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COMPARATIVE COMPUTATIONAL ANALYSIS OF THE SELECTION OF BATTERY ENERGY STORAGE FOR CIVIL OBJECTS AND PARKING WITH PHOTOVOLTAIC PLANTS

Abstract: *One of the disadvantages of solar power plants is that they do not produce electricity at night, so they cannot support the load of consumers. One of the reliable methods of increasing the efficiency of the use of photovoltaic power station (PPS) for consumers is the installation of energy storage. This study aims to investigate the efficiency of using a battery energy storage system (BESS) that is designed to power a civil facility and a parking lot. This study presents a feasibility analysis of BESS using System Advisor Model (SAM) software. The following objects were chosen as objects of research: a cottage; 19-story residential building with built-in non-residential premises (BNP); 9th floor parking lot for 979 cars. These facilities have solar power plants installed on the roof. BESS is planned to be used for power supply of the entire facility and power consumers. For the existing PPS, taking into account the peak load, the selection of the storage energy and modeling of the system operation modes was performed.*

The modes of use of the usage accumulator have been studied. The most effective mode of operation is mode 1, which involves charging the electricity storage during the day, and feeding the load in the evening. It is advisable to use this mode throughout the year. Mode 2 should be used to cover the load only during the spring-winter-autumn period, when the electricity generation from the FES is not sufficient.

The simulation results showed that BESS has the highest economic efficiency for the electricity supply of BZB with a payback period of 10.5 years with a battery utilization efficiency of 96.49%.

Keywords: *PPS; BESS; System Advisor Model; battery energy storage*

Introduction

Energy production from PPS has a number of advantages and disadvantages. One of the disadvantages is that PPS does not produce electricity at night, so they cannot support the load of consumers. To solve the problem of stability of electricity supply at night battery energy storage (BES) are used [1]. BES in combination with a solar power plant is called a battery energy storage system (BESS). This system absorbs and releases energy in different periods. There is no doubt that the additional investment and operating costs of BESS will affect the cost-effectiveness of the PPS. The purpose of this work is to develop the BESS design methodology of civil objects and parking.

Materials and Methods

In this study, the selection of the BES and the simulation of the operation modes of the PPS, which is installed on the roof of civil facilities and a parking lot, are carried out. The system consists of PPS, charge controller, inverter and BES. SAM software was used for research.

The structural diagram of the power supply system with PPS and BES is shown in Figure 1.

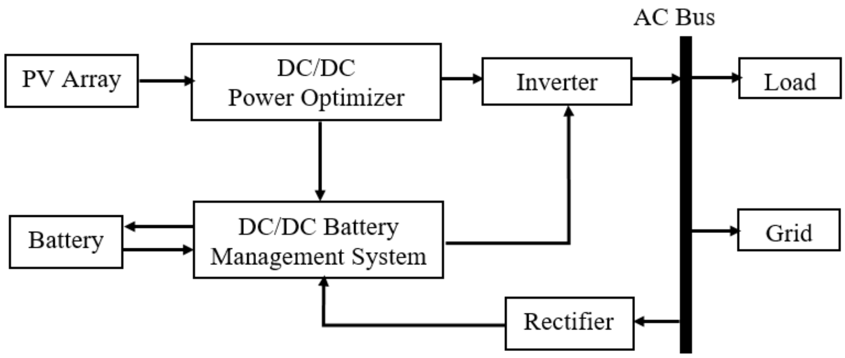

FIGURE 1. *Model of BESS [2]*

The principle of operation of BESS is that the energy produced in the PPS charges the BES, and then, when there is no solar insolation, the storage is discharged. At the same time, energy can be used to supply electricity to public housing facilities (parking lots) or can be fed into the electrical grid [3].

The selection of an EE storage unit for an existing PPS involves the following stages:

1. Determining the load capacity of public transport facilities (parking lots).
2. Based on the data on the installed capacity of the PPS, the forecast of the annual EE generation.
3. Calculation of the peak annual load in the SAM software.
4. Calculation of the power and capacity of the BES based on the peak annual load.
5. Choice of BES type: lead-acid or lithium-ion.
6. Selection of the mode of use of the BES.
7. Modeling of BESS operating modes in the SAM software to determine the value of the generated energy of the PPS and evaluate the efficiency of using the BES.
8. Economic analysis and evaluation of the economic performance of the hybrid system using the SAM software, taking into account the daily, monthly and annual volumes of electricity generated by the PPS, BES data and electricity consumed by the facility.

Results and Discussions

In this work, calculation studies of efficiency using BES for power supply of objects using PPS were carried out. The research objects are located in the city of Kyiv (latitude: 50.4; longitude: 30.45). Weather data was selected for 2021 from (https://energyplus.net/weather).

TABLE 1. *Deviation of air temperature in the room from the average. Design loads and parameters of PPS with peak load (option 1)*

Type of house	Nominal power of the existing PPS, kW	Estimated power of consumers (AC), kW	Estimated power of power consumers (AC), kW	Peak annual power of consumers (AC), kW	Peak annual power of power consumers of BZHB (AC), kW
K	60	25	–	40	–
B	124.95	–	16.32	–	26
A	676.2	398	–	151.49	–

For comparison, a BES for half the peak load was selected.

Table 2. *Design loads and parameters of the PPS with half the peak load (option 2)*

Type of house	Nominal power of the existing PPS, kW	Estimated power of consumers (AC), kW	Estimated power of power consumers (AC), kW	Half of the peak annual power of consumers (AC), kW	Half peak annual power of power consumers (AC), kW
K	60	25	–	20	–
B	124.95	–	16.32	–	13
A	676.2	398	–	75.75	–

K – cottage; B – 19-story residential building with built-in non-residential premises (BNP); A – 9th floor parking lot for 979 cars. The cottage is powered only by PPS. The PPS of a residential building is used to supply energy consumers. The parking lot is powered only by the PPS.

Using the calculated parameters of the peak load, the capacity of the BES is determined. The storage was selected taking into account the condition that the peak load should be less than the nominal power of the PPS. A Vipow lithium-ion (lithium-iron-phosphate) battery with a capacity of 50Ah and a voltage of 3.2 V was selected for the designed PPS. For each object of research using the SAM software, the selection of the choice of BES, the time of operation at maximum power and the capacity BES. The results of the calculations are presented in Tables 3 and 4.

Table 3. *Selection of BES and capacity (option 1)*

Variant number	The power of the BES consumers (DC), P1	Time of operation at maximum power, t1	Capacity of the BES of consumers (DC), Q1 = P1 · t1
K	32	2	64
B1	21	4	128
B2	21	8	258
B3	21	12	384
A1	152	4	608
A2	152	8	1216
A3	152	12	1824

Table 4. *Selection of BES and capacity (option 2)*

Variant number	The power of the BES of consumers (DC), P2	Time of operation at maximum power, t2	Capacity of the BES of consumers (DC), Q2 = P2 · t2
K1	20	2	40
B4	13	4	52
A4	76	4	304

With the use of SAM software, the following modes of operation of the BES were simulated by programming the drive dispatch controller:

1. Mode 1: BES charge during the day, feeds the load in the evening.
2. Mode 2: At night (11:00 p.m. – 7:00 a.m.) it does BES fully charge from the power grid (low electricity tariff), in the morning (7:00 a.m. – 8:00 a.m.) it gives electricity to the electric grid, and then charges from the PPS.

Such working periods are BES defined:

Period 1. All energy from the PPS is directed to battery charging.

Period 2. Discharge of BES and power supply of consumers.

Period 3. Charging of the battery from the electrical grid and subsequent return of energy from the BES to the electrical grid.

The BES discharge is carried out gradually: the BES will be discharged every hour by 20% of the total 80% depth of discharge. This will allow for an even discharge of the battery system during each hour of peak time. The minimum state of charge is 20% and the maximum state of charge is 100%, giving a depth of discharge (DOD) of 80%. This ensures the highest battery life.

The results of BESS modeling for various research objects are presented in Figures 2-10.

1. Cottage. Similar graphs are obtained for other variants of the cottage study.

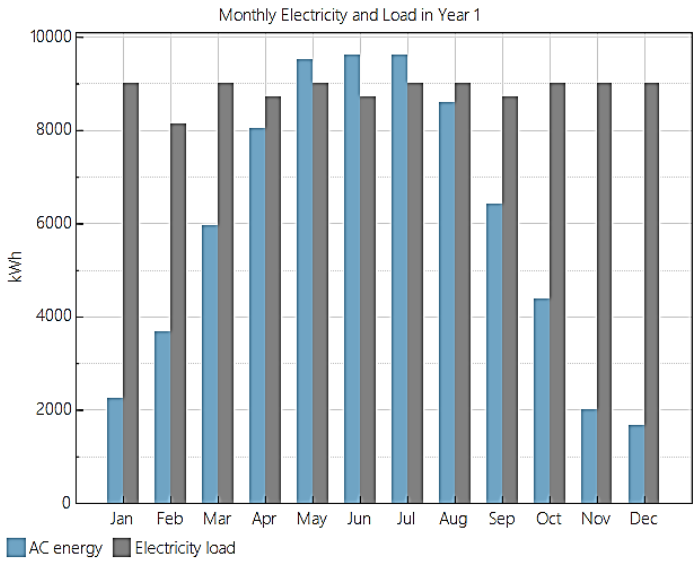

FIGURE 2. *Schedule of average monthly electricity production of the PPS and consumption of the facility K*

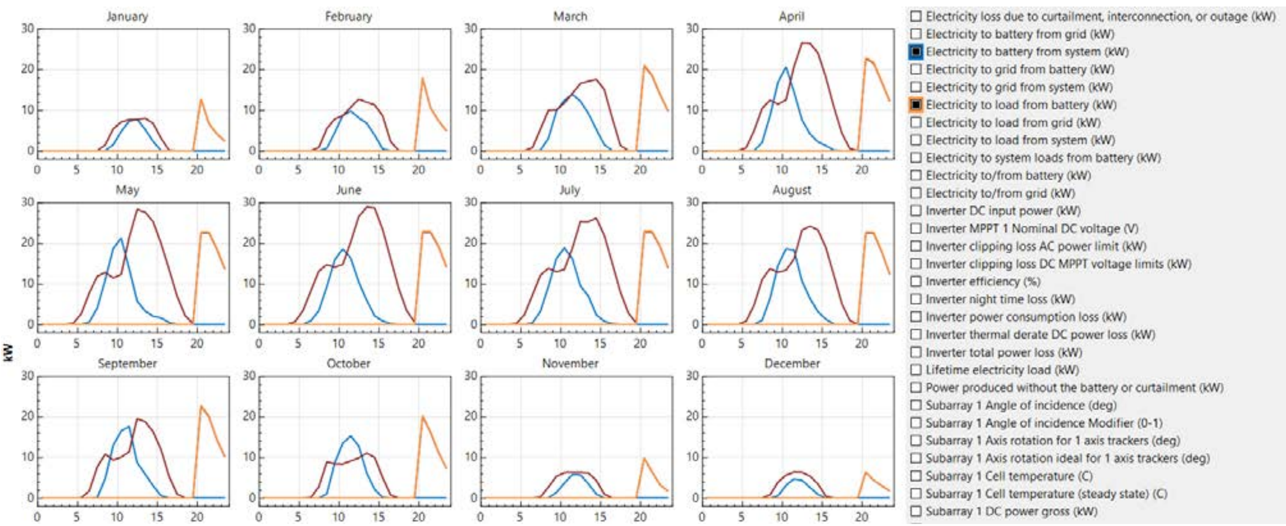

FIGURE 3. *Graphs of the average monthly electricity generation of the PPS, the electricity that is stored and the electricity that is delivered to the consumer according to mode 1*

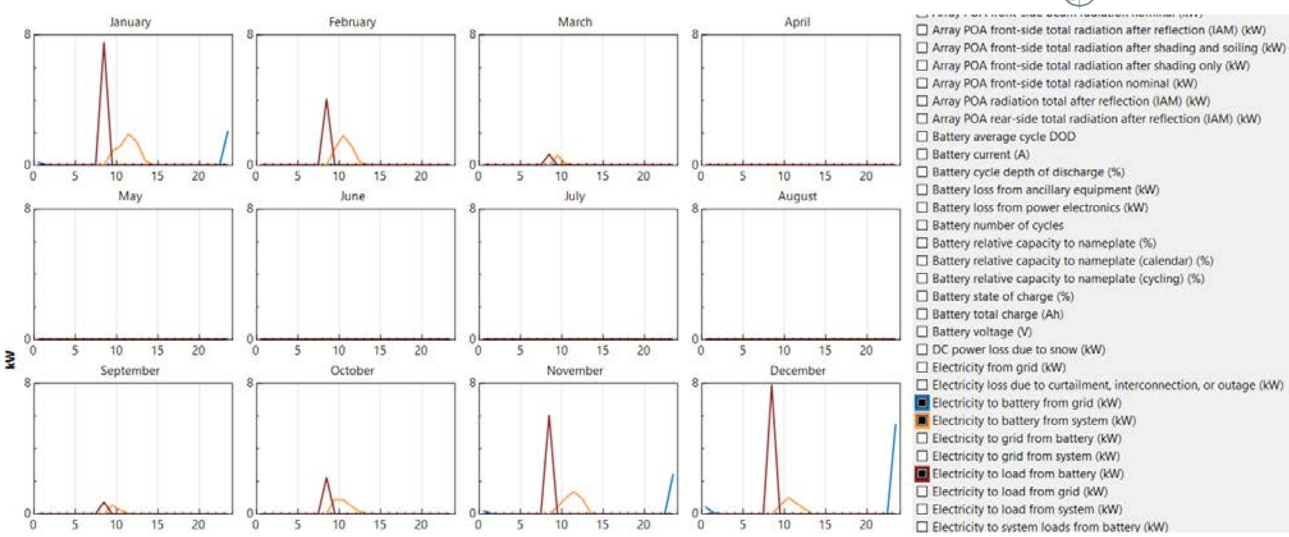

FIGURE 4. Graphs of electricity accumulated from the PPS and the electrical grid and electricity delivered to the consumer in mode 2

2. 19-story residential building with built-in non-residential premises (BNP). Similar graphs were obtained for other variants of the BZH study.

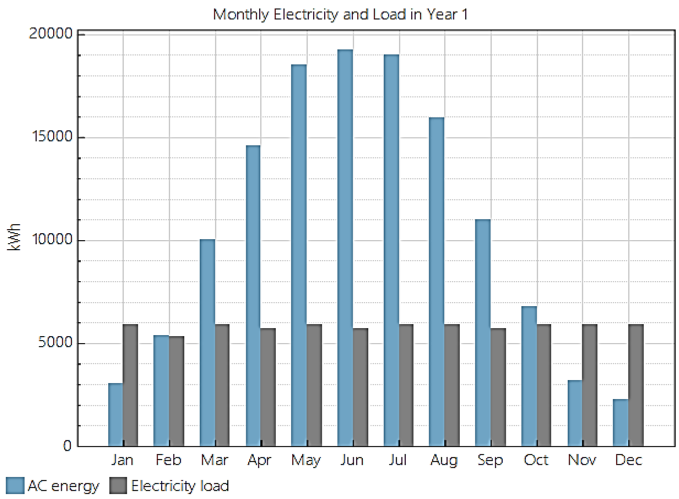

FIGURE 5. Schedule of average monthly electricity production of the PPS and consumption of facility B

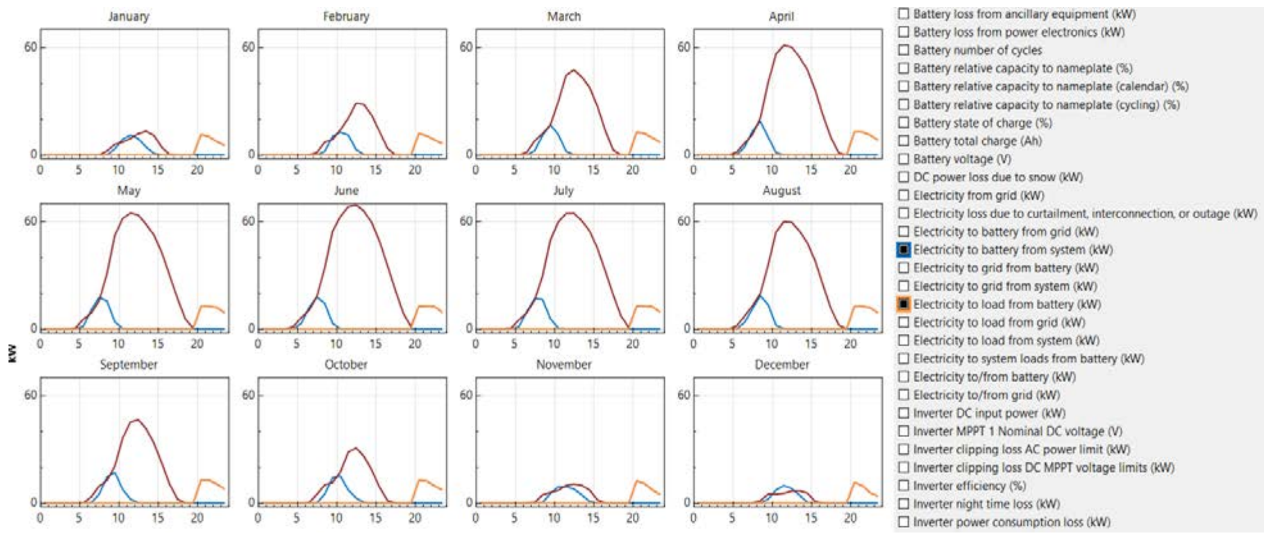

FIGURE 6. Graphs of the average monthly electricity generation of the PPS, the electricity that is stored and the electricity that is delivered to the consumer according to mode 1

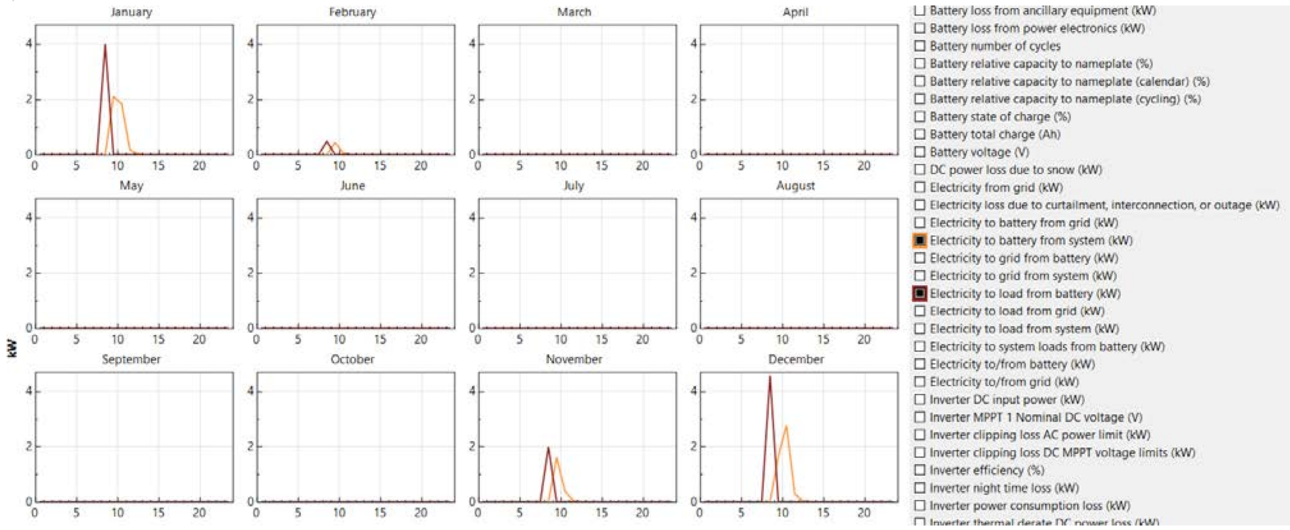

***FIGURE 7.** Graphs of electricity accumulated from the PPS and the electrical grid and electricity delivered to the consumer in mode 2*

3. 9th floor parking lot for 979 cars. Similar graphs are obtained for other variants of the parking lot study.

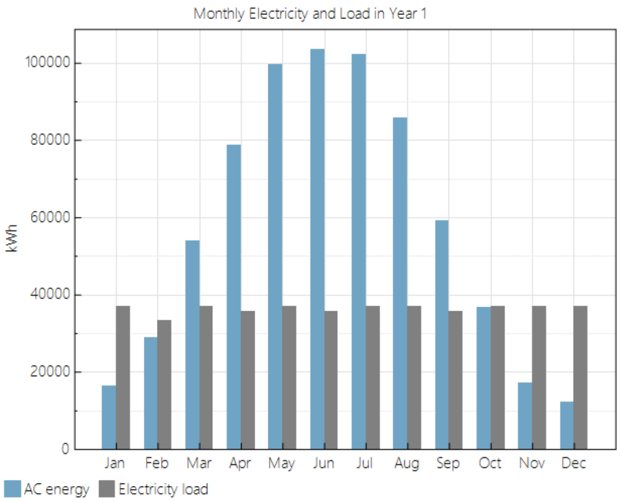

***FIGURE 8.** Schedule of average monthly electricity production of the PPS and consumption of object A*

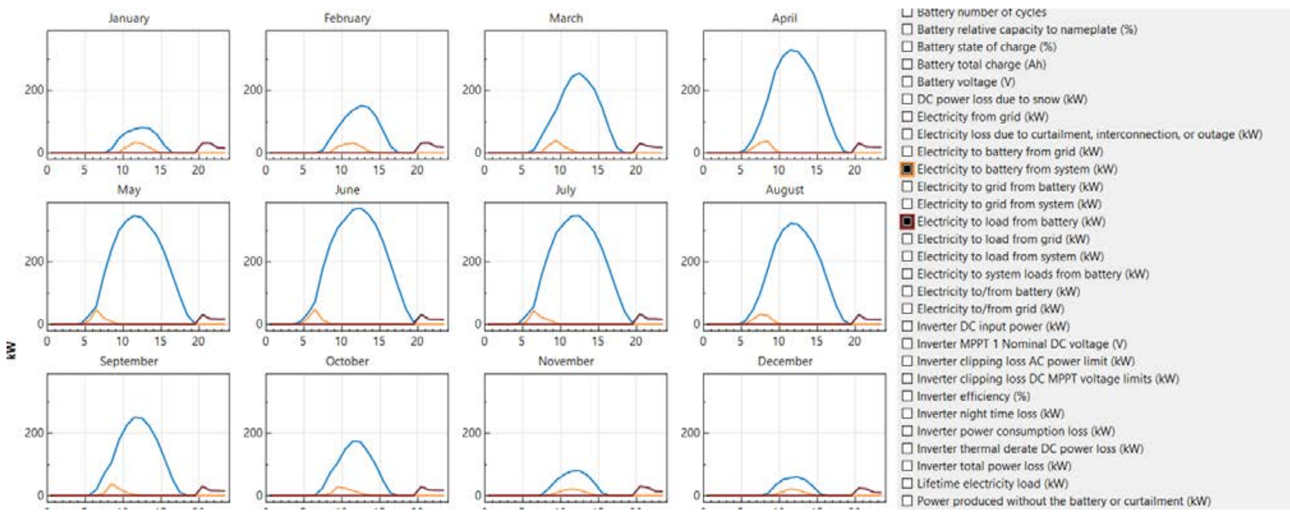

***FIGURE 9.** Graphs of the average monthly electricity generation of the PPS, the electricity that is stored and the electricity that is delivered to the consumer by mode 1*

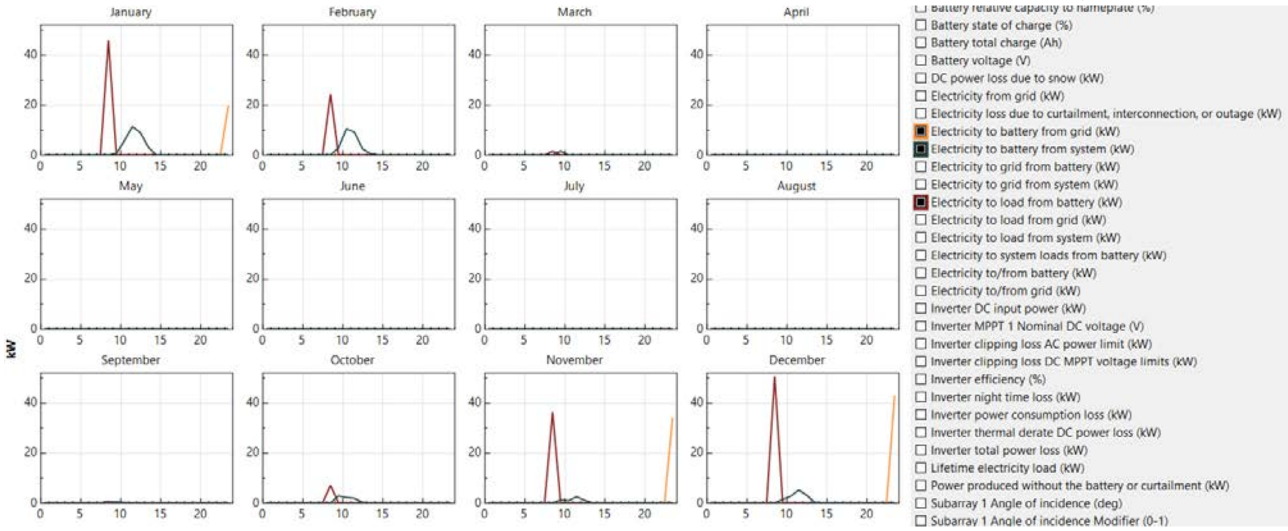

FIGURE 10. *Graphs of electricity accumulated from the PPS and the electrical grid and electricity delivered to the consumer in mode 2*

Comparing Figures 2, 5 and 8, it can be concluded that the energy of the PPS is not enough to cover the load during the spring-winter-autumn period. Using mode 1 shown in Figures 3, 5 and 8 BES is charged during the day, in the evening it supplies the load for a year. Mode 2, shown in Figures 4, 7 and 10, the BES, is used only to cover the load during the spring-winter-autumn period, when there is not enough electricity.

Using the calculated parameters of BESS, an economic assessment of projects of electricity supply of research objects with the use of PPS was performed.

The results of the economic assessment of BESS design for various research objects are presented in Table 5.

TABLE 5. *Results of the economic evaluation of the BESS project*

Mode of use of the electricity storage	Total cost of BESS construction	Battery efficiency	Battery charge energy from PPS	Payback period
Mode 1 for K	$133763	94.60%	100.0%	13.2
Mode 2 for K	$133763	95,48%	71.9%	13.1
Mode 1 for B1	$230152	94.98%	100.0%	12.5
Mode 1 for B2	$254415	96.01%	100.0%	14.6
Mode 1 for B3	$278238	96.28%	100.0%	17
Mode 2 for B1	$230152	96.44%	100.0%	12.5
Mode 2 for B2	$254415	96.61%	100.0%	14.6
Mode 2 for B3	$278238	96.67%	100.0%	16.9
Mode 1 for A1	$1359378	94.44%	100.0%	11.6
Mode 1 for A2	$1488894	95.58%	100.0%	13.7
Mode 1 for A3	$1618411	95.8%	100.0%	16.1
Mode 2 for A1	$1359378	92.12%	45.4%	13.2
Mode 2 for A2	$1488894	94.12%	45.8%	15.9
Mode 2 for A3	$1618411	94.88%	45.9%	19
Mode 1 for K1	$127464	94.2%	100.0%	12.7
Mode 2 for K1	$127464	94.98%	100.0%	12.5
Mode 1 for B4	$219431	94.5%	100.0%	11.7
Mode 2 for B4	$219431	95.85%	99.7%	11.7
Mode 1 for A4	$1264194	92.62%	100.0%	10.5
Mode 2 for A4	$1264194	96.28%	52.0%	11.3

Analysis of the data given in the Table 5 showed that the project with the use of PPS for powering the parking lot in mode 1 for A4 with a payback period of 10.5 years has the highest economic efficiency. For civilian objects, the most effective project is a B4-19-story residential building with a payback period of 11.3 years and a cost of $219,431.

Conclusions

1. For the most efficient use of the power supply system with PPS and storage throughout the year, it is advisable to use mode 1, which involves charging the BES during the day, and feeding the load in the evening.
2. Mode 2 should be used to cover the load only during the spring-winter-autumn period, when the generation electricity from the FES is not sufficient.

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