A System for Storing and Processing the Results of Energy Test Facility Data Monitoring

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Abstract — **Substantiation and verification of the energy and economic calculations for solar power plants require initial data and experimental results. The paper proposes a device developed for monitoring and processing information from the experimental solar panel facility. The facility aims to obtain reliable data for the verification of models designed to assess solar resource indices used to justify the performance of solar power plants in the eastern regions of Russia. The device developed for monitoring the energy characteristics of solar panels has additional capabilities to transmit data to the server. A method proposed to transfer data to a server employs a Bluetooth module and a single-board computer Raspberry Pi as an intermediate communication center. The results of the preparatory work for monitoring weather conditions and the Peleng SF-06 pyranometer readings, which employs the developed logger and relies on the proposed method of data transfer to the server are described.**

Index Terms: **Arduino, data logger, pyranometer, solar power, raspberry.**

I. Introduction

Designing and upgrading solar plants require energy and economic calculations to justify them [1–3]. Energy estimates can be obtained by theoretical calculations and experimental observations with subsequent comparison of the collected solar radiation data for their verification.

Experimental data can be obtained in several ways, but they all have drawbacks. Satellite data is expensive and relatively inaccurate because the result of their observations is the difference between the incoming radiation and reflected radiation from the earth's surface. The results of observations from ground-based meteorological stations are given in climate reference books published in the last century. In addition, weather stations, especially those making actinometric measurements, are sparse and if they are far from the area of interest, their data is not always up-to-date [4–5]. Solar radiation can also be estimated using parametric models. These models employ climatic parameters such as temperature, humidity, wind speed, and pressure [6–8].

The main purpose of the study is to verify the results of model calculations performed to assess the solar resource indicators and experimental data obtained using the developed device for storing and subsequently processing the information on the energy performance of solar panels.

II. Description of an Experimental Solar Panel Facility

The solar panel facility at issue is located at the Melentiev Energy Systems Institute of Siberian Branch of the Russian Academy of Sciences in the city of Irkutsk. The test facility consists of three differently oriented solar panels and additional equipment, including hybrid inverters and batteries. A more detailed description of the experimental facility is given in [9].

The primary objectives for the facility are to obtain reliable information to assess the efficiency of solar power plants for various regions, substantiate the optimal inclination angle for the panels and the need to build an automated sun-tracking system. Similar work is carried out by researchers from other institutions too, for example [10].

The inverters installed at the facility have screens that display some instantaneous characteristics, such as voltage and current. Data from inverters can be recorded using additional equipment, which has some drawbacks, including high price and closed software, which does not allow flexible settings and works in the manufacturer's language, most often Chinese [11]. These factors make it necessary to develop a proprietary device for recording and processing the necessary parameters.

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http://dx.doi.org/10.38028/esr.2022.03.0004
Received September 15, 2022. Revised September 26, 2022.
Accepted October 23, 2022. Available online December 5, 2022.

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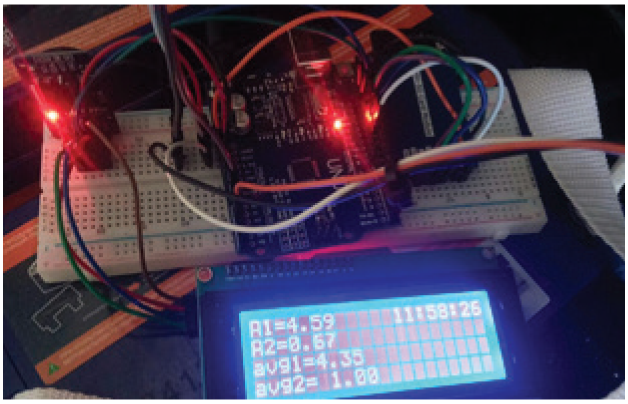


Fig. 1. Data logger based on Arduino microcontroller and shunt ammeter

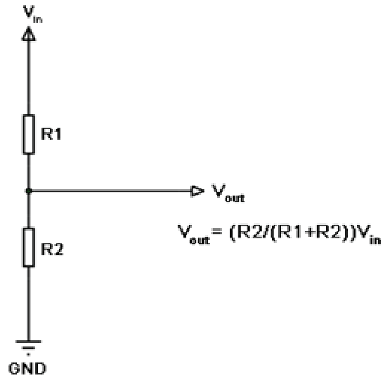


Fig. 2. Voltage divider circuit.

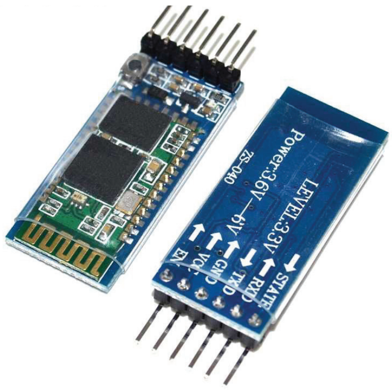


Fig. 3. Bluetooth module HC-06.

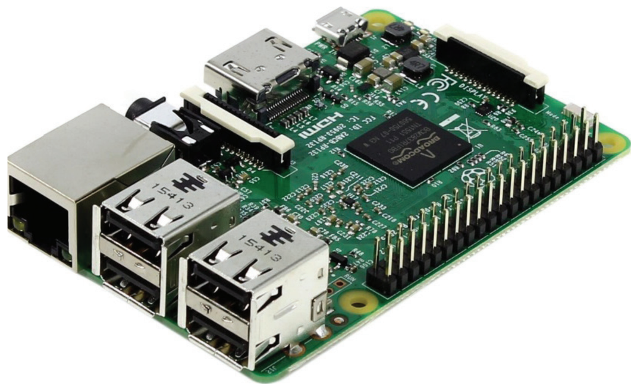


Fig. 4. Single-board computer Raspberry Pi 3.

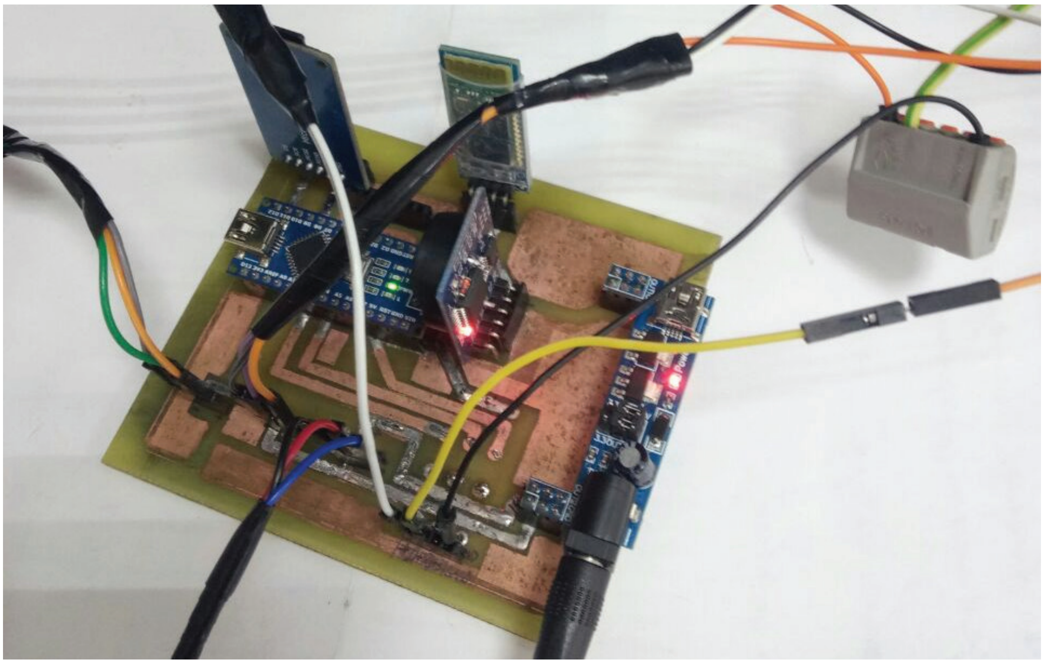
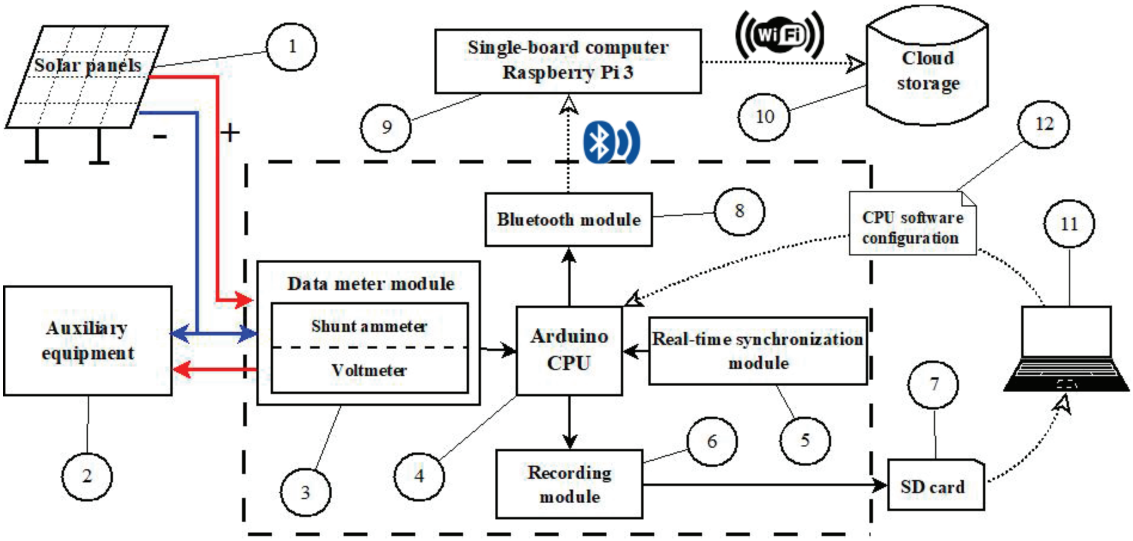


Fig. 5. Customized printed circuit board for the data logger.



— — — the meter circuit; 1 – solar panel; 2 – auxiliary equipment: hybrid inverter and a battery array; 3 – data counter block: shunt ammeter and voltmeter; 4 – Arduino microcontroller; 5 – quartz real-time clock; 6 – device that records data from the meter; 7 – memory card for data storage; 8 – Bluetooth protocol module ; 9 – single-board computer Raspberry Pi 3; 10 – remote server with cloud storage; 11 – computer; 12 – programming instructions for CPU.

Fig. 6. Block diagram of a data logger based on the method of wireless data transmission.

III. Description of the First Version of the Solar Energy Data Logger

The initial stage of the data logger development was aimed at creating a prototype to provide visual monitoring of characteristics.

The Arduino microcontroller was used as a basis, and an ACS712 shunt ammeter based on the Hall effect was used to measure current [12]. An LCD screen was connected to calibrate the sensors.

The next version of the data logger (Fig. 1) was equipped with a real-time module with a built-in lithium battery for independent power supply and acquired the capability to write data to an SD card [9].

This data collection and recoring device is connected to a break in the power circuit and has several modules that are controlled by a microcontroller.

IV. The Current Version of the Solar Energy Data Logger

Previous versions of the data logger were unable to measure voltage. To this end, a voltmeter implemented by a voltage divider (Fig. 2) was chosen for the new version.

With this method, the incoming voltage is reduced from a maximum of 55 V to 5 V and then, the central processor, given the installed resistors, converts the values to those that were before the reduction, with an error of about 0.6 V.

Data is recorded to the server through the Bluetooth module HC-06 (Fig. 3) connected to the data logger and the Raspberry Pi 3 single-board computer (Fig. 4), which runs under a linux-based OS, as an intermediate communication center.

After debugging the sensors, the data logger was assembled on a customized printed circuit board providing modular connection of all components (Fig. 5). The block diagram of this board is shown in Fig. 6.

This board worked in a test mode for several days and showed the good performance of the circuit. Factory-made boards with modular installation of all components were ordered to replace parts that could fail (Fig. 7).

V. Method of Data Transfer to the Server

A bluetooth module is connected to the data logger to transfer data. In our case, this module does not require program code modification. The Raspberry Pi 3 is automatically connected to the data recorder via the Bluetooth protocol and, using a written program in the

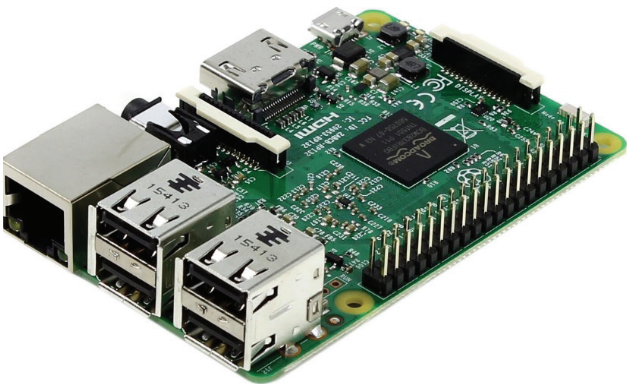


Fig. 7. Data logger assembled on a factory-made printed circuit board.

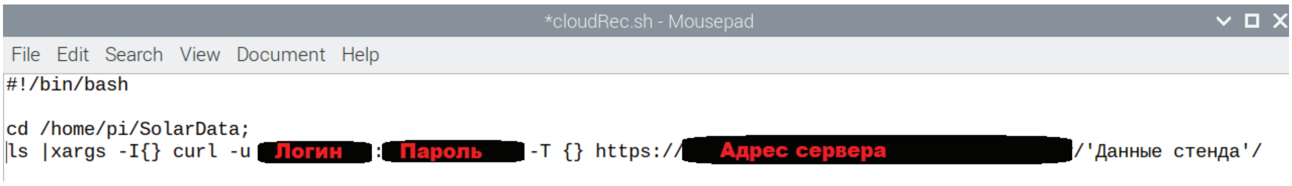


Fig. 8. Terminal command to connect and upload data to the server.

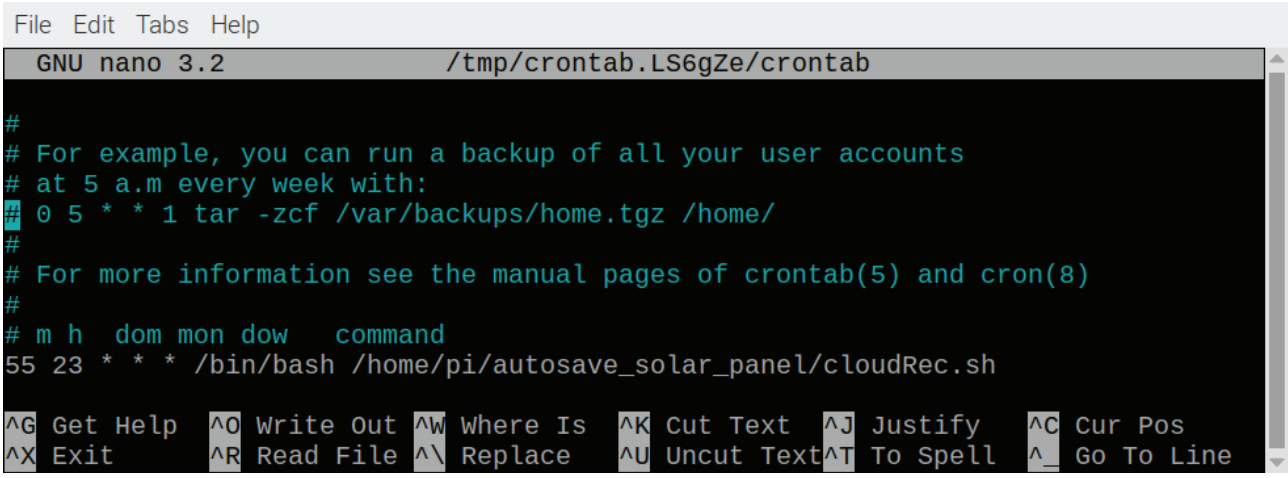


Fig. 9. Crontab utility.

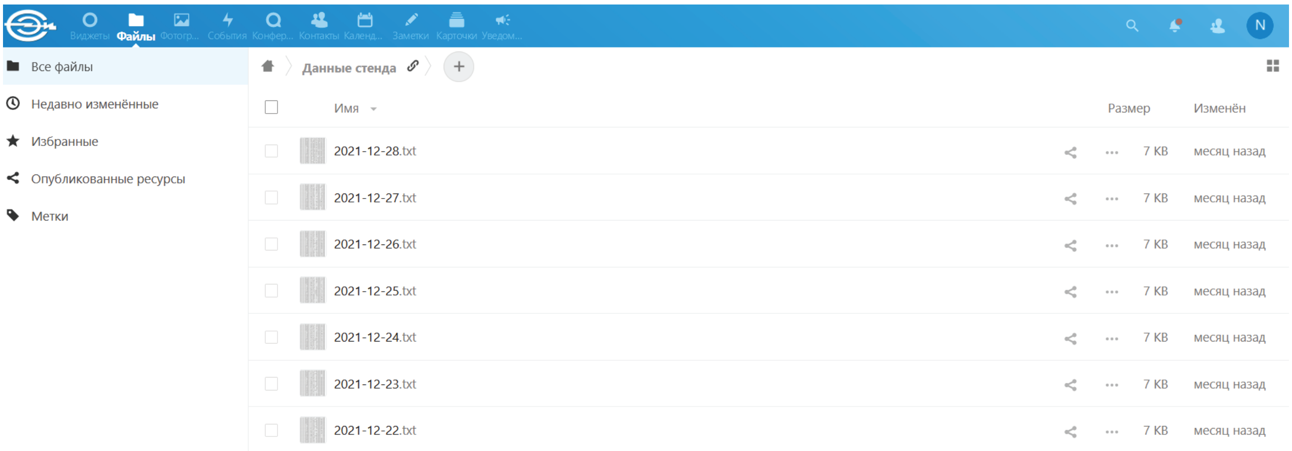
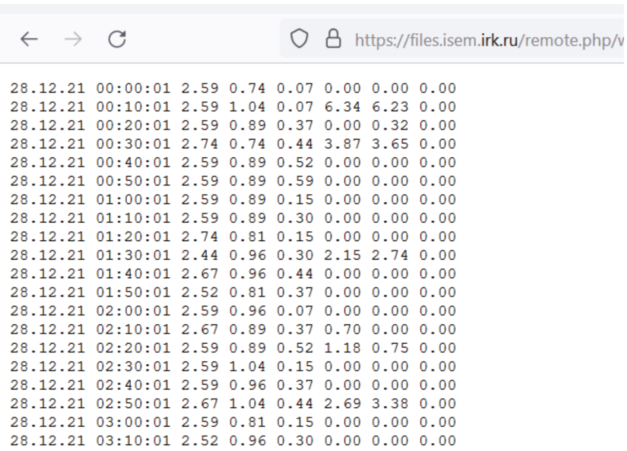


Fig. 10. Data received at the server.



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https://files.isem.irk.ru/remote.php/v
28.12.21 00:00:01 2.59 0.74 0.07 0.00 0.00 0.00
28.12.21 00:10:01 2.59 1.04 0.07 6.34 6.23 0.00
28.12.21 00:20:01 2.59 0.89 0.37 0.00 0.32 0.00
28.12.21 00:30:01 2.74 0.74 0.44 3.87 3.65 0.00
28.12.21 00:40:01 2.59 0.89 0.52 0.00 0.00 0.00
28.12.21 00:50:01 2.59 0.89 0.59 0.00 0.00 0.00
28.12.21 01:00:01 2.59 0.89 0.15 0.00 0.00 0.00
28.12.21 01:10:01 2.59 0.89 0.30 0.00 0.00 0.00
28.12.21 01:20:01 2.74 0.81 0.15 0.00 0.00 0.00
28.12.21 01:30:01 2.44 0.96 0.30 2.15 2.74 0.00
28.12.21 01:40:01 2.67 0.96 0.44 0.00 0.00 0.00
28.12.21 01:50:01 2.52 0.81 0.37 0.00 0.00 0.00
28.12.21 02:00:01 2.59 0.96 0.07 0.00 0.00 0.00
28.12.21 02:10:01 2.67 0.89 0.37 0.70 0.00 0.00
28.12.21 02:20:01 2.59 0.89 0.52 1.18 0.75 0.00
28.12.21 02:30:01 2.59 1.04 0.15 0.00 0.00 0.00
28.12.21 02:40:01 2.59 0.96 0.37 0.00 0.00 0.00
28.12.21 02:50:01 2.67 1.04 0.44 2.69 3.38 0.00
28.12.21 03:00:01 2.59 0.81 0.15 0.00 0.00 0.00
28.12.21 03:10:01 2.52 0.96 0.30 0.00 0.00 0.00
```

Fig. 11. Open data file.

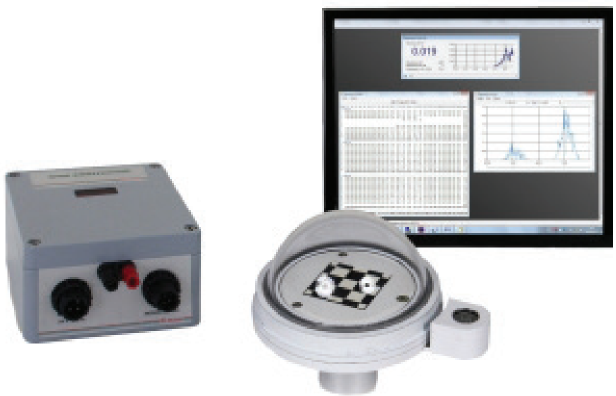

Fig. 12. Pyranometer Peleng SF-06.

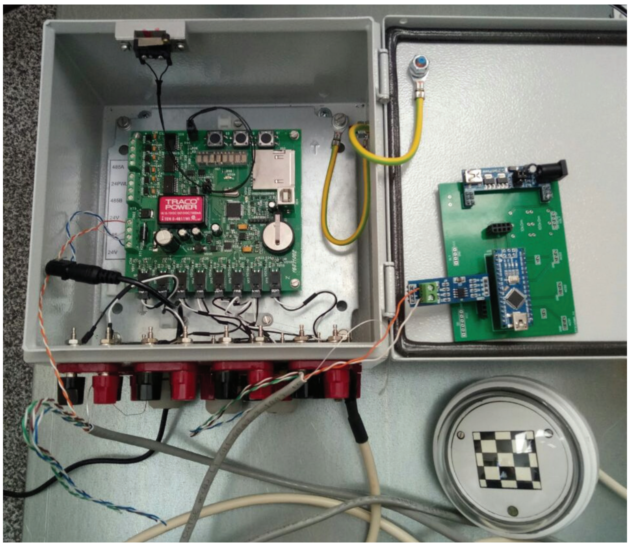

Fig. 13. Pyranometer Peleng SF-06 connected via RS-485.

Python programming language, stores the incoming data in a *.txt file. The created file is named according to the date of data recording. Thus, every day, the data is written to different files for further processing. The generated data is sent to the cloud storage via an Internet connection. In addition, the data is backed up to an SD card to provide backup in case of failure.

To automate the data transfer from the Raspberry Pi 3 to the server, a terminal command was written. It enters the login and password from the account to the server and uploads the data to the desired directory (Fig. 8).

The written command is added to the built-in crontab utility for execution at a specified time (Fig. 9).

The data is stored in a *.txt format convenient for further processing and is available for download. All files are numbered by dates, the file itself keeps a record of the time each line was recorded (Fig. 10 and 11). Data is accessed through a link to the storage.

VI. Logging the Data on Weather Conditions

Theoretical models of solar radiation require data on weather conditions such as temperature, wind speed, pressure, and others. There are ways to develop one's own weather station based on the Arduino microcontroller [13]. These devices use weather sensors and expansion boards to implement the method of data transfer described above. Such devices can be developed directly on the Raspberry Pi 3 with the connection of such sensors [14].

For the objectives of this study, we use the method of data recording from free online weather services of open weather stations. The service is openweathermap.org. This service has a free library for the Python programming language and enables the display of the following data:

- Data update time;
- Temperature (°C);
- Wind speed (m/s);
- Wind direction (°);
- Humidity (%);
- Cloudiness (%);
- Pressure (mm Hg);
- Visibility (m).

To obtain weather data, a program storing the data in a *.txt file was written in the Python programming language. The stored weather data is written to the servers by the same method as the data from solar panels. The terminal program added for automatic execution at specified time on Raspberry Pi 3 connects to the server and uploads files to the specified directory.

It is planned to additionally test the theoretical models using the pyranometer Peleng SF-06 (Fig. 12).

This pyranometer makes it possible to measure the solar irradiance in the spectral wavelength range from 0.3 to 2.4 μm, but does not have convenient tools for data logging. Currently, the proposed solar panel data logger is employed to develop a device for monitoring data from a pyranometer using the RS-485 protocol (Fig. 13).

Since the developed data logger uses the Arduino microcontroller as a central processor, it is possible to correct the firmware and connect other modules to receive the signal.

VII. Conclusion

The new version of the developed device for monitoring the energy performance of solar panels is capable to transmit data to cloud storage for remote access. The paper describes the proposed method for data transfer to a server, which uses a Raspberry Pi 3 single-board computer. It also records the data on weather conditions from open weather stations in real time. The modularity of the developed device makes it possible to replace components in case of a failure or the need to measure another parameter. The SD card allows additional recording of data in the event of the wireless network disconnection. Further data processing will be carried out on a computer and involves the following main steps:

- accumulating data on the total power output for each of the panels;
- visualizing data in the form of graphs, both overall and over a certain period of time;
- comparing data on solar panel instantaneous power.

The work was supported by the grant No. 075-15-2020-787 in the form of a subsidy for a Major scientific project from the Ministry of Science and Higher Education of Russia (project "Fundamentals, methods and technologies for digital monitoring and forecasting of the environmental situation on the Baikal natural territory").

References

[1] O. S. Popel, S. V. Kiseleva, M. O. Morgunova, T. S. Gabderakhmanova, A. B. Tarasenko, "The use of renewable energy sources for energy supply to consumers in the Arctic zone of the Russian Federation," *The Arctic: Ecology and Economy*, vol. 1, no. 17, pp. 64–69, 2015. (In Russian)

[2] I. Yu. Ivanova, T. F. Tuguzova, V. A. Shakirov, N. A. Khalgaeva, “On the need to consider various factors in the justification of the use of solar potential for the purpose of power supply on the example of Yakutia,” *Proceedings of the Russian Academy of Sciences. Power Engineering*, no. 2, pp. 41–54, 2018. (In Russian)

[3] S. E. Frid, N. V. Lisitskaya, O. S. Popel, “Results of the analysis of the applicability of satellite observation data and reanalysis for modeling autonomous solar power plants,” *Doklady Akademii Nauk*, vol. 488, no. 6, pp. 609–611, 2019. (In Russian)

[4] *Reference book on the climate of the USSR.* Issue 22. Irkutsk region and the western part of the Buryat ASSR. Part 1. Solar radiation, radiation balance and sunshine. Leningrad, Russia: Gidrometeoizdat, 1966, 72 p. (In Russian)

[5] *NASA Prediction of Worldwide Energy Resources.* The POWER Project. Available: https://power.larc.nasa.gov/. Accessed on Mar. 12, 2021.

[6] *Scientific and applied reference book on the climate of the USSR. Series 3*. Long-term data. Parts 1–6. Issue 22. Irkutsk region and the western part of the Buryat ASSR. Leningrad, Russia: Gidrometeoizdat, 1991, 609 p. (In Russian)

[7] D. Myers, *Solar Radiation: Practical Modeling for Renewable Energy Applications*. CRC Press/Taylor & Francis Group, 2013, 182 p.

[8] M. J. Ahmad, G. N. Tiwari, “Solar radiation models – A review,” *International Journal of Energy Research*, vol. 35, no. 4, pp. 271–290, 2011. DOI: 10.1002/er.1690.

[9] R. Ivanov, N. Maksakov, “Development of a solar energy meter for an experimental array,” *E3S Web Conf.*, vol. 289, p. 05001, 2021. DOI: 10.1051/e3sconf/202128905001.

[10] S. V. Mitrofanov, A. Yu. Nemaltsev, D. K. Baikasenov, “Primary testing of an automated two-coordinate solar tracker in the climatic conditions of the Orenburg region as a prospect for creating a software and hardware complex,” *International Scientific Journal for Alternative Energy and Ecology*, no. 07–09, pp. 43–54, 2018. (In Russian)

[11] R. A. Ivanov, N. V. Maksakov, “Organization of monitoring the parameters of experimental solar panel facility,” *Information and Mathematical Technologies in Science and Management*, vol. 4, no. 24, pp. 77–87, 2021. DOI: 10.38028/ESI.2021.24.4.008. (In Russian)

[12] *A brief overview of Allegro ACS712 current sensor.* Available: https://www.radiolocman.com/shem/schematics.html?di=113339. Accessed on Feb 04, 2022.

[13] *Analysis of weather station data based on Arduino*. Available: https://habr.com/ru/post/256413/. Accessed on Feb. 04, 2022.

[14] *How to Capture Weather Data with your own IoT Home Station.* Available: https://towardsdatascience.com/how-to-capture-weather-data-on-your-home-400716bde645. Accessed on Feb. 04, 2022.