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Monitoring System for a Hybrid Photovoltaic-Diesel Power System: Web-Based SCADA Approach

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Abstract— This paper presents a low-cost open-source web-based SCADA monitoring system that will provide a new application of real-time instrumentation for monitoring a hybrid photovoltaic-diesel power system. The system's purpose is to monitor parameters such as the voltage and current of the AC and DC buses. A cheap Arduino acquisition board is the foundation for the system design, as documentation of the board is widely available. Data are displayed through a local host Node-Red and web real-time database system, and the acquisition is accomplished using a reasonably priced current and voltage sensors. To improve the stability and operability of the newly constructed monitoring system, a secure and cost-effective internet connection has been created between external clients and the primary network webserver. Amazon web server is configured to allow access to remote clients when credentials and certificates are verified. The proposed system shows its ability to acquire real-time data by monitoring the hybrid system and storing the data in the client database for future access. Since the proposed system is less costly and time-consuming, and can assimilate and record data more easily, it can readily replace human intervention to avoid errors associated with multimeters' readings. Eventually, analyzing such data, will lead to enhance both the performance and operational efficiency of the monitored hybrid power system.

Keywords— Renewable energy; Hybrid photovoltaic-diesel power system; SCADA system; Arduino Uno; Node-Red.

1. INTRODUCTION

The proper management of energy systems includes process modeling, process optimization, hardware and software configuration, suitable setup design, and monitoring operation. New energy strategy development is a common topic of scientific and industrial research. The complexity of energy system modeling increases when many variables are involved. The key to reaching this goal is scaling the model to provide an appropriate framework for measurements and simulation related to the effective energy situation.

Renewable sources are crucial in economic and political initiatives for a nation's energy independence. Biomethane/biogas, solar, wind, wave, geothermal, hydrogen, thermoelectric, and hydroelectric power plants have recorded significant technological advancements. Energy harvesting from alternative and widely available sources is a significant developing study area. The complete integration of renewable energy sources into sophisticated grid systems considers the deployment of sensor and storage systems and the potential to use cutting-edge data processing methodologies; because of this, many conventional instruments, including multimeters, are employed in this situation [1].

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However, when the environment is rapidly changing, it might be challenging for humans to read these devices accurately [2]. Because only a small number of samples can be collected, the features that may be manually measured and traced do not adequately describe the system's status. Oscilloscopes that can capture data using USB communication exist, but they are more expensive and not readily available to most researchers [2]. Therefore, an earlier research paper explored hybrid power systems based on PV solar panels and diesel power generation systems [3], where this paper aims to develop an experimental low-cost open-source SCADA monitoring system for a remote hybrid power system developed in the earlier paper.

2. LITERATURE REVIEW

Photovoltaic systems are becoming increasingly popular around the world. According to previous research, establishing these energy systems maximizes solar energy while lowering installation costs [4]. A rooftop solar system that is connected to a grid was optimized for a university campus in Australia by Mokhtar et al. [5]. ArcGIS, Homer optimizer, and Ecotec software were used in the project to increase energy production and reduce energy costs (COE). The PV panel installation can be installed in 60 percent of the roof space of the building, according to the experiment's results [5]. Various economic aspects, including component costs, were assessed through a sensitivity analysis. Solar systems for buildings have been the subject of several studies.

Furthermore, PV panels installation system for different roof types was explored by Asif and Ghaleb [6]. The study aimed to identify several difficulties inhibiting PV system installation. A utilization factor, as well as regression analysis, was offered to range the various buildings. The data shows structures with outstanding qualities for PV system installation [6]. The structure of traditional energy resources has been transformed and changed due to the widespread usage of renewable energy sources. Supervisory control and data acquisition system (SCADA) has been implemented to automate power system substations and recently gained attention from electric utilities.

Moreover, industrial enterprises need SCADA systems because they process data to make better choices, maintain efficiency, and notify system problems to minimize downtime. The SCADA software processes distribute and displays data to evaluate the information and make critical choices [7]. Furthermore, there are four primary roles for a SCADA system which are the following: network data communication, data acquisition, presentation of data, and finally, system control [7].

In research published in 2009, Hu Guozhen and Cai Tao described the central SCADA system component utilized in PV-generating facilities [8]. This study offered a security access control approach and a redundancy mechanism as two valuable techniques to enhance the security and dependability of the SCADA system in PV facilities. Role-based access control, data encryption, and security authentication were all included in the proposed security access control approach. These procedures helped fix communication security issues between the configuration server for SCADA and remote terminal units [8].

Moreover, in a report published in 2011, Palma-Behnke and Ortiz suggested a hybrid solution that combined a social SCADA method with demand response software. Consequently, there were lower maintenance expenses and better coverage [9]. A social

SCADA solution ensured the community's engagement through effective communication and information sharing. It allowed them to carry out responsibilities related to the surveillance and maintenance of the microgrid as well as the repair of various pieces of equipment [9].

Furthermore, a study case prepared using IEEE 34 node test feeder by Rangel-Damian and Vazquez in 2017 demonstrated how information from electrical equipment, such as voltage and current measurements, could be incorporated into an impedance-based algorithm for fault location, which led to improved performance when we took into account equipment along the feeder's mainline as well as at the substation [10]. Moreover, Georgescu published a paper in 2014 that categorized SCADA software as the cornerstone for establishing a solar park dispatch center [11]. Drivers for electrical operators and an industrial database that could be used for data collection were two technologies used in developing SCADA software.

Using operational data from PV plants obtained from the supervisory control and data collection systems, Dong and Kang released a paper in 2017 outlining problem diagnostic and classification methodologies (SCADA) [12]. The suggested remedy specifically included three methods, which were as follows:

a) A new statistical method for fault identification.
b) A fault isolation method-based corrective performance ratio (CPR).
c) A method for classifying and analyzing fault recoverability based on the anomaly degree index (ADI).

The year 2017 saw the presentation of a context-aware and cost-effective technique by Liu and Shang for identifying string-level anomalies in large-scale PV systems [13]. The proposed approach was based on unsupervised machine learning techniques and did not require any extra hardware support beyond the commonly used data acquisition and supervisory control (SCADA) systems. Moreover, a paper by Hilal and Nangim from 2017 was given in which the development and design of SCADA infrastructure, as well as an analysis of SCADA network security vulnerabilities, were carried out [14]. The results of this study demonstrate how programmable logic controllers (PLCs) and human-machine interfaces (HMIs) can be attacked and solidified by using Kali Linux. SCADA systems were vulnerable to malware threats and attacks because of the penetration testing, which crashed because of high traffic on a dense network. Several recommendations and security measures are provided in this study

The results of a test campaign to obtain coupling paths into a lab configuration of a power grid substation SCADA electronic system were published by Lanzrath and Pusch in 2017 [15]. Using a transverse electromagnetic (TEM) waveguide and a close-range TEM horn antenna, the devices were put to the test for hazards using a bulk current injection (BCI) configuration [14].

3. METHODOLOGY

The previous paper explored and simulated different configurations and sizing of hybrid power systems to determine the most efficient power system to feed a local remote area in Newfoundland. The results show that a daily average power load of 1632 kWh would require a total number of 1077 solar panels to provide a total of 381 kW, while the rest of the load would be provided by a 250-kW diesel generator to satisfy the load demand, which can be viewed in details in the previous paper as mentioned in the introduction section [3]. Moreover, this paper presents the idea and includes only a demonstration of the proof of concept on the application and integration of different systems into a whole SCADA system.

To proceed with this study, the monitoring system would be implemented by measuring the DC line of the circuit powered by a battery and the AC system power supply, which in theory, should measure the lines of the previously proposed power system. Arduino UNO would be used to form a connection between the voltage and current sensors and the Node-Red server on the computer to measure the current and the voltage. As the sensors will take readings from the PV panels, the readings will be direct current (DC) and alternative current (AC). This is done to monitor the power outcome of the previous hybrid power system, including PV solar panels, which provide DC power, and a Diesel generator, which provides AC power. The Arduino connects to the Node-Red and is implemented through the serial port COM4 port. The processed real-time data is then displayed through the Node-Red local dashboard and posted to a web server that can be accessed remotely. Fig. 1 below shows a detailed block diagram of the proposed SCADA system.

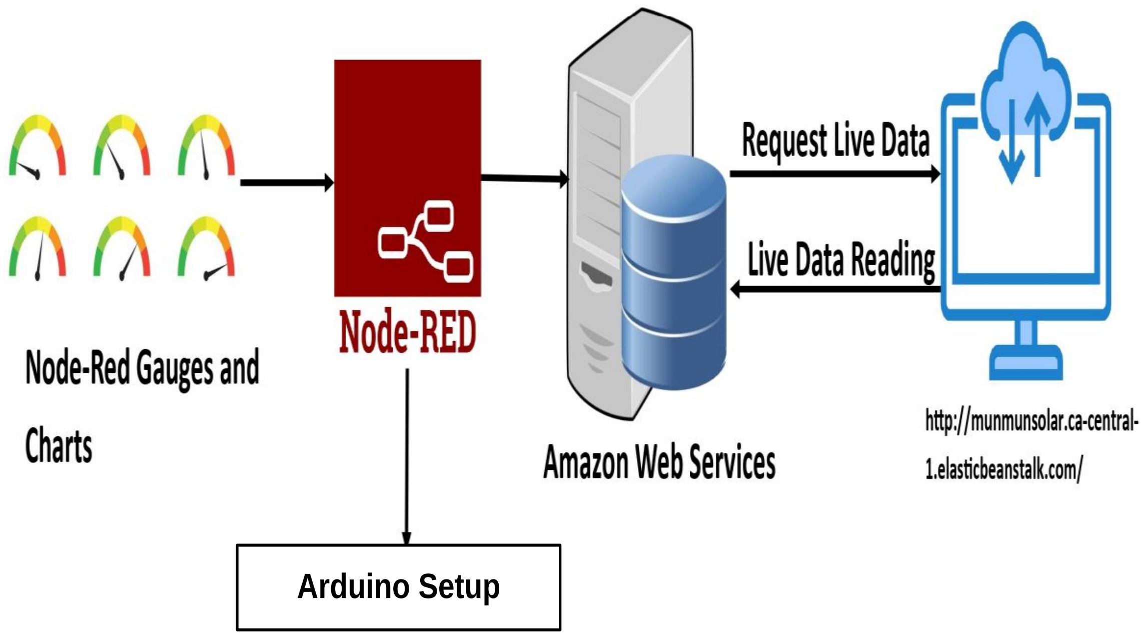

Fig. 1. Block diagram of the SCADA web system.

To test the system, the SCADA system would be tested on a DC source and the AC source with different resistors to control the current outcome and to test the accuracy of the reading of the Node-Red monitoring system.

3.1. Arduino Setup

Arduino Uno is the embedded board that is used in this research. ATMega328 is the integrated microcontroller in the Arduino, which is programmed through the Arduino IDE software. The Arduino can be powered through a USB connection with a computer. The board provides 5 V, ground pin output, six analog inputs, and 14 digital inputs/outputs pins, as seen in Fig. 2.

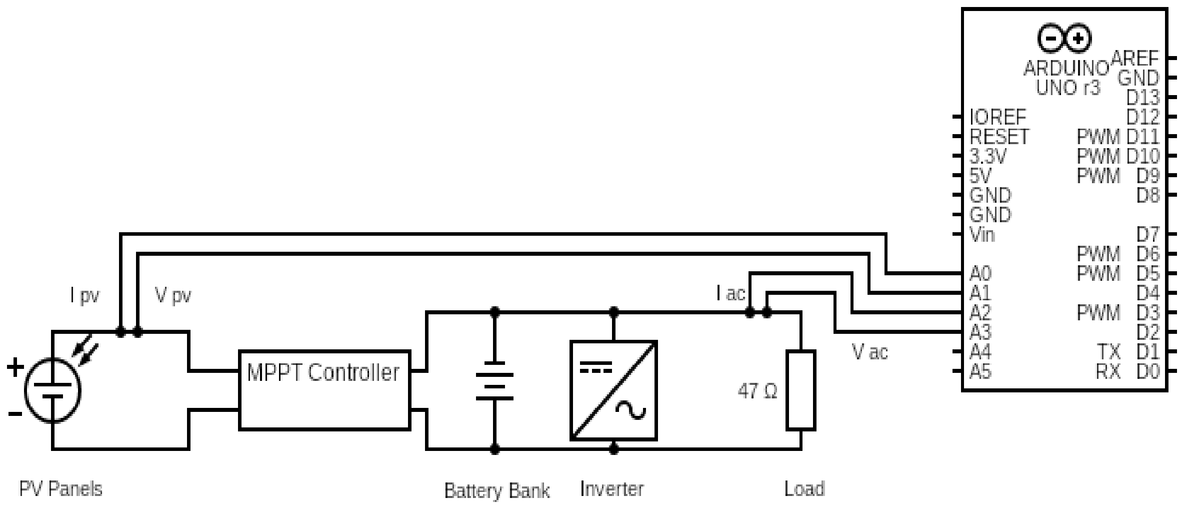

Fig. 2. Arduino connection layout.

In the test setup, the DC voltage sensor module can measure voltage up to 25 V. However, the Arduino can only measure up to 5 V. ADC of Arduino receives the voltage sensor's output, which is parallel-connected with the load. ADCs generate digital values (Vout1) that range from 0 to 1023 by converting the latter to 10 bits. This voltage sensor module measures 0.02445 V (0.00489 V5) at the minimum input voltage, and it measures analog voltage with a resolution of 0.025 V; Therefore, 0.00489 V (5V/1023). The voltage ratio of the divider is utilized to determine the actual voltage because of the voltage range of the sensor module. On the other hand, the AC voltage sensor has a mini transformer that reads peak-to-peak voltage value and then transforms it to RMS value. A photo of the basic setup is shown in Fig. 3.

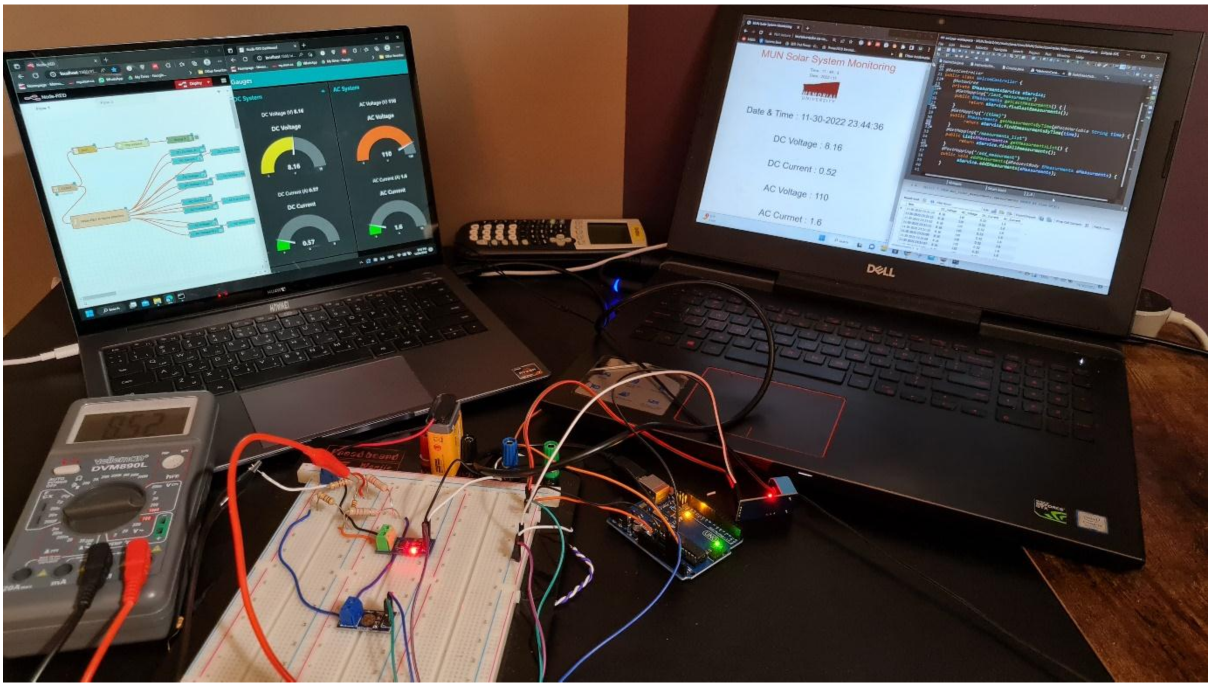

Fig. 3. Basic test setup.

With a precise linear Hall sensor circuit and a copper conduction channel near the die surface, the current sensors provide low-offset measurements. This copper conduction path creates a magnetic field when an applied current passes through it. A Hall IC senses this magnetic field and converts it into a proportional voltage, which Arduino can process. The block diagram for the Arduino code can be seen in Fig. 4.

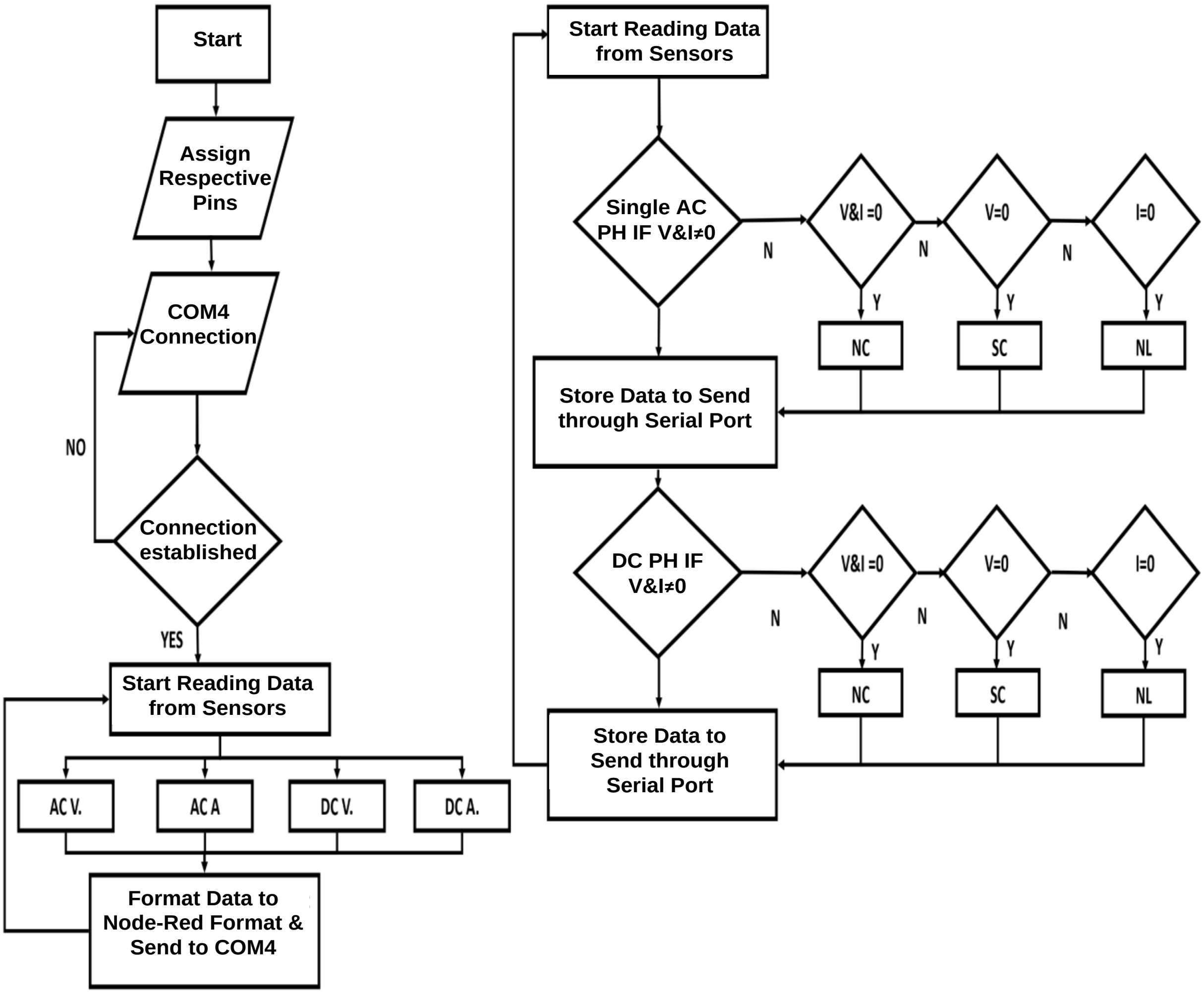

Fig. 4. Block diagram for the Arduino code.

3.2. Node-Red

Node-Red is a Node.js based open-source flow-based tool, IoT platform, and dashboard created by IBM. Arduino is coded to form a delay between each reading with an interval of 5 ms. Furthermore, the Arduino's payload is a string to display the data in Node-Red dashboard. Therefore, the string was divided through Javascript to display the signal into four different data in four gauges corresponding to the DC voltage, DC current, AC voltage, and finally, AC current.

Furthermore, the diagram for the configuration and the setup of Node-Red can be seen in Fig. 5. The connection between Node-Red and Arduino is configured through serial port input data, which then is connected to a function that splits the incoming data from the Arduino to show the current and voltage through 4 independent outputs.

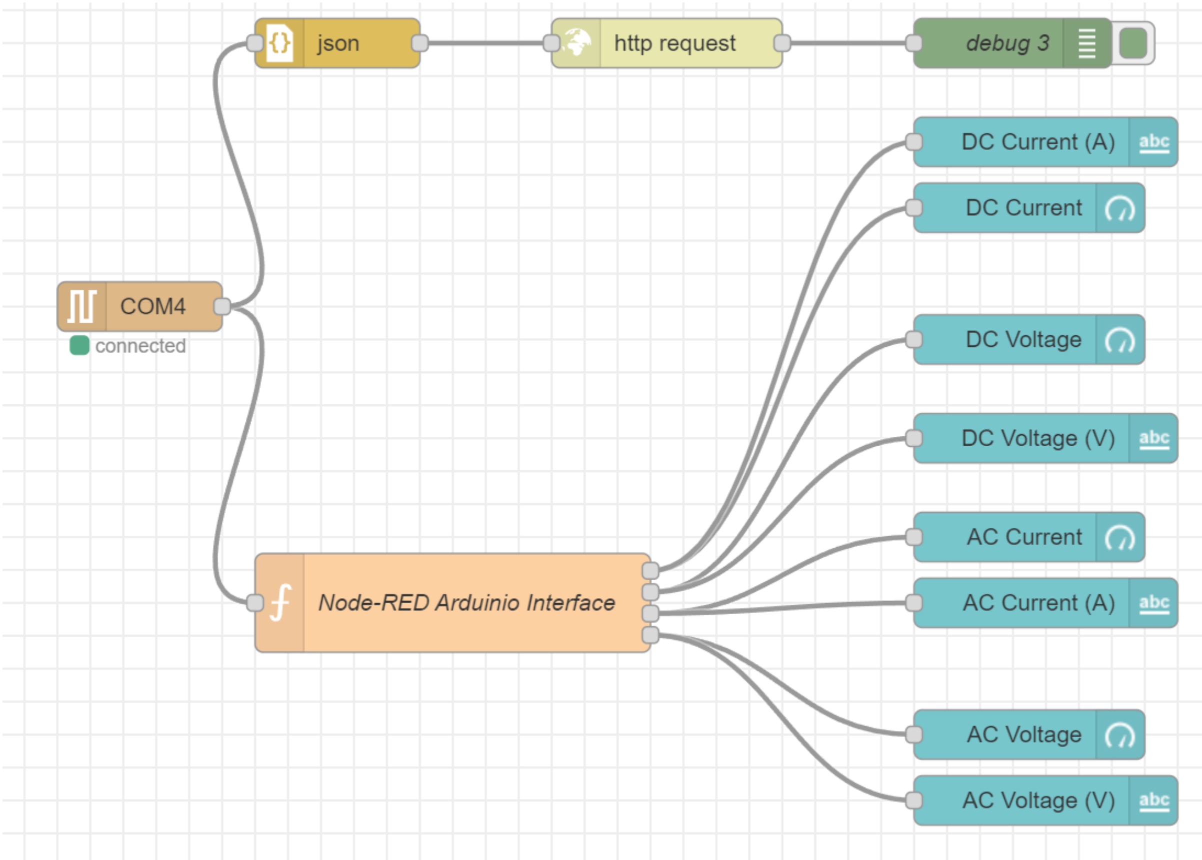

Fig. 5. Node-Red flow layout.

The serial port input data is also connected to a JSON block that is used to convert the payload string to a JSON object. The JSON object is then sent to the web server by an HTTP POST request to be displayed immediately on the website as a live monitoring system.

3.3. Website Technology Stack

The website was created using Spring boot in the backend, which adds many powerful features to the website, such as security, in addition to the RESTful services with hibernate connected to MySQL database and a simple frontend using Thymeleaf and JavaScript. The website was deployed by amazon web services (AWS).

Spring Security is a strong and highly configurable framework for access control and authentication. It is the best standard for securing Spring-based applications. Spring Security offers a password encoding feature. It is a one-way transformation. Thus, the password can only be encrypted; it cannot be decrypted to return to its original plaintext form. Also, Spring Security offers different giving roles to the users, and then, it can limit some website features to specific roles, for example, reaching some endpoints or different HTTP requests. On the website, there are two prominent roles [STUDENT, PROFESSOR], and it is required to have an account with any role to have access to the live measurements, but there are some limitations for the student's accounts which is the default role for all the new users, for example limiting the HTTP POST requests and the access to the measurement's full history page to any account with PROFESSOR role only.

All The endpoints of the website are controlled by Security and REST controllers, which call the service layer, and then the service layer calls the data access object (DAO) layer to connect to the MySQL database, then it can create, read, update, or remove any data from the database, the backend flow architecture is shown in Fig. 6.

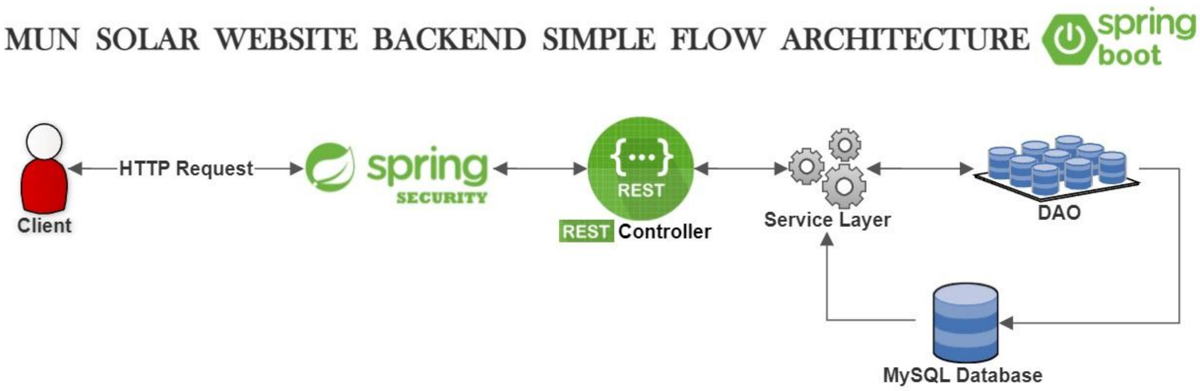

Fig. 6. Block diagram of the web-based monitoring system.

The Rest controller can get the measurements from an HTTP POST request as a JSON object. Then, it converts the JSON object into measurements object that can be saved to the MySQL database by hibernate. Also, it can retrieve any measurements object from the database by hibernate, then, it converts the measurement object into a JSON object to be returned to an endpoint as needed to be accessible by the HTTP GET requests. The MySQL database UML (Unified Modeling Language) diagram is shown in Fig. 7.

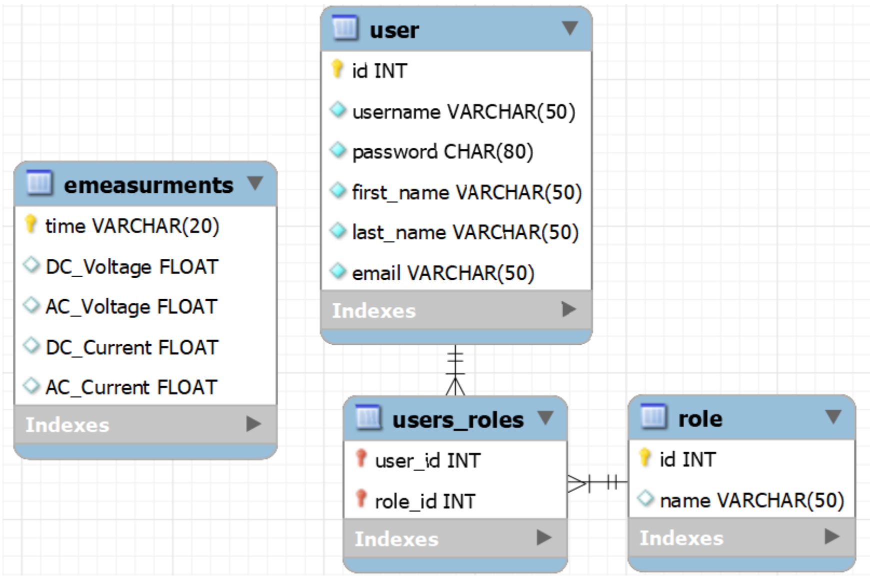

Fig. 7. MySQL database diagram.

4. RESULTS AND DISCUSSION

The local host monitoring system gauges show that the reading from the Arduino sensors occurs on an average of 1-second intervals. The results show that the data were displayed in real-time, which is the actual goal of the project. Furthermore, voltage and current are presented on the SCADA screens, as seen in Fig. 8, for November 19, 2022. The figure displays time in relation to DC and AC voltage. Additionally, the variation of DC and AC currents over time is shown in Fig. 9.

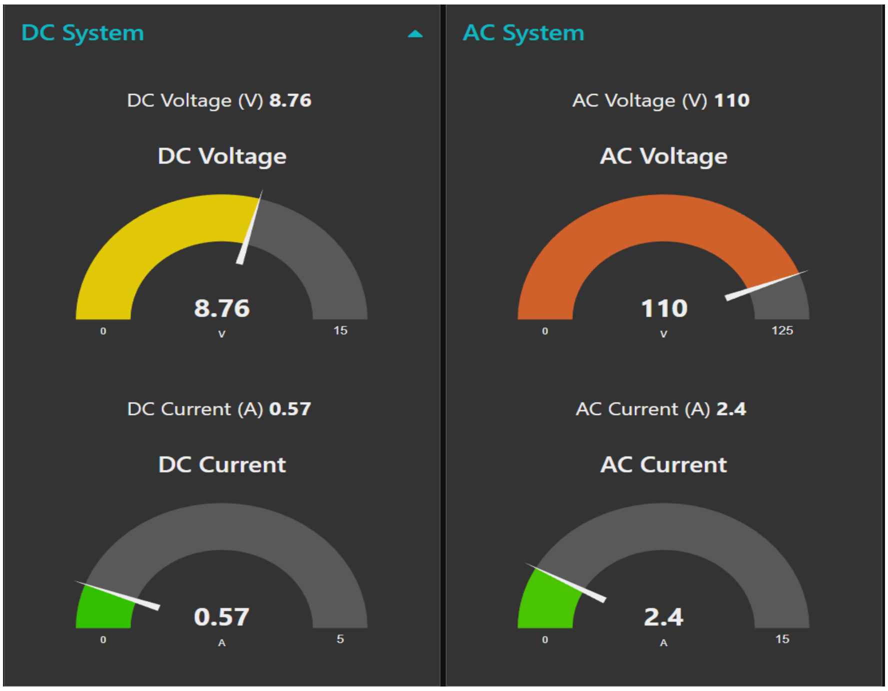

Fig. 8. Node-Red monitoring gauges.

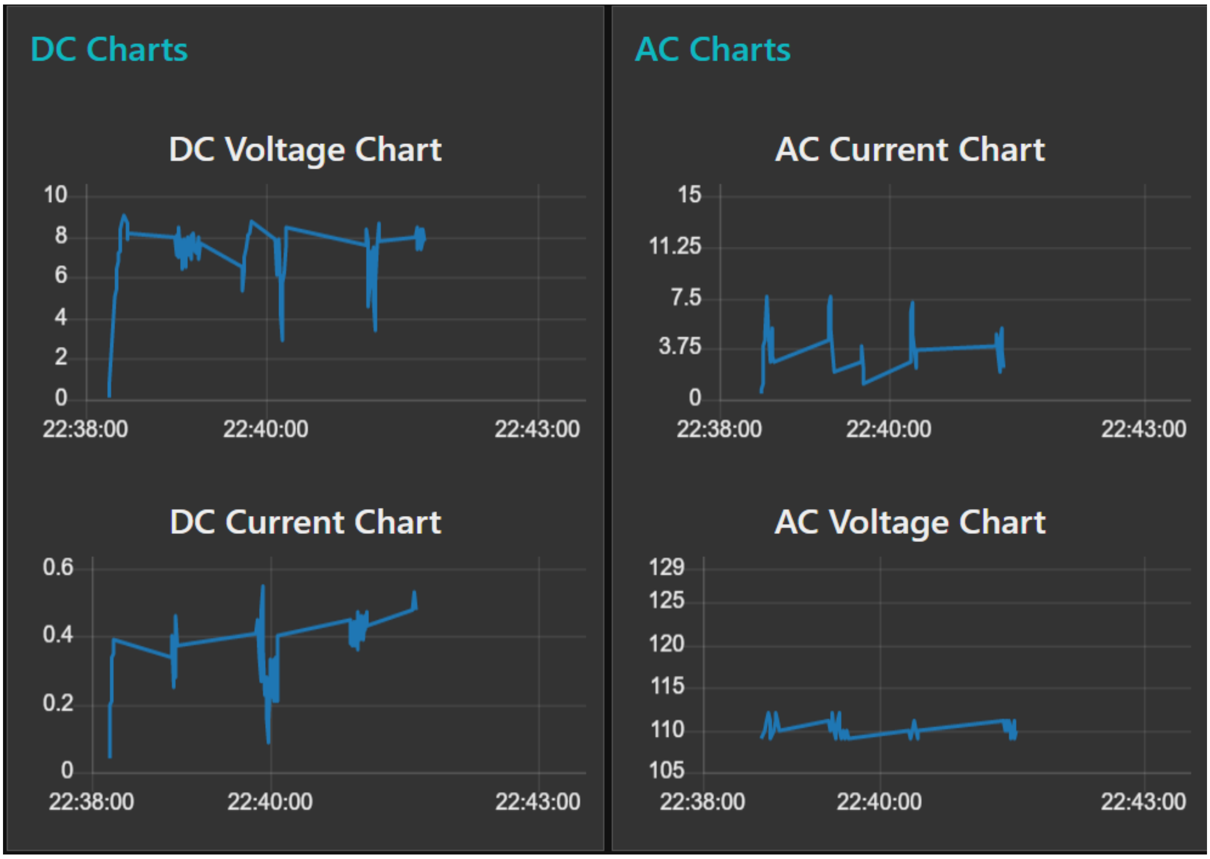

Fig. 9. Node-Red monitoring chart.

Now moving on to the web-based server approach, it can be seen in Fig. 10 that the web-based system has a login page that can only be accessed through the verified account credentials approved by the system administrators. Furthermore, different account types have different access to the monitoring system, such as accessing the system's database.

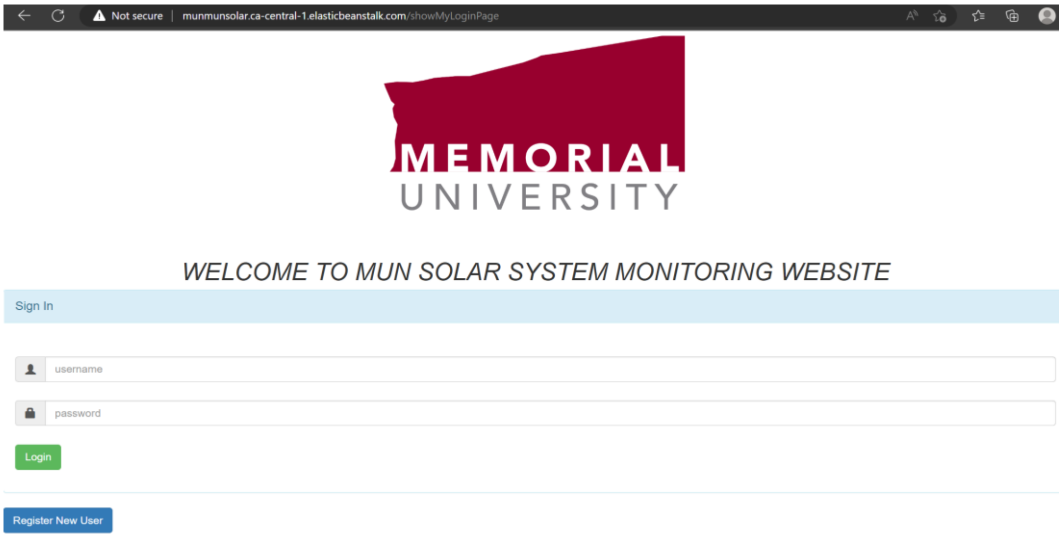

Fig. 10. Login page of the Web-based SCADA system.

Furthermore, the web-based system will show the values of the Arduino measurements in real time, as seen in Fig. 11. It can be seen that the DC voltage and current are 8.76 V and 9.57 A, respectively, while the AC voltage and current are 110 V and 2.4 A, respectively, which corresponds to the data shown in the local host gauges of the Node-Red dashboard in Fig. 8.

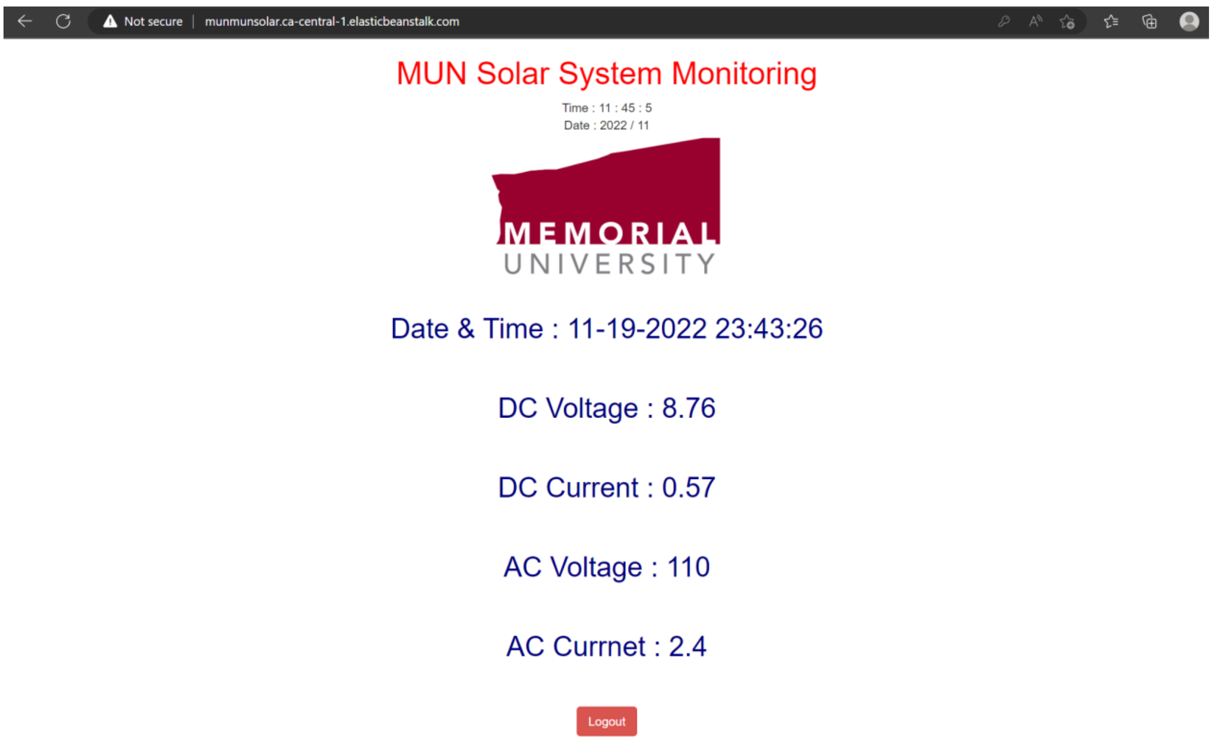

Fig. 11. Web-based SCADA real-time monitoring.

As mentioned previously, different account types have different authorities on the system. For example, Professor has the highest authority in the system; therefore, he has access to the stored measurements in the system's database. The system's database, as seen in Fig. 12, shows the measurements saved for every second the system is online. The database can be accessed by adding measurement lists in the URL. A lower-level authority account would not be able to access the database list of the system as it will be taken to a web page displaying an invalid service.

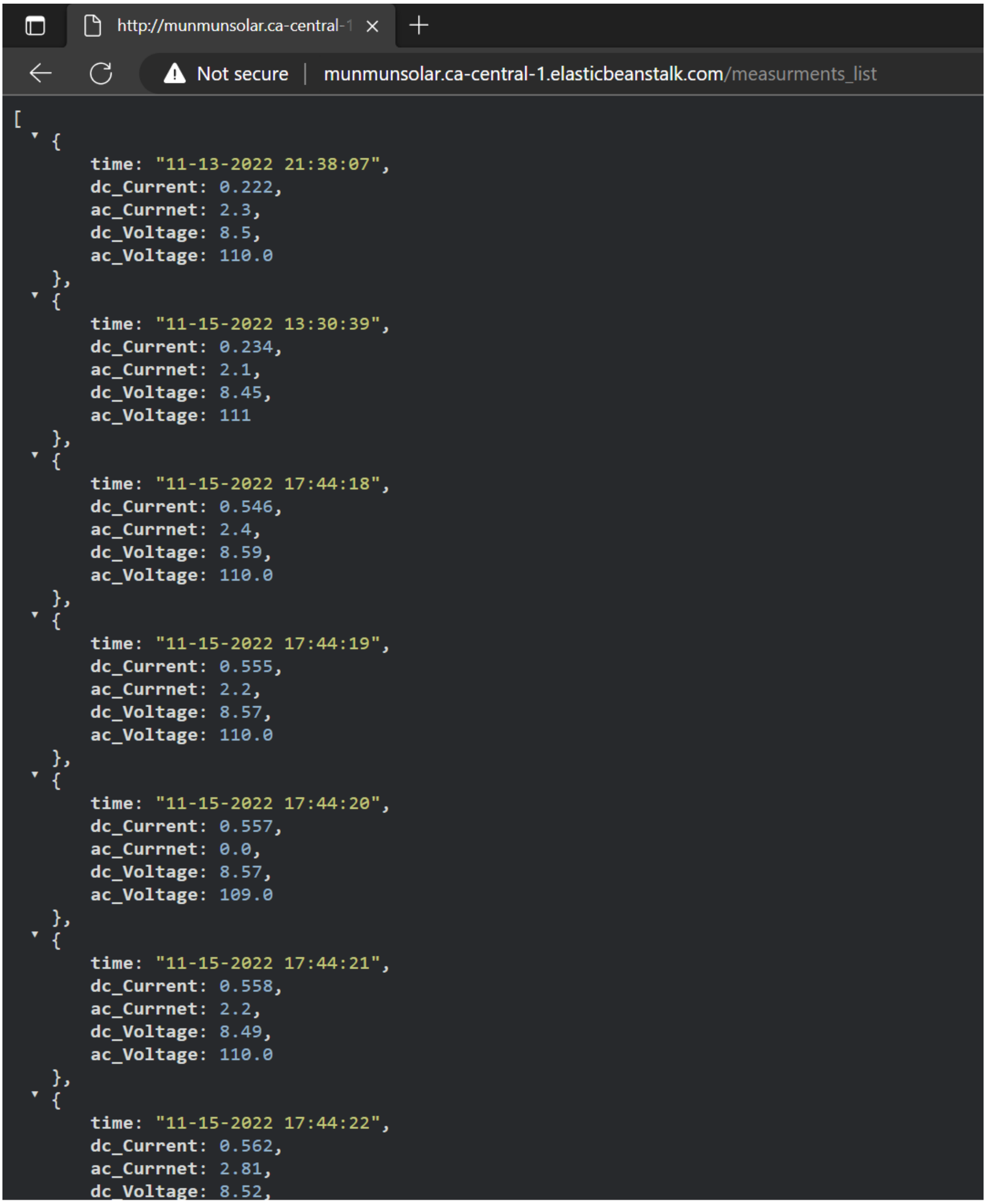

Fig. 12. Web-based database virtual access.

Furthermore, another feature of the website for high-level authority accounts is the ability to search directly for a measurement. This is done by linking each set of measurements to a reference point, with the date as the master reference point, followed by the time. Therefore, measurements can be filtered and searched by searching for a specific date or time of the day, as seen in Fig. 13.

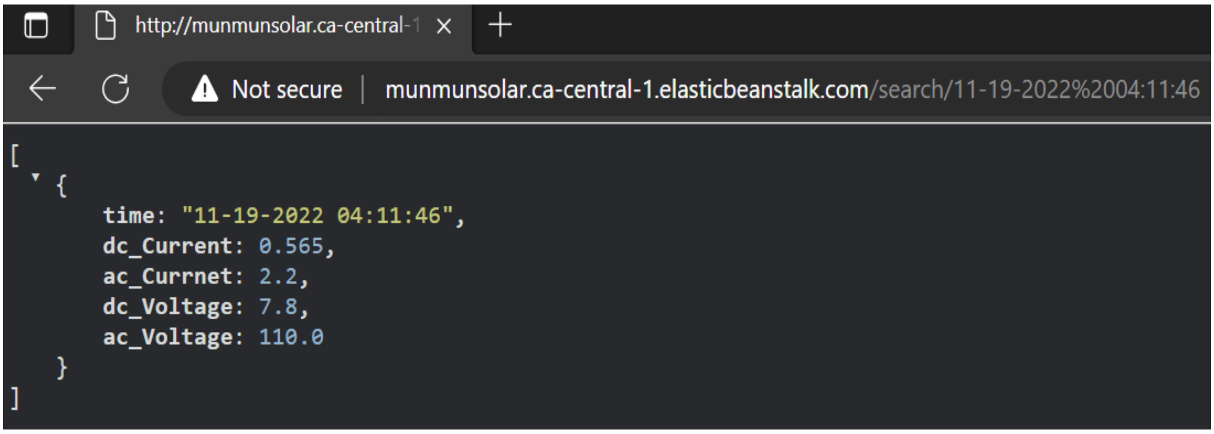

Fig. 13. Web-based database search.

5. CONCLUSIONS

For effective administration, a network of computers linked to a GUI application operating on various programmable peripheral devices can be employed with a SCADA monitoring system. SCADA systems may help any organization improve productivity, use data to make more informed decisions, and communicate system problems to reduce downtime. This paper explained a basic setup of a low-cost SCADA monitoring system for a hybrid power system through a local host, Node-Red, and a web-based system.

The proposed instrumentation system can acquire real-time data by implementing the Arduino system, monitoring and storing the data in the client database for future access. Since it is less costly and time-consuming, it can replace human intervention to avoid errors associated with multimeter readings. Data can therefore be assimilated and recorded more easily with the proposed system. The hybrid power system's performance and operational efficiency could be improved by analyzing such data.

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