Calculation of electrical loads for decentralized power supply systems and the choice of power gas piston installations which use electrochemical energy storage

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Abstract. In autonomous electric power supply systems of remote areas of the country where there are no centralized electric power supply, diesel generator units (DGU), and gas piston installations (GPI) is used as a source of electrical power. Selection of their nominal power determined load value, for which the preliminary calculation using the standard values. Researches of electric power profiles for apartment and public buildings of the Republic of Tatarstan showed a significant difference from the current regulatory values. At present, the regions are granted the right to independently set specific loads for such objects. The article proposes a method for selecting the power of autonomous power plants for actual loads for urban and rural settlements.

1 Introduction and relevance of the study

The Russian Federation is the largest state in the world in terms of the area of decentralized power supply zones, in which consumers supply power independently, i.e. when electricity is generated exclusively by internal sources. Usually, they are DGU and GPI [1-4]. Such territories include the Far East, the Arctic zone, areas of the Far North, where economic activity is carried out. For the long-term living of staff creates rural settlements. However, apart from them, settlements are developing on a permanent basis. They require the creation of an appropriate infrastructure, which includes children's and school educational institutions, medical institutions. And first of all, a housing fund is created, which includes both individual houses (cottages) and apartment buildings up to 5 floors inclusive. In some cases, higher buildings may occur.

The power supply systems of urban-type facilities are designed on the basis of the values of design loads given in [5]. The fact that they differ significantly from the actual ones can be seen in Figure 1. Substations with a load factor of transformers k_z less than 30% of their nominal electric power account for 70% or more of their total. This circumstance is explained by the outdated values of standards [5], which do not take into account the impact of energy-saving technologies on household and office equipment. As a result of the use of these standards, the excess electric power is set in advance in the power installations supplying the power supply systems for housing objects.

Fig. 1. Upload diagram of transformer substations 0,4/10 kV.

In the Republic of Tatarstan, over the past few years, specialists of the Association “Roselectromontazh” were carried out on the basis of information provided by OJSC “Grid Company”, Kazan, a great job of verifying the loads of apartment and public buildings, which showed significant differences from [5] towards their reduction, which is shown in Table 1, where the first group includes apartment buildings without elevator up to 5 floors, the second group includes apartment buildings with elevators 6 to 10 floors, both groups have gas-stove.

Regional specifics of the nature of the loads are viewed in Figures 2 and 3. The smaller specific power consumption in Magnitogorsk compared to Kazan, Figure 2, is explained by lower specific loads, Figure 3. At the same time, the nature of the load qualitatively coincides between the two cities. This gives grounds for the dissemination of the results of studies of specific loads of one region on other regions, adjusted for the amount of electrical consumption.

Table 1. The specific rated electrical load of apartment buildings.

№	Developers of the values of the specific loads	Specific rated electrical load for the number of apartments in buildings according to standard projects [kW /apt.]						
		12	15	18	24	40	60	100
1	Offers of the Association “Roselectromontazh”, apartment buildings up to 5 floors with gas-stove	0.53						
2	Set of rules 256.1325800.2016	2	1.8	1.65	1.4	1.2	1.05	0.85
3	Offers of the Association “Roselectromontazh”, apartment buildings up to 6-10 floors with gas-stove	0.61						
4	Set of rules 256.1325800.2016	2	1.8	1.65	1.4	1.2	1.05	0.85

Fig. 2. Specific power consumption in apartment buildings.

Fig. 3. Daily power graphs for two cities.

Its value is readily available, in contrast to electric power profiles, which can be used selectively to evaluate new specific electric power values introduced in the region.

2 Experimental research

For the correct choice of power installation, you must use daily load patterns. Figures 4 show daily power profiles for two cottages in different villages. Figures 5 show daily power profiles of different groups of cottages in the same village. The overall increase in the load of the rural settlement and the effect of the electric boilers on increasing the minimum load pays attention. Observed jumps and load drops of individual cottages are averaged when they are jointly consumed from a single source.

Figures 6 shows the results of the summation of daily power profiles for two rural settlements. The presence of

electric boilers significantly narrowed the range of daily power variations - up to 12.6%. While for a village with gas heating, the maximum power is 2.28 times the minimum.

The graphs in Figure 6 also show that local dump and rise of load are smoothed out when summing up, and one can practically disregard the factor of their effect on GPI, which are extremely sensitive to rapid load changes. For the settlement «a» the average load is equal to $P_m = 79.4$ kW, for the settlement «b» $P_m = 373$ kW. Analysis of loads of several cottage villages has shown that it is possible to single out the main (first) group of cottages, comprising 85% of their total number, for which the loads obey the law of normal distribution. For them, in the range, $P_m \pm 1.64\sigma$ will be with the probability of 0.9 values of all loads. As a result, we have for rural settlements - 7.5 kW / cottage. This value is recommended to use when the number of objects more than 10. The second group (15%) are cottages with a high load, which is random in nature. With a probability of 95% of the surveyed more than 250 houses, it can be assumed that the maximum load does not exceed 25 kW.

Figure 7 shows, as an example, a combined chart of daily power graphs for three apartment buildings (AB) and three kindergartens (KG).

The graphs of Figure 7 show that the maximum loads of the apartment buildings and pre-school educational institutions are shifted in time: the maximum load of the pre-school educational institutions accounts for daytime, while for the apartment buildings it is the evening time. The maximum load of school educational institutions falls on the morning hours, Figure 8a, which further smooths the total load pattern.

Load patterns of shops and catering enterprises do not have pronounced short-term highs and dips, Figure 8b.

Taking the baseload graphs of apartment buildings, we can write the following formula for calculating the maximum total capacity of a residential community (1):

$$P_{\max} = P_{u1}N_{ap1} + P_{u2}N_{ap2} + k_m N_c (0.85P_{c1} + 0.15 P_{c2})P_{GS} + P_{CF} + k_{Kg} P_{Sc} + k_{Sc} P_{Sc} \quad (1)$$

P_{u1} and P_{u2} – specific load for apartment buildings of the first and second group;

Fig. 4. Daily power graphs for two cottages: a – gas heating, b – electric heating.

Fig. 5. Daily power profiles of rural cottages with partial use of electric boilers: a – is a sample with maximum loads, b – is a sample with smaller loads.

Fig. 6. The power profile of the total load of the village: a - village with gas heating, b - a village with electric boilers.

N_{ap1} and N_{ap2} – total number of apartments in apartment buildings of the first and second group;
 k_m – coefficient of simultaneity of the maximum load cottages and apartment buildings;
 P_{c1} – power cottage main (first) group;
 P_{c2} – power cottage second group;
 P_{GS} and P_{Cf} – total maximum power respectively, for a food store and cafe;

k_{Kg} and k_{Sc} – participation rates in maximum load for school and children's educational institutions;

P_{Kg} and P_{Sc} – maximum capacities, respectively, for school and children's educational institutions, where $P_{Kg} = p_{Kg}N_{Kg}$, $P_{Sc} = p_{Sc}N_{Sc}$.

In turn, p_{Kg} , p_{Sc} , N_{Kg} , N_{Sc} – respectively, the specific loads and the number of children in kindergarten and in school.

Fig. 7. Profiles of specific power apartment buildings and pre-school educational institution.

Fig. 8. a - Daily profile of the specific power of the school for 270 students, b - Power profiles food store and cafe.

Fig. 9. Frequency deviation during discharge and load spikes: 1 - GPI without storage, 2 - GPI with a storage.

Based on the studies performed, the following values of specific loads can be recommended: $P_{u1} = 0.53$ kW/apt.; $P_{u2} = 0.61$ kW/apt.; $P_{c1} = 7.5$ kW; $P_{c2} = 25$ kW; $p_{Kg} = 2.2$ kW/children(ch) (up to 55 places); $p_{Kg} = 1$ kW/ch (more than 55 places and up to 110 places); $p_{Sc} = 1$ kW/ch (up to 300 children); $k_{Kg} = 0.7$ and $k_{Sc} = 0.6$.

Formula (1) is used to select the rated power of autonomous power installations. In the absence of

energy storages, given the social importance of uninterrupted decentralized power supply in the northern territories, it is necessary to use at least two independent power sources. Then the rated power of each satisfies the condition:

$$P_{nom} > P_{max} / 2. \quad (2)$$

Table 2. Cost indicators storages.

View	Type	P = 1 MW	P = 5 MW	P = 10 MW
Battery LT-LFP 700P	U _{bat} = 470 V C = 700 Ah W = 329 kWh N=147 7.2 million rubles	U _{bat} = 2352 V C = 700 Ah W = 1645 kWh N=735 36.01 million rubles	U _{bat} = 4 700 V C = 700 Ah W = 3290 kWh N=1469 71.9 million rubles
Supercapacitor BMOD0094 P075	U _{sc} = 526 V C = 94 F W = 5 MJ N=19 3.9 million rubles	U _{sc} = 2632 V C = 94 F W = 25 MJ N=95 19.7 million rubles	U _{sc} = 5263 V C = 94 F W = 50 MJ N=189 39.4 million rubles

When using the GPI as a power source, the emergency shutdown of one of them will lead to a shutdown and the second due to a sudden load rise. Figure 9 shows a diagram of the variation of the frequency of electric current with a step load change within the limits of permissible values for one of the Caterpillar GPI.

According to the ISO 8528-5 standard, for the class of generators G3, the frequency range is allowed during rises and load dumps within + 10 / -15% (frequency recovery time 3 s). At the same time, already at idle speed of the GPI operation, the allowable load increase does not exceed 15%. It is obvious that the adoption of an emergency load when one of the two sources is disconnected will require the use of electrochemical storage. If you use the formula (2), then its power should be at least half the power of the entire load.

The optimal combination of the GPI and the drive is to increase the number of GPI. At the same time, the opportunities for their mutual redundancy in the autonomous power supply system increase and the required storage power is reduced [6-10].

Perform an approximate estimate of the economic effect [10-15]. So, if the load by the equation (1) is 2 MW, then you can install two GPI with an electric power of 2 * 2.0 MW or four GPI with an electric power of 4 * 1.0 MW. In the first case, an electrochemical storage unit with an electric power of 2 MW is required, in the second case - 1 MW. If the storage is used only to compensate for short-term power outages, then it suffices to use supercapacitors. In the first case with an electric power of 2 MW, in the second case 1 MW. Based on the duration of their work of 5 seconds, energy of 5 MJ, the cost of a 1 MW storage will be 3.9 million rubles plus 2.6 million rubles on the device coordination with the grid (inverter and transformer). Total on the storage will be required in the second variant 5.5 million rubles and 11 million rubles in the first variant, table 2.

In the case when the smoothing of the load graph is intended in order to save fuel, batteries are used as a storage. Consider them at the same electric power - 1 MW. Under the condition of their work for issuing a 0.25 MW operating mode for 1 hour, the daily cost of a 1 MW storage will be 7 million rubles. We take into account that in the mode of short-term battery discharge, it is permissible to work with an increased current, which for most batteries is 5C. This means that the rated power

of the battery can be reduced to 250 - 300 kW and the price will be about 3 million rubles. In this case, in normal mode, the battery serves to smooth the load pattern.

Load dump from the operating power installations when the source is turned back on occurs rather slowly, with a predetermined set speed of the power installation turned on.

3 Conclusions

Electrical loads of residential low-rise settlements and urban apartment buildings differ by 2–3 times from their calculated values given by regulatory documents. For children's and school educational institutions, design loads also give values of maximum power that are 1,5 to 2 times overestimated. The choice of power installations in autonomous power supply systems in these cases according to design data leads to a significant overestimation of their installed electric power.

The load rises and dumps, which take place in the operation of an apartment and public buildings, are relatively small and are smoothed out when they are summed up in the busbar sections of the switchgear. Thus, the inclusion of boilers in children's educational institutions leads to an almost instantaneous increase in power by 20 - 40 kW, and the inclusion of a fire alarm emergency exhaust ventilation - up to 100 kW. The greatest danger to the GPI is the emergency shutdown of one of the generation sources. For the successful application of GPI operating on associated petroleum gas, the stabilization of the frequency in an electrical AC grid can be achieved by installing electrochemical batteries on the corresponding currents of relatively low electrical intensity. At the same time, issues of fuel economy for them become secondary.

The use of associated petroleum gas in remote areas, for which the cost of imported liquid fuel increases many times and with its transport capacities creates an additional environmental burden, when using storage devices, it has no alternative.

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