Study of operation modes of hybrid microgrid with using solar energy

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Abstract. In developing countries, rural and remote areas are rarely connected to the centralized grid due to lack of transmission and distribution infrastructure. The development of a hybrid renewable energy model is an alternative solution to ensure the availability of electricity in such areas. In addition, the introduction of renewable and cleaner energy sources in power system operation has become a subject of interest to achieve deep reductions in greenhouse gas emissions. However, the intermittency of wind and solar energy has hindered the large-scale implementation of renewable energy sources (RES) in the power system. Hybrid energy systems (HES) utilizing RES are an alternative way to solve stability and reliability problems. The article covers the design and operation of HES in both stand-alone and grid-connected modes.

1 Introduction

Renewable energy sources are used to replace conventional energy sources such as: coal, oil and natural gas. The development of renewable energy sources is an important direction in the development of modern economies while preserving environmental quality and reducing CO_2 emissions. Hybrid energy combines different energy sources, energy storage and consumption devices into a single system, improving the overall benefits compared to a system dependent on a single energy source. Solving environmental problems associated with the use of fossil fuels is an important goal of many scientists in different countries. The use of renewable energy sources, including solar and biomass technologies, in hybrid energy systems is playing an increasingly important role to reduce harmful emissions from systems running on conventional fuels, and also helps to address energy shortages in decentralized areas. However, many hybrid systems have a number of drawbacks: the instability of solar energy, the lack of storage of excess energy, and the low reliability of hybrid systems due to the difficulty of harmonizing different energy sources into a single system, which significantly limit the development of renewable energy hybrid energy systems.

Renewable energy sources can play an important role in providing reliable energy supply. Most rural areas are rich in renewable resources, which include biomass, hydropower, wind, solar insolation [1]. Utilization of these resources will also provide

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additional economic benefits by selling excess power generation to the grid. A hybrid system utilizes one or more energy resources to convert them into electricity. Such a system utilizes renewable resources along with fossil fuels to generate electricity. These systems may not be connected to the power grid. The main objective of a hybrid system is to reduce the consumption of fossil fuels [2].

Two types of connection can exist for electrification of decentralized areas: off-grid and grid-connected. An off-grid renewable energy system is a system that operates autonomously and has no connection to the power grid [3]. While grid-connected system, or On-grid system, consists of renewable energy sources to generate electricity, and grid connection ensures the continuity of electricity flow during shortage or surplus of power generation. In areas with poor grid connection, intermittent and unreliable power supply, grid-connected renewable systems will increase the reliability of power supply.

Therefore, it was proposed to develop a laboratory microgrid, to investigate and modernize hybrid power systems in order to improve their reliability and efficiency.

2 Description and justification of the chosen design, indicating which parts are borrowed from previously developed products

As part of the project, a hybrid energy system (HES) sample was developed, the schematic diagram of which is shown in Figure 1.

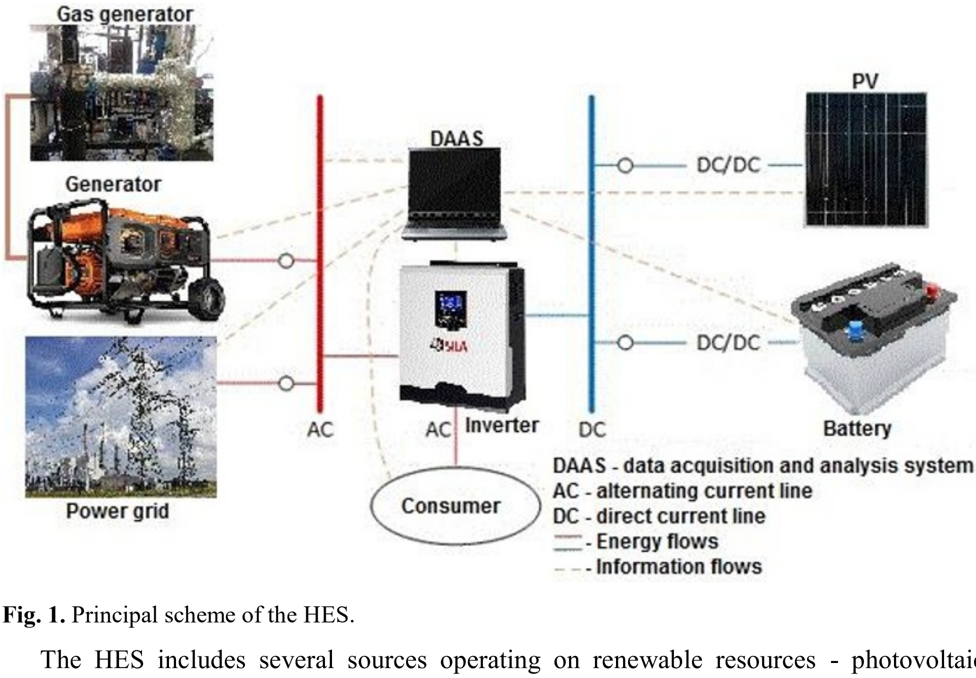

Fig. 1. Principal scheme of the HES.

The HES includes several sources operating on renewable resources - photovoltaic panels (PV, solar energy) and a gas-fired power plant (GFPP, biomass). Energy storage is also foreseen. The power plant can also be connected to the grid and run from a diesel electric generator (DEG). The power plant utilizes an inverter as well as a data acquisition and analysis system (DAAS). In future, a distributed multi-agent microgrid control module will be developed to control this hybrid power plant to maximize the economic efficiency and reliability of the microgrid. The total power of the HES is about 1 kW. This power is sufficient to develop efficient control and modeling solutions for cyber-physical systems and further scaling of the hybrid power system. Several consumers are connected to the

HES: one consumer with a constant load of about 400 W and another with a variable load power of also about 400 W.

2.1 Choice of components

The components of HES are selected to provide the necessary requirements for the proper functioning of the system, as well as taking into account their availability and low cost. The HES is developed from the equipment available in the laboratory.

When selecting an inverter for the HES, the power characteristics were considered so as to cover the power requirements at the existing load capacity.

The photovoltaic converters were selected at a power comparable to that of the generator.

The capacity of the accumulation unit was selected based on the load capacity of the system, because it is necessary to have sufficient power reserve for the system to operate in autonomous mode. The accumulators were also selected according to the price/quality ratio.

The gas generator is designed according to the most optimal technology available at the moment. The use of a screw in the reactor significantly simplifies the operation of the unit and increases its efficiency. The system of condensation and filtration of synthesis gas is developed on the basis of experimental data [4].

The generator is chosen to match the total system capacity as well as the volume of gas consumed.

2.2 Composition of HES equipment

2.2.1 Hybrid solar inverter SILA V 1000P

Hybrid solar inverter SILA V 1000P is a multifunctional inverter/charger with a capacity of 1 kW (short-term 2 kW), which combines the functions of an inverter, solar battery charge controller and battery charger from the 220V network to ensure uninterrupted power supply, with the ability to select charging and load priorities.

2.2.2 Photovoltaic converter SilaSolar SIM280 (5BB)

Two SilaSolar SIM280 (5BB) solar panels with a total capacity of 560 W are included in the HES. Figure 2 shows the appearance of the photovoltaic converters used.

2.2.3 Batteries

The HES includes four parallel-connected AGM type accumulators. Operating voltage is 11-14V, capacity of the battery pack is 400 Ah (Capacity of each battery is 100 Ah). Figure 3 shows the external view of the battery pack with inverter.

2.2.4 Gas-fired power plant

The HES includes a gas generator power plant. The GFPP is based on a unique multistage gas generator developed by the laboratory, which operates both on wood chips and pellets. The peculiarity of this gas generator is that it implements a step-by-step scheme of biomass gasification, which allows obtaining practically tar-free generator gas (1-1.5 mg/Nm3). This generator gas without additional purification can be used in gas piston engines. At the same time, the generator gas has a satisfactory calorific value of 1.4 - 1.6 kcal/nm3. A Kronwerk

LK 1500 gasoline generator modified for operation on generator gas is used as an electric generator. Experiments have shown that the power obtained with the use of generator gas in the stationary mode is 60-80 % of the nominal, at a voltage of 220±20 V, and the efficiency(e) is 22 % [5, 6].

Fig. 2. Appearance of photovoltaic converter.

Fig. 3. External view of the battery pack with inverter.

2.3 Software

WatchPower is an inverter monitoring software that can monitor multiple devices via serial port at the same time. The main functions of WatchPower monitoring software include data log for devices, alarm messages, fault messages and parameter setting for devices.

The software allows you to set battery voltage thresholds, allows to monitor in real time the readings of the measuring devices built into the inverter (load power, input/output mains voltage and frequency, battery pack voltage, solar panel voltage, and their power factor). Figure 4 shows the appearance of the WatchPower program interface.

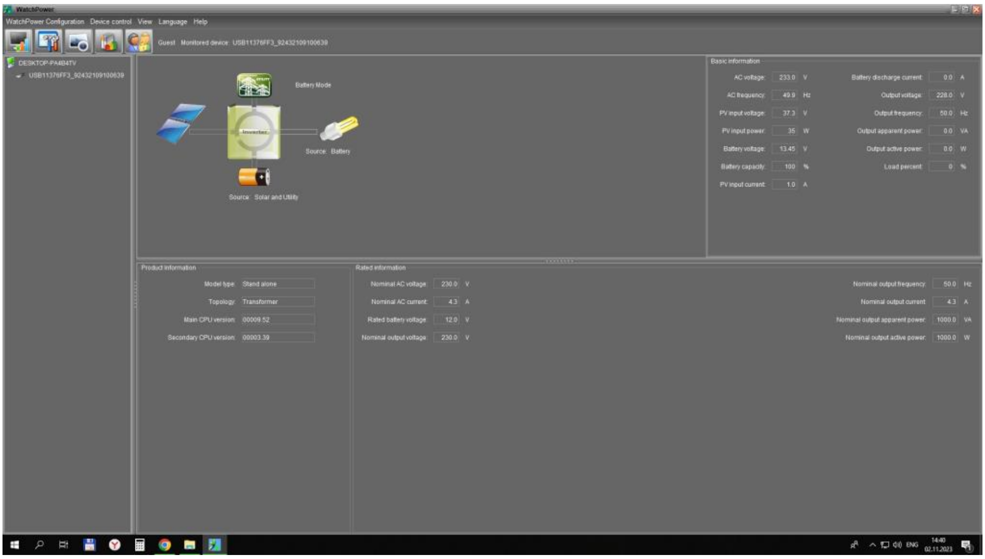

Fig. 4. Appearance of the WatchPower program interface.

3 Results and discussion

The paper analyzes the emergency and steady-state operation modes of solar hybrid power systems (“High-Temperature Circuit Multi-Access Research Center”, project no 13.CKP.21.0038).

The operating modes of the HES were investigated, one of which simulates the shutdown of all energy sources except for the photovoltaic converter (Mode № 1), the second mode simulates the normal operation of the hybrid microgrid with power supply from the external grid (Mode № 2). Before starting the analysis of the first mode, the battery charge was brought to 100%.

Mode № 1. The test started at 8:00 am on January 12, 2023, the hybrid microgrid was disconnected from the common grid/generator and the system was put into stand-alone mode. Figures 5-7 show the plots of the voltage drop across the battery, PV, and the graph of the load power variation in standalone mode over a day.

Mode № 2. For mode 2 of operation, the graphs of voltage drop across the solar panel unit and load power are shown in Figures 5 and 6.

Investigation of the voltage drop on the battery pack showed that in Figure 5, the voltage drop on the battery pack of about 0.3V when the microgrid is disconnected from the common grid/generator indicates that the system is switched to stand-alone mode.

The resulting battery discharge graph shows a uniform voltage drop. In the period from 12:00 to 16:30, the voltage rises by 0.4-0.5V, which is due to the PV generating enough electricity to charge the battery and cover the load.

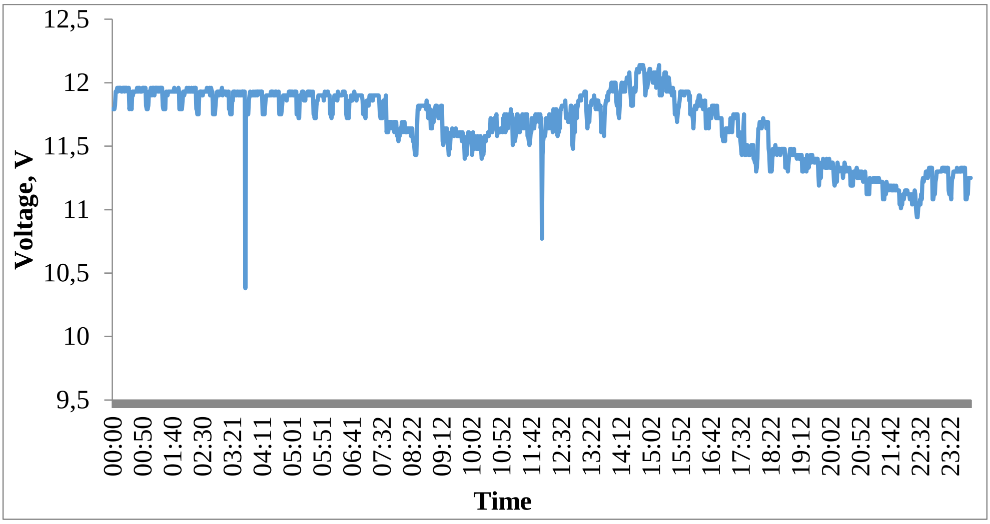

Fig. 5. Graph of battery voltage variation over a day.

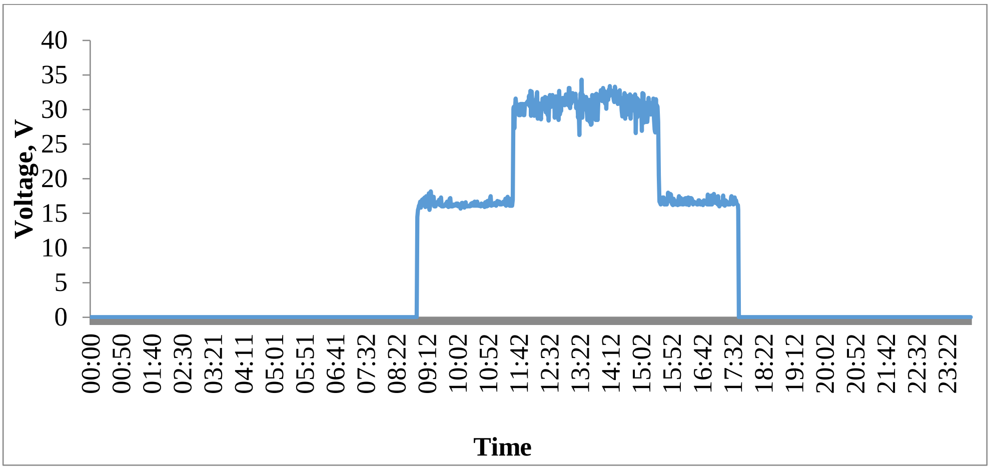

Fig. 6. Graph of voltage variation on solar panels per day.

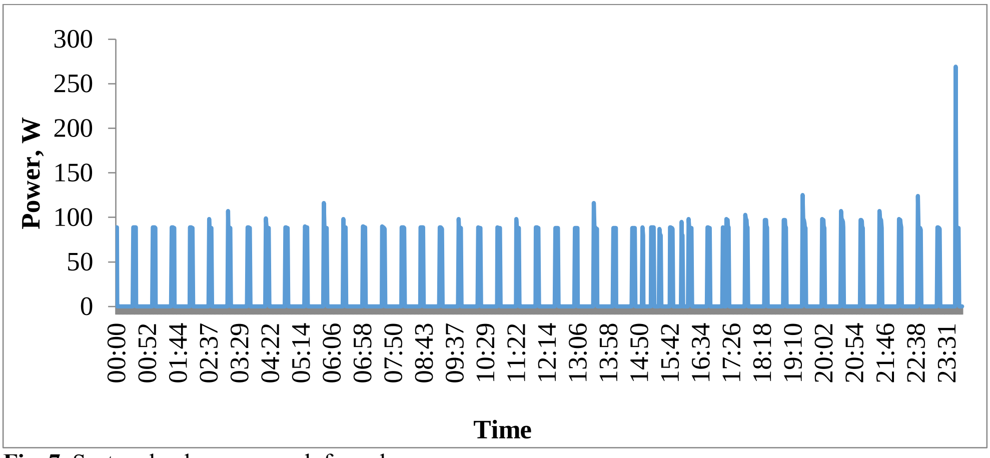

Fig. 7. System load power graph for a day.

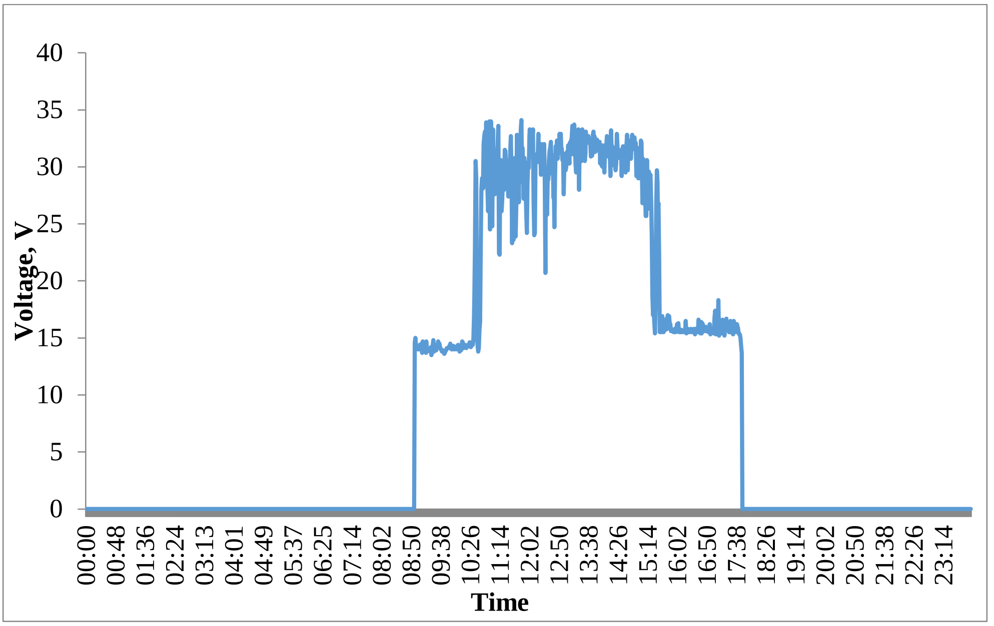

Fig. 8. Graph of voltage change on photovoltaic converters per day.

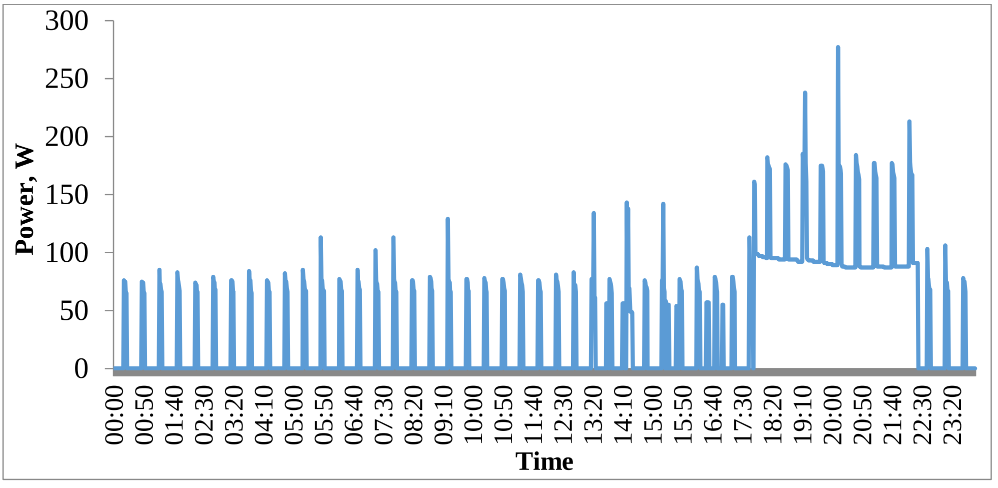

Fig. 9. System load power graph for a day.

When studying the voltage drop on the battery, it was found out: in the morning hours with weak solar activity (for example, at 8:30 (Figures 6 and 7)), the low voltage provided by PVs (15 V) does not allow to charge the battery. When the voltage rises above 30 V, the PVs already provide battery charging (e.g., between 12:00 and 16:40, depending on weather conditions). Analysis of graphs of voltage drop on PVs (Figures 7, 9) shows different character of voltage curves depending on the inverter operation mode. In mode № 1 there are periodic drops of voltage produced by the PV by the value of 5-20 V. This is due to the natural voltage drop on the battery pack and the algorithm of the inverter operation in the autonomous mode when connecting and removing the load. For mode № 2 such voltage drops are not observed.

A household refrigerator (maximum power consumption of 200 W) is used as the system load for mode № 1. For mode № 2 as a load was used electrical equipment of the

household room (lighting, exhaust fan from the motion sensor). The maximum total power consumption was about 400 W.
Since the WatchPower software does not have the ability to record load values more often than once a minute, in this case it is not correct to measure peak load power, because this system records only continuous load.

Figures 8 and 9 are the load power graph for a day on 12.01.23 and 13.01.23 respectively. From 07:00 to 22:00 the electrical equipment of the utility room starts to be actively used, which leads to an increase of the load power up to 200-250W.

4 Conclusion

The developed microgrid has been tested in two modes. According to the study of autonomous operation mode, it was found that with this configuration, autonomous operation was maintained and satisfied the demand of consumers. Due to the PV, it was achieved to maintain autonomous operation during the daytime, and the battery pack accumulated excess electricity for the subsequent operation of the HES during the nighttime. During the development and operation of the HES, a number of changes were proposed for the PV. For more efficient operation of the PV, it is necessary to develop a system that allows the panels to be positioned relative to the sun as correctly as possible.

Based on the obtained data, it can be concluded that the developed hybrid microgrid functions well and enables research in improving the reliability and efficiency of hybrid power systems using renewable energy sources and can serve as a basis for further research in the field of hybrid power systems.

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