Design of IoT Based Remote Renewable Energy Laboratory

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Abstract—With continuous increase in the number of students enrolled in universities, e-learning has become an urgent necessity in modern education systems. However, applied programs face challenges in adopting this type of learning because of their need for laboratories and training workshops. With the advancement in computers and wireless communications technologies, and advent of Internet of Things technology, it has become possible to design real laboratories that can be accessed remotely. Remote labs are an advanced step that enables students to interact remotely with real laboratory devices using personal computers or smartphones from anywhere and at any time. This paper presents the use of Internet of Things technology in the design of the renewable energy laboratory, where the experiments are designed in a way that allows the student to choose the required experiment remotely, study its components, and measure many variables in order to obtain the necessary skills.

Keywords—e-learning, blended learning, remote laboratory, IoT, renewable energy lab

1 Introduction

Recent developments in wireless communications and microelectronics are a major reason for the emergence of new applications that have had a significant impact on our lives. These developments were reflected in modern learning systems, especially after the Corona pandemic [1]. E-learning systems are a necessary need to provide online learning, teaching and training opportunities for those who wish to achieve their educational goals in proportion to their circumstances. Global experiences have indicated that e-learning can improve the quality of teaching and learning by selecting the best teaching materials, lecturers and smart platforms to increase students' skills [2] [3]. Moreover, e-learning provides educational opportunities at an affordable cost compared to traditional learning. Despite the advantages of e-learning, it faces a number of challenges, the most important of which is providing the infrastructure for a high-speed communications network, as well as the difficulty of integrating this learning style into applied disciplines in terms of laboratories and training workshops [4] [5].

E-learning and blended learning are the necessary alternative to traditional programs to face the continuous increase in the number of students enrolled in educational institutions, as well as to face natural disasters and epidemics [6]. The application of e-learning has been limited to a large extent in the delivery of educational material in the humanities and some scientific disciplines that do not need practical application. Applied majors still face difficulty in integrating e-learning due to the need for such programs to have specialized laboratories to help students acquire scientific skills and knowledge. Universities seek to establish new programs that are required by the local and international labor market, and most of these programs are applied disciplines and costly, in addition to the shortage of qualified trainers [2] [7]. E-learning can contribute to the establishment of applied specializations if remote laboratories are available online to develop students' skills. The main purpose of using remote laboratories in e-learning systems is to achieve practical activities for training students through which they can acquire skills. Such laboratories require the use of physical equipment and/or simulation components as well as reliable software to manage laboratory experiments. These laboratories can operate 24 hours a day, 7 days a week, without human assistance, and contribute significantly to reducing cost and effort [5].

Recently, research centers and universities have worked on applying Internet of Things (IoT) technology in designing remote laboratories that enable students to access experiments via the Internet. The IoT is an ideal platform for designing computer-based systems that can be accessed through the Internet. This technology can be adapted to design remote laboratories and training workshops that contribute to the development of e-learning. These laboratories aim to enable students to access remote laboratories and deal with experiments to obtain real data for analysis and to acquire basic practical skills that enhance the study plan in applied disciplines. In the past few years, a number of universities have established IoT-based laboratories and induction centers in collaboration with global companies [7] [8] [9]. Google has allocated half a million dollars to the Carnegie University Living Lab for IoT Laboratory to turn the university's campus into a testing ground for the IoT and its applications [10]. The University of Wisconsin-Madison's IoT Lab serves as a research and training platform on campus and a hub for university-industry collaboration [11]. Many universities have also set up a specialized interdisciplinary IoT research lab to explore and develop various IoT applications.

This paper addresses the use of IoT technology in designing remote laboratories that enhance e-learning systems for applied disciplines. Such a laboratory consists of a set of experiments, where each component, instrument and device can be considered as a node in a wireless sensor network and can be accessed by students remotely through an internet-connected computer or smartphone. The rest of the paper is organized as follows; the importance of IoT technology in remote laboratories is outlined in Section 2. The requirements for designing a remote laboratory (in general), and a renewable energy laboratory (in particular) are discussed in Sections 3 and 4 respectively. A discussion of the experimental results is given in Section 5. Finally, the conclusion and some proposed future work are given in Section 6.

2 IoT-based remote laboratory

The IoT is a technology that uses physical objects embedded with wireless communication capabilities, enabling data exchange between these devices as well as with other Internet-enabled systems. Over the past years, many IoT products have emerged, including smart lighting, monitoring and alarm systems, as well as controllers for smart home and smart city applications [10] [11] [12]. The IoT technology is considered the most important technological development in this decade, as it bridges the gap between the physical and digital worlds. The skills related to the IoT and its technologies are in high demand. The IoT technology has entered many industrial and service applications including energy, transportation, agriculture, healthcare, and more. This technology has contributed to the development of computer systems connected to the Internet, as reports indicate that the number of devices connected to the Internet has exceeded 50 billion devices in 2020 [13]. Cisco stated in 2014 that the IoT will create $19 trillion in value over the next decade [14]. This was an impressive number at the time, and with the passage of time IoT technology has become very important in many applications. There are significant investments made by companies to develop infrastructure and software for the IoT and enhance it with cybersecurity solutions. Hence the importance of integrating IoT related activities into a wide range of core and elective courses in applied disciplines, especially in faculties of engineering and information technology. Selected courses include microprocessors, computer networks, programmable devices, embedded systems, digital signal processing, wireless communications, computer control, real-time systems, and others. One of the most important factors responsible for the growth of the IoT is the availability of the necessary infrastructure that allows immediate access to IoT devices.

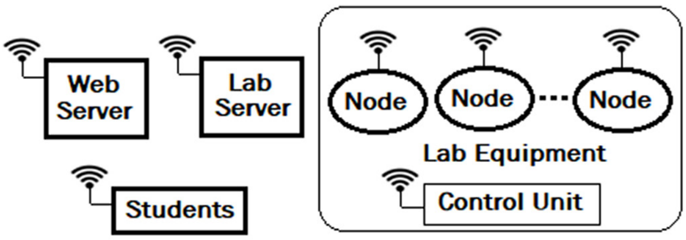


Fig. 1. IoT-based remote laboratory

In the field of e-learning, the importance of IoT technology in designing remote labs and training workshops has increased. This paper aims to design an IoT-based remote laboratory to provide a number of laboratory experiments in the field of renewable energy. This lab will be a platform for acquiring basic skills related to IoT technology as well as renewable energy experiments, for the purpose of developing students' abilities to innovate and be creative. The proposed laboratory consists of a set of experiments, and each experiment includes a group of devices and components based on their setup. Each component can be considered as a node in the wireless sensor network, as shown in Figure 1. A node is a device or instrument equipped with an integrated microcontroller and wireless communication module. The remote laboratory server includes control and measurement units for laboratory equipment and instruments. While the web server is responsible for the learning management system that provides the required procedures for conducting each experiment and related information for each component in the experiment, as well as scheduling access to the experiments. The learning management system also secures the necessary channels of communication and conversation between students and professors. Such labs can also be directed to motivate students by engaging them in scientific research and projects in an educational environment that enhance critical thinking, personal and technical skills.

The IoT-based remote laboratory not only provides high-quality applied education at an affordable cost, but also has other advantages, which are:

- High flexibility in the use of laboratory equipment.
- The necessity of providing a fast communication network in the laboratory environment.
- Enable students to remotely access multiple labs in different locations.

3 Remote laboratory design requirements

The IoT technology is used in the design of a remote lab that includes several experiments in the field of renewable energy, in line with the requirements of e-learning systems. These labs are accessible online and students can interact with the experiments as if they were in a real lab. Figure 2 shows the general layout of the IoT-based remote laboratory. Each experiment contains a microcontroller connected to an array of sensors and actuators. The microcontroller is equipped with a WiFi module to transmit data to the laboratory server. This design enables students to remotely access a renewable energy plant, choose an experiment and manipulate its components for data.

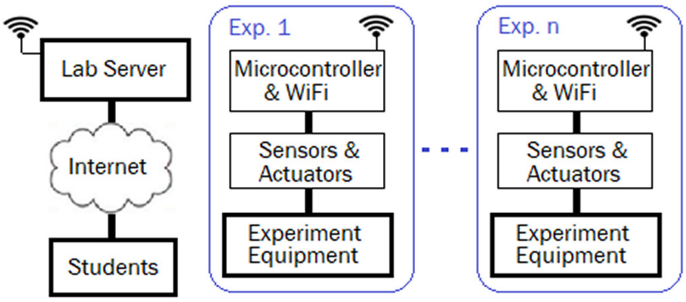


Fig. 2. General layout of IoT-based laboratory

The student can access the laboratory through a personal computer or smartphone connected to the Internet. The student can choose the experiment, deal with its setup and components, adjust the parameters, read the instructional instructions, and get help or more relevant information. The student can interact with the experiment by changing the set points and parameters, obtaining readings and analyzing the data to achieve the goal of the experiment. The laboratory server is equipped with the necessary software that organizes the services of the laboratory in terms of scheduling experiments, collecting data and providing students with data and any information related to each experiment.

This paper deals with the use of IoT technology in the design and implementation of remote laboratories to enhance the role of e-learning in applied disciplines. In this case, authorized students can accomplish several tasks related to the chosen experience, including [15] [16]:

- Online access to the remote laboratory anytime, anywhere.
- Reservation of the required experience.
- Identify the experiment objective, its components and setup.
- The student can get practical readings directly through a personal computer or smartphone.
- Analyze and discuss the data obtained.

4 Renewable energy lab design

Designing and implementing a remote laboratory for solar energy experiments using the IoT platform is an advanced step to enhance the role of e-learning in applied disciplines. Most of the renewable energy laboratories need outdoor spaces to install photovoltaic panels or a wind tower, so the use of IoT technology will help the learner to access any experiment in the remote laboratory, from anywhere and at any time, using a computer connected to the Internet or a smart phone. The laboratory includes a set of indoor devices and instruments used in the design of experiments. Each experiment has a control unit that connects to the central control unit through a Wi-Fi module as shown in Figure 2, or Ethernet connection, as given in Figure 3. While each of the units installed outside the laboratory, such as PV panels and wind towers, is equipped with a microcontroller-based control unit with a WiFi module. The microcontroller is connected to a set of sensors to obtain the data required in the experiment. The communication between the outdoor control unit and the laboratory central control unit is done wirelessly.

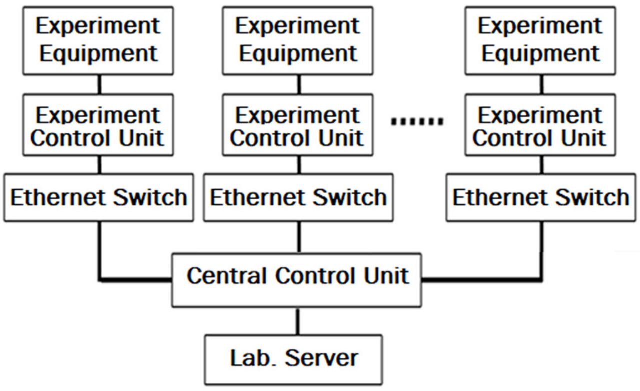


Fig. 3. Layout of a remote laboratory

There is a need to design a realistic Graphical User Interface (GUI) in order to provide an interactive environment for the learner very similar to a real lab.

4.1 Experiment control unit

Each experiment has a microcontroller-based control and measurement unit. The microcontroller is interfaced with sensors, measurement and control units of the devices used in the experiment. As for the units outside the laboratory, each unit can be considered as a node in a wireless sensor network and interfaced with local control unit of the laboratory.

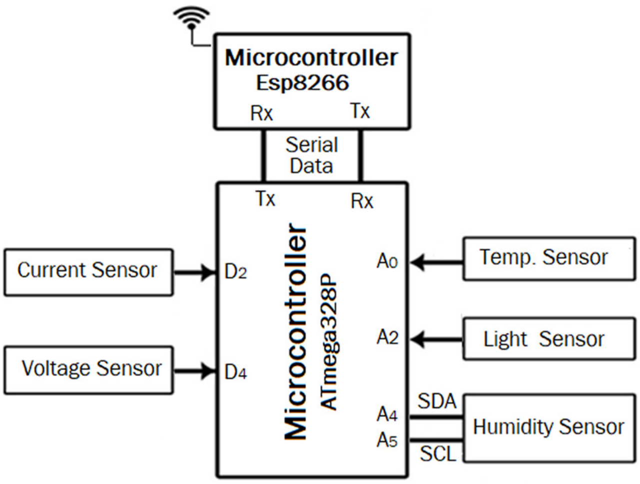


Fig. 4. Experiment control unit hardware design

For example, one of the laboratory experiments deals with "Measure the power output efficiency of a photovoltaic panel". The experiment aims to study the energy generated by photovoltaic units under different conditions in terms of temperature and light radiation. In this experiment, the PV module is equipped with five sensors that are used to measure temperature, humidity, light intensity, current and voltage, as shown in Figure 4. This microcontroller is used to scan all sensors and measured parameters. All measured data will be sent to the web server after being collected by the laboratory server.

4.2 Laboratory control unit

It is a microcontroller-based central control unit in the laboratory that communicates wirelessly with each local controller of the experiment. Each experiment is a node in the wireless network, so that setup commands and measured data can be transmitted between the experiment controller and the central control unit wirelessly. The central control unit communicates directly with the laboratory server to enable students to access experiences via the Internet.

A. Laboratory server

The laboratory server is equipped with suitable software to manage the laboratory, control its equipment, and enable students to access the laboratory via the Internet.

All data from the local server is also stored in the web server. Laboratory supervisor and technician can perform necessary maintenance and modifications related to laboratory experiments by accessing the laboratory server. The laboratory server is equipped with software and an operating system to enable students to easily choose the required experiment and use the laboratory. The laboratory server sends the collected data to the web server and database. Through the laboratory server software:

– The student can access the laboratory by entering the "User Name" and "Password"
– The student can choose the experiment and adjust its settings.
– The laboratory server sends the actual data of the experiment to the database.

B. Web server

The web server allows students to access remote lab experiments, anytime and anywhere, via the Internet, as illustrated in Figure 5. All data related to the experiment is stored in an SQL database to enable students to view, store, analyze data and draw necessary conclusions.

C. User interface

Students interact with the remote laboratory through a flexible user interface that makes them feel like they are in the laboratory environment. Students can access the specific experience through the web page that provides:

– Read the theoretical part of the experiment and know the specifications of each component.
– Check the experiment setup and choose the appropriate parameters.
– Monitor all units and components in the experiment via IP-Camera.
– Record the readings obtained from the experiment.
– In addition, the student can also contact the laboratory supervisor for assistance.

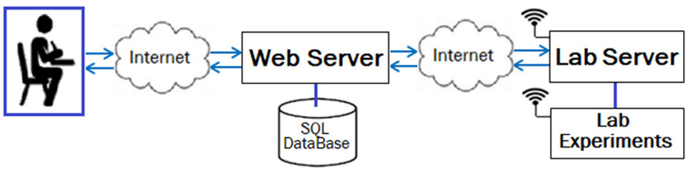


Fig. 5. Student communication with the remote laboratory

5 Results and discussion

The experiments in the remote renewable energy plant are designed to achieve the objectives required from the practical side in enhancing technical skills. There are a number of experiments in the lab, and this section will discuss one of the selected experiments "measuring the energy output efficiency of the photovoltaic panel" in terms of the extent to which the objectives of the experiment are achieved according to the experiment procedures:

– Measuring current and voltage and calculating power at regular intervals and in changing weather conditions in terms of temperature and radiation.
– Measuring current and voltage and calculating the power generated from photovoltaic panels connected in series and parallel.

The objectives of this experiment are:

– Object 1: Study of the impact of temperature and radiation change on the I-V curve and PV curve of a photovoltaic panel.
– Object 2: Study how to obtain the required energy using photovoltaic panels connected in series, parallel, and series-parallel.

5.1 Impact of temperature and radiation

The student receives current and voltage readings from the photovoltaic panel at different irradiation levels (1000, 600 and 200 W/m^2) with constant temperature (25°C), as shown in Table 1. The student calculates the power and displays the results show the effect of the irradiation change on the I-V and P-V curves, as shown in Figure 6. On the other hand, the effect of temperature change (40, 30, 20°C) on the I-V and P-V curves, with the same irradiation (1000 W/m^2) is given in Table 2 and Figure 7. By analyzing these results, the student achieves the first objective of this experiment. The main conclusion is that the energy generated by photovoltaic panels is affected by weather conditions from temperature change and irradiation change.

Table 1. Readings at different radiation and constant temperature

Irradiation (KW/m^2)	200	600	1000
Voltage (V)	27.59	28.41	28.5
Current (A)	1.45	4.33	7.19
Power (W)	39.91	122.91	204.92

Table 2. Readings at different temperature and constant irradiation

Temperature °C	20	30	40
Voltage (V)	29.06	27.92	26.82
Current (A)	7.18	7.21	7.23
Power (W)	208.50	201.92	193.97

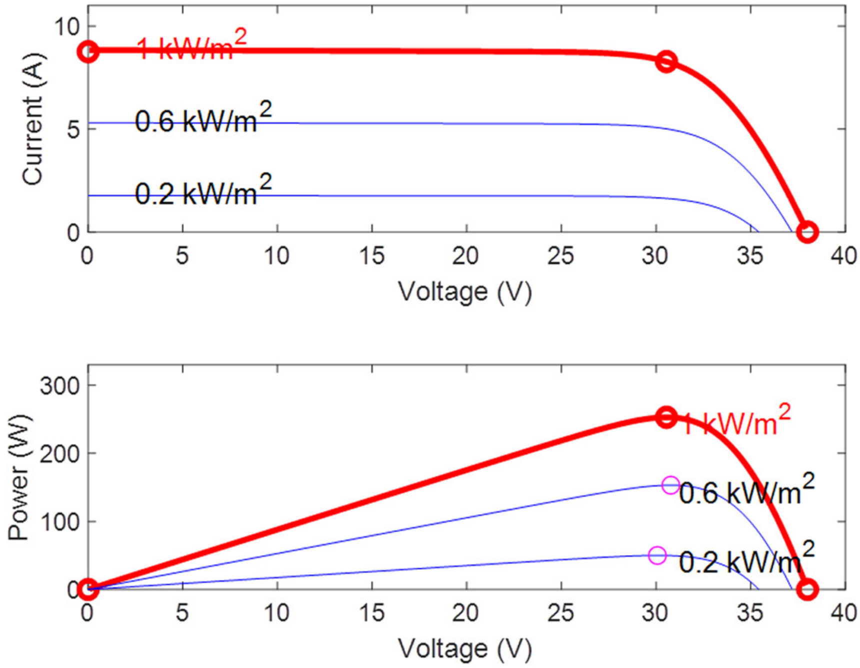


Fig. 6. I-V and P-V curves with irradiation change

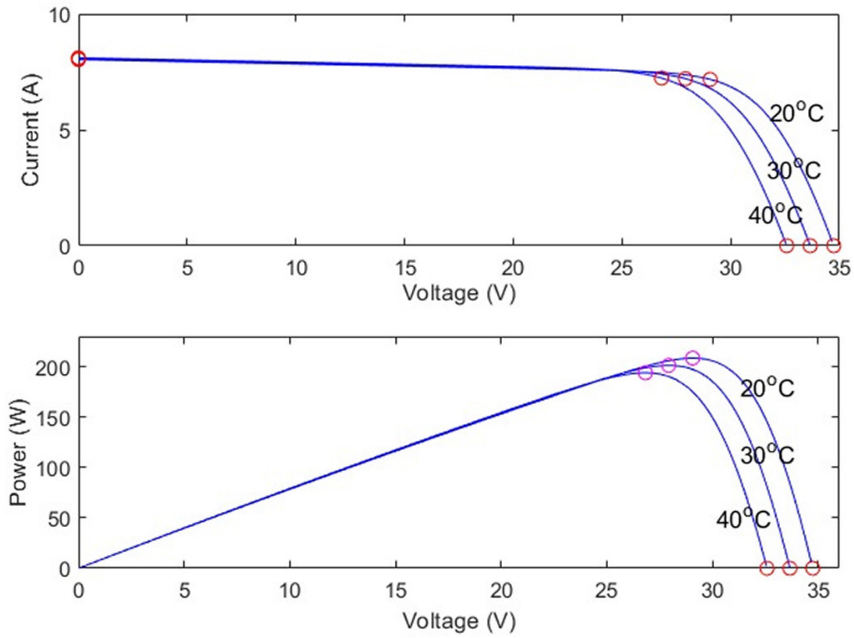


Fig. 7. I-V and P-V curves with temperature change

5.2 Series, parallel and series-parallel connection

The student can record the readings from the experiment when a group of PV panels are connected in series, parallel and series-parallel, as shown in Table 3 and Figure 8. It is clear from Figure 9 that the voltage in the system increases when a number of PV panels are connected in series. While the current increases when a number of PV panels are connected in parallel. Also, when large power generation from a PV system is required, there is a need to use series-parallel configuration. The main objective of the experiment will be achieved when the student can calculate the number of PV panels required in series and in parallel that give the required power from the PV system.

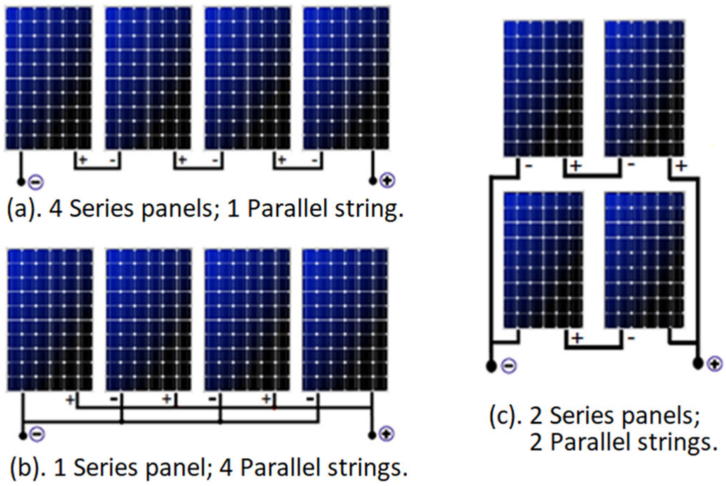
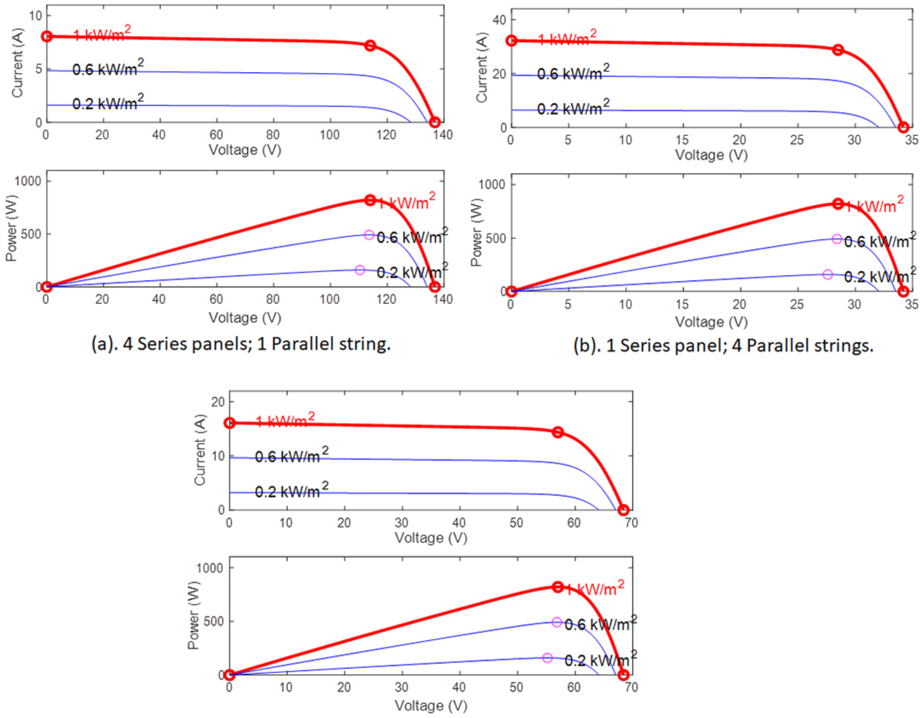


Fig. 8. Series, parallel & series-parallel connection of PV panels

Table 3. Readings from different PV panels configurations at (1000 W/m^2) irradiation

Connection	4 Modules Series	4 Panels Parallel	(2 Series) Parallel (2s Series)
Voltage (V)	114	28.5	57.00
Current (A)	7.19	28.76	14.38
Power (W)	819.66	819.66	819.66



(a). 4 Series panels; 1 Parallel string.

(b). 1 Series panel; 4 Parallel strings.

(c). 2 Series panels; 2 Parallel strings.

Fig. 9. I-V and P-V curves Series, parallel and series-parallel connection of PV panels

6 Conclusion

This paper presented design of laboratory experiments in renewable energy for a remote laboratory based on IoT. The IoT technology was used to collect real-time data from renewable energy sources via sensors to measure several variables and indicators in the experiment. Using this technology enables students to collect variables remotely without having to be at the station. Experiments in the renewable energy lab are an essential part of renewable energy engineering education because they improve understanding of theoretical concepts.

The use of IoT-based remote laboratories in e-learning systems has many advantages, including;

- Renewable energy laboratories need large areas and are mostly off-campus, which makes the IoT technology very important for transmitting data to the trainee.
- The proposed laboratory needs a limited set of components connected to a computer in the lab that acts as a host server for a large number of experiments.
- The laboratory can work continuously, which provides an opportunity to increase the number of trainees and raise the capacity of the program.

- Students interact remotely with the components of the experiment as if they were actually dealing with the components of the real laboratory.
- Providing the opportunity for cooperation between educational institutions by sharing the resources available in their laboratories.

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