end{matrix} \right\} \quad (1)$$

$$P_{PV}(t) = \begin{matrix} \zeta_{PV} \\ \xi_n \end{matrix} \left\{ \begin{matrix} P_{PV}^{ins}, \eta_{PV}, S_{PV}^{ins} \\ p_a(t), T_a(t), T_{PV}(t), I_S(t) \end{matrix} \right\} \quad (2)$$

$$P_{DG}(t) = |\zeta_{DG}| \{ P_{DG}^{ins}, b_{DG}, P_{DG}^{min} \} \quad (3)$$

We will write matrix A by following the rule: if the i-th segment and direction from the node belong to the j-th node, the matrix element equals -1, otherwise the matrix element equals +1. Thus, we have:

$$A = \begin{matrix} \mathcal{X} \\ WT \\ PV \\ DG \\ ES \end{matrix} \begin{bmatrix} \underline{1} & \underline{2} & \underline{3} & \underline{4} & \underline{5} & \underline{6} & \underline{7} \\ -1 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & -1 & 1 & 1 & 1 \end{bmatrix} \quad (4)$$

Matrix elements are constant numerical values, whereas elements for node L can be obtained by summing up the columns multiplied by -1. Thus, matrix A can be written in the form of block matrices

$$A = [A_d; A_c] \quad (5)$$

where

$$A_d = \begin{matrix} \mathcal{K} \\ WT \\ PV \\ DG \\ ES \end{matrix} \begin{bmatrix} \underline{1} & \underline{2} & \underline{3} & \underline{4} \\ -1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix} \quad (6)$$

and

$$A_c = \begin{matrix} \mathcal{K} \\ WT \\ PV \\ DG \\ ES \end{matrix} \begin{bmatrix} \underline{5} & \underline{6} & \underline{7} \\ -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \\ 1 & 1 & 1 \end{bmatrix} \quad (7)$$

We will write matrix B according to the following rule: if the i -th segment belongs to the c -th loop and direction of the segment coincides with the loop direction, the matrix element equals $+1$, otherwise, the matrix element equals -1 , hence we have:

$$B = \begin{matrix} \mathcal{K} \\ I \\ II \\ III \end{matrix} \begin{bmatrix} \underline{1} & \underline{2} & \underline{3} & \underline{4} & \underline{5} & \underline{6} & \underline{7} \\ -1 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & -1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & -1 & 1 & 0 & 0 & 1 \end{bmatrix} \quad (8)$$

This matrix can also be represented in a block form

$$B = [B_d; B_c] \quad (9)$$

where

$$B_d = \begin{matrix} \mathcal{K} \\ I \\ II \\ III \end{matrix} \begin{bmatrix} \underline{1} & \underline{2} & \underline{3} & \underline{4} \\ -1 & 0 & 0 & 1 \\ 0 & -1 & 0 & 1 \\ 0 & 0 & -1 & 1 \end{bmatrix} \quad (10)$$

and

$$B_c = \begin{matrix} \mathcal{K} \\ I \\ II \\ III \end{matrix} \begin{bmatrix} \underline{5} & \underline{6} & \underline{7} \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (11)$$

An analysis of matrices A_d, A_c, B_d, B_c shows that vertex ES has the maximum degree of the digraph. Moreover, the node has direct connection to load in the case when:

$$P_S(t) < 0 \quad (12)$$

where

$$P_S(t) = P_{WT}(t) + P_{PV}(t) - P_L(t) - \Delta P_\Sigma(t) \quad (13)$$

where

$$\Delta P_\Sigma(t) = \Delta P_{PL}(t) + \Delta P_{PV-INV}(t) + \Delta P_{SB-INV}(t) + \Delta P_{SB}(t) \quad (14)$$

Hence, energy storage in decentralized power system is a stabilizing link operating in the buffer conditions [10-13]. The smoothing effect is observed virtually at any time instant, since $P_{WT}(t)$, and $P_{PV}(t)$ are defined by stochastic, oscillating functions.

4. Cost-effectiveness of renewable energy sources and storage batteries in a decentralized power supply system in the Far East of Russia.

To assess the cost-effectiveness of RES and SB we use the technique of levelized cost of electricity (LCOE) [30]. LCOE for decentralized power supply systems with diesel power plants lies in the range from 0.4 to 0.6 €/kW·h, which are extremely high values. Such high values are related to high cost of arctic diesel fuel (considering delivery) which makes up 816.38 - 1041.98 €/ton [31]. Also, another important factor is technical state of diesel generator in the decentralized power supply system. For example, in the decentralized power supply system of Lensky area (Republic of Sakha (Yakutia)) specific consumption of diesel fuel accounts for 474.8-539.8 g/kW·h. At the same time at night, when the load is the least, the specific consumption of diesel fuel rises. Such a situation is observed virtually in all decentralized power supply systems in the Far East.

The involvement of RES and SB allows us to considerably save diesel fuel and, thus, decrease the index of LCOE to 0.21 – 0.35 €/kW·h [5]. In the territory of the Far East there are only 3 decentralized power supply systems that use RES with SB (Table 1).

Table 1 Decentralized power supply systems using RES with SB in the Far East

Settlement	Batamay	Uchugey	Verkhnyaya Amga
Geographical coordinates	63.52N 129.48W	63.44N 142.50W	59.38N 127.06W
P_{PV}^{ins} , kW	60	30	36
P_{DG}^{ins} , kW	160	250	44
P_{SB}^{ins} , kW h	86.4	144	144
P_{PV-INV}^{ins} , kW	60	30	36
P_{SB-INV}^{ins} , kW	36	36	24
Fuel consumption ton/year*	32.27 (51.22)	18.27 (30.50)	17.69 (34.80)
Fuel saving ton/year**	18.95 (37 %)	12.23 (40 %)	17.11 (49 %)

* Diesel fuel consumption when only diesel-generators are used; ** reduction in diesel fuel consumption (%) when RES and SB are used.

Operation of the decentralized power supply systems with RES with SB shows that diesel fuel consumption declines by 37% – 49%.

The LCOE index in Batamay is 0.31 €/kW·h, in Uchugey - 0.32 €/kW·h, and in Verkhnyaya Amga - 0.28 €/ kW·h.

The presented results demonstrate that the use RES with SB saves greatly diesel fuel in decentralized power supply system in the Far East and decreases the index of LCOE.

5 Operating indices of storage batteries in the decentralized power supply systems

In the autumn-winter period, from November 1 to March 1, PV and SB are disconnected from the decentralized systems. They are conserved while maintaining the charge of the SB at one level. This is related to low values of solar radiation (PV output) and high level of load (Figure 2). The conservation allows us to avoid cyclic deep discharges of SB at this period. Such conditions are characteristic of many decentralized power supply systems in the Far East.

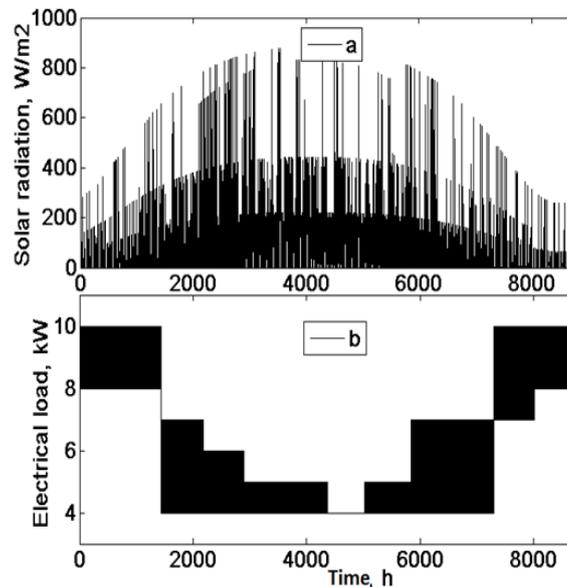


Fig.2 – a – Solar radiation and b – Electrical load in the system Verkhnyaya Amga during a year

During this period power is supplied from a diesel power plant operating in parallel with PV without SB. However, in the northern areas of the Far East where air temperature can reach -65°C PV as well as SB are mothballed.

An analysis of operating parameters of SB makes it possible to determine the effectiveness of their application. Figure 3 demonstrates a change in the state of charge (SOC) of SB in the decentralized power system Verkhnyaya Amga during a year.

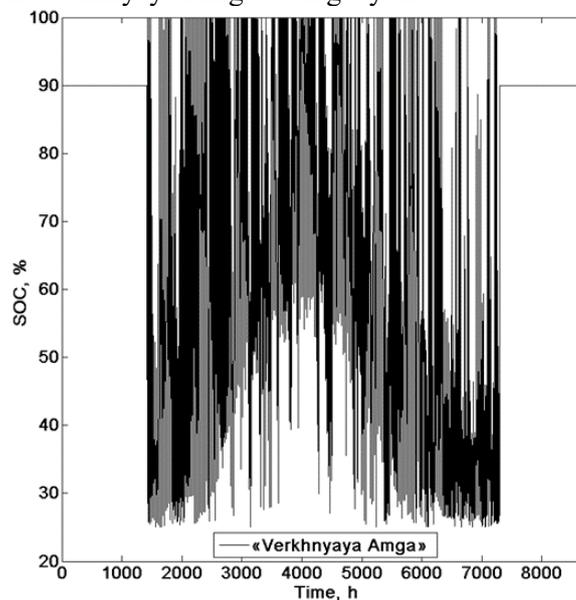


Fig.3 SOC of SB in Verkhnyaya Amga

Storage battery is first charged from PV at the time when

$$P_S(t) > 0 \quad (16)$$

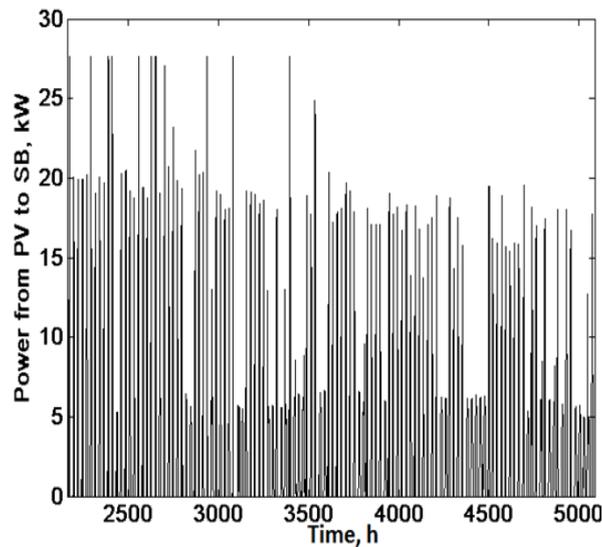


Fig.4 Power from PV to SB in the system Verkhnyaya Amga (April → August)

Diesel generator is connected at the time when:

$$SOC(t) \leq SOC_{DOD}^{min} \quad (17)$$

In the decentralized power supply systems of the Far East the depth of discharge (DOD) is normally 70-80%. In this case, when condition (17) is met, diesel generator starts operating at full capacity, and thus has the maximum efficiency and minimum fuel consumption [11, 13].

In spring-summer period diesel generator is virtually not connected. The amount of power generated from PV in the decentralized power supply system Verkhnyaya Amga is sufficient to supply consumers and charge SB. The annual power used to charge storage batteries from PV makes up 16389 kW·h (15.97%), and from DG – 5388 kW·h (5.25%). Direct supply to consumers from PV is 27312 kW·h (26.59%), and from DG – 53596 kW·h (52.19%).

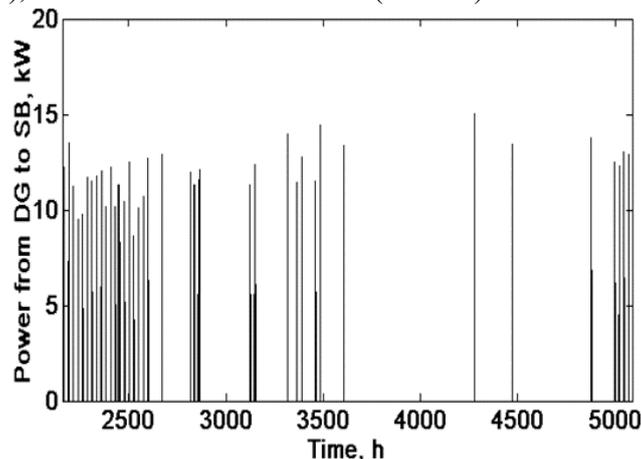


Fig.5 Power from DG to SB in Verkhnyaya Amga (April → August)

To analyze the operation of SB, a very useful approach is used in the research to categorize SB in decentralized power supply systems. The approach makes it possible to determine potential internal processes that occur in SB throughout the entire period of operation [32]. To determine the SB category it is necessary to calculate some stress factors. These factors include: charge factor (CF), Ah throughput, the highest discharge rate, time between full charges, time at low SOC (TLS), and partial

cycling (PC). Combinations of stress factors as well as classification of systems using PV and SB are presented in [33].

$$CF = \frac{Ah_{charged}}{Ah_{discharged}} = \frac{\int I_{bat}H(I_{bat})dt}{\int I_{bat}H(-I_{bat})dt} \quad (18)$$

$I_{bat} > 0$ – charging, $I_{bat} < 0$ – discharging.

$$Q_{thrp} = -\frac{\int I_{bat}H(-I_{bat})dt}{C_N} \quad (19)$$

$$I_{max1\%_{aver}} = \frac{0,01 \cdot Q_{thrp} \cdot C_N}{I_{10} \cdot \sum_{i=n-x}^n t_i} \quad (20)$$

Where

$$\sum_{i=n-x}^n I_{10} \cdot t_i = 0,01 \cdot Q_{thrp} \cdot C_N \quad (21)$$

$$t_{bfc} = \frac{\int H(90-SOC)dt}{n_{90\%}} \quad (22)$$

$$PC = \frac{(A \times 1 + B \times 2 + C \times 3 + D \times 4 + E \times 5)}{5} \quad (23)$$

where

$$A = \frac{\int I_{bat}H(SOC-85)H(100-SOC)H(-I_{bat})dt}{\int I_{bat}H(-I_{bat})dt} \cdot 100 \quad (24)$$

Defined SOC ranges; A–E represent cumulative Ah throughput (% of the yearly total) in the particular SOC range: *A* – (100-85%), *B* – (85-70%), *C* – (70-55%), *D* – (55-40%), *E* – (40-0%).

$$TLS = 100 \cdot \left(\frac{\int H(35-SOC)dt}{\int dt} \right) \quad (25)$$

A more detailed description of calculated stress factors and operating conditions of SB in the systems with PV are presented in [32-34].

An analysis of operating conditions of storage batteries was made on the example of the decentralized power supply system Verkhnyaya Amga. The obtained results were compared with the levels of stress factors that describe different categories of operating conditions of storage batteries [32]. The calculation results and levels of stress factors are presented in Table 2.

Table 2 Calculation results and levels of stress factors for the decentralized power supply system Verkhnyaya Amga

Stress factors	Verkhnyaya Amga	Level of stress factors
Charge factor, [<i>CF</i> in %]	101,85	1
Ah throughput, [Q_{thrp}/C_N]	131,17	5
Highest discharge rate, [$I_{max1\%_{aver}}$ in I_{10}]	0,80	3
Time between full charges, [t_{bfc}/day]	5,94	4
Time at low SOC, [<i>PC</i> in %]	9,95	3
Partial cycling, [<i>PC</i> in %]	67,86	4

The obtained calculation results and levels of stress factors show that the operating conditions of SB in the decentralized power supply system Verkhnyaya Amga belong to *Category 1*.

Figure 6 presents radar plot diagrams of six categories of similar operating conditions relating *Category 1* with the discussed levels of stress factors of the decentralized power supply system Verkhnyaya Amga.

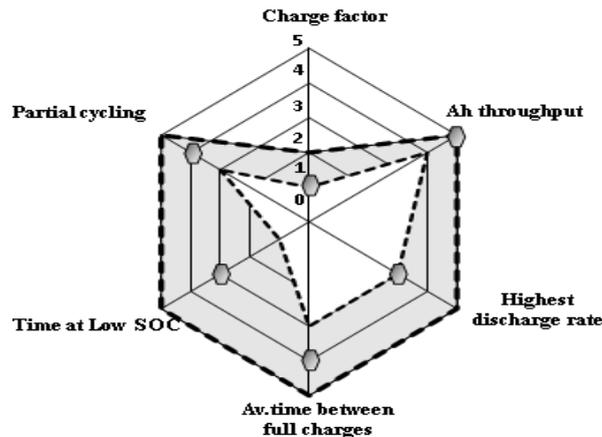


Fig.6 Radar plot diagrams of the decentralized power supply system Verkhnyaya Amga

Category 1 is typical and the most widely spread among decentralized power supply systems in the Far East. It is characterized by cyclic operation, frequent partial state of charge of SB, deep discharges of SB up to 20%, and rare full states of charge.

Storage batteries that belong to *Category 1* operate under rather severe conditions which affect largely the aging processes in SB and the number of their replacements throughout the entire cycle of operation. The degrees of aging are shown in Table 3.

Table 3 Evaluated ageing degrees of *Category 1*

Ageing mechanism	Degree of ageing
Corrosion of the positive grid	Low
Hard/irreversible sulphation	Very high
Shedding	High
Water loss/drying out	Very low
Active mass degradation	Very high
Electrolyte stratification	Very high
Reverse polarisation of cell	Very high
Electrolyte freezing	Very high at $T < 0, ^\circ\text{C}$

It is worth noting that based on the obtained category (*Category 1*) we can take into account some measures to reduce the degree of SB ageing. These measures include: acid circulation system or VRLA battery, heavy duty battery, resistance to active mass shedding (i.e. tubular plate, pocket separators); sulfation resistance (special charge method, auxiliary generator) [32].

Moreover, these measures can considerably extend the period of SB operation in the decentralized power supply systems. These measures were taken into account in design of the decentralized power supply system Verkhnyaya Amga. The following was done:

- Lead-carboxylic SB were applied because they are resistant to the processes of hard/irreversible sulfation, active mass degradation and electrolyte stratification [35-38]. Moreover, the lead carboxylic SB compared to the lead-acid batteries (OPZV, OPZS) have a greater number of cycles at a 70% DOD. The lead-carboxylic SB have 4200 [39] cycles at 70% DOD, whereas lead-acid batteries – 1500 [40-41].
- The battery management system was installed to provide normal operating conditions of SB and connection of backup generators.
- One diesel generator was additionally installed to charge SB at the time when $\text{SOC} < 25\%$.

Implementation of these measures allows operating the SB in the decentralized power supply system Verkhnyaya Amga within rated values established by manufacturer, and reduce the degree of storage battery ageing

6 Hidden problems arising in the decentralized power supply systems in the Far East and possible ways of solving them

The operation of decentralized power supply system with RES and SB shows that during the first 5 years the hidden problems arise that have a considerable influence on the operating conditions of the system. In some cases underestimation and absence of timely actions can lead to very bad consequences.

The hidden problems include a progressive increase in the residential load. These increase represent uncertainty which should be taken into consideration at the stage of predesign evaluation.

What is the reason for the progressive increase in the residential load? Unfortunately, it is connected with a very poor social and economic development of remote settlements in Russia. When power is supplied only from diesel generators (as a rule 2-4 hours a day), people do not use different electric devices: refrigerators, washing and dish washing machines, furnaces, heaters, boilers and others. Why to have these devices if there is no electricity? However, when the accessible power from RES with SB appears (24-hour power supply) people start to buy all the domestic appliances necessary for normal living [42].

Under such circumstances, the load increases by 2-3 times. RES do not cope with such a load, storage batteries get discharged in a matter of few hours. And two diesel generators instead of one are connected as a reserve. With time, service life of diesel generators comes to a limit and a failure, which causes emergency disconnection of the system due to a critical frequency deviation. Also, the diesel generators can fail because of constraints on the frequency of their connection. Thus, everything returns to the initial point, i.e. power supply only from a diesel generator during 2-4 hours a day.

Unfortunately, such a situation occurred in the decentralized power supply system Onguren (Irkutsk region). The decentralized power supply system Onguren included 15 kW wind turbines, 81 kW photovoltaics, 75 kW diesel generators, and 100 kWh SB. This system was completely placed into service in 2012 with capital investment above €675 thousand (43.9 million rubles). In winter 2015 half of storage batteries failed (electrolyte got frozen) which caused their breakdown. In August 2016 the system failed completely and it was shut down [42].

Load in the decentralized power supply system Batamay was also increased. This was caused by the construction of an elementary school and kindergarten [43] which raised load of RES and SB. Eventually, the decentralized power supply system was reconstructed. The installed capacity of PV was increased from 10 to 60 kW and capacity of SB increased up to 144 kWh.

In the first and second cases the increase in the residential load was caused by the desire of residents and local authorities to improve social and economic situation for people and for the development of the populated area.

In such conditions it is necessary to perform optimization at the stage of predesign evaluation, considering various scenarios of load increase [11]. Such an approach provides the possibility of timely coping with the situation and avoiding serious consequences. Однако достоверность таких прогнозов требует дополнительных исследований, анализа и верификации в будущем [5,7-8,45-47].

7. Discussion

The paper presents three decentralized power supply systems using RES and SB. At the stage of design of these decentralized systems the problem of the installed capacity of RES and SB was solved. The installed capacity of RES in the considered systems lies in the range from 30 to 60 kW which is economically sound for the microsystems of such a level [45]. At the same time, RES and SB made it possible to use electricity during 24 hours a day. This considerably improved living conditions of

people and stopped their migration to large cities. Thus, the conclusions presented in studies [5-8] are confirmed.

A considerable rise in load is observed during the first year of operation of the system with RES and SB. This rise in load was really recorded in the decentralized systems of Batamay and Uchugey. The increase is related to the improvement in socioeconomic indices of the living conditions of the population.

Consequently, to design and optimize such systems it is necessary to take into account both a existing load and its possible change in time (from year to year), considering the processes of system expansion, which is put forward as a hypothesis in [46]. To forecast the level of load, considering climatic factors and a great number of uncertainties it is planned to apply artificial neural network [48]. In this case it is necessary to take into consideration the issues of social, demographic, and political character as well as the issues of long-term development of the power supply system.

Therefore, in the future it is necessary to devise a comprehensive approach to an analysis of load level in the decentralized power supply systems, considering the presented uncertainty factors [45-48].

8. Conclusion

At first sight the decentralized power supply systems of the world are quite simple systems. However, they hide a great number of invisible problems that arise during the operation of RES and SB. On the whole, we can place an emphasis on four major points to be considered to involve RES and SB in the decentralized power supply systems of the world.

- RES and SB in the decentralized power supply systems in the world are of great importance for the creation of comfortable living conditions of the population.
- The use of RES and AB makes it possible to significantly save diesel fuel. The projects on RES and SB, implemented in the Far East reduce diesel fuel consumption by 37% and more.
- The conditions of storage battery operation in the decentralized power supply systems are as a rule severe, with often incomplete state of charge of storage batteries and deep discharge of storage batteries up to 20% and very rare full state of charge.
- To solve the optimization problem it is necessary to take account of various uncertainties and specific features of the considered region. For example, the involvement of RES and SB in the decentralized systems of the Far East leads to a progressive increase in load, which affects technical and economic indices of the system.

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