Advances in Science and Technology Research Journal

Advances in Science and Technology Research Journal, 2025, 19(4), 229–240
https://doi.org/10.12913/22998624/200329
ISSN 2299-8624, License CC-BY 4.0

Received: 2024.12.19
Accepted: 2025.01.20
Published: 2025.02.19

Analysis of the parameters of local power system devices with solar power plants and energy storage facilities and determination of operating modes during various periods of power outages

Lina H. Hussienat[1], Patrycja Walichnowska[2*], Huthaifa Al Issa[3], Mohamed Qawaqzeh[3], Weronika Kruszelnicka[2], Andrzej Tomporowski[2], Oleksandr Moroz[4], Andriy Pavlov[4], Oleksandr Miroshnyk[4], Taras Shchur[5]

[1] Department of Electrical Power Engineering, Al Balqa Applied University, 19117, Al Salt, Jordan
[2] Department of Renewable Energy Sources Engineering and Technical Systems, Faculty of Mechanical Engineering, Bydgoszcz University of Science and Technology, Al. Prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Poland
[3] Department Electrical and Electronics Engineering, Al Balqa Applied University, 19117 Al Salt, Jordan
[4] Department of Electricity Supply and Energy Management, State Biotechnological University, 61052 Kharkiv, Ukraine
[5] Cyclone Manufacturing Inc, Mississauga, Ontario, Canada
* Corresponding author's e-mail: patrycja.walichnowska@pbs.edu.pl

ABSTRACT

The development of renewable energy sources (RES) and energy storage technologies is a key element of the transformation of modern power systems. The growing importance of solar energy, as one of the cleanest and most accessible energy sources, requires the optimization of its use in local power systems. This study analyzes the parameters of local power system (LES) devices with solar power plants and energy storage devices and determines their operating modes during different periods of power outages. As part of the research, an analysis of the reliability of electricity supply to LES recipients were carried out using the REopt platform for 4 different dates – December 22, June 22, March 22 and September 22. In the second step, the solar energy system modes were analyzed using the System Advisor Model (SAM) software. The analysis showed that the orientation of the module subassemblies with deviations of ± 45° from the south direction allows for higher power output in the morning and evening hours. It was also shown that the arrangement of the modules in two subassemblies allows for reducing the power cut-off by the inverters at noon, so with one module arrangement, the cut-off value is 1.743%, and with two subassemblies – 0.339%.

Keywords: solar power plant, battery, local electrical systems, REopt platform, System Advisor Model, critical load, grid outages.

INTRODUCTION

One of the critical factors affecting Ukraine's ability to resist the military aggression of the Russian Federation, ensure the necessary level of industrial development and create the necessary conditions for the population's living is the state of the country's energy sector. As of the end of the autumn-winter period of 2024, due to the destruction and occupation, the energy system of Ukraine temporarily lost 44% of nuclear generation, 78% of thermal power plants (TPP) capacity, 42% – block TPP, 72% – non–block TPP, 59% – hydroelectric power station (HPP), 16% – hydro storage power plants, 70% – wind generation and about 20% – solar generation [1]. As a result of massive missile and drone strikes by the enemy, the losses of Ukraine's power system as of June 2024 amount to about 9 GW, the expected capacity deficit in the summer period will be up to 4 GW, and in the winter – up to 5 GW [2, 3].

One of the ways to solve the energy crisis in Ukraine is the creation of distributed electricity generation based on local electrical systems (LES), in particular from renewable energy sources [4, 5, 6].

The most promising type of energy for LES is solar energy, as evidenced by its rapid development in the world. So, over the past two decades, the share of solar electricity in the structure of the world electricity industry has grown from 0.01% in 2000 to 4.5% in 2022 [7]. Renewables are set to contribute 80% of new power capacity to 2030 in the Stated Policies Scenario STEPS, with solar PV alone accounting for more than half. Solar has become a major global industry and is set to transform electricity markets. But there is significant scope for further growth given manufacturing plans and the technology's competitiveness. By the end of the decade, the world could have manufacturing capacity for more than 1 200 GW of panels per year [8]. Solar manufacturing growth is outpacing the rise of solar PV deployment, creating some risks of imbalances but huge opportunities for the world to accelerate energy transitions. Global solar electricity generation in 2022 was 220 GW of the 640 GW generated by renewable energy sources. The projected generation of solar power plant (SPP) in 2030 will be 500 GW out of 1260 GW. Renewable energy will continue to expand quickly in 2024, with combined solar and wind energy consumption growing by about 11% year on year [9, 10]. In addition, the production of energy from renewable energy sources (RES) has a significant impact on ecological benefits, contributing to the protection of the natural environment and sustainable development. The use of solar or wind energy allows for the reduction of greenhouse gas emissions, which are the main cause of global warming and climate change [11,12].

The state of renewable energy development in Ukraine and legislative support for this development

Ukraine has a high energy potential of solar energy, so according to the Institute of Renewable Energy of the National Academy of Sciences of Ukraine, the theoretical installed capacity of SPPs is 82,768 MW, and the annual potential of electricity production of SPPs in Ukraine is about 100 billion kWh/year [13, 14]. Renewable energy in Ukraine developed rapidly before the start of the war and continued its development during the war. Thus, at the beginning of 2022, the installed capacity of RES facilities was 9.5 GW. During the war years 2022–2023 in Ukraine, more than 660 MW of new RES capacities have been put into operation, in particular, in 2022, SPPs with a capacity of 220.1 MW, including household SPPs – 206 MW, and in 2023–150 MW. Today, the energy system of Ukraine has 7.6 GW of RES capacity. Such a rapid development of renewable energy is possible on the basis of the existing legal framework and government support. So, in June 2024, the Cabinet of Ministers of Ukraine approved the National Energy and Climate Plan (NECP) for the period up to 2030 [15, 16]. NECP is a strategic document aimed at harmonizing environmental, energy and economic policies for the sustainable development of Ukraine. Among the main goals of NECP, in particular, are: reduction of greenhouse gas emissions by 65% compared to the level of 1990; achieving a 27% share of renewable energy sources in the total final energy consumption.

In addition, Ukraine has adopted other laws that contribute to the development of renewable energy, in particular the Law of Ukraine "On Amendments to Certain Laws of Ukraine Regarding the Development of Energy Storage Facilities" [17, 18], which entered into force on June 16, 2022, aims to contribute to the increase in the use of RES in Ukraine, in particular through the development of the market for balancing and auxiliary services. The implementation of energy storage facilities (ESF) is an important stage in the optimization of the electricity grid. The use of ESF will help to balance and increase the stability of the unified energy system (UES) of Ukraine, since such installations are able to store excess electricity produced by SPP in periods when demand is low, and then use it in times of high demand, as well as contribute to increasing the stability of microgrids. Another law that stimulates the development of renewable energy is the Law of Ukraine "On Amendments to Certain Laws of Ukraine Regarding the Restoration and "Green" Transformation of the Energy System of Ukraine" No. 3220-IX of June 30, 2023 [19, 20]. This law introduces a mechanism of self-production, which is an analogue of the support mechanism widely used in the world for renewable energy facilities - Net Energy Billing.

The successful development of local electrical networks with renewable energy sources and energy storage facilities is possible on the basis of a comprehensive technical and economic justification of such projects, which would consider the peculiarities of their operation and interaction with the networks of UES of Ukraine.

Feasibility studies of a local energy system with a solar power plant and electric batteries using the REopt platform

Feasibility studies of local electrical systems with solar electricity and electric batteries are possible using the REopt platform [21, 22], that is allows make an analysis services optimize planning of generation, storage, and controllable loads to maximize the value of integrated distributed energy systems for buildings, campuses, and microgrids and also estimate how long a system can sustain critical load during a grid outage.

Since the biggest problem in Ukraine today is constant power outages, which can be up to 50% of the time during the day, the task of the research is to determine the optimal parameters of the equipment of the local electric network, which consists of a solar power plant, an energy storage installation, and which is connected to the UES of Ukraine. The local electrical network [23], which supplies a group of household consumers connected to a transformer substation with a capacity of 63 kVA, in the territory of the village of Utkivka, Merefyansk territorial community, Kharkiv region, was chosen as the object of the study.

The input parameters of the REopt platform are the following indicators: location of LES, composition of LES elements, load profile, magnitude of critical load and duration of power outages. Depending on these parameters, the REopt platform determines the optimal size of the SPP, the power and capacity of the storage batteries, and also evaluates the economic performance of the LES [24]. The location of the SPP LES is defined as an area with coordinates of 49.79 degrees north latitude and 36.01 degrees east longitude.

The estimated annual consumption for LES is approximately 200 MWh. Modeling using the REopt platform to analyze economic indicators and the reliability of electricity supply to LES consumers was conducted for four specific dates. Simulation scenarios were chosen for the smallest and largest SPP capacities (December 22 and June 22, respectively) and for the equinoxes (March 22 and September 22). The selected days represent extreme (maximum and minimum) and moderate solar radiation conditions during the year. Analysis of these days allows for the assessment of the solar system's performance at different times of the year, which is crucial for designing a system that is resilient to changing conditions. In addition, comparing the results from low and high generation days allows for the assessment of how much energy storage is needed to ensure continuous power supply. December 22 is the day with the shortest sunlight duration in the year, when solar power plants generate the least amount of energy. Analysis of such a day allows for the assessment of the efficiency of the system with energy storage in difficult conditions and the ability to work at low intensity of solar radiation. In photovoltaic (PV) systems with energy storage, the analysis of high and low energy production days allows for system optimization. High-generation days, such as June 22, allow for the assessment of the storage capacity of the storage facilities to store surpluses and manage energy transmission. In turn, low-generation days, such as December 22, require precise design of storage capacity to ensure continuity of power supply. Considering seasonal differences in energy generation allows for the assessment of system stability over a longer time horizon. Additionally, the analysis of the equinoxes allows for the design of an efficient installation under variable annual conditions. The duration of disconnection from the grid was set at 24 hours, beginning at 8:00. Additional input parameters were specified, including allowing the grid to charge the battery, setting the critical load at 50%, the minimum battery state of charge at 20%, and the initial battery state of charge at 50%.

The optimal parameters of SPP and battery were previously determined to ensure Resilience and Financial. The optimal parameters are the SPP power of 207 kW on direct current (DC) and the battery power on alternating current (AC) of 27 kW and capacity of 245 kWh. Such parameters ensure the minimum cost of energy during the period of operation of the LES and have optimal economic indicators.

The analysis of the operating modes of the LES equipment in normal mode was carried out for the most critical days of the year for June 21 and 22 (Fig. 1).

As can be seen from the graphs, the start of SPP generation begins at 5 o'clock (black circle) and all the energy is directed to cover the load

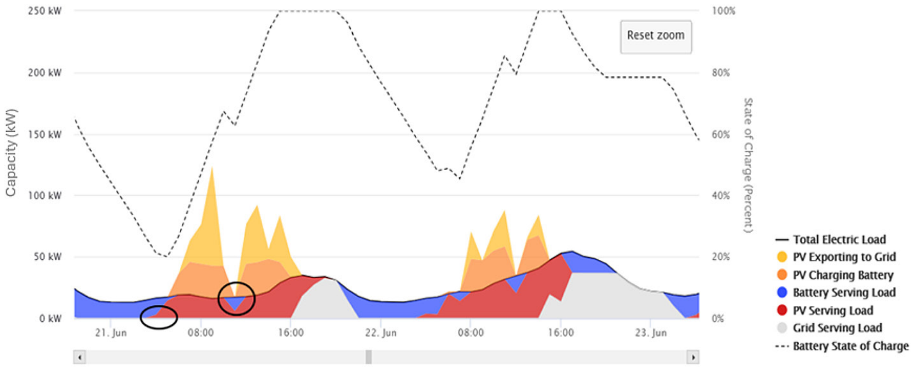

Figure 1. Operating schedules of local electrical network equipment when it connected to the network on June 21 and 22 (capacity of SPP is 207 kW)

of the LES and charge the battery, the minimum charge of which was 20%. On June 21, from 6 to 10 a.m., SPP generation was sufficient to cover the load and charge the battery, and excess electricity was exported to the grid. From 10 o'clock, SPP generation decreased, so around 11 o'clock (black circle), part of the load was covered by battery discharge. From 16 hours on June 21, energy from the grid was used to meet the load. During the night period from June 21 to June 22, the load was supplied by the battery. On June 22, the solar radiation was less intense, resulting in lower SPP generation, but there was enough electricity to charge the battery. On June 22, a significant part of the load was supplied by electricity from the grid, with a minimum battery charge level of 45% on June 22.

Another mode of operation of the LES is observed on December 22 (Fig. 2), when the generation capacity of the SPP is not enough to cover the load, so the demand is met at the expense of the UES. No energy is used from the battery and the charge level remains at 100%.

The analysis of the graphs on the days of outages showed that the stability of the LES on March 22 (Fig. 3) is ensured even at zero level of battery

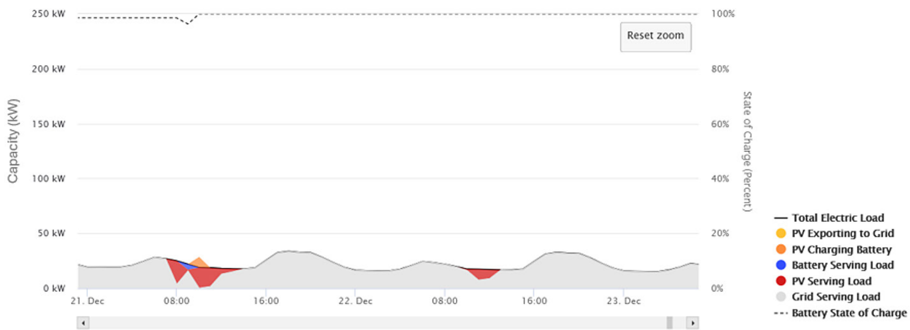

Figure 2. Operating schedules of local electrical network equipment when it connected to the network on December 22 (capacity of SPP is 163 kW)

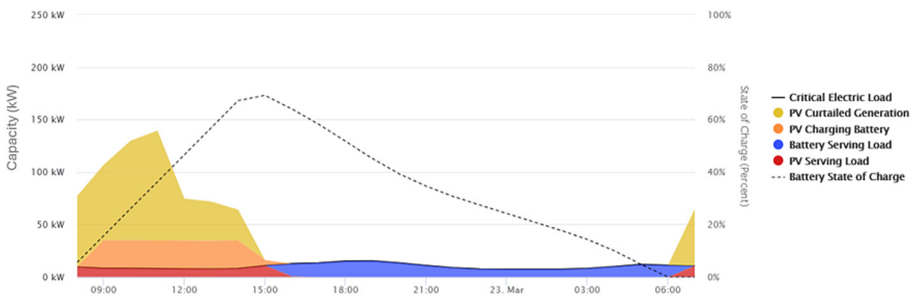

Figure 3. Chart of meeting the critical load of local energy system by PV and storage on outage 22 March at 8 am (capacity of SPP is 207 kW)

charge. At the moment of shutdown, the critical load of the system is provided by the SPP, from 8 am the battery start charging from the SPP, which continues until 3 pm. The maximum value of the battery charge reaches about 70% at 3 pm, the maximum capacity of the SPP on March 22 reaches about 140 kW. From 4 pm on March 22 to 6 am on March 23, the critical load will be supplied exclusively by the battery. Starting from 6 am on March 23, the load will be supplied by SPP generation.

A feature of the provision of LES consumers during the disconnection from the grid on June 22 is that the SPP generation in some hours exceeds the needs of consumers and the battery charge, therefore, the peak SPP generation, which reaches a capacity of more than 80 kW, is cut.

The maximum battery charge level on 22 of June reaches a value of about 85%, providing consumers with 50% critical load during the period of disconnection from the network is ensured at zero battery charge level at the time of disconnection (Fig. 4). The peculiarity of the operation of the LES, with its optimal parameters determined by REopt, when it is disconnected from the network on December 22, is that the generation of the SPP is insignificant and to cover the load is provided by the battery, the charge level of which at the time of disconnection should be about 95% (Fig. 5).

The REopt web tool reports results for up to three cases: Business-as-Usual, Financial, and Resilience. In the case Business-as-Usual, the site purchases energy solely from the utility. In the case Financial is defining the minimum present value of all future energy costs over the analysis period by a combination of utility, PV and battery [25]. The case Resilience is optimized to sustain a critical load in the event of a grid outage while minimizing the present value of all future energy costs over the analysis period. The interactive graph Net Load Duration (Fig. 6) shows the reduction in peak load that occurs when the REopt recommended technologies are implemented. The total number of hours during which the LES reduces consumption from the UES is about 4.600, that is, these hours make up about 52.5% of the LES's operating hours.

Determination of SPP and battery parameters and equipment when creating a local electrical system based on the existing electrical network

A transformer substation with a capacity of 63 kVA is used to supply consumers of the electrical network under investigation. To determine the optimal configuration of the LES, the issue of building two network SPP of households with

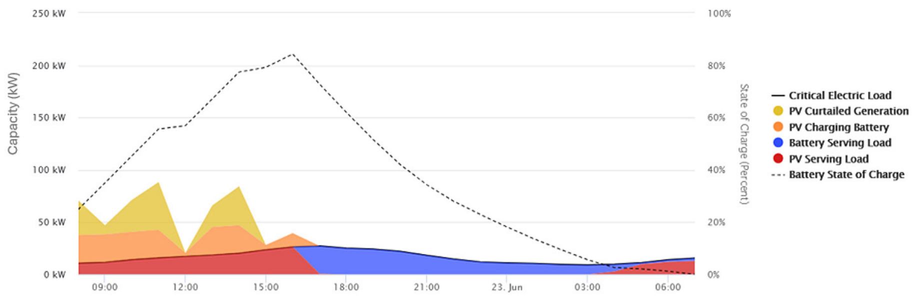

Figure 4. Chart of meeting the critical load of local energy system by PV and storage on outage 22 June at 8 am (capacity of SPP is 207 kW)

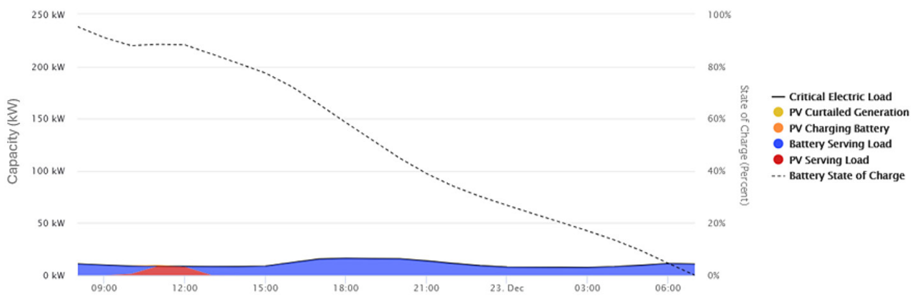

Figure 5. Chart of meeting the critical load of local energy system by PV and storage on outage 22 December at 8 am (capacity of SPP is 207 kW)

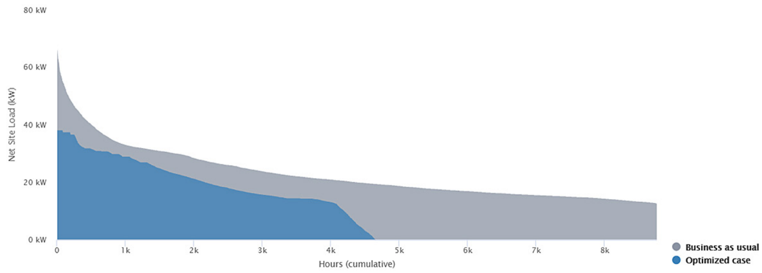

Figure 6. Interactive graph Net Load Duration of local electrical system

a capacity of 36 kW of photovoltaic modules (PVM) and a capacity of 30 kW of inverters is considered. These values were adopted depending on the factor that the permitted power of SPP of households installed on land plots should not exceed 30 kW by inverters [26, 27] and DC/AC the ratio 1.2 is economically feasible [28, 29].

Preliminary studies of SPP parameters were carried out with the help of the program Photovoltaic Geographical Information System (PVGIS) [30] which made it possible to determine the optimal angles of inclination and azimuth of the PVM surface to determine the maximum generation when all modules are oriented to the south. The obtained values are as follows: inclination angle 360, azimuth angle -10. The annual generation of the SPP with the installed capacity of the modules of 72 kW according to the PVGIS program is 81,662 kWh.

Since the task of a local electrical network with SPP and energy storage facilities is to provide consumers with electrical energy in the event of a disconnection from the unified energy system, it is advisable to place the surfaces of the stations with different orientations relative to the south, which will allow for more uniform generation during daylight hours [31, 32].

Comparative analysis of SPP operation at different azimuths of PVM surface orientation was performed with the following options: PVMs of one station are installed with an azimuth of -45°, and of the second - with an azimuth of +45º relative to the south. Using the PVGIS program, the optimal angles of inclination of the surfaces at such azimuths were determined. Accordingly, the optimal angle of inclination of the modules of the first station was determined at 330, and the angle of inclination of the surface of the modules of the second station was determined at 310. As a result of this placement of the PVM surfaces of the stations, their total generation will be lower by 6% compared to the generation when the PVM surfaces are placed to the south, but this will allow to increase the generation in the morning and evening hours and reduce losses due to power cuts in the hours close to noon [33, 34]. Total losses in the system during calculations in the PVGIS program were taken as 14%.

Technical issues of designing and researching solar energy systems (SES) modes were carried out using the System Advisor Model (SAM) program [35, 36]. SunPower SPR-M400-BLK FEMs with a power of 400 W (W_{dc}) were selected for SPP, which have a nominal efficiency of 21.41%, maximum voltage at maximum power V_{mp} = 39.1V_{dc}, open circuit voltage V_{oc} = 48.1V_{dc}, temperature coefficient of power is -0.29 %/^{0}C or -1.161 W/^{0}C. Two Huawei Technologies Co – LTD inverters were chosen to convert direct current from the FEM to alternating current: SUN2000-30KTL-US [480 V] with a maximum DC power of 30562 W_{dc} and a maximum AC power of 30000 W_{ac}, weighted efficiency 98.146 % and nominal AC voltage 480 V_{ac}. The MPPT DC voltage values are next: minimum MPPT DC voltage 560 V_{dc}, maximum MPPT DC voltage 800 V_{dc}, nominal DC voltage 730 V_{dc}. The configuration of the SPP is shown in Fig. 7. The total number of station modules was 192 units, which were connected in 6 strings of 16 modules. Ground coverage ratio SPP is 0.3.

The program SAM was used to analyze the generation schedules in different configurations of module placement, which is developed by the National Renewable Energy Laboratory (NREL). The analysis of the generation schedules for different configurations of the placement of modules was carried out for May 21 and 22, when there was no cloud cover. The analysis showed that the orientation of subarrays of modules with deviations of ±45° with respect to the direction to the south, allows to obtain higher capacities in the morning and evening hours. So, for example, the power of the SPP with two subarrays at 5 am on

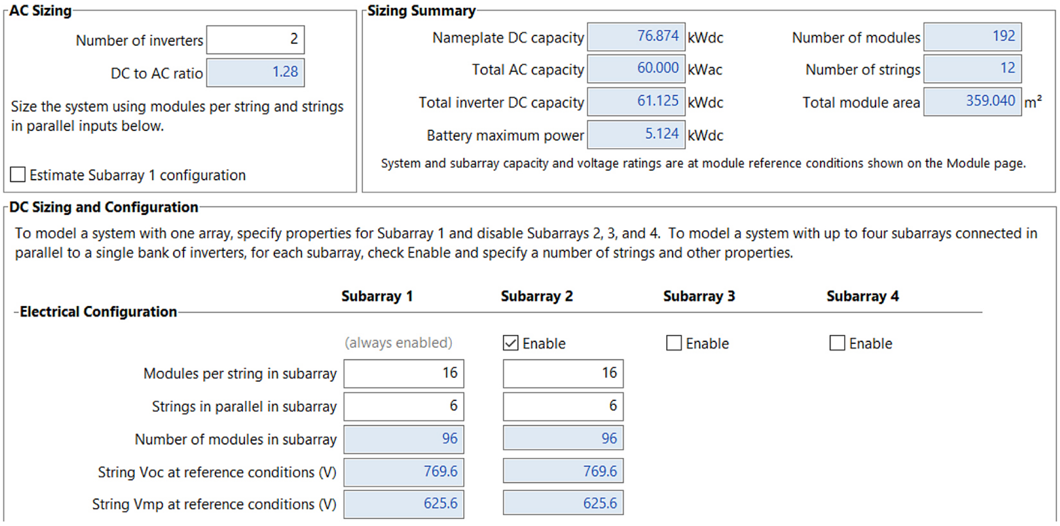

Figure 7. The configuration of the SPP

May 21 was 10 kW, at 6 am – 18 kW, at 7 am – 28 kW, at 5 pm – 19 kW, at 6 pm – 11 kW, at 7 pm – 5 kW (Fig. 8, 9). The SPP capacity with one array of modules at the same hours on May 21 has the following values: at 5 am – 3 kW, at 6 am – 11 kW, at 7 am – 26 kW, at 5 pm – 10 kW, at 6 pm – 3 kW, at 19 pm – 1 kW. In this way, the placement of photovoltaic modules with two sub-arrays with the azimuth of one sub-array at 135° and the second one at 225° allows to obtain higher capacities in the morning and evening hours, which is an especially important factor for covering peak loads. In addition, the placement of modules in two subarrays allows reducing the power cut by inverters in the noon hour (Fig. 8, 9), so with one array placement of modules, the amount of cut is 1.743%, and with two subarrays – 0.339%.

The optimal parameters of the LES battery at the SPP capacity of 72 kW were determined using the REopt platform and have the following indicators: power of 27 kW, capacity of 261 kWh. For the analysis, we selected days with different solar activity, so on June 19, the sun's activity was high, and on June 22, the sun's activity was not high (Fig. 10).

The simulation of the operation mode of the LES with the SPP capacity of 72 kW when it is disconnected from the network on June 19 at 8:00 am for 24 hours showed that the minimum battery charge level to pass this shutdown period should be around 10%, the maximum battery charge level will be around 55% (Fig. 11).

In case the system was disconnected from the grid on June 22, the minimum battery

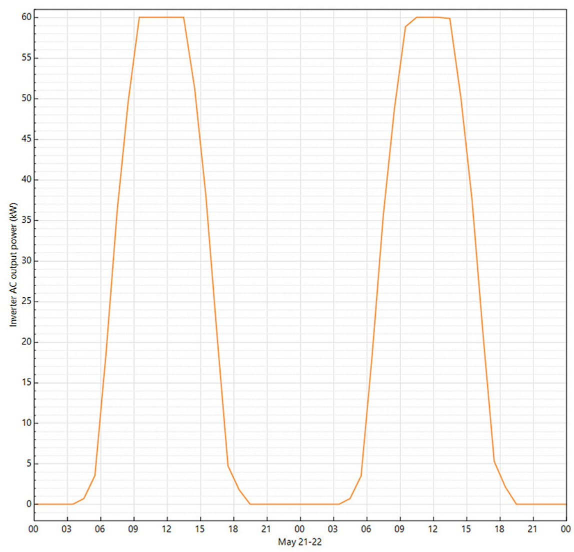

Figure 8. Inverter AC output power, kW (azimuth of PV modules is 179°)

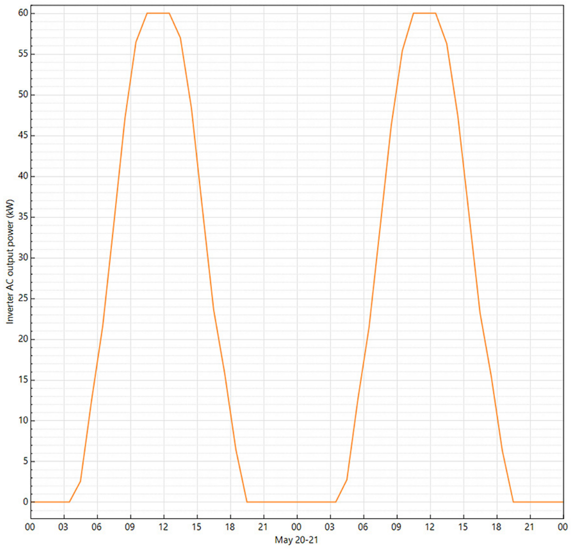

Figure 9. Inverter AC output power, kW (azimuth of PV modules of 1-st subarray is 135°, 2-d – is 225°)

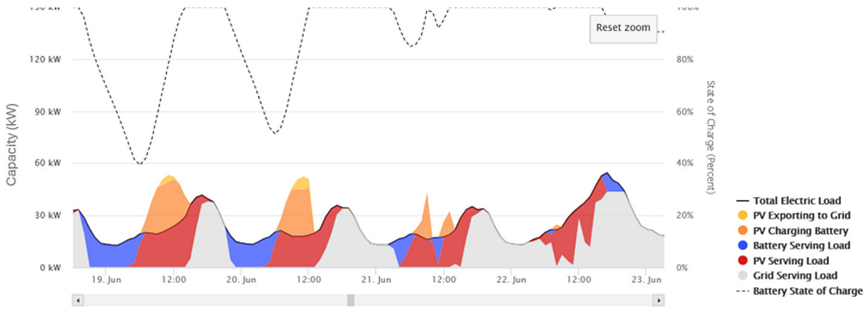

Figure 10. Operating schedules of local electrical network equipment when it connected to the network on June 19 (capacity of SPP is 72 kW)

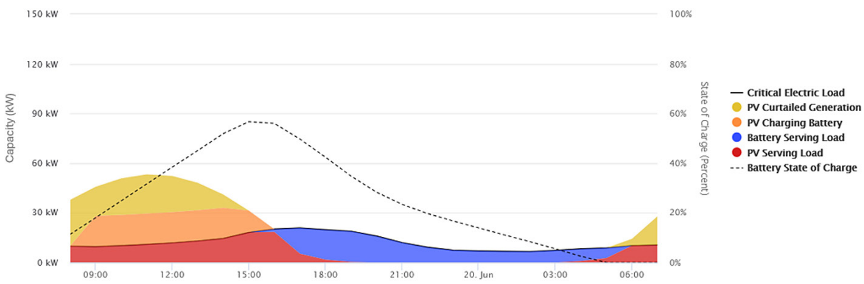

Figure 11. Chart of meeting the critical load of local energy system by PV and storage on outage 19 June at 8 am (capacity of SPP is 72 kW)

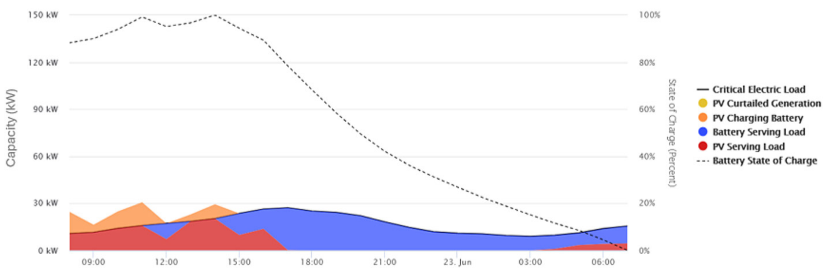

Figure 12. Chart of meeting the critical load of local energy system by PV and storage on outage 22 June at 8 am (capacity of SPP is 72 kW)

charge level to pass the outage period must be at least 90% (Fig. 12).

A feature of the provision of LES consumers during the disconnection from the grid on June 19 is that the SPP generation from 8 am to 3 pm exceeds the needs of consumers and the battery charge, therefore, the peak SPP generation, which reaches a capacity of more than 55 kW, is cut. The nature of consumer load coverage on December 22 at the SPP capacity of 72 kW has almost not changed, since the load is provided by batteries, their minimum charge level should be around 97%.

The analysis of the performance indicators of the LES on June 19 showed that the SPP generation was 432 kWh, of which 148 were consumed, 124 were used to charge the battery, 159 kWh were trimmed by inverters, the Battery Serving Load was 139 kWh. The analysis of the performance indicators of the LES on June 22 showed that the SPP generation was 192 kWh, of which 135 were consumed, 57 were used to charge the battery, the Battery Serving Load was 257 kWh. The analysis of the performance indicators of the LES on December 22 showed that the SPP generation was 7 kWh and the Battery Serving Load was 245 kWh.

For the energy system of Ukraine today, disconnection from the network of consumers several times during the day is an urgent issue [30, 36]. Depending on the number of outage queues, the duration of outages during the day can be more than 12 hours. The study of LES parameters, for the case of four disconnections from the network per day for 3 hours, for June 22, were carried out using the REopt platform. According to the results of the calculation the optimal parameters of the SPP were defined as a power of 60 kW, a battery power of 24 kW, and a battery capacity of 93 kWh.

During the first shutdown from 0 am to 3 am, the minimum battery charge level to cover the critical load must be 22%, during the second shutdown from 6 am to 9 am, the load is covered by the SPP, the total generation of the SPP during this time period was 109 kWh, of which 43 kWh were spent on the load, and 93 kWh were spent on charging the battery, 16 kWh of electric energy were cut by inverters. Thus, during the second power outage, the power of SPP was sufficient to provide consumers and charge the battery to full charge.

During the third disconnection from the network from 12 pm to 3 pm, the load is covered by the SPP, the total generation of the SPP during this time period was 136 kWh, of which 80 kWh was spent on the load, 109 kWh of energy was lost due to cutting by inverters, battery charging was not occurred because they are fully charged. When disconnecting from 18 pm to 21 pm, the minimum battery charge level to cover the critical load should be 75%. When studying the parameters of the LES on December 22 with 4 outages in the same time intervals as on June 22, it was established that during the first outage from 0 am to 3 am, the minimum battery charge level to cover the critical load should be about 40%, while the consumption of battery will be 32 kWh. During the second disconnection from 6 am to 9 am, the load is covered by the battery that was charged from the network from 3 am to 6 am, and the minimum level should be 55%, the consumption of electricity from the batteries during this time period was 44 kWh. The largest amount of electricity consumed from the batteries on December 22 with 4 outages is when the grid is disconnected from 18 pm to 21 pm, which is 62 kWh, the minimum battery charge level at 18 pm should be 75%.

The results of a comparative analysis of options for the stability of the LES, equipment parameters and net present value are shown in Fig. 13. The first two options determine the parameters of the batteries at the same SPP capacity of 72 kW. The first option is aimed at determining

Evaluation Comparison	RESILIENCE Мерефа Харьковская область Украина 62472 2024-07-18 12:16 PM ID: 5276	RESILIENCE Мерефа Харьковская область Украина 62472 2024-07-18 12:12 PM ID: 7a25	RESILIENCE Мерефа Харьковская область Украина 62472 2024-07-18 9:56 AM ID: be62	RESILIENCE Мерефа Харьковская область Украина 62472 2024-07-18 9:51 AM ID: cdb9
Net Present Value	$97,951.23	$92,661.98	$78,552.92	$29,886.11
Lifecycle Cost	$NaN	$NaN	$NaN	$NaN
Initial Cost	$0	$0	$0	$0
Hours of Resilience	not evaluated	not evaluated	not evaluated	not evaluated
PV Size	72 kW	72 kW	135 kW	72 kW
Battery Capacity	92 kWh	65 kWh	251 kWh	257 kWh
Battery Power	24 kW	16 kW	38 kW	31 kW

Figure 13. Comparative analysis of the composition of the LES under different variants of the duration of disconnections from the network and power of the SPP

the stability of the LES during four three-hour outages at equal intervals during June 22, the second option determines the battery parameters during the same outages on December 22. As can be seen, to ensure the stability of the LES on June 22, a larger battery capacity and power is required, since the loads on this day are greater than on December 22, the net present value for these options does not differ significantly, by only 5.5%. The third option determines the optimal size of the LES equipment, when the power of the SPP is 135 kW, and the capacity and power of the battery are 252 kWh and 38 kW, respectively. The fourth option determines the parameters of the battery at a SPP capacity of 72 kW. As can be seen, battery capacity differs by 2.3%, power by 22.6%, and net present value by 62.8%. The third option is more economically feasible during the period of operation of the LES of 25 years, but the fourth option is less economically costly, which is a determining factor in the current economic and energy circumstances.

CONCLUSIONS

The losses of Ukraine's power system are about 9 GW, the expected capacity deficit in the summer period will be up to 4 GW, and in the winter - up to 5 GW. In winter, energy demand will increase even more, mainly due to heating and shorter days, which increase electricity consumption. In the summer months, the demand for electricity will exceed the available capacity in the system by up to 4 GW. This may be due to greater needs related to air conditioning, industrial production or economic reconstruction. One of the ways to solve the energy crisis in Ukraine is the creation of distributed electricity generation based on local electrical systems, in particular from solar power plants and batteries.

Successful design of local electrical systems with renewable energy sources and energy storage facilities is possible based on the use of modern software, in particular the REopt: Renewable Energy Integration & Optimization platform and the System Advisor Model.

The input parameters of the REopt platform for determining the optimal sizes of equipment of local electrical systems are the following indicators: location and composition of LES elements, load profile, magnitude of critical load and duration of power outages.

When introducing SPPs and energy storage facilities to the existing electrical network, it is necessary to consider the capacity of the transformer substation. The analysis carried out showed that:

- stability of the LES on March 22 is ensured even at zero level of battery charge,
- implementing the recommended REopt technologies results in the total number of hours that the LES reduces consumption from the UES is approximately 4600, which means that these hours represent approximately 52.5% of the LES operating hours,
- to ensure LES stability on June 22, more battery capacity and power are required due to the heavier loads on that day,
- the required battery capacity for the third option (SPP power 135 kW) is 251 kWh and the battery power is 38 kW,
- the battery capacity of the fourth option studied differs by 2.3%, power by 22.6%, and net present value by 62.8% compared to the other options,
- decisions regarding LES stability and option selection must consider both economic costs and long-term operational benefits,
- energy consumption from the grid at critical moments highlights the importance of appropriate selection of battery and SPP parameters for the energy independence of the system.

Research into increasing the efficiency of photovoltaic (PV) installations plays a key role in energy transformation. The increase in panel efficiency allows for better use of solar energy, which is particularly important in the face of growing energy needs and climate change. Modern PV technologies can significantly reduce the costs of energy production, making it more accessible to society and supporting the development of a green economy. The research undertaken in the article can be continued in the area of modern PV technologies, such as sun tracking systems (trackers), which allow for the optimization of the operation of panels by setting them at an ideal angle to the sun's rays, which significantly increases the amount of energy generated [37].

REFERENCES

1. The Ministry of Energy estimates the loss of TPP capacity at 78%, nuclear generation at 44%. Ukrainian energy industry. Accessed online: http://surl.li/sutbyg (November 2024).

2. Buslavets O., Lezhniuk P. Renewable energy in the modern energy balance of Ukraine. Accessed online: http://surl.li/hvxuut (September 2024)
3. Miroshnyk O., Moroz O., Shchur T., Chepizhnyi A., Qawaqzeh M., Kocira S. Investigation of Smart Grid Operation Modes with Electrical Energy Storage System. Energies. 2023, 16(6), 2638. https://doi.org/10.3390/en16062638
4. Kostenko G. and Zgurovets O. Current state and prospects for development of renewable distributed generation in Ukraine. System Research in Energy, 2023, 2(73), 4–17. https://doi.org/10.15407/srenergy2023.02.004
5. Lezhnyuk P., Gunko I., and Lysiy V., Macro-modeling of forecasting the balance of local power supply systems using fractal properties of load and generation schedules. Naukovi Pratsi VNTU, September 2023, 3. https://doi.org/10.31649/2307-5376-2023-3-1-8
6. Lezhniuk P., Komar V., Belik M., Rubanenko O. and Smaglo I., Analysis of technical conditions influencing the operation of PV power stations cooperating with controlled power grids. 2022 IEEE 4th International Conference on Modern Electrical and Energy System (MEES), Kremenchuk, Ukraine, 2022, 1–6, https://doi.org/10.1109/MEES58014.2022.10005686
7. Global Electricity Review 2023. Accessed online: https://cutt.us/VfVOM (November 2024).
8. World Energy Outlook 2023. Accessed online: http://surl.li/unveiz (November 2024).
9. Energy outlook 2024. Accessed online: https://www.eiu.com/n/campaigns/energy-in-2024/ (November 2024).
10. Halko S., Suprun O. and Miroshnyk O., Influence of Temperature on Energy Performance Indicators of Hybrid Solar Panels Using Cylindrical Cogeneration Photovoltaic Modules, 2021 IEEE 2nd KhPI Week on Advanced Technology (KhPIWeek), Kharkiv, Ukraine, 2021, 132–136, https://doi.org/10.1109/KhPIWeek53812.2021.9569975
11. Walichnowska P., Kruszelnicka W., Piasecka I., Flizikowski J., Tomporowski A., Mazurkiewicz A.,... & Polishchuk O. Analysis of the impact of the post-consumer film waste scenario and the source of electricity on the harmfulness of the mass packaging process. Polymers, 2024, 16(24), 3467, https://doi.org/10.3390/polym16243467
12. Korobka S., Kasner R., Walichnowska P., Shchur T., Stukalets I., Syrotyuk S., & Kruszelnicka W. Analysis of the design and technological parameters of the designed solar dryer with a heat pump. Advances in Science and Technology. Research Journal, 2024, 18(7), 18–32. https://doi.org/10.12913/22998624/192263
13. Markowska K., Zhuk D., Zhuk O., Kozlov M., Stepenko S., Voskoboenko V., Stecuła K., Miroshnyk O., Shchur T. Analysis and improvement of power quality in the onboard electrical power systems within a self-propelled floating crane. International Journal of Electrical Power & Energy Systems, 161, 2024, 110179. https://doi.org/10.1016/j.ijepes.2024.110179
14. Atlas of the energy potential of renewable energy sources of Ukraine / by general ed. S. Kudria – Kyiv: Institute of Renewable Energy of the National Academy of Sciences of Ukraine, 2020, 82. Accessed online: https://cutt.us/eRNQ0 (July 2024)
15. Szafraniec A., et al. Magnetic field parameters mathematical modelling of windelectric heater, Przeglad Elektrotechniczny 97(8), 2021, 36–41. https://doi.org/10.15199/48.2021.08.07
16. Ukraine approves National Energy and Climate Plan on the day of the start of EU accession negotiations. Accessed online: http://surl.li/afiiuf (November 2024).
17. Qawaqzeh M., Al_Issa H., et al. The assess reduction of the expected energy not-supplied to consumers in medium voltage distribution systems after installing a sectionalizer in optimal place. Sustain. Energy, Grids and Networks 2023, 34, 101035. https://doi.org/10.1016/j.segan.2023.101035
18. On Amendments to Certain Laws of Ukraine Regarding the Development of Energy Storage Facilities. Document 2046-IX, valid. Acceptance from 02/15/2022. Accessed online: https://zakon.rada.gov.ua/laws/show/2046-20#Text (September 2024).
19. Al_Issa, H.A., Qawaqzeh, M., et al. Correct cross-section of cable screen in a medium voltage collector network with isolated neutral of a wind power plant, Energies 14, 2021, 3026. https://doi.org/10.3390/en14113026
20. Law of Ukraine. On making changes to some laws of Ukraine regarding restoration and "green" transformation of the energy system of Ukraine. Accessed online: https://zakon.rada.gov.ua/laws/show/3220-20#Text (November 2024)
21. Rubanenko O., Yanovych V., et al. Hydroelectric Power Generation for Compensation Instability of Non-guaranteed Power Plants. 2020 IEEE 4th International Conference on Intelligent Energy and Power Systems (IEPS), Istanbul, Turkey, 2020, 52–56. https://doi.org/10.1109/IEPS51250.2020.9263151
22. REopt: Renewable Energy Integration & Optimization. Accessed online: https://reopt.nrel.gov/tool (November 2024)
23. Halko S., Suprun O., Miroshnyk O. Influence of Temperature on Energy Performance Indicators of Hybrid Solar Panels Using Cylindrical Cogeneration Photovoltaic Modules, 2021 IEEE 2nd KhPI Week on Advanced Technology (KhPIWeek), Kharkiv, Ukraine, 2021, 132–136. [https://doi.org/10.1109/

KhPIWeek53812.2021.9569975]
24. Law of Ukraine "On the Electric Energy Market". Accessed online: http://surl.li/wxekij (November 2024)
25. Karaiev O., Bondarenko L., Halko S., Miroshnyk O., Vershkov O., Karaieva T., Shchur T., Findura P., Prístavka M. Mathematical modelling of the fruit-stone culture seeds calibration process using flat sieves. Acta Technologica Agriculturae 2021, 24(3), 119–123. https://doi.org/10.2478/ata-2021-0020
26. Gilman P., Dobos A., DiOrio N., Freeman J., Janzou S., and Ryberg. SAM Photovoltaic Model. Technical Reference Update. National Renewable Energy Laboratory. Accessed online: https://www.nrel.gov/docs/fy18osti/67399.pdf
27. Al_Issa H.A., Drechny M., Trrad I., Qawaqzeh M., Kuchanskyy V., Rubanenko O., Kudria S., Vasko P., Miroshnyk O., Shchur T. Assessment of the Effect of Corona Discharge on Synchronous Generator Self-Excitation. Energies 2022, 15(6), 2024. https://doi.org/10.3390/en15062024
28. Photovoltaic geographical information system. Accessed online: https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html.
29. Komada P., Trunova I., Miroshnyk O., Savchenko O., Shchur T. The incentive scheme for maintaining or improving power supply quality. Przeglad Elektrotechniczny, 2019, 95(5), 79–82. https://doi.org/10.15199/48.2019.05.20
30. Gönül Ö., Can Duman A., Barutçu B., Güler Ö. Techno-economic analysis of PV systems with manually adjustable tilt mechanisms. Engineering Science and Technology an International Journal. 35, 2022, 101116. https://doi.org/10.1016/j.jestch.2022.101116
31. Khasawneh A., Qawaqzeh M., Kuchanskyy V., Rubanenko O., Miroshnyk O., Shchur T., Drechny M. Optimal Determination Method of the Transposition Steps of An Extra-High Voltage Power Transmission Line. Energies. 2021, 14(20), 6791. https://doi.org/10.3390/en14206791
32. System Advisor Model Version 2022.11.29 (SAM 2022.11.21). National Renewable Energy Laboratory. Golden, CO. Accessed online: https://sam.nrel.gov (26.07.2024).
33. Qawaqzeh MZ., Miroshnyk O., Shchur T., Kasner R., Idzikowski A., Kruszelnicka W., Tomporowski A., Bałdowska-Witos P., Flizikowski J., Zawada M. et al. Research of Emergency Modes of Wind Power Plants Using Computer Simulation. Energies. 2021, 14(16), 4780. https://doi.org/10.3390/en14164780
34. Miroshnuk O., Tymchuk S. Uniform distribution of loads in the electric system 0.38/0.22 kV using genetic algorithms. Technical Electrodynamics 2013; 4: 67-73. http://www.scopus.com/inward/record.url?eid=2-s2.0-84885913005&partnerID=MN8TOARS
35. On Tuesday, July 16, the schedules of power outages will be applied during the day. Economic truth. Accessed online: https://www.epravda.com.ua/news/2024/07/15/716668/
36. Trunova I., Miroshnyk O., Savchenko O., and Moroz O., The perfection of motivational model for improvement of power supply quality with using the one-way analysis of variance, Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu 2019, 6, 163–168. https://doi.org/10.29202/nvngu/2019-6/24
37. Walichnowska P., Mroziński A., Idzikowski A. and Fröhlich S. R. Energy efficiency analysis of 1 MW PV farm mounted on fixed and tracking systems. Construction of Optimized Energy Potential Budownictwo o Zoptymalizowanym Potencjale Energetycznym, 2022, 11(1), 75–83. https://doi.org/10.17512/bozpe.2022.11.09