Deanship of Graduation Studies Al-Quds University

Remote Smart Grid Lab

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Remote Smart Grid Lab

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Declaration:

I Certify that this thesis submitted for the Degree of Master is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for a higher degree to any other university or institution.

Signed by: ....

Mays'a Fahmi Ahmad Abushams

Date: 2019/12/22

Dedication

I dedicate this work to my late father who always believed in me.

Mays'a Fahmi Abushams

Acknowledgement

While I am printing the last words of my thesis, I would like to thank my supervisor, Dr. Imad AlZeer who has been a tremendous mentor for me. I would like to thank him for encouraging my research. His advice to my research has been valuable.

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Abstract

Getting to access remote facilities anywhere is a new way for teaching and learning. New technology that can help achieving many goals in the research field, it stands up against the impossibility to access labs over the world.

This provide a practical approach for limited budget research institutions to provide cost effective research facilities. Online remote lab is a new technology in the learning arena. It can be said that it is the first step in developing the research labs to become accessible worldwide. This thesis aims to make labs remotely accessible for students and researchers even in the developed countries. Through the Internet, it became easy for researches to access the needed facilities for their research.

This thesis works on converting smart grid labs by using Raspberry Pi B+ 3 board to become online labs that can be operated from any location. By using JSON programming language and an online website to connect the modules with each other for the chosen experiment, and then observe the results in SCADA. By this way any student at any time can use the lab to implement their experiments and obtaining the results.

In the end of establishing a Remote lab using Raspberry Pi B+ 3 board and relay modules, connect them with each other and the lab module, so the user can execute the connection through the web site, and the module will connected to each other according to experiment procedure, each input will be connected to each output through Raspberry Pi B+ 3 board and using the right code to

execute that, solar panel experiment has been chosen for its importance to research area, the experiment has been connected, the SCADA showed the result remotely, through Internet connection.

A complete experiment has been connected online remotely with all its components and the result showed remotely also, with minimum hardware and cost.

تشغيل مختبر الشبكة الكهربائية الذكية عن بعد

إعداد: ميساء فهمي احمد ابوشمس

إشراف :د.عماد الزير

ملخص:

تتمحور الرسالة حول تشغيل المختبرات عن بعد و مساعدة الطلاب و الباحثين على اجراء التجارب او حتى اعادة اجراءها للحصول على النتائج المرجوة ، و سنقوم باعادة ربط مختبر الشبكة الذكية بلوحة الكترونية(Raspberry Pi B+ 3) بحيث يتمكن الطالب اما من اجراء التجارب داخل المختبر نفسه او حتى اجراءها باستخدام موقع الكتروني و الحصول على النتائج من خلال برنامج سكادا موصول بجميع وحدات المختبر ليقوم بقياس النتائج و القيم،و تهدف الرسالة الى الاستفادة بشكل كامل من المختبرات بكافة انحاء العالم و خاصة في الجامعات التي قد لا تتمكن من الحصول على مختبرات لارتفاع اسعارها.

تم توصيل وحدات المختبر ببعضها البض باستخدام Raspberry Pi B+ 3 و relay module لتنفيذ تجربة solar panel و ذلك لاهميتها للباحثين، و تم التوصيل عن بعد باستخدام الموقع الالكتروني حيث ان التوصيل يتم باستخدام وحدات افتراضية تشابه تلك الموجودة في المختبر ببعضها البعض حسب اجراءات التجربة كما هو موجود في ملحق المختبر.

و نجحت التجربة و تم توصيل كافة الوحدات ببعضها البعض عن بعد، و تم اظهار النتائج باستخدام SCADA و الذي يعتبر جزء من المختبر عن بعد باستخدام اعدادات خاصة به لتشغيله من خلال الشبكة.

في نهاية الامر تمت توصيل التجربة بكامل مكوناتهاعن بعد و تم الحصول على كافة النتائج الخاصة بها من خلال الموقع الالكتروني بأقل التكاليف و بأقل مكونات الكترونية.

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List of Acronyms

SoC	System on Chip
SCADA	Supervisory control and data acquisition
AC	Alternating current
DC	Direct current
MCU	Microcontroller unit
PLC	programmable logic controller
COM	Communication port
ES	Embedded systems
RL	Remote laboratories
EEPROM	Electrically erasable programmable read-only memory
LCD	liquid-crystal display
GPIO	General purpose input output
CPS	Cyber physical systems
FPGA	Field Programmable Gate Arrays
PC	Personal Computer
MIMO	Multiple-input and multiple-output
HTTPS	Hypertext Transfer Protocol Secure
URL	Uniform Resource Locator
HTML	Hypertext Markup Language
CSS	Cascading Style Sheets
JS	JavaScript
RF	Radio frequency
USB	Universal Serial Bus
Wi-Fi	Wireless Internet
3G	Third Generation
GUI	Graphical user interface
HTTP	Hyper-Text Transfer Protocol
TCP	Transmission Control Protocol
JSON	JavaScript Object Notation
LAN	local area network
Mbps	Megabits per second
IP	Internet Protocol
DOE	Department of Energy

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Chapter 1

Introduction

Remote laboratory can solve a lot of issues. It can make a difference in learning, and in teaching fields. This chapter contains remote lab overview, and how it can contribute to research areas.

1.1 Motivation

Laboratories form an important educational resource in engineering education and training using equipment's in addition to teaching theories in lectures. The laboratories give the opportunity for learners and engineering to use equipment's correctly, and to train them on how to deal with instruments they will interact later with in real life and in professional conditions, thus gaining practical knowledge and familiarizing themselves with such equipment's. However, maintaining the equipment and getting new laboratories imply a large amount of money that can be afforded only by few numbers of universities and institutions.

A lot of limitations are considered in equipping laboratories in universities and institutions such as budget limitations, and the increasing number of engineering students make existing labs insufficient, and it becomes harder to universities to provide the necessary training for students, and teaching in labs become insufficient.

The availability of new technologies of communication and computing capabilities make it easier to develop tools to interact with virtual instrument. Open and shared resources provide the possibility to develop, and implement e-learning technologies that give the students access to different labs through the globe without location restrictions, time limitation, or lake of money, and will absorb the huge increase in number of students, who want to access labs for practical training.

1.2 Problem statement

A lot of considerations was taken to achieve this work:

1. Physical access to labs is not available at all time. Most labs are occupied most of the times.
2. Most of the labs equipment’s are expensive, and cost a lot to educational institutions high budgets.
3. Simulation labs can give results in ideal environments. It can’t simulate real life circumstances.

1.3 Thesis goals

The aim of the thesis is to modify a local lab to be used remotely and locally. So, the lab could be used in any circumstances at any time, in the site location with the real instruments and the existent of the user, and with remote location with the same used instruments but with a different physical user location. This gives the opportunity for researchers to run experiments and rerun them at any time they need. Nevertheless. researchers will have data that touches real life problems, not to mention cost saving if proper lab scheduling is set, and the students will have the chance to access such data at any time needed to run the experiments again.

The lab meant to be modified is the smart grid lab, it’s a research lab for all grid component, it studies the impact of the smart grid component with each other.

The obtained modified remote lab model will serve researchers, teachers, student, and other educational communities. Smart grid lab can give us a good idea about the real grid, how to develop it and how to solve its problems.

1.4 Thesis contribution

Several collaborative schemes that aimed at engineering education, have been developed in recent years for the remote execution of experiments from distant laboratories and on different engineering fields.

For example, Labwork has been established in Hong Kong at Polytechnic University (PolyU). It gives the users the opportunity to execute physical experiments. It has scheduling feature to reserve any appropriate date and time to start connecting with the lab and execute any wanted experiment.

A Labwork [1] is a living example of applied remote lab offers real-time online laboratory to execute lab experiments at their own space, anytime, anywhere. The lab provides the ability to execute physics experiments without sacrificing having accurate data through Labwork platform, and through time the teachers can track students’ performance, and assist them when it is needed.

The remote laboratory system, where experiments conducted at control engineering laboratories can be remotely operated through the network in which Internet makes it easy to deal with such connections [2]. On the same trend, a more recent work [3] reports on the remote control of a nonlinear system as a tool for teaching several engineering subjects. Likewise, experiments with analog electronic circuits have been studied [4] with the aid of remote laboratories based on an existent and previously validated platform. This system aim to use nonproprietary solutions in order to promote sharing among institutions; it also performs remote measurements over real instruments in an effort to make it as reliable as a hands-on laboratory.

Remote laboratories for experimental training on mechatronics local labs have also been implemented [5], where experiments using a two-degree of freedom robot and a servomotor can be carried out remotely. Other works have also reported the development of remote experiments implemented as web-based systems in other engineering fields such as fluid mechanics [6] and electrical engineering [7].

In general, remote laboratories deal with manipulation of real equipment's and experiments, and although they make use of tools such as virtual instruments (VI) and e-learning environments, they should not be confused with either simulations or virtual laboratories. There are systems, such as using different approaches, more on the style of virtual laboratories, that involve the use of expensive equipment and topologies for the emulation of sophisticated laboratories, which are rarely available in public institutions [8].

In the research, the smart grid lab will be modified to serve as remote lab, A smart grid lab can provide a complete study on smart electrical grid connected to multiple sources of power with all components of electrical grid to control and monitor the effect of other sources of power on the traditional grid. Reusing this lab at times the lab is not in use, by adding hardware and software and converting it to a remote lab, can help researchers get a closer practical look to improve and study the electrical grid. One of the most important reasons I'm going to improve remote lab is to provide practical results that is closest to what happens in real life. Simulation labs can provide ideal results and data with ideal experiment environment but real labs designed to simulate the real-life conditions.

Engineering and scientific studies can expand the usage of remote labs in order to allow students to perform real, non-simulated experiments and lab tasks over the Internet without physically existing in the lab [9]. In our system we intend to add the availability of real lab and the smart grid lab to work remotely.

The intent is to connect the module of smart grid lab to SoC (system on chip) device such as a Raspberry Pi B+ 3 so we can use a website that control the connections between the modules, and the result will be shown from SCADA remotely which is connected to the lab in the first place. Two servers will be used, one of them for the Raspberry Pi B+ 3 and the website and the connection through the Internet, and the other for getting result from SCADA remotely.

For the first time, a large number of modules in a lab is intended to be modified to work remotely, also a chip with operating system has been used with a lot of properties that help build a lab to works online remotely.

The website compensations have chosen carefully, so online remote lab can be achieved, with real time server.

The Figure 1.1 show the mechanism used in the system, SoC device with web server and website had been added to the smart grid lab so its modified to a remote lab, by using the

SCADA which is a component of the lab to be used and connected remotely to get the results from the experiments conducted.

However, The previous implemented systems focused on using few numbers of modules to build small models of the lab to implement experiments remotely, in addition; those systems used devices with limited capabilities and limited number of outlets, and the most important limitation of such devices that those outlets are specified for specific functionality, and no capability for adding or developing on the systems.

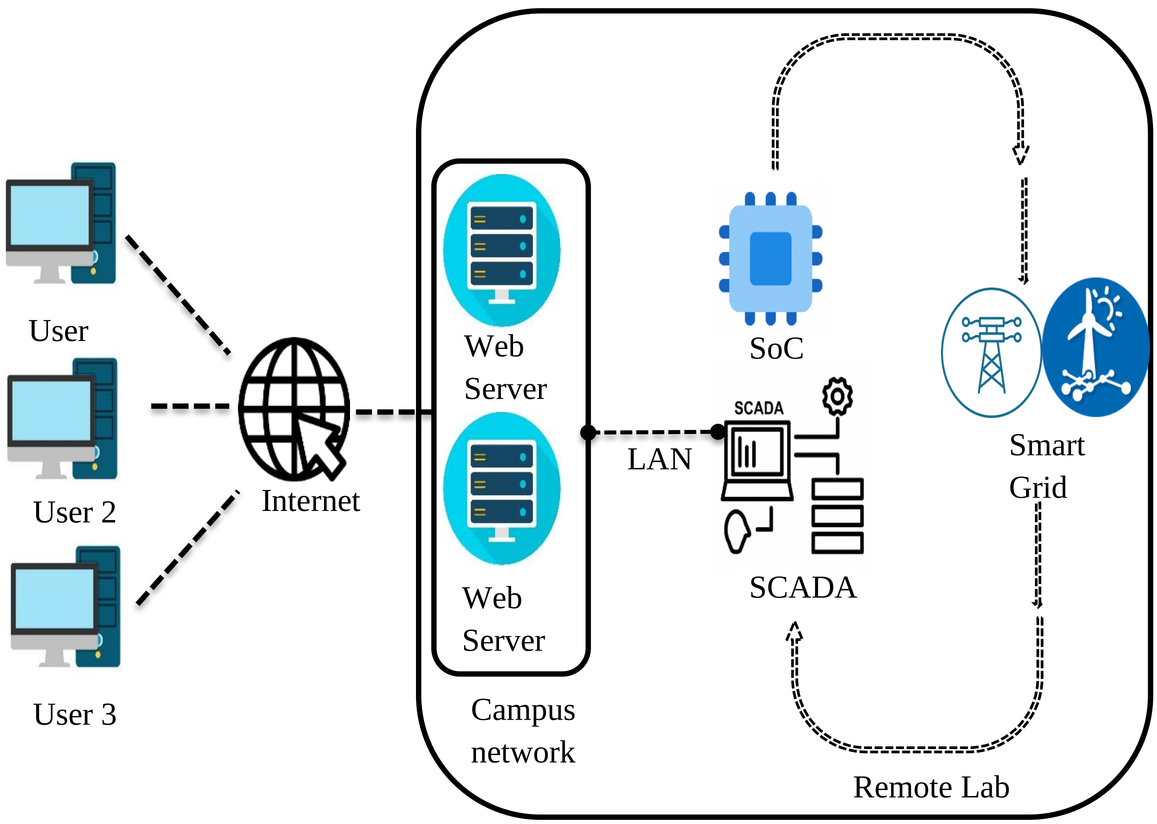


Figure 1.1: The proposed system.

1.5 Thesis organization

The content of this thesis is arranged as follows:

Chapter 2: Literature review. This chapter will present a detailed literature survey about the technical background information needed to understand the underlying technologies related to model design.

Chapter 3: Methodology. In this chapter, I'll present the mechanism of converting the smart grid lab to remote lab, how to perform it, how to connect with SCADA in remote locations, and what is needed to perform an ideal experiment.

Chapter 4: Hardware module. In this chapter, will present the hardware components, how it is combined with each other.

Chapter 5: Software module. In this chapter, will present the software algorithm used in Raspberry Pi B+ 3, and the web page designed to connect the experiments.

Chapter 6: Integration method. In this chapter integration method in the system was explained, how to integrate the component of the system with each other.

Chapter 7: Testing and Results. In this chapter, will examine the connection through Internet by trying the web site and observe the results in lab room.

Chapter 8: Conclusions and future work. A conclusion of the overall work is given in this chapter, and the future work that can be done.

Chapter 2

Literature Review

This chapter contains all needed components for constructing a Remote lab, including the lab meant to be modified. The hardware components needed to add to the lab, so it can be used remotely, including the Raspberry Pi B+ 3, the connections between modules, the relay module used to complete the connection, the communication mechanism through internet, how to operate through a website, and finally reviews to related work for the proposed system.

The lab meant to be modified is the smart grid lab developed by De Lorenzo which is an Italian Company specialized in design, development and production of technical and vocational training equipment. De Lorenzo has developed the lab I intend to modify to a remote lab. The Lab contains typically the grid components such as a protection device, electrical production station, solar panel, and all sub components of the smart grid system. The company developed full laboratories for several specialties such as electrical, power, telecommunication, electronics, automotive, and others engineering specialties [10].

The lab is considered very useful to research areas, as a result of the importance of smart grid field to researchers. This topic forms one of the important areas of development because of the increment of resources of power, and dealing with these resources to obtain maximum benefits of them, have occupied the attention of researchers and governments. The electrical power is one of the most important elements to human's future.

2.1 Smart grid

The definition of a smart grid can be represented as an electricity grid network update, which enable the collection of information about power exchange between suppliers and consumers, by using an intelligent network, a monitor and a management system; to control the flow of power over electrical networks [11].

The basic elements of a smart grid begin with the idea of smart metering infrastructure (AMI) to improve the management of the consumer demand, and increase power efficiency, and improve dependent grid that is capable of self- healing, and building a reliable grid protection against machine faults and natural disasters [12].

A Smart grid system is the way all electrical sources distributed in a smart method. it enables us to know and observe all user's consumption, manage and redistribute the flooded power, reuse it in other areas where it's needed, depending on real value. Figure 2.1 shows the components of a smart grid.

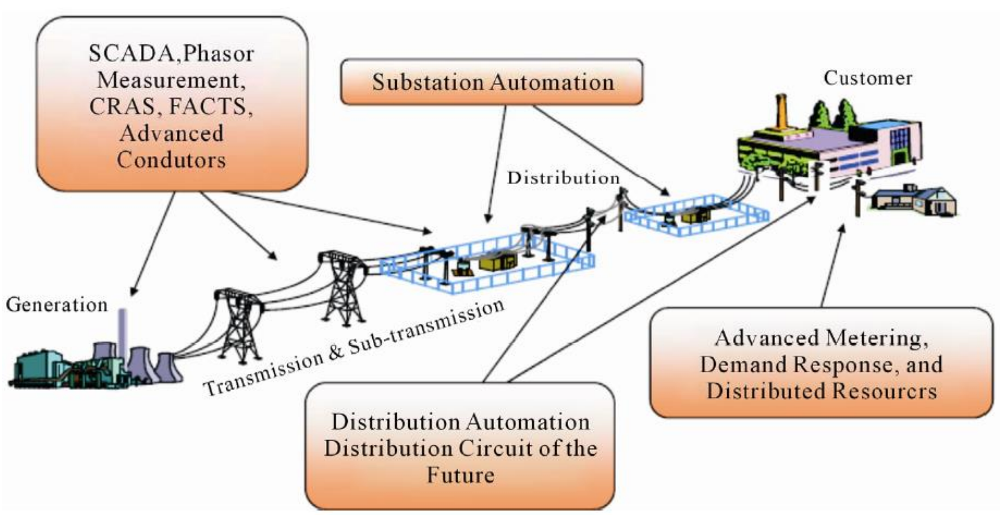


Figure 2.1: Components of smart grid [12].

Smart grids are the biggest technological revolution since the Internet. They have the potential to reduce carbon dioxide emission, increase the reliability of electricity supply, and increase the efficiency of our energy infrastructure [13]. Smart grid applications, communications, and security; explain how diverse technology play hand-in-hand in building and maintaining smart grids around the globe [14].

The software gives us the ability to manage the grid, monitor the flow of the electrical current, and the distribution to users. It manages the integration between the traditional power sources and renewable energy sources. Knowledge of consumption about each sector enable us to control the value of traditional electricity production. This way; we can reduce the expenses and provide all sectors with the power needed.

Different techniques are used to build a full concept of smart grid, these techniques are provided to the grid to provide flexibility and allow coordination and control by the smart grid.

The following are the applied technologies that are used:

1- Distributed Energy Resources: It's a combination between traditional and renewable energy sources. The traditional power source provides highly efficient local power to supply electricity to customers, the renewable energy might be installed in house hold or as production station like solar panels or wind turbines.

2- Demand Response (DR): The US Department of Energy (DOE) defined DR as "a tariff or program established to motivate changes in electric use by end-use customers, in response to changes in the price of electricity over time, or to give incentive payments designed to induce lower electricity use at times of high market prices or when grid reliability is jeopardized" [15]. The idea of DR is to manage the power usage for consumers and power grid [16], the improvement of smart grid efficiency, and to increase the grid reliability [17][18].

3- Electricity Storage: It is very important to complete the system. It is considered as a key role in power generation through renewable energy production. With the proper type of storage, the dependency on renewable energy will increase, so carbon emission will be reduced, and increase encouragement of developing of both renewables and storage [19].

4- Automatic Meter Reading: It is a device or system installed to measure the electricity consumption or production for each household.

5- Energy Service Gateway: It's a low power PC installed in the meter cabinet of each household. It works as a controller of all various devices running on specific configuration.

6- Data Communication Network: It's the communication network between households and the central server to coordinate and control, as well as collect data by the server using the network to manage and prevent failure [20].

7- Detailed Data Access: It is opened up by three portals, a user portal: gets information about consumer consumption and production energy, an operator portal: provides faults detection and monitoring, and a data analysis portal. The data analysis portal generates automated reports for data mining for all the data collected in the experiment.

8- Advance Distribution Automation: It’s defined as a group of technologies that give the ability to the electric corporation to monitor, operate, and coordinate the distribution component remotely in real time condition [21].

2.2 Remote Lab

Remote lab is an experiment done with real labs through ethernet, in which the user control them remotely, the experiments include real modules or instruments [22] that will be reused as a remote lab, it's hard for universities to supply a real laboratory for all researchers and students, especially when we are taking about a large number of students, or the need of space or instrumentation. Some universities don't have enough space or the budget for getting these labs, especially the expensive ones.

The universities depend on virtual labs to solve budget issues such as MATLAB, and other Simulink labs, that simulate labs environment. Those labs can be used with unsafe or dangerous experiments such as chemical labs, with the absence of real environment, those labs can’t give the user a real data that simulate the real lab experiment, also can’t give the student the skills dealing with real equipment’s.

Remote lab (*RL*) has been used and put under trial at the university of south Australia (UniSA), the main goal was to increase the usage of labs, this kind of projects will give the opportunity to graduated students to power up with knowledge and skills [23].

To modify any lab to a remote lab, a lot of utilities will be needed to complete the lab. The users can perform the same experiment as if it is performed in the lab. Interconnection components will be used to connect remotely between modules, visual mechanism will be needed to see the connections between modules., a server with ethernet connection will be needed to execute the experiment on the website. some labs will need actuator's to be operated. however, with the proper and cost-effective utilities, any lab can be converted and reused to achieve our goals as in real labs.

2.2.1 Typical Remote Lab System Architecture:

For any remote lab architecture [24], there are main components to be completed and operated remotely, Stevens Institute of Technology proposed a system of three-levels as follows:

- The user's PC with a software application: It is a JavaScript-based web browser that is capable of establishing a connection with the Internet.
- The resource manager: It is combined of a web server which respond to HTTP request from users, and the result data of the lab session.
- The third component: It includes the SoC interface with actual instruments and actuators.

2.3 Smart grid lab

The smart grid lab consists of eight subsystems. Each system has a lot of modules to simulate the real smart grid system. The first four subsystems simulate power sources of energy. The first one is the traditional coal plant with three phase supply unit, and the other subsystems represent clean power sources like wind, hydroelectric and solar.

The lab includes all protection modules. Other modules that simulate a real grid, and measurement modules. The lab is designed to simulate a real smart grid with SCADA software.

The reasons I chose this lab is to improve the grid and convert it to smart grid lab with less cost and less problems with integration between the renewable sources that are being used a lot now a days at which users have renewable energy at their homes.

2.4 SCADA

Supervisory control and data acquisition (SCADA) system is a very important component to each infrastructure. IT controls every utility in any smart city like pipelines, water, etc.., and its very crucial for manufacturing operations [25].

SCADA collects and shows real-time data of the system and transfer it to the central unit, to represent it to the user interface, it's a hardware operated by a software [26].

SCADA system in remote lab grid collects the data through measuring units using serial ports to connect each sensor in each module to sense these values and then represent the collected data through the user interface by using graphical screen and a software.

The SCADA performs the following functions:

1- Acquisition of physical quantities, the data is used to control the system and supervise.

2- Control, the system is capable of controlling the actuators, and all its operations.

3- Supervision, the system has the ability to monitor all data and information gathering from the system, the status of the system, and alarm from faults and others, etc...

SCADA systems supervise, control, optimize and manage the systems for the generation and transmission of electrical energy as well as the distribution networks.

They have the ability to collect, store and analyze data from hundreds of thousands of data points in national or regional networks, and have the ability to establish model networks, to simulate operations, detect faults, and control them to prevent their occurrence.

It’s an essential part of a smart network. It enables establishing and building smart grids, that are capable of dealing with enormous amounts of energy from renewable sources which can be produced by generators of large and small scale. Also; to maintain network stability despite the intermittency of these sources and the bi-directionality of the energy flow [27].

The SCADA system is divided to four main components:

1- Sensors (either digital or analog) and it controls relays that directly interface with the managed system.

2- Remote telemetry units (RTUs). These are small computerized units deployed in the field at specific sites and locations. RTUs serve as local collection points for gathering reports from sensors and delivering commands to control relays.

3- SCADA master unit. It’s a larger computer console that serve as the central processor for the SCADA system. The master unit provides a human interface to the system and automatically regulate the managed system in response to sensor inputs

4- The communication network that connects the SCADA master unit to the RTUs in the field.

SCADA allows a utility operator to monitor and control processes that are distributed among various remote sites. The goal of using SCADA is to collect data through different types of modules, and control the production methodology [28].

2.5 Electronic devices

2.5.1 Raspberry Pi 3 Model B+

The Raspberry Pi B+ 3 is a small device compared to other similar devices with the same proprieties. It’s called system on chip (SoC); it means that it has an operating system that controls the hardware. One of the important properties that its cost effective for the operations that it provides. It can be used to browse the web or play games, etc.…

The Raspberry Pi B+ 3 is known as a single-board computer, which means exactly what it sounds like. It’s a computer, just like a desktop, laptop, or smartphone, but built on a single printed circuit board.

The Raspberry Pi B+ 3 has a lot of proprieties that have been used to achieve the project goals such as:

1- The Raspberry Pi B+ 3 has several extensions with the main device such as network card, wireless card to ease access to the main device, and it functions without the need to for any additional extensions or programming.

2- The Raspberry Pi B+ 3 has a processor with four cores and very high speed that can reach 1.3 GHz.

3- Memory storage can reach to 256 Gb, and it provides the capability to upload several different programs for the OS to operate with it easily.

4- Different operating systems support the device. Therefore; The main processing unit provides excellent capability to manage different operations, and supports many programming languages and applications without restrictions on the used programming language like Arduino.

5- The device has more than 26 input and output ports in addition to the power outlets.

6- The device Has the capability to connect with other devices like Arduino and has the capability to control them easily.

7- The operating system supports multi-threading for programs that needs parallel operations and that’s what is needed to my application.

such features give the capability to upgrade the project regardless of the type of what new technology might emerge.

2.5.1.1 Performance

1. Hardware

The Raspberry Pi Model B+ third generation has been powered with a 1.4 GHz quad core CPU, dual band 802.11ac, faster Wi-Fi and ethernet but running off a USB 2.0 bus, it can easily be converted to function over a USB 3.0 bus. Also; it supports power over ethernet (PoE).

The Raspberry Pi B+ 3 is developed over the years to work as SoC, the new B+ 3 generation model used, solved two major issues, heat dissipation, and RF emissions, by adding a metal cover to the SoC, and metal shield to the Wi-Fi and Bluetooth circuitry.

2. Networking efficiency

This model has improved the on-board LAN, by replacing the 10/100 controller with 10/100/1000 Gigabit LAN controller. which means; the built-in port is no longer limited to 100 Mbps. Therefore; it can transfer more bandwidth to B+ 3 model to help achieving a real time system. Therefore; we can see that, the Pi B+ 3 generation became faster than any other Pi board. By using iperf measuring which measures network performance shown in Figure 2.2, iperf has client and server functionalities, and can create data streams to measure the throughput between the two ends in one or both directions.:

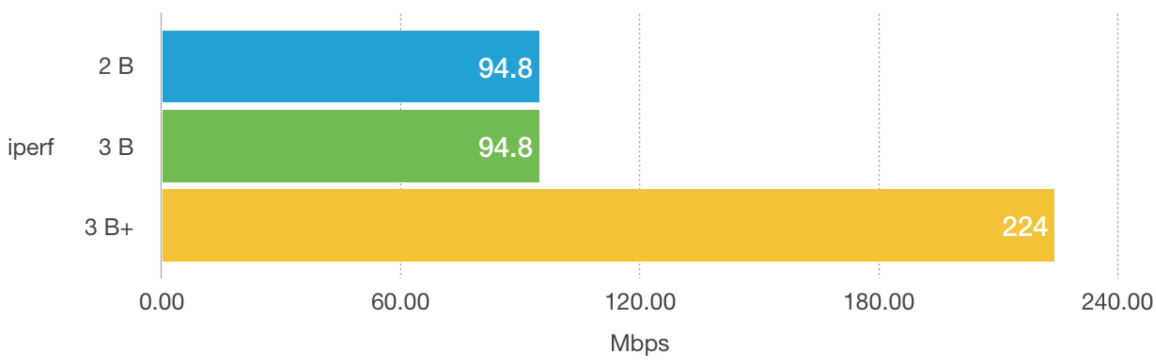


Figure 2.2: iperf -onboard LAN [29].

Similar measuring approach can be performed using iperf on Wi-Fi performance and the result will be shown in Figure 2.3:

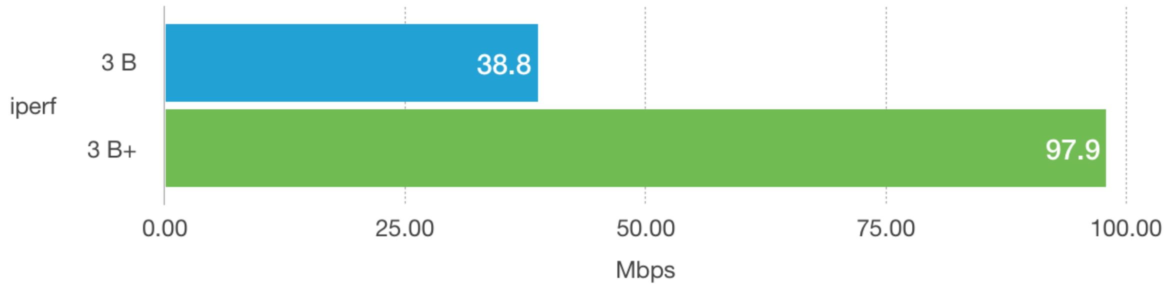


Figure 2.3: iperf -Wi-Fi [29].

3. Power consumption

Using this model instead of previous models can consume a lot of power as shown in Figure 2.4. However; the obtained performance can justify the cost of the consumed power.

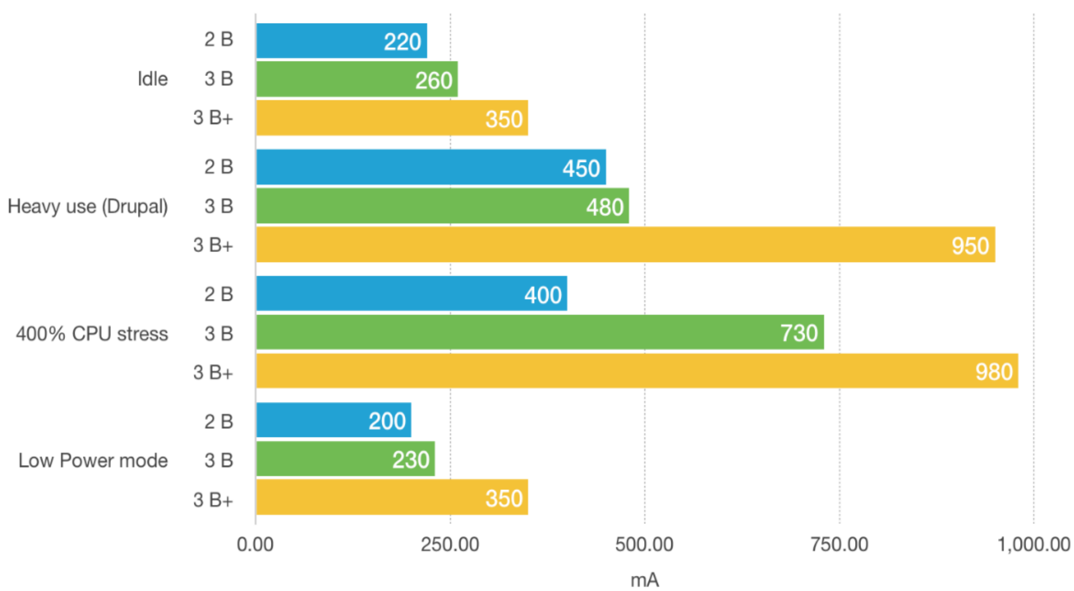


Figure 2.4: Power consumption [29].

2.5.2 Relay module

Relays are not only protection device that are used in different places with a lot of application and operation. They are used as switch devices to control processes or equipment’s. It works to isolate different current levels.

There are different types of relays such as:

1- Electromagnetic relays: These relays are built with electrical, magnetic, and mechanical components, with operating coil and mechanical contacts. When the supply system (AC or DC) works, the coil will be activated, then the mechanical contacts will open or close according to the type of the relay. Normally open or normally closed.

2- Solid state relays: This type of relays is triggered on or off without any need to moving parts.

3- Hybrid relays: These relays are constructed with electromagnetic and electronic components. The input includes the rectification circuit and other control elements, the output includes electromagnetic relay.

4- Thermal relays: This type of relay functionality is heat effective. It means that increasing the temperature to a certain level will trigger the switch to the other position. These types of relays mainly used in motor protection.

5- Reed relays: This type of relay is constructed with a pair of magnetic strips (reed) that is sealed within a glass tube. It acts as armature and a contact blade, the switching operation performed when the magnetic field applied to the coil.

I chose mechanical relays for this application because it is compatible with AC and DC power sources. It has hard separation system. It isn’t affected by current leakage. Therefore; there is no need for a heat sink. it has low cost and the ability to deal with normally open or normally closed contacts [30].

Smart grid lab works on high volts; 220 AC volts and 3 A, while the Raspberry Pi B+ 3 works in low volts 15 DC volts, a mechanism is needed to connect both of them to each other without causing any damage to any component. Never the less; and since multiple input and output ports are used, we decide to use relay modules.

The relay module has the capability to control any electrical appliance. It supports all MCU controls, PLC controls, smart home controls, and the common end COM of each relay is independent, which makes it convenient for users to access different signals. Each relay is equipped with an ON or OFF indicator light. The working status indicator light is good for safe use.

2.6 Related Work

Engineers work as trouble shooters; they have to solve problems in real life and “make things work”. [31] something as remote lab can support that and make it possible, a combination of real lab with hardware module and software can be used to perform a real experiment at any time at any location, Remote labs are also being used to support life-long learning and student's independent learning activities [32].

Nowadays Embedded Systems (ES) are getting more and more complex and require creativity in shortening periods of design time. Under these conditions, the development of systems "from scratch" is not effective. Therefore, one of the key areas to improve the efficiency of ES design is the accumulation of technical solutions for reuse. This idea can be realized by using the Remote Laboratories (RL). materials which contain theoretical background and exercises reusing smart grid lab [33].

A brief overview has been done for state-of-the-art technologies in the development of remote laboratories and presentations of recent and interesting examples of remote laboratories in several areas related to industrial electronics education, some current trends and challenges are also identified and discussed [34].

Low-Cost Remote Lab Platform has been developed. The researcher describes how to create and deploy a low-cost platform for remote control of experiments via web page and a PIC microcontroller from Microchip. Thus, we have a tool easily applied, by plug-and-play method, to optimize the learning and possibly spanning several types of students and institutions.

The platform is based in Microchip Tech.© "PICDEM.net2" commercial. It includes PIC18F97J60 Microcontroller, input/output expansion port, Ethernet connection (RJ-45), 32K bytes EEPROM memory, 2x16 alphanumeric LCD, 4 buttons, temperature sensor, etc.… [35].

Online remote laboratories have been developed and can be shared among universities. This will not only offer the reduction of cost but also the utilization of modern technology that meets expectations of the new generation of students. The researchers present the development of one such laboratory that aims to incorporate renewable generation technologies [36].

Generic or convertible remote labs have been described, which use the new paradigms from Cyber Physical Systems (CPS) and service-based automation for their creation. As a result, any remote lab can be created, operated and utilized simply and quickly via web-based engineering [37].

Working environment of the remote lab consists of Digilent Nexys 2 FPGA platform that is connected with a PC. Students can connect with the remote lab PC through CEyeClon viewer which also need to be installed on their PCs together with each other. The usage of this experiment enables engineering students to achieve practical experiences and skills for designing and simulating digital circuits using FPGA and to better understand and learn theory of designing digital circuits [38].

All the details on the latest addition to the University Network of Interactive Laboratories: a virtual and a remote laboratory of a two electric coupled drive systems have been described. These two new activities allow performing control practices in a 2x2 MIMO system. The virtual and the remote labs are accessible for anyone in a new open course that contains several other experiments in the automatic control field [39].

Chapter 3

Methodology

In this chapter I will discuss the architecture of the system that includes the topology for the prototype, and the flow chart of the system. It will give a clear idea how the system works in both the hardware and the software level.

3.1 System architecture

3.1.1 Prototype topology

The prototype topology is shown in Figure 3.1. The system is divided into two basic categories: the hardware consisting of the Raspberry Pi 3 B+, copper connecters, and relay modules, the software consisting of SCADA system, web application, and Raspberry Pi 3 B+ programming. First, the SCADA should be connected remotely to view the results of each experiment. The web application consists of server and webpage for the connection purpose, and finally the programming of Raspberry Pi B+ 3 to achieve connection between modules, and the relays to interface with power level differences between model items.

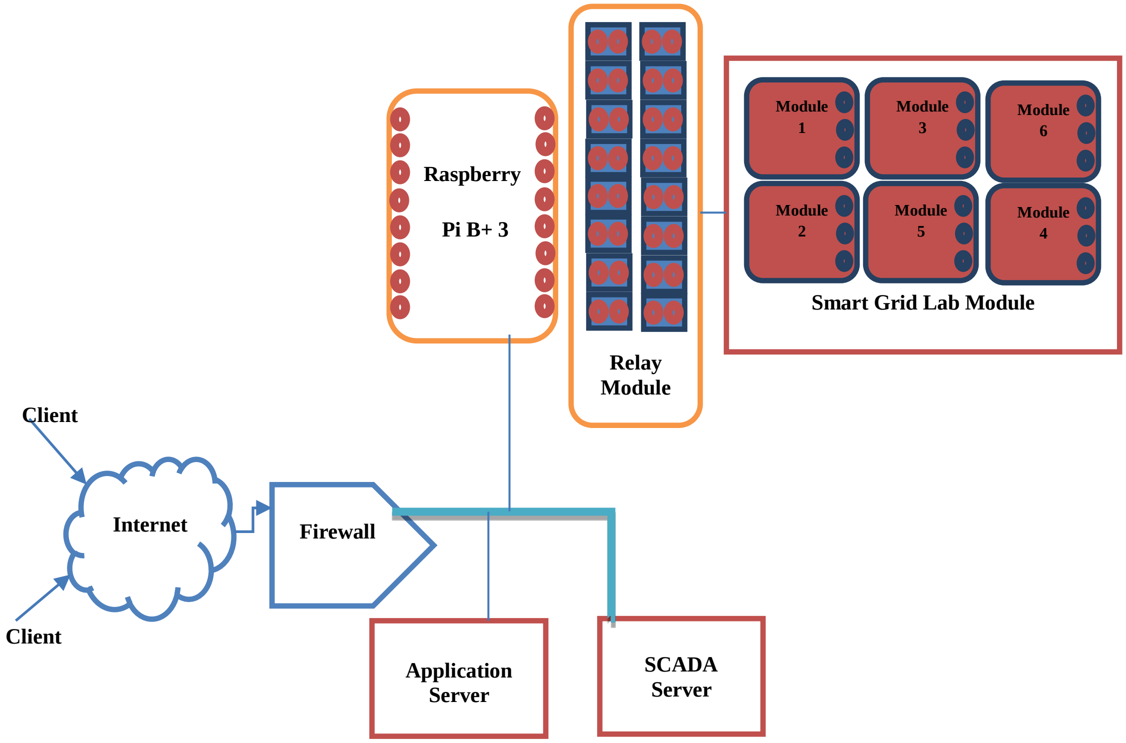


Figure 3.1: Topology of the prototype for the remote lab

3.1.2 System Flow Chart

The Figure 3.2 shows the flow chart of the system. It's divided to subroutines; each one of them contains several operations, as follows:

1- User registration and login: first login, the user register via the web site by connecting to the database, to create a new user on the system. The user information needed to enter include: Email, name, password, study major, mobile number, university or institution name, and the aim of using the lab. The system then sends verification to the email or phone number to make sure that the user is verified. After approving the process, the system changes the user status to become active.

Login is the operation that give us access to the web site by interring the user information. The system will check if the user is active or not, if not the system show a message telling the user to inter a verification code, it will be received through the phone number or email. After accessing the web site, the user can from the homepage check the lab components and the experiment that can be performed, if a user wants to perform an experiment, a date and time should be reserved.

2- Reservation: using this feature enable the users via the website to perform experiments when the lab is available, by choosing specific date and appropriate slots of time, that information will be saved in the scheduling table on database.

3- Select topic: the lab has several topics that includes all components of the smart grid from the electricity production factory to the wind turbine. Each topic covers several experiments. The user can choose any topic of interest to execute its experiments. If the user fails to reserve a date to perform an experiment, a massage will appear to tell him to reserve a date to be able to use the lab as needed. The website provides a procedure file to each experiment.

4- Execution: after downloading the experiment procedure and choosing the experiment, the user will start selecting all modules and connecting them to each other depending on the procedure steps, and after that the user will have to press ON to get the connection. If the connections are correct, the execution will be done in the lab. If not, a fault message will appear to the user asking the user to fix it. After correcting the connections, a message will appear to till the user to go to SCADA page, so the user can see the results and monitor the experiment. The reset option is available to clear the board of all connections to start a new experiment or to restart the current one.

5- Get the result: This operation can be done by using the SCADA webpage, it collects the data, graphs, and numbers so the user can have what is intended from the experiment in the first place.

Finally, if the time session the user reserved is over, the system will display a message to the user showing that the session will expire, and the system will log the user out of the website.

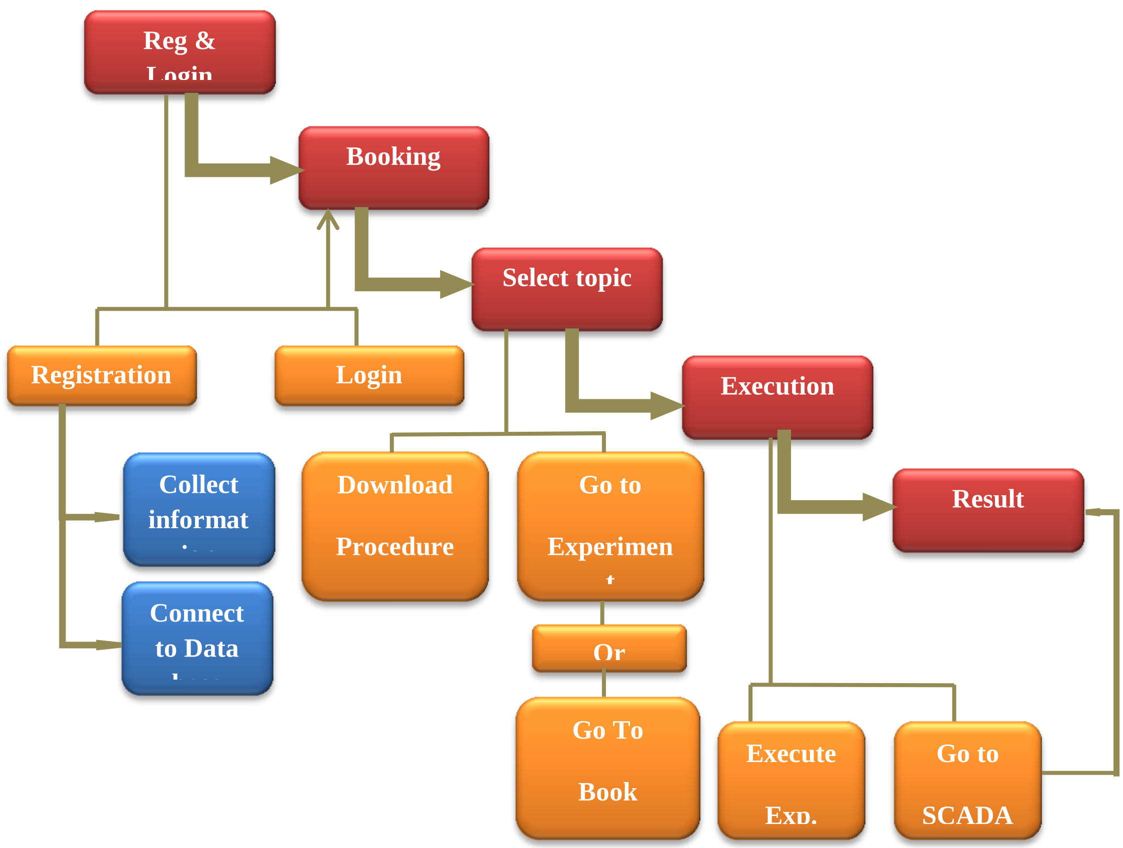


Figure 3.2: System flow chart

Chapter 4

Hardware module

The module attends to be built requires electronic components to complete the work. In the project; lab modules will be needed, the Raspberry Pi B+ 3, and cabling between the Raspberry Pi B+ 3 and the lab modules. A relay module is needed to complete the connection between the Raspberry Pi B+ 3 and the module due to the voltage and current difference between both units, so the website can operate the connection remotely. Finally, the SCADA needs to converted so it can run over Ethernet to get the experiment results.

The model hardware consists of:

1- Controller/ SoC
2- Wires
3- Interface method
4- Lab modules

First Stage: Installing an operating system on the Raspberry Pi B+ 3 which supports different operating systems such as Windows, and Linux. Linux system has been chosen, it works without back ground operations, so a lot of power will be saved during the Raspberry Pi B+ 3 operation, which make the device more efficient for real time applications. Also, Linux supports web server programs.

Second Stage: installing Node.JS as a web server, because it works as asynchronous request and response to make the server achieve real time systems.

Third Stage: Raspberry Pi B+ 3 contains 40 GPIO interfaces, which allows to control a lot of modules with different properties and different types of inputs and outputs, the processor works with those pins using input/output drivers, which are implemented by the server. It also controls those pins using code that is implemented on the server. Those pins work in parallel. which means, the processor can activate them together.

Forth Stage: Raspberry Pi B+ 3 is connected to the Internet using ethernet and Wi-Fi. Controlling Raspberry Pi B+ 3 using a program over a network (VNC), which gives administrator privileges on the system, so it gives the ability to connect to the Raspberry Pi B+ 3 directly, the system can be operated over internet, which makes the system flexible and maintainable over the Internet.

Fifth Stage: Considering different power levels with the lab modules and the Raspberry Pi B+ 3, a relay module has been used to solve the problem, and I chose a mechanical relay module to give the model hardware safety through operation. The relay module terminals will be connected with the Raspberry Pi B+ 3 and lab modules.

The relay module has led indicators, so it can give an indication if the relay is active or not, and it can give an indication if there is any fault occurring in the module's pins.

Sixth Stage: Start making connections between the interfaces and the lab modules using different types of wires that can handle high voltage and ampere without causing any damage to the lab modules or the Raspberry Pi B+ 3. This give the lab the ability to work for several days without fear of high load that might occur, each output and input on each lab module connected to one of the GPIO on Raspberry Pi B+ 3 board, it is also identified on the programing with the name of each module and it's outlets as shown in Figure 4.1 below, also each one of those outlets connected to a relay module pines to balance power levels between all the lab components.

```
"DL 1017L": {
  "DL 10065N": {
    L1: pin4,
    L2: pin5,
    L3: pin6,
    N: pin8
  }
},
```

Figure 4.1: GPIO identifications for lab modules.

Chapter 5

Software module

Remote smart grid lab model requires multiple components to set it up, such as; software that will give the ability to connect the lab modules with each other via Raspberry Pi B+ 3 module. However, and to be able to connect the modules to the Internet, a proper interface will be needed.

5.1 Remote Smart Grid Application Software

The software I intend to build has specific architecture, which makes it suitable for public use. Web servers will host the web application and process the requests.

5.1.1 Web Server

A web server is the hardware part that will host and run a combination of software's that will operate websites. It will enable and facilitate the process of incoming requests through different protocols (HTTP, HTTPS, …. etc.). Nevertheless; it can also serve as data storage, in addition to processing and delivering web pages.

"Node.js" is an open source web application, that is a cross-platform and is capable of executing JavaScript code in a run-time environment outside a browser. It can handle a huge number of simultaneous connections with high throughput, so it can deal with all module's outlets with Realtime situation.

Another software application on the web server; is the JavaScript run-time environment which executes JavaScript code outside a browser. It’s a lightweight application and perform efficiently when handling data-intensive Realtime applications. Therefore; it enables us to build fast, scalable and Realtime network applications.

5.1.2 Data transmission to the server

HTTP (Hyper Text Transfer Protocol) is a method for encoding and transporting information between a client (such as a web browser) and a web server. It runs at the application level layer protocol. It uses TCP (Transmission Control Protocol) to communicate over Ethernet network, using URL (Unique Resource Locator) which enable it to identify web server resource across the Internet. It also uses angular-7 to send requests to Node.JS using HTTP requests.

5.1.2.1 Why Angular-7 with Node.JS

Angular-7 is compatible with Node.JS as both uses java script framework, which gives the power to run Realtime scalable remote lab.

5.1.2.2 JSON (JavaScript Object Notation)

JSON is a lightweight format for storing and transporting data. It is used when data is sent from a server to a web page. It is preferred to use JSON because its "self-describing" and easy to understand. It works by storing an array of key, value, and send it in one JSON object to the server. The Figure 5.1 shows JSON document of connection data.

```
▼ (4) […]
  ▼ 0: {…}
      sinkName: "DL 1017L"
      sinkPort: "L3"
      sourceName: "DL 10065N"
      sourcePort: "N"
    ▶ <prototype>: Object { … }
  ▼ 1: {…}
      sinkName: "DL 9031(g2)"
      sinkPort: "Gnd"
      sourceName: "DL 10065N"
      sourcePort: "L3"
    ▶ <prototype>: Object { … }
  ▶ 2: Object { sinkName: "DL 9031(g2)", sinkPort: "L1", sourceName: "DL 10065N", … }
  ▶ 3: Object { sinkName: "DL 9031(g1)", sinkPort: "L2", sourceName: "DL 10065N", … }
    length: 4
  ▶ <prototype>: Array []
```


Figure 5.1: JSON document of connection data.

5.1.3 Web interface

Is the client side accessed through a web browser in the form of HTML language, CSS style sheet and Java Scripts, A combination of (HTML, CSS, JS) gives the user an interactive interface which makes the webpage easy to explore. In order to use this combination in an optimal way:

The use of front-end framework gives the ability to achieve an organized work in a simple way.

This concept can be applied by using angular 7 framework which provides real-time framework which in turn enables us to build a friendly user interface closer to real experiment environment.

5.1.3.1 Angular 7

Angular 7 is a leading typescript based on open source framework for front-end application development. Also; typescript is a superset of JavaScript which primarily provides optional static typing, classes and interfaces. Using angular 7 as framework will include a handy resource for utilizing HTML templates, delivering dependency injection and assembling data services for applications.

In addition, it offers a long list of other significant features and benefits such as:

1- Enhanced application performance

2- Progressive Web Apps

3- Code Splitting into (Component, service, pipe and directive)

4- Structured build like photo.

The Figure 5.2 below shows the Structure of angular 7, each file defined with lab modules names, and each file has defined all outlets on it. At the end, angular 7 is very suitable for the model that has been built, it gives the application the ability to deliver a real environment about what happen in a real lab.

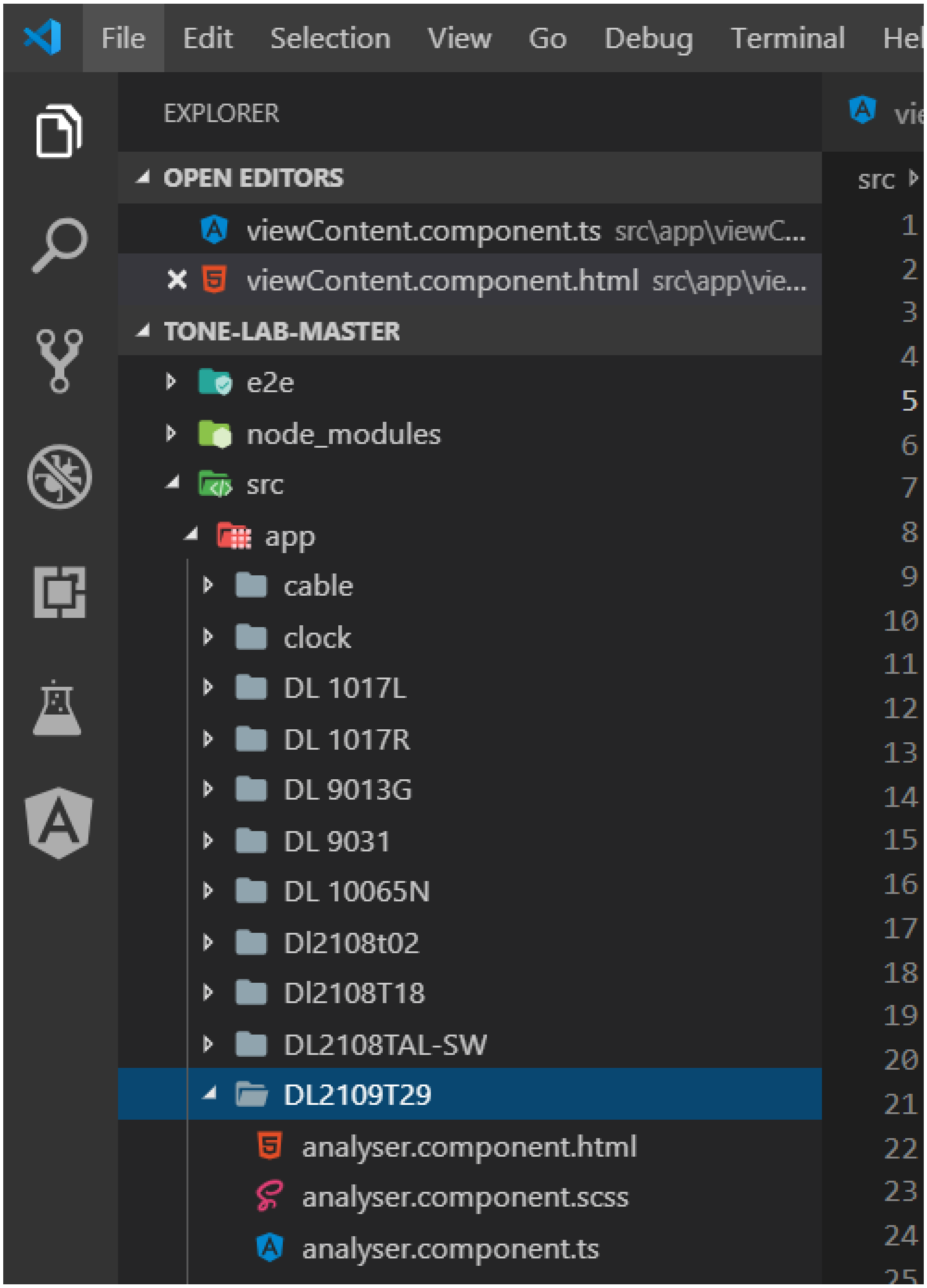


Figure 5.2: Structure of angular 7.

5.1.4 Data Base

A Realtime database has been chosen, it’s called firebase database, which is a cloud-hosted NoSQL database with SDK support for iOS, Android, and the web. It is used to store user’s names, information, and lab occupation schedule, the data which is stored as JSON. The database has a lot of capabilities such as:

- Realtime: The database does not use HTTP requests, the database has Realtime property which uses data synchronization, when any modification occurred, any connected devices will receive all those changes in milliseconds.
- Offline: The firebase has the ability to track all changes even when offline, as the database saves the data to disk, and when the connection is reestablished again the client will receive all changes and modifications.
- Accessibility: No need for application server to make any modification on the system, firebase Realtime database can be accessed directly from any mobile device or web browser, the security rules can provide security and data validation, those rules are executed when data is read or written.
- Scale across multiple databases: The database provides the ability to support data needs at scale by splitting the database to multiple database instances in the same firebase project, the authentication process becomes simpler.
- Data types: Realtime database has no definition of data types, it can deal with all data types, it allows the user to save values as strings or numbers, or as nested and arrays of strings and numbers to any field the user wants.

It was the most proper database used for my application. It gave the system the ability to send check massages through the phone or email for confirming the users who registered on the system.

The system can track multiple streams of data in Realtime, it gives the ability to make a lot of writing and reading, so any huge modification can be performed easily without the need to reboot or waiting for modification upload, it can be done while the lab is in use.

Chapter 6

Integration Method

6.1 Communication Methods: 3G/Wi-Fi/Ethernet

3G is the third generation of communication. It's the update of the previous method to communicate. It has the ability to establish fast Internet connection. It is used with mobile phone communication. Also, we can use Wi-Fi connection or ethernet, Wi-Fi depends on wireless connection, and ethernet depends on wire connection. No matter which way users try to reach the system, the most important thing is the ability to establish fast data transmission to achieve real time system, and my system supports that.

This communication method has been used several times, to access Raspberry Pi B+ 3 through (VNC) over internet, to establish remote connection to the SCADA over internet, and to access the website.

6.2 Accessing SCADA Remotely

SCADA is one component of the smart grid lab. It used to real, collect data, and show results. To complete converting the lab to remote lab, SCADA is needed to be accessed remotely through ethernet. SCADA has additional software to establish a remote access. There are two settings to access the lab over ethernet with local network using LAN setting in the software and, it's property that the software provides it to users, and the other with an outside network. WAN setting has been used to reach the software through the Internet from outside local network, the following setting must be chosen:

1- Open project manager, choose the topic to establish a connection, smart grid has been chosen using the right click, web project creation will appear as illustrated in appendix A (Figure 1).

2- Choose the template that the user wants to convert and publish. A copy of smart grid will appear on the other side as illustrated in appendix A (Figure 2).

3- After choosing the templates intended to be used, must enter LAN/WAN setting to publish the web project. By adding HTTP server network IP address, and TCP ports for both HTTP server, and web server, the conversion will start as illustrated in appendix A (Figure 3).

4- On the right of the smart grid, Click and choose test web project, the connection to Winlog will be established, and the port will be ready to get accessed remotely as illustrated in appendix A (Figure 4).

5- On the other side, a client SCADA file will appear, so the client can access the system remotely and can get all the results the user wants from the experiments as illustrated in appendix A (Figure 5).

Chapter 7

Model Testing and Results

7.1 Testing

Model testing has been performed at each stage of the hardware and software development, to ensure that all model required components are installed and correctly function without causing any damage to lab modules nor to the Raspberry Pi B+ 3.

Hardware Testing

The hardware includes the smart grid lab, Raspberry Pi B+ 3, high voltage relay modules, user interface, and electrical copper connectors. The experiment executed remotely as the last step of the thesis, to make sure the results comes out as expected, all the steps of the experiment executed remotely are explained in appendix B.

Smart grid lab experiment

Two experiments have been chosen; as it requires a few modules and a few connections to build a medium size model, not to mention; no human intervention is needed. The experiment has been performed to understand the mechanism the lab works on, and to understand the needed components.

Hardware interface test

Raspberry Pi B+ 3, relay modules, and Electrical copper connectors have been used to connect between experiment modules, relays, and the Raspberry Pi B+ 3. 2.5 mm^2 Copper connectors have been chosen based on the lab manual recommendation to perform the required work at 3 Amps current and 220 AC voltage. Also; a relay has been used to avoid causing any damage to the Raspberry Pi B+ 3 module, the interface between experiment components has been tested to make sure, every connection has been built, is working correctly without causing any harm, and all components work perfectly with each other.

7.2 Results

Later according to thesis goals, I established a device that can control the lab I chose remotely. The first step was to choose the lab to control it through ethernet, the smart grid lab was the most suitable lab for its importance and it was categorized as a research lab. Then I have to choose a device that establish remote control. A number of devices appears suitable for this goal, but Raspberry Pi B+3 has all what I need at a cheap cost, small size model, and few extensions.

The first step was to perform a suitable experiment in a real lab, then connect them through the website, during performing the experiment, the results obtained was right, the measuring units and SCADA gave me correct measurements.

Repeating another experiment at the lab. achieved the same results. The remote lab worked probably without causing any troubles. If all labs are to be converted to remote one's, extra extensions will be needed, to be connected to Raspberry Pi B+3 with the same programming language but by adding the rest of the modules to the website.

The website is capable of connecting the modules to each other, and give each experiment procedure, clear the connections if any mistake might occur, and get the results from SCADA software.

7.3 Evaluation

7.3.1 Limitation

During the different phases of this research and model implementation, many challenges have been encountered. These limitations are:

- "FPGA DE10 standard" has been tried to use, which uses the matrix principle, to connect all modules through the same board without the need for additional boards, but the complexity of setting up the module and the lack of resources to establish a server and program the module, made it impossible to use.
- The shipping of "FPGA DE10" took a long time, so the latency of "FPGA DE10" made it difficult to take the right decision to continue with FPGA module or to move on and search for an alternative module.
- Using real IP's can be subject to security policy at various institutions. Such policies my pause limitations on accessing the smart grid lab remotely.
- The Raspberry pi B+3 has limited number of ports, which can serve only one remote experiment. Multiple remote lab experiments will require board extensions or additional Raspberry boards.
- Some modules can't be easily controlled, they need actuators like potentiometers.
- One user only can access and use the system for each session.

7.3.2 Software Testing

The connections formation of the experiment performed on the webpage, will send the data to Raspberry Pi B+3. The Raspberry Pi B+ 3 will execute the data and connect modules to each other, once all the connections are done in the right way, the user will be able to press the GO to SCADA button; which will get all the measurements of the experiment , this way will ensure that the system built will work correctly refer to appendix C, a server on Raspberry Pi B+ 3 has been established, and the identification of each lab module has been identified, each output and each input in those modules have been identified. Connection between the Raspberry Pi B+ 3 server and the website is established to execute all user requests.

Appendix D include brief programing about front end include all configuration that is done on the website.

7.3.2.1 WEB Pages

The home page will enable the user to login by entering the user name or e-mail and the password as shown in Figure 7.1. once the user is logged in, the user will then move to the main page, which will give him access to the modules as needed.

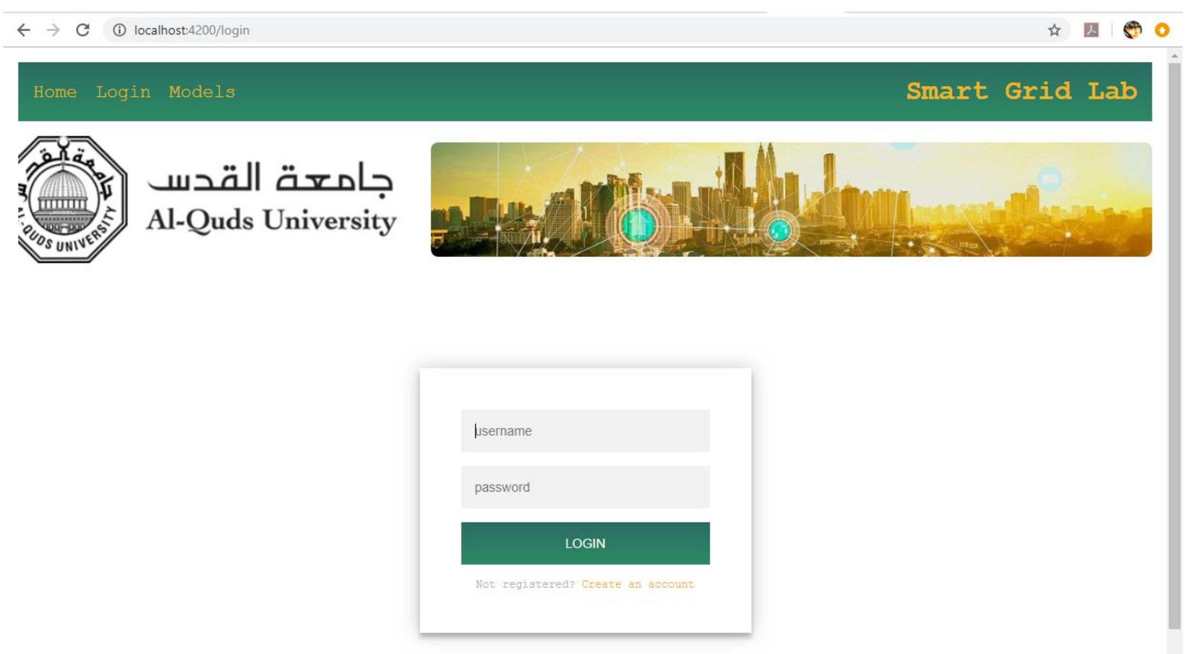


Figure 7.1: Login page screenshot.

After entering the user information, the website will login the user to the experiments list and will provide brief information about each section, as shown in Figure 7.2.

Figure 7.2: Main page screenshot.

7.3.2.2 Reservation Schedule

When the user logs in, and tries to access an experiment, the system will show a message to reserve a date on the website schedule so the user can perform an experiment whenever the user wants and when the lab is available.

The system will provide a calendar in Figure 7.3 to assist the user to select the suitable and available dates in Figure 7.4 and time sessions to reserve the lab in Figure 7.5, so the user can perform an experiment.

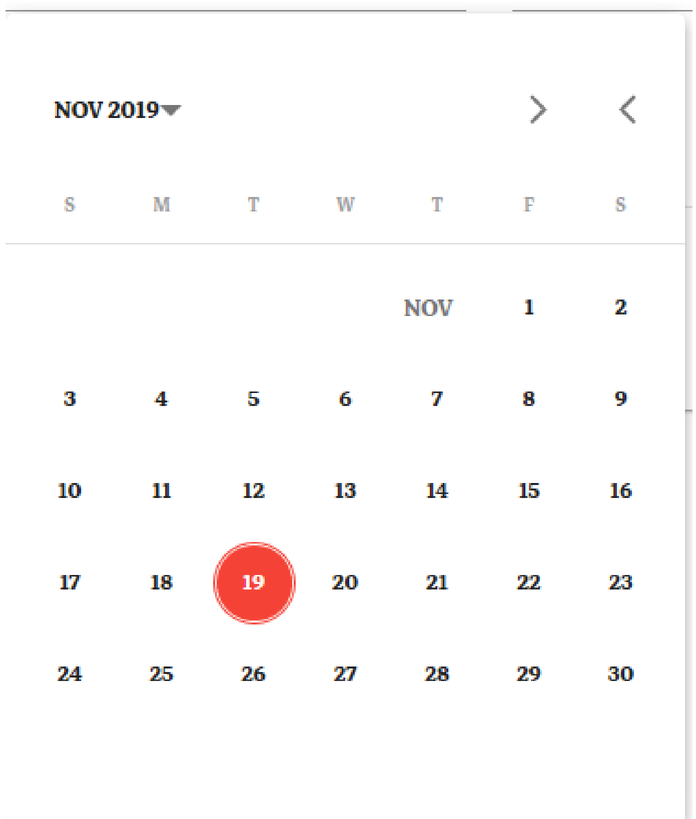


Figure 7.3: book calendar.

No.	Date	TimeSession
1	10-11-19	9:00-10:00
2	10-11-19	10:00-11:00
3	10-11-19	12:00-13:00

Figure7.4: screen shot of book time session.

StartTime	EndTime	TimeSession
9:00	10:00	UnBook
10:00	11:00	UnBook
11:00	12:00	Book

Figure7.5: screen shot of book and unbook schedule.

After having a suitable date and starting the implementation on the website, the user session will remain open until the reserved time ends, after that the system will display a message so the user will end the session because the reserved time has expired as shown in Figure 7.6.

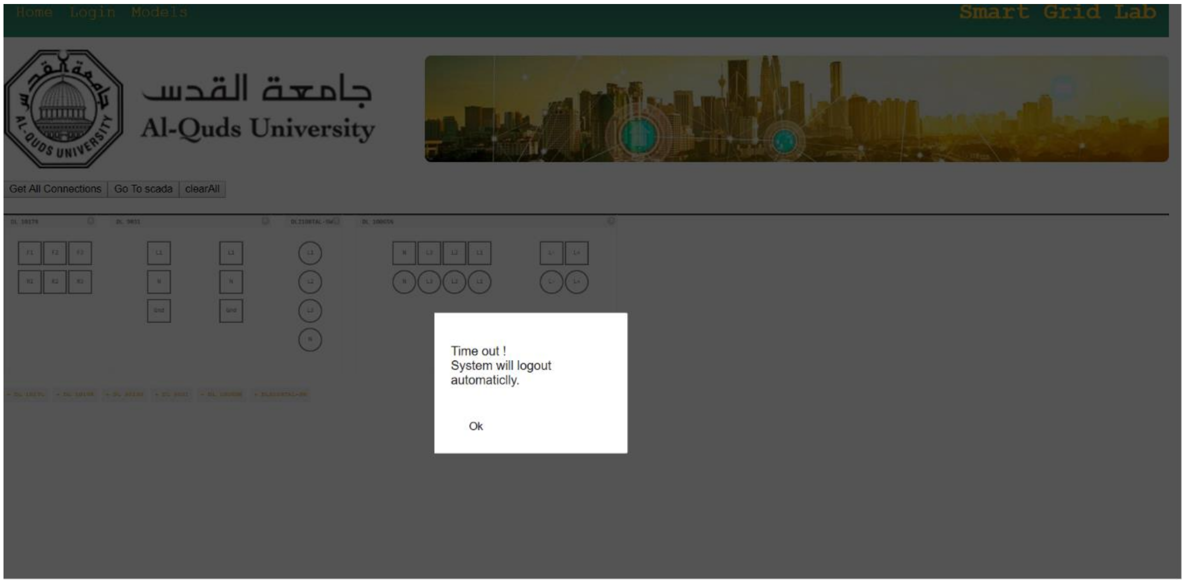


Figure7.6: screen shot of time out session.

7.3.2.3 User page

Once the user enters the login data, the website will move to the main page. By pressing any lab category, the user will move to the list of experiments as in figure 7.7, and each experiment has a PDF file that contains the procedure, objectives and requirements.

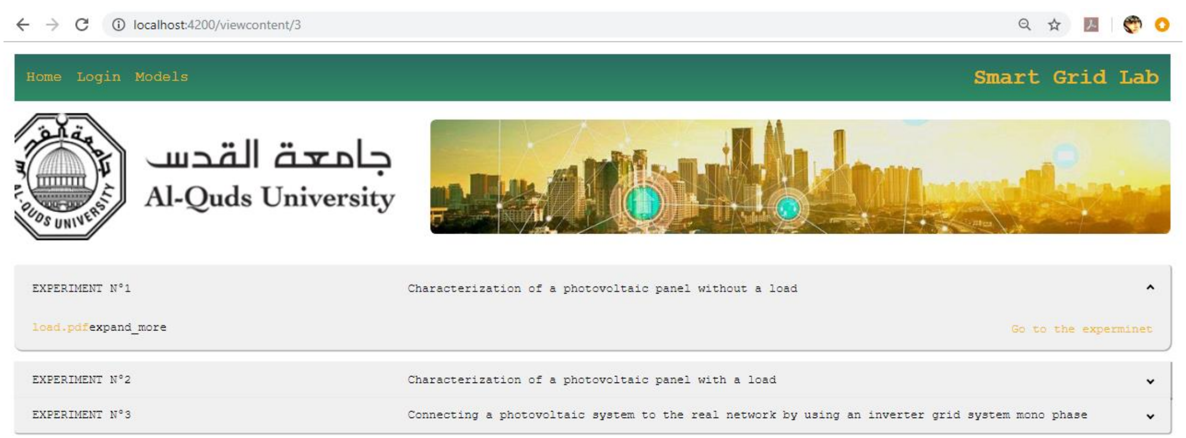


Figure7.7: screen shot of experiment list to one lab category.

7.3.2.4 Module connector

When the user presses any experiment, the webpage will move to the corresponding module page. The user can choose the appropriate modules and initiate the connection. The webpage will send the matrix of connections to Raspberry Pi B+ 3 to execute all the instructions at once as in Figure 7.8.

After the execution is done, and all the connections are ready. the user can continue to SCADA in order to get the results and measurements of the experiment.

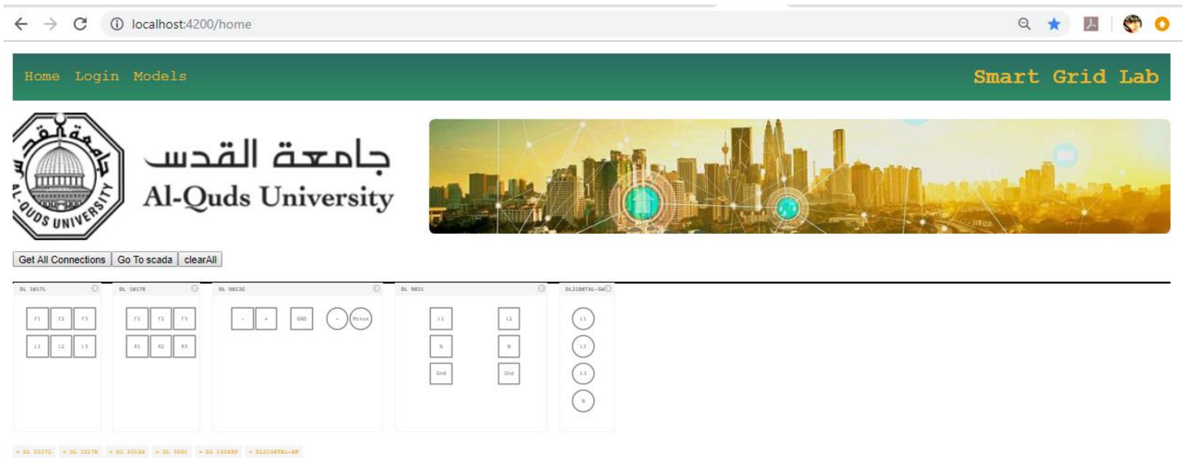


Figure7.8: Experiment module page.

7.3.3 Features of the model

1. Flexibility

The built system can help researcher and students to access labs at any time needed. the model can be modified at any time without causing the system to crash.

2. Availability

To get access to labs at any time users need it.

3. Reliability

Any modifications to the model can be implemented while the lab is running without causing any failure to the system.

4. Real-time

The system can control and monitor labs within critical times, Hardware and software real-time synchronization reflect the execution of software instruction by the hardware as it's happening on the web interface.

Software Real-time: Data instructions received from the web interface implemented by the hardware components simultaneously

Hardware Real-time: the SCADA receive instructions from the web interface to be implemented simultaneously.

5. Benefits of relevant users

Research institutions can benefit from other research institutions lab facilities.

Students can access study material for exams without the need to be physically present at the lab, the data can be archived for future use. Also; experiments can be re-done many times if the results are not satisfactory.

Researchers can gather all data they need from any lab at any location all over the world.

7.4 Discussion

In my discussion about remote labs, many strategies have been adopted. The concept of remote labs, its benefits over the years, and the related applications that remote labs was built on it.

The 1st used application for remote labs was the low-cost PIC system; unfortunately; it had limited features.

As time passed by, PIC system has been improved and more developed in which multiple modules can be connected and operated.

Remote labs have been used in many aspects other than engineering labs, such as physics labs, … etc.

MIMO has been adapted in additional developments to remote labs to achieve affective connection and fast communication through the Internet and websites.

As a result, in my research, the used lab has been carefully chosen to achieve maximum benefits. Never the less; the model built, modified all the labs to remote labs that can be operated through a website from any location, achieving the needed results.

The model has been constructed with minimum devices at a low cost. As a result; the model has achieved the required goals, and the website simulates the real lab connection that help the users simulate the real lab connection.

Chapter 8

Conclusion and future work

8.1 Conclusion

The thesis proposes an online remote lab that can be operated any time from any location around the world. The users will get the opportunity to benefit from labs, using Raspberry Pi B+ 3 generation board, and 3G/Ethernet/WIFI connection technology. The main components of the proposed system are Raspberry board, SCADA, web server, and web Interface.

The labs operate on demand at any time the users can access the web interface to login to the webpage and start performing experiments on lab modules. The board gives the ability to connect modules with each other, by using the simulated modules on the webpage, and when finishing the experiment, the results can be obtained from the SCADA application.

The thesis discusses the planning process, experimental configurations of hardware and software. Results of this thesis prove the feasibility of capturing data using a remote system, and visualizing the information in real-time. The hardware and software are proven to be successful for meeting the goals set for this research.

8.2 Future Work

In future development of the proposed system I suggest some ideas that can be considered in any future work:

- Building a hardware device that can control actuators like resistors to convert the lab to be fully remote controlled.
- Using a dedicated server with real IP just for remote labs to be fully operated from outside any campus or lab facility.
- Using boards with more GPIO’s to convert all the labs to remote labs that can conduct more different experiments within the same lab.
- Using boards with matrix principle such as FPGA.

References

[1] https://www.labwork.com.hk/

[2] Barrios, A., Panche, S., Duque, M., Grisales, V. H., Prieto, F., Villa, J. L., ... & Canu, M. (2013). A multi-user remote academic laboratory system. Computers & Education, 62, 111-122.

[3] Cardoso, A., Sousa, V., & Gil, P. (2016). Demonstration of a remote control laboratory to support teaching in control engineering subjects. IFAC-PapersOnLine, 49(6), 226-229.

[4] Hernandez-Jayo, U., & Garcia-Zubia, J. (2016). Remote measurement and instrumentation laboratory for training in real analog electronic experiments. Measurement, 82, 123-134.

[5] Rojko, A., Hercog, D., & Jezernik, K. (2011). E-training in mechatronics using innovative remote laboratory. Mathematics and Computers in Simulation, 82(3), 508-516.

[6] Dai, S., Song, Z., & Jia, R. (2010, June). Web based fluid mechanics experimental system. In 2010 International Conference on Electrical and Control Engineering (pp. 3134-3137). IEEE.

[7] Irmak, E., Bayindir, R., Colak, I., & Soysal, M. (2011). A remote laboratory experiment for 4- quadrant control of a DC motor. Computer Applications in Engineering Education, 19(4), 747-758.

[8] Carpeño, A., Contreras, D., López, S., Ruiz, M., Sanz, D., de Arcas, G., ... & Castro, R. (2016). 3D virtual world remote laboratory to assist in designing advanced user defined DAQ systems based on FlexRIO and EPICS. Fusion Engineering and Design, 112, 1059-1062.

[9] Villar-Zafra, A., Zarza-Sánchez, S., Lázaro-Villa, J. A., & Fernández-Cantí, R. M. (2012, July). Multiplatform virtual laboratory for engineering education. In 2012 9th International Conference on Remote Engineering and Virtual Instrumentation (REV) (pp. 1-6). IEEE.

[10] https://www.delorenzoglobal.com/

[11] Giordano, V., & Bossart, S. (2012). Assessing smart grid benefits and impacts: eu and us initiatives. Joint report of EC JRC and US DOE, JRC, 73070.

[12] Rahimi, F., & Ipakchi, A. (2010). Demand response as a market resource under the smart grid paradigm. IEEE Transactions on smart grid, 1(1), 82-88.

[13] Berger, L. T., & Iniewski, K. (2012). Smart grid applications, communications, and security. John Wiley & Sons.

[14] Vijayapriya, T., & Kothari, D. P. (2011). Smart grid: an overview. Smart Grid and Renewable Energy, 2(04), 305.

[15]Qdr, Q. J. U. D. E. (2006). Benefits of demand response in electricity markets and recommendations for achieving them. US Dept. Energy, Washington, DC, USA, Tech. Rep.

[16] Safdarian, A., Degefa, M. Z., Lehtonen, M., & Fotuhi-Firuzabad, M. (2014). Distribution network reliability improvements in presence of demand response. IET Generation, Transmission & Distribution, 8(12), 2027-2035.

[17] Brooks, A., Lu, E., Reicher, D., Spirakis, C., & Weihl, B. (2010). Demand dispatch. IEEE Power and Energy Magazine, 8(3), 20-29.

[18] Greening, L. A. (2010). Demand response resources: Who is responsible for implementation in a deregulated market?. Energy, 35(4), 1518-1525.

[19] GRID, S. (2009). ENERGY STORAGE–AKey ENABLER OF THE SMART GRID.

[20] Bliek, F., van den Noort, A., Roossien, B., Kamphuis, R., de Wit, J., van der Velde, J., & Eijgelaar, M. (2010, October). PowerMatching City, a living lab smart grid demonstration. In 2010 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe) (pp. 1-8). IEEE.

[21] Zavoda, F. (2010, September). Advanced distribution automation (ADA) applications and power quality in Smart Grids. In CICED 2010 Proceedings (pp. 1-7). IEEE.

[22] Chen, Xuemin & Song, Gangbing & Zhang, Yongpeng. (2010). Virtual and Remote Laboratory Development: A Review. 10.1061/41096(366)368.

[23] Maiti, A. (2016). Enabling peer-to-peer remote experimentation in distributed online remote laboratories (Doctoral dissertation, University of Southern Queensland).

[24] Li, Y., Esche, S., & Chassapis, C. (2007). An Architecture for Real-Time remote Laboratories. Proceedings of the American Society for Engineering Education 2007

Conference & Exposition. Retrieved November 2, 2012 from asee.org through the links Publications, Papers and Conference Proceedings.

[25] Krutz, R. L. (2005). Securing SCADA systems. John Wiley & Sons.

[26] Tabish, A. N., & Abbas, S. Z. Process Dynamics and Control.

[27] Mackay, S., & Fisher, D. (2008). The Impact of Remote Laboratories in Improving Blended Learning in the Science and Technology Arena. Science Mathematics and Technology Education: Beyond Cultural Boundaries, 367.

[28] Li, Y., Esche, S., & Chassapis, C. (2007). An Architecture for Real-Time remote Laboratories. Proceedings of the American Society for Engineering Education 2007 Conference & Exposition. Retrieved November 2, 2012 from asee.org through the links Publications, Papers and Conference Proceedings.

[29] https://www.jeffgeerling.com/blog/2018/raspberry-pi-3-b-review-and-performance-comparison.

[30] Denno, K. (1994). Electric Protective Devices: Protection with Energy Saving. McGraw-Hill Companies.

[31] Frerich, S., Kruse, D., Petermann, M., & Kilzer, A. (2014, April). Virtual labs and remote labs: practical experience for everyone. In 2014 IEEE Global Engineering Education Conference (EDUCON) (pp. 312-314). IEEE.

[32] Gomes, L., & Bogosyan, S. (2009). Current trends in remote laboratories. IEEE Transactions on industrial electronics, 56(12), 4744-4756.

[33] Parkhomenko, A., Sokolyanskii, A., Gladkova, O., & Kurson, S. (2015, September). Investigation of remote lab design technologies. In 2015 XI International Conference on Perspective Technologies and Methods in MEMS Design (MEMSTECH) (pp. 92-95). IEEE.

[34] Gomes, L., & Bogosyan, S. (2009). Current trends in remote laboratories. IEEE Transactions on industrial electronics, 56(12), 4744-4756.

[35] Campos, B., Angulo, I., Dziabenko, O., Orduna, P., Rodriguez, L., & Garcia-Zubia, J. (2012, July). Easily deployable low-cost remote lab platform. In 2012 9th International Conference on Remote Engineering and Virtual Instrumentation (REV) (pp. 1-4). IEEE.

[36] Nedic, Z., & Nafalski, A. (2015). Development of Online Power Laboratory with Renewable Generation. International Journal of Online Engineering, 11(3).

[37] Langmann, R., & Jacques, H. (2016, April). Generic remote labs in automation engineering. In 2016 IEEE Global Engineering Education Conference (EDUCON) (pp. 130-135). IEEE.

[38] Luković, V., Krneta, R., Damnjanović, Đ., & Peulić, A. (2017, June). The remote lab “Nexys 2 FPGA platform” aimed for learning design of digital circuits. In 2017 4th Experiment@ International Conference (exp. at'17) (pp. 101-102). IEEE.

[39] Saenz, J., Chacon, J., de la Torre, L., Visioli, A., & Dormido, S. (2015, July). A virtual and remote lab of the two electric coupled drives system in the university network of interactive laboratories. In 2015 American Control Conference (ACC) (pp. 5623-5628). IEEE.

Appendix A

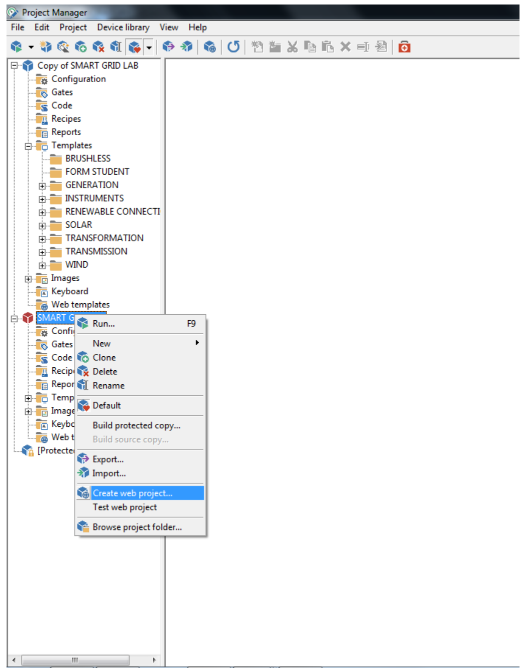


Figure (1): create web project.

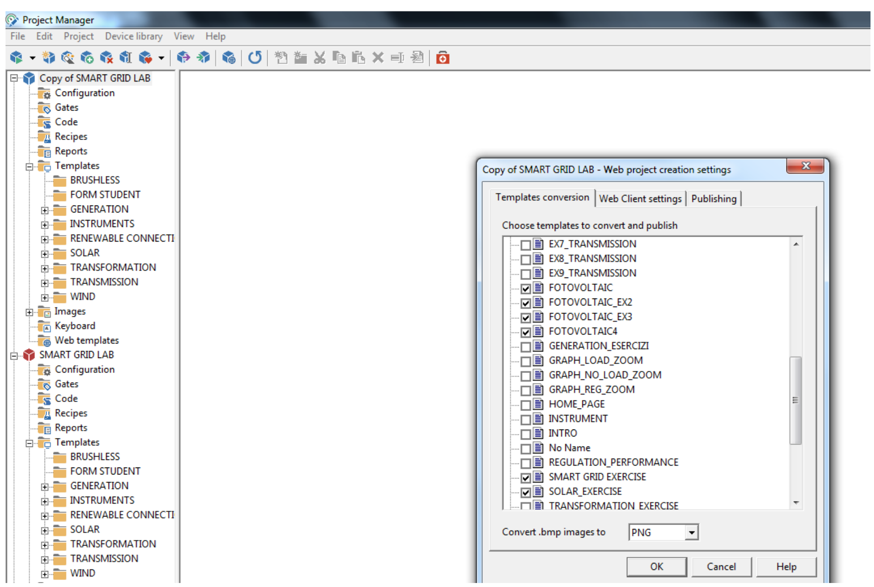


Figure (2): web project creation setting.

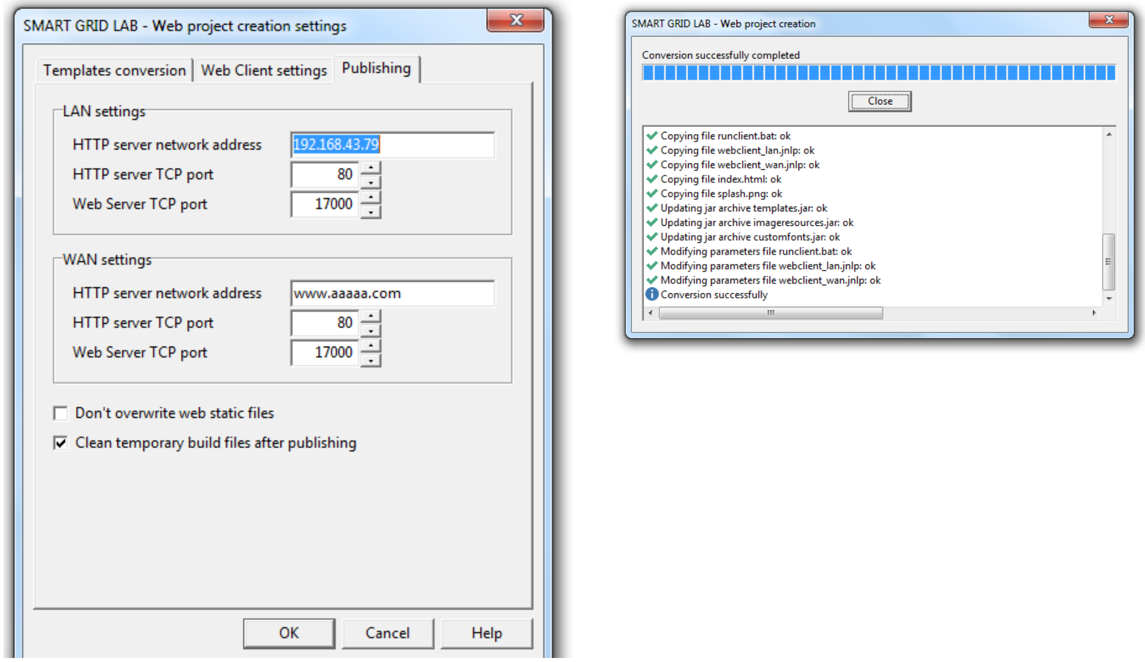


Figure (3): publishing setting and conversion.

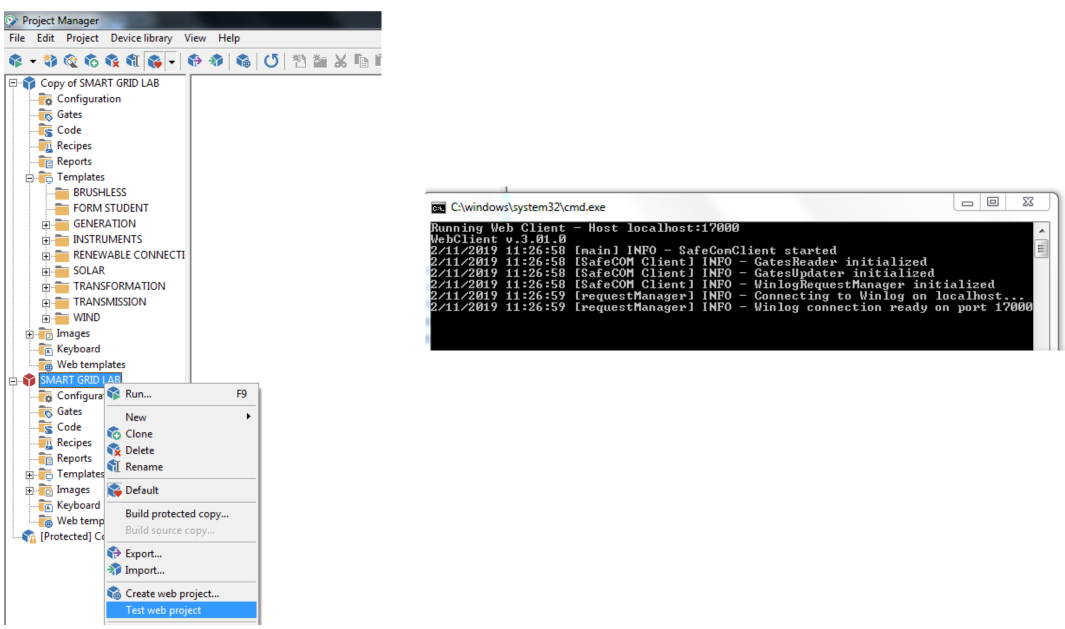
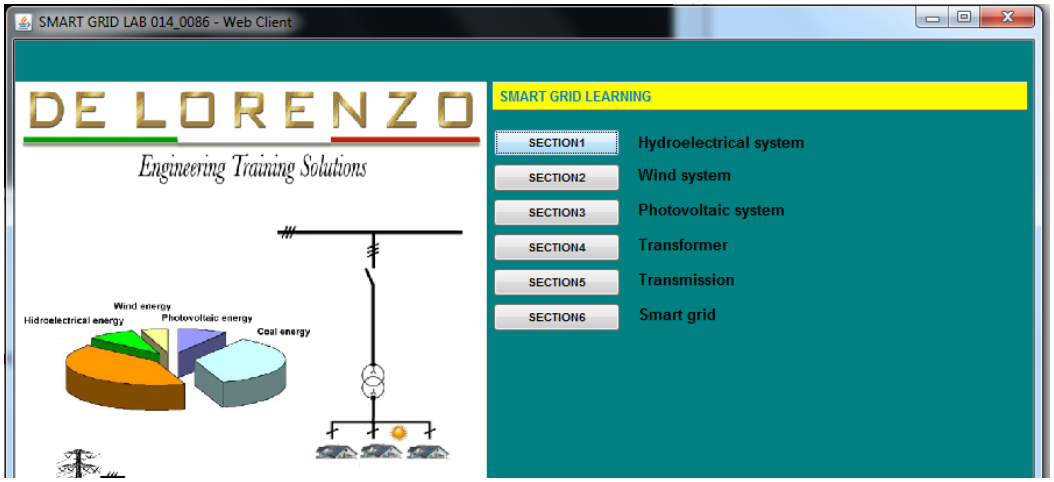


Figure (4): Testing & establish remote access.



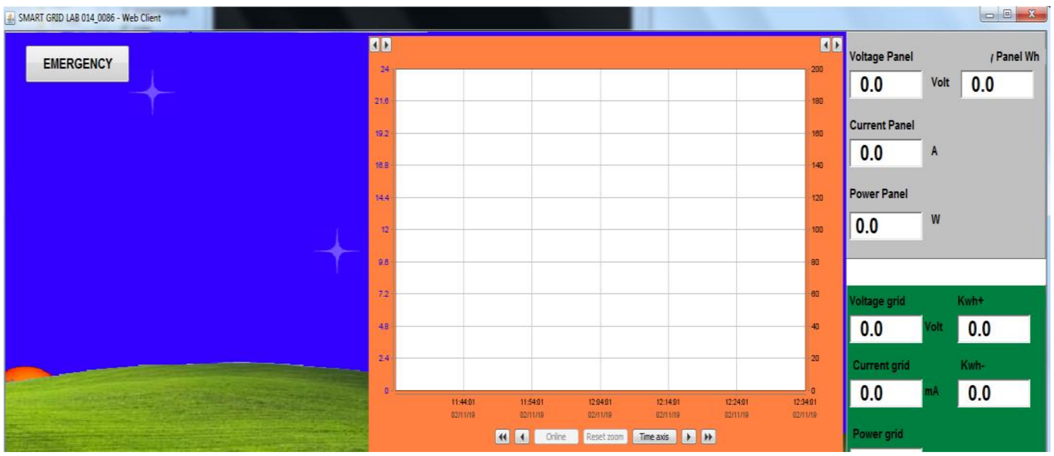
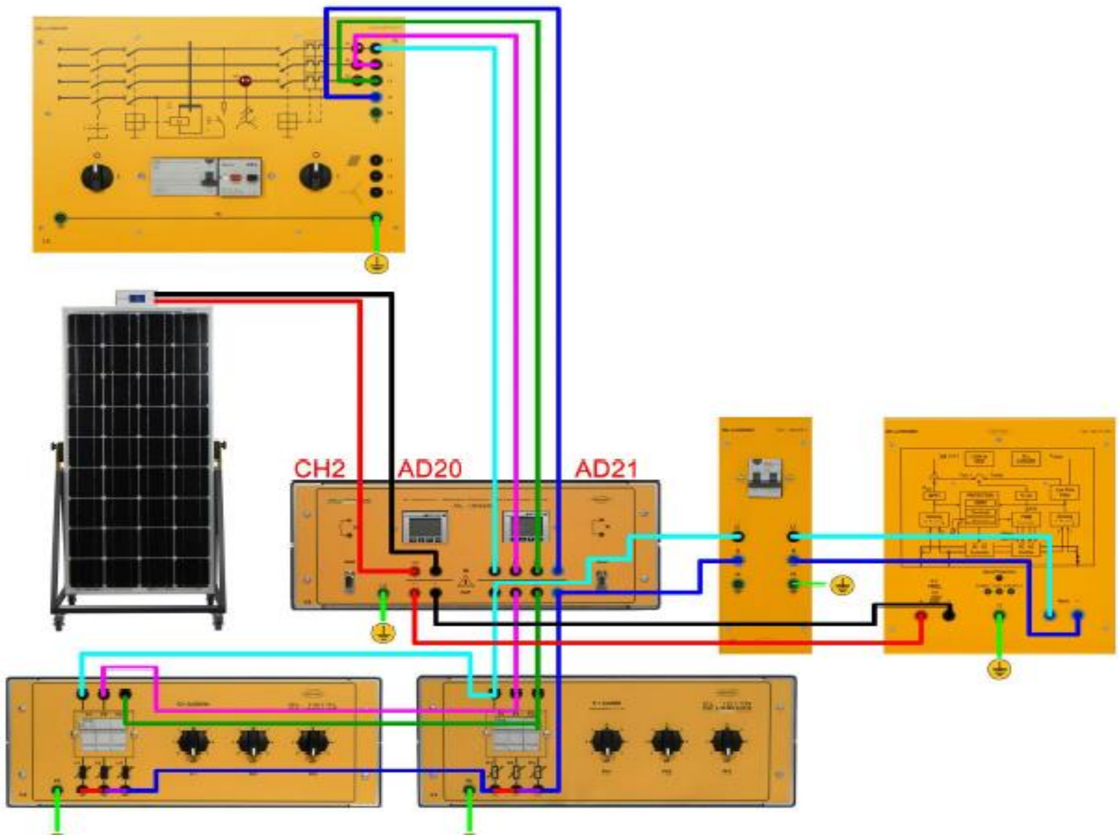


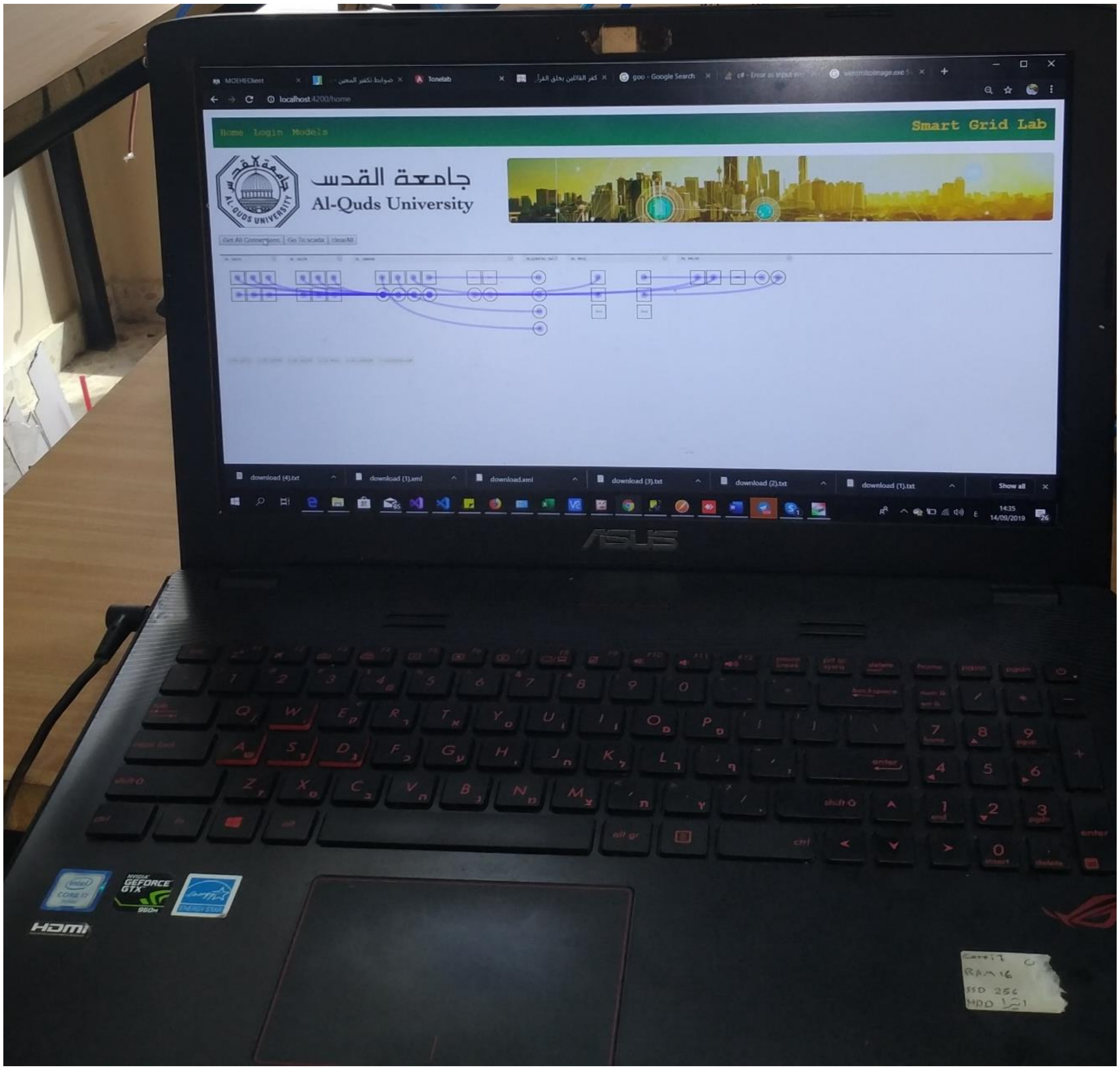
Figure (5): smart grid web client interface.

Appendix B

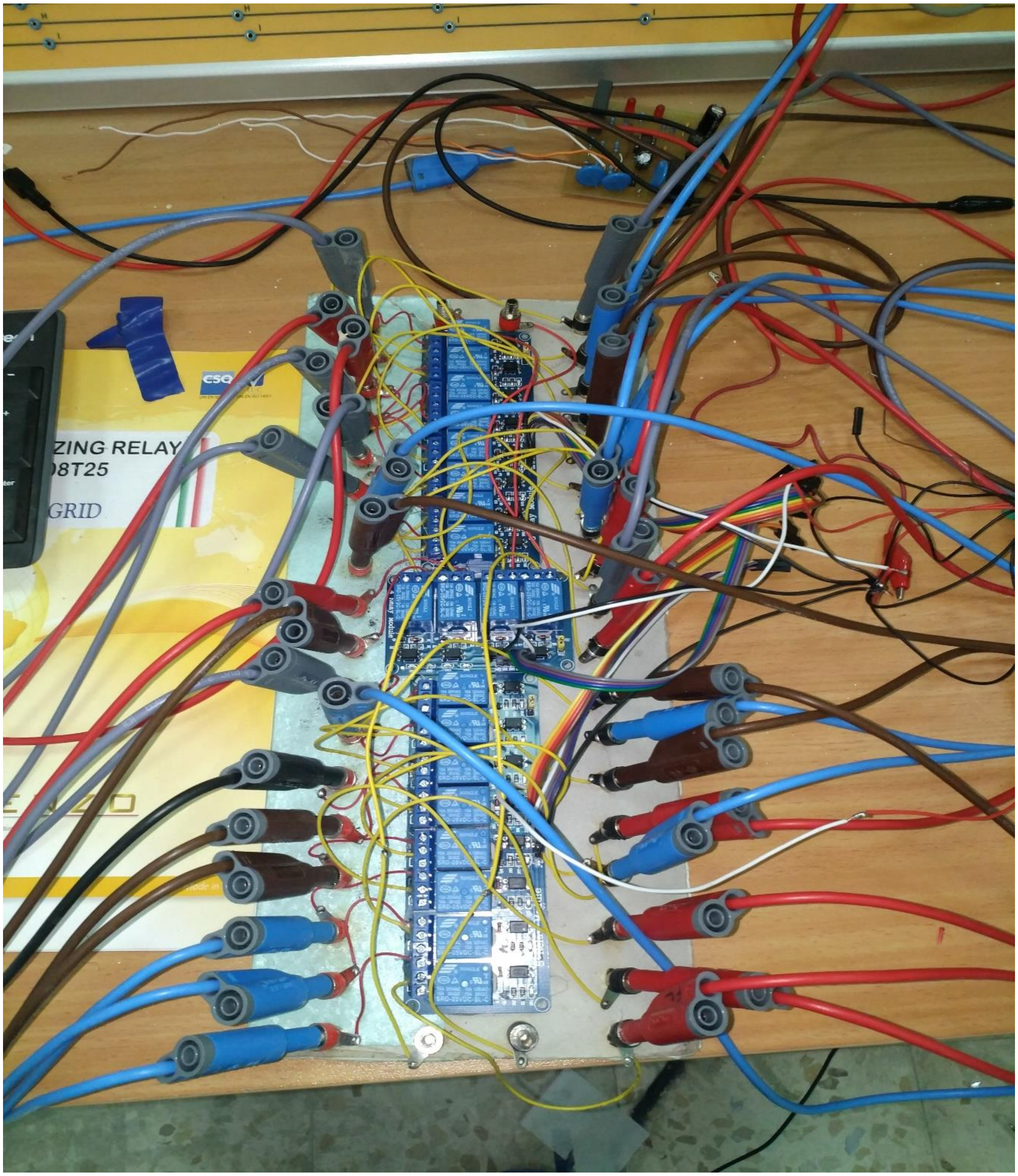
An appropriate experiment has been chosen, experiment with great benefits to the research area, and has a medium number of connections comparing with other experiments to make it easy to build the model of the remote lab. The experiment is connecting a photovoltaic system to the real network by using a single phase on grid inverter as following below:

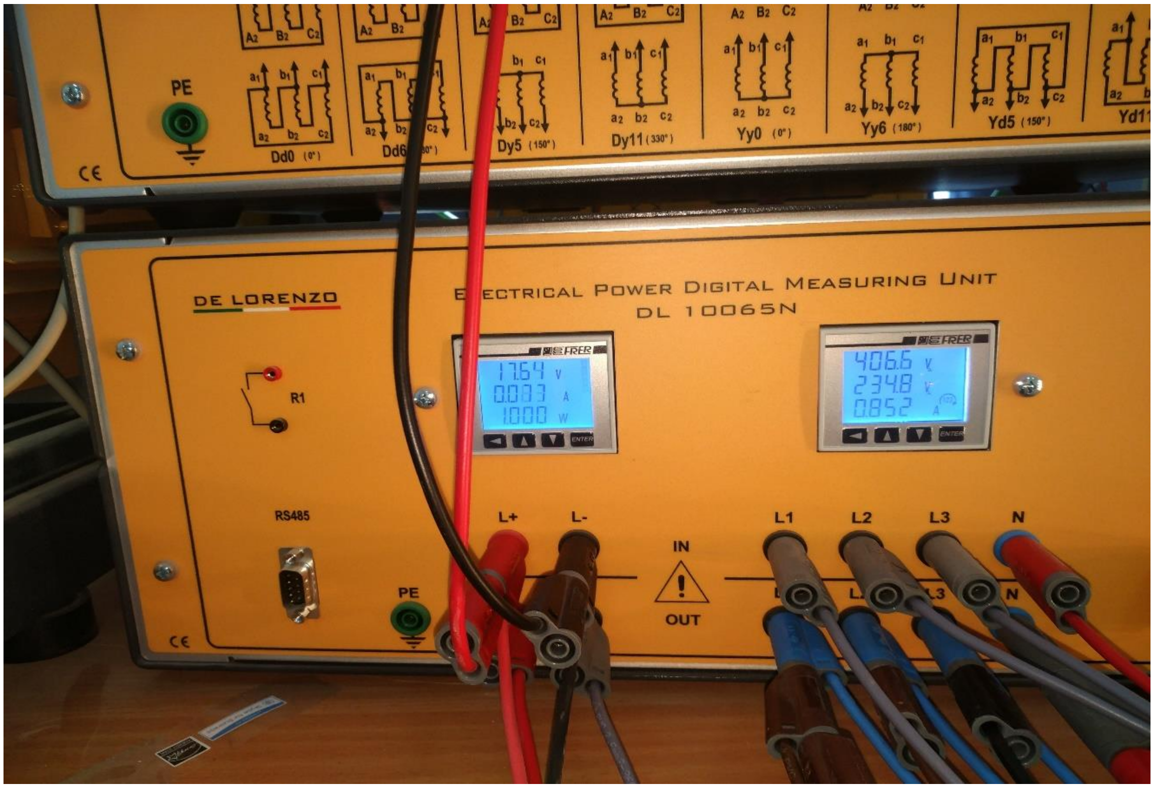


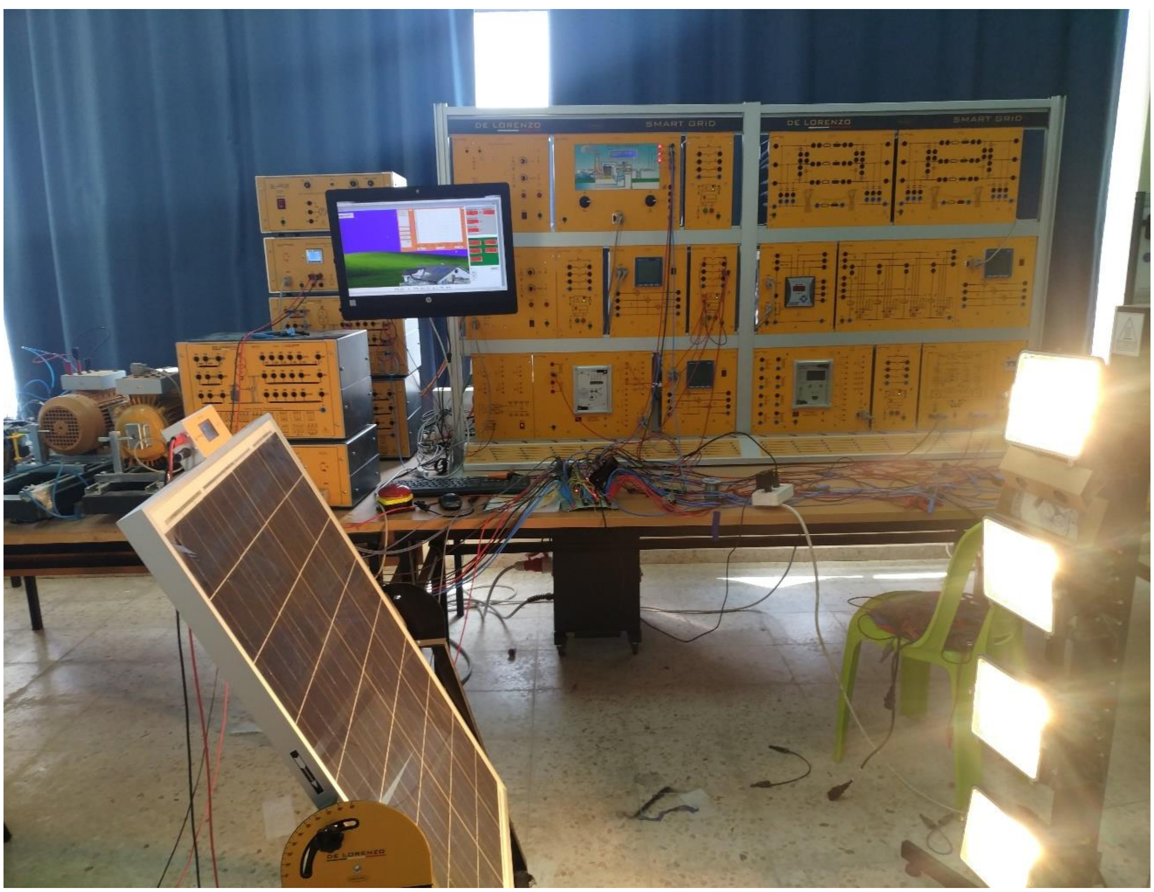
Connection the experiment through the website after login, choosing the experiment and downloading the experiment procedure as illustrated below:



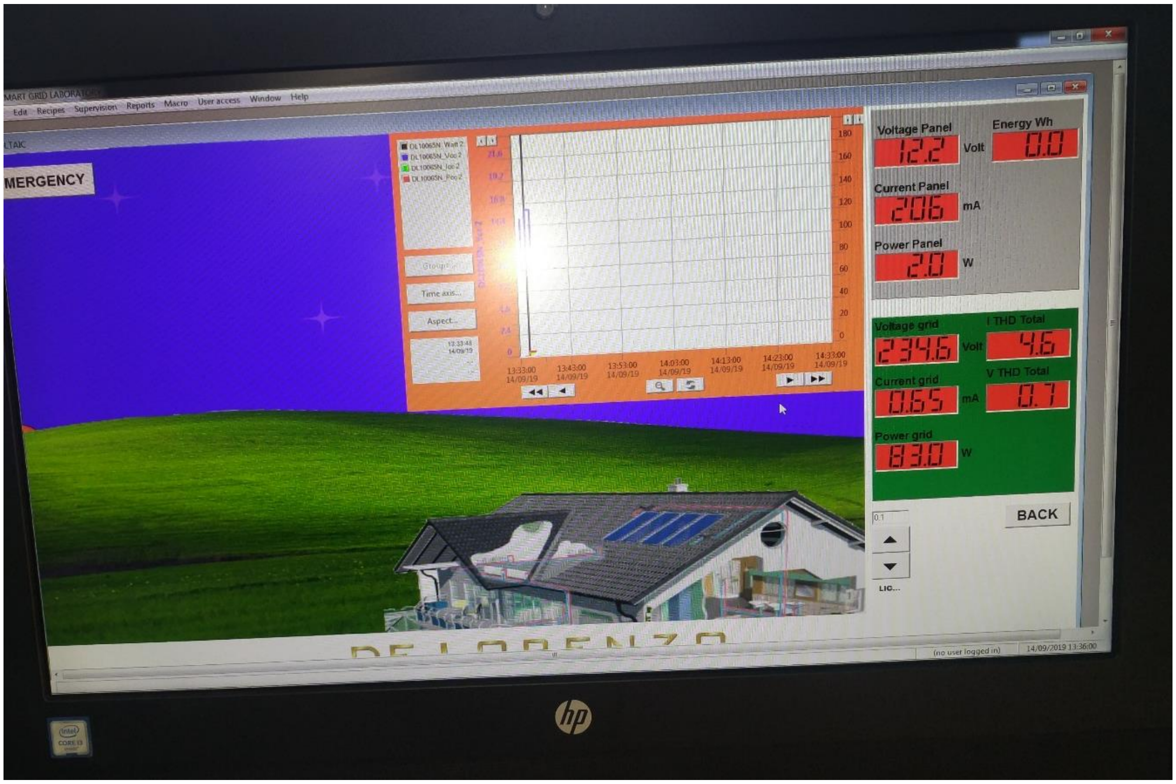
After finishing the connections, I press on Get All Connections, the raspberry takes the function and execute all connections through the relay module as below:




PE
Dd0 (0°)
Dy5 (150°)
Dy11 (330°)
Yy0 (0°)
Yy6 (180°)
Yd5 (150°)
DE LORENZO
ELECTRICAL POWER DIGITAL MEASURING UNIT
DL 10065N
R1
RS485
PE
L+
L-
IN
OUT
L1
L2
L3
N


DE LORENZO
SMART GRID

After the experiment is performed, the results will be displayed on the SCADA through Winlog program as the following below:



When obtaining all of the results, I press on “clear all” to turn the connection off, and reset the system.

Appendix C

- The definition of the library used by the server to connect with raspberry:

```
var gpio = require("array-gpio");
```

- The Definition of the outputs:

```
let pin1 = gpio.Output(12);

var pin2 = gpio.Output(13);

var pin3 = gpio.Output(15);

var pin4 = gpio.Output(16);

var pin5 = gpio.Output(18);

var pin6= gpio.Output(19);

var pin7 = gpio.Output(21);

var pin8 = gpio.Output(22);

var pin9 = gpio.Output(23);

var pin10 = gpio.Output(24);

var pin11 = gpio.Output(26);

var pin12 = gpio.Output(29);

var pin13 = gpio.Output(31);

var pin14 = gpio.Output(32);
```

var pin15 = gpio.Output(33);

var pin16 = gpio.Output(35);

var pin17 = gpio.Output(36);

var pin18 = gpio.Output(37);

var pin19 = gpio.Output(38);

var pin20 = gpio.Output(40);

- Definition of the JSON file to access to the right output through the receiver device:

const devices = {

- Receiver device:

"DL 1017R": {

- Output device:

"DL 10065N": {

- The outputs used to establish connection:

L1: pin1,

L2: pin2,

L3: pin3,

N: pin7, },},

"DL 1017L": {

"DL 10065N": {

L1: pin4,

L2: pin5,

L3: pin6,

N: pin8 }   },

"DL 10065N": {

"DL 2108TAL-SW": {

L1: pin13,//31

L2: pin14,//32

L3: pin15,//33

N: pin16,//35 },

"PFS-85": {

"L+": pin19,

"L-": pin20   }   },

"DL 9031(g1)": {

"DL 10065N": {

```
L1: pin9,

N: pin10,  }   },

"DL 9031(g2)":{

"DL 9013G":{

"Minus":pin11,

"~":pin12 }    },

"DL 9013G": {

"DL 10065N": {

"L-": pin17,

"L+": pin18 }   }}
```

- Announce the file for using it:

```
module.exports =devices;
```

- The definition of needed library to turn the server on:

```
var express = require("express");

var app = express();

var path = require("path");

var bodyParser = require("body-parser");
```

- Using the file, I defined above:

```
var  devices =require( "./constat");

var jsonParser = bodyParser.json();

app.set("view engine", "ejs");

app.use(express.static(path.join(__dirname, "public")));

console.log(path.join(__dirname, "public"));

app.get("/", function (req, res) {

res.send({ ssd: 'sdfds' }); });

app.use(function (req, res, next) {

res.header('Access-Control-Allow-Origin', "*");

res.header('Access-Control-Allow-Methods', 'GET,PUT,POST,DELETE');

res.header('Access-Control-Allow-Headers', 'Content-Type');

next(); })
```

- Receive the request from front end on the link below:

Localhost:3000/api/relay/on/

```
app.post("/api/relay/on/", jsonParser, (req, res) => {
```

- Take the data from request body:

```
sinkName = req.body.sinkName;

sinkPort = req.body.sinkPort;

sourceName = req.body.sourceName;

sourcePort = req.body.sourcePort;
```

- Turn off all relays:

```
Object.keys(devices).map(a=>{

Object.keys(devices[a]).map(b=>{

Object.keys(devices[a][b]).map(c=>{

devices[a][b][c].on(); })      })   })
```

- Start connect all relays depending on the user connection:

```
if (Array.isArray(req.body)){

req.body.forEach(a => {

devices[a.sinkName][a.sourceName][a.sourcePort].off();    });

}else if(Array.isArray(req.body)){

devices[req.body.sinkName][req.body.sourceName][req.body.sourcePort].off(); }
```

- Send the connection request:

```
res.send(devices); });
```

```
Object.keys(devices).map(a=>{

Object.keys(devices[a]).map(b=>{

Object.keys(devices[a][b]).map(c=>{

devices[a][b][c].on();  });    });    });
```

- Turn the server on:

```
app.listen(3000,'192.168.43.20', function () {

console.log("Server Started on Port: 3000!"); });
```

Appendix D

- Establishing connection point for the source:

```
const down = fromEvent(this.socket.nativeElement, 'mousedown')
            .filter((e: MouseEvent) => !((e.which && e.which == 3) || (e.but
ton && e.button == 2)))
            .do((e: MouseEvent) => e.preventDefault())
            .do((e: MouseEvent) => this.cable.startPatch(this.socket, e))
            .do((e: MouseEvent) => {
                // const old = this.patches.removeConnectionsFor(this);
                // this.signal.disconnect(old.signal);
            });

        const up = fromEvent(document, 'mouseup')
            .do((e: MouseEvent) => e.preventDefault());

        const mouseMove = fromEvent(document, 'mousemove')
            .do((e: MouseEvent) => e.stopPropagation());
        const scrollWindow = fromEvent(document, 'scroll')
            .startWith({});
        const move = combineLatest(mouseMove, scrollWindow);

        const drag = down.mergeMap((md: MouseEvent) => {
            return move
                .map(([mm, s]) => mm)
                .do((mm: MouseEvent) => {
                    this.cable.movePatch(mm);
                    this.patches.resetSelection();
                    const target = this.patches.locateTarget(mm);
                    console.log(target)
                    if (target) {
                        target.isSelected = true;
                    }
                })
                .skipUntil(up.take(1).do(() => this.cable.endPatch()))
                .take(1);
        });

        this.draggable = drag.subscribe((e: MouseEvent) => {
            const target = this.patches.locateTarget(e);
            if (target && this.patches.notConnected(this, target)) {
                this.patches.connect(this, target);
                this.signal.connect(target.signal);
            }
            this.patches.resetSelection();
```

```
        });
```

- Connection process, access data when cable connected:

```
this.pt = this.slider.nativeElement.createSVGPoint();

        const down = Observable.fromEvent(this.slider.nativeElement, 'moused
own')
            .do((md: MouseEvent) => md.preventDefault());
        const move = Observable.fromEvent(document, 'mousemove')
            .do((mm: MouseEvent) => mm.preventDefault());
        const up = Observable.fromEvent(document, 'mouseup')
            .do((mu: MouseEvent) => mu.preventDefault());

        const drag = down.mergeMap((md: MouseEvent) => {
           return move.startWith(md).takeUntil(up.take(1));
        });

        this.handle = drag
            .subscribe((md: MouseEvent) => {
                this.pt.x = md.clientX;
                this.pt.y = md.clientY;
                this.cursorPt = this.pt.matrixTransform(
                    this.slider.nativeElement.getScreenCTM().inverse());
                this.cursorPt.y = _.clamp(this.cursorPt.y, 0, 128);

                const normalValue = 1 - (this.cursorPt.y / 128);
                const scaledValue = (normalValue * (this.max -
 this.min)) + this.min;
                this.signal.setValueAtTime(scaledValue, 0.1);
                this.change.emit(scaledValue);
            });
```

- Send information to back-end

```
  DoConnection(data){
    return this.http.post(`${environment.api}api/relay/on`,data);
  }
```

- The operation of gathering all the communication and convert it to JSON file:

```
public get AllConnections(): any[] {
        return this.connections.map((data: Connection) => {
            return {
                sinkName: data.sink.parent, sinkPort: data.sink.name,
                sourceName: data.source.devicename, sourcePort: data.source.
name
            }
        })
    }
```