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Experience in implementing modern energy storage systems in Uzbekistan

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Abstract. This article studies the features of the project and operation of a modern energy storage system (ESS) in the climatic conditions of the Republic of Uzbekistan. The technical features of the ESS are revealed, the connection diagrams and operating modes of the ESS are analyzed. Recommendations are given for the project of similar systems to increase their efficiency, considering the climatic characteristics of the Republic of Uzbekistan.

1. Introduction

In recent years, in the Republic of Uzbekistan, as well as throughout the world, solar energy has been developing rapidly [1]. The development strategy of the Republic of Uzbekistan until 2030 provides for the construction of solar photovoltaic stations (PVS) with a total capacity of 8 GW [2, 3, 4, 5, 6]. The share of solar power plant generation in the total generation of the Republic is rapidly increasing, which creates new challenges in terms of the stability of the energy system and control modes [1, 7, 8, 9]. The high rate of implementation of solar systems in the field of agriculture and water resources requires an analysis of the operation of already implemented technologies for the project of subsequent solar power plants, taking into account the energy storage system in order to increase its efficiency [10, 11].

As is known, the grid-tied solar power plants do not generate electricity if there is no reference voltage in the grid or the power quality indicators deviate greatly from the regulated values, which leads to a decrease in the production of solar electricity. During the failure in the grid, the functionality of the PV station can be partially restored by transferring it to an isolated system with a local reference voltage source (local grid). The most popular and relatively safe source of reference voltage in a local grid is a diesel generator. The main disadvantage of such a system is the inability to accumulate excess active energy. Excess active energy increases the speed of the diesel generator and increases the frequency of electricity in local grid. To ensure stable parallel operation of a grid-tied inverter and a diesel generator in local grid, it is necessary to install an additional control unit that will regulate the power balance in the local grid. As a rule, the power of a diesel generator is selected based on the full supply of electricity to consumers in a local grid, because the failure in the grid can happen at night or during the periods of low solar radiation, when the production of PV plants drops significantly. However, a diesel generator cannot operate in idle mode for a long time, therefore, as the load decreases, the control unit limits the power of the PV station down to zero to provide the diesel generator with the necessary load. In this regard, full-fledged operation of a grid-tied PV station without losses in generation in an isolated system is, as a rule, not possible. Moreover, such a solution cannot provide continuous power supply to the critical load, because it takes time for the automatic transfer switch (ATS) to separate the system from the grid and the diesel generator to enter operating mode.

Another disadvantage of grid-tied PV station is the instability and high dependence of the output power on weather conditions, which in turn creates an additional load to the grid.

One solution to the above problems is the implementation of an energy storage system (ESS). The implementation of ESS allows:

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- provide guaranteed and continuous power supply to consumers connected to the ESS;
- make maximum use of solar energy in off-grid mode by storing excess energy in a battery system;
- improve the operating mode of the grid due to the ability to regulate the charge and discharge of batteries over time and thereby unload the grid during periods of high load, and load it during periods of low load.

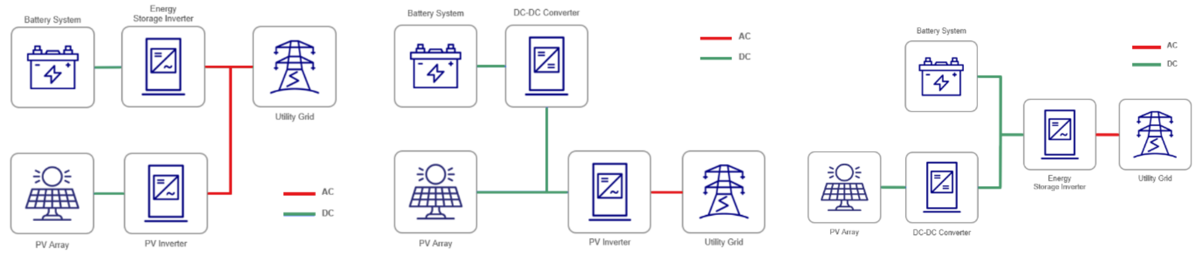
Basically, ESS is divided into two types:
- AC (alternative current) coupled ESS;
- DC (direct current) coupled ESS;

In turn, depending on the installation location of the DC-DC converter, as well as the type of inverter used, DC coupled ESS is also divided into two types:
- DC coupled ESS - ESS where the DC-DC converter is installed between the batteries and the DC bus;
- Reverse DC coupled ESS - ESS where the DC-DC converter is installed between the solar panels and the DC bus.

Fig. 1 shows block diagrams of various types of ESS. Without going into details, we emphasize that for operating in local grids Reverse DC coupled ESS is the most optimal solution.

The main advantages of AC coupled ESS are:
- Possibility of integration into an existing solar system because the ESS and the existing PV station are combined on the AC side;
- absence of a strict connection to the distance from solar panels to the ESS;
- the ability to easily increase the capacity and power of the ESS by adding new units.

The main disadvantages of AC coupled ESS are:
- lower efficiency compared to DC coupled ESS due to the need for three-time conversion: DC-AC in the solar inverter, AC-DC for charging ESS batteries, DC-AC for discharging ESS;
- higher cost because installation of two inverters and additional components are required;
- a short-term loss of power to a critical load during the operation of the ATS in the event of grid failure.



AC coupled ESS DC coupled ESS Reverse DC coupled ESS

Fig.1. Block diagrams of various types of ESS

The main advantages of DC coupled ESS are:
- high efficiency due to a single conversion of energy from DC to AC (losses in the DC-DC converter can be neglected due to their small value);
- optimal operation in Microgrid mode in the event of a power outage;
- possibility of continuous power supply to critical load (switching time less than 10 ms);
- Lower cost due to the use of one inverter.

The main disadvantages of DC coupled ESS are:
- difficulty of integration into existing solar systems;
- the need to place the ESS closer to the solar panels because they are connected directly to the ESS.

2. Materials and research method

For C&I sector (commercial and industrial) of Uzbekistan, the most actual tasks in the field of electricity supply are:
- guaranteed and continuous power supply;
- improving power quality parameters, primarily voltage, by reducing the load on the power supply cables and transformer during hours with increased power consumption;
- energy arbitrage - reducing energy costs by reducing consumption during periods of high cost and increasing during periods of low cost.

To solve the problems described above, the most optimal solution is to use Reverse DC coupled ESS. In this article, we will share the experience of implementing Reverse DC coupled ESS with a rated power of 50 kW and a capacity of 135 kW*h in Tashkent. The conclusions made in the article are relevant and useful when projecting similar ESS.

The block diagram of the ESS is shown in Fig. 2 [12]. Main technical parameters of the ESS:

- Three-phase hybrid inverter with a rated power of 50 kW;
- Rechargeable batteries with a total nominal capacity of 135 kW*hour;
- PV system with a rated power of 28.3 kW;
- Responsible load with guaranteed power supply. Rated load power 36 kW, average operating power 12 kW;
- Three-level management and control system.

The ESS is made in a container design in an explosion-proof housing. The container is divided into two modules - one module for batteries with a microclimate, the second module for the inverter and control module. The container is equipped with fire extinguishing, ventilation, air conditioning, heating systems, and water leakage sensors.

The main elements of a hybrid inverter are a DC-DC converter with a controller for maximum power point tracking (MPPT), a DC-AC converter, a high-speed ATS, a transformer, etc.

The battery system consists of 11 battery packs connected in series and a forming battery rack. Each battery pack consists of 40 battery cells (2 strings with 20 cells each). The main characteristics of the battery pack are 64V, 192A*h, 12.29 kW*hour. The nominal voltage of the battery rack is 704V, the minimum voltage is 616V, the maximum voltage is 796V. A battery management system monitors the voltage and temperature levels on each of the 440 cells and turns off the battery rack if the cell parameters fall outside the acceptable range.

To determine the azimuth of installation of photovoltaic modules (PVMs), the parameters of the roof, the operating mode of the critical load and the load of the enterprise as a whole were analyzed. The roof configuration was such that it was possible to install solar panels with an azimuth of 140 and 230 degrees. The critical load was server equipment with a rated power of 36 kW. The operating power of the critical load was in the range of 11-15 kW. Because critical load operates round-the-clock and generally constant, an azimuth decision was made based on an analysis of the total load. It was found that in the period from 9:00 to 11:00 the total load at the enterprise is 30 - 40% higher compared to the lunch and evening periods. The grid voltage in the period from 9:00 to 11:00 was lower by 5 - 10% compared to other periods. In order to reduce the load on the power cables, as well as to stabilize the voltage, it was decided to install a solar power generator with an azimuth of 140 degrees in order to reach full power supply of server equipment from solar energy by 9:00.

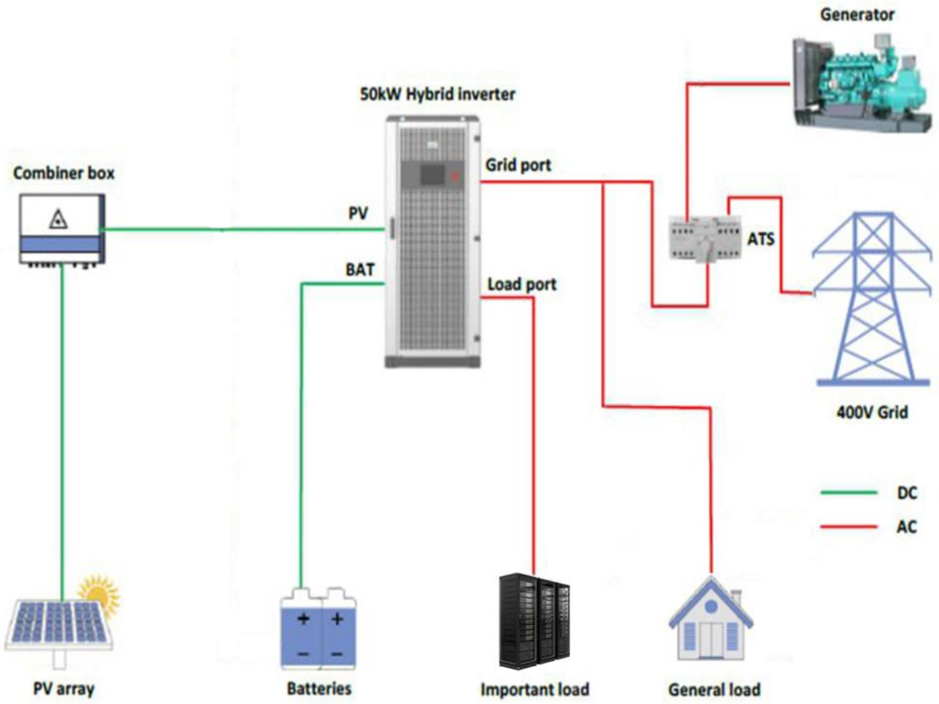


Fig. 2. ESS block diagram

3. Results and Discussion

Fig. 3 shows the graph of ESS loads from 03/17/2024. The graph shows that from 8:30 to 21:30 the critical load was fully provided by solar energy. At 21:30, the state of charge (SOC) of battery system dropped below 60% (the necessary reserve in case of power failure in the grid when PV power is not available) and the ESS was connected back to the grid. At night, the load in the enterprise is minimal and the ESS does not create additional load on the power supply system.

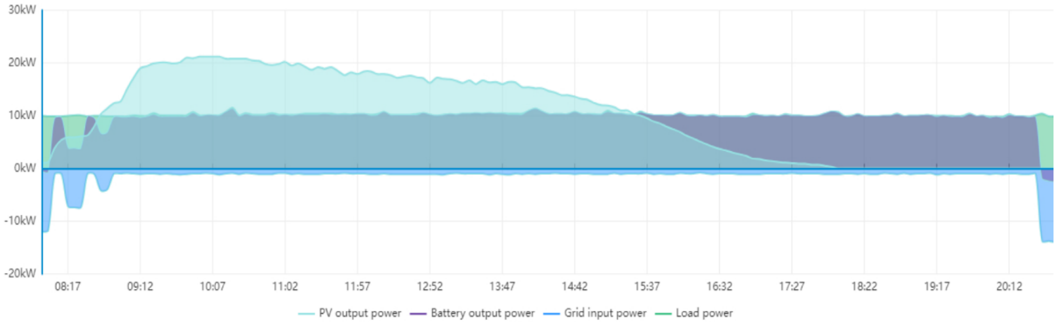


Fig. 3. Diagram of active power loads of the ESS

On the considered ESS, the DC-DC converter operates only in the direction of reducing the photovoltaic voltage (PVV) of PV string to the voltage level on the DC bus. Therefore, to charge the batteries from the PV system, the voltage of the PV string must be greater than the voltage of the battery rack by at least 20V, and optimally greater by 50V. That is, unlike to grid-tied inverters, the operating area of MPPT of hybrid inverter in a DC coupled ESS is additionally limited by the voltage of the battery rack. Moreover, as the SOC of batteries increase the voltage on the DC bus will also increase, as a result of which the MPPT operating area will shift to the area with higher voltage. Therefore, for efficient generation of solar energy, it is important to compare the operating voltage ranges of PV string, the DC-DC converter and the battery rack.

The ideal amount of PVMs in the PV string is determined from the condition of ensuring the operation of the PVMs at the point of maximum power at the time of charging the batteries at the maximum temperature at the site of installation of the ESS:

$$N_{id} = \frac{V_{BAT}+50}{V_{mp}\times(1+K_V\times\frac{t_{max}-25}{100})} = \frac{796+50}{41{,}77\times(1-0{,}25\times\frac{60-25}{100})} = 22,$$

Where

$V_{max\ BAT}$ – maximum voltage of the battery rack, V;

V_{mp} – voltage of maximum power under STC conditions of a PVM with a rated power of 555 W (Standard test conditions), V;

t_{max} – calculated maximum temperature of the PVM cell, C^0.

In practice, a full battery charge is achieved at a voltage level of 756V, and to export solar energy back to the grid, 20V is sufficient, therefore the optimal number of PVM is:

$$N_{opt} = \frac{V_{BAT}}{V_{mp}\times(1+K_V\times\frac{t_{max}-25}{100})} = \frac{756+20}{41{,}77\times(1-0{,}25\times\frac{60-25}{100})} = 20.$$

The maximum permissible number of photovoltaic modules (PVMs) in PV string is determined from the condition that the open-circuit voltage of the PV string does not exceed the maximum voltage of the DC-DC converter at the minimum temperature at the installation site of the ESS. For the ESS under consideration, the maximum number of panels is:

$$N_{max} = \frac{V_{DC-DC\,max}}{V_{oc\,(STC)}\times(1+K_V\times\frac{t_{min}-25}{100})} = \frac{950}{50{,}47\times(1-0{,}25\times\frac{-15-25}{100})} = 17{,}11,$$

Where,

$V_{DC\text{-}DC\ max}$ – maximum operating voltage of the DC/DC converter, V;

V_{oc} - is the open-circuit voltage of the PVM under STC conditions, V;

K_V – temperature coefficient of PVM voltage;

t_{min} – calculated minimum temperature of the cell, C^0.

For the current configuration of the ESS, the permissible number of PVMs in the PV string turned out to be less than optimal. Increasing the amount of PVM on PV string above the permissible level creates a risk of equipment damage in winter. Therefore, taking into account the power of the critical load and the capacity of the battery system, it was decided to connect a PV system with a total power of 28.3 kW (3 PV strings with 17 PVM with capacity 555W each) to the ESS. This configuration of the ESS leads to a decrease in the efficiency of the system as the ambient temperature increases. On the ESS under consideration, the operating voltage on the DC bus is in the range from 720V to 756V in battery charging mode under the condition when battery SOC level is maintained above 60%. Considering that the PV string voltage must be at least 20V higher than battery rack voltage, the MPPT operating range is in the range of 740V and higher, depending on the battery SOC level. Fig. 4 shows a graph of the dependence of PV power on PV string voltage for different temperatures of PVMs cells at a radiation level of 800 W/m2, which corresponds to the conditions of Central Asia [13,14,15,16,17].

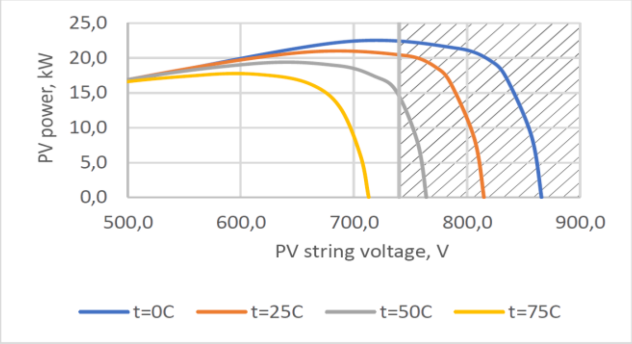


Fig. 4. Graph of the dependence of the PV power on the PV string voltage for an ESS with 11 battery packs connected in series

The MPPT work area is highlighted on the graph. As can be seen from the graph, approximately at a cell temperature of 15-25C and above, the working area of MPPT doesn’t include the maximum power point. The temperature in PVM cells is, as a rule, 10–25 degrees higher than the ambient temperature, depending on the earlier weather conditions. It turns out that with this configuration, at an ambient temperature of 5-10 degrees and above, the maximum power point is located outside of MPPT operating zone. This conclusion was confirmed experimentally. Identical PV string with 17 identical PVM and same azimuth were connected to a separate MPPT of grid-tied inverter. The generation of the ESS and the grid-tied inverter were almost the same in the range from minus 5 to plus 10 degrees. As the ambient temperature increased, the grid-tied inverter’s MPPT voltage began to decrease in search of the optimal power point, but the voltage of ESS PV string increased due to increasing the batteries SOC, and the PV power generation difference between the two systems began to increase. It must be emphasized that the power of any PV station decreases as the temperature rises. For this project, the natural level of power reduction due to an increase in the temperature of the PVM cell is approximately 3% for every 10 degrees. But the non-optimal ratio of the voltages of the PV string and the battery rack contributes to an additional decrease in the power of the solar power plant due to the shifting of the operating voltage MPPT from the maximum power voltage point towards open-circuit voltage area.
There are 2 options to solve this problem:
1) Replacing the DC-DC converter with another converter with a higher operating voltage, which will increase the number of PVMs in the PV string. This solution is not optimal because most DC-DC converters on the market have similar characteristics, and it is possible to increase the amount of PVM’s in the string only to one PVM. Moreover, adding one PVM can lead to an increase in the open-circuit voltage to a value above 1000V, which is undesirable for solar power plant installed on the roof of an urban agglomeration.
2) The most optimal solution is to reduce the voltage of the battery rack by reducing the number of battery packs.

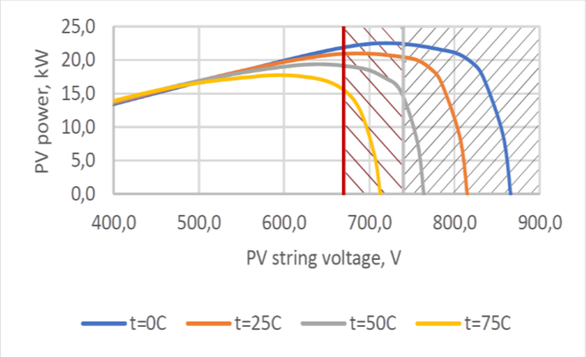


Fig. 4. Graph of the dependence of the PV power on the PV string voltage for an ESS with 10 battery packs connected in series

Reducing the battery pack voltage will increase the operating area of MPPT. Fig. 5 shows a graph of the dependence of PV power on PV string voltage for different temperatures of PVM’s cells at a radiation level of 800 W/m2 for a ESS with 10 battery packs. As can be seen from the graph, the MPPT operating area has expanded towards lower voltage area (the expansion area is highlighted in red). The graph shows that approximately up to a temperature of 50C^0 in the cell, the operating range of MPPT includes the maximum power voltage point. By eliminating one battery pack, it is possible to expand the temperature range of operation of the ESS in the maximum power generation mode approximately by 35 degrees.

4. Conclusion

Thanks to the installation of the ESS, it was possible to provide a guaranteed power supply to the critical load, reduce the load on the power cables of the enterprise during the daytime, especially during the morning rush hour, and reduce the voltage drop from the transformer substation to the input terminals of the enterprise. Therefore, it is very important to analyze the load diagram during the project of the ESS.

To make the most of the capabilities of DC coupled ESS all year round, it is necessary to properly project the system taking into account the natural and climatic factors of its installation location. The following sequence of actions is proposed when projecting similar ESS:

- Determine the maximum number of panels in the PV string so that the open-circuit voltage of the PV string at the minimum temperature does not exceed the maximum permissible voltage of the DC-DC converter;
- Determine the optimal number of battery modules in the battery rack so that the operating voltage of the battery rack in charging mode is less than the maximum power voltage of the PV string duing the hot season, taking into account the voltage drop on the DC-DC converter. It should be noted that a decrease in the number of battery packs connected in series leads to an increase in the cost of the storage system per kW*h because each battery pack requires its own individual protection and control unit.

Also, during the project and selection of equipment, it is necessary to remember that in order to increase the service life of batteries, it is necessary to ensure optimal operating temperature conditions. When choosing a modular ESS, it is important that the batteries are located in a separate section, and the power of the heating and cooling system is sufficient to ensure optimal temperature conditions inside the section during the coldest and hottest periods.

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