Study on IoT based SCADA System for Rooftop Solar Power Systems in Vietnam

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Abstract- Rooftop solar power projects in Vietnam are increasingly popular and have certain impacts on the distribution power grid. Thus, solar panel systems are designed and built with many scales and features that are increasingly flexible, easy to install as well as in use. Moreover, the management and operation of distribution power grids with solar power stations also need to be improved so that local power companies can monitor the operation current status of the system. In this study, an Internet of Things (IoT) - based Supervisory control and data acquisition (SCADA) system is proposed to serve the management and supervision of the operation of rooftop solar power stations on the typical distribution grid of Ha Tinh Power Company, Vietnam. The test research results show that the SCADA - IoT system operates stably, data is sent fully to the server and there are no signs of loss, except in cases of WiFi signal loss or unstable 4G network signal due to the WiFi network. Therefore, Ha Tinh Power Company can control the operation of all rooftop solar power systems and make appropriate distribution grid operation strategies.

Keywords- solar power system; monitoring; SCADA, IoT, distribution power grid.

1. Introduction

The world is using renewable power sources [1,2] to meet electricity demand without harming the environment [3-5]. One of the most widely used renewable energy sources is solar power because of its advantages [6] such as simplicity of use, low maintenance requirements, and environmental friendliness. However, the operation of the solar power system is not stable due to high dependence on weather conditions such as temperature and solar radiation [7-9]. Therefore, the SCADA system [10-12] is used to evaluate the status of the solar power supply in real-time and make appropriate management decisions to optimize the operation process and detect unexpected faults.

On the other hand, the Internet of Things (IoT) [13-15] refers to the billions of physical devices around the world that are now connected to the Internet to collect and share data. IoT can be applied to smart health services [16], smart homes [17], smart cities [18], smart environments [19], smart industries [20], and smart agriculture [21].

Many researchers around the world have studied the application of IoT-based SCADA systems to manage the working process of solar power systems. S. Begum et al [22] comparative study to improve the performance of solar power plants through IoT-based SCADA systems and predictive analytics. Md Ohirul Qays et al [23] proposed a SCADA system based on the Internet of Things diagram to monitor a hybrid power system consisting of photovoltaic, wind, and battery energy storage systems. Electrical parameters such as voltage, current, and power are monitored in real time through the ThingSpeak website. The online operator can control the components of the hybrid power system using the proposed SCADA system. L. O. Aghenta and M. T. Iqbal [24] developed a low-cost, open-source SCADA system for remote monitoring and control of solar photovoltaic (PV) systems. The proposed SCADA system is based on the SCADA architecture of the Internet of Things (IoT), which combines web services with conventional SCADA to enhance control and monitoring. The study by F. M. Q. Silva et al [25] presents a monitoring system based on open source tools for photovoltaic power plants, using IoT devices and adapting non-IoT devices for the current new generation of automation. This new monitoring system improves the existing monitoring system because it adds new features, and increases collection time. According to empirical research by M. Del Río et al [26], the SCADA system for the proposed solar power station is based on IoT and Machine Learning. The application of the developed platform improves photovoltaic maintenance management, detecting a decrease in performance rate. V. Voicu et al [27] proposed the design of industrial IoT network architecture for SCADA systems in solar power plants with functions including monitoring and control part of the former and data analysis of the latter. An IoT solution for monitoring photovoltaic plants based entirely on Open Source software was proposed by Pedro de Arquer Fernández et al [28]. Solutions aimed at overcoming the identified weaknesses of the latest IoT-based monitoring systems are also studied in detail.

Vietnam has strongly developed solar power [29.30] in recent years with a total installed solar power capacity by the end of 2021 of 17.4 GW [31]. In general, large-capacity solar power projects have been installed with traditional SCADA systems to serve the task of monitoring the operation and supervision of power companies [32].

However, SCADA systems for new rooftop solar power projects are deployed alone or as experimental research models [33,34]. Although the tracking information on the application provided by the manufacturer is relatively complete, these programs are not suitable for the management needs of power companies. In particular, the majority of these built-in monitoring applications only work with the manufacturer's server system and it is often difficult to get information from that server system. Therefore, when there is a higher need for monitoring, especially from the perspective of the size of the manager of the power supply system for an entire area or the need to manage multiple PV systems installed and distributed in multiple locations, it will become more difficult. At that time, managers have to use many applications as well as different accounts. Such management methods will become unfeasible as the number of rooftop solar power systems (RSPS) that need to be monitored increases.

Therefore, it is necessary to build a monitoring and data collection system that meets the parameter monitoring of rooftop solar power systems in many places through a monitoring interface based on independent metering devices after grid-connected inverters. The measurement results can directly send data to the server system of the local power company without interfering with the customer's rooftop solar power system. Thereby, operators can monitor the operation of all solar power systems in real time. According to the requirements for monitoring parameters of the solar panel system, the monitoring and data collection system will need to meet some requirements for data collection and extraction to be able to be used for analysis and reporting.

In this study, an IoT-based SCADA system has been implemented to assess the impacts of rooftop solar power supply on the distribution power grid of Ha Tinh Power Company, Vietnam. The research results will evaluate the quality and working efficiency of the IoT-based SCADA system before deploying it in other regions in Vietnam. In addition, local power companies will also improve the efficiency of distribution power grid operation when the density of rooftop solar power projects is increased.

2. System Description

2.1. Principle of operation

Fig. 1. Working principles of the monitoring and data acquisition system

To monitor the transmitting power of each RSPS, the power monitoring devices are proposed to be used for 2 groups of customers using 1-phase and 3-phase inverters. The principle of the data acquisition and monitoring system is shown in Figure 1. These devices will be connected to the output side of the inverter at selected rooftop solar power stations. The data collected has been sent to the cloud server for online monitoring. Finally, the information will be processed, stored, and displayed by the server on the monitoring interface.

Since the monitoring points chosen are mostly household or corporate office buildings, the WiFi network infrastructure is almost available and can be used for connected and operational equipment. In cases where there is already a WiFi network at the installation site, the power monitoring device could be directly connected to the WiFi network as well as configured the device to connect to the server. After completing the configuration, the device will measure and send the measured data to the server automatically and continuously.

In addition, for monitoring points without WiFi network at the installation location or the WiFi network is not secured, an additional fourth-generation (4G) transmitter will be installed to provide the Wifi network for the device and the power monitoring device after being set up will connect to the WiFi network created by the WiFi transmitter. By which, the data will be through the 4G telecommunications network to send data to the online server. Then, the data will be stored, processed, and displayed normally on the monitoring interface.

2.2. Power monitoring equipment

Because the current status of selected monitoring points is scattered at different locations, the monitoring system needs to be designed to be able to collect all operating data of the systems and gather information about a system so that simultaneous monitoring can be performed through a single software interface. Therefore, the system has selected the power monitoring device after the inverter as shown in Figure 2 to monitor information at the output side of the inverter.

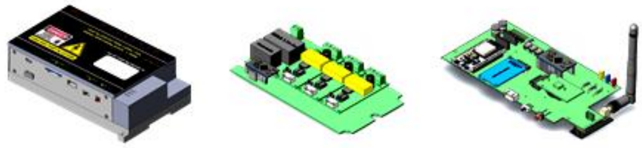
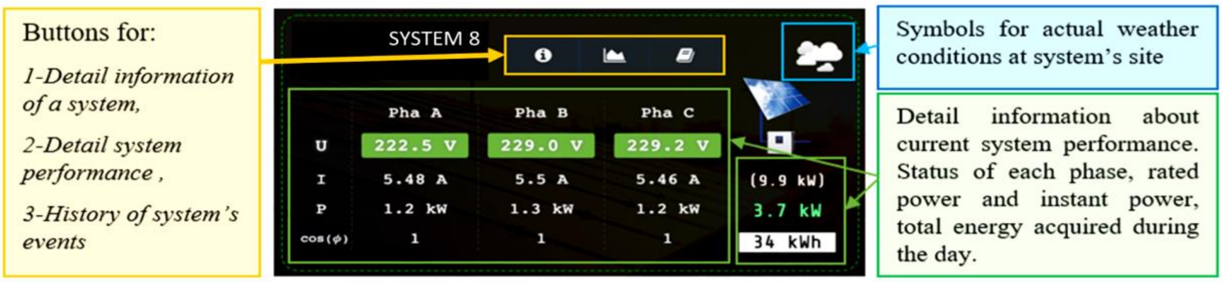


Fig. 2. Power monitoring equipment

2.3. Web server interface



a. Monitoring information for a roof solar power station

b. Monitoring interface of multiple rooftop solar power stations

Fig. 3. General monitoring interface for rooftop solar power systems

Measurement data, and operational parameters (such as voltage, current, and power) of rooftop solar power systems obtained from the installation and deployment of measuring equipment are monitored in real time using the website interface. The management interface for user, monitoring is implemented as a web app (web application on the online platform). In addition, web-based programs are also needed to receive data sent from measuring equipment and store data in the database. The selected web server is the most commonly used web server of NGINX. The immediate operation information of each rooftop solar power system is designed to represent each frame as shown in Figure 3. The information displayed includes:

- Instantaneous value of parameters such as voltage, current, power, and power factor of each phase.

- Rated power and total instantaneous power.

- View detailed information about the system, and look up activity history, and events.

Information of the operation of each system will be updated automatically every minute, making any changes almost instantaneously to the monitoring interface. The actual weather icon in the area is updated automatically every 5 minutes. The weather data source is updated directly from the application programming interface (API) of the Open Weather Map weather data service. This is a service that provides free and reliable weather data and is widely used in many fields with a system of weather stations as well as sites providing data around the world.

Information about the operating status of each system is presented visually. If there is a problem that needs the user's attention, relevant information will be prominently displayed to attract attention as can be seen in Table 1.

Table 1. Voltage's threshold alert

Compared with 220V	≥ 5%:	> 5% and ≤ 10%	> 10%
Color code	Green	Orange	Red

3. Methodology

Figure 4 presents the flowchart of SCADA - IoT system for RSPS. Firstly, the device starts the hardware and connects to the network. The measuring device is selected to measure and monitor the alternating current (AC) parameters in real time in terms of voltage, current, power, and power factor with a sampling time of up to 1 minute. In addition, the device is designed to connect and operate with existing wireless networks such as WiFi or dedicated RF networks. The data collected has been sent to the cloud server for online monitoring. Finally, the information will be processed, stored, and displayed by the server on the monitoring interface.

As a result, the device can be installed and set up simply without changing or affecting the current state of the existing solar panel system. In particular, the device supports popular IoT communication protocols such as Message Queuing Telemetry Transport (MQTT) and the user can set the device to send information to the server. Thanks to the above feature, the SCADA system can actively receive measurement information and store it at the owner's server (or grid management unit such as power companies) without the need to depend on the server of the inverter manufacturer.

The measurement devices will be connected to the output side of the inverter at 15 selected points and connected to the RSPS to measure the operating parameters of the system. After completing the measurement, the device will go through the configured WiFi network to send parameters to the pre-set online server for online monitoring. Finally, the information will be processed, stored, and displayed by the server on the monitoring interface.

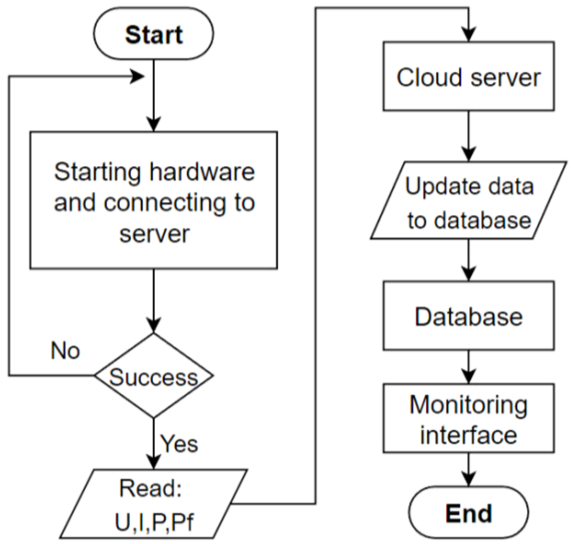


Fig. 4. Flowchart of SCADA - IoT system

4. Actual Measurement Equipment System at Rooftop Solar Power Stations

The distribution power grid of the experimental research area is managed by Ha Tinh Power Company. The measurement of the generation capacity of solar power systems helps to provide important data in analyzing the impact of the RSPS on the utility grid. Therefore, the project monitors rooftop solar power systems on low-voltage power grids with criteria such as RSPS connect low-voltage, centralized, and belong to a low-voltage substation; the need to loads such as residential home or mixed load objects.

In Figure 5, energy monitoring systems were selected to be deployed in 15 rooftop solar power systems near each other in the center of Ha Tinh city to meet the above criteria, and also to facilitate the deployment, installation, and operation management.

In addition, the deployment of energy monitoring systems for solar power systems must also meet requirements such as the deployment of installation in areas where Internet via WiFi or 4G network coverage is required, the deployment of installation should be fast, without affecting the current state of the customer's home electrical system.

Fig. 5. Installation locations of the energy monitoring system for rooftop solar power systems in Ha Tinh city

After evaluating based on technical criteria and cooperation capabilities of customers, the measurement devices are installed in 15 rooftop solar power systems with designed capacity from 3.47 kWp to 43 kWp in Bac Ha, Tran Phu, and Tan Giang wards of Ha Tinh city. Information about 15 RSPS systems is listed in Table 2.

Table 2. List of 15 selected rooftop solar power systems

Rooftop Solar Power Station	Capacity (kWp)	Inverter
1	9.48	2x5kW/ 1 phase
2	10	10kW/ 3phase
3	5.34	5kW/ 1 phase
4	5.22	5kW/3phase
5	16.8	15kW/ 3phase
6	3.47	3kW/1 phase
7	12.18	2x5kW/ 1 phase
8	9.9	10kW/ 3phase
9	10.44	10kW/ 1phase
10	4.89	5kW/ 1 phase
11	12.18	10kW/ 3phase
12	7.8	8 kW/ 1 phase
13	10.68	10kW/ 3phase
14	43	40kW/3 phase
15	40.5	50kW/3 phase

According to technical requirements, the installation of monitoring devices in Figure 6 does not interfere with the current status of the rooftop solar power system. The power shut-off only takes place for a short time to help ensure safety in operation and not interrupt the electricity use of families, ensuring the specifications of measurement equipment.

a. Inverter 1 phase   b. 3 phase inverter

Fig. 6. Installation of energy monitoring equipment for rooftop solar power system using 1-phase Inverter (a) and 3 phase Inverter (b)

5. Experimental Study Result

The users can monitor the operation of all rooftop solar power systems with the help of online parameters of the software interface. The parameters help users understand the current parameters of the systems including voltage, current, and power parameters.

a. 1-phase grid-tied inverter

The rooftop solar power system No. 6 was selected as a typical case to evaluate the operation of a 1-phase grid-tied inverter. Figure 7 shows that the rooftop solar power system starts with electricity output from 7 am and stops at 6 pm with a total daily output of about 14 kWh, and the output power of the inverter is nearly 2500 W.

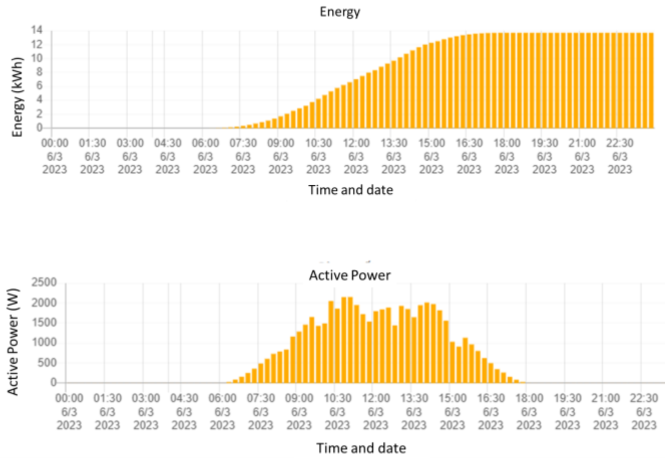


Fig. 7. Power output and capacity of rooftop solar power system No. 6

In Figure 8, the SCADA - IoT systems have started to monitor and record electricity output since 1/11/2021. The total recorded electricity output has reached nearly 6300 kWh. The yield curve also exhibited a steep slope between March 2021 and October 2021, coinciding with a period of large amounts of solar radiation.

In Figure 9, the inverter output voltage of rooftop solar power system No. 6 ranges from 234-250 V, which is a high voltage level compared to the dynamic voltage at the load (exceeding 5%). A voltage level higher than the nominal voltage level can affect household appliances that use electricity if the device is directly used in the output of the inverter. The voltage must be large enough to generate solar power capacity to the utility grid, but the voltage level has exceeded the specified voltage threshold for the load, so the monitoring system has also recorded and warned on the system.

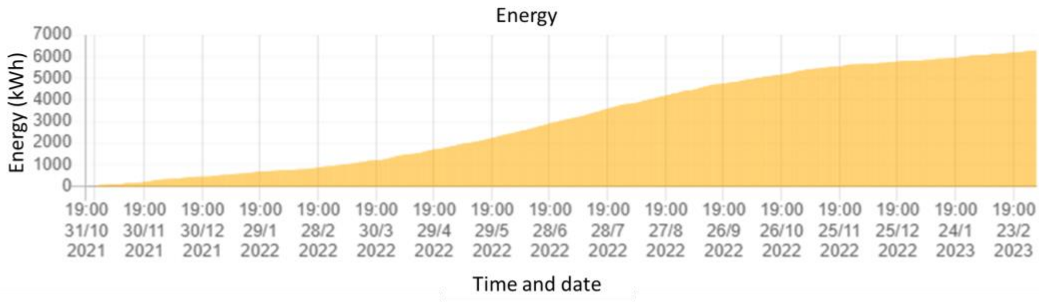


Fig. 8. Total energy output of the RSPS from November 2021 to February 2023

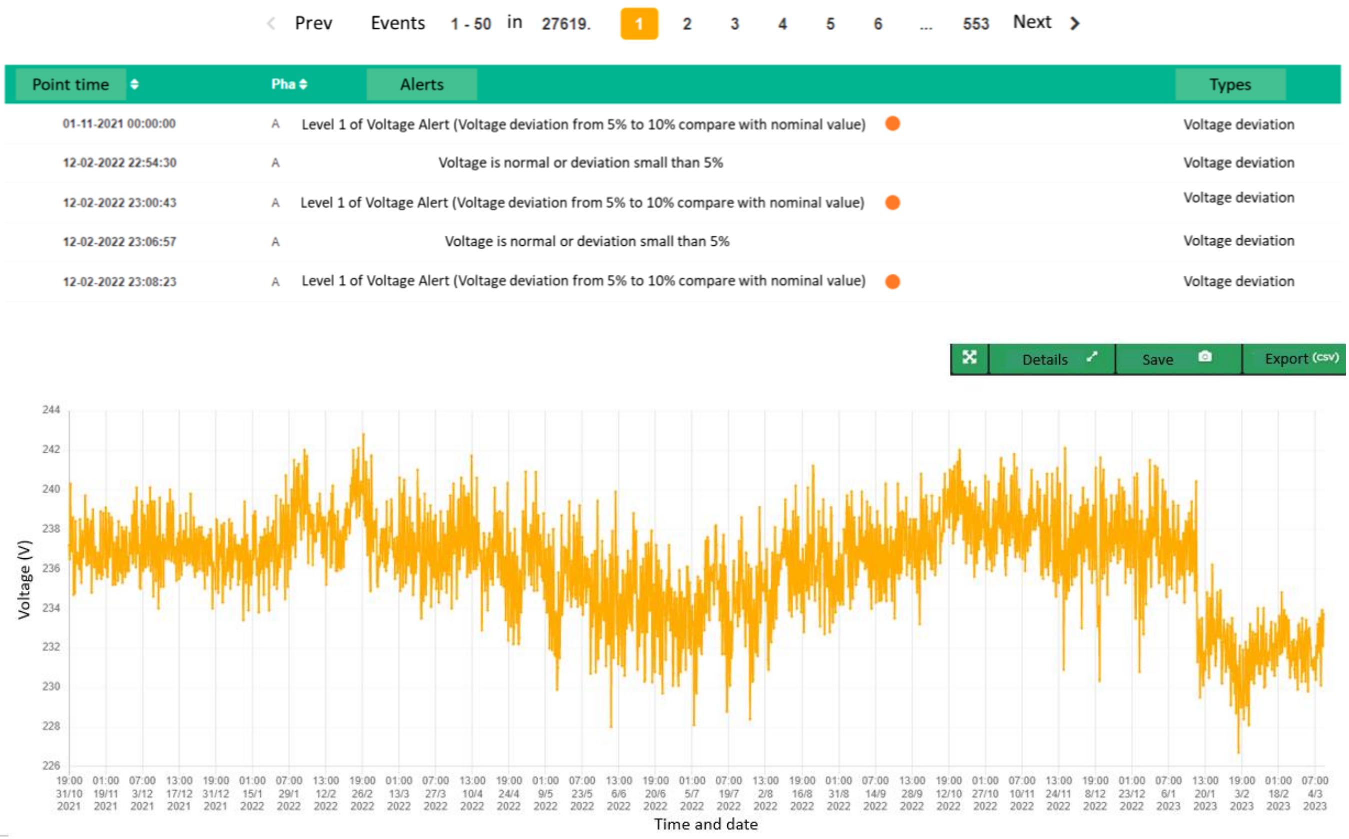


Fig. 9. Inverter output voltage and high voltage alarm of rooftop solar power system No. 6

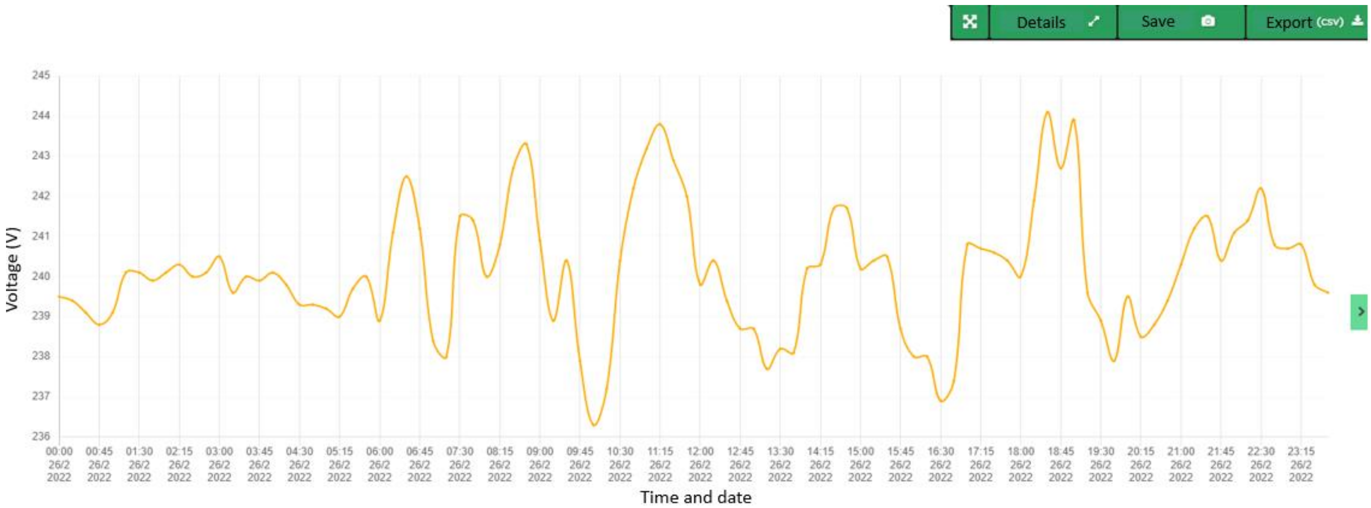


Fig. 10. Inverter output voltage and high voltage warning of rooftop solar power system No. 6

Figure 10 shows the inverter output voltage and high voltage warning of rooftop solar power system No. 6 dated 26/2/2022. The power system has a fairly high voltage level when fluctuating between 236 V - 245 V. Typically, the voltage level jumps to approach 245 V at times at 11:15 and 18:45 during the day. Thus, devices can be damaged if they are directly supplied by the power supply.

b. 3-phase grid-tied inverter

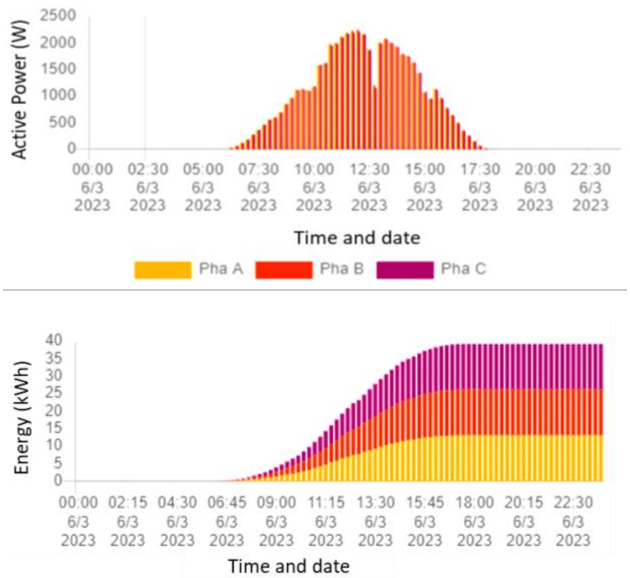


Fig. 11. Power capacity and output of rooftop solar power system No. 11

RSPS No. 11 was selected as a typical case to evaluate the 3-phase grid-tied inverter operation as shown in Figure 11. This is a 3-phase rooftop solar panel system with a total capacity of 12.18 kWp. The monitoring system records the power time and outputs the power output of the system between 06:45 and 18:00. However, the power output of the system is different when the total electricity output for the day is nearly 40 kWh with an average of about 13 kWh per phase. The maximum output power of each phase increases by nearly 2500 W at midday when the intensity of sunshine is the highest value.

In Figure 12, the total output of the RSPS was analyzed since the start of monitoring on 1/11/2021. The system recorded that the total output of the system reached 13974.27 kWh, corresponding to each phase with an output of about 4600 kWh. The line also shows a steep slope around April to September that coincides with summer time and has a large amount of solar radiation.

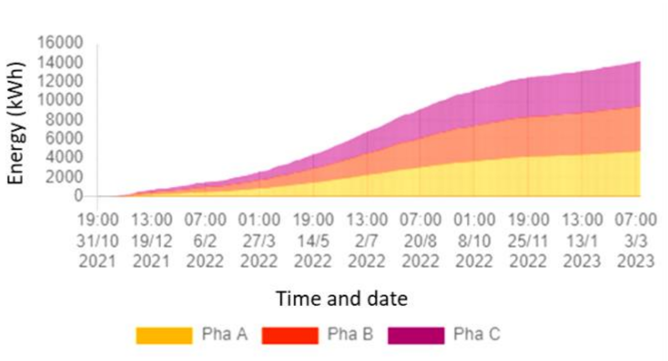


Fig. 12. Total output of the RSPS from November 2021 to March 2023

In terms of power quality, the system records quite a lot of events related to system overvoltage, these overvoltage events are occurring in all 3 phases as can be seen in Figure 13. However, due to the requirement to generate electricity for the power grid, so the voltage part of the system must be brought up. The voltage of the whole system usually fluctuates at around 230 V - 238 V, but it drops to around 224 V - 226 V in short periods.

In Figure 14, it can be seen that the voltage remained stable within the allowable threshold from 0:00 until about 11:00 on the same day and then it began to show signs of jumping to 235 V, where the prescribed overvoltage threshold was exceeded.

Prev Events 1 - 50 in 136804. 1 2 3 4 5 6 ... 2737 Next

Point time	Pha	Alerts	Types
01-11-2021 00:00:00	A	Voltage is normal or deviation small than 5%	Voltage deviation
01-11-2021 00:00:00	B	Voltage is normal or deviation small than 5%	Voltage deviation
01-11-2021 00:00:00	C	Voltage is normal or deviation small than 5%	Voltage deviation
12-02-2022 22:50:14	A	Level 1 of Voltage Alert (Voltage deviation from 5% to 10% compare with nominal value)	Voltage deviation
12-02-2022 22:51:07	A	Voltage is normal or deviation small than 5%	Voltage deviation

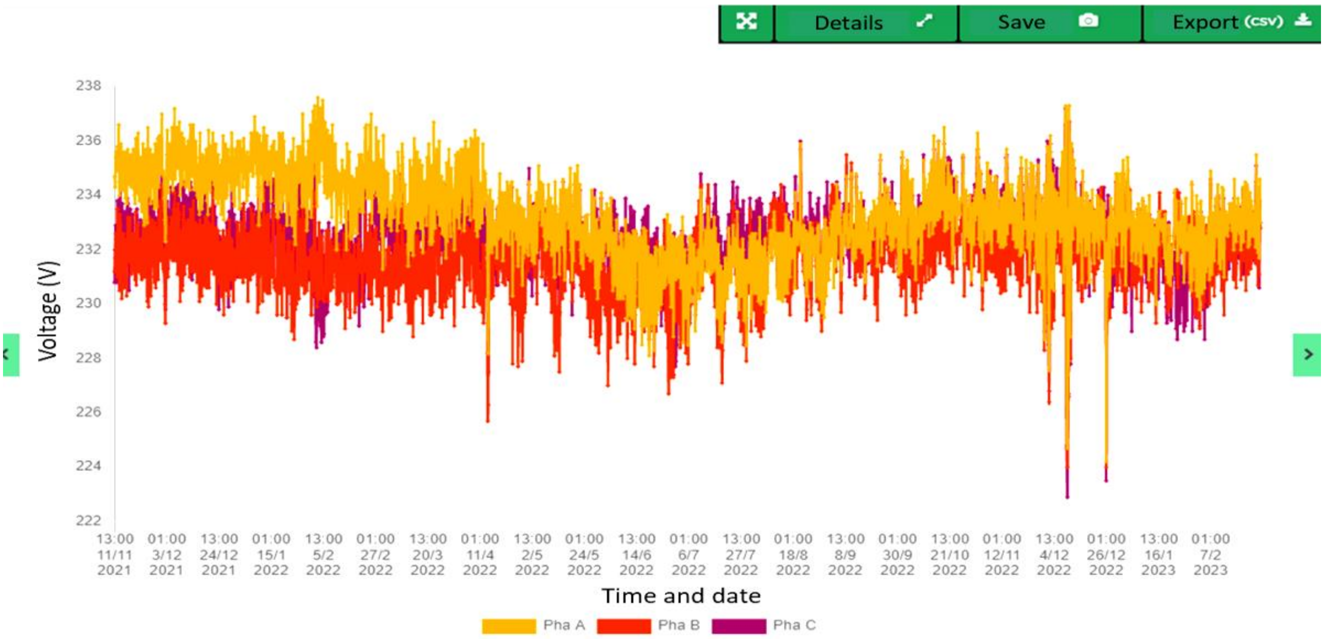


Fig. 13. Inverter output voltage and high voltage alarm of rooftop solar power system No. 11

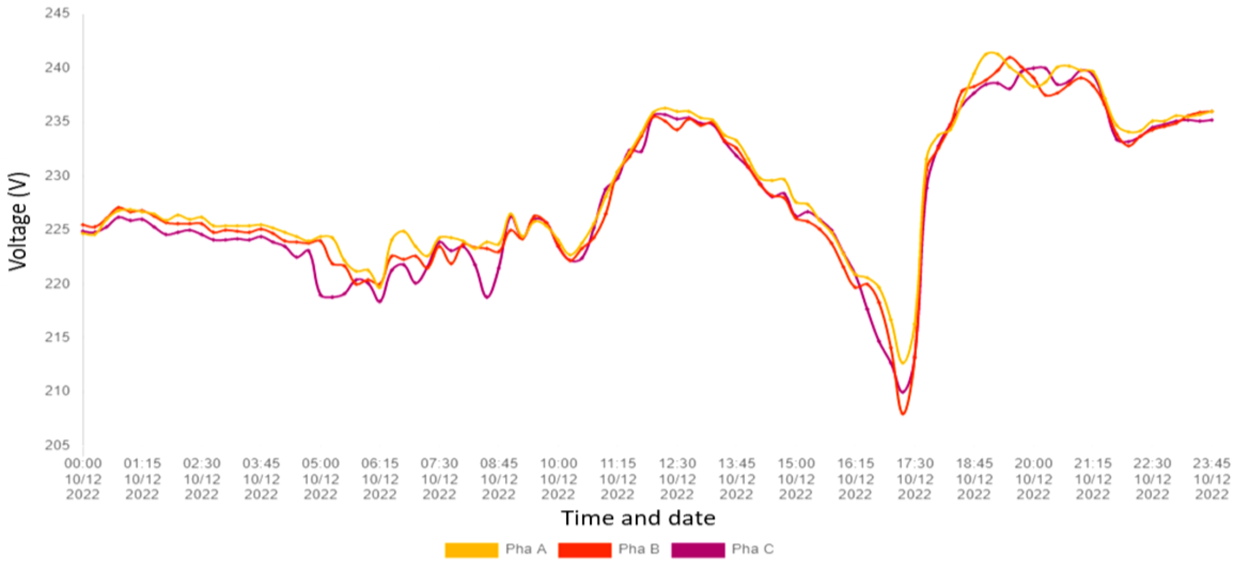


Fig. 14. Inverter output voltage and high voltage warning of rooftop solar power system No. 11 dated 26/2/2022

However, the voltage of the system dropped to nearly 205 V by about 17:30, which is also a value that exceeds the prescribed low voltage threshold. However, the voltage continues to jump to nearly 245 V, this is a very high voltage threshold and there is a risk of damage to electrical equipment if connected directly to the equipment.

The test operation results of the SCADA - IoT system present that the system operates stably, data is sent to the server fully and there are no signs of loss. The data obtained shows that the measurement information is accurate and true to reality, showing the characteristics and operation of the system. Thus, the monitoring and data collection system is ready to be put into operation and collect data to serve the management and supervision of the distribution power grid of the power company in Ha Tinh city.

c. Problems arising during operation

During the operation of the SCADA - IoT system of RSPS stations, there are some problems arise in the collection of affected data because of the connection with the available network infrastructure at the installation site, including WiFi network infrastructure available at home or 4G telecommunications network through WiFi transmitter. Some specific cases are as follows:

- RSPS No. 4: This is a typical system for deploying monitoring equipment and using additional Wifi broadcasting modules with data from 4G telecommunications infrastructure. During the monitoring period from 1/12/2021 to 31/12/2021, the system lost data on 17/12/2021 and 25/12/2021. This data was lost because of instability in 4G network waves in the region, affecting the information sent to the server.

- RSPS No. 8: The typical system using the available Wifi network at the construction site for the connection to the server system. Similarly, during the monitoring period from 1/12/2021 to 31/12/2021, the system recorded 4 times that data loss on 5/12/2021, 9/12/2021, and 13/12/2021. This is the time when the WiFi network infrastructure of the building also encounters transmission problems, leading to data not being updated in the system.

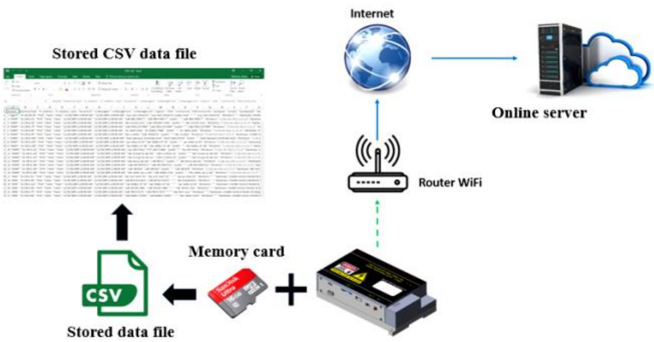


Fig. 15. A hybrid solution between sending data to the server and storing it on-site

Based on the current status of problems in data collection due to instability, some solutions are proposed to overcome the above error problems. Figure 15 presents the tentative principle for the proposed solution to overcome the problem of unstable connection of the system. Monitoring devices are supplemented with a memory card, along with sending data to the server. Data will be synthesized and stored in the memory card in real time. This data is stored in a standard format file such as comma-separated values (CSV). When data loss occurs in the system, the data file in the memory card can be retrieved and operators can use directly or put it into the database on the system to use for more in-depth analysis purposes.

6. Conclusion

In this paper, the SCADA - IoT system has been proposed to monitor the operation of RSPS in a distribution power grid in Ha Tinh city, Vietnam. The measurement devices were installed in 15 RSPS systems of Ha Tinh city power grid, including both 1-phase and 3-phase with the capacity from 5 kWp to 30 kWp. The experimental research results show that the system operates stably, data is sent to the server fully and there are no signs of loss. The data obtained shows that the measurement information is accurate and true to reality, showing the characteristics and operation of the system. Thus, the SCADA - IoT system is ready to be put into operation and collect data to serve other works of the power company.

Acknowledgments

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