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Efficient Use of Photovoltaic System Using Modern Control Approaches

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إهداء

إلى معلمنا و قائدنا وحبيبنا وشفيعنا و قدوتنا محمد صلى الله عليه وسلم.

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Abstract

Under difficult political and economic circumstances which suffering by the inhabitants of Palestine and due to the compulsory controlling of power sources. In addition, expensive electricity cost compared to other countries, it is necessary to exploit solar energy as Palestine exposed to considerable hours of radiation and good solar radiation throughout the year, the period of highest efficiency of solar cells is not invested to run the devices and this was shown after measuring the power consumption of several houses , the energy generated must be stored or sold to the network; moreover, the cost of operation and establishment of photovoltaic system still expensive. After study and analysis show that harmonic problem will occur if connect PV system to the grid which is called (on-grid) system, On the other hand, storage of energy for use at the time of need is expensive because of the high price of storage batteries as well this system appellation (off-grid). In this project design, and implementation a fuzzy logic controller to control working times of some electrical appliances in the home without affecting end- user's comfort, to move the on-peak into the off-peak to reduce the number of batteries and cells used in the system and save electricity cost purchase.

الملخص

في ظل الظروف السياسية والاقتصادية الصعبة التي يعاني منها سكان فلسطين، والتحكم القسري بالطاقة من قبل المصدر. وبالإضافة إلى ذلك، تكلفة الكهرباء باهظة الثمن بالمقارنة مع البلدان الأخرى، فإنه من الضروري استغلال الطاقة الشمسية حيث ان فلسطين تتمتع باسقاط شمسي جيد و ساعات طويلة من الإشعاع الشمسي على مدار السنة، ان فترة أعلى كفاءة للخلايا الشمسية لا يتم استغلالها لتشغيل الأجهزة وتبين ذلك بعد قياس الاستهلاك الكهربائي لعدة منازل لذلك يمكن تخزين الطاقة المتولدة من الخلايا الشمسية أو بيعها للشبكة؛ وعلاوة على ذلك، فإن تكلفة التشغيل وإنشاء نظام الخلايا الشمسية لا يزال باهظ. بعد الدراسة والتحليل، تبين أن مشكلة عدم توافق الجهود ستحدث إذا وصل النظام بالشبكة وهذا النظام يسمى (نظام موصول بالشبكة) . من ناحية أخرى، تخزين الطاقة للاستخدام في وقت الحاجة مكلف بسبب ارتفاع أسعار بطاريات التخزين وكذلك هذا النظام يسمى (نظام غير موصول بالشبكة). في هذا المشروع سوف يكون العمل على تصميم متحكم يقوم بالتحكم بأوقات عمل بعض الأجهزة الكهربائية في المنزل دون التأثير على راحة المستخدم ، لنقل اعلى ذروة استهلاك في المنزل الى أوقات ذروة الخلايا الشمسية من أجل تقليل عدد البطاريات والخلايا وتوفير تكلفة شراء الكهرباء.

CHAPTER ONE

Introduction

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1.9 conclusion of the chapter.

1.1 Introduction

Energy and the exploitation of energy from the basics of building civilizations and the advancement and progress of nations, so, energy plays an important role in economic and social development [1]. With the increase in energy consumption in homes and the large electronic and electrical devices increased energy demand, the economic crisis we are living with the increasing population density are all reasons led to thinking about renewable energy and how to exploit and control, energy saving and renewable energy sources are considered as methods of solving home energy problem. Both energy consumption and generation should be simultaneously considered to save the home energy cost [2].

The primary sources, such as heavy oil, natural gas and other conventional are limited resources formed by geological processes through solar energy accumulation into the earth over millions of years. Because of their fluctuations in reserves and prices and due to the increased costs of power stations, it is very important to consider new measures for energy conservation in both developed and developing countries. Energy conservation could be defined as an applied technique in energy utilization without affecting the standard of living in the society. Energy conservation will definitely save investments in constructing and generating capacities of electrical energy and consequently will enhance the current economy of the nation's [3].

The existence of alternative energy and exploitation of the right form of energy conservation, so Palestine enjoys the presence of solar energy throughout the year, it has high solar energy potential and a high annual average of solar radiation [1]. But photovoltaic efficient time doesn't at the maximum peak time of the home loads, so the energy produced from PV it must storage in batteries which is expensive or sold to the grid system which has the harmonic problem.

The energy sector situation in Palestine is highly different compared to other countries in the Middle East due to many reasons: non-availability of natural resources, unstable political conditions, financial crisis and high-density population. Furthermore, Palestine depends on another country for 100% of its fossil fuel imports and for 87% of its electricity imports [1].

The Palestinian population also pay a relatively high price for energy. Electricity constitutes about 10% of the average household income, which is much higher than the 2% of neighboring countries like Jordan, Lebanon, and Syria, another problem that is 26% of energy is lost in transit due to poor infrastructure and theft [4].

Electricity in Palestine lies in that it is limited and weak, and the distribution of loads is wrong. So, there is an urgent need to implement more efficient ways of energy consumption in Palestine and design effective techniques to achieve maximum possible efficiency and effectiveness. It is, therefore, necessary for the management and control of domestic electricity consumption so that it becomes less and more consistent with the consumption of electricity without affecting the uses of individuals [1]. Fortunately, Palestine is located within the solar belt countries and considered as one of the highest solar potential energy; the climate conditions of the Palestinian Territories are predominantly very sunny with an average solar radiation on a horizontal surface about 5.4 kWh/m2 days. the solar energy available in Palestine at large hours per year and thus can exploit this energy and control it [5].

1.2 Palestine Potential of Solar Energy

Palestine has high solar energy potential about 3000 sunshine hours per year and a high annual average of solar radiation amounting to 5.4 kW h/m2/day on the horizontal surface [1]. These values are relatively high and receptive to the use of solar energy for solar water heating, Photovoltaic (PV) applications or other applications. Figure (1.1) presents the monthly average of daily solar radiation incident on a horizontal surface in a location in North part of West Bank.

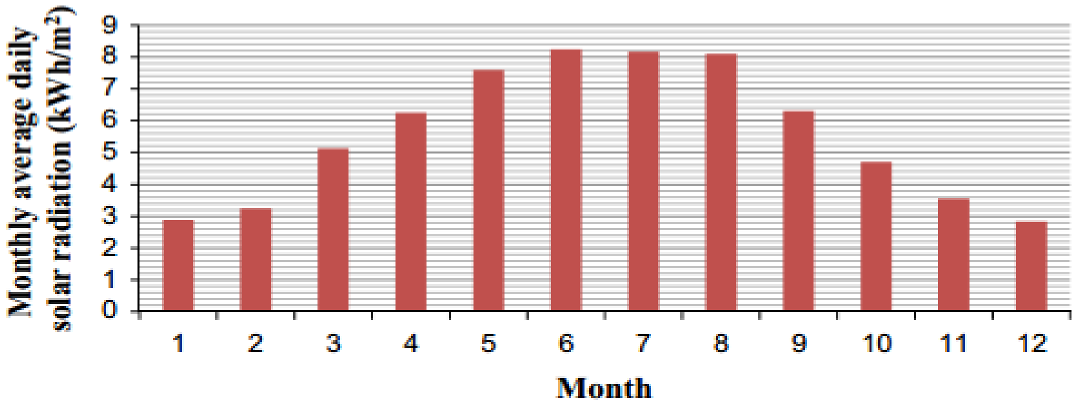


Figure 1.1: Monthly average daily solar radiation in north of West Bank [6].

Different challenges are facing the implementation of PV projects, both on small or large scales. These challenges may limit the spread of this technology. Any solar energy project generally requires high financing and technological requirements, availability of highly qualified persons for design and installation, availability of space, and infrastructure for storage system, standby energy source if required, and connection to the grid. Obtaining finance for small-scale standalone PV projects is usually easier. Success in these projects in the pilot scale will lead to more investment in larger scale projects, so the plan for investment in PV applications should begin from small projects. [6]

Photovoltaic (PV) electrification in isolated rural villages and communities in Palestine is considered feasible and effective compared with other alternatives like electrical grid and diesel generators. The PV electrification could be using the decentralized stand-alone and centralized systems depending on the nature of the load and the distribution of houses. Photovoltaic electrification is limitedly used in different rural areas in Palestine mainly for schools, clinics, Bedouins communities, agricultural and animal farms, and private homes. The total installed capacity is about to 50 kWp [7].

According to the strategic plan of the Palestinian Energy, the 10% target in 2020 is equivalent to 130 MW, and it has been identified as follows: 45 MW on ground and rooftop PVs, 20 MW from concentrated solar power plants, 21 MW biogases from both landfill and animal waste, and 44 MW from both wind farms and small-scale wind turbines. The implementation stages of this plan are divided into two phases: The first phase (2012–2015) involves the generation of 25 MW by the various suggested sources. The first step in this phase, called the Palestinian Solar Initiative (PSI), has been launched. This initiative consists of three phases over a period of 3 years, from mid-2012 until mid-2015, and aims to set up small PV systems with a capacity of up to 5 kW for each project to be installed on the roofs of homes in order to realize a total of 5 MW at the end of three years. Each subscriber will attain a preferable electricity tariff for energy generated by the installed PVs according to the incentive bonuses set aside for this purpose [6].

The considerable potential for PV applications in Palestine is available that relies on the following facts:

- The high average of solar radiation intensity and sunshine hours of about 3000 h per year.
- Availability of a large number of rural villages, settlements a public utility isolated from the electric grid that will not be connected to it in the near future.
- High fuel cost in Palestine makes PV more feasible than diesel-powered electric generators in supplying power to different applications in rural areas [1].

1.3 Photovoltaic System (PV)

A photovoltaic system, also PV system or solar power system, is a power system designed to supply usable solar power by means of photovoltaics. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current from DC to AC, as well as mounting, cabling and other electrical accessories to set up a working system [8].

1.3.1 Types of PV system

1. On Grid System

On Grid Solar Power Systems are connected to the mains power supply just like a regular home. This means that mains power can still be used any time your solar panels generate less electricity than is needed, e.g. at night. In many countries, solar homes can also capitalize on times when the panels generate more electricity than is needed by selling the surplus back to the electricity company -usually at a nice profit as shown in **figure 1.2** [8].

2. Off Grid Systems

Off Grid Solar Systems do not need to be connected to mains power. As there is no ready source of reserve power, they rely on generators or storage batteries to provide electricity on days when the solar panels generate less electricity than is required, e.g. on cloudy days or at night time. The idea is that at times when the system provides more electricity than required the surplus can be used to recharge the batteries as shown in **figure 1.3** [8].

Figure 1.2: On Grid Systems [8].

Figure 1.3: Off Grid Systems [8].

1.3.2 Problem of PV

Solar energy production cannot be programmable, as solar energy is available only during daylight hours and production depend on the presence of clouds or not, making it difficult to have a constant match between production and consumption [9], with the increasing penetration of residential and commercial PV, the PV power generation could not only offset the load but could also cause reverse power flow through the distribution system. Significant reverse power flow may cause operational issues for the traditional distribution system [10].

Balanced conditions occur very rarely for low, medium and high penetration levels of PV systems, the effects on harmonics in case of multiple PV systems, it is strongly recommended that PV inverters are operated at unity power factor. It is not advised to use PV inverters with a variable power factor as this, at high penetration levels, may increase the number of balanced conditions and subsequently increase the probability of is landing [8]. The high costs of the PV system consisting of (PV panel, Inverters, Batteries) [1].

1.3.3 Cost of Installing PV for Single House

An economic analysis that will evaluate the feasibility of installation on-grid PV system and a fuzzy controller for three story-building will be based on market cost, the price of the PV system and its installation are important factors in the economics of PV systems. Which includes the prices of PV modules, inverters, maintenance, and all other auxiliaries. The following **table 1.1** shows the total on-grid system cost related to house chosen in Hebron city consume 5 KW per month [10].

Table 1.1: PV system cost

Details	Quantity	Price (Nis)
PV panels: Hanwha solar (HSL72P6-3-320T), (16 Panels)	16	12,480
Grid Interactive Inverters: one phase, SMA 5 KW	1	6,000
Surge protection: AC breaker 25 A,2pole, DC breaker 10A,800V	3	480
Galvanized steel structure: supply and installation of galvanized steel structure for PV module "16 module" the cost including all connection, fixing on roof.	40 m	1,200
Installation of PV system: installation of PV system (16 module,320 W) on the steel structure, the cost should include all the fixing and connection materials.	-	1,000
Cable: Supply and installation of "cable DC 1000 V,6mm, cable AC 3*10mm,25 m for inverter connection with distribution boar, fixing cables through trench: cable shoes 32.	-	480
Junction box: supply and installation of junction box, plastic, including fuses " cylindrical" for each array, terminal for income and outcome cable, fixing on steel structure, connections, bus bars, all according to drawings, specifications, distribution company and direction of engineer.	2	160
Earth system: supply and installation of earthing system for PV installation, the cost including mast, earth conductors from ground to steel structure, connections the earth with steel structure with electronic equipment, Earth cable 10mm,30m , Earth lakge breaker 40A ,300mA.	-	440
lightning arrestor: supply and installation of lightning arrestors to protect the PV system from lighting,800V	2	490
Accessories: concert Breakers, MC4, fixed screw, jumbo screw		500
Transport	-	300
Total price		**23,530**

1.4 Project Problem Definition

The situation in the energy sector in Palestine is very different compared to other countries in the Middle East for many reasons: lack of natural resources, unstable political conditions, financial crisis and high population density. In addition, Palestine relies on 100% of its imports of fossil fuels and 87% of its imports of electricity. In addition, high population growth, rising living standards and the rapid growth of the industry have led to the massive demand for energy in Palestine in recent years. The total energy consumption per citizen in Palestine is the lowest in the region (0.79 MWh) and costs more than anywhere else in the Middle East [1]. Also, PV generation times is not on the peak consumption of the homes or buildings, so inefficient use of PV cells. Also, to cover the peak consumption of the homes which is usually do not coincide with PV generation times, oversized PV systems are needed. Moreover, and depending on PV systems designs. Either Off-grid design where a costly short life storage batteries are needed to compensate for the consumption during night time. Or On-grid design where the excess PV produced energy is injected into the grid, and the night time end-user consumption is supplied from the grid. An on-grid design has many problems, the main problem of injection the excess energy into the grid will not be succeeded except under very stable unfluctuating grid voltage.

1.5 Project Idea

The main idea of the project is to reduce the storage battery bank size in Off-grid design and to reduce the excess power that needs to be injected into the grid in On-grid design, in addition, to reduce the size of PV system needed for a single house which is usually oversized to cover end-users consumption. Through, control and shift the operation time of some of the end-users home appliances to be operated automatically during the generation time of the PV system. This is due to the fact that the end-user's consumption of electrical energy reaches to maximum only in particular hours, which depletes the capacity of power stations to meet the needs of the individual which impacts automatically the houses, electrical company, and government economically. Therefore, it is necessary to manage and control the domestic electrical consumption so that it becomes less and more uniform electrical consumption patterns as possible without affecting the uses of the individuals. By implementing such controlling approaches, the cost of installing PV systems will be reduced due to reducing the size of both PV cells and batteries, as a result saving end-users money and an efficient use of PV systems.

1.6 Project objectives and Methodology

This project aims to improve the energy efficiency in buildings without compromising indoor comfort conditions which could be attained by introducing control techniques in order to achieve the maximum efficiency at a certain capacity while reducing peaks levels at the same time. The importance of this project can be summarized in the following objectives:

1. Measuring the power pattern consumption for a sample of houses in different Palestine occupied areas using data loggers which measure the voltage and the current on one second base time interval. The importance of these measurements is to determine what end-users home appliances are the most electric power consumers and can be shifted without any violation to end-users comfort level. Also, to determine the effect of some of the human socio-demographic factors such as family members, income, and availability.
2. Analysis of questionnaire information distributed to households that have been measured. To determine the operation scenarios of home appliances, home appliances nominal powers and to determine the effect of socio-demographic factors on power consumption.
3. Measuring the power pattern consumption for the same sample of houses during the coldest month in the winter period (February) and the hottest month (July) in the summer period, to test the effect of heating and cooling power requirement on the total power pattern.
4. Design a fuzzy logic controller to shift the operation of home appliances determined from item 1 from peak consumption hours to be operated during the PV generation time. The use of the PV energy produced will be compared before and be applying the controller.
5. Building an experimental prototype for the purpose of control of power pattern consumption for homes.

6. Implementing and developing the controller in order to optimize our control prototype using MATLAB.
7. Implementing the advanced control.

1.7 Literature Review

System Design of Photovoltaic-Solar Home Lighting for Household in Gaza strip, this paper talks about the need of alternative and urgent power source to supply hospitals and medical centers is a very important issue especially in the situation we live in Gaza sector; enjoined siege, shortage in fuel supplies, and increasing in the mortality rate. Palestine is considered one of the sunny countries with marvelous solar radiations over the year. In this paper, a PV-lighting system for small houses in Gaza Strip has been evaluated, all PV system components have been measured and designed. The use of the Photovoltaic technologies in Gaza Strip has much more advantages, so that man cannot ignore. In Gaza case, it is independent of Israel supply of fuels and electricity that have the opportunity to cut it under any circumstances, and according to the political situation and the mandatory siege since 2006 by the Israeli occupation after Palestinian election, the power generation sector faced several obstacles starting with destroying main generators of Gaza Power Plant in June 2006 through blocking fuel entry into Palestinian Territories in 2008 ending to unknown and horrible situation[5].

Techno-Economic Analysis and Energy Management of Installation on Grid PV Systems "An-Najah National Hospital as Case, this project analyses the performance of the implementation of on-grid PV systems and energy management system in Palestine, from the technical and financial point of view. Also, the design and simulation of a 104kWp grid-connected PV system and a Demand Side Management (DSM) system for An-Najah National Hospital and summarizes its performance results using PV system computer software. The simulation results were positive as the peak demand was reduced from 240kW to 160kW for building This PV system and DSM system is an embrace of the following components. An array consists of PV modules produced from a polycrystalline solar cell of 330W, making up a total peak power of

104 kW. In addition, there are five dual mode inverters of 20kW and an energy storage system of 68 kWh which used in energy management and insufficiency cases. The system will produce about 187000kWh per year. From economical viewpoint PV systems and DSM systems have high initial cost which was about 187000$, but the economic evaluation of the system shows that unit cost of the system was about 0.19$/kWh and 0.15$/kWh for PV system with DSM and for PV system without DSM which was less than from energy cost from NEDCO which selling energy to consumer by 0.21$/kWh this means the unit cost is acceptable in both cases and makes annual saving about 40000$ in electrical energy bills. In the economic evaluation, the Rate of Return (ROR) method and Simple Payback Period SPBP was considered and the ROR was about 23% and the SPBP was 7 years including battery replacement cost and these results show that the system has high revenues and profit for the lifetime, in other words, the project is highly feasible [11].

Experimental investigation of power consumption patterns oriented for energy auditing and management in homes, the paper turns out the improvement of the energy efficiency in buildings without compromising indoor comfort conditions could be attained by introducing management techniques and energy efficient behavioral measures. This paper aims to lay a base for developing a strategy for electric power consumption auditing and management. The sought strategy will be based on the recognition and control of consumption pattern. This helps to avoid maximum load during high demand hours, which depletes the capacity of power stations. For this purpose, consumption measurement for reconstruction of patterns for a resolution of one second was used. The study is based on the assumption of possible modifications in the energy consumption modes. It highlighted the possibility of adopting hybrid energy systems for private use efficiently and economically [12].

Battery Energy Storage System usage in a Distribution Grid for PV exploitation: A Middle-East Case Study, by analysis of this study the Photovoltaic (PV)generation offers the opportunity to exploit the huge amount of solar radiation available. However, a possible wide diffusion of PV distributed generation system into the grid must deal with the time mismatch between production and consumption. The introduction of Battery Energy Storage Systems like electrochemical batteries (BESS), could represent an efficient solution to optimize resource exploitation and locally increase self-consumption. Starting from the experience of the Renewable Energy for Palestine (RENEP) project, funded by the Palestinian Municipality Support Program (PMSP) of the Italian Ministry of foreign affairs and International Cooperation, this paper shows how a (BESS) system can be used to raise the PV exploitation into the grid of Hebron city in Palestine where the power flux inversion at primary substation is strictly limited. The evaluation of the BESS impact is performed by means of a model of the distribution grid and an optimization procedure called D-XEMS13 used to minimize the power losses in the grid through an approximated linear model. Results of the simulations were also compared to the ones obtained by NEPLAN simulator [9].

PV and Building Energy Efficiency Measures Impact on the Grid in a Middle East Case Study, the analysis performed in this paper highlights the interaction between the energy efficiency measures adopted to reduce the energy needs of the buildings and the grid management of Hebron in Palestine. In particular, the penetration factor (PF)shows that the maximum PV generation that potentially can be connected to the grid at LV and MV stage is approximatively equal to 218 MWp if energy efficiency measures were not adopted in the buildings. Otherwise, if energy efficiency measures were adopted in the buildings, the maximum penetration factor that can be reached is instead approximatively equal to 210 MWp. These results highlight the possibility to foster the exploitation of PV distributed generation systems in Hebron. In fact, the grid is able to accept a significant contribution from PV systems at LV and MV. without any violations of grid limits (i.e. transformer overload cable ampacity and voltage rise). Moreover, the high level of PV penetration at LV level promotes the installation of a large number of small PV size plant for domestic/residential and commercial end-users. Likewise, the PV penetration at MV level fosters the installation of a significant number of medium size PV plant to potentially supply industrial end-users like small and medium enterprises. This condition can be potentially amplified in these parts of Middle-East by lower installation costs of the PV systems with respect to ones in Europe (e.g. Italy). Furthermore, a large PV diffusion can also contribute to reducing the energy cost for space heating and cooling since the generation units are electrically driven in the Hebron context [13].

1.8 Project schedule

The time plan views the stages of establishing the project with its components, shown in the following tables.

Table 1.2: Timing schedule of first semester.

Process	**Week**													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Collecting data and literature	■	■	■	■	■	■	■	■						
Analysis of data						■	■	■	■	■				
Process calculation								■	■	■	■			
Control strategy planning										■	■	■	■	
Write the documentation										■	■	■	■	■

Table 1.3: Timing schedule of second semester.

Process	**Week**														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Analysis of data															
Control programming and design															
Process calculation and simulation															
Write the documentation															
Design and implementation of the porotype															

1.9 Conclusion of the chapter

Palestine enjoys solar radiation throughout the year, so it is good to use solar energy in electricity generation and exploitation, the main idea of the project to utilization solar energy by using PV system to reduce the storage battery bank size in Off-grid design, and to reduce the excess power that need to be injected into the grid in On-grid design, in addition to reduce the size of PV system needed for a single house which is usually oversized to cover end-users consumption.

The analysis of literal review of the papers and articles there is no controlling in their systems to reduce the PV system quantity and save money end-user.

CHAPTER TWO

Measurement and Analysis

Contents:

2.1 Introduction.

2.2 Measurement tools.

2.3 Case study.

2.4 Analysis.

2.5 Building Selection.

2.6 Conceptual design.

2.7 Conclusions of chapter

2.1 Introduction

The main type of houses in Palestine are the single houses as shown in figure 2.1, with the increase in population density, the limited amount of land permitted for construction and the high prices. In addition to a large amount of land being expropriated every day by the Israel occupation to build settlements and build the Apartheid Wall, people are now moving towards vertical construction.

Electricity from Israeli side reaches a high voltage of 33 KV to the main stations in Hebron that reduce the voltage to 11 KV, which in turn feed transformers as shown in the figure 2.3 then it distributed to one phase (220 volt,32 ampere) or three phase (380 volt, 30-300 ampere) for end-users [14].

As previously explained, it is possible to shift some of the end-uses load to be operated by using intelligent control approaches in the generation time of the PV systems. In other words, the electrical such as dishwashers, washing machines can be shifted without disturbing the end-users comfort level.

In this chapter, study and analyze the electricity power pattern consumption of one apartment of a three-apartment building as shown in **figure 2.2**, to find out which of the home appliances can be shifted and has an effect on the total power pattern consumption. Also, some of the human socio-demographic factors which affect the power consumption can be estimated.

Through this study and based on the measured loads of the apartment, the electrical energy required from the PV systems to cover loads of the building and similar other buildings are to be calculated. By calculating the surface area and the energy generated from the cells, thus determining the number of cells needed according to the existing loads.

Figure 2.1: Single home. **Figure 2.2:** Multi-story building.

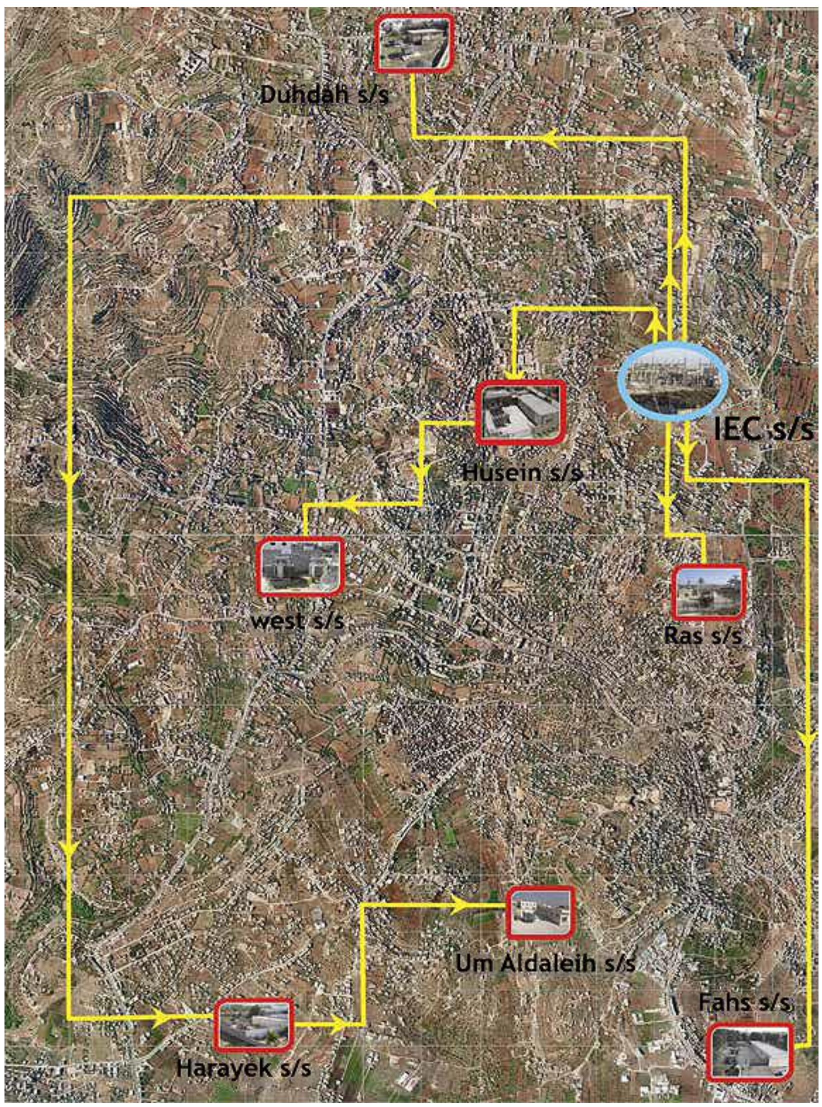


Figure 2.3: Distribution of main power stations in the city of Hebron. [14].

2.2 Measurements Tools

2.2.1 Voltage measurement

The voltage measurement shown in **figure 2.4** is required during experimentations and power consumption management. The measurements were performed using Potential Voltage Current Transformers SPT-0375, which is a voltage-current transformer with 115 to 460-volt AC, which provides a linear output voltage proportional to the input voltage, linearity accuracy ±1 [15].

Figure 2.4: Potential voltage current transformers [15].

2.2.2 Current measurement

Split core AC current sensor shown in **figure 2.5** was used to measure current (0-20A) which compatible with Hobo U12 devices with external inputs, approximation response time 440 msec, accuracy±4.5% at full scale. [15]

Figure 2.5: Split core AC current sensor [15].

2.2.3 Data Logger

A data logger was used to record the obtained voltage and current data over time. They are based on digital processor and battery powered. The data loggers used in the system are:

1. HOBO Energy Logger Pro

The HOBO Energy Logger is a modular, reconfigurable data logging system used in energy and industrial monitoring applications, memory 512K nonvolatile flash data storage, Time accuracy 0 to 2 seconds for the first data point and ±5 seconds per week at 25°C (77°F). The data were recorded every 1 second to obtain high resolution, shown in **figure 2.6** [15].

Figure 2.6: HOBO energy logger [15].

2. HOBO U12 Data Logger

The HOBO U12 Temperature/Relative Humidity Data Logger is a two-channel logger with 12-bit resolution and can record up to 43,000 measurements or events. The logger uses a direct USB interface for launching and data readout by a computer. The data were recorded every 1 second to obtain high resolution, shown in **figure 2.7** [15].

Figure 2.7: HOBO U12 data logger [15].

2.2.4 HOBO ware Pro program

HOBO ware Pro program is software for easy launch readout of HOBO data logger as well as the flexible plotting of data as shown in figure 2.8, data can be exported for more in-depth analysis using other programs including spreadsheets. The software allows to set launch parameters such as which channels to record, sample interval, and start type (immediate, delayed, interval, or triggered); monitor battery level; and synchronize logger clocks to computer clock. With the graphing capability, it can be view multiple parameters from a single logger on one graph, zoom in on data of interest, set axes ranges, display data in different formats, and display recorded events in graphs or file exports. It can be also verifying logger operation before launch or during logging, as well as displaying real-time sensor reading, memory used and battery voltage. One clicks conversion allows for easy data upload into Microsoft Excel or other programs. The windows version offers enhanced feature which allows for the combination of data from multiple loggers or deployments, saving of current data for future use, linear scaling for external inputs listing of recently-accessed files, and automatic internet updates. Software, USB interface cable and manual included.

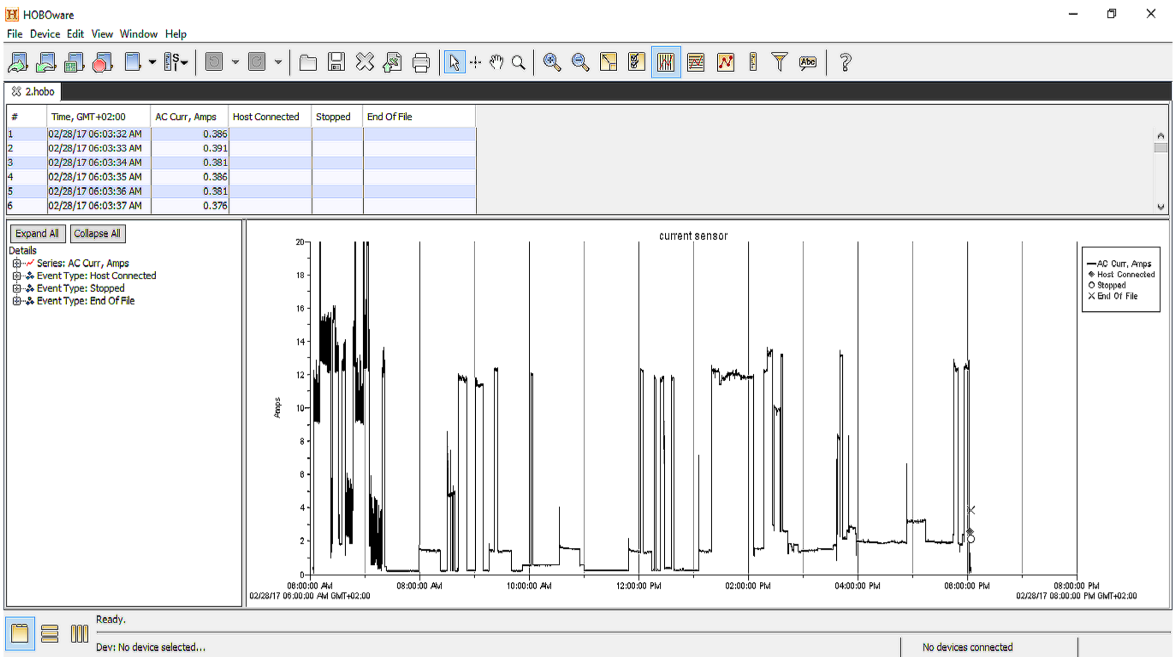


Figure 2.8: HOBO ware Pro program software [15].

2.3 Case Study

2.3.1 Place of Study

Hebron city has been selected for this study because of it suffers greatly from the problem of power outages. It is located in the West Bank to the south of Jerusalem by about 35 km, **figure 2.9**. It is considered today one of the largest cities in the West Bank in terms of population and area, where the population in 2016 about 684 thousand people and an area of 42 Km^2. The annual solar radiation rate in the city is estimated of 71.7 MJ/ m^2, where a large percentage of this radiation can be used in the production of electric power [16].

Figure 2.9: Location of Hebron, Palestine

A measurement of the electrical power pattern consumption of ten houses in Hebron was performed. The measurement of the power pattern consumption of these houses is shown in Appendix A. In this section. These power consumption patterns were analyzed in integration with the distributed questioner (see Appendix B) to determine the most end-users home appliances power consumers, and the priorities of which home appliances can be shifted to operate during PV generation time without disturbing end-users comfort level. Moreover, an information about the effect of socio-demographic factors such as the number of families' members, income of the family and the availability of power consumption was estimated. A sample of the analysis of these measurements of three houses was presented in following sections. The information estimated from the analysis was considered in this project to be applied in designing the fuzzy logic controller for reshaping the power pattern of the three-story building.

2.3.2 Questioner

A questionnaire was distributed to houses where the measurements have been taken. To determine the operation scenarios of home appliances, home appliances nominal powers and to determine the effect of socio-demographic factors on power consumption, and to extract important information such as the number of household members, number of rooms, area, Average monthly income، more hours of consumption (see Appendix B).

2.4 Analysis

2.4.1 Questioner Analysis

The questionnaire information was unloaded in the table below, **Table 2.1**. This information will be linked with the pattern of power consumption for every home.

Table 2.1: Summary of the questionnaires:

Home	**address**	**number of family members**	**Members at the school**	Members at the university	Work of the head of the family	Monthly income level	Home area [**m2**]	Number of rooms in the house
Home 1	Hebron	7	2	1	dealer	More than 6000	180	5
Home 2	Hebron	7	3	2	Employee	3000-6000NIS	150	5
Home 3	Hebron	8	3	2	Electricity technician	3000-6000NIS	180	4

Home 4	Hebron	6	3	1	dealer	3000-6000NIS	170	4
Home 5	Hebron	8	1	1	dealer	3000-6000NIS	170	7
Home 6	Hebron	9	4	1	dealer	3000-6000NIS	120	4
Home 7	Hebron	7	3	1	Technical	3000-6000NIS	150	4
Home 8	Hebron	6	1	2	dealer	3000-6000NIS	150	4
Home 9	Hebron	7	2	1	Government employee	More than 6000	180	5
Home 10	Bethlehem	6	4	1	Technical	3000-6000NIS	140	3

Table 2.2 shows a summary of the common home appliances in the houses where the measurements were taken. Based on the nominal power rate of each device and after knowing the nature of the loads a priority degree of a 1-5 scale was given to each load. The high priority degree means that this load is a power consumer and can be shifted to be operated during PV system energy production time without disturbing the comfort level of the end-users. Where loads that cannot be shifted, takes priority 1 and loads that can be shifted take priority 5.

Table 2.2: Loads in homes, and priority degrees of shifting.

Device	Power(watt)	priority
Washing Machine	700-3000	5
Hair Dryer	700-1000	1

Microwave	1250	1
Toaster	1000	2
Clothes Dryer	2000	5
Electric furnace	1500	1
Water pump	560-2240	5
Boiler	2500	5
Water Heater	1000-1500	5
Air conditioner	2500	1
Vacuum Cleaner	1400	1
Electric Fireplace	1000-3000	1
Dishwasher	2200	5

2.4.2 First House

Electricity consumption in city houses is almost similar in the same part of the city because the standard of living of civilians in the same environment receives the same electrical power from the same power source, and daily work is also similar and any change in energy consumption means a different city or different part of the city.

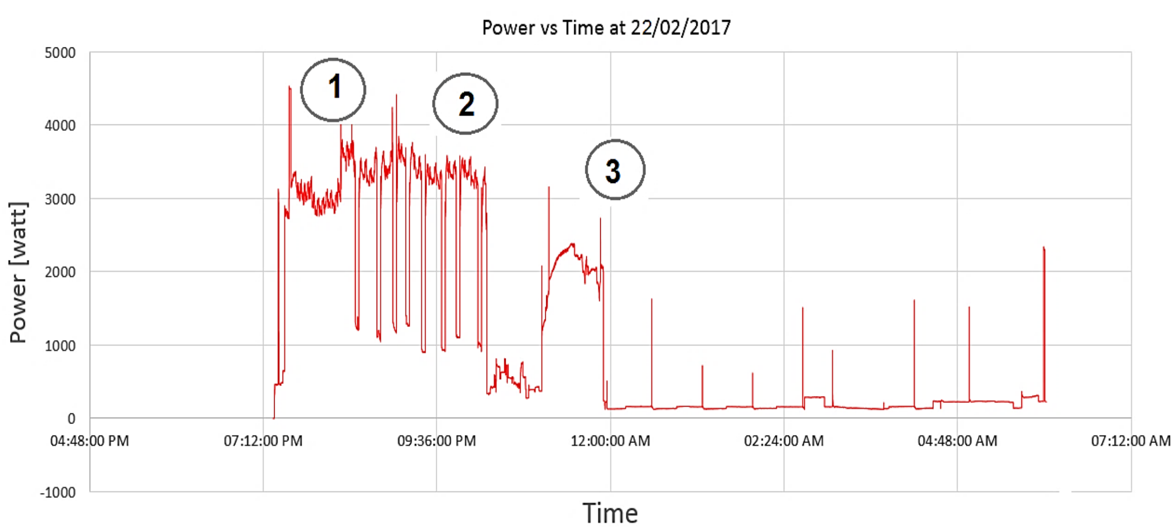


Figure 2.10: Electrical power consumption from 7:00 pm to 7:00 am.

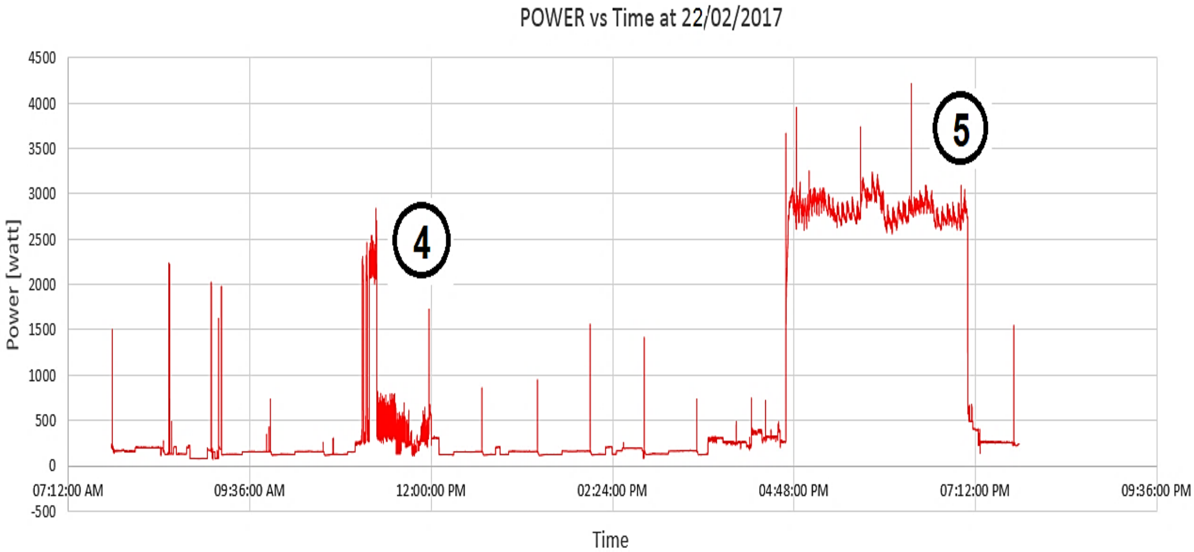


Figure 2.11: Electrical power consumption from 7:00 am to 7:00 pm.

Figure 2.10 and **figure 2.11** show a chart of the electrical power consumption in the first house for 24 hours. As shown (see **figure 2.10**), see the point 1 and point 2, represent the devices that were working at that time and they were TV, water heater, and air condition. While at point 3 heater was working. As shown in the **figure 2.11**, point 4 and 5 represent the devices that were in operation, which were the washing machine and the air condition respectively.

According to information obtained from the first house questionnaire, electricity consumption was low from 7 am to 4 pm due to non-attendance at home (schools, universities, and work). It was noted that from 4 pm to 11 pm high consumption was found and therefore due to the presence of all individuals in the house.

It was also noted that the monthly income of the house was high, resulting in additional loads such as air conditioners that increase consumption.

2.4.3 Second House

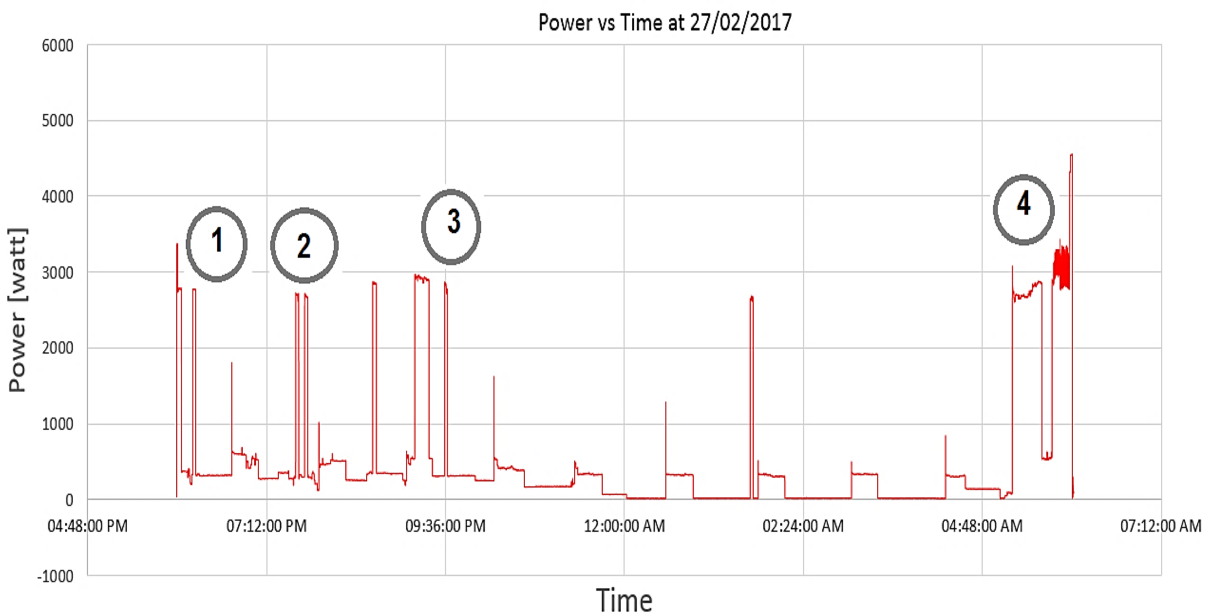


Figure 2.12: Electrical power consumption from 6:00 pm to 6:00 am.

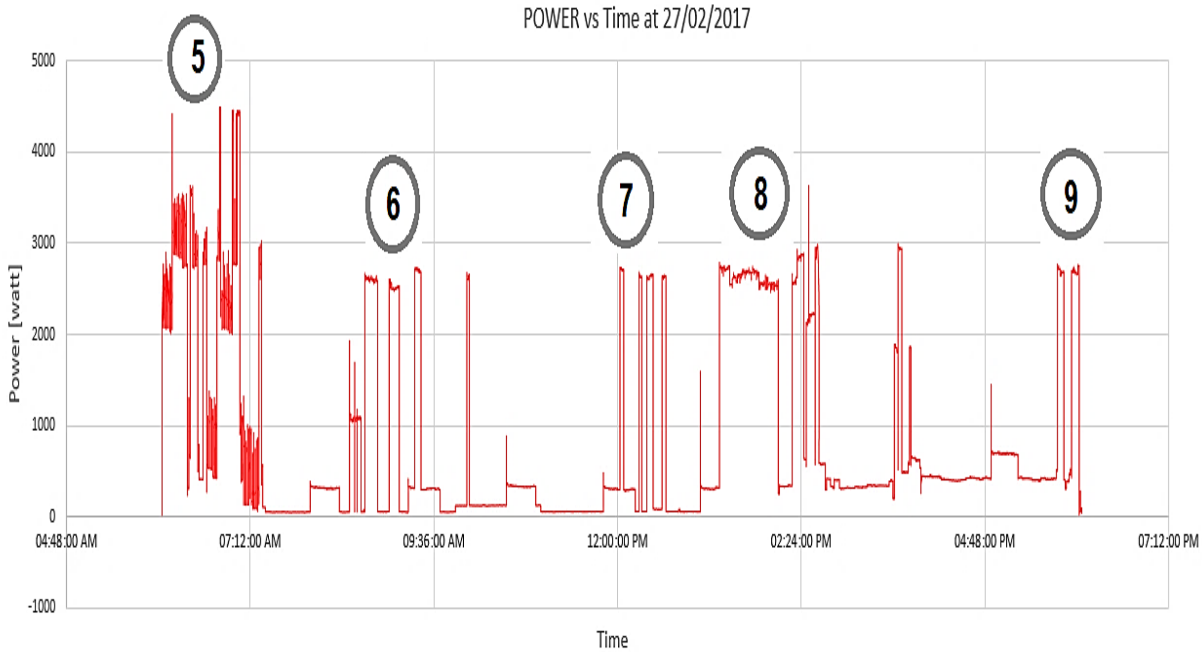


Figure 2.13: Electrical power consumption from 6:30 am to 6:30 pm.

Figure 2.12 and **figure 2.13** show a chart of the electrical power consumption in the second house for 24 hours. As shown (see **figure 2.12**), see the point 1, point 2 and point 3 represent the devices that were working at that time and they were a water heater, microwave, and boiler respectively. While at point 4 boiler was working. As shown in the **figure 2.13**, point 5 represents the devices that were in operation, which were the washing machine, boiler and hairdryer. Point 6 and point 9 vacuum cleaner was working while point 7and point 8 microwave and electric fireplace was working respectively.

According to information obtained from the questionnaire of the second house, it was found that the consumption of electricity was high during most of the day because of the presence of people in the house, and the wife of the family to carry loads such as washing machine and vacuum cleaner and also Boiler. It was also noted that the monthly income of the house is normal, but consumption is high.

2.4.4 Third House

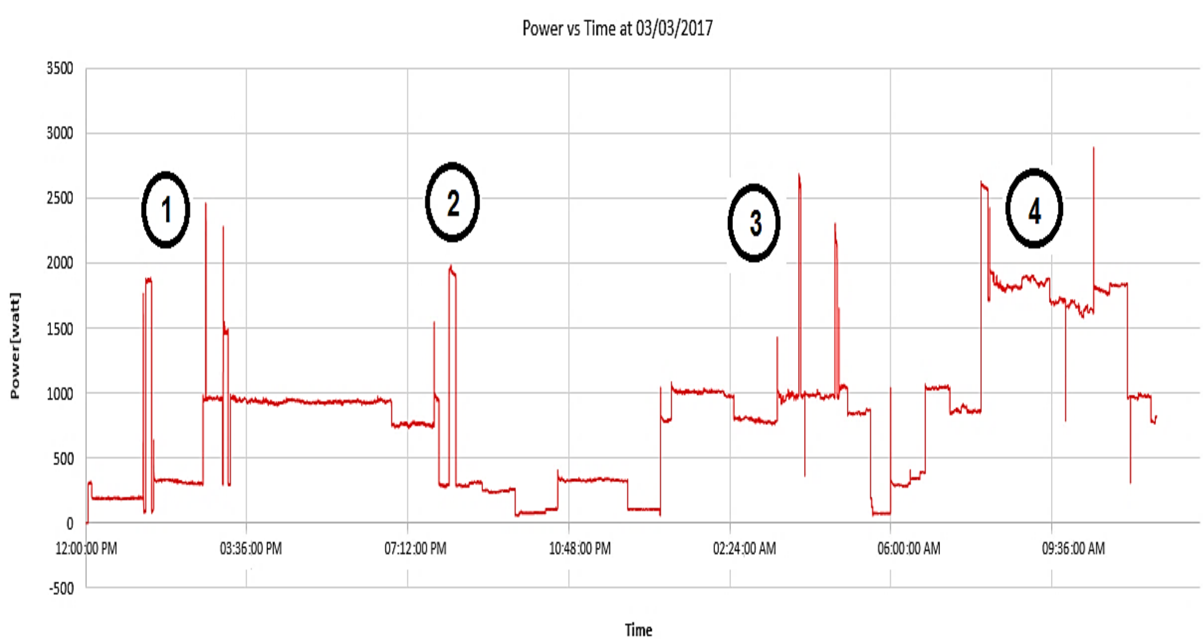


Figure 2.14: Electrical power consumption from 12:00 pm to 10:00 am.

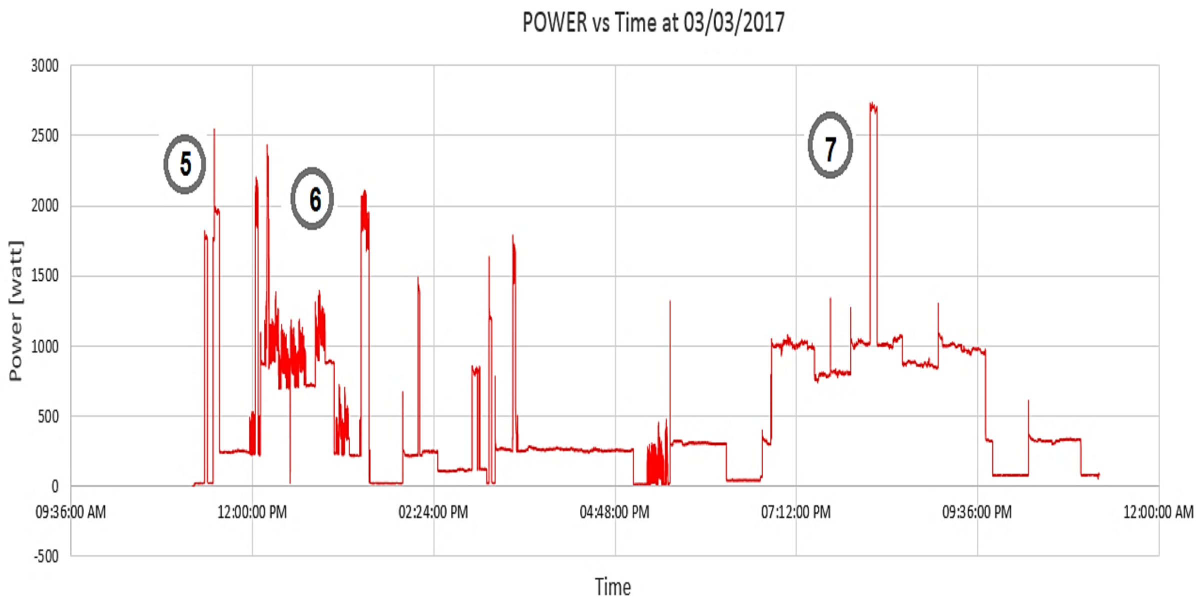


Figure 2.15: Electrical power consumption from 10:00 am to 12:00 pm.

Figure 2.14 and **figure 2.15** show a chart of the electrical power consumption in the third house for 24 hours. As shown (see **figure 2.14**), see the point 1and point 2 represent the devices that were working at that time and they were water heater and water pump respectively. While at point 3 and point 4 electric fireplace was working. As shown from the **figure 2.15**, point 5 and point 6 represent the devices that were in operation, which were the water heater and washing machine respectively. while point 7 electric fireplace and water heater was working.

According to information obtained from the third house questionnaire, shows that electricity consumption was high during most of the day because he was on the end of the week, and the presence of all members of the family inside the house, that result in high consumption. The housewife runs loads such as washing machine and vacuum cleaner on holidays. Study university students in late hours and run loads such as electric fireplace.

2.4.5 Conclusion of Analysis

Based on the measurements that were observed for 10 homes, there are devices that consumes high power as follows boiler, air condition, electric fireplace, water heater, washing machine, iron and the dishwasher. Analysis of questionnaires and measurements shows that loads depend on human behavior as explained previously.

In this project by changing the operating times of some devices without compromising the convenience of the end-user as follows: Washing machine, water pump, boiler, dishwasher and refrigerator as these devices do not directly affect the user and consume high power.

2.5 Building Selection

After selecting the city of Hebron, and studying a sample of houses in it, an ideal house containing all the electrical appliances was chosen. This house is the first house mentioned in the previous section.

The house is located in the Wadi Abu Dajan, northwest of Hebron as shown in the **figure 2.16**. The surface of the house is 180 m^2. The **figure 2.17** shows the roof of the house and the area where the solar cells can be installed.

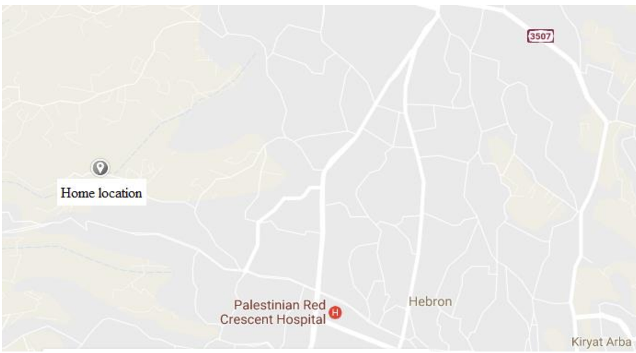


Figure 2.16: The location of the chosen house.

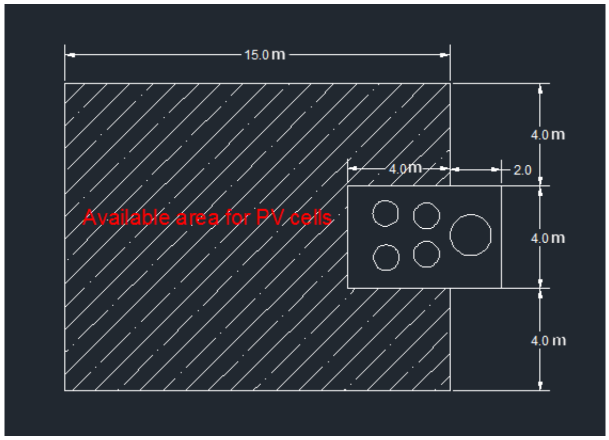


Figure 2.17: The vertical projection of the house.

2.6 Conceptual Design

The control approach proposed in this study was designed to be implemented to the three-story building which was selected in the sections above.

2.6.1 Single house model

After selecting the house and selecting the devices to be controlled, the project will apply to a single house and then the results will be distributed to three houses in one building.

Figure 2.18 shows the Method distribution of loads inside the home, where it contains all the electrical appliances. The first row contains the devices that will be applied to the controller.

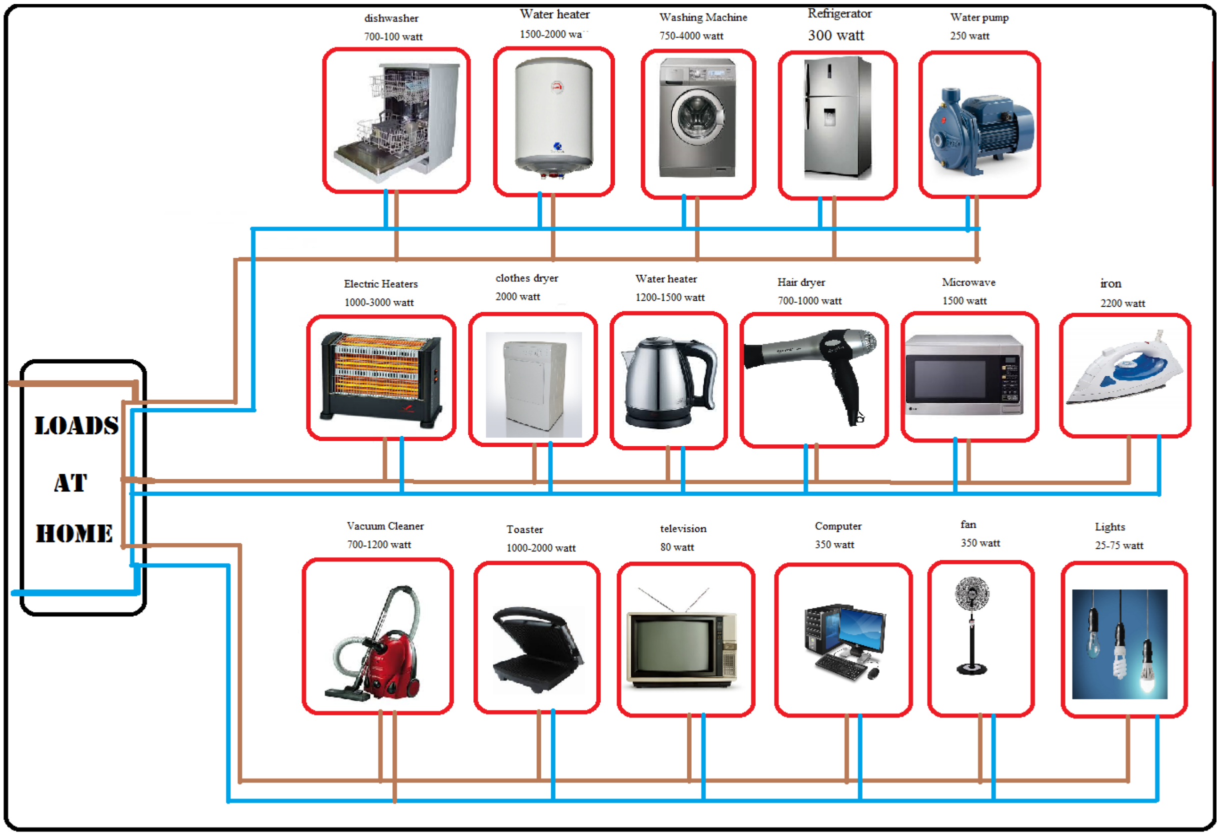


Figure 2.18: Method distribution of loads inside the home.

The controller was building as shown in **figure 2.19** using current sensor which measures the summation of current devices then controller receives this value to send to Fuzzy logic controller (the heart of controller), which decide is it the value accepted or not in accordance with particular standard then controller send the command to turn on or off devices.

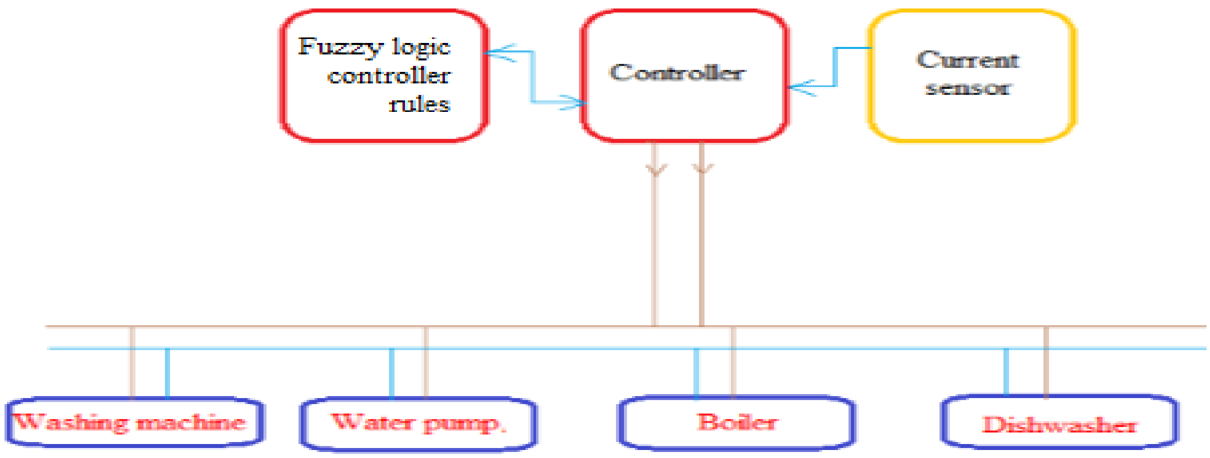


Figure 2.19: Single house model.

2.6.2 Multi-story model

After chosen single house, the results were generalized to the three-story building, with each floor containing one apartment**.** There are solar cells on the roof of the building that feed three apartments, as shown in **figure 2.20**.

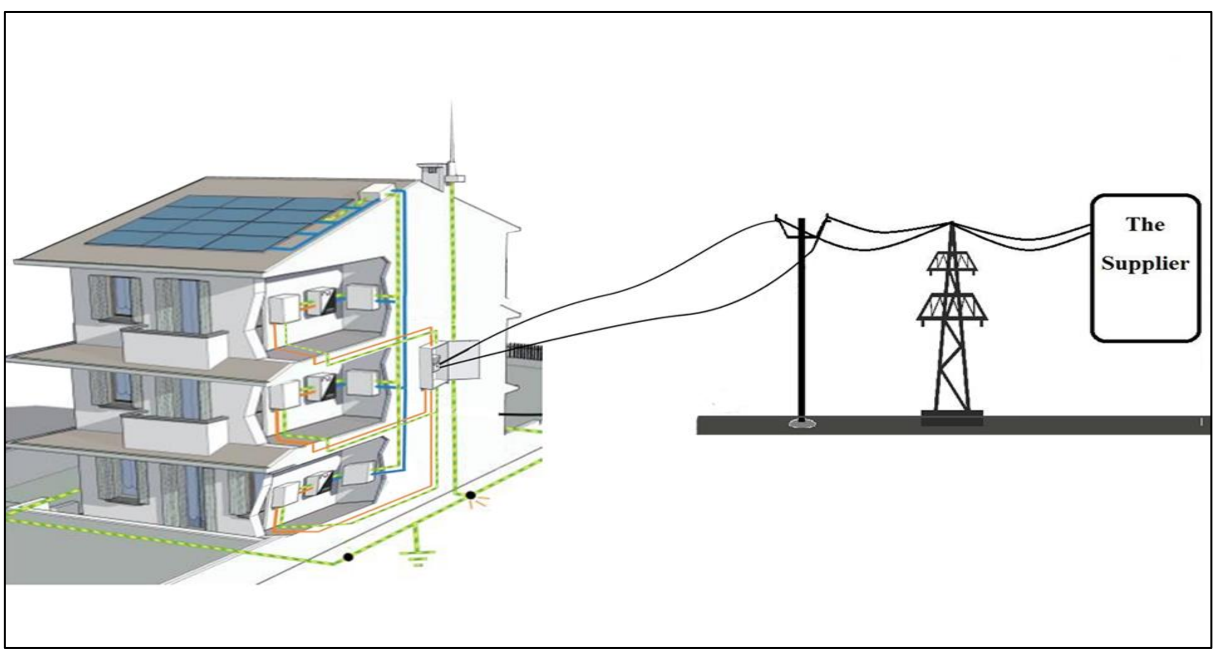


Figure 2.20: Model of multi-story building.

This building has a main controller that manages the controllers for each apartment, where it takes power from the supplier, solar cells and stored energy by batteries and distributed to the apartment controllers, as shown in **figure 2.21**.

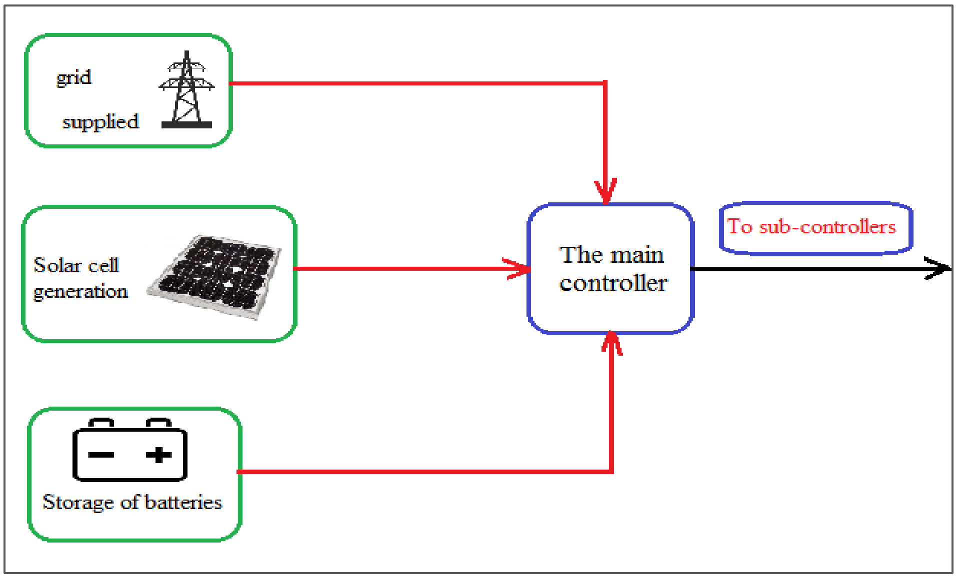


Figure 2.21: Input and output of the main controller.

The main controller calculates the total power coming to him and determines the loads that can be operated and then send information to the apartment controllers. If the power is very high and cannot be consumed, it is used for other purposes such as heating water in winter or cooling in the summer, as shown in **figure 2.22.**

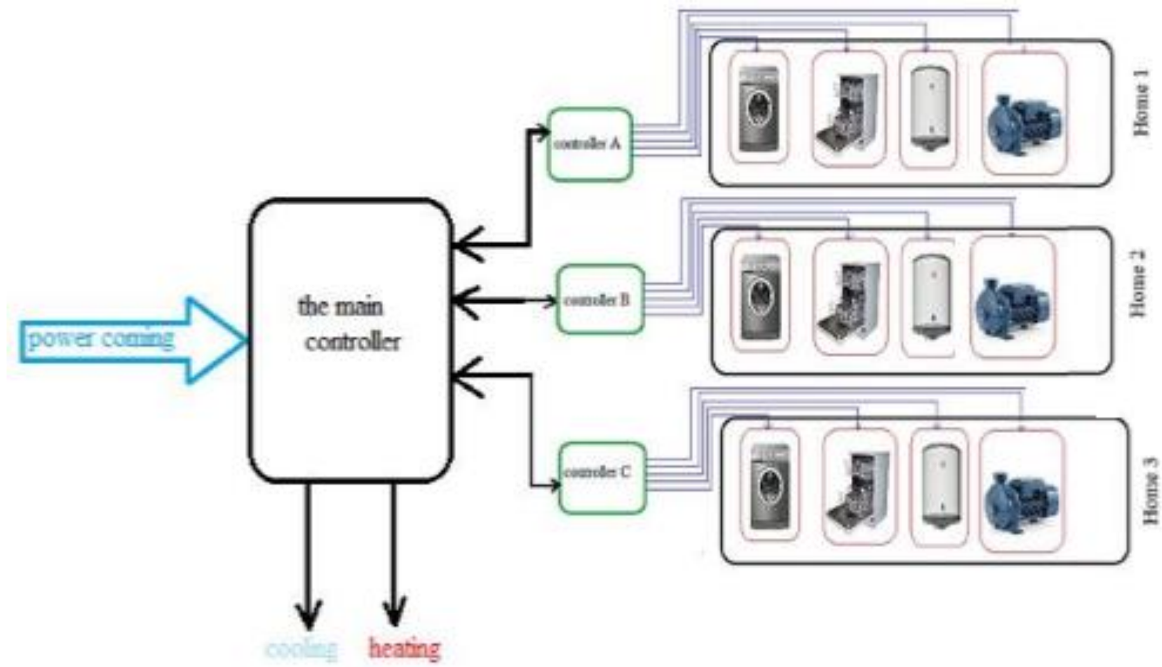


Figure 2.22: Principle work of the main controller.

2.7 Conclusions of chapter

The increasing consumption of electricity in the Hebron city and population growth made it an appropriate for study. Loads were measured for a sample of a house to study human behavior and its relation to electricity consumption. The socio-economic factors that affect power consumption are defined as (household members, monthly income, educational level).

Conclude that there are devices inside the house that can be controlled according to the priority time without compromising the end-users comfort as (boiler, washing machine, refrigerator, water pump, dishwasher). In order to customize the study, an ideal home was chosen, in which has most loads and after that the study was generalized to other houses.

In this chapter developed a manner to design and apply the controller that we will work on the project the increasing consumption of electricity in the Hebron city and population growth made it an appropriate for study. Loads were measured for a sample of a house to study human behavior and its relation to electricity consumption.

CHAPTER THREE

Mathematical Model

Contents:

3.1 Introduction.

3.2 MATLAB and Simscape.

3.3 Mathematical Model.

3.4 Solar Cells Readings and analysis.

3.5 Conclusion.

3.1 Introduction

In this chapter, a mathematical model using MATLAB/Simscape was formulated for a typical electric load found in any house. The purpose of the model is to estimate the power consumption pattern for different operation scenarios of home appliances. Such that each home electric load was represented by its equivalent electric circuit. The model was validated based on the consumption patterns that were measured during five days for a single house (apartment) considered in chapter two. The parameters of each equivalent circuit were adjusted based on the measurement recorded for each home appliance.

Solar cells were monitored for five days, to compare power consumption for first house with solar cell generation. Choose a fuzzy logic controller to build a controller on MATLAB to control home appliances.

3.2 MATLAB and Simscape

3.2.1 MATLAB

The MATLAB platform is optimized for solving engineering and scientific problems. The matrix-based MATLAB language is the world's most natural way to express computational mathematics. Built-in graphics make it easy to visualize and gain insights from data. A vast library of prebuilt toolboxes lets you get started right away with algorithms essential to your domain. The desktop environment invites experimentation, exploration, and discovery. These MATLAB tools and capabilities are all rigorously tested and designed to work together.

MATLAB helps you take your ideas beyond the desktop. You can run your analyses on larger data sets and scale up to clusters and clouds. MATLAB code can be integrated with other languages, enabling you to deploy algorithms and applications within web, enterprise, and production systems [17].

3.2.2 Simscape

Simscape enables you to rapidly create models of physical systems within the Simulink environment. With Simscape, you build physical component models based on physical connections that directly integrate with block diagrams and other modeling paradigms. You model systems such as electric motors, bridge rectifiers, hydraulic actuators, and refrigeration systems, by assembling fundamental components into a schematic. Simscape add-on products provide more complex components and analysis capabilities.

Simscape helps you develop control systems and test system-level performance. You can create custom component models using the MATLAB based Simscape language, which enables text-based authoring of physical modeling components, domains, and libraries. You can parameterize your models using MATLAB variables and expressions, and design control systems for your physical system in Simulink. To deploy your models to other simulation environments, including hardware-in-the-loop (HIL) systems, Simscape supports C-code generation [17].

3.3 Mathematical Model

All loads in the house are connected in parallel and based on this principle the Simscape model was constructed. By returning to the data sheets of all electric devices found in the house. Some devices were represented by a resistance such as water heater. Some of them were represented by RLC circuit such as the refrigerator. And some of them were represented by RL circuit such as the air conditioner. Each device is controlled by a switch which is connected to a Repeating Sequence Source. This sequence is set based on the operating scenario of that device (see **figure**

3.1). Where zeros express appliance operation off-times and ones express on-times. The switches will be controlled using fuzzy Controller.

The Simscape model shown in **figure 3.2**, It is for a typical home that contains all the electrical appliances, while it can be applied to any other home and obtain the power consumption for this home by adjusting the operating scenario of the devices.

To obtain the power consumption, the main rms current is multiplied by the main rms voltage according to power law equation (1).

$$P = V * I \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

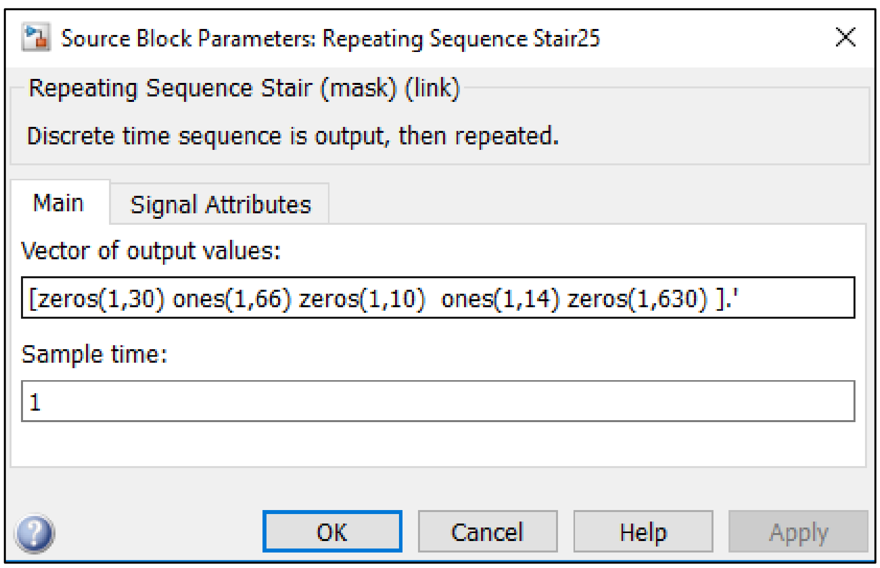


Figure 3.1: Repeating Sequence Source [17].

An appropriate scale was made for the day so that the results of the Simscape are more realistic, the scale 1minute in fact: 1secand in MATLAB.so the day becomes the 1440s and half day 720s.

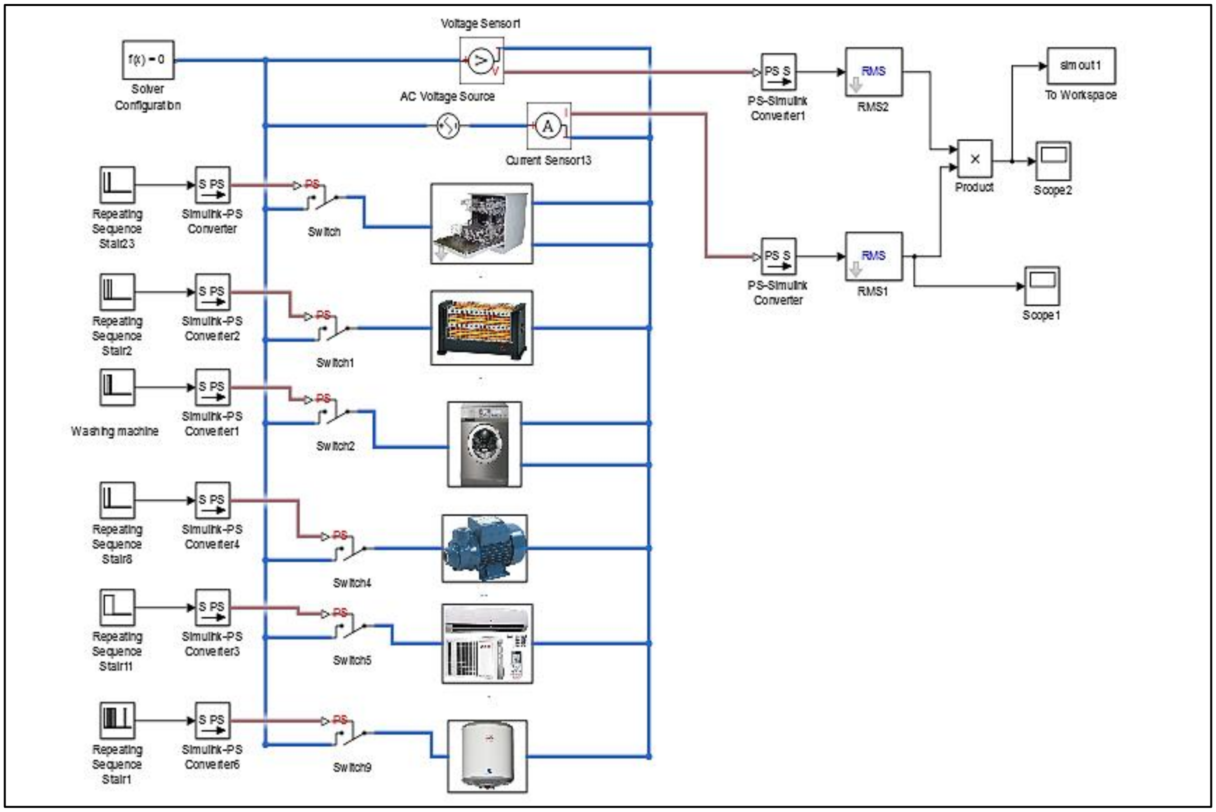


Figure 3.2: Simscape model for first house.

3.3.1 Simscape Parameters Validation

Through the measurements recorded for home appliances consumed electric current, all the parameters of the Simscape devices electric circuits are adjusted for example:

Boiler:

Manufacturer company: Nieroukh Industrial Company, rated power 2200 watt.

Figure 3.3 shows a Current data for Boiler measurement and **figure 3.4** shows a Current data for Boiler by Simscape.

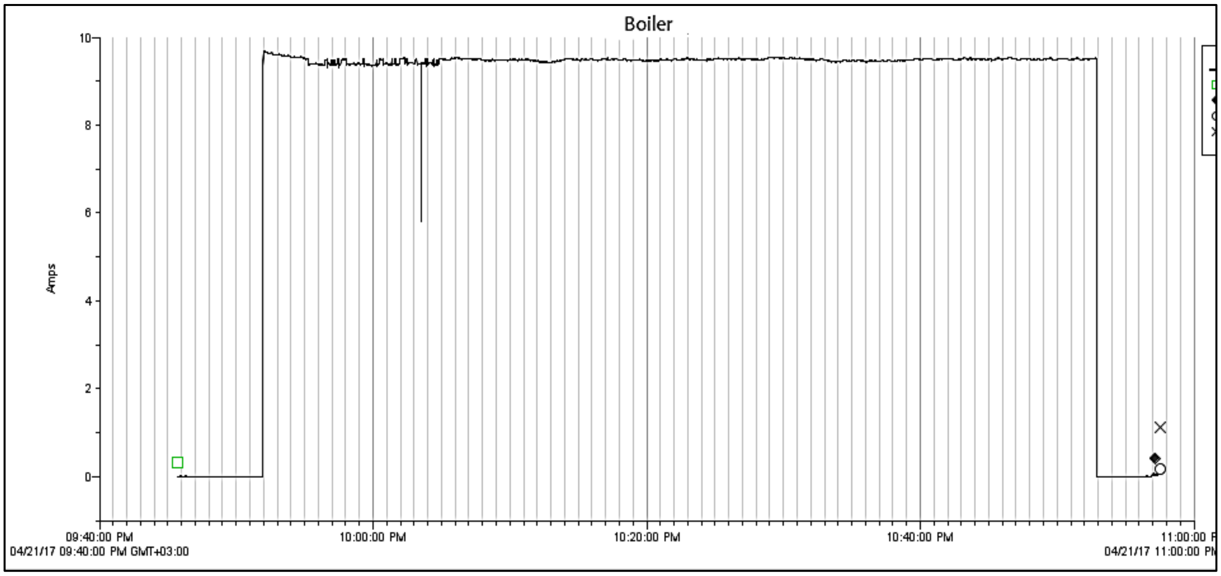


Figure 3.3: Current data for Boiler by measurement.

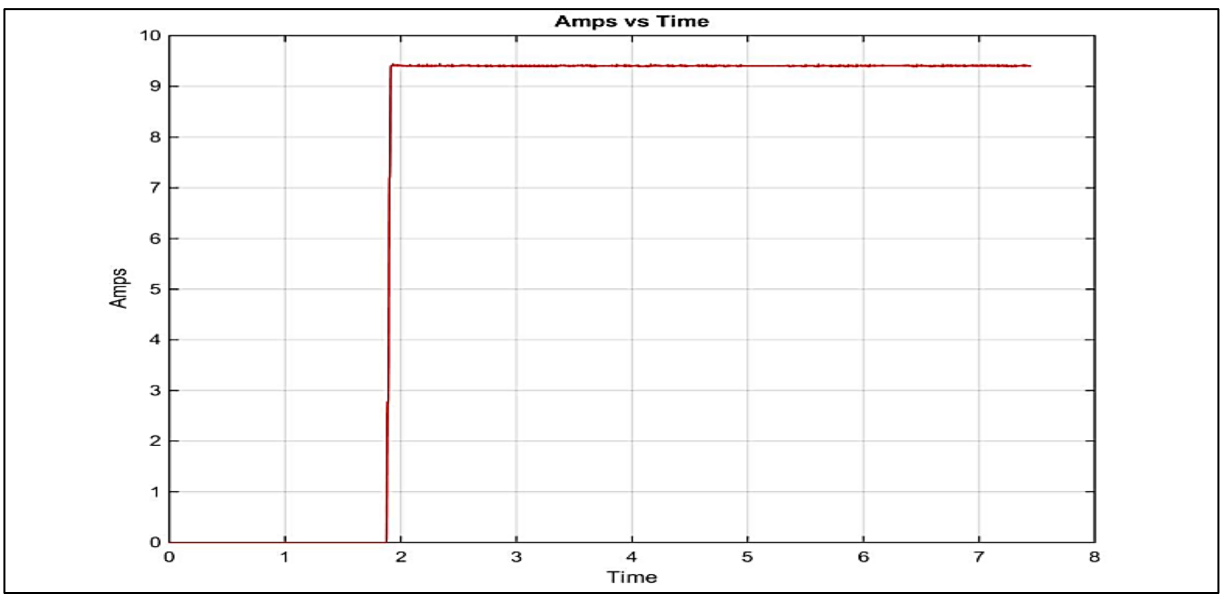


Figure 3.4: Current data for Boiler by Simscape**.**

Toaster:

Manufacturer company: ARISTON, rated power 1200 watt.

Figure 3.5 shows a Current data for Toaster by measurement and **figure 3.6** shows a Current data for Toaster Simscape.

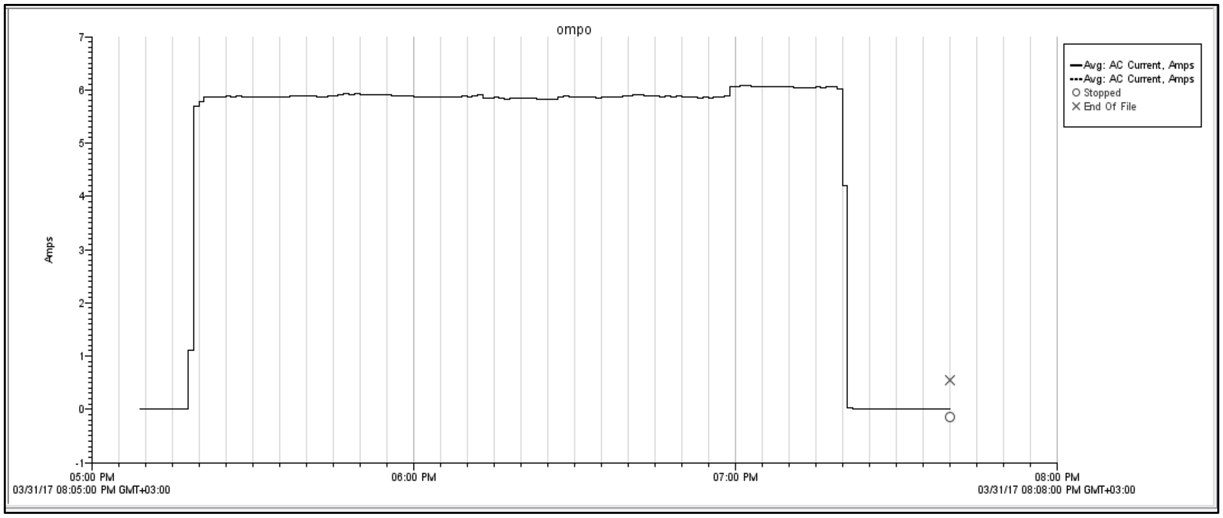


Figure 3.5: Current data for Taster by measurement.

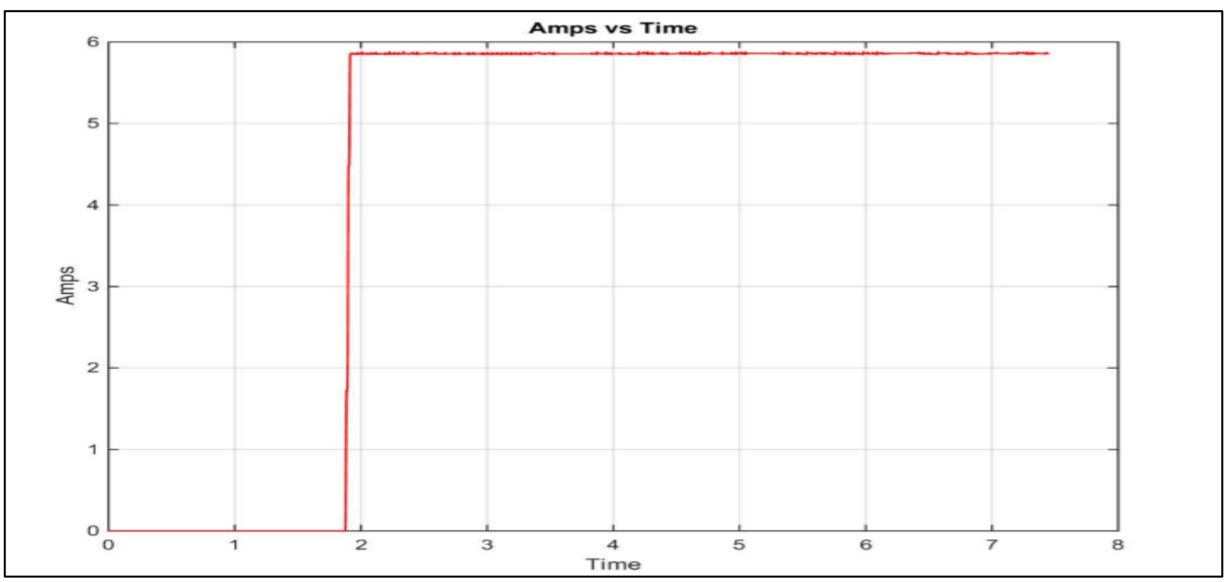


Figure 3.6: Current data for Toaster by Simscape.

All devices have been measured (see Appendix C).

3.3.2 Simscape Model Output Validation

The first house consumption was measured for five days, to monitor the human behavior, then do Verification using Simscape.

Operating scenario: **Figure 3.7** and **figure 3.8** show a chart of the electrical power consumption at 6/4/2017 from 9:00 am to 9:00 pm, the boiler is turned on from (9:00-9:10) am, the iron is turned on from (9:10-9:20) am, washing machine is turned on from (12-12:50) pm, water heater is turned on from (7:34-7:38) pm and TV from (7:40-9:00) pm.

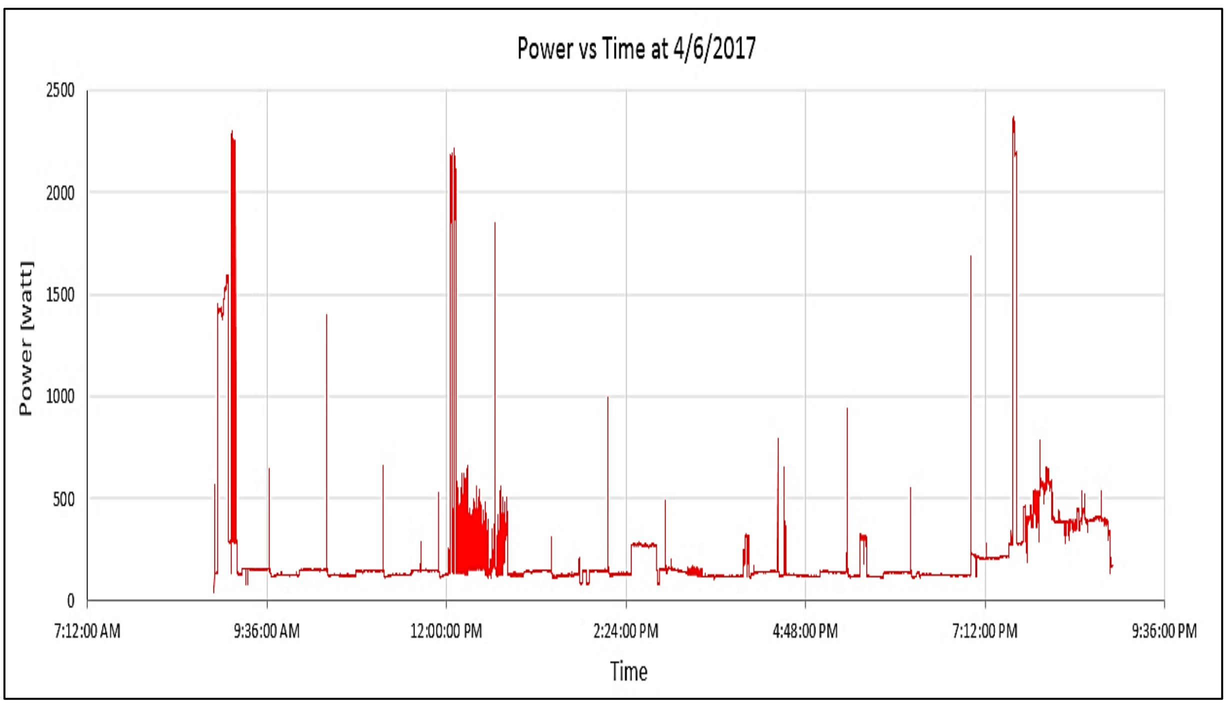


Figure 3.7: Electrical power consumption at 6/4/2017 from 9:00 am to 9:00 pm.

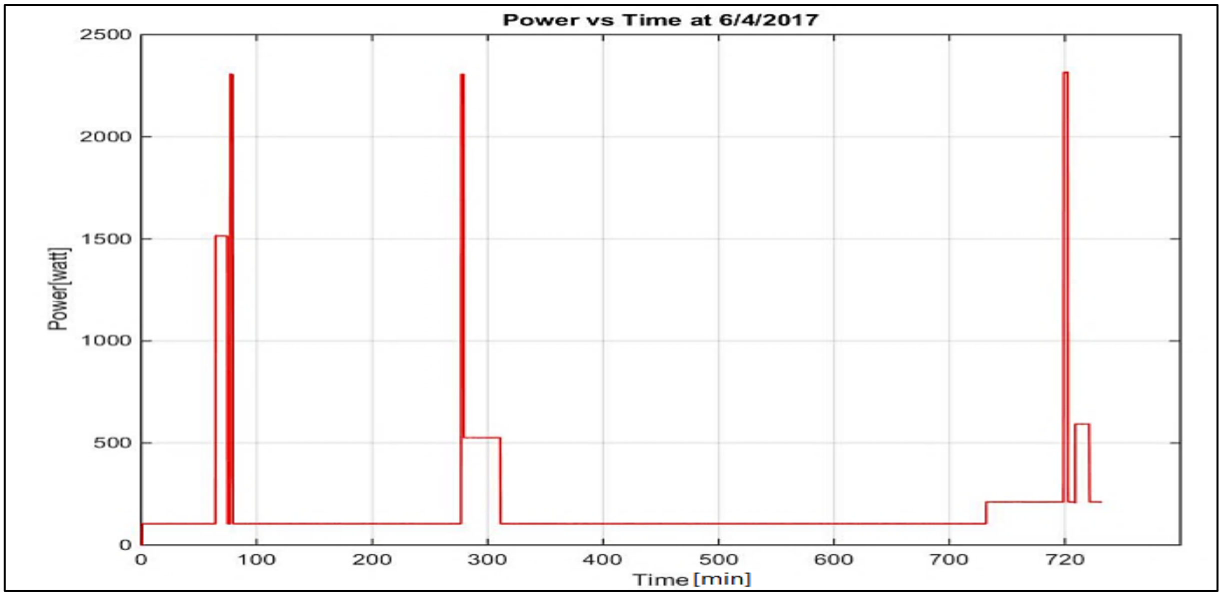
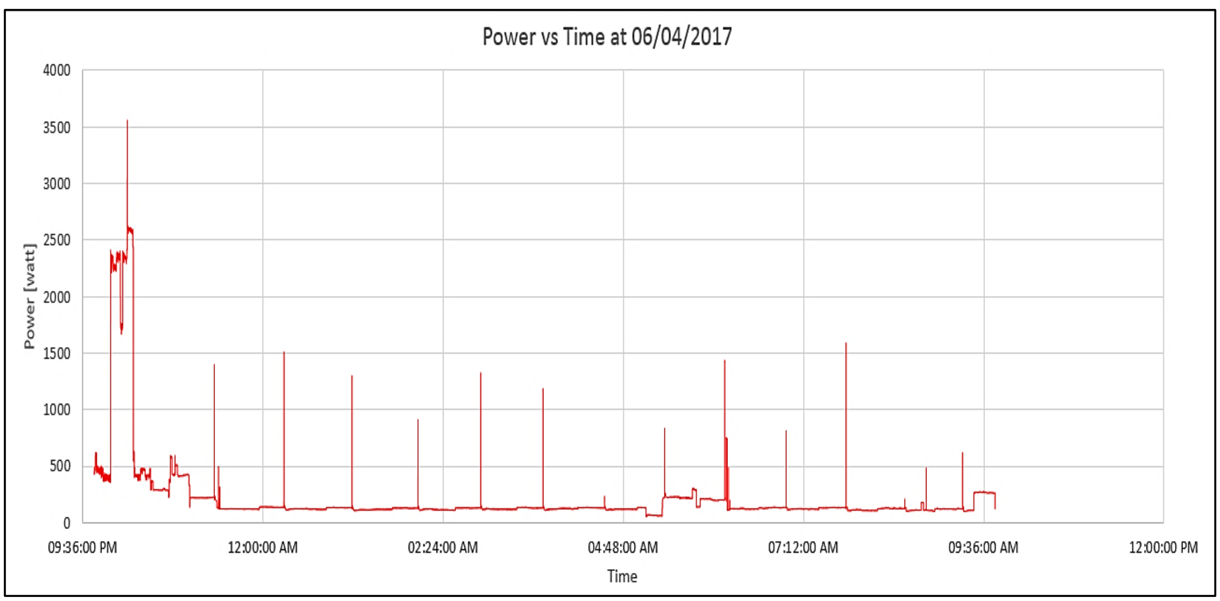


Figure 3.8: Electrical power consumption at 6/4/2017 from 9:00 am to 9:00 pm by Simscape.

Operating scenario: **Figure 3.9** and **figure 3.10** show a chart of the electrical power consumption at 6/4/2017 form 9:00 pm to 9:00 am, the water heater is turned on from (9:40-10:15) pm, and TV from (9:00-11:00) pm.



. **Figure 3.9:** Electrical power consumption at 6/4/2017 from 9:00 pm to 9:00 am.

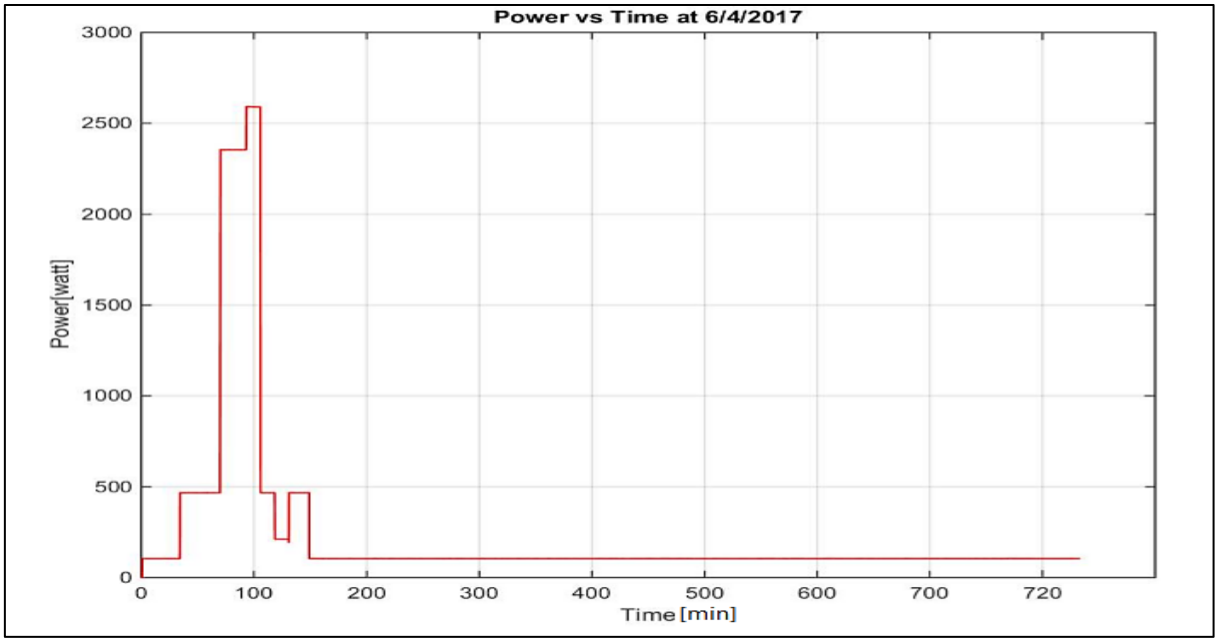


Figure 3.10: Power consumption at 6/4/2017 from 9:00 pm to 9:00 am by Simscape.

Operating scenario: **Figure 3.11**and **figure 3.12** shows a chart of the electrical power consumption at 9/4/2017 form 7:00 am to 7:00 pm, the pump and washing machine are turned on from (12.58-1.07) am, the washing machine is turned on again from (1.07-1.50) am, the pump is turned on again from (3:36-3:41) pm, TV and lights from (3-7) pm.

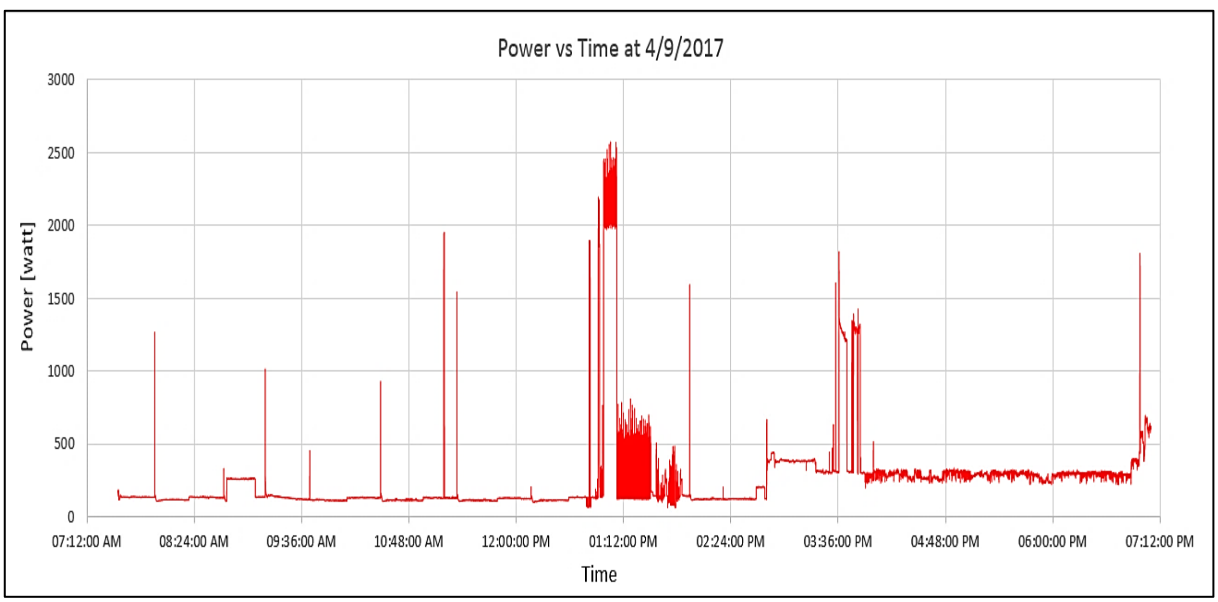


Figure 3.11: Electrical power consumption at 9/4/2017 from 7:00 am to 7:00 pm.

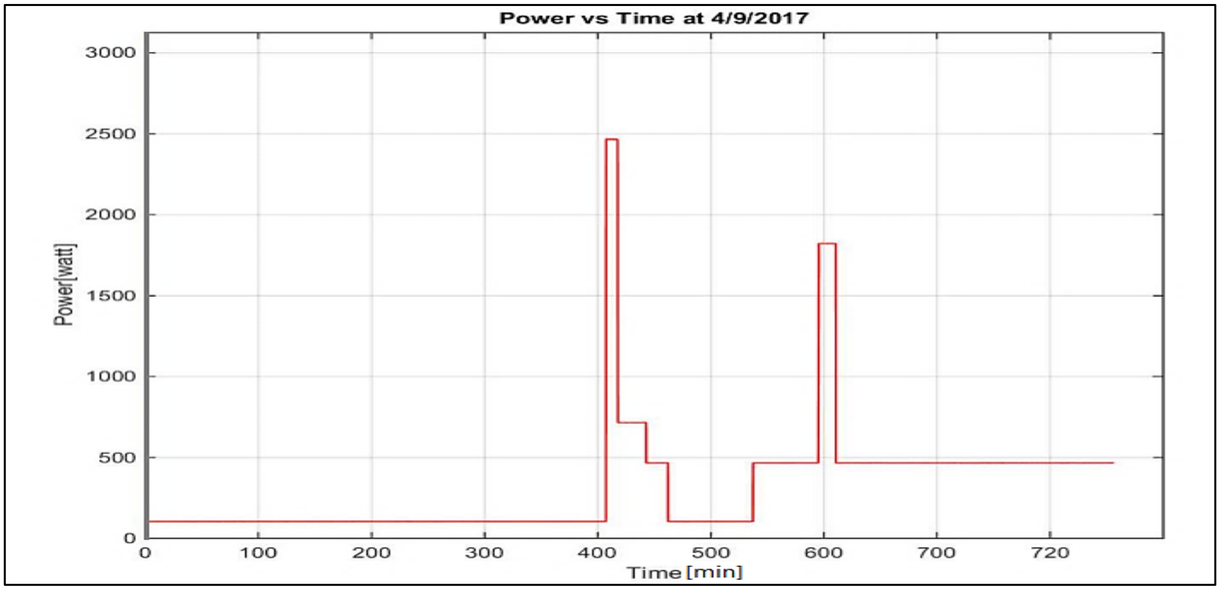


Figure 3.12: Electrical power consumption at 9/4/2017 from 7:00 am to 7:00 pm by Simscape.

Operating scenario: **Figure 3.13** and **figure 3.14** show a chart of the electrical power consumption at 9/4/2017 form 7:00 pm to 7:00 am, the fireplace is turned on from (7.30-9.36) pm, the water heater is turned on from (8.30-8.38) pm and (10.20-10.34) pm.

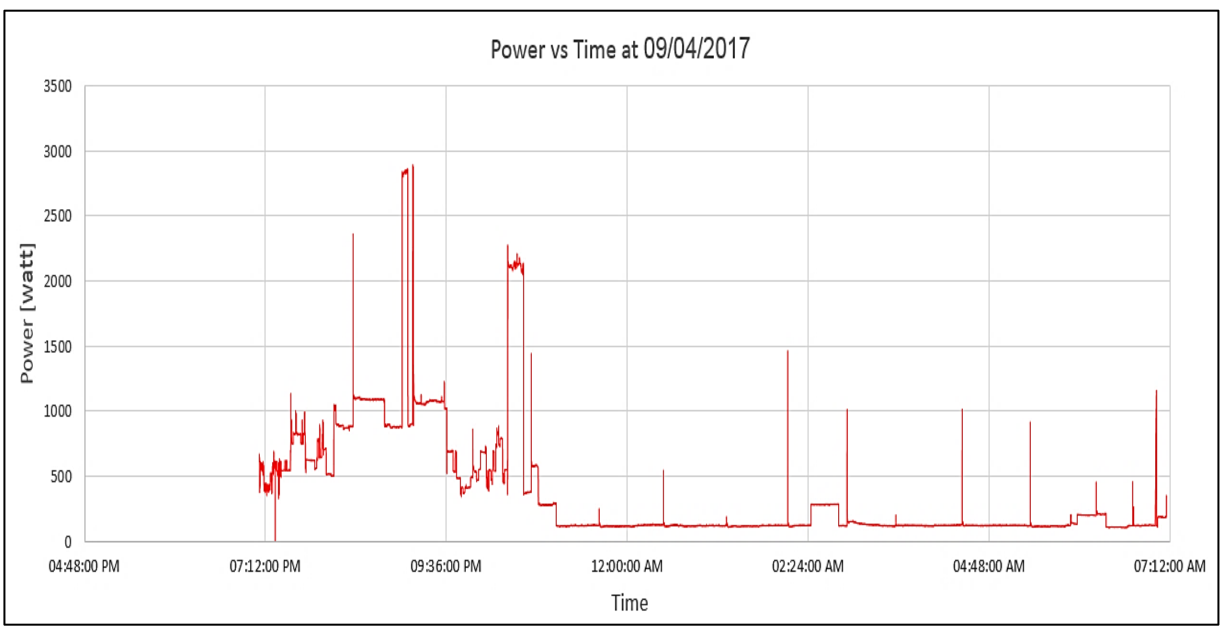


Figure 3.13: Electrical power consumption at 9/4/2017 from 7:00 pm to 7:00 am.

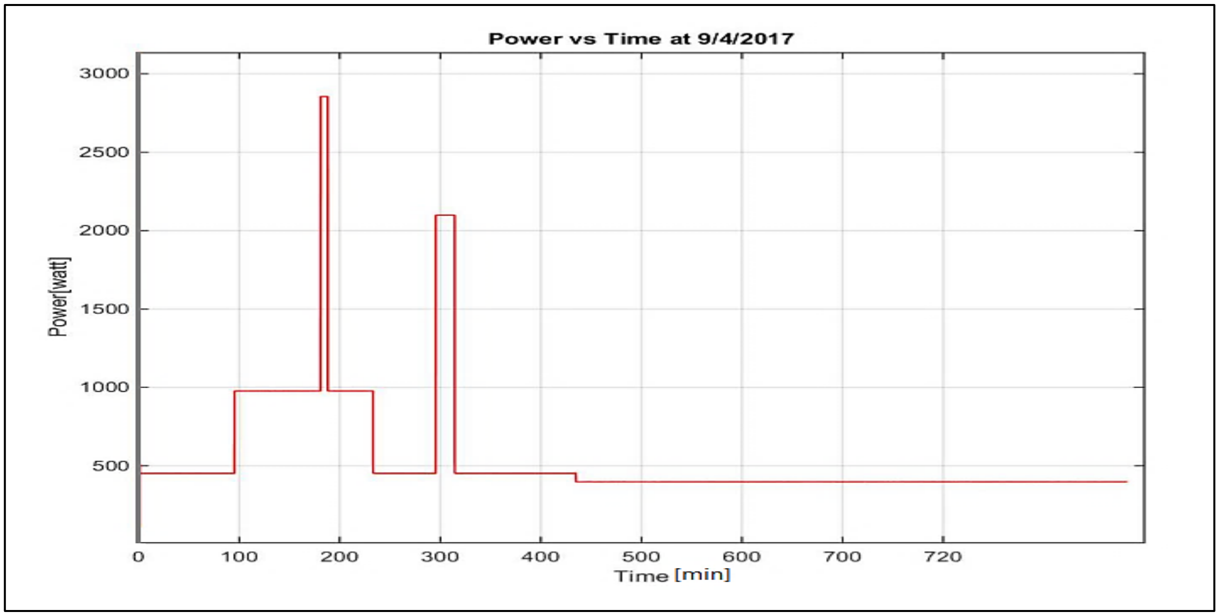


Figure 3.14: Electrical power consumption at 9/4/2017 from 7:00 pm to 7:00 am by Simscape.

Operating scenario: **Figure 3.15 and figure 3.16** show a chart of the electrical power consumption at 10/4/2017 form 7:00 am to 7:00 pm, the water heater is turned on from (7.30-8.10), (8.20-8.50), (9.36-10.20), (11.10-11.38), (3.40-4) am, the iron is turned on from (7.50-8.05), (8.55-9.05) am, the fireplace is turned on from (9.10-9.36), (10.40-11.10) am, the hairdryer is turned on from (11.59-12.01) am.

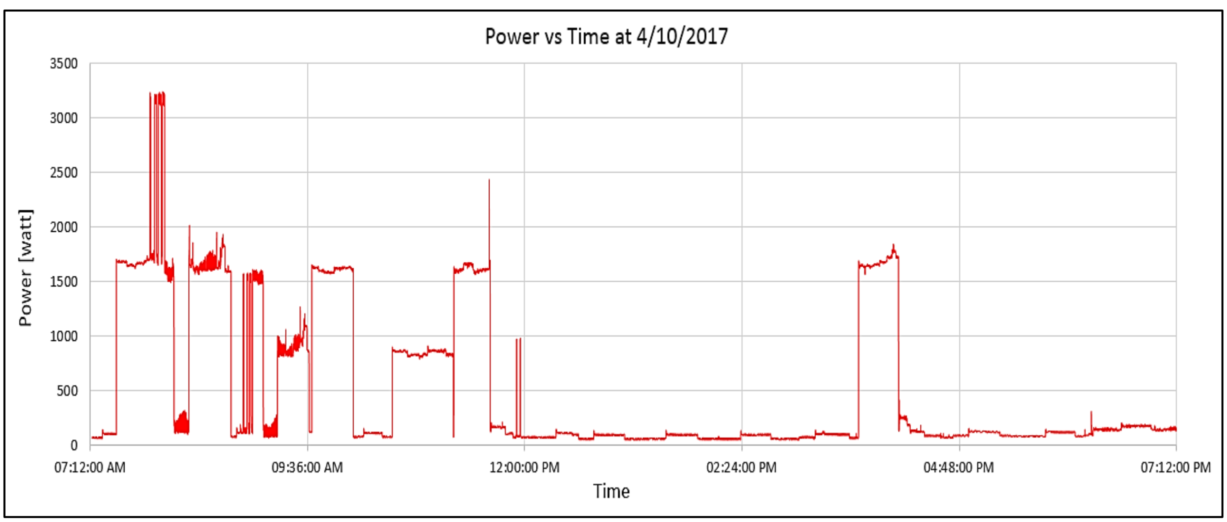


Figure 3.15: Electrical power consumption at 10/4/2017 from 7:00 am to 7:00 pm.

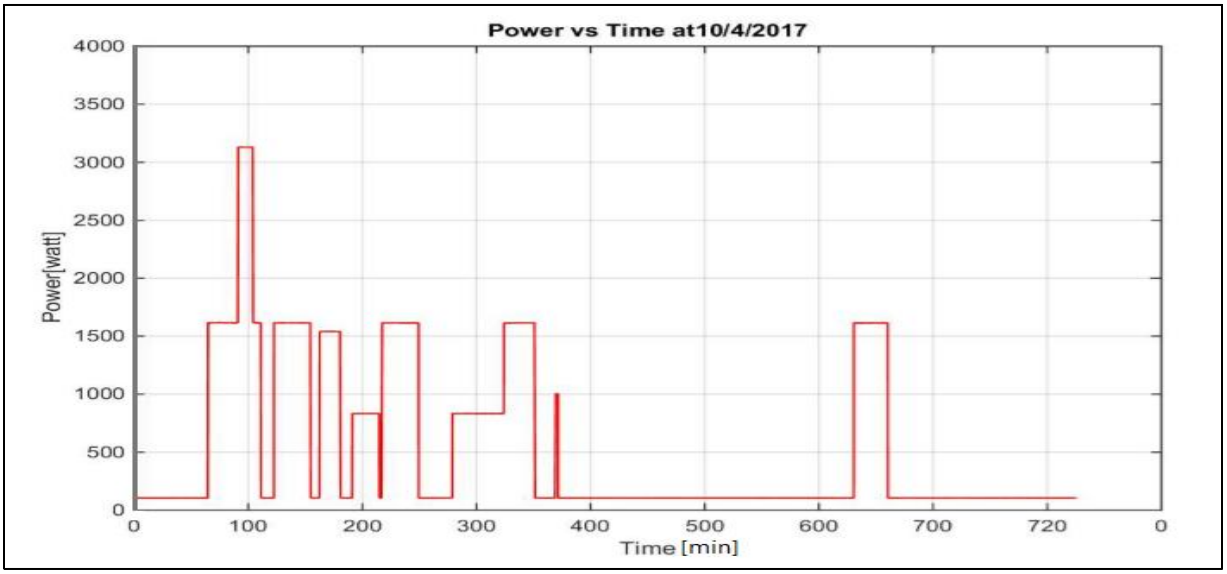


Figure 3.16: Electrical power consumption at 10/4/2017 from 7:00 am to 7:00 pm by Simscape.

Operating scenario: **Figure 3.17** and **figure 3.18** show a chart of the electrical power consumption at 10/4/2017 form 7:30 pm to 7:30 am, the condition is turned on from (7:30-8:15) pm, the fireplace is turned on from (9:03-1.9:36) am, the pump is turned on again from (10:10-10:50) pm, TV and lights from (7-11:30) pm.

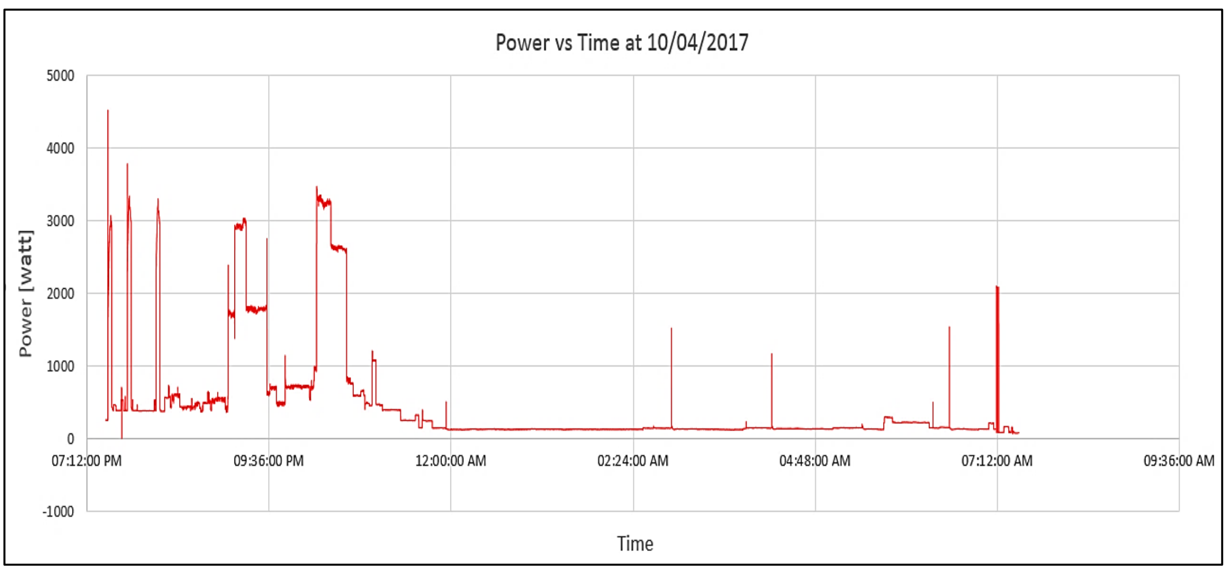


Figure 3.17: Electrical power consumption at 10/4/2017 from 7:30 pm to 7:30 am.

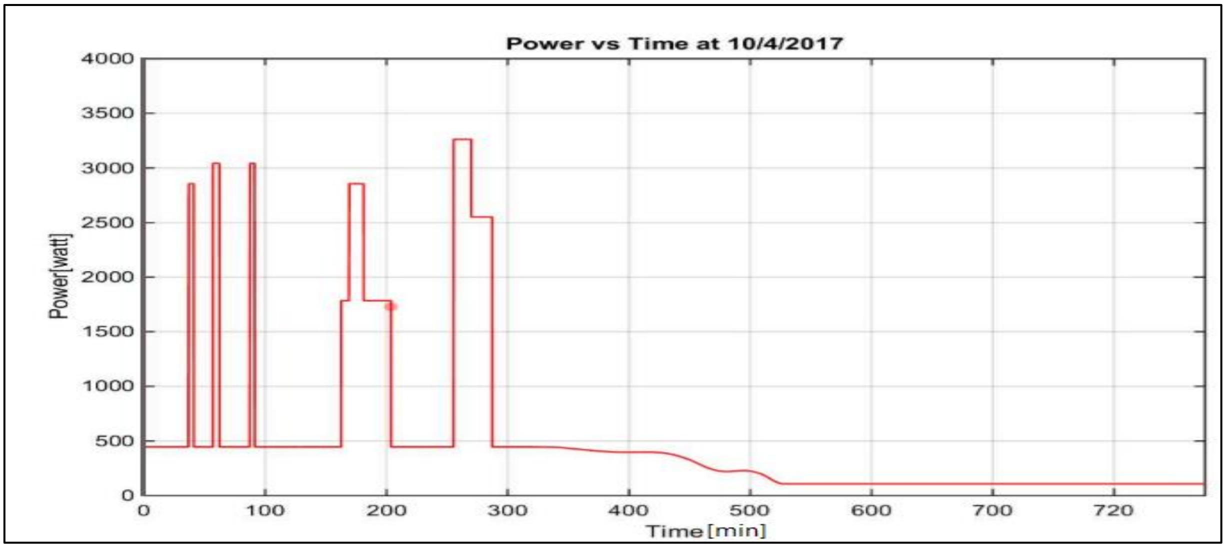


Figure 3.18: Electrical power consumption at 10/4/2017 from 7:30 pm to 7:30 am by Simscape.

3.4 Solar Cell Readings and analysis

The actual generated power was monitored for five days in April from the PV system which is consists of 'Hanwa' solar cells installed in Adna village located to the south of Hebron (**see figure 3.19**). The maximum nominal power of these cells is equal to 25000 watts, the number of cells is 78 cells. Each cell power is 320 watts with a cell area of 2 m^2. The PV cell was installed toward the south with an inclination angle of 13 degrees, shown in **figure 3.20**.

Figure 3.19: Adna village in Hebron, Palestine.

Figure 3.20: Hanwa cell.

Cell readings for 5 days in a month of April are as shown in the following figures:

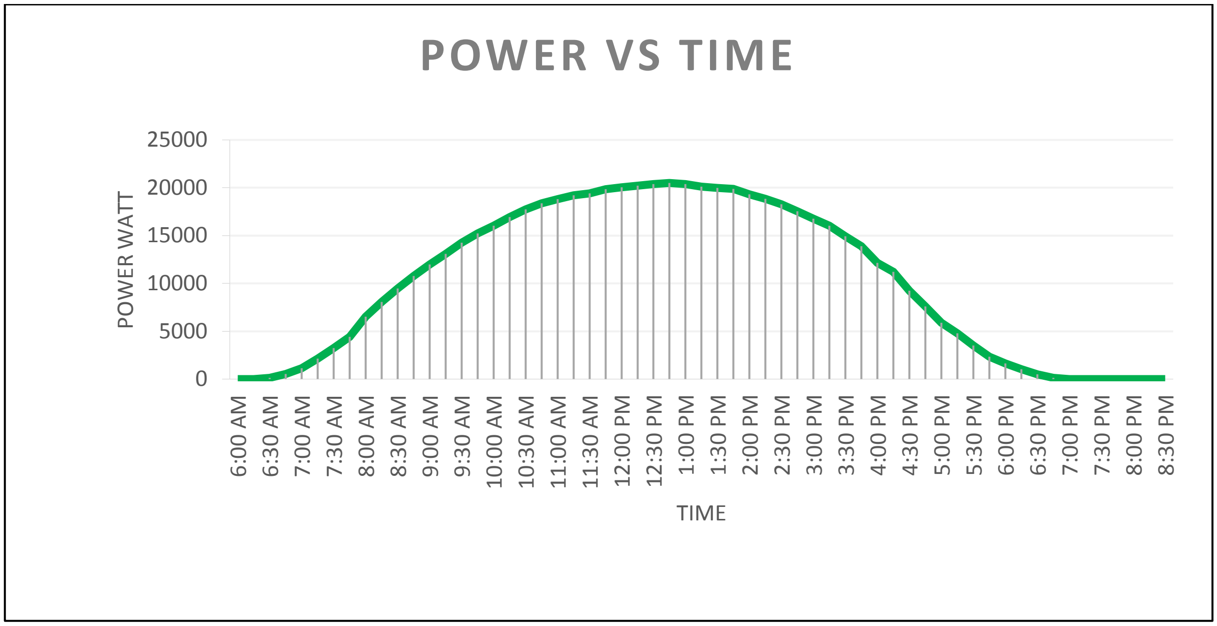


Figure 3.21: Generation of complete solar cell plant on date 6/4/2017.

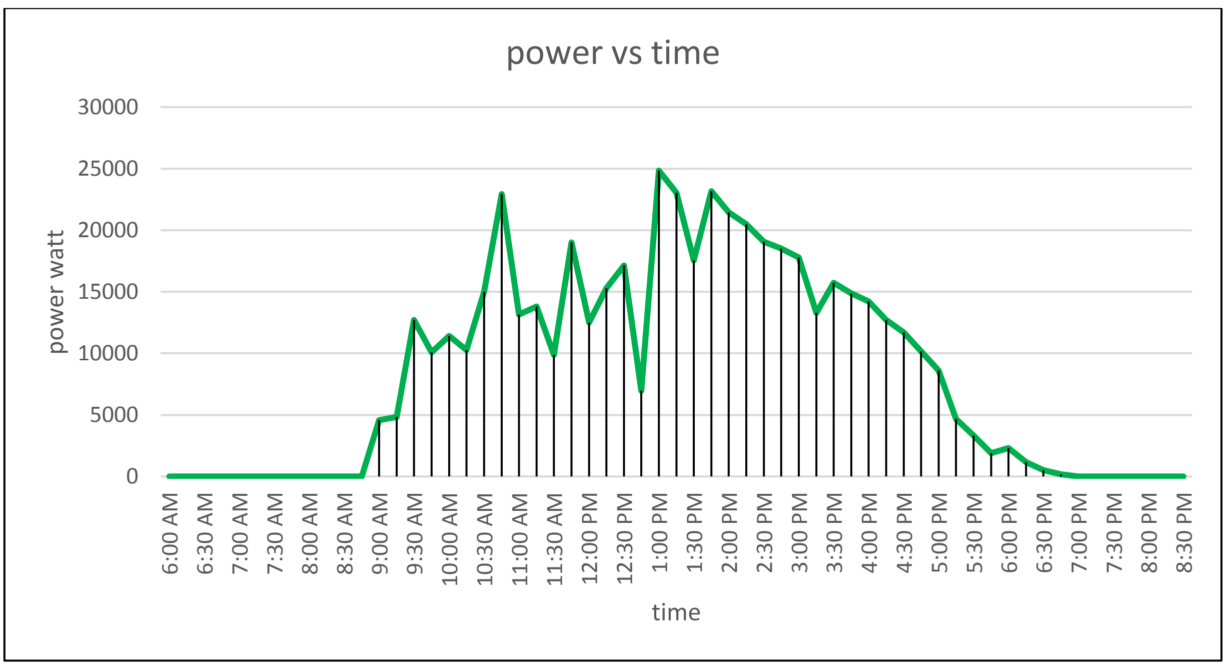


Figure 3.22: Generation of complete solar cell plant on date 7/4/2017.

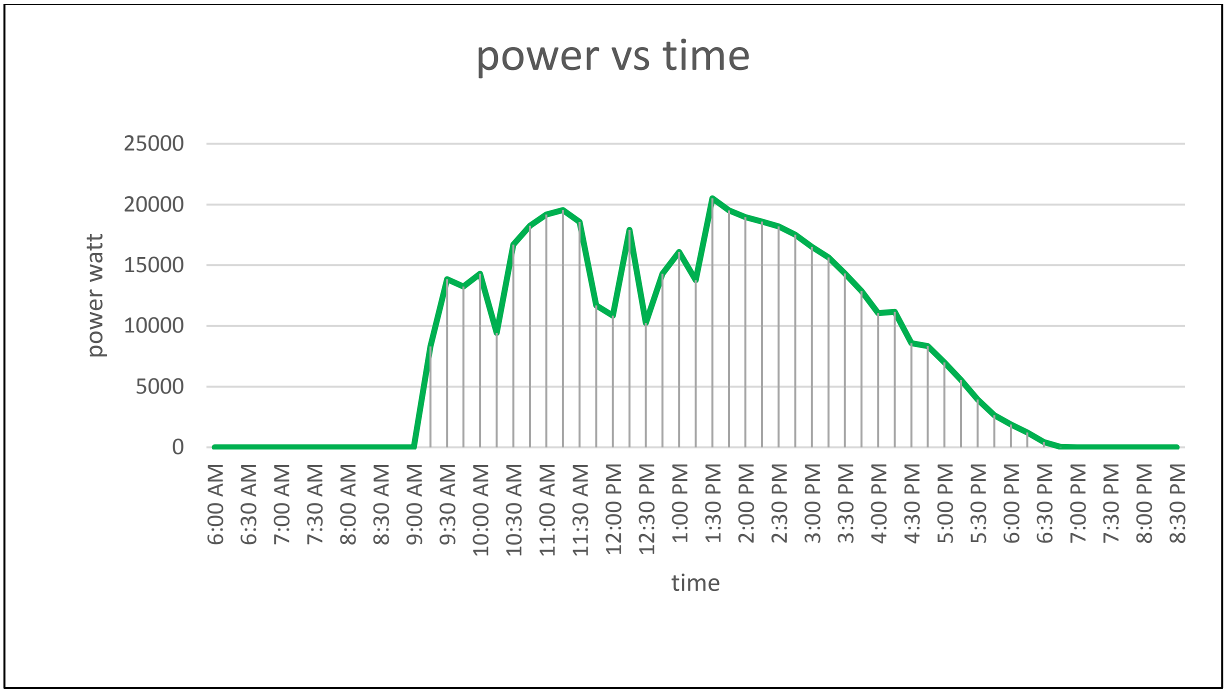


Figure 3.23: Generation of complete solar cell plant on date 8/4/2017.

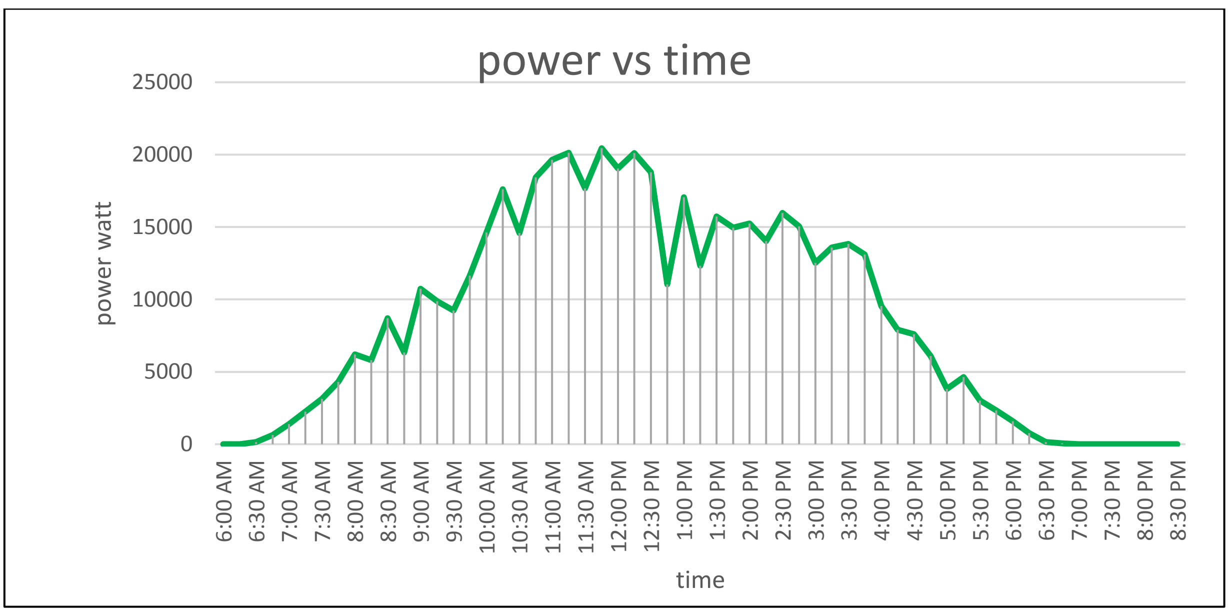


Figure 3.24: Generation of complete solar cell plant on date 9/4/2017.

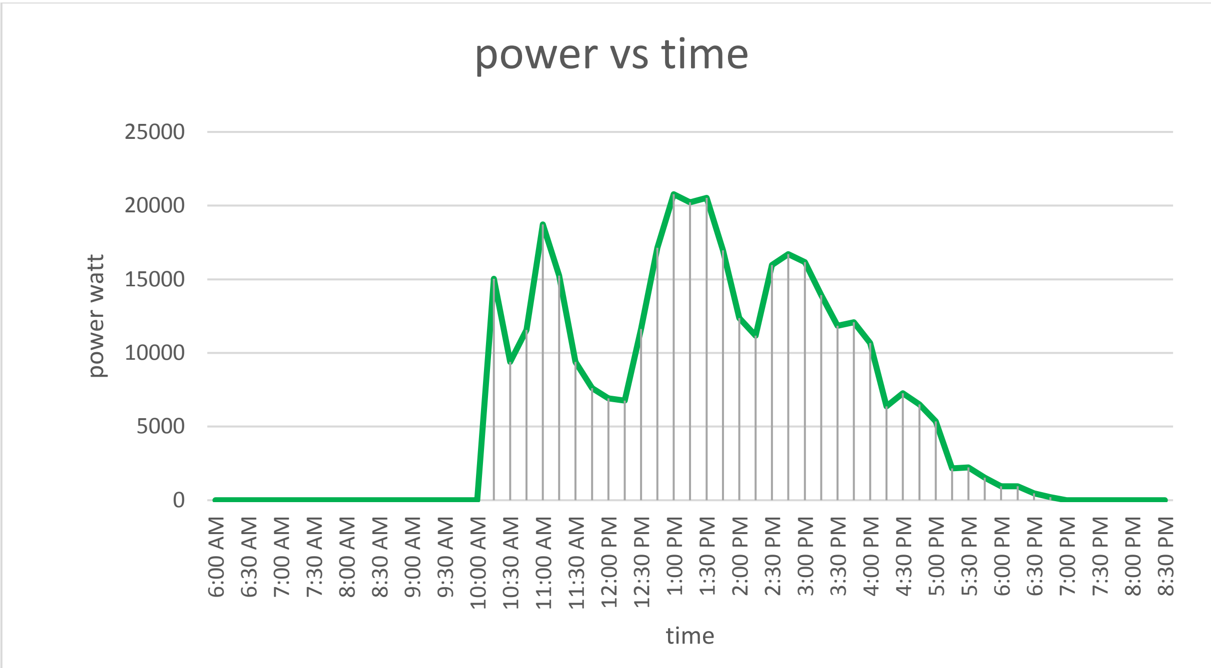


Figure 3.25 :Generation of complete solar cell plant on date 10/4/2017.

Figure 3.26 shows a solar radiation for five days.

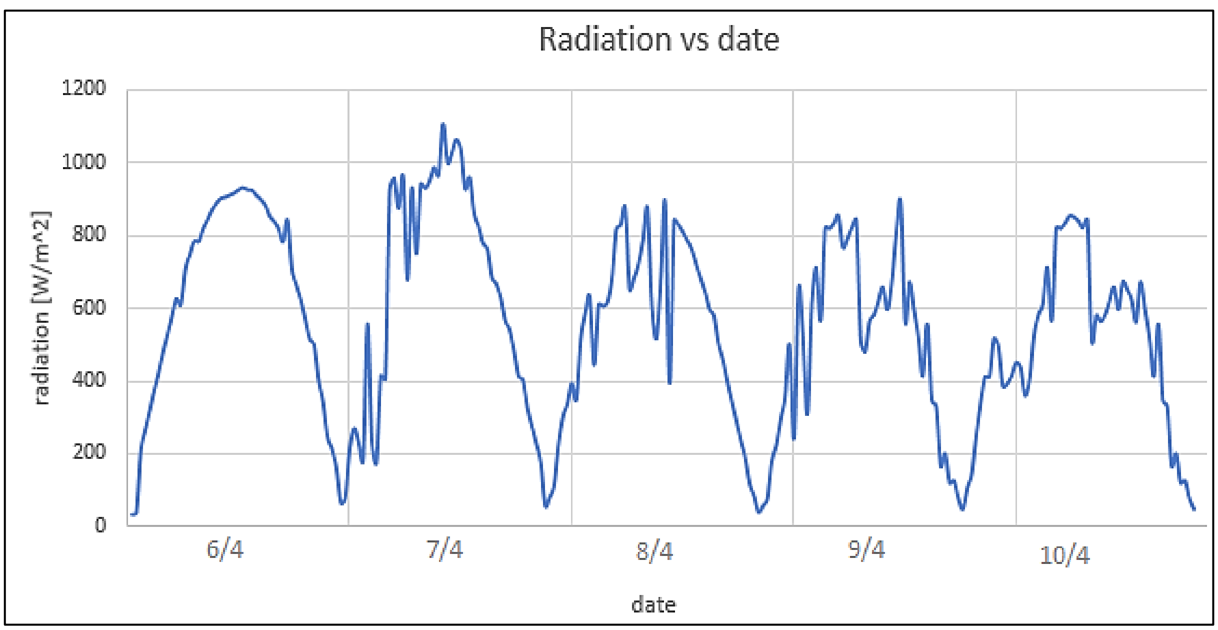


Figure 3.26: Solar radiation for five days from 6/4/2017 to 10/4/2017.

After measuring first house roof area which was equal to180m^2, 40 solar cells can be installed in this area. From the measurement of the power pattern consumption the maximum value of power consumption was about 4500 watts, thus, the house needs 14 solar cells

Figure 3.27 shows a power consumption at 6/4/2017 from 9:00 am to 9:00 pm, **figure 3.28** shows a generation of 14 solar cells for the same day.

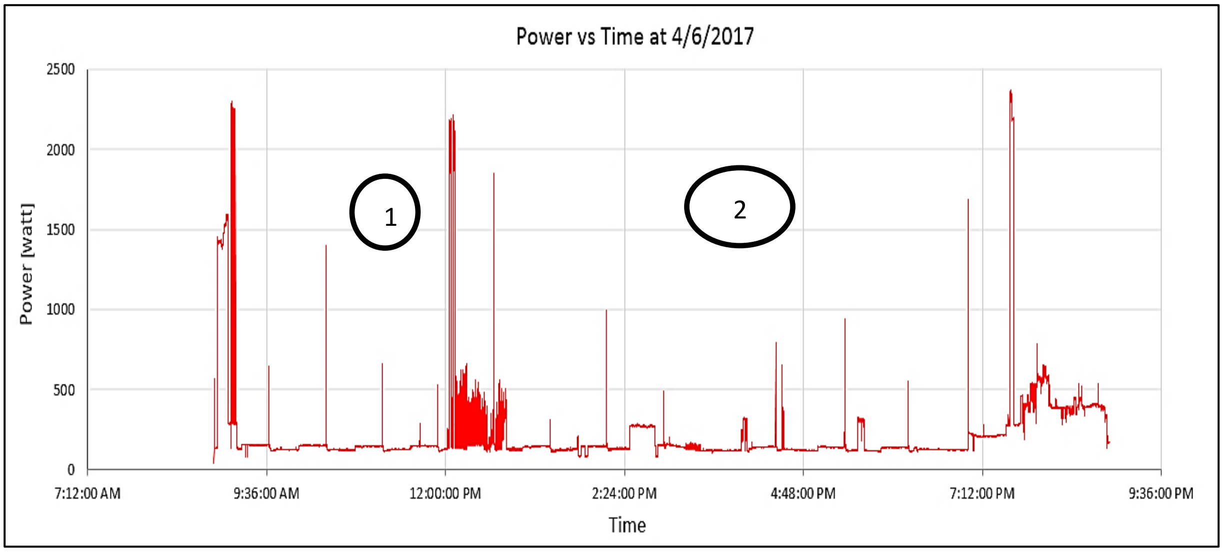


Figure 3.27: Electrical power consumption at 6/4/2017 from 9:00 am to 9:00 pm.

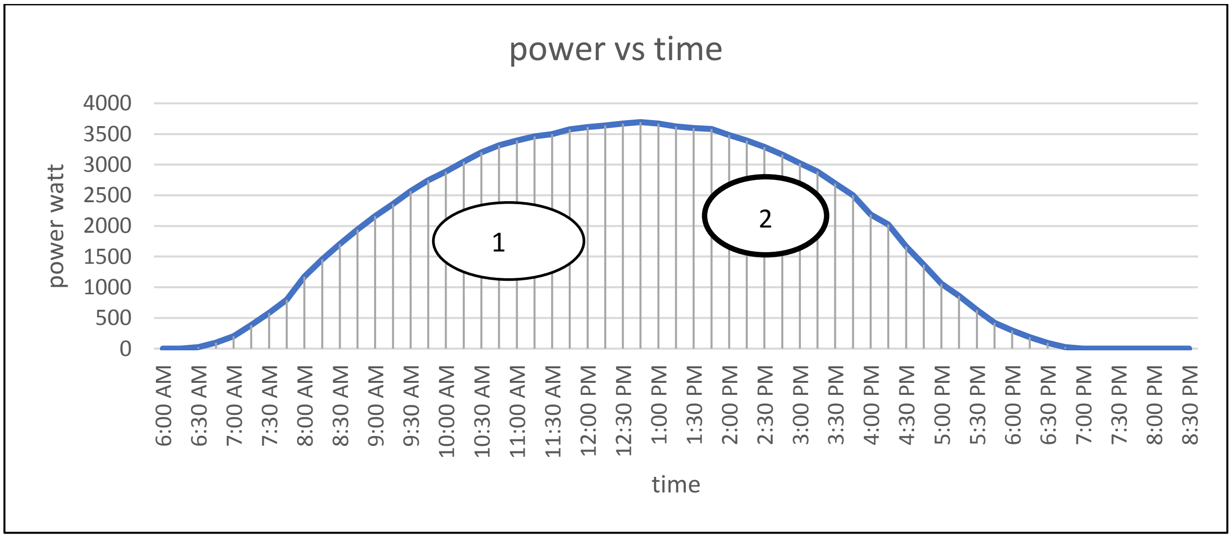


Figure 3.28: Generation of 14 solar cells at 6/4/2017.

At the point 1 and point 2 which **Figure 3.27** note that there is no electricity consumption, where are these point1and point 2 which **Figure 3.28** generation of 14 cells, after determining that there is a difference in values can transfer the work of selected which devices at this time, and the use of excess power for other purposes for example (Cooling in summer and heating in winter).

At point 1 the average power from (9.30am-12.00pm) for power consumption equals 433 W and the average power generated from PV equals 2562 W, to calculate the energy, equation (2).

$E_{(kWh/day)} = P_{(W)} \times t_{(h/day)} / 1000_{(W/kW)}$ ………………………………. (2)

for power consumption: E= (433 *2.5)/1000 =1 kWh.

for PV: E= (2562*2.5)/1000=6.4 kWh.

Excess energy = 6.4 – 1 = 5.4 kWh.

This excess energy is very large. Therefore, it will be exploited by using the controller to reduce the number of batteries used to store it. for all points will have the same story.

Figure 3.29 shows a power consumption at 7/4/2017 from 9:00 am to 9:00 pm, **figure 3.30** shows a generation of 14 solar cells for the same day.

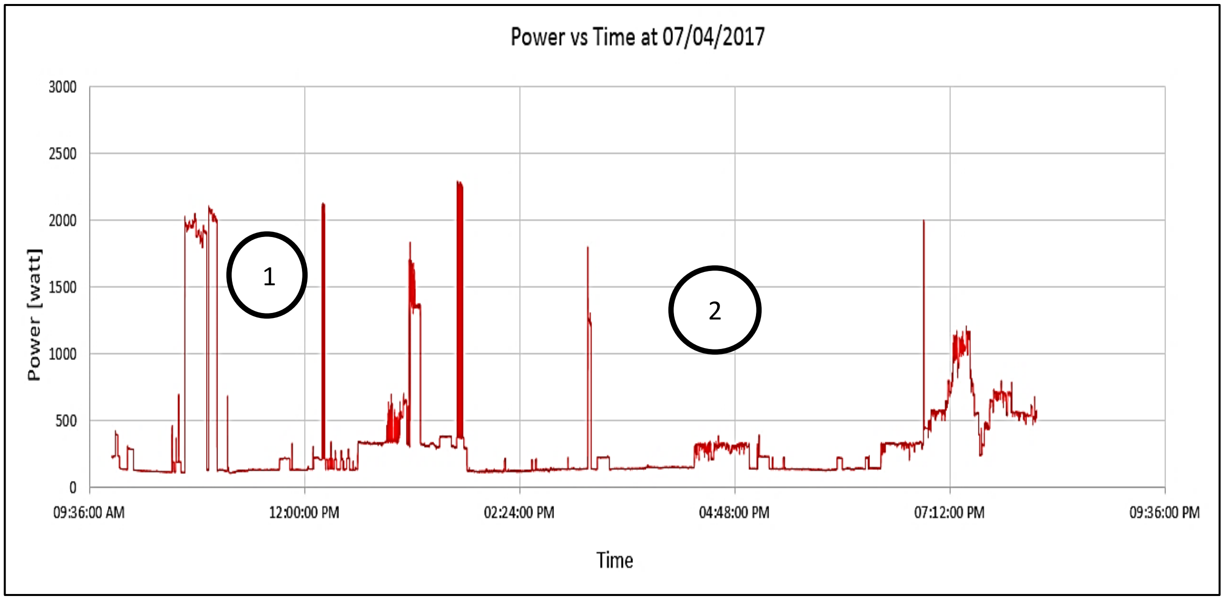


Figure 3.29: Electrical power consumption at 7/4/2017 from 9:00 am to 9:00 pm.

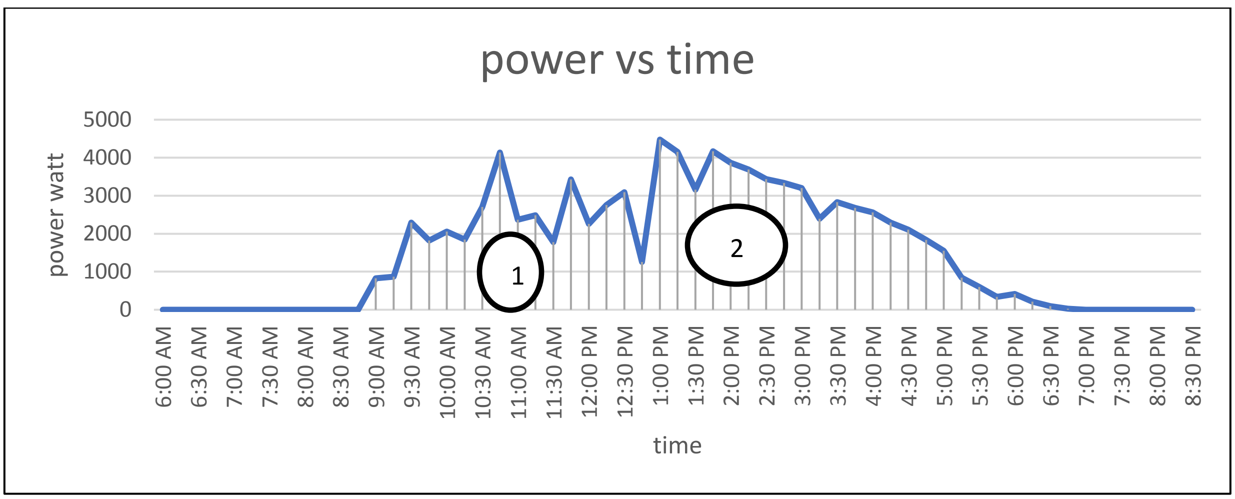


Figure 3.30: Generation of 14 solar cells at 7/4/2017.

At the point 1 and point 2 which in **figure 3.29** note that there is no electricity consumption, where are these points 1,2 which in **figure 3.30** generation of 14 cells, through this note the difference power.

Figure 3.31 shows a power consumption at 8/4/2017 from 9:00 am to 9:00 pm, **figure 3.32** shown generation of 14 solar cells for the same day.

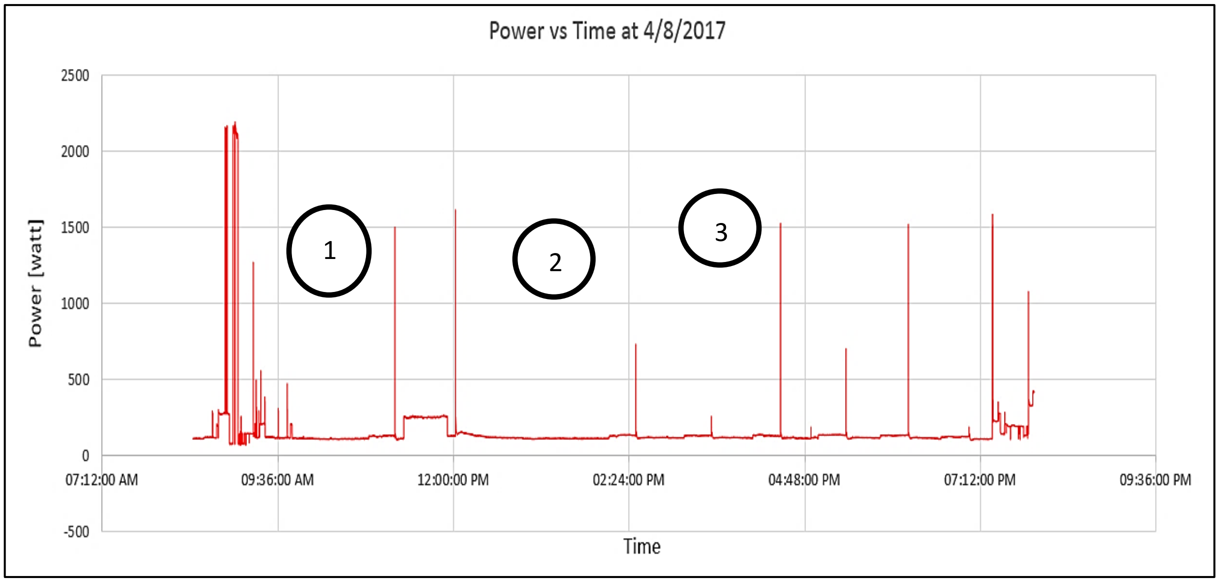


Figure 3.31: Power consumption at 8/4/2017 from 9:00 am to 9:00 pm.

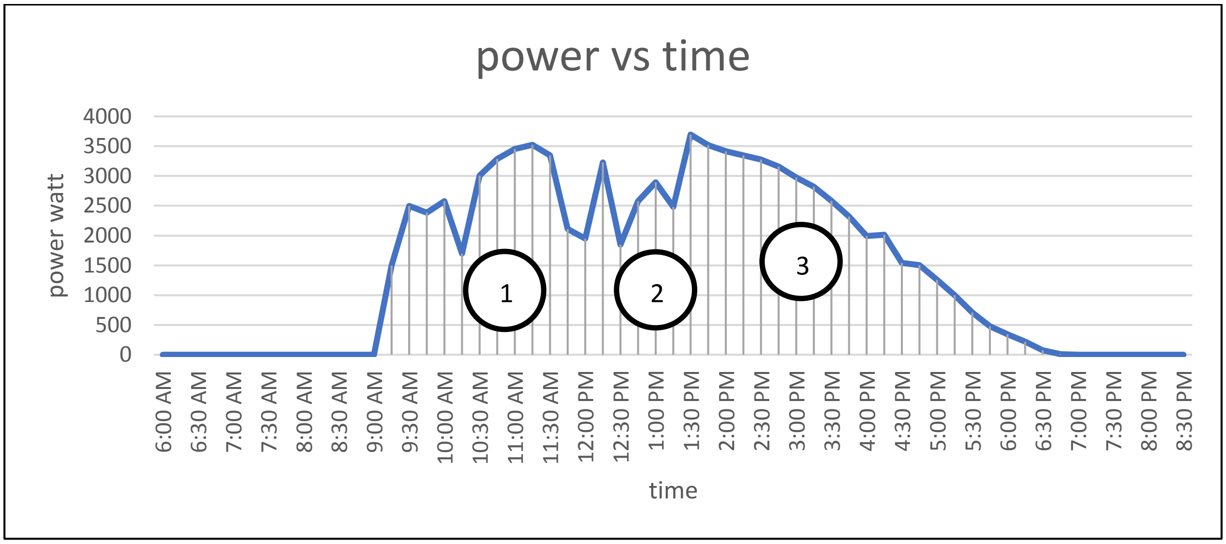


Figure 3.32: Generation of 14 solar cells at 8/4/2017.

At the point 1, point 2 and point 3 which in the **figure 3.31** note that there is no electricity consumption where are these points 1, point 2 and point 3 which in the **figure 3.32** Generation of 14 cells, through this note the difference power.

Figure 3.33 shown a power consumption at 9/4/2017 form 7:30am to 7:30pm, **figure 3.34** shown generation of 14 solar cells for the same day.

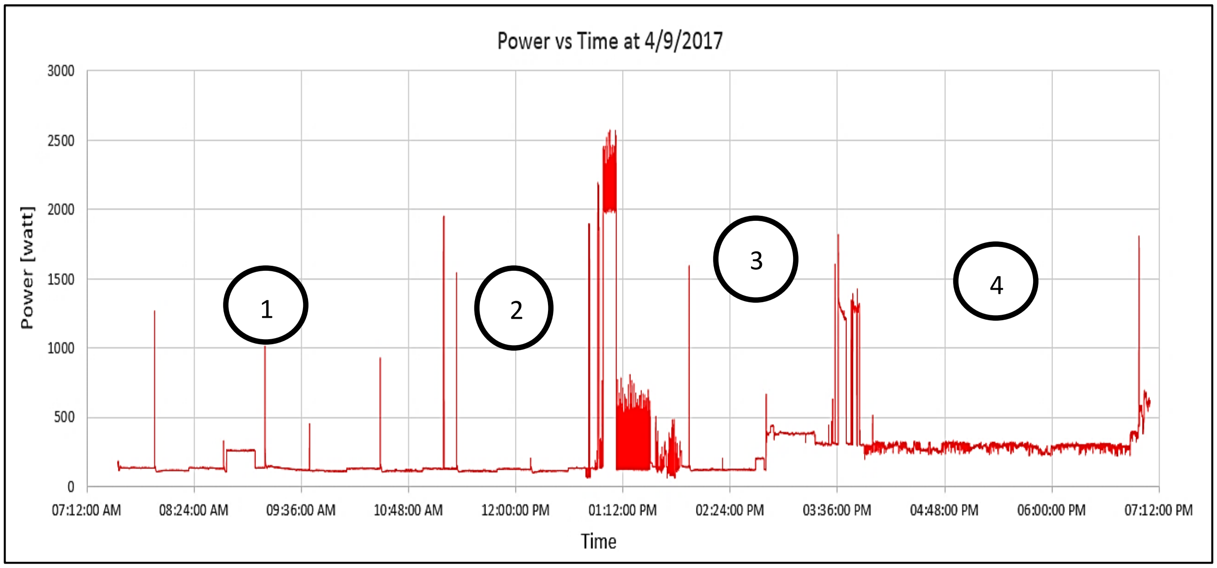


Figure 3.33: power consumption at 9/4/2017 form 7:30am to 7:30pm.

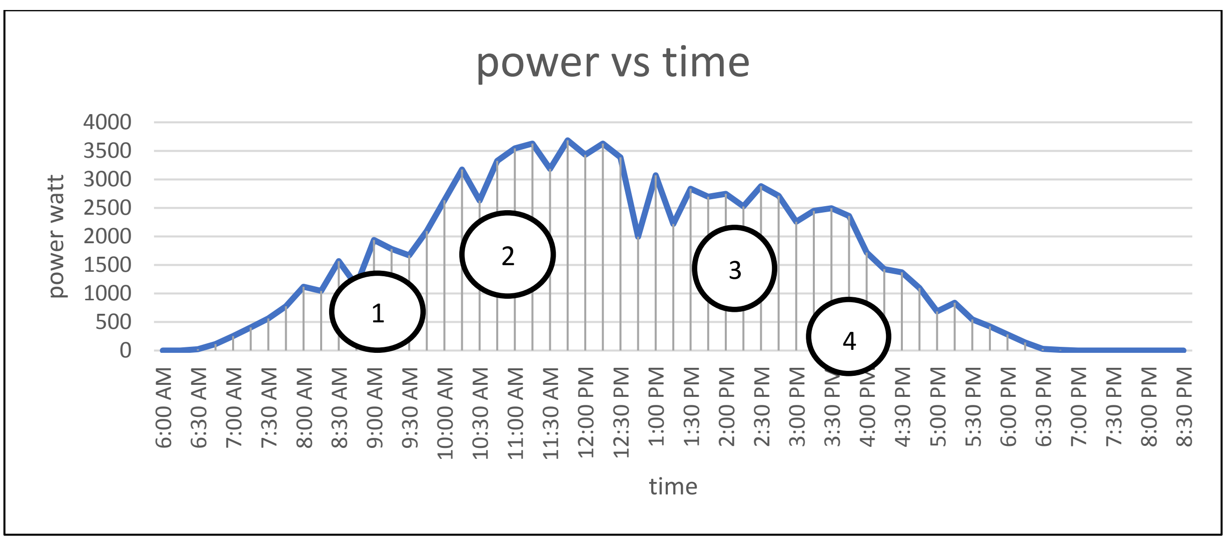


Figure 3.34: Generation of 14 solar cells at 9/4/2017.

At the points (1,2,3,4) which in the **figure 3.33** note that there is no electricity consumption where are these points (1,2,3,4) which in the **figure 3.34** Generation of 14 cell, through this note the difference power.

Figure 3.35 shows a power consumption at 10/4/2017 from 7:30 am to 7:30 pm, **figure 3.36** shown generation of 14 solar cells for the same day.

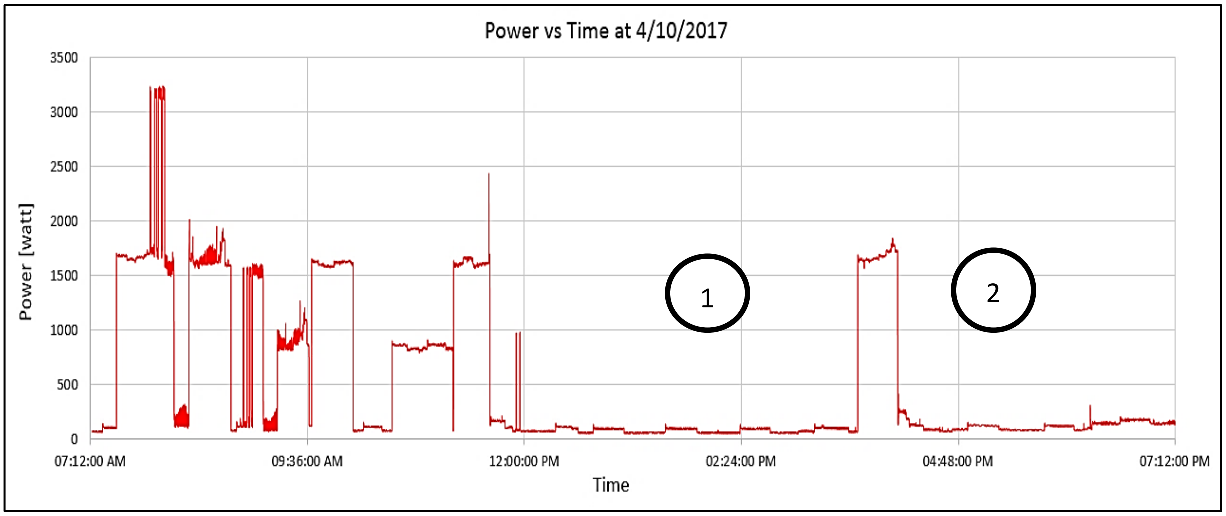


Figure 3.35: power consumption at 10/4/2017 from 7:30 am to 7:30 pm.

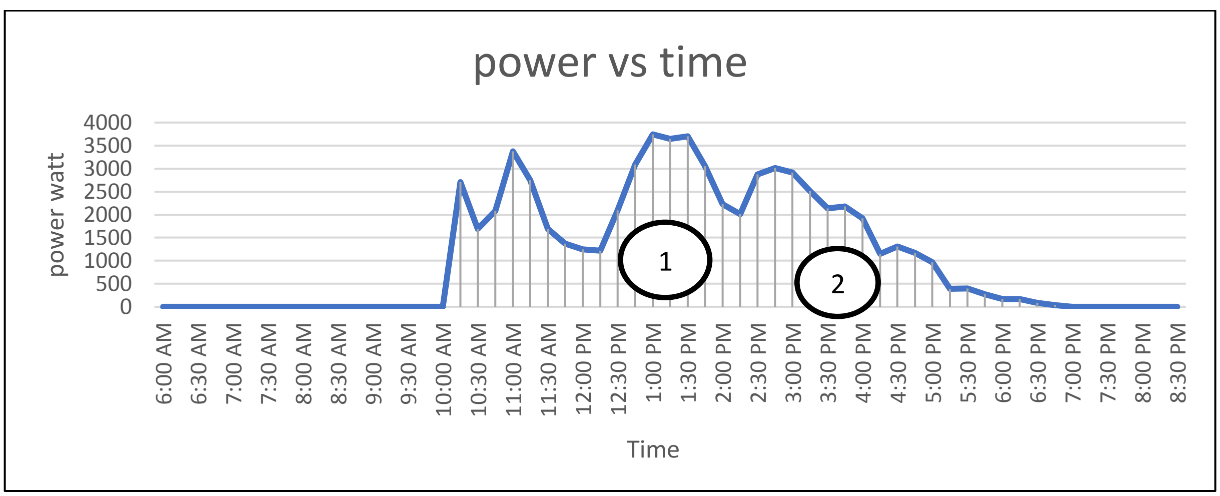


Figure 3.36: Generation of 14 solar cells at 10/4/2017.

At the point 1and point 2 which in the **figure 3.35** note that there is no electricity consumption, where are these point 1and point 2 which in the **figure 3.36** generation of 14 cells Through this note the difference power.

3.5 Conclusion

Verification of measurements by means of MATLAB/Simscape. There is an excess amount of energy generated from the cells compared to the consumption of the house and this quantity will be stored in batteries or sold to the network before the design of the controller.

CHAPTER FOUR

Fuzzy logic Controller Design

Contents:

4.1 Introduction.

4.2 Fuzzy Compensator Design.

4.3 Simulation.

4.4 Results.

4.1 Introduction

There are specific components characteristic of a fuzzy logic controller (FLC) to support a design procedure. **Figure 4.1** shows the controller between the preprocessing block and post processing block.

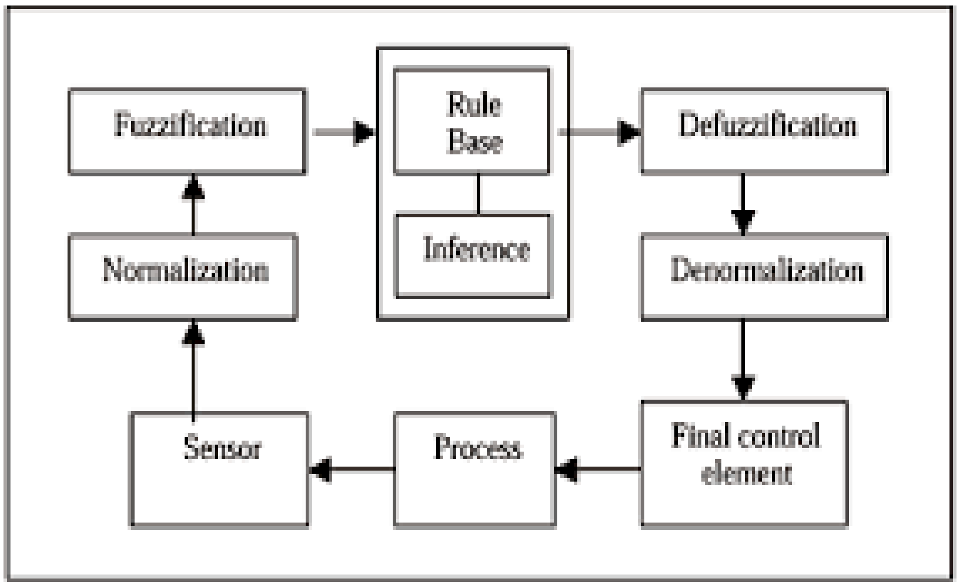


Figure 4.1: Fuzzy control block diagram**.**

In recent years, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection.

Fuzzy Logic Toolbox provides MATLAB functions, apps, and a Simulink block for analyzing, designing, and simulating systems based on fuzzy logic. The product guides you through the steps of designing fuzzy inference systems. Functions are provided for many common methods, including fuzzy clustering and adaptive neuro-fuzzy learning.

The toolbox lets you model complex system behaviors using simple logic rules, and then implement these rules in a fuzzy inference system. You can use it as a stand-alone fuzzy inference engine. Alternatively, you can use fuzzy inference blocks in Simulink and simulate the fuzzy systems within a comprehensive model of the entire dynamic system, as shown in **figure 4.2** [17].

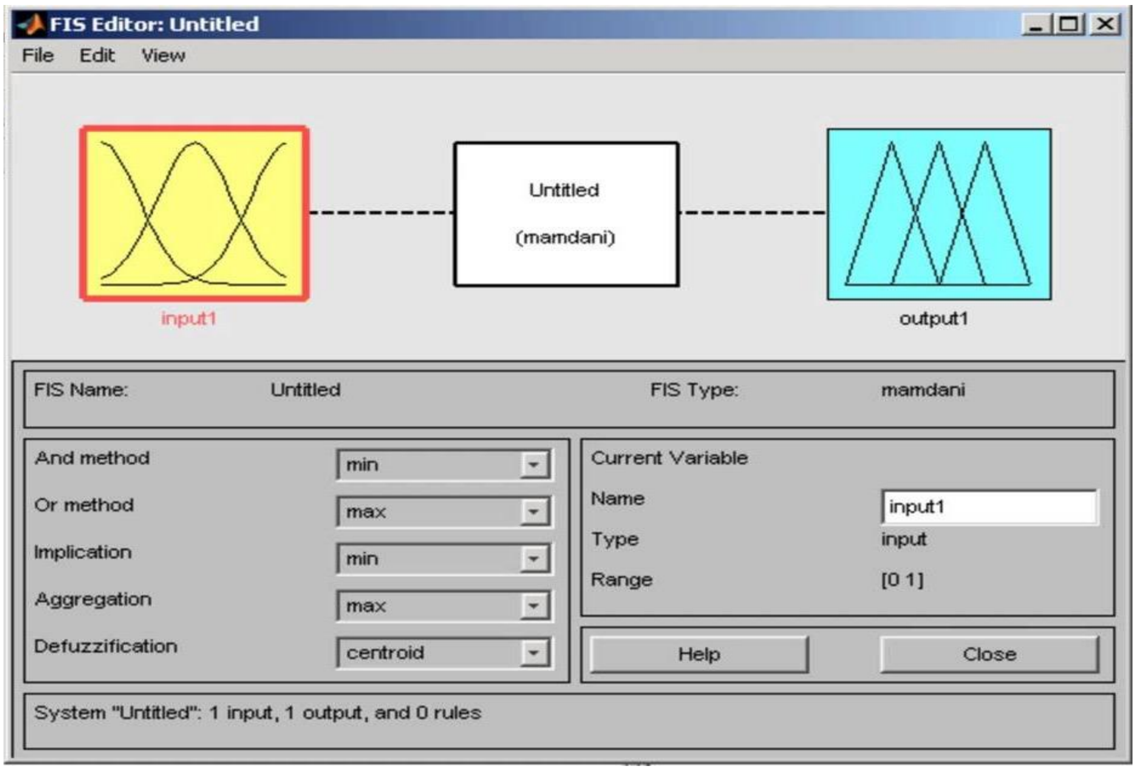


Figure 4.2: Fuzzy logic in MATLAB [17].

4.1.1 Why use Fuzzy Logic Controller

The structure of the controller that needed it a complex process and because of nonlinearities or time-varying responses it is impossible to mathematically model the process. Often, traditional control methods such as PID control can't provide adequate control for this type of system. So, the Fuzzy logic is extremely useful in this system [17].

Other reasons for using fuzzy logic controller:

- Fuzzy logic can use multiple inputs and outputs sources.
- Fuzzy logic can deal easily with human behavior and don't effect on it.
- Fuzzy logic is conceptually easy to understand. The mathematical concepts behind fuzzy reasoning are very simple. Fuzzy logic is a more intuitive approach without the far-reaching complexity.
- Fuzzy logic is flexible. With any given system, it is easy to layer on more functionality without starting again from scratch.
- Fuzzy logic can model nonlinear functions of arbitrary complexity. You can create a fuzzy system to match any set of input-output data.

4.2 Fuzzy Compensator Design

In a closed loop system with step inputs, fuzzy controlling four devices (boiler, water pump, washing machine, dishwasher) depending on PV extra current. The controller built as 8 inputs and 4 outputs as shown in the **table 4.1** and **figure 4.3**.

Table 4.1 Inputs and outputs for fuzzy logic controller**.**

Inputs	Outputs
PV Extra current	
washing machine switch	Washing machine
washing machine state	
Dishwasher switch	Dishwasher
Dishwasher state	
Boiler switch	Boiler
Pump switch	Pump
Low level tank	

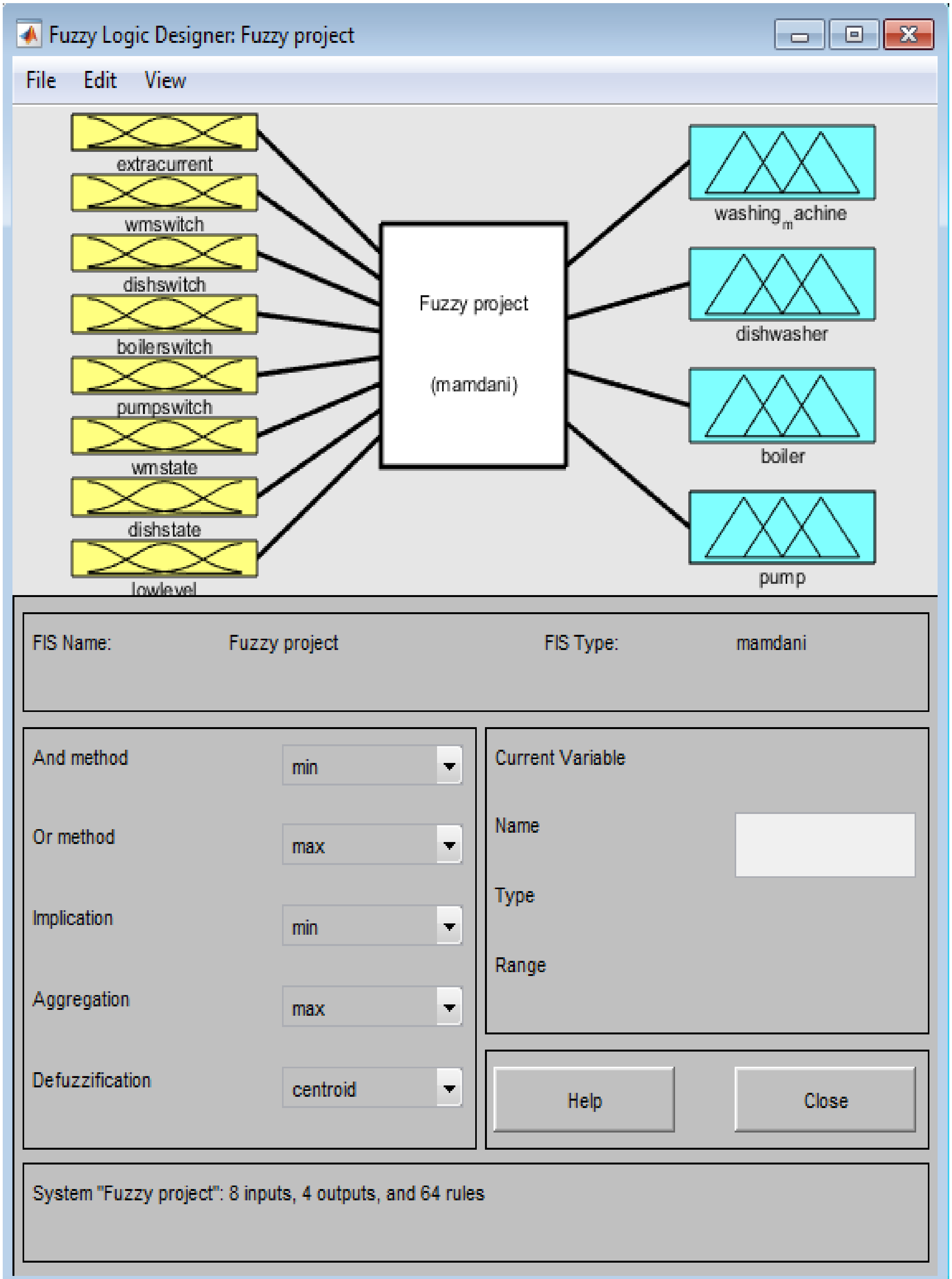


Figure 4.3: Inputs and outputs of fuzzy logic controller**.**

The input extra current of fuzzy logic controller was distributed into four ranges from 0-17 Ampere related to PV current generation (minimum, medium, maximum and very maximum) and the type membership functions are trapezoidal as shown in **figure 4.4**.

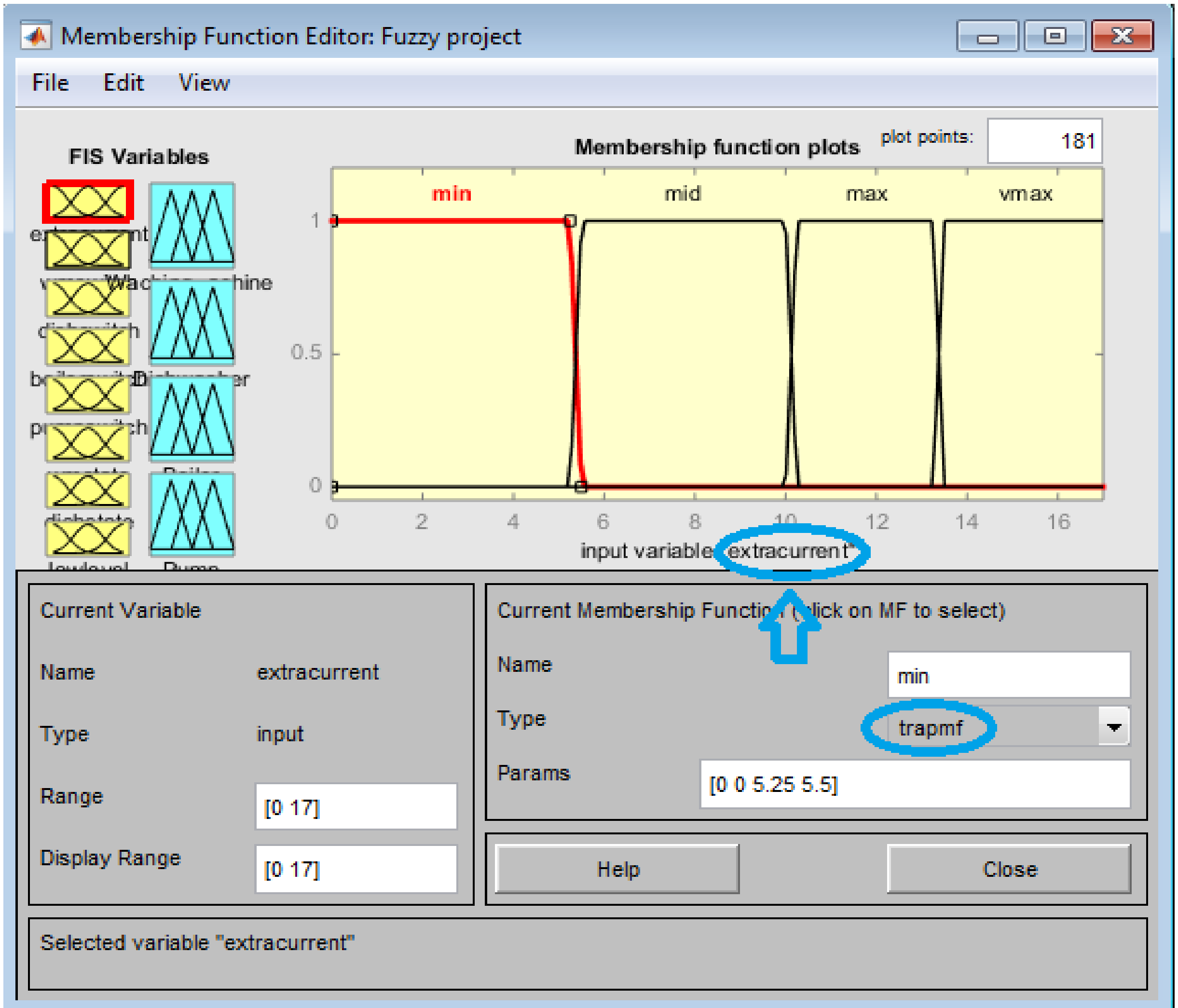


Figure 4.4: Memberships function for extra current input

After selecting the inputs and outputs it is necessary to defining the ranges for every device, as example the following **figure 4.5** shows input variable washing machine and parameters for input ranges ON (0.5-1.0) and OFF (0-0.5).

Where the membership format is type triangle due to control switch either 0 means off or 1 means on.

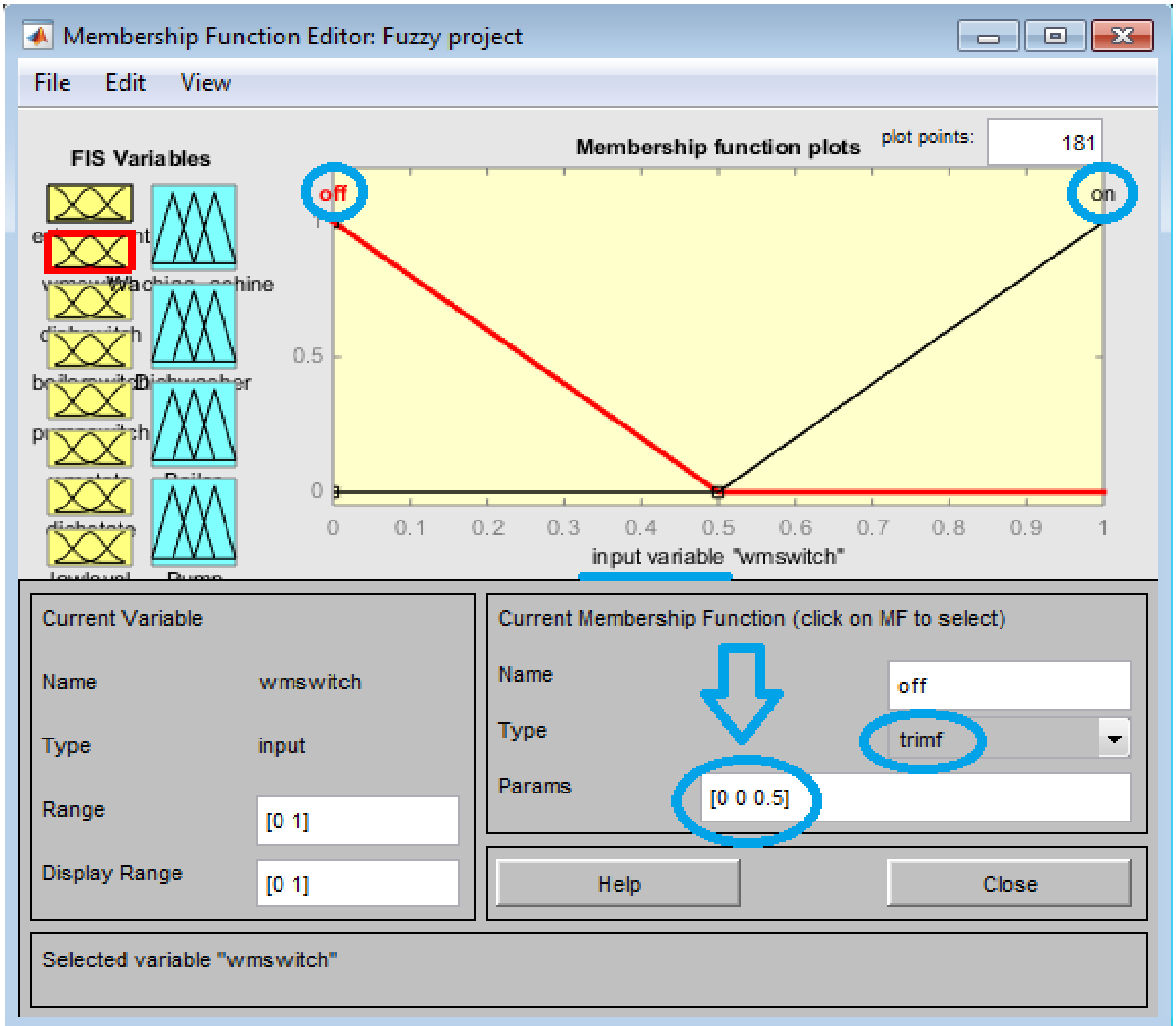


Figure 4.5: Membership function for washing machine input

Figure 4.6 shows output variable washing machine and parameters for output ranges ON (0.5-1.0) and OFF (0-0.5).

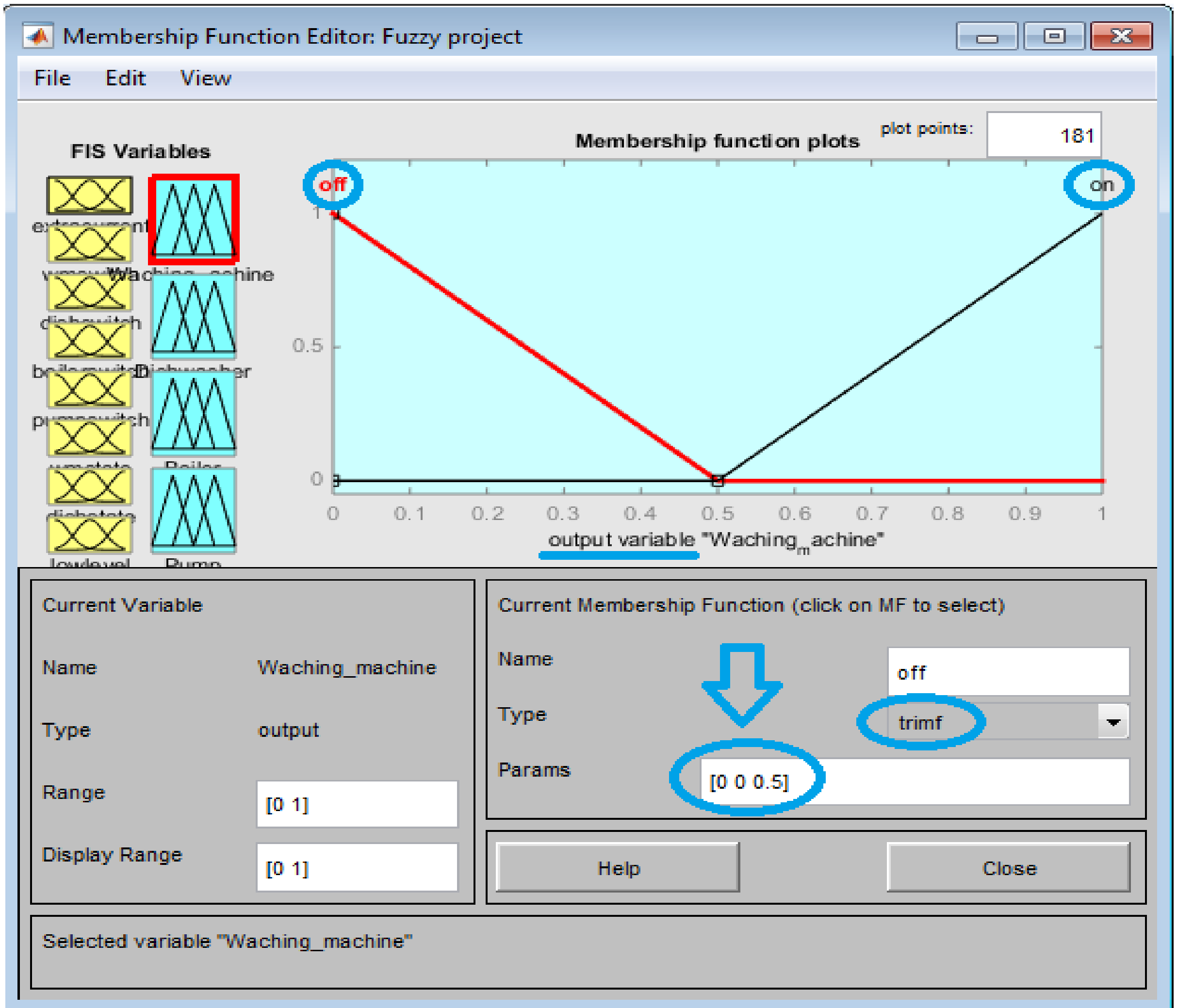


Figure 4.6: Membership function for washing machine output.

4.2.1 Fuzzification rules

processing stage (fuzzification stage); fuzzy control rules are characterized by a collection of fuzzy IF-THEN rules in which the preconditions (antecedents) and consequents involve linguistic variables.

The general form of the fuzzy control rules in the case of multi input single output systems (MISO) is:

Ri : IF x is Ai , …, AND/OR y is Bi , THEN z is Ci . i=1~ n. where x, …, y and z are linguistic variables representing the process state variable and the control variable, respectively, and Ai … ,Bi ,Ci are the linguistic values of the linguistic values of the linguistic variables x, …, y and z in the universe of discourse U, …,V and W.

In this project there is a multi-input and multi output (MIMO), based on the multiple inputs the controller will make decisions based on priorities through the 64 rules, Later samples are shown an example of rules samples.

Sample of rules:

- If extra current is minimum and washing machine switch is on and washing machine state is on then washing machine is on.
- If extra current is medium and dishwasher switch is on then dishwasher is off.
- If extra current is maximum and boiler switch is on the boiler is on.
- If extra current is very maximum and washing machine switch is on and dishwasher switch is on and boiler switch is on and pump switch is off and washing machine state is off and dishwasher state is on and low level is off then washing machine is off, dishwasher is on, boiler is on and pump is off. (see appendix D).

Figure 4.7 below shows some of fuzzification rules.

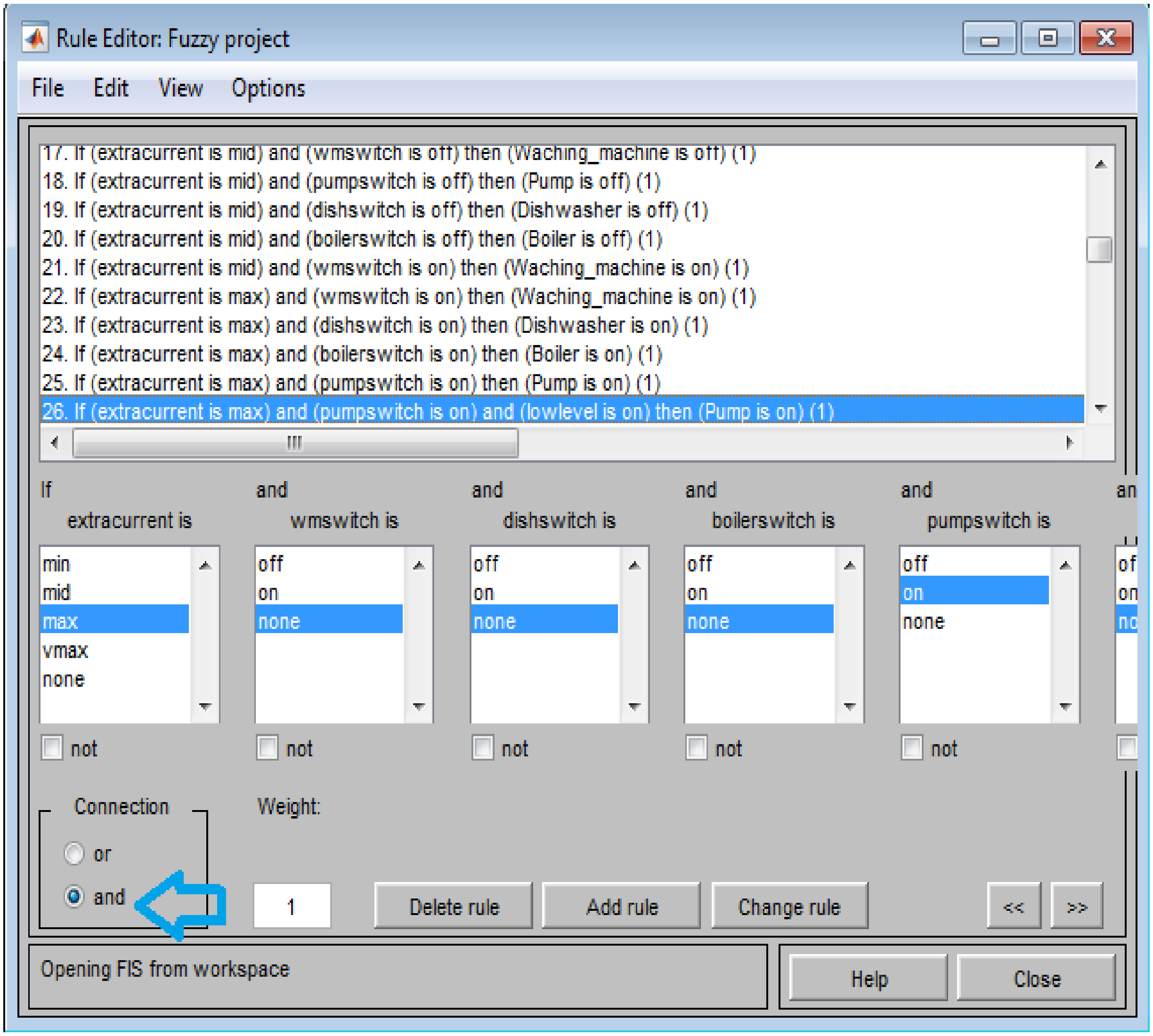


Figure 4.7: Fuzzification rules.

4.3 Simulation

In this section, the controller was interfaced with Simscape MATLAB as shown in the **figure 4.8** to control the switches of the four devices, after that it runs to get scenarios where the devices were time shifted to the peak of PV depending on the rules in the fuzzy logic controller and showed some results before control and after control.

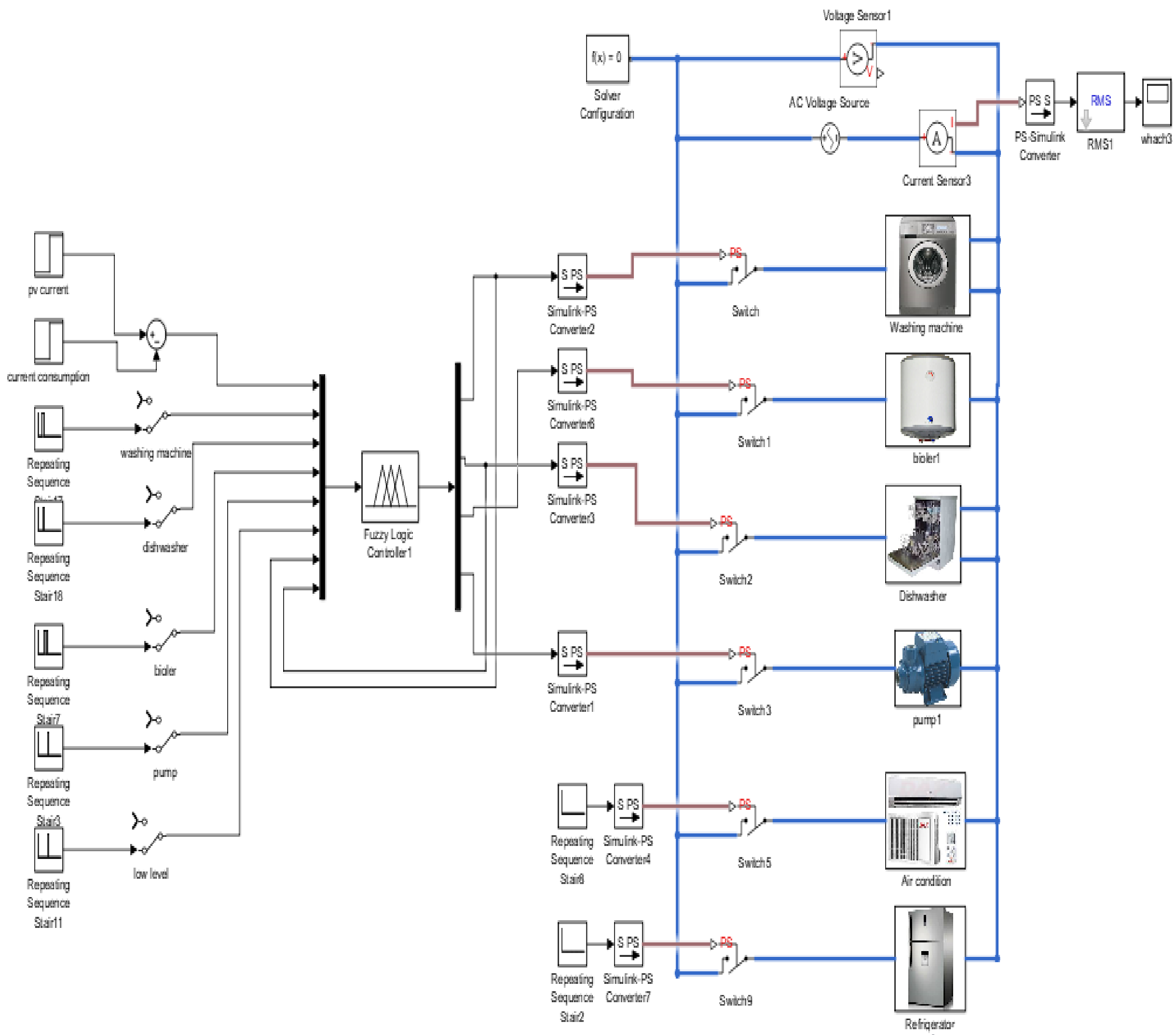


Figure 4.8: Fuzzy logic controller with Simscape interface.

4.4 Results

Figure 4.9 shows a chart of the electrical current consumption before controller, the boiler is turned on from (8:10-8:40) am, the dishwasher is turned on from (9:00-9:42) am and represents point 1, washing machine is turned on from (10:00-11:00) am, pump is turned on from (1:05-1:42) pm.

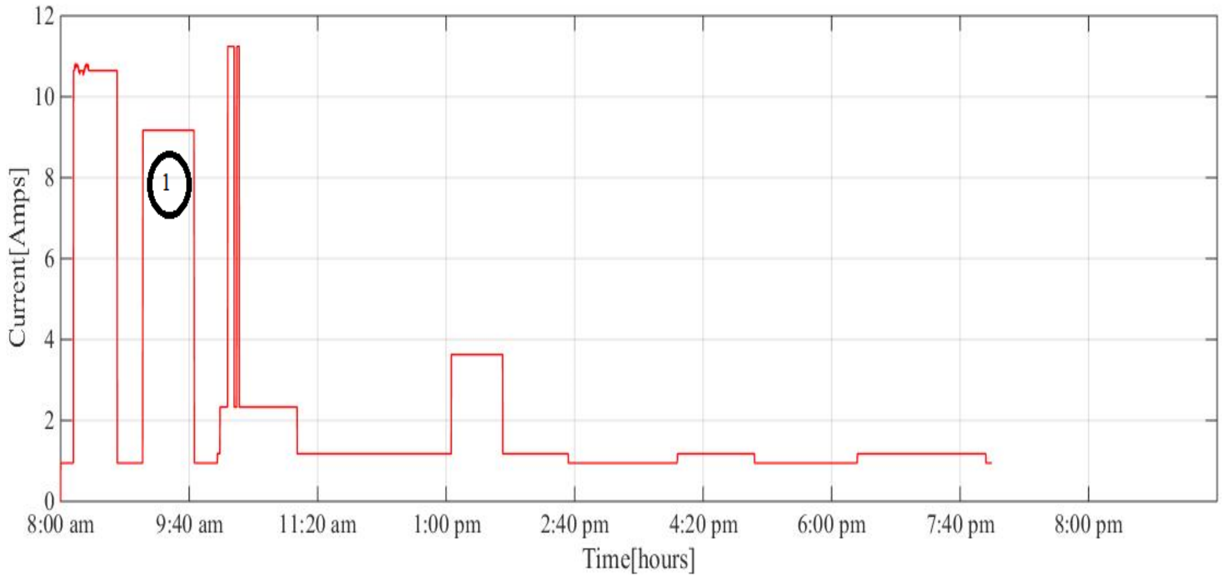


Figure 4.9: Electrical current consumption before controller.

Figure 4.10 shows a chart of the electrical current consumption after controller, see the point 1 represents the dishwasher is shifted from 9:00 am to 10:25 am, boiler is not shifted because the water temperature less than 25˚, and the pump is not shifted because the current generated by PV is enough to turn on.

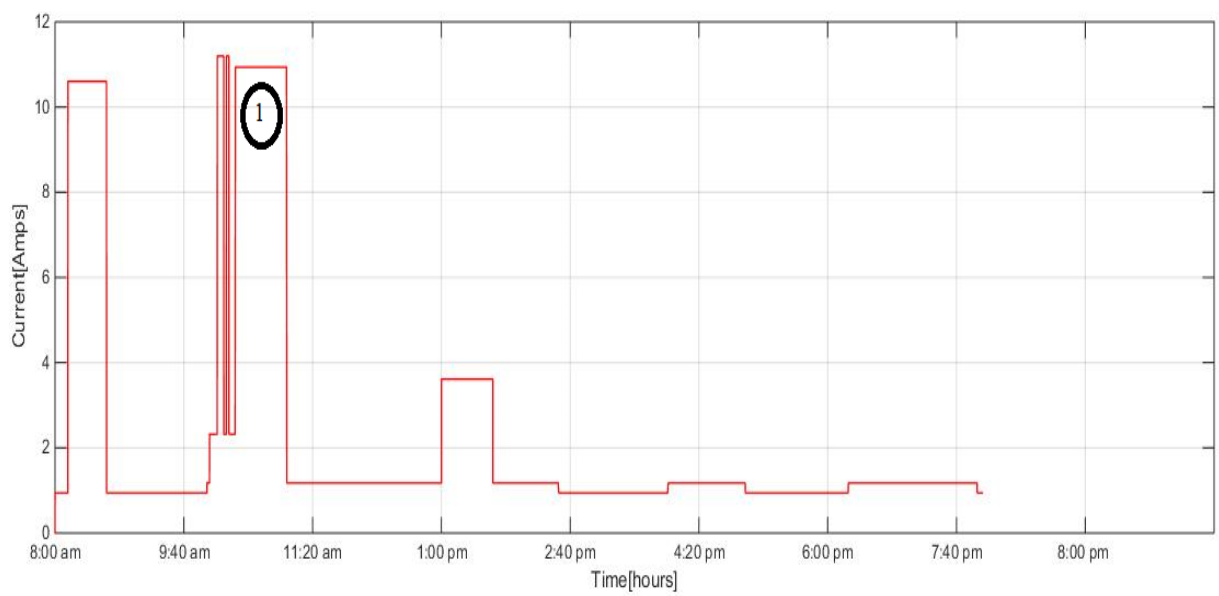


Figure 4.10: Electrical current consumption after controller.

Figure 4.11 shows a chart of the electrical current consumption before controller, the boiler is turned on from (9:00-9:40) am and from (5:10-5:45) represents point 2, the dishwasher is turned on from (9:20-9:55) am represents point 1 and from (5:37-6:18) pm represents point 3, washing machine is turned on from (1:10-2:07) am and pump is turned on from (6:30-7:10) pm represents point 4.

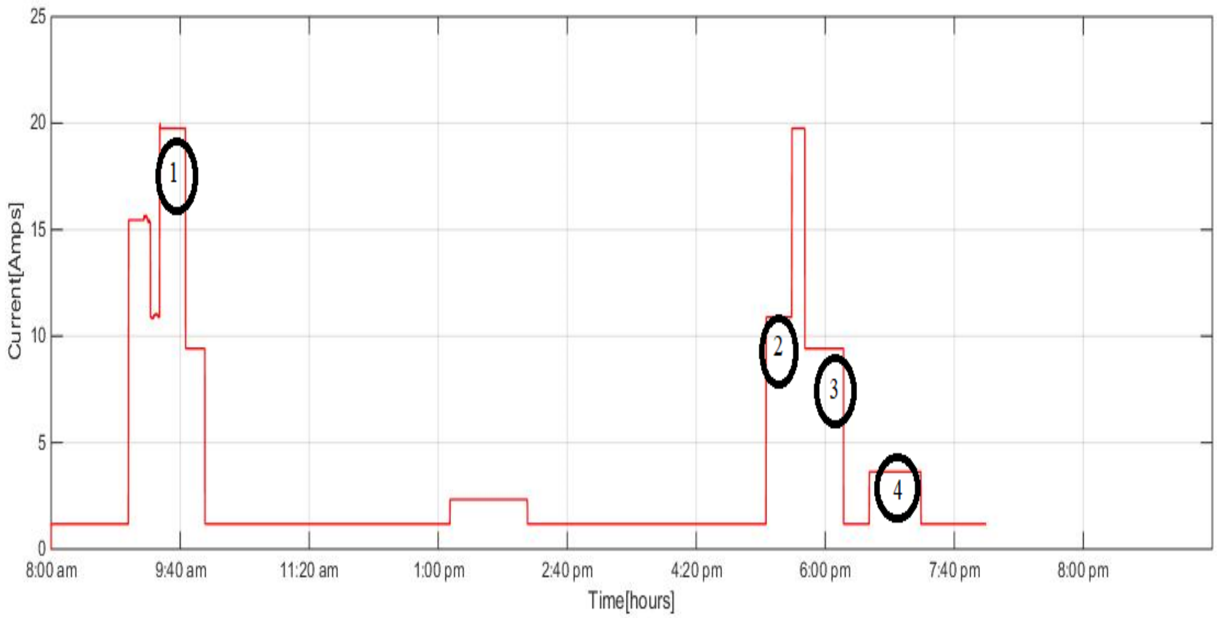


Figure 4.11: Electrical current consumption before controller.

Figure 4.12 and **figure 4.13** show a chart of the electrical current consumption after controller, see the point 1 represents the dishwasher is shifted from 9:20 am to 10:35 am, boiler at 9:00 am is not shifted because the water temperature less than 25˚ but at point 2 is shifted from 5:10 pm to 8:05 am, see the point 3 represents the dishwasher is shifted from 5:37 pm to 10:50 am and see the point 4 represents the pump is shifted from 6:30 pm to 10:00 am.

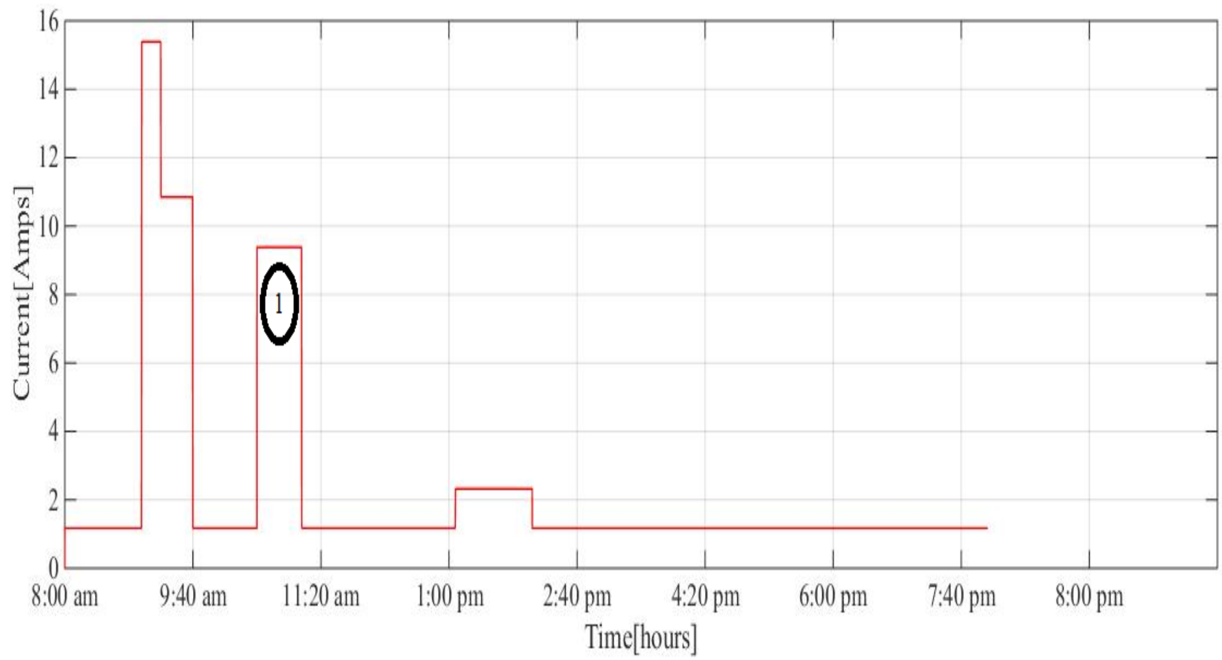


Figure 4.12: Electrical current consumption after controller.

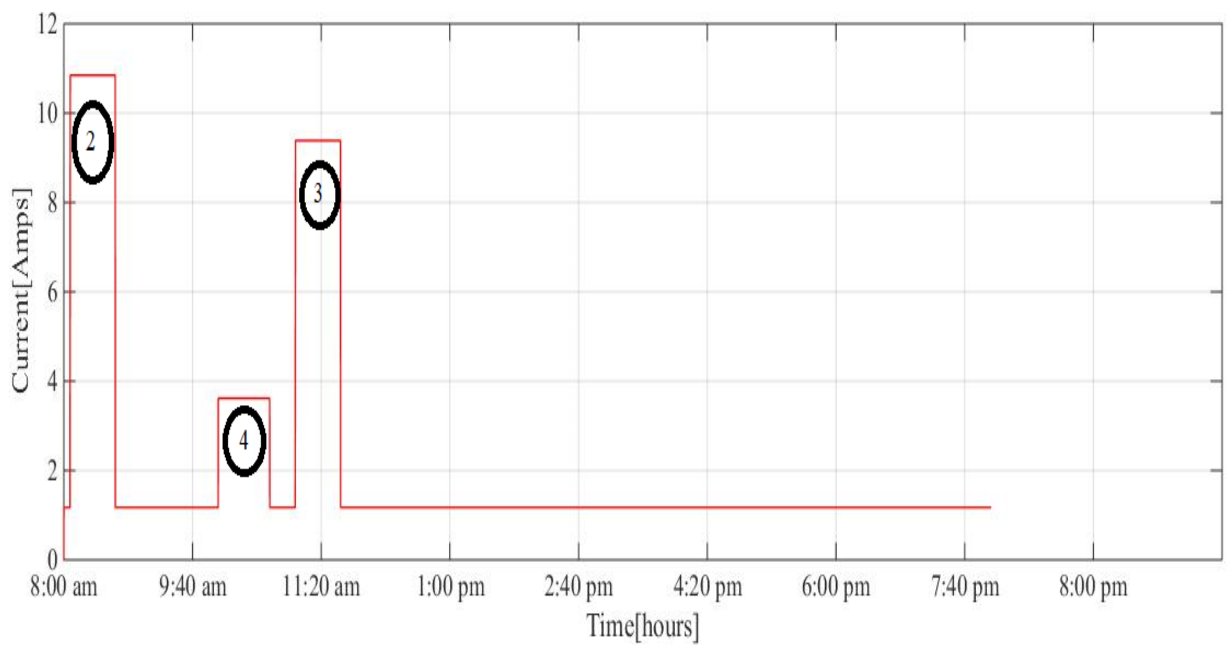


Figure 4.13: Electrical current consumption after controller.

Figure 4.14 shows a chart of the electrical current consumption before controller, the dishwasher is turned on from (9:10-10:10) am represents point 1, the boiler is turned on from (10:00-10:20) am represents point 2 and from (12:00-12:30) represents point 3, pump is turned on from (12:10-1:40) pm and washing machine is turned on from (2:43-3:50) pm.

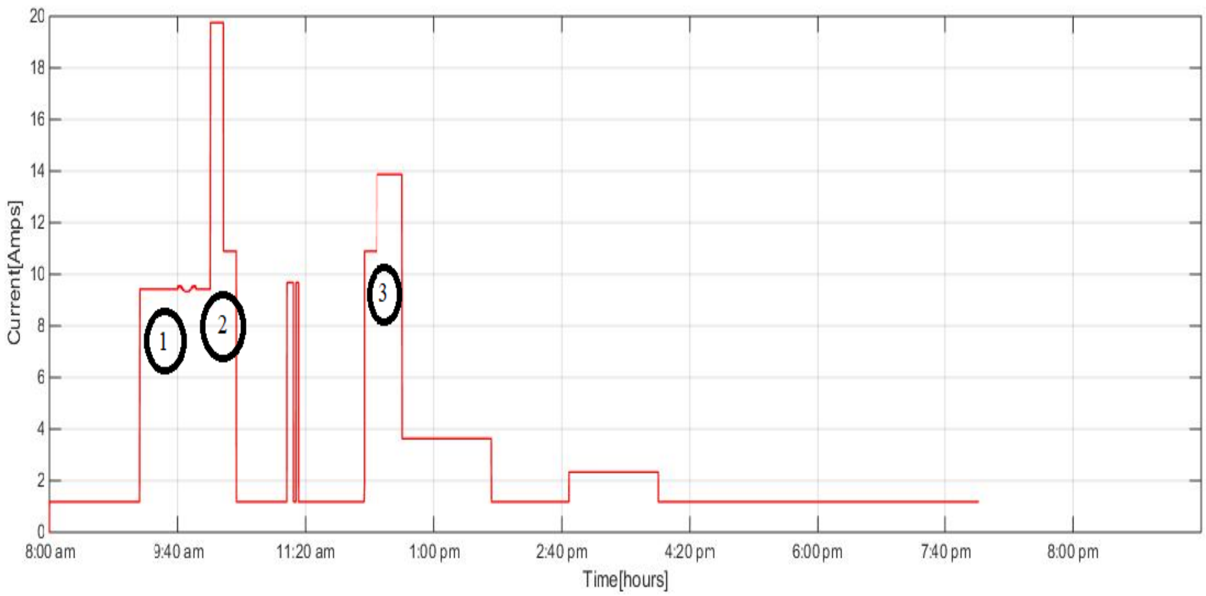


Figure 4.14: Electrical current consumption before controller.

Figure 4.15 shows a chart of the electrical current consumption after controller, see the point 1 represents the dishwasher is shifted from 9:10 am to 11:00 am, see point 2 represents the boiler is shifted from 10:00 am to 11:35 am and point 3 is shifted from 12:10 pm to 1:30 pm, and the washing machine is not shifted because the current generated by PV is enough to turn on.

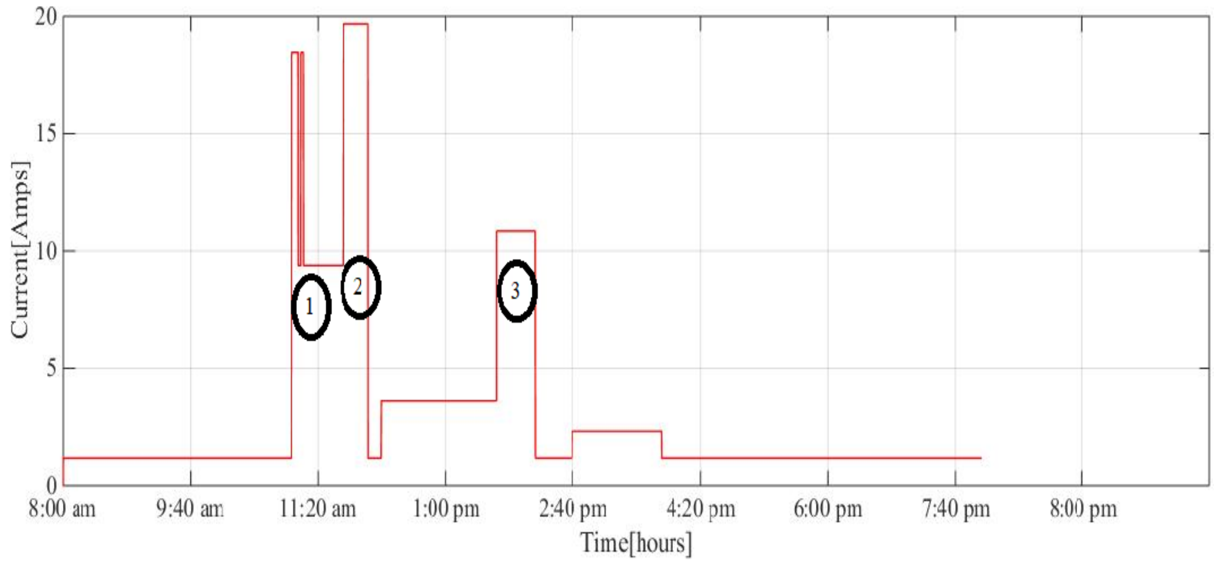


Figure 4.15: Electrical current consumption after controller.

Figure 4.16 shows a chart of the electrical current consumption before controller, the boiler is turned on from (8:30-9:10) am represents point 1 and from (12:30-12:55), the dishwasher is turned on from (10:10-10:45) am represents point 2, washing machine is turned on from (11:40-12:50) pm.

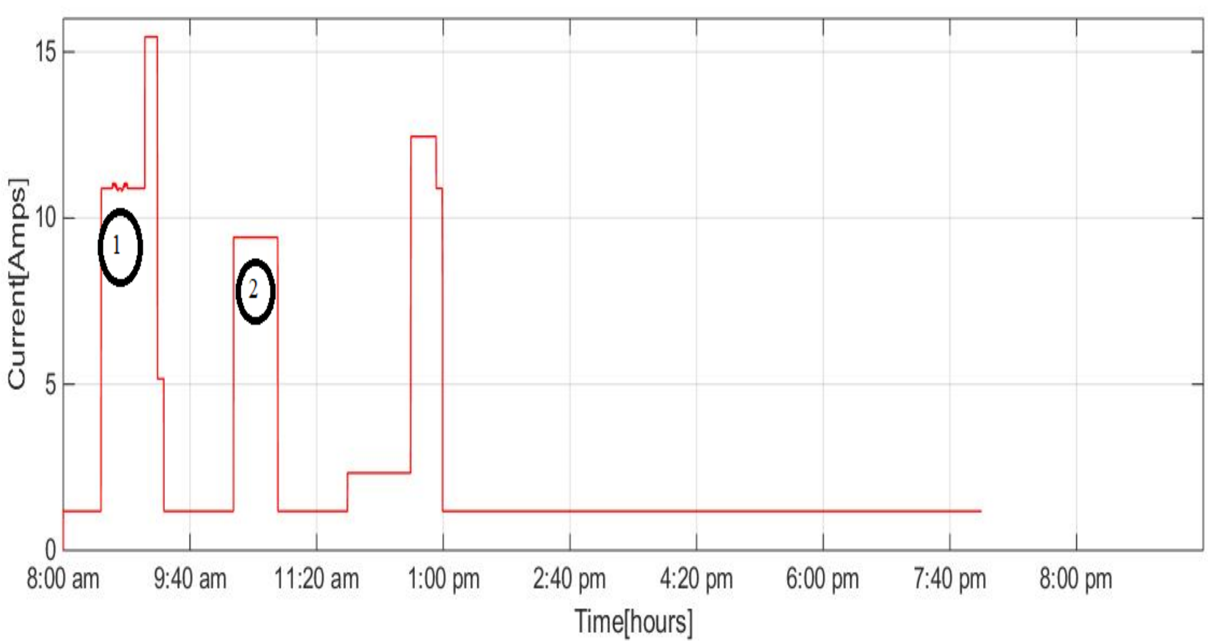


Figure 4.16: Electrical current consumption before controller.

Figure 4.17 shows a chart of the electrical current consumption after controller, see the point 1 represents the boiler is shifted from 8:30 am to 10:58 am, see point 2 represents the dishwasher is shifted from 10:10 am to 11:50 am and the washing machine is not shifted because the current generated by PV is enough to turn on.

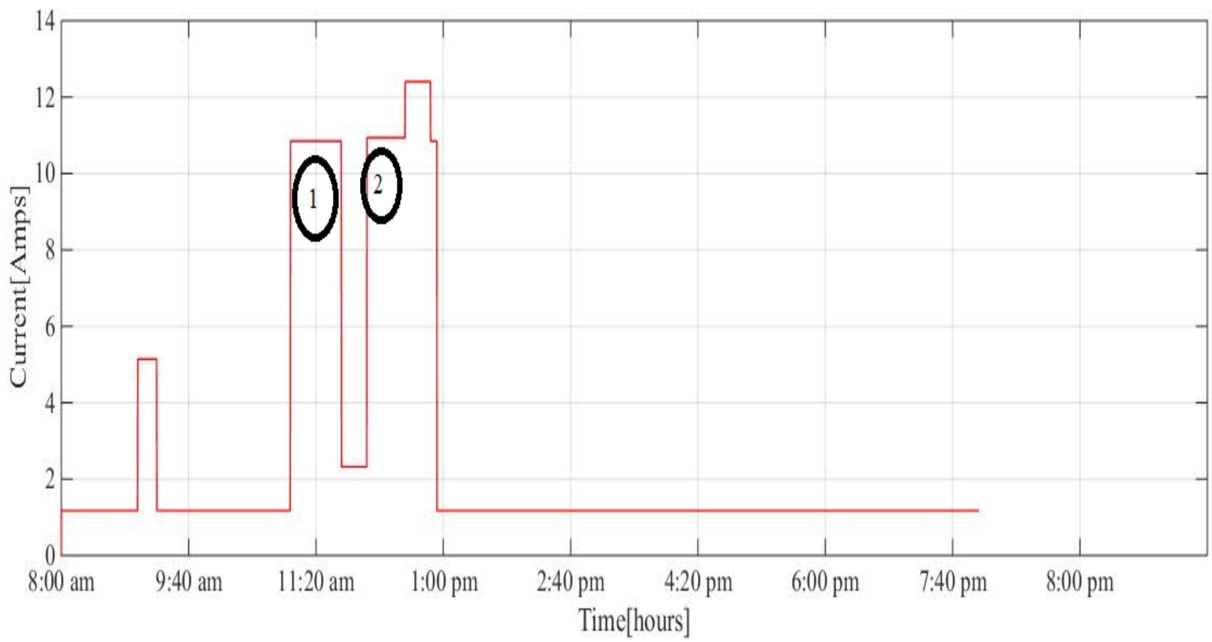


Figure 4.17: Electrical current consumption after controller.

CHAPTER FIVE

Experimental System Description

Contents:

5.1 Introduction.

5.2 Programming

5.3 Project components

5.4 Proteus Results

5.5 Prototype Results

5.1 Introduction

This chapter explains how to program and interface the software with the hardware to run the project and get practical results. The Arduino microcontroller was used as the hardware controller to manage all the project components.

5.2 Programming

Programming snag is converting files formats to suit each other. The first step after the designing of the fuzzy logic controller code is to convert it into Arduino code, then representing the output code using Proteus program to certain its run and represent the project theoretically.

5.2.1 Interface Arduino and Fuzzy Logic Controller

After programming the fuzzy logic controller, it was obtained a file (. fis) format as shown in **figure 5.1** that contains code in a format not compatible with the Arduino programming, so it is converted to a compatible format using an internet link as shown in **figure 5.2.** [18]

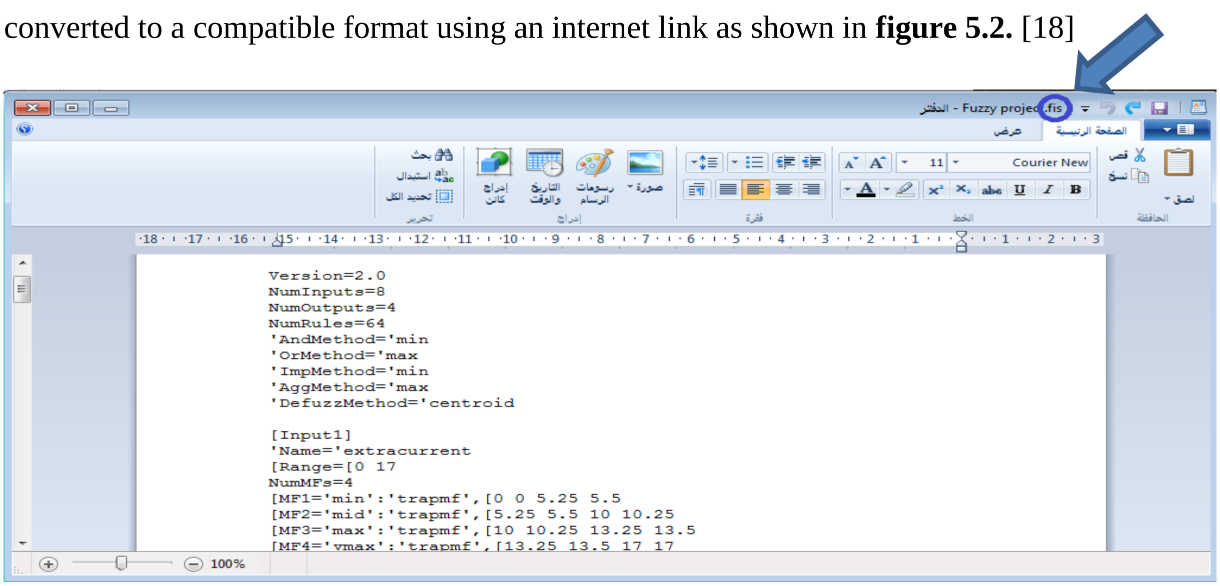


Figure 5.1: fuzzy file (fis) format.

Figure 5.2: Website to convert (fis) into Arduino code [18].

5.2.2 Arduino code

Figure 5.3 shows the compressed file after it was converted by the link, which contains the Arduino code then it was uploaded to the Arduino program. **[19]**

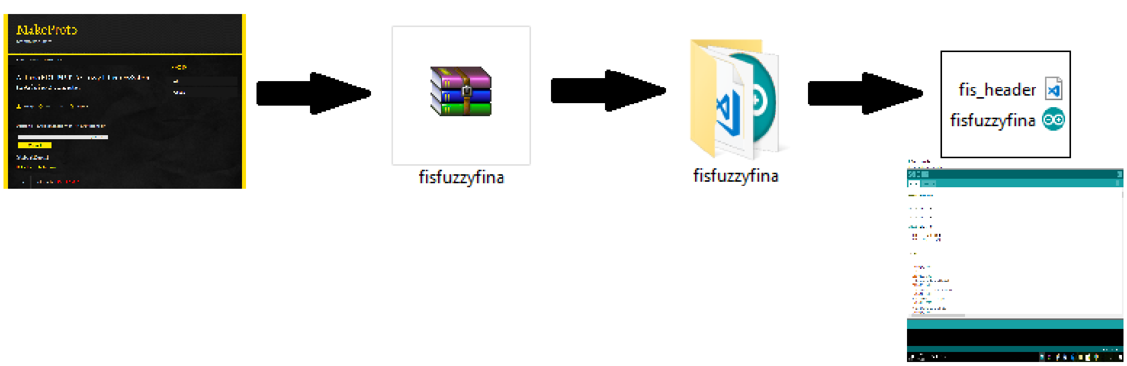


Figure 5.3: Steps of convert (fis) file to Arduino code.

In the code the inputs and the outputs were analog, so they have been normalized to digital inputs and outputs, because the inputs statuses which they are switches were either 0 or 1 except the extra current value remains analog, and the output of the relays is 0 (off) or 1(on) as shown in **figure 5.4. (**see Appendix E)**.**


```
fis_evaluate();
if(g_fisOutput[0]>0.6){
digitalWrite(wash,HIGH);
}else if  (g_fisOutput[0]<=0.6){digitalWrite(wash,LOW);
  }
if(g_fisOutput[1]>0.6){
  digitalWrite(dish,HIGH);
}else if(g_fisOutput[1]<=0.6)  {digitalWrite(dish,LOW);
  }
  if(g_fisOutput[2]>0.6){
  digitalWrite(boil,HIGH);
}else if  (g_fisOutput[2]<=0.6){digitalWrite(boil,LOW);
  }
if(g_fisOutput[3]>0.6){
  digitalWrite(pump,HIGH);
}else if  (g_fisOutput[3]<=0.6){digitalWrite(pump,LOW);
  }
```

Figure 5.4: normalized Arduino code. [19]

5.2.3 Proteus Programming

Proteus Virtual Systems Modeling is a tool that combines a variety of software tools in electronic systems simulations to provide the engineer and the professional with an integrated environment that contains all the tools needed for a realistic simulation process. It combines SPICE systems to simulate circuits and electronic elements handling, accuracy and microprocessor models to facilitate a later stage of simulation of microcontroller-based electronic systems. The first tool developed the methods of testing and simulation of these systems as a pre-practical phase of their circuit schematics. [20]

The project was represented using the Proteus program as shown in **figure 5.5**.

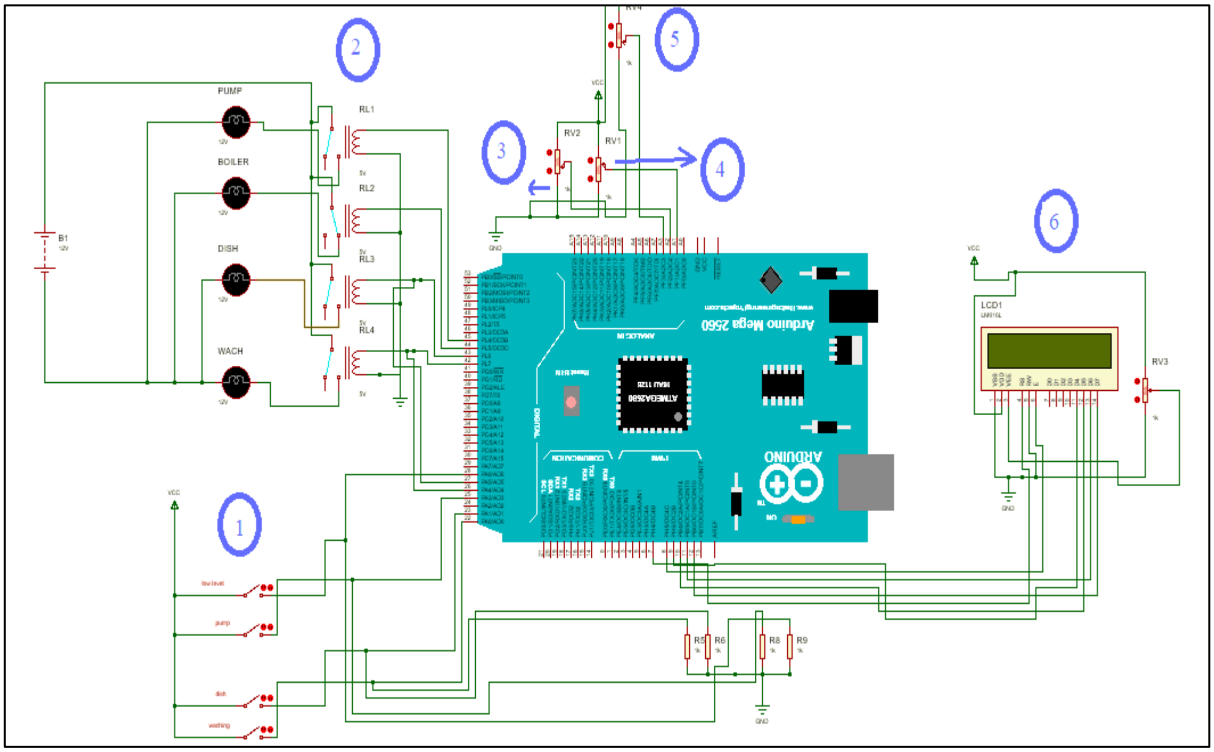


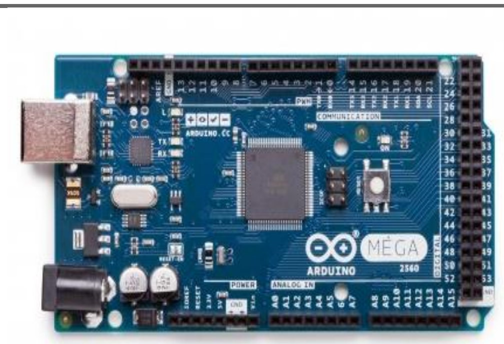
Figure 5.5: Project circuit on Proteus program. [20]

Figure 5.5 shows a Project circuit on Proteus program, see point 1 which represents the input switches, point 2 represents output (relays and loads), point 3 represents potentiometer that expresses the current consumed, point 4 represents potentiometer that expresses the generation solar cell, point 5 represents potentiometer that expresses the boiler temperature (if this value less than 25C° the boiler turns on without the controller else it turns depending on the controller) and point 6 represents LCD to display the extra current.

5.3 Project Components

This section will explain all the components and the description of each one as shown in **table 5.1.**

Table 5.1: Project components.

#	Name	picture	Specifications
1	Arduino mega 2560		It has 54 digital input/output pins16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz. [19]
2	Relays		4 Channel 5V Relay Module 10A
3	switches		Switch on off
4	Led		12v DC, 5 Watt

5	LCD display		16 x 2-character
6	Current sensor		ACS712 (0-5A) DC or AC [19].
7	Photovoltaic panel		6.6 watts 11.0V 0.75A 25˚C 340*190*28 mm

5.4 Proteus Results

Check the results of in the project using Proteus program.

The LCD screen displays two values, the first value expresses the current generated from the PV, the second value expresses the current consumption of the devices ،(the extra current value = the current generated - the current consumption).

The range of extra current value:

- (0A to 5A) = minimum extra current.
- (5.1A to 10A) ≡ medium extra current.
- (10.1A to 13.5A) ≡ maximum extra current.
- (13.6A to 17A) ≡ very maximum extra current.

Figure 5.6 shows the project simulation in Proteus program when the extra current is minimum.

- Point 1 represents extra current which equals 2A (3A-1A).
- Point 2 represents the dishwasher and washing machine switches were pressed.
- Point 3 represents the output devices weren’t turned on because the extra current is not enough to turn on any device, the controller rules control it.

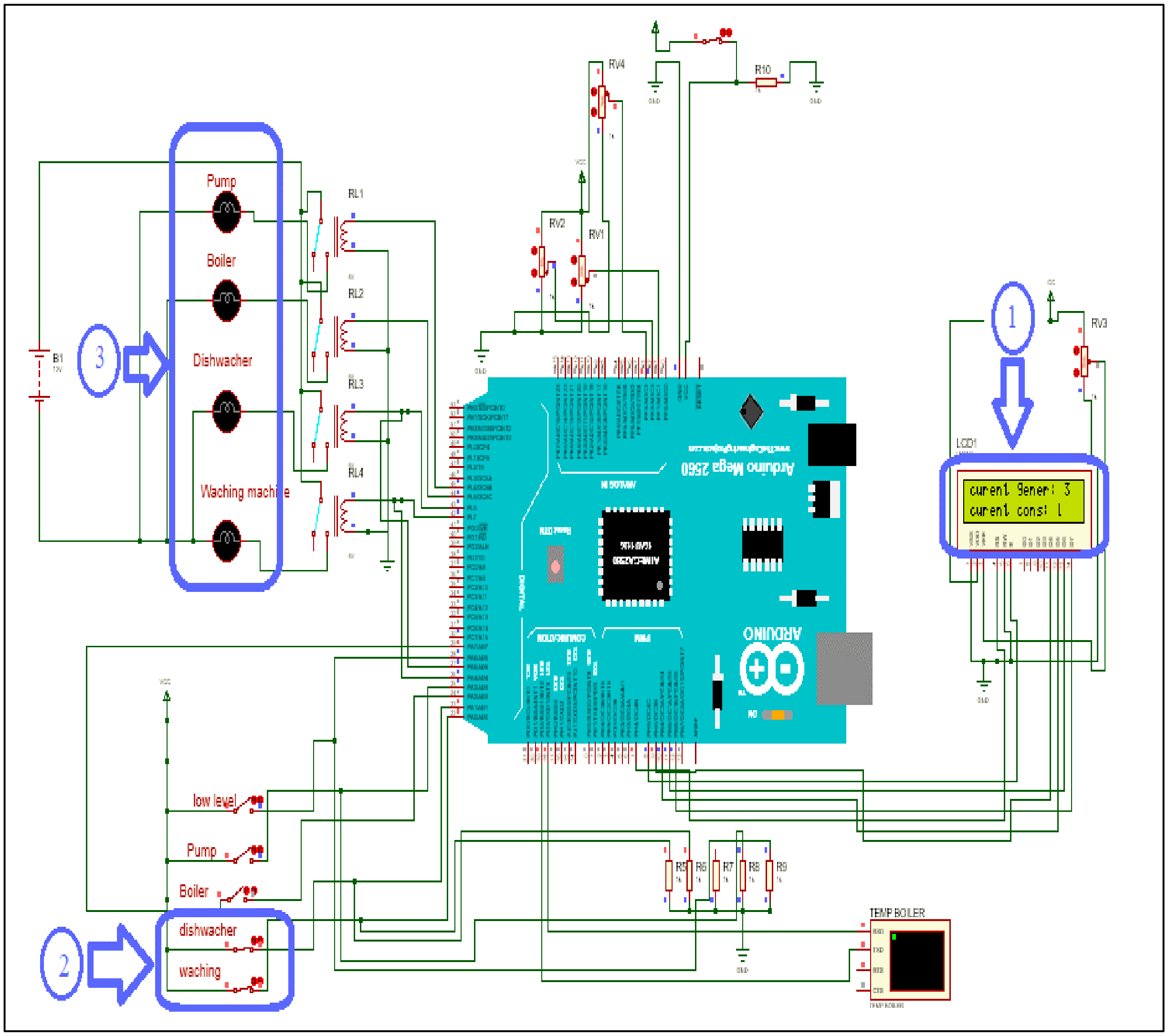


Figure 5.6: Project simulation in Proteus program at minimum current.

Figure5.7 shows a project simulation in Proteus program when the extra current is maximum.

- Point 1 represents extra current which equals 13A (14A-1A).
- Point 2 represents the dishwasher and washing machine switches were pressed.
- Point 3 represents the output devices were turned on because the extra current is enough to turn on, the controller rules control it.

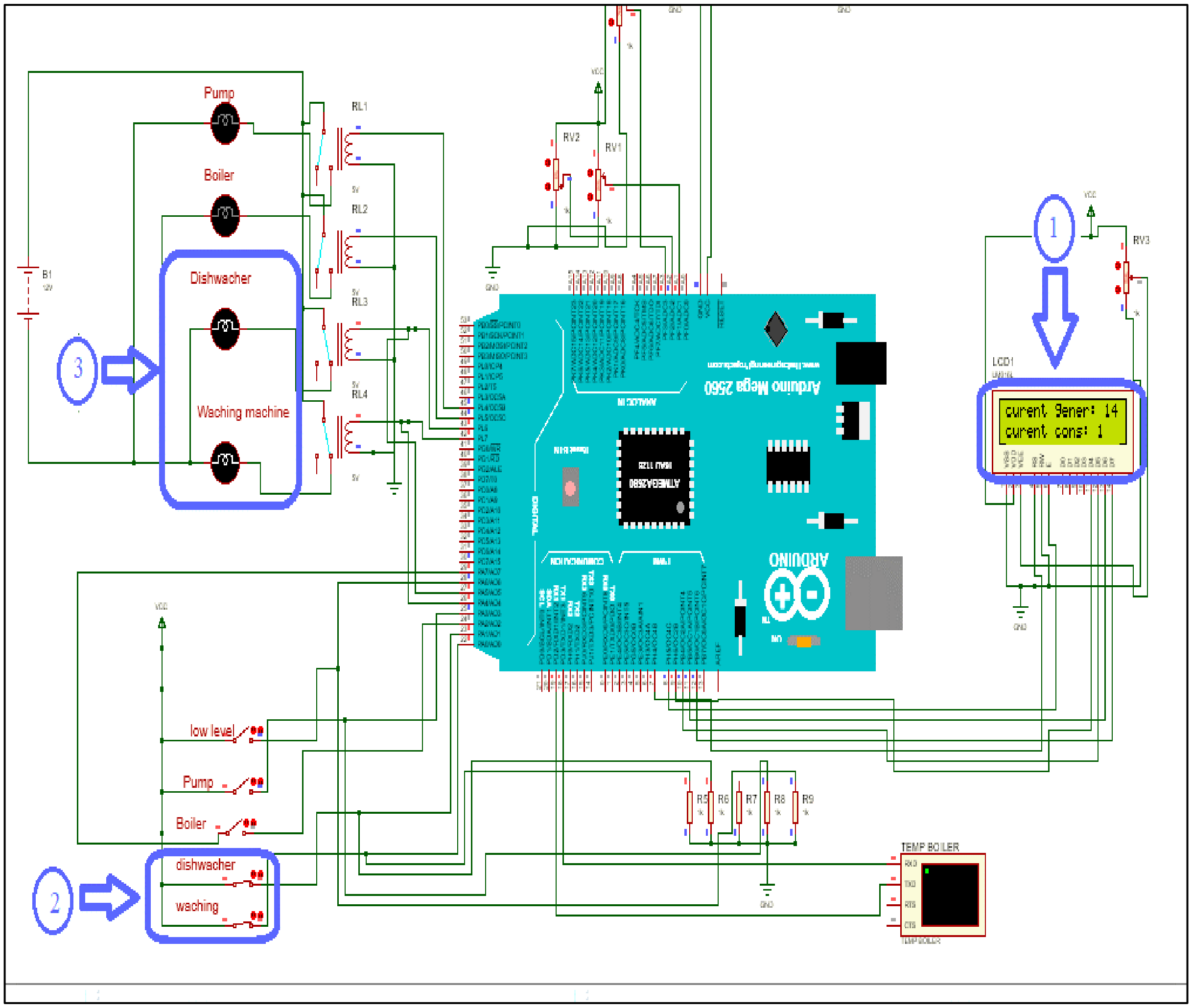


Figure 5.7: Project simulation in Proteus program at maximum current.

Figure 5.8 shows a project simulation in Proteus program when the extra current is very maximum.

- Point 1 represents extra current which equals 14A (15A-1A).
- Point 2 represents the boiler and water pump switches were pressed.
- Point 3 represents the output devices were turned on because the extra current is enough to turn on, the controller rules control it.

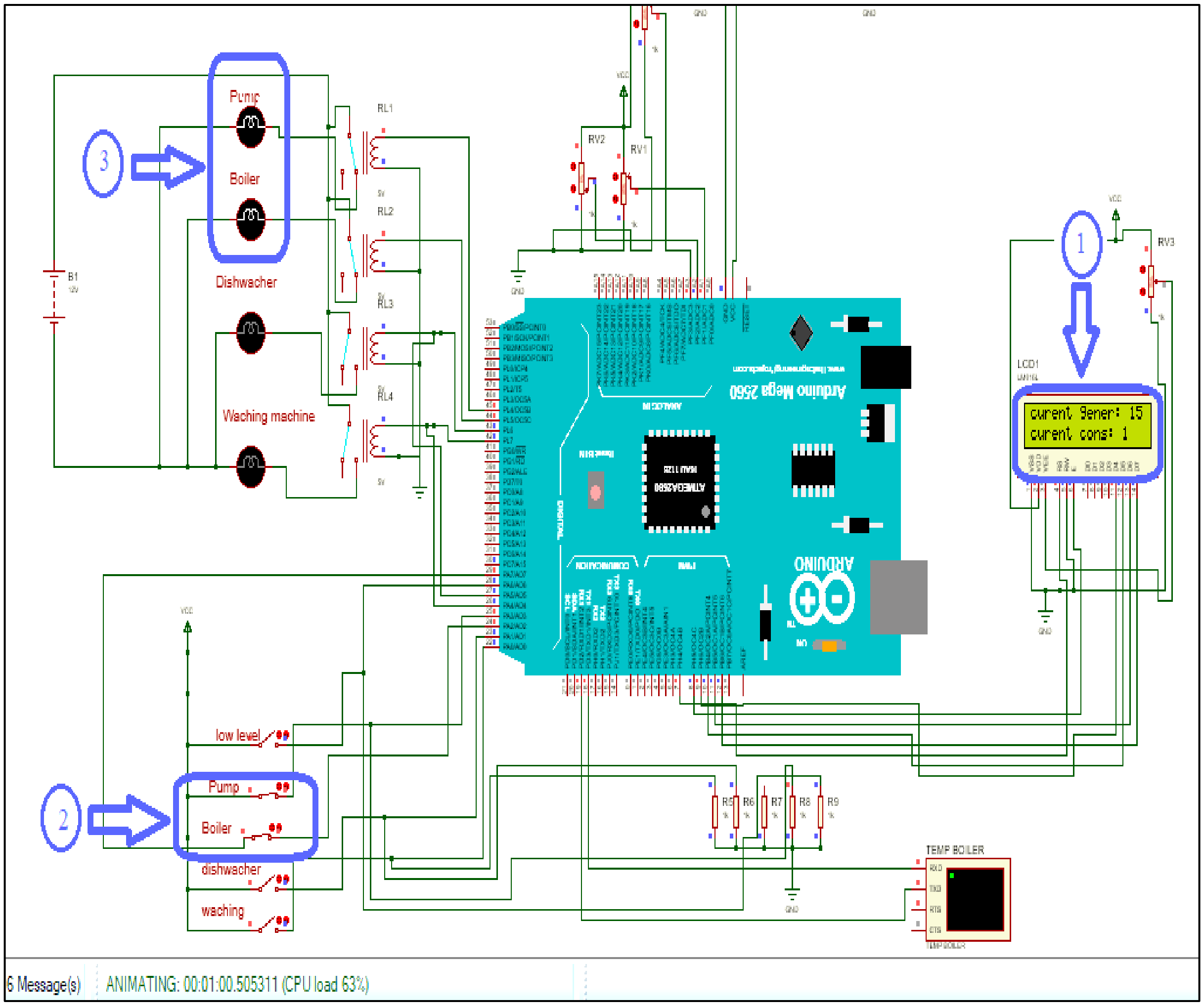


Figure 5.8: Project simulation in Proteus program at very maximum current.

Figure 5.9 shows a project simulation in Proteus program when the extra current is medium.

- Point 1 represents extra current which equals 7A (11A-4A).
- Point 2 represents (boiler, dishwasher, washing machine, water pump, low level) switches were pressed.
- Point 3 represents the output devices, the Washing machine and pump devices were turned on because the extra current is not enough to turn on all devices, controller rules control it.
- Point 4 represents Water temperature in boiler equal 51 ˚C it's suitability, there is no need to run.

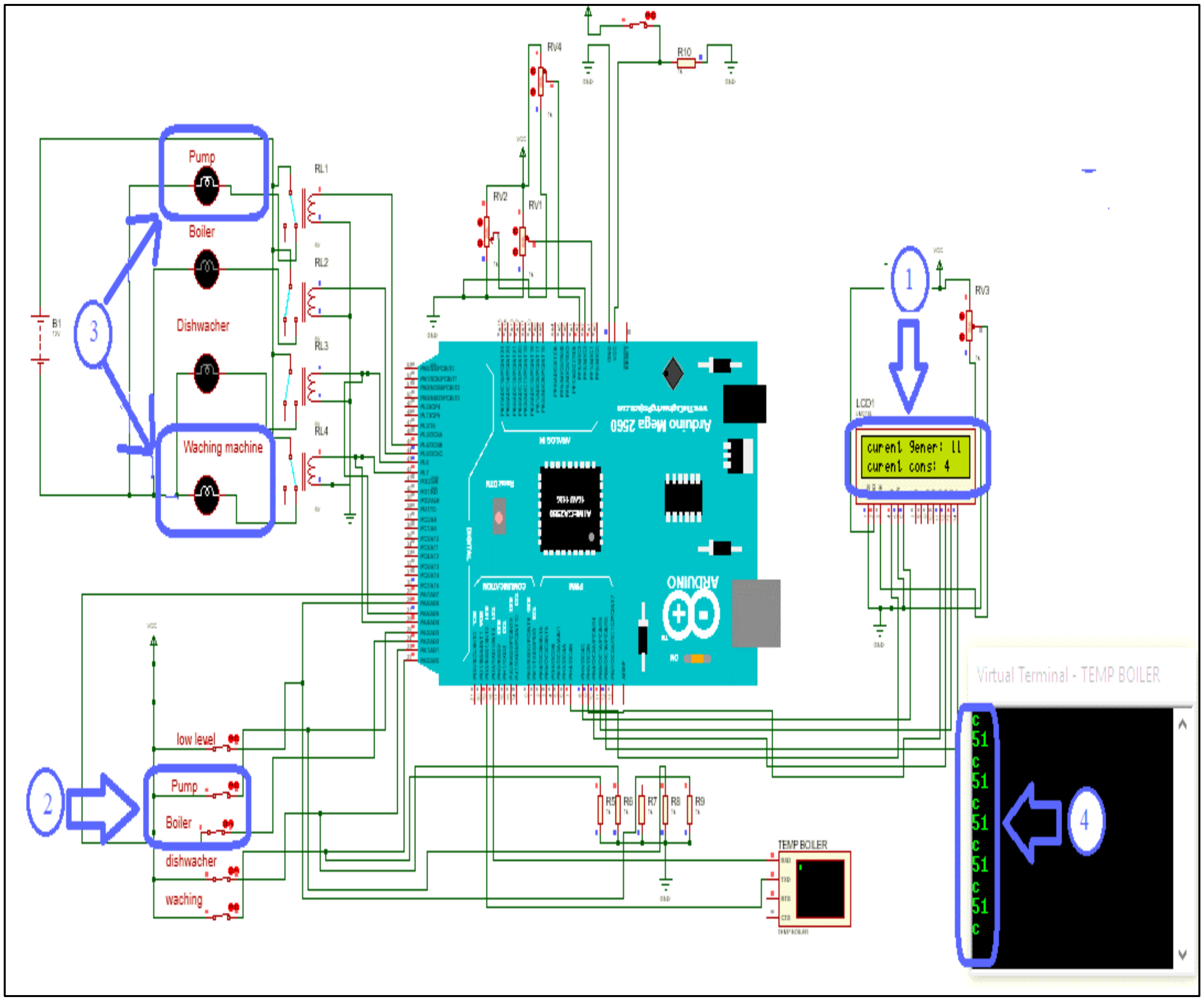


Figure 5.9: Project simulation in Proteus program at medium current.

Figure 5.10 shows a project simulation in Proteus at when the extra current is very maximum.

- Point 1 represents extra current which equals 15A (16A-1A).
- Point 2 represents (boiler, dishwasher, washing machine, water Pump, low level) switches were pressed.
- Point 3 represents the output devices, the dishwasher, washing machine and water pump devices were turned on because the extra current is not enough to turn on all devices, the controller rules control it.
- Point 4 represents water temperature in boiler equal 51 ˚C it's suitability, there is no need to run.

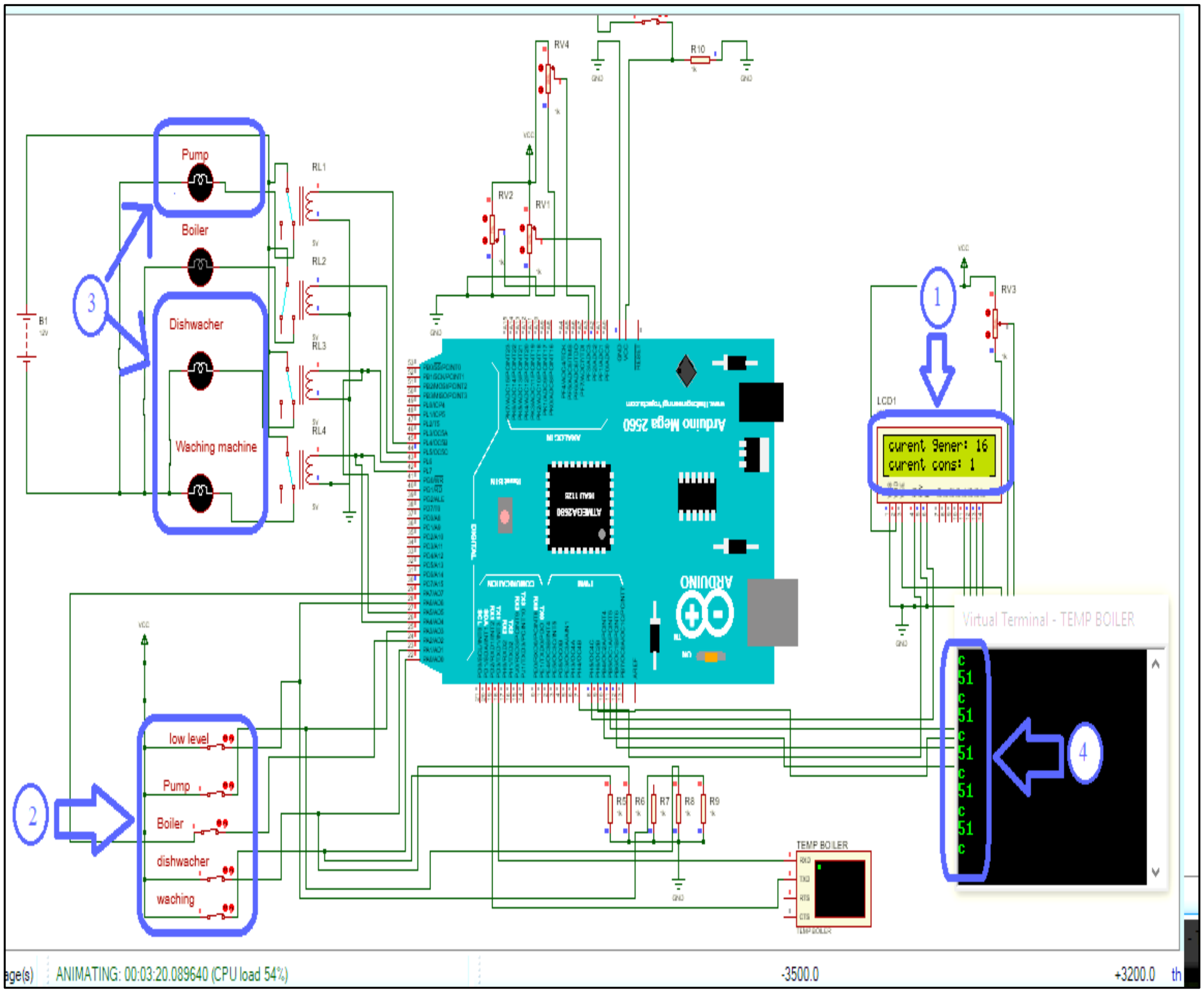


Figure 5.10: Project simulation in Proteus program at very maximum current.

Figure 5.11 shows a project simulation in Proteus program at very maximum extra current.

- Point 1 represents extra current which equals 16A (17A-1A).
- Point 2 represents (boiler, dishwasher, washing machine, water pump, low level) switches were pressed.
- Point 3 represents the dishwasher, washing machine and pump devices were turned on because the controller rules were run devices in this state due to the extra current is very maximum, the controller rules control it.

- Point 4 represents water temperature in boiler equal 18 ˚C it's not suitability, there is need to run.

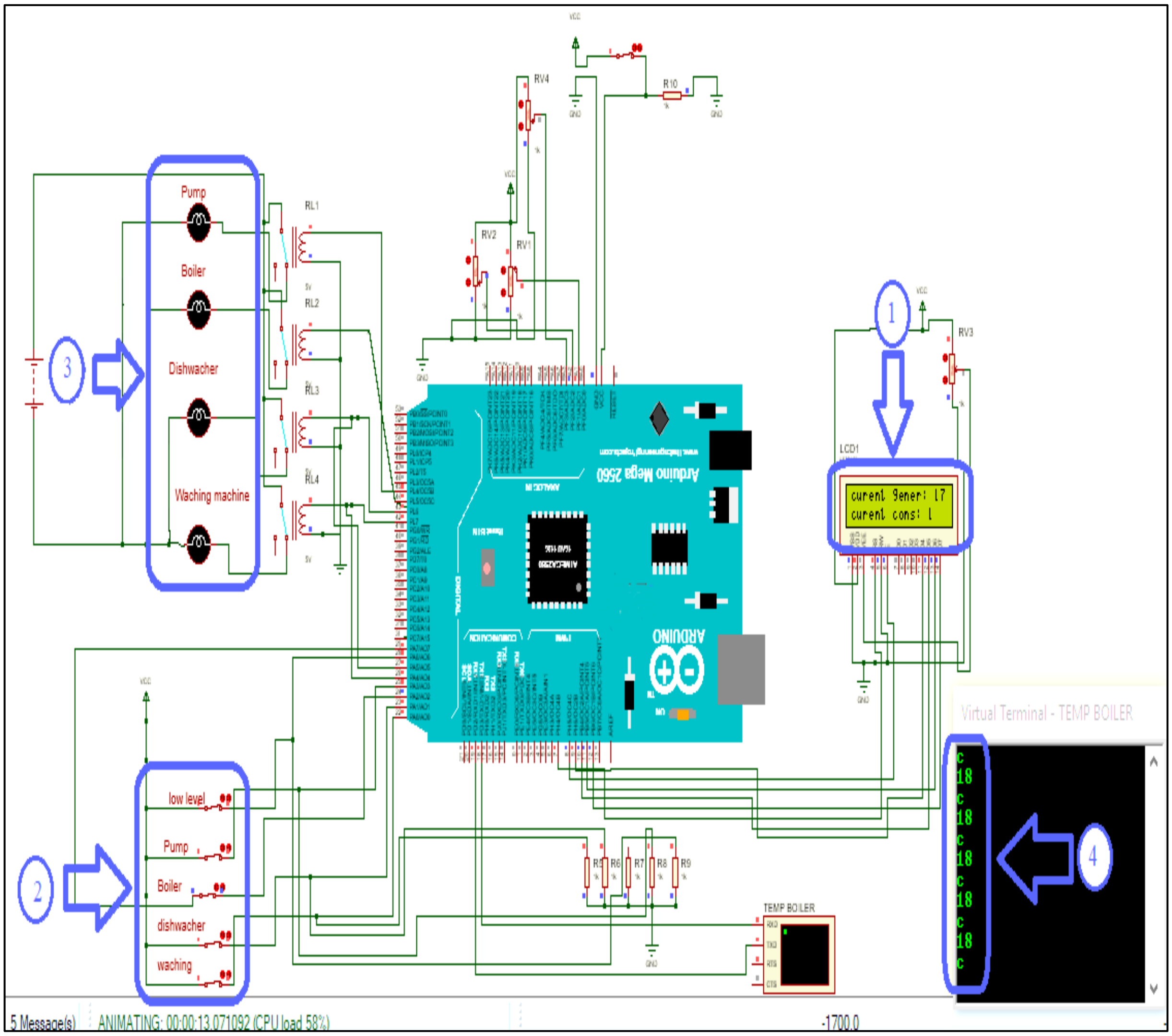


Figure 5.11: Project simulation in Proteus program at very maximum current.

5.5 Prototype Results

The project was practically represented as a prototype, the electrical devices were represented by LEDs, the solar system was represented by two small solar cells, each device was connected with the switch, the boiler was connected with a potentiometer and the LCD display the currents shown in **figure 5.12**.

Figure 5.12: Picture of project prototype.

Figure 5.13 shows a prototype at minimum extra current, the switches of (boiler, dishwasher, washing machine, water pump) were pressed, the output devices weren't turned on because the extra current is not enough to turn on any device, the controller rules control it.

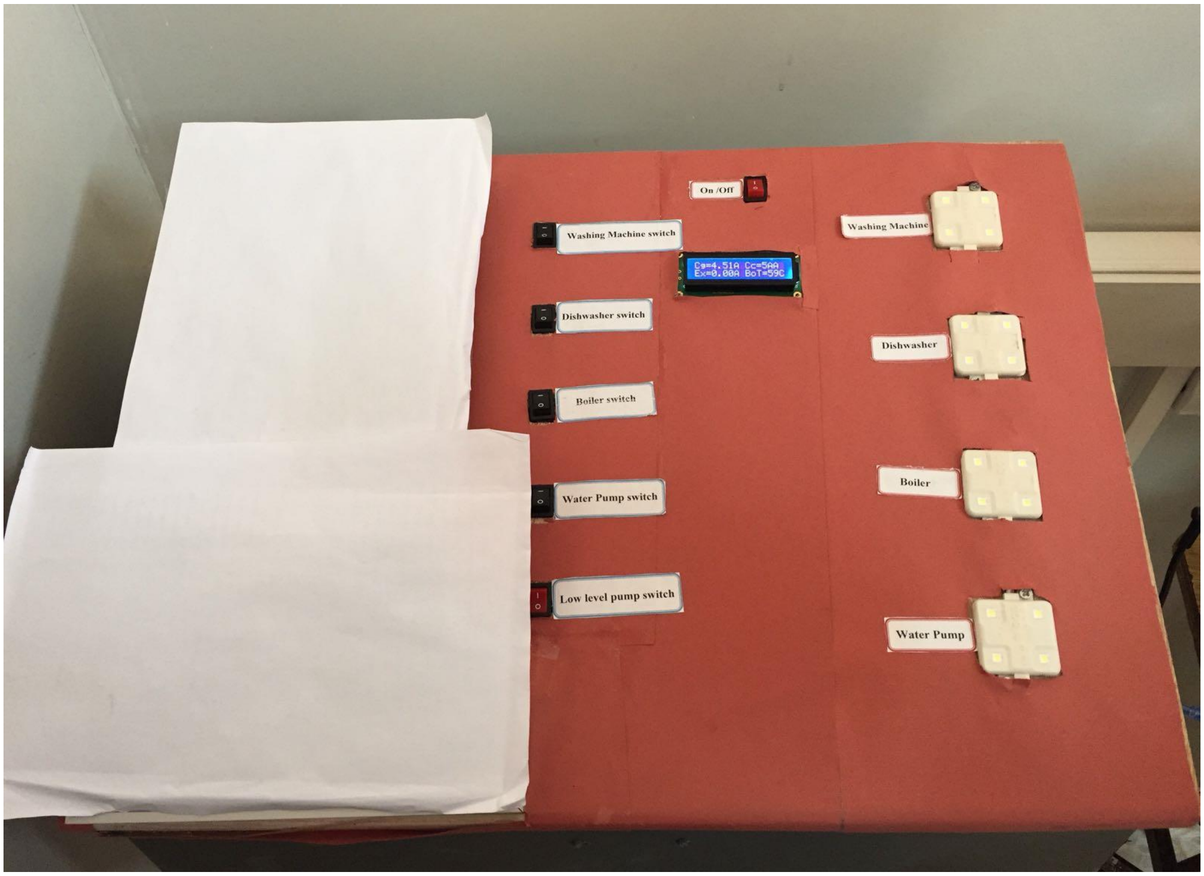


Figure 5.13: Prototype at minimum extra current.

Figure 5.14 shows a prototype at maximum extra current, the switches of (dishwasher, washing machine) were pressed, the output devices were turned on because the extra current is enough to turn on the devices.

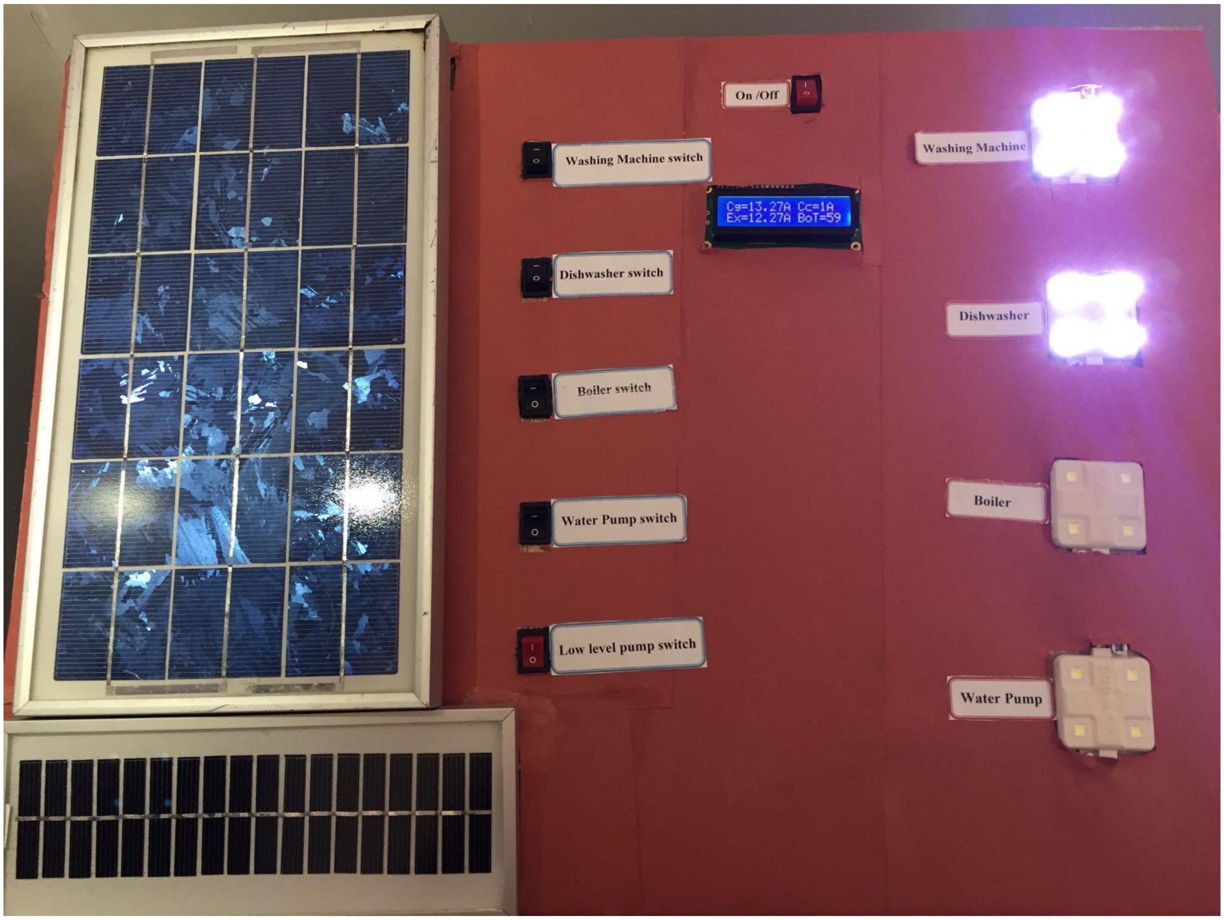


Figure 5.14: Prototype at maximum extra current.

Figure 5.15 shows a prototype at maximum extra current, the switches of (boiler, water pump) were pressed, the output devices were turned on because the extra current is enough to turn on the devices.

Figure 5.15: Prototype at maximum extra current.

Figure 5.16 shows a prototype at very maximum extra current, the switches of (boiler, dishwasher, washing machine, water pump) were pressed, the output devices were turned on because the extra current is enough to turn on any device.

Figure 5.16: Prototype at very maximum extra current.

CHAPTER SIX

Conclusion and Recommendations

Contents:

6.1 Conclusion.

6.2 Recommendations.

6.1 Conclusion

It was found that the solar energy can be effectively exploited by this controller. By means of this controller, the number of batteries in the off-grid system can be reduced because of the optimal exploitation of solar energy, if it is used in the on-grid system its reduces the sales to network because of the optimal utilization of energy and in both systems the money is saved.

The use of logical strings in the controller gives high accuracy and fast performance depending on the division of PV generation into periods and regulation of operating times of devices depending on the current generated from the PV and the capacity of each device.

6.2 Recommendations

- Make the project control more than four devices based on priorities and consumer behavior.
- Make the system more economical by using the excess power after operating the required equipment, where the devices that are heating in the winter and in the summer, is cooling.
- After the implementation of the project on a multi-story building, control of each floor by a microcontroller of the building, many buildings can be controlled by a main controller connected to the buildings and the electricity company.
- The project can be developed using an application on the phone that can turn on and off the devices.

Appendix A

A measurement of the electricity power pattern consumption of houses in Hebron.

1. **Home 4**

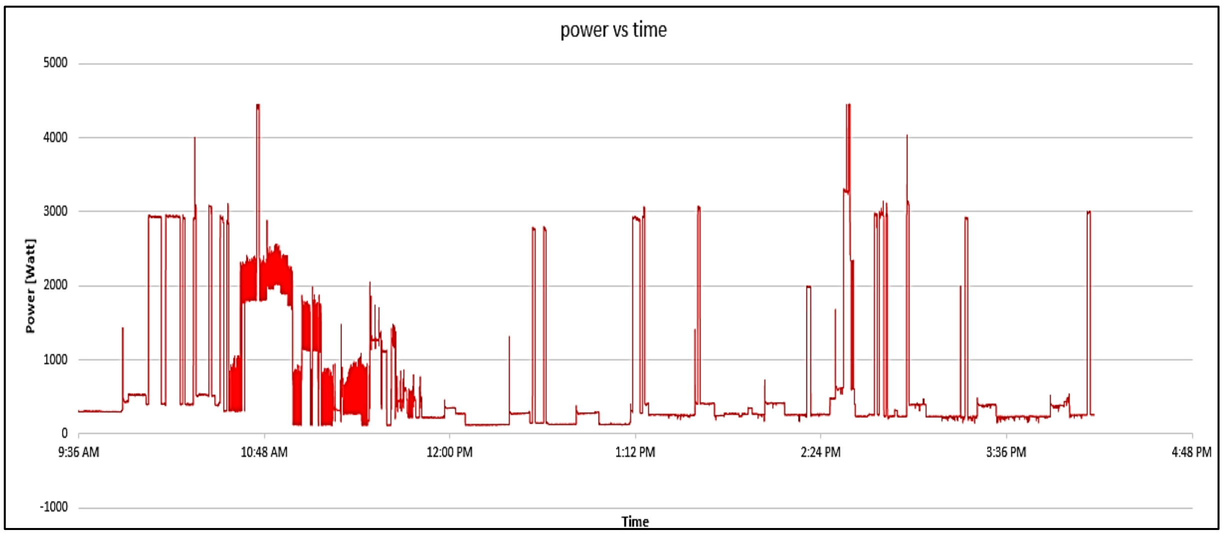


Figure 1: Electricity consumption of the home 4 from 9 am to 5 pm.

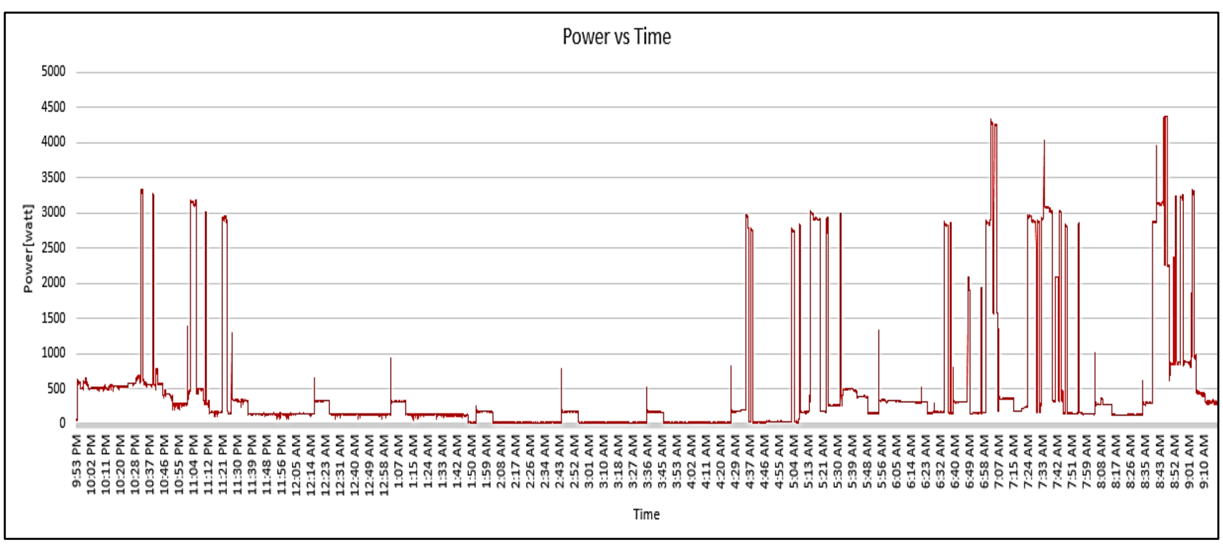


Figure 2: Electricity consumption of the home 4 from 9 pm to 9 am.

2. Home 5

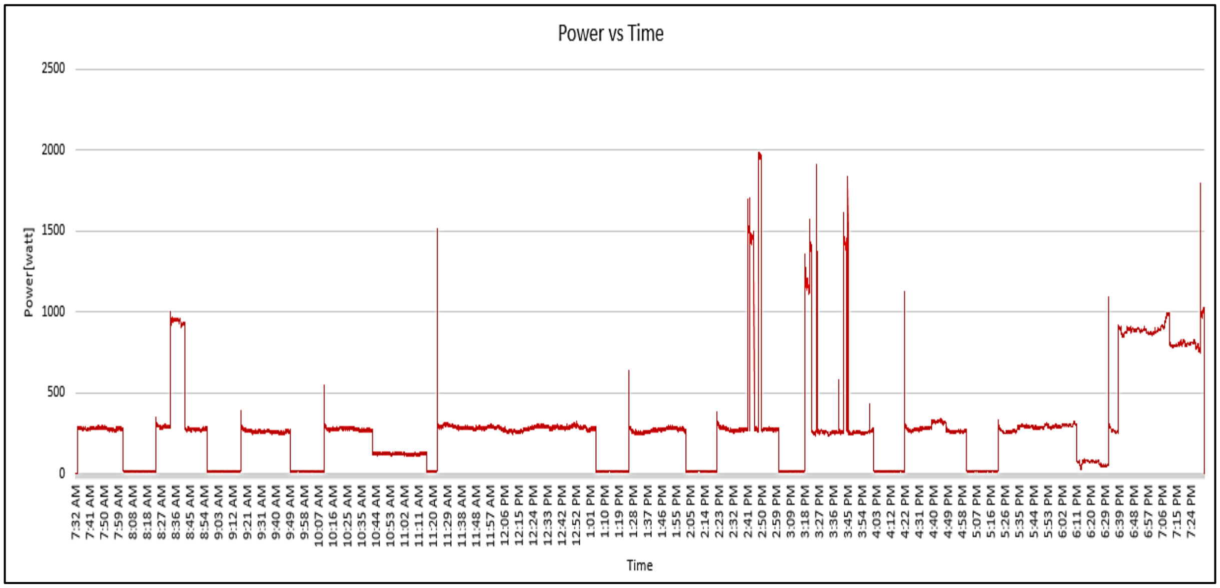


Figure 3: Electricity consumption of the home 5 from 7 am to7 pm.

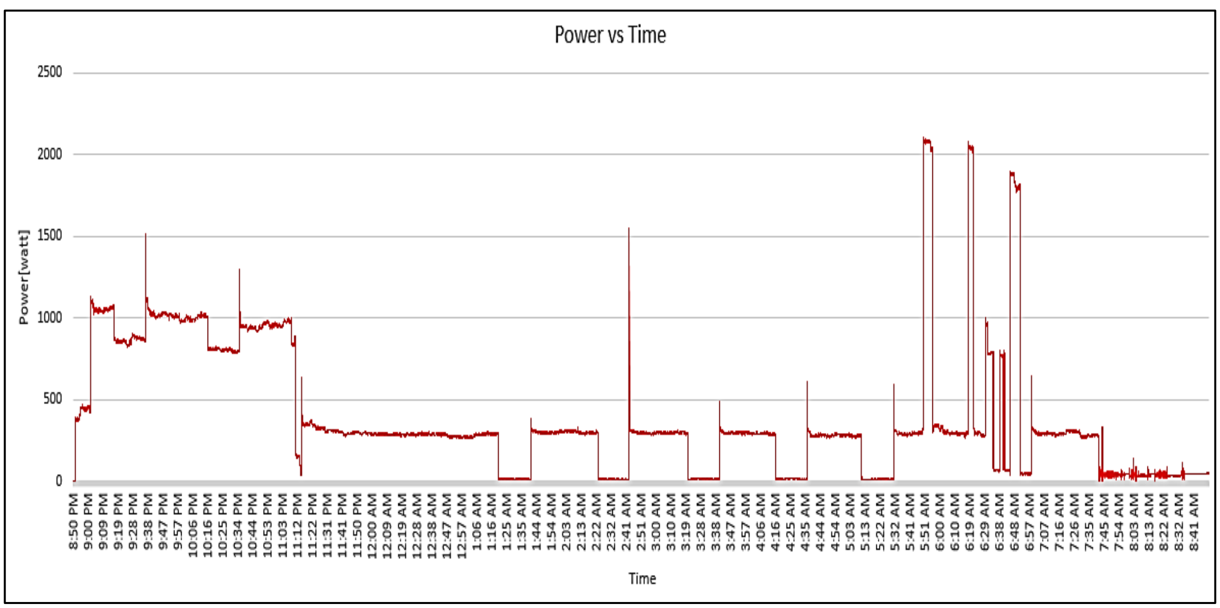


Figure 4: Electricity consumption of the home 5 from 8 pm to 8 am.

3. Home 6

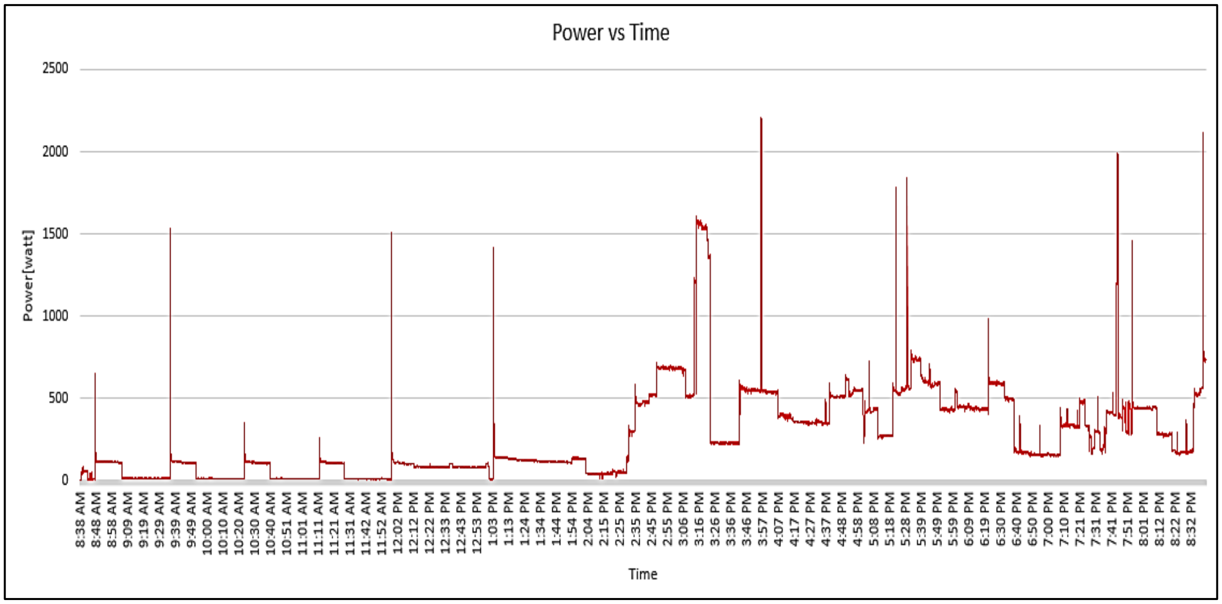


Figure 5: Electricity consumption of the home 6 from 9 am to9 pm.

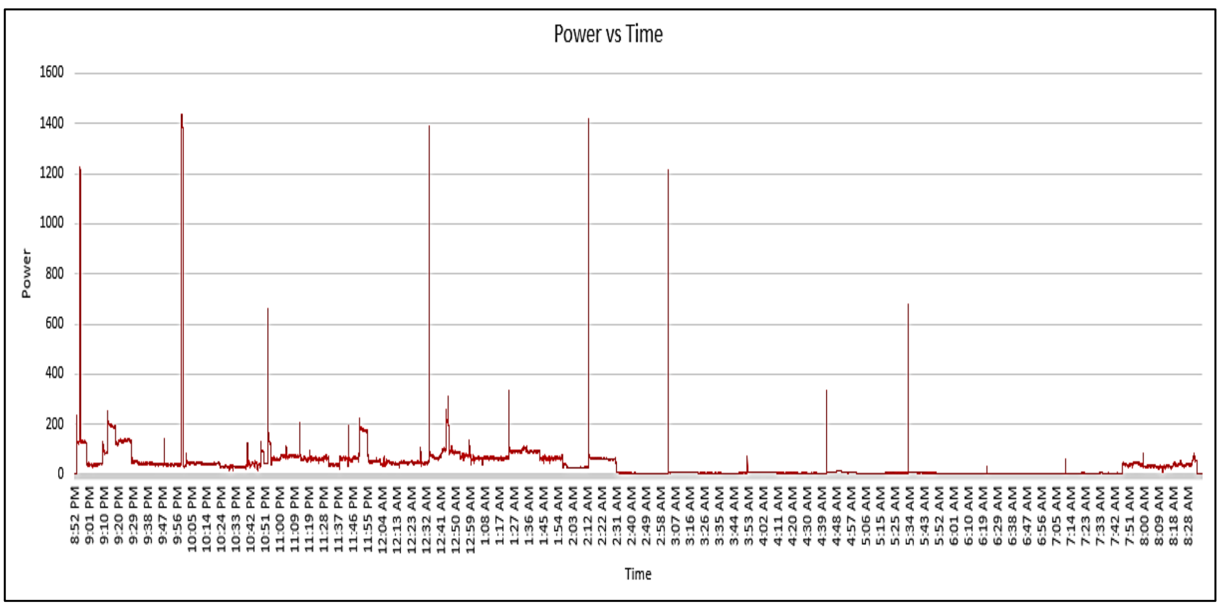


Figure 6: Electricity consumption of the home 6 from 9 pm to 9 am.

4. Home 7

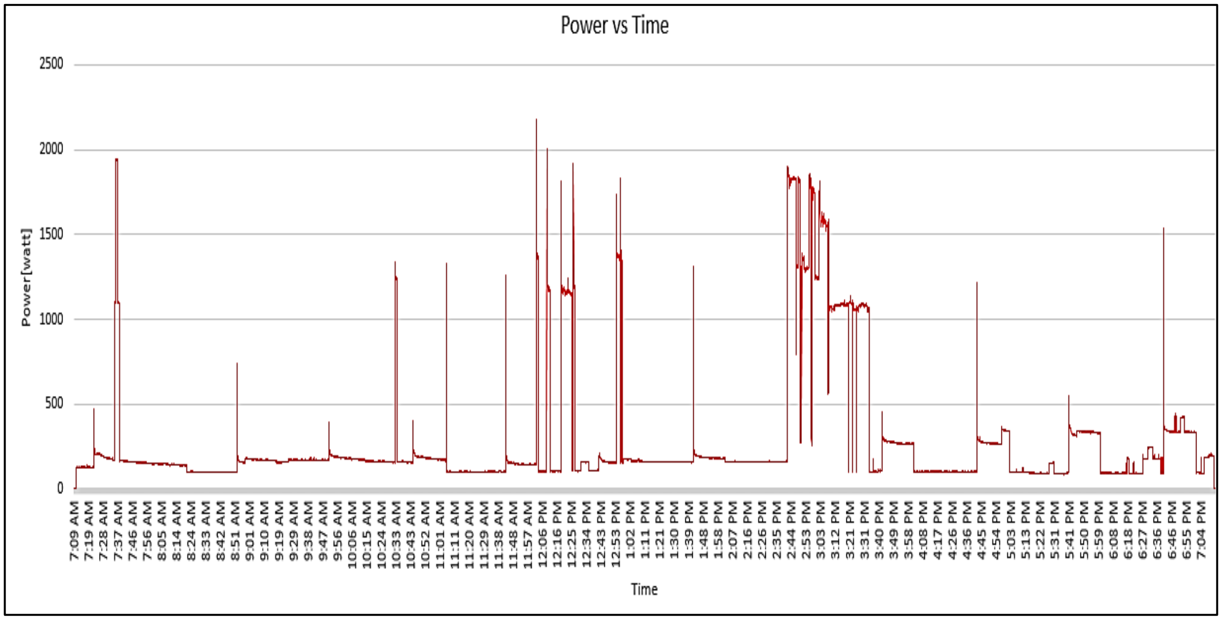


Figure 7: Electricity consumption of the home 7 from 7 am to 7 pm.

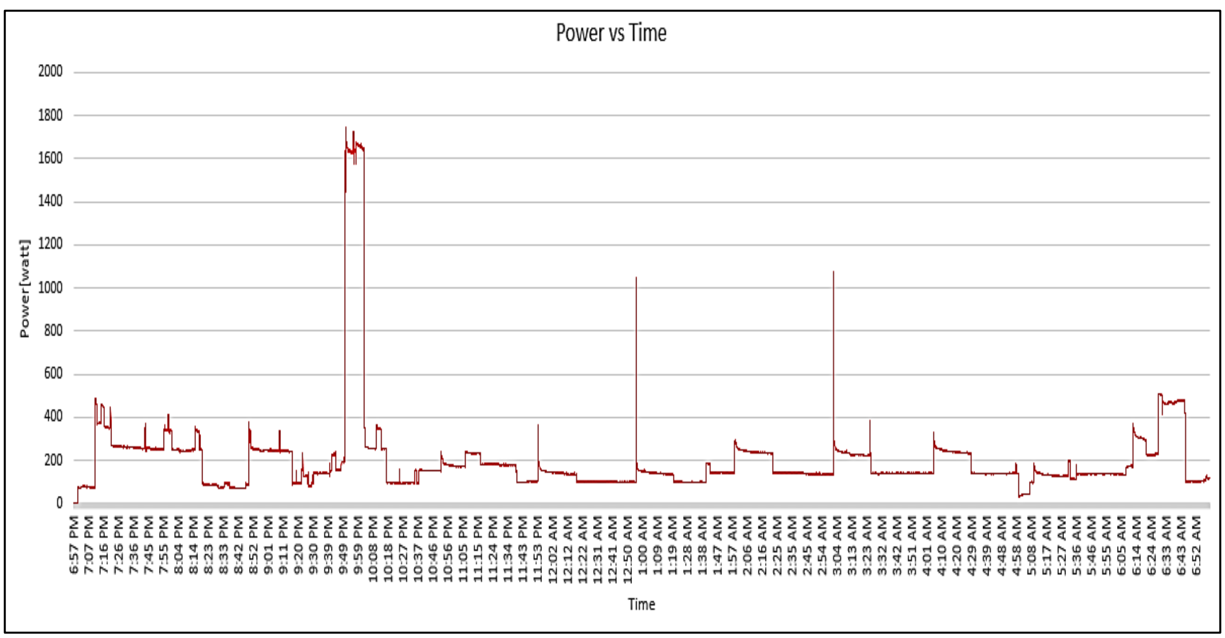


Figure 8: Electricity consumption of the home 7 from 7 pm to 7 am.

5. Home 8

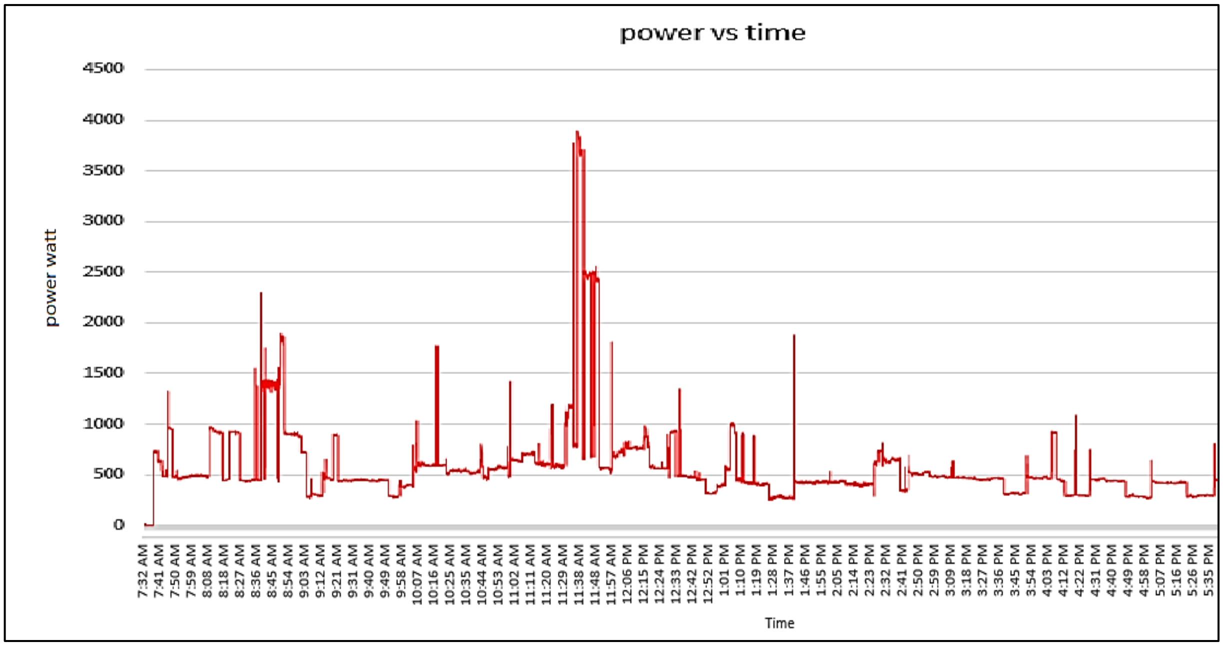


Figure 9: Electricity consumption of the home 8 from 7 am to 6 pm.

6. Home 9

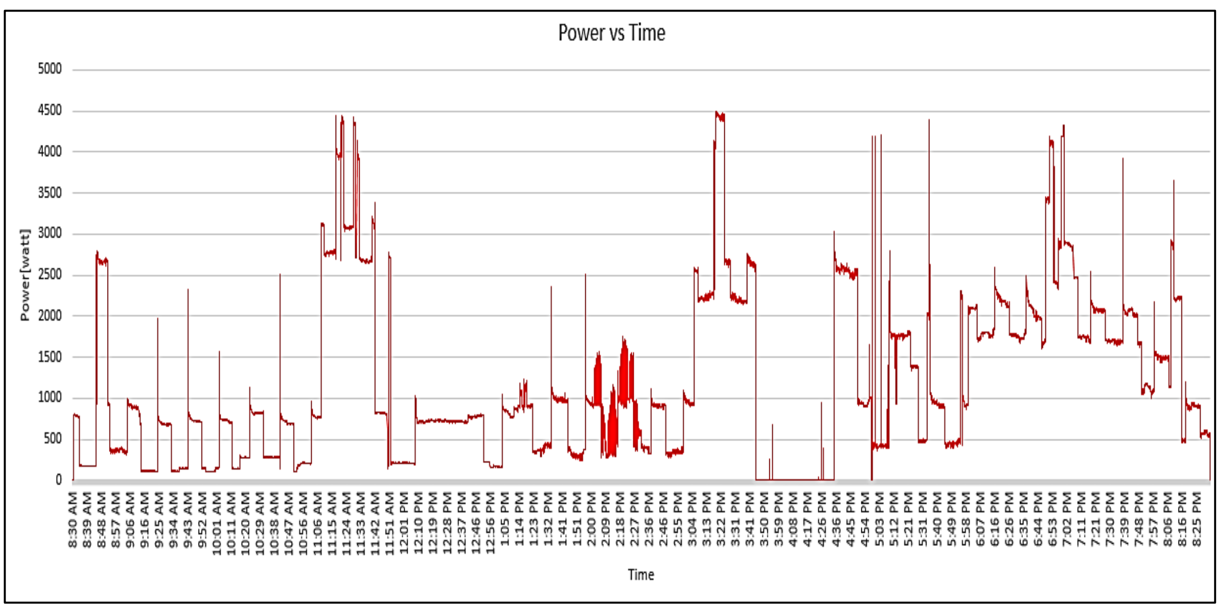


Figure 10: Electricity consumption of the home 9 from 8:30 am to 8:30 pm.

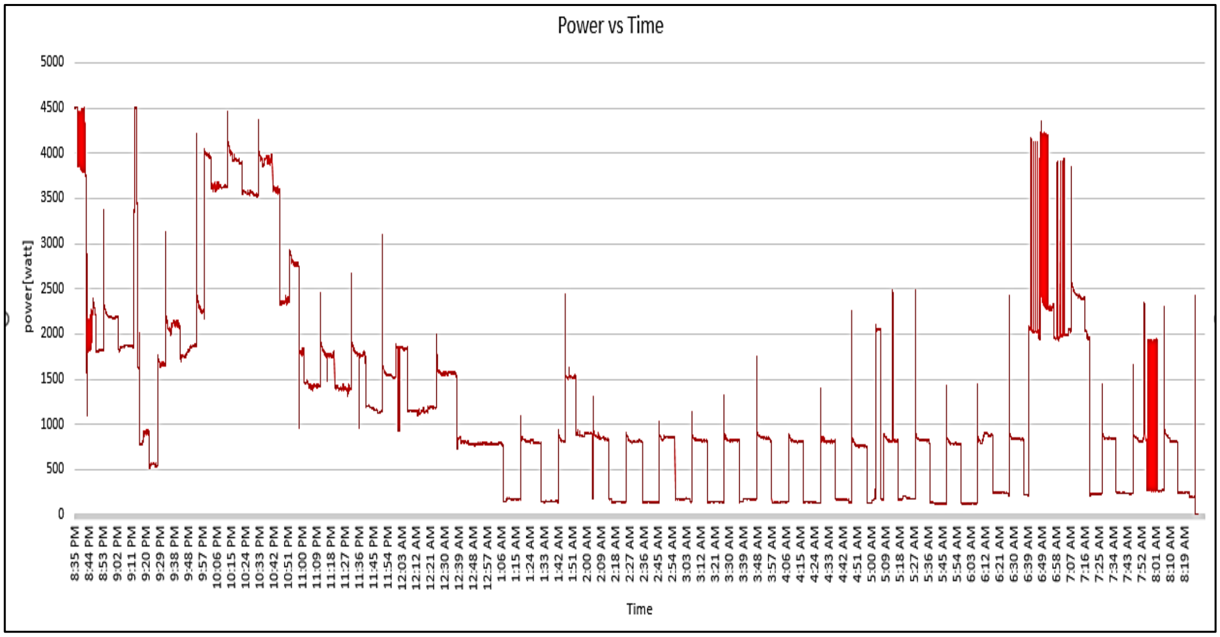


Figure 11: Electricity consumption of the home 9 from 9 pm to 9 am.

7. Home 10

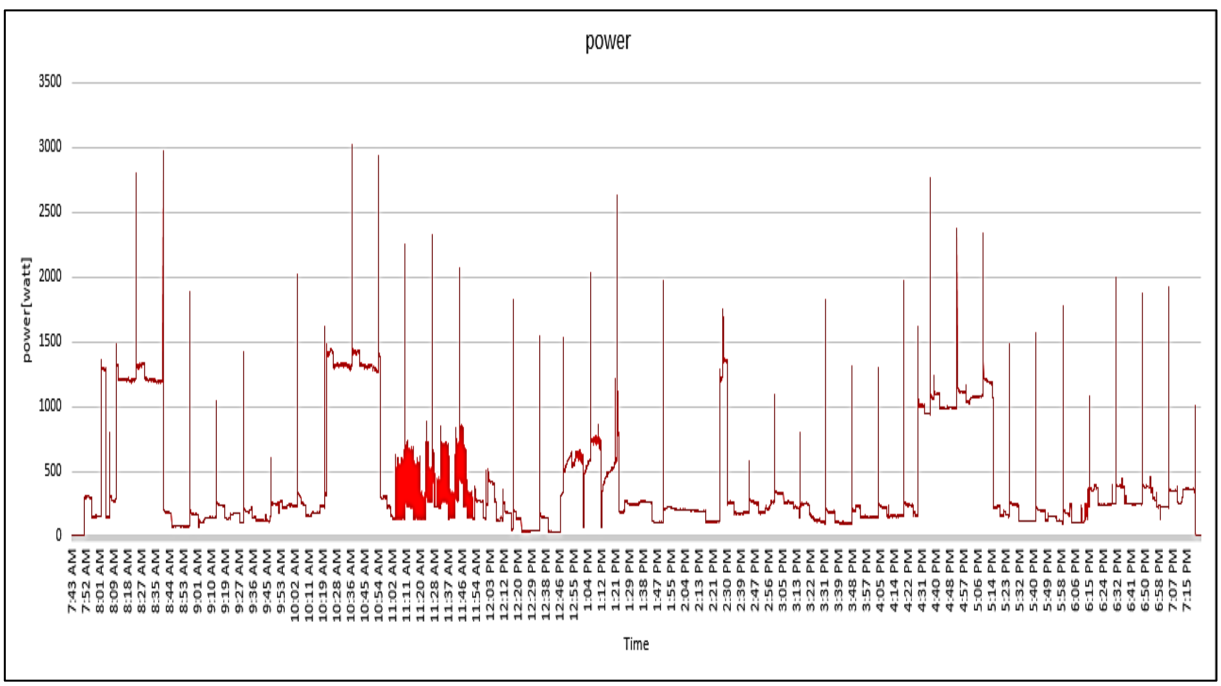


Figure 12: Electricity consumption of the home 10 from 7:45 am to 7:15 pm.

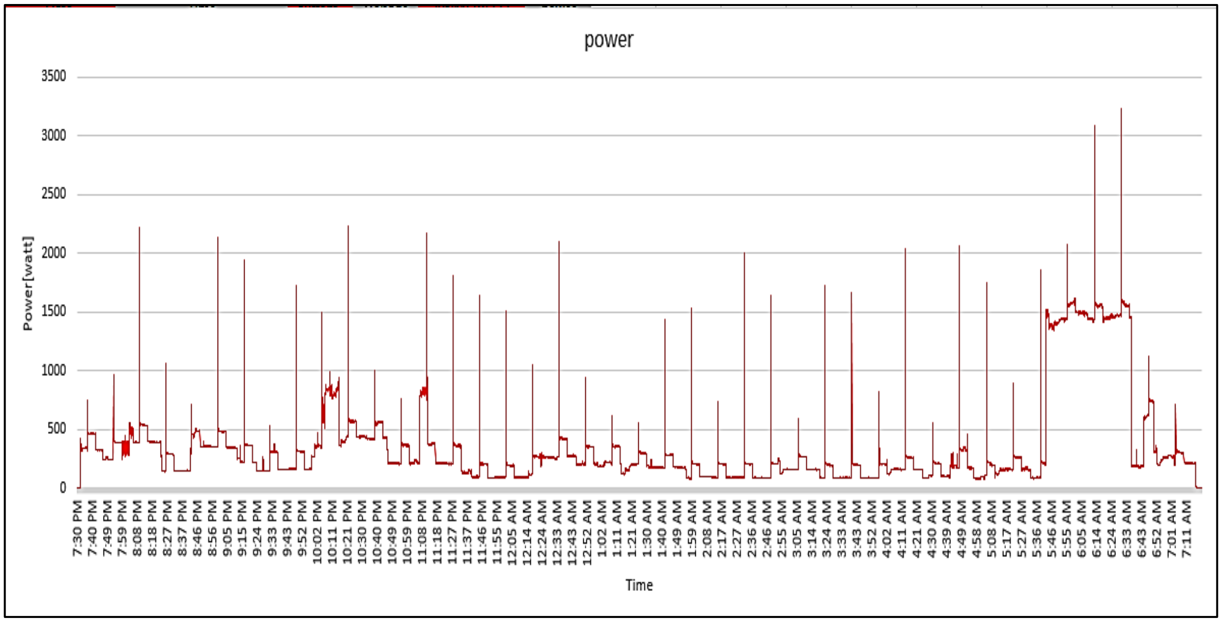


Figure 13: Electricity consumption of the home 10 from 7:30 pm to 7:15 am.

Appendix B

Questionnaire

Questionnaire

We are Palestine Polytechnic university students: **(Ahmad Abu Sharkh, Mohammad Rafat Nofal, Hamza Salahat and Mohammad Al Qasrawi)** we will be studying project about electrical power management.

Objective: To study the electrical energy consumption in homes and the factors influencing them. Please answer all the questions and will be using the information provided for the purposes of scientific research.

---

1. Address: ………………………………………………………………………………………….

2. Number of house persons: ………….

School students: ………....

Universal students: …………

3. Educational level of the head: ☐ Universal. ☐ Low than universal.

4. Head job: ………………………………………………

5. family incomes level monthly: ☐ 800$ or less. ☐ 800 _ 1600$. ☐ 1600$ or more.

6. Nature housing: ☐ Own. ☐ Rent.

7. Home area: …………... m^2.

8. No. of rooms: …………

9. committed to pay electricity bill: ☐ Monthly. ☐ Many months. ☐ Not committed.

10. How do you see the consumption of electricity in your home?

☐ Low. ☐ Normal. ☐ High. ☐ Very high.

11. Do you save electricity in your home?

☐ Sometimes. ☐ Yes. ☐ No.

Devices in your home:

No.	Device	Exist	Doesn't exist	Watts
1	Washing Machine			
2	Hair Dryer			
3	Microwave			
4	Toaster			

5	Clothes Dryer			
6	Electric furnace			
7	Water pump			
8	Boiler			
9	Water Heater			
10	Air conditioner			
11	Vacuum Cleaner			
12	Electric Fireplace			
13	Dishwasher			

بسم الله الرحمن الرحيم

استبيان حول طبيعة استهلاك الطاقة الكهربائية في المنازل

نحن الطلاب (**محمد نوفل ،حمزة صلاحات،احمد أبو شرخ، محمد قصراوي**) من جامعة بوليتكنك فلسطين نود القيام بمشروع بعنوان ادارة الطاقة الكهربائية
.

الهدف:يهدف هذا الاستبيان الى طبيعة استهلاك الطاقة الكهربائية في المنازل والعوامل المؤثرة عليها . فيرجى التكرم بالإجابة على جميع الأسئلة الواردة في الاستبيان وسوف تستخدم المعلومات الواردة لأغراض البحث العلمي.

1- مكان السكن:_____ ______________________________.

2-عدد سكان المنزل:_____ ______________________________.

- أفراد بالمدرسة:__ _____.
- أفراد بالجامعة:____ ____.

3- المستوى التعليمي لرب الأسرة: ☐ جامعي ☐ اقل من جامعي .

4- طبيعة عمل رب الأسرة :____ ____.

5- مستوى الدخل الشهري للأسرة: 3000ش فما دون ☐ . 3000ش_6000ش ☐ ☐ 60ش فأكثر

6- طبيعة السكن : ☐ ملك ☐ ايجار

7- مساحة المنزل : ______ متر مربع.

8- عدد غرف المنزل :_ _____.

9- هل منزلكم : ملتزم بدفع فاتورة الكهرباء شهريا ☐ .
تدفع فاتورة كل عدة أشهر ☐ .
غير ملتزم ☐ .

10- كيف ترى طبيعة استهلاك الكهرباء في منزلك : قليل ☐ عادي ☐ مرتفع ☐ مرتفع جدا ☐

11- أكثر ساعات تستهلك بها الكهرباء : من __ ____.

مرفق للأجهزة الموجودة بالمنزل:

الرقم	الجهاز	موجود	غير موجود	القدرة (watts)
1	آلة غسل(غسالة) Washing Machine			
2	مجفف شعر Hair Dryer			
3	ميكروويف Microwave			
4	محمصة Toaster			
5	مجفف ملابس Clothes Dryer			
6	فرن كهربائي Electric Furnace			
7	مضخة ماء Water pump			
8	سخان المياه(بويلر) Water Heater			
9	سخان المياه Water Heater(Atmore)			
10	مكيف الهواء Air conditioner			
11	مكنسة كهربائية Vacuum Cleaner			
12	مدفئة كهربائية Electric Fireplace			
13	جلاية Dishwasher			

Appendix C

Devices measured

1. Air-condition

Manufacture company: ELECTRA, rated power 2800 W.

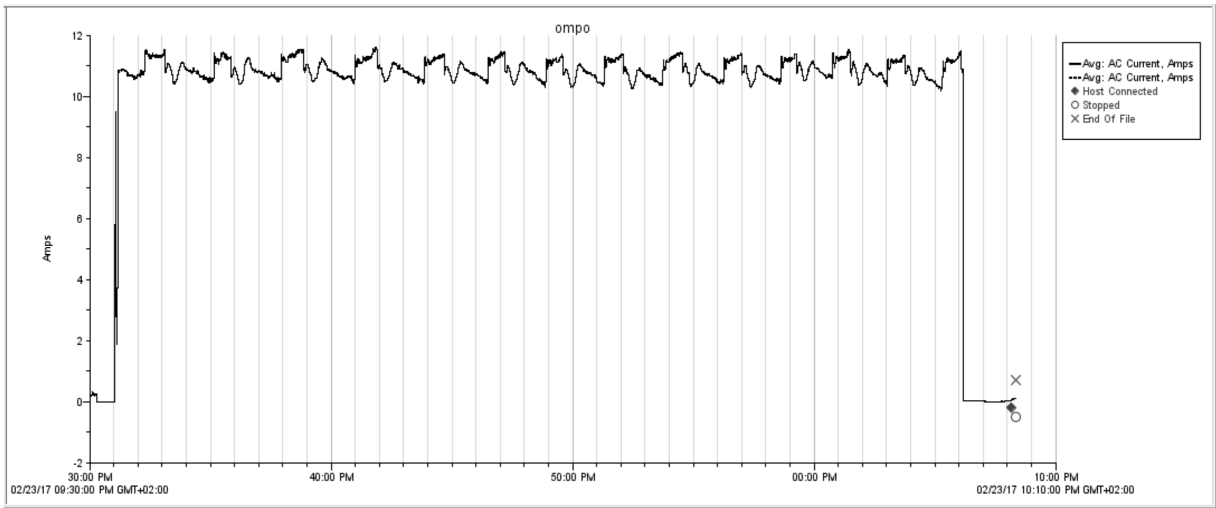


Figure 1: Current data for Air-condition.

2. Refrigerator

Manufacture company: LG, rated power 160 W.

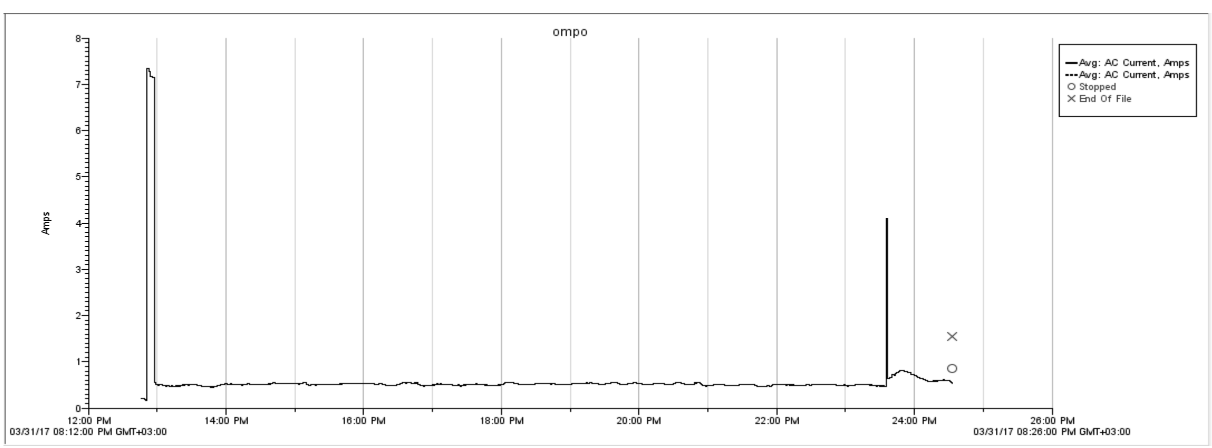


Figure 2: Current data for Refrigerator.

3. TV and Receiver

Manufacture: LG, rated power 200 W

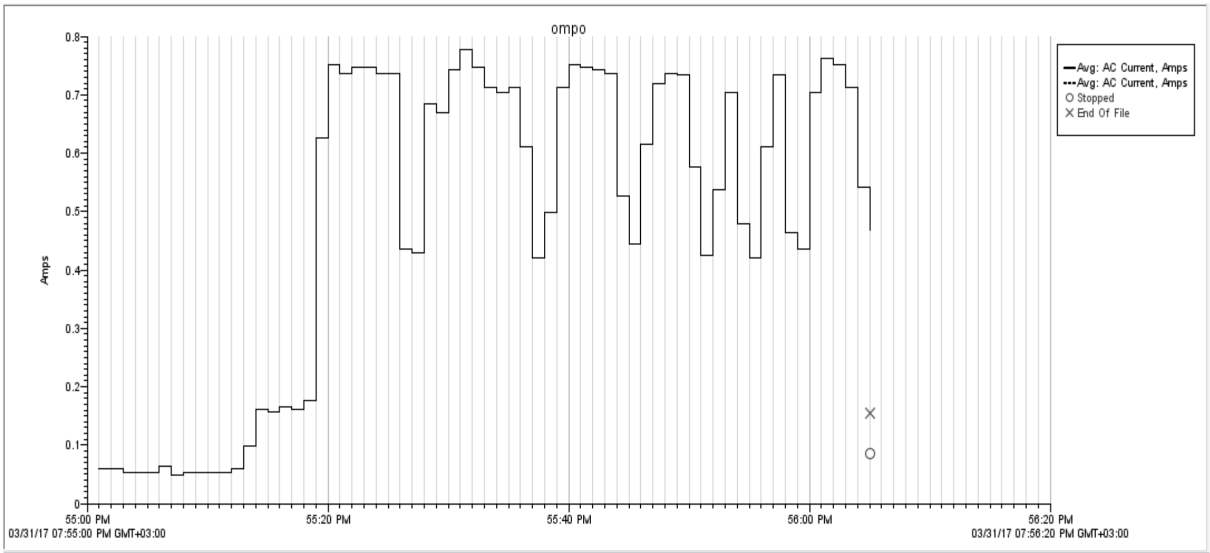


Figure 3: Current data for TV and Receiver.

4. Dishwasher

Manufacture company: Ariston, rated power 2000 W

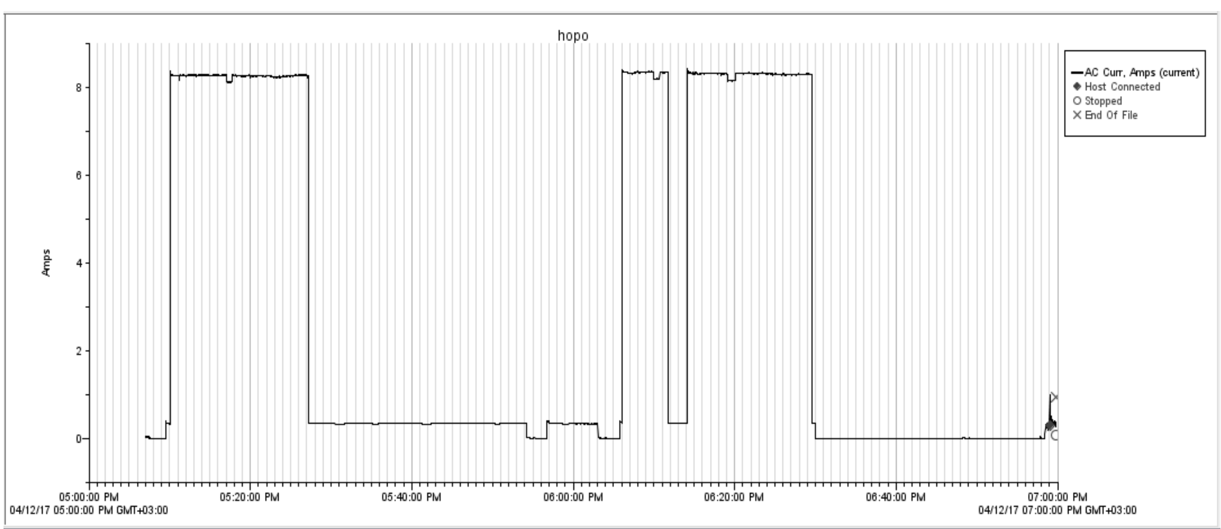


Figure 4: Current data for Dishwasher.

5. Hair dryer

Manufacture company: Super Solano, rated power 2000 W.

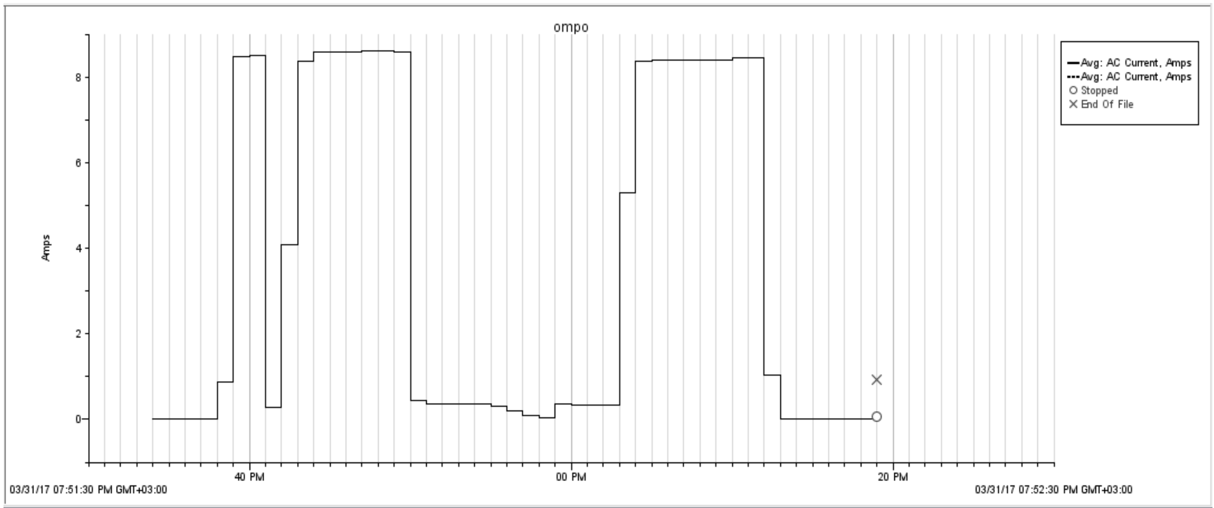


Figure 5: Current data for Hair dryer.

6. Electric Fireplace

Manufacture company: Mega, rated power 2400 W.

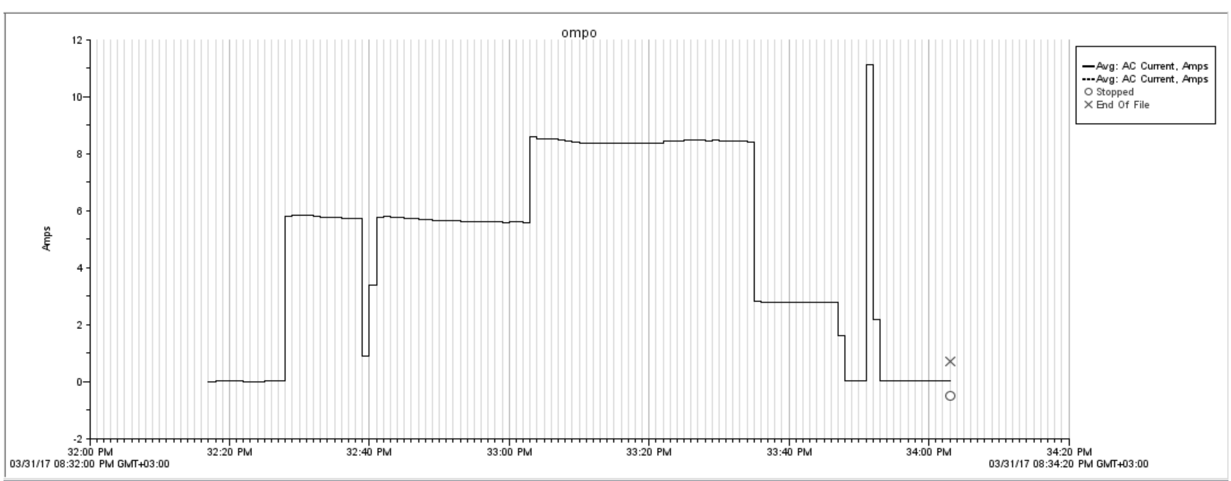


Figure 6: Current data for Electric Fireplace.

7. Washing machine

Manufacture company: LG, rated power 1800 W.

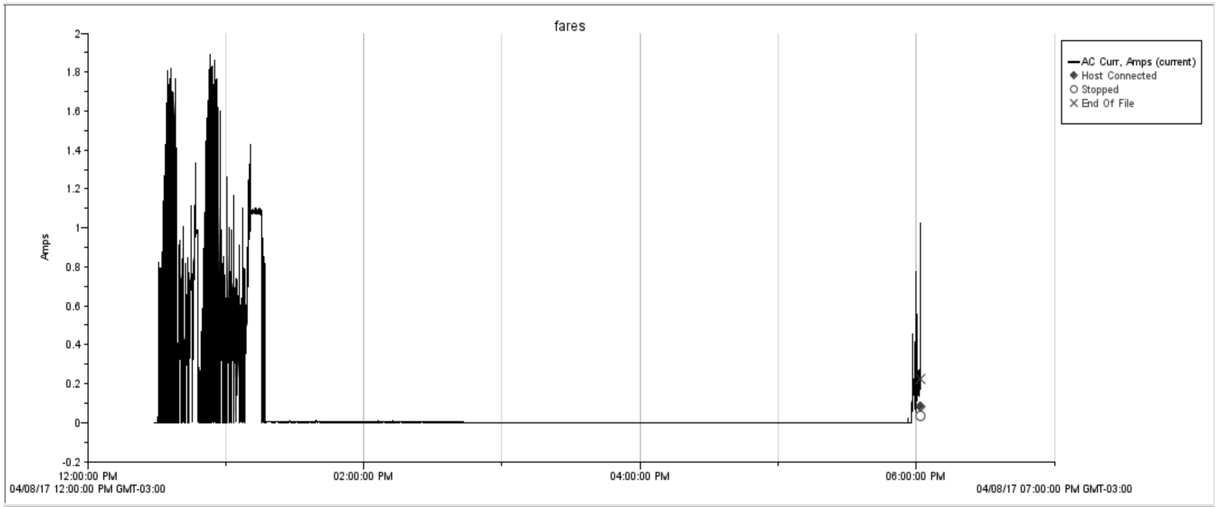


Figure 7: Current data for Washing machine.

8. Water heater

Manufacture company: Mienta, rated power 2000 W.

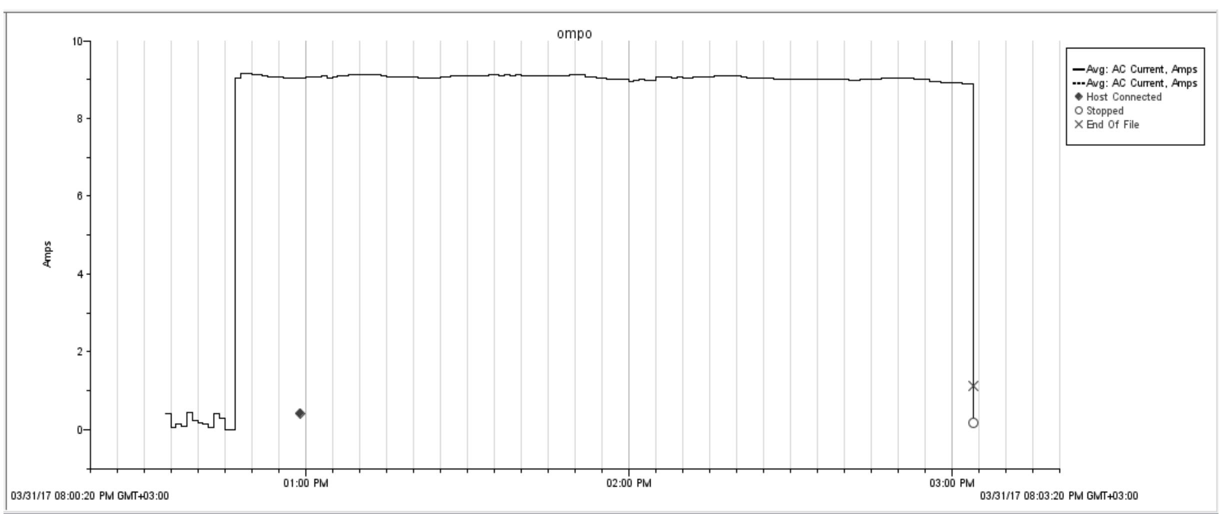


Figure 8: Current data for Water heater.

9. Vacuum cleaner

Manufacture company: Hommer, rated power 1200 W.

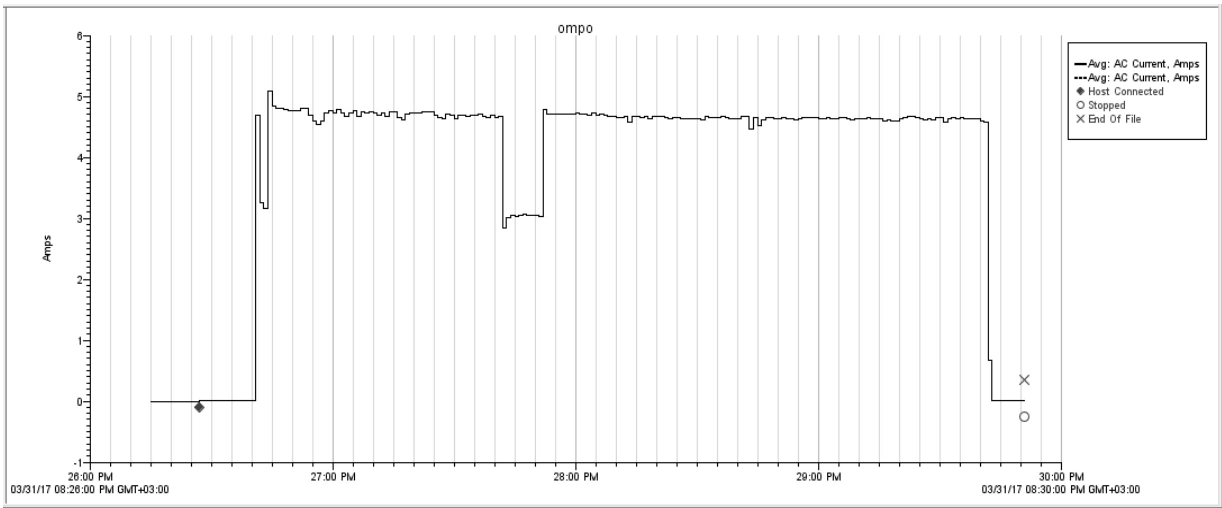


Figure 9: Current data for Vacuum cleaner.

10. Iron

Manufacture company: Ariete, rated power 1900 W.

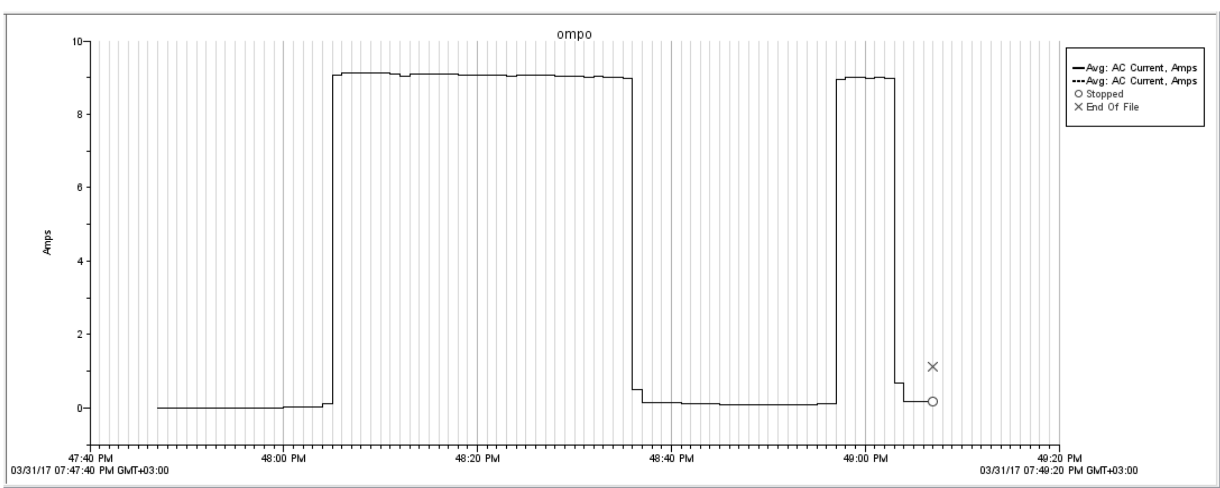


Figure 10: Current data for Iron.

Appendix D

Fuzzy logic controller rules (8 inputs and 4 outputs)

1. If (extracurrent is min) and (pumpswitch is off) then (pump is off) (1).
2. If (extracurrent is min) and (wmswitch is off) then (washing machine is off) (1).
3. If (extracurrent is min) and (dishswitch is off) then (dishwasher is off) (1).
4. If (extracurrent is min) and (boilerswitch is on) then (boiler is off) (1).
5. If (extracurrent is min) and (pumpswitch is on) then (pump is on) (1).
6. If (extracurrent is min) and (wmswitch is on) and (wmstate is on) then (washing machine is on) (1).
7. If (extracurrent is min) and (dishswitch is on) and (dishstate is on) then (dishwahser is on) (1).
8. If (extracurrent is min) and (pumpswitch is on) and (low level is on) then (pump is on) (1).
9. If (extracurrent is min) and (wmswitch is on) and (dishswitch is on) and (pumpswitch is on) and (wmstate is on) and (dishstate is on) and (lowlevel is off) then (washing machine is on) (dishwasher is on) (pump is off).
10. If (extracurrent is mid) and (dishswitch is on) then (dishwasher is off) (1).
11. If (extracurrent is mid) and (boilerswitch is on) then (boiler is off) (1).
12. If (extracurrent is mid) and (pumpswitch is on) then (pump is on) (1).
13. If (extracurrent is mid) and (wmswitch is on) and (dishswitch is off) and (wmstate is on) and (dishstate is off) then (washing machine is on) (dishwasher is off) (1).
14. If (extracurrent is mid) and (wmswitch is off) and (dishswitch is on) and (wmstate is off) and (dishstate is on) then (washing machine is off) (dishwasher is on) (1).
15. If (extracurrent is mid) and (pumpswitch is on) and (lowlevel is on) then (pump is on) (1).

16. If (extracurrent is mid) and (wmswitch is on) and (dishswitch is on) and (wmstate is on) and (dishstate is on) then (washing machine is on) (dishwasher is on) (1).
17. If (extracurrent is mid) and (wmswitch is off) then (washing machine is off) (1).
18. If (extracurrent is mid) and (pumpswitch is off) then (pump is off) (1).
19. If (extracurrent is mid) and (dishswitch is off) then (dishwasher is off) (1).
20. If (extracurrent is mid) and (boilerswitch is off) then (boiler is off) (1).
21. If (extracurrent is mid) and (wmswitch is on) then (washing machine is on) (1).
22. If (extracurrent is max) and (wmswitch is on) then (washing machine is on) (1).
23. If (extracurrent is max) and (dishswitch is on) then (dishwasher is on) (1).
24. If (extracurrent is max) and (boilerswitch is on) then (boiler is on) (1).
25. If (extracurrent is max) and (pumpswitch is on) then (pump is on) (1).
26. If (extracurrent is max) and (pumpswitch is on) and (lowlevel is on) then (pump is on) (1).
27. If (extracurrent is max) and (wmswitch is on) and (dishswitch is off) and (wmstate is on) and (dishstate is off) then (washing machine is on) (dishwasher is off) (1).
28. If (extracurrent is max) and (wmswitch is off) and (dishswitch is on) and (wmstate is off) and (dishstate is on) then (washingmachine is off) (dishwasher is on) (1).
29. If (extracurrent is max) and (wmswitch is on) and (dishswitch is on) and (wmstate is on) and (dishstate is on) then (washingmachine is on) (dishwasher is on) (1).
30. If (extracurrent is max) and (pumpswitch is off) then (pump is off) (1).
31. If (extracurrent is max) and (boilerswitch is off) then (boiler is off) (1).
32. If (extracurrent is max) and (dishswitch is off) then (dishwasher is off) (1).
33. If (extracurrent is max) and (wmswitch is off) then (washing machine is off) (1).

34. If (extracurrent is max) and (wmswitch is on) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is on) and (wmstate is on) and (dishstate is on) and (lowlevel is on) then (washingmachine is on) (dishwasher is on) (boiler is off) (pump is on) (1).

35. If (extracurrent is max) and (wmswitch is on) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is on) and (wmstate is on) and (dishstate is on) and (lowlevel is off) then (washing machine is on) (dishwasher is on) (boiler is off) (pump is off) (1).

36. If (extracurrent is max) and (wmswitch is on) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is on) and (wmstate is off) and (dishstate is on) and (lowlevel is off) then (washing machine is on) (dishwasher is on) (boiler is off) (pump is off) (1).

37. If (extracurrent is max) and (wmswitch is on) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is on) and (wmstate is off) and (dishstate is on) and (lowlevel is on) then (washing machine is off) (dishwasher is on) (boiler is off) (pump is on) (1).

38. If (extracurrent is max) and (wmswitch is on) and (dishswitch is on) and (boilersiwtch is off) and (pumpswitch is on) and (wmstate is on) and (dishstate is on) and (lowlevel is on) then (washing machine is on) (dishwasher is on) (boiler is off) (pump is on) (1).

39. If (extracurrunt is max) and (wmswitch is on) and (dishswitch is on) and (biolerswitch is off) and (pumpswitch is on) and (wmstate is on) and (dishstate is on) and (low level is off) then (washing machine is on) (dishwasher is on) (boiler is off) (pump is off) (1).

40. If (extracurrunt is max) and (wmswitch is on) and (dishswitch is on) and (biolerswitch is off) and (pumpswitch is on) and (wmstate is off) and (dishstate is on) and (low level is off) then (washing machine is off) (dishwasher is off) (boiler is off) (pump is on) (1).

41. If (extracurrunt is max) and (wmswitch is on) and (dishswitch is on) and (biolerswitch is on) and (pumpswitch is on) and (wmstate is off) and (dishstate is off) and (lowlevel is off) then (washing machine is off) (dishwasher is off) (boiler is on) (pump is on) (1).

42. If (extracurrunt is max) and (wmswitch is on) and (dishswitch is on) and (biolerswitch is on) and (pumpswitch is on) and (wmstate is off) and (dishstate is off) and (lowlevel is on) then (washing machine is off) (dishwasher is off) (boiler is on) (pump is on) (1).

43. If (extracurrunt is max) and (wmswitch is on) and (dishswitch is on) and (biolerswitch is on) and (wmstate is off) and (dishstate is off) then (washing machine is off) (dishwasher is off) (boiler is on) (pump is off) (1).

44. If (extracurrunt is max) and (wmswitch is on) and (dishswitch is on) and (biolerswitch is on) and (wmstate is off) and (dishstate is on) then (washing machine is off) (dishwasher is on) (boiler is off) (pump is off) (1).

45. If (extracurrunt is max) and (wmswitch is on) and (dishswitch is on) and (biolerswitch is on) and (wmstate is off) and (dishstate is on) then (washing machine is off) (dishwasher is on) (boiler is off) (pump is off) (1).

46. If (extracurrunt is vmax) and (wmswitch is on) then (washing machine is on) (1).

47. If (extracurrunt is vmax) and (dishswitch is on) then (dishwasher is on) (1).

48. If (extracurrunt is vmax) and (biolerswitch is on) then (boiler is on) (1).

49. If (extracurrunt is vmax) and (pumpswitch is on) then (pump is on) (1).

50. If (extracurrunt is vmax) and (pumpswitch is on) and (lowlevel is on) then (pump is on) (1).

51. If (extracurrent is vmax) and (wmswitch is on) and (dishswitch is off) and (wmstate is on) and (dishstate is off) then (washing machine is on) (dishwasher is off) (1).

52. If (extracurrent is vmax) and (wmswitch is off) and (dishswitch is on) and (wmstate is off) and (dishstate is on) then (washingmachine is off) (dishwasher is on) (1).

53. If (extracurrent is vmax) and (wmswitch is on) and (dishswitch is on) and (wmstate is on) and (dishstate is on) then (washingmachine is on) (dishwasher is on) (1).

54. If (extracurrunt is vmax) and (wmswitch is on) and (dishswitch is on) and (biolerswitch is on) and (pumpswitch is on) and (wmstate is on) and (dishstate is on) and (lowlevel is on) then (washing machine is on) (dishwasher is on) (boiler is off) (pump is on) (1).

55. If (extracurrent is vmax) and (wmswitch is on) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is on) and (wmstate is on) and (dishstate is on) and (lowlevel is off) then (washingmachine is on) (dishwasher is on) (boiler is off) (pump is on) (1).

56. If (extracurrent is vmax) and (wmswitch is on) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is on) and (wmstate is off) and (dishstate is on) and (lowlevel is off) then (washingmachine is on) (dishwasher is on) (boiler is off) (pump is on) (1).

57. If (extracurrent is vmax) and (wmswitch is off) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is on) and (wmstate is on) and (dishstate is on) and (lowlevel is off) then (washingmachine is off) (dishwasher is on) (boiler is off) (pump is on) (1).

58. If (extracurrent is vmax) and (wmswitch is off) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is off) and (wmstate is off) and (dishstate is on) and (lowlevel is off) then (washingmachine is off) (dishwasher is on) (boiler is on) (pump is off) (1).

59. If (extracurrent is vmax) and (wmswitch is on) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is off) and (wmstate is off) and (dishstate is on) and (lowlevel is off) then (washingmachine is on) (dishwasher is on) (boiler is off) (pump is off) (1).

60. If (extracurrent is vmax) and (wmswitch is on) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is off) and (wmstate is off) and (dishstate is off) and (lowlevel is off) then (washingmachine is on) (dishwasher is off) (boiler is on) (pump is off) (1).

61. If (extracurrent is vmax) and (wmswitch is on) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is on) and (wmstate is off) and (dishstate is off) and (lowlevel is off) then (washingmachine is on) (dishwasher is off) (boiler is on) (pump is on) (1).

62. If (extracurrent is vmax) and (wmswitch is on) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is on) and (wmstate is off) and (dishstate is off) and (lowlevel is on) then (washingmachine is on) (dishwasher is off) (boiler is on) (pump is on) (1).

63. If (extracurrent is vmax) and (wmswitch is on) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is on) and (wmstate is off) and (dishstate is on) and (lowlevel is on) then (washingmachine is on) (dishwasher is on) (boiler is off) (pump is on) (1).

64. If (extracurrent is vmax) and (wmswitch is off) and (dishswitch is on) and (boilersiwtch is on) and (pumpswitch is on) and (wmstate is off) and (dishstate is on) and (lowlevel is on) then (washingmachine is off) (dishwasher is on) (boiler is off) (pump is on) (1).

Appendix E

Arduino Code

```
#include "fis_header.h"

#include <LiquidCrystal.h>

LiquidCrystal lcd(7,8,9,10,11,12);

const int fis_gcI = 8;

const int fis_gcO = 4;

const int fis_gcR = 64;

int wash =42;

int dish =43;

int boil =44;

int pump =45;

int pot=A1;

int pot1=A2;

int pot2=A3;

int val1=0;

int val2=0;

int val3=0;

int co;

int curt1, curt2;

FIS_TYPE g_fisInput[fis_gcI];

FIS_TYPE g_fisOutput[fis_gcO];
```

```
void setup ()
{
  Serial1.begin(9600);
 lcd.begin(16, 2);
lcd.clear();
    pinMode(22 , INPUT);//washing machine
    pinMode(23 , INPUT);//dishwasher
    pinMode(24 , INPUT);//boiler
    pinMode(25 , INPUT);//pump
    pinMode(26 , INPUT);//washing machine state
    pinMode(27 , INPUT);//dishwasher state
    pinMode(28 , INPUT);//low level pump
    pinMode(29 ,OUTPUT );
    pinMode(30 ,OUTPUT );
    pinMode(42 , OUTPUT);//washing machine
    pinMode(43 , OUTPUT);//dishwasher
    pinMode(44 , OUTPUT);//boiler
    pinMode(45 , OUTPUT);//pump

}
void loop()
{
val1= analogRead(pot);
```

```
val2= analogRead(pot1);
val3= analogRead(pot2);
curt1=val1/56;
curt2=val2/56;
co=curt1-curt2;
lcd.setCursor(0,0);
lcd.print("curent gener: ");
lcd.print(analogRead(pot)/56);
lcd.setCursor(0,1);
lcd.print("curent cons: ");
lcd.print(analogRead(pot1)/56);
Serial1.println(val3/17);
Serial1.println('c');
  // Read Input: extracurrent
  g_fisInput[0] = co;
  // Read Input: wmswitch
  g_fisInput[1] = digitalRead(22);
  // Read Input: dishswitch
  g_fisInput[2] = digitalRead(23);
  // Read Input: boilerswitch
  g_fisInput[3] = digitalRead(24);
  // Read Input: pumpswitch
  g_fisInput[4] = digitalRead(25);
```

```
    // Read Input: wmstate
    g_fisInput[5] = digitalRead(26);
    // Read Input: dishstate
    g_fisInput[6] = digitalRead(27);
    // Read Input: lowlevel
    g_fisInput[7] = digitalRead(28);
    g_fisOutput[0] = 0;
    g_fisOutput[1] = 0;
    g_fisOutput[2] = 0;
    g_fisOutput[3] = 0;
  if(val3<=425){
  digitalWrite(30,HIGH);}
  else if (val3>425){digitalWrite(30,LOW);}
   if(val3>425){digitalWrite(29,HIGH);}
    else if (val3<=425){digitalWrite(29,LOW);}
fis_evaluate();
if(g_fisOutput[0]>0.6){
digitalWrite(wash,HIGH);
}else if (g_fisOutput[0]<=0.6){digitalWrite(wash,LOW);
  }
if(g_fisOutput[1]>0.6){
  digitalWrite(dish,HIGH);
}else if(g_fisOutput[1]<=0.6) {digitalWrite(dish,LOW);
```

```
  }
  if(g_fisOutput[2]>0.6){
  digitalWrite(boil,HIGH);
}else if (g_fisOutput[2]<=0.6){digitalWrite(boil,LOW);
  }
if(g_fisOutput[3]>0.6){
  digitalWrite(pump,HIGH);
}else if (g_fisOutput[3]<=0.6){digitalWrite(pump,LOW);
  }
if (digitalRead(28)==1){
  digitalWrite(pump,HIGH);}
}
FIS_TYPE fis_trapmf(FIS_TYPE x, FIS_TYPE* p)
{
    FIS_TYPE a = p[0], b = p[1], c = p[2], d = p[3];
    FIS_TYPE t1 = ((x <= c) ? 1 : ((d < x) ? 0 : ((c != d) ? ((d - x) / (d - c)) : 0)));
    FIS_TYPE t2 = ((b <= x) ? 1 : ((x < a) ? 0 : ((a != b) ? ((x - a) / (b - a)) : 0)));
    return (FIS_TYPE) min(t1, t2);
}
FIS_TYPE fis_trimf(FIS_TYPE x, FIS_TYPE* p)
{
    FIS_TYPE a = p[0], b = p[1], c = p[2];
    FIS_TYPE t1 = (x - a) / (b - a);
```

```
    FIS_TYPE t2 = (c - x) / (c - b);
    if ((a == b) && (b == c)) return (FIS_TYPE) (x == a);
    if (a == b) return (FIS_TYPE) (t2*(b <= x)*(x <= c));
    if (b == c) return (FIS_TYPE) (t1*(a <= x)*(x <= b));
    t1 = min(t1, t2);
    return (FIS_TYPE) max(t1, 0);
}

FIS_TYPE fis_min(FIS_TYPE a, FIS_TYPE b)
{
    return min(a, b);
}

FIS_TYPE fis_max(FIS_TYPE a, FIS_TYPE b)
{
    return max(a, b);
}

FIS_TYPE fis_array_operation(FIS_TYPE *array, int size, _FIS_ARR_OP pfnOp)
{
    int i;
    FIS_TYPE ret = 0;
```

```
    if (size == 0) return ret;
    if (size == 1) return array[0];

    ret = array[0];
    for (i = 1; i < size; i++)
    {
        ret = (*pfnOp)(ret, array[i]);
    }

    return ret;
}
_FIS_MF fis_gMF[] =
{
    fis_trapmf, fis_trimf
};

int fis_gIMFCount[] = { 4, 2, 2, 2, 2, 2, 2, 2 };
int fis_gOMFCount[] = { 2, 2, 2, 2 };
FIS_TYPE fis_gMFI0Coeff1[] = { 0, 0, 5.25, 5.5 };
FIS_TYPE fis_gMFI0Coeff2[] = { 5.25, 5.5, 10, 10.25 };
FIS_TYPE fis_gMFI0Coeff3[] = { 10, 10.25, 13.25, 13.5 };
FIS_TYPE fis_gMFI0Coeff4[] = { 13.25, 13.5, 17, 17 };
```

```
FIS_TYPE* fis_gMFI0Coeff[] = { fis_gMFI0Coeff1, fis_gMFI0Coeff2, fis_gMFI0Coeff3, fis_gMFI0Coeff4 };

FIS_TYPE fis_gMFI1Coeff1[] = { 0, 0, 0.5 };

FIS_TYPE fis_gMFI1Coeff2[] = { 0.5, 1, 1 };

FIS_TYPE* fis_gMFI1Coeff[] = { fis_gMFI1Coeff1, fis_gMFI1Coeff2 };

FIS_TYPE fis_gMFI2Coeff1[] = { 0, 0, 0.5 };

FIS_TYPE fis_gMFI2Coeff2[] = { 0.5, 1, 1 };

FIS_TYPE* fis_gMFI2Coeff[] = { fis_gMFI2Coeff1, fis_gMFI2Coeff2 };

FIS_TYPE fis_gMFI3Coeff1[] = { 0, 0, 0.5 };

FIS_TYPE fis_gMFI3Coeff2[] = { 0.5, 1, 1 };

FIS_TYPE* fis_gMFI3Coeff[] = { fis_gMFI3Coeff1, fis_gMFI3Coeff2 };

FIS_TYPE fis_gMFI4Coeff1[] = { 0, 0, 0.5 };

FIS_TYPE fis_gMFI4Coeff2[] = { 0.5, 1, 1 };

FIS_TYPE* fis_gMFI4Coeff[] = { fis_gMFI4Coeff1, fis_gMFI4Coeff2 };

FIS_TYPE fis_gMFI5Coeff1[] = { 0, 0, 0.5 };

FIS_TYPE fis_gMFI5Coeff2[] = { 0.5, 1, 1 };

FIS_TYPE* fis_gMFI5Coeff[] = { fis_gMFI5Coeff1, fis_gMFI5Coeff2 };

FIS_TYPE fis_gMFI6Coeff1[] = { 0, 0, 0.5 };

FIS_TYPE fis_gMFI6Coeff2[] = { 0.5, 1, 1 };

FIS_TYPE* fis_gMFI6Coeff[] = { fis_gMFI6Coeff1, fis_gMFI6Coeff2 };

FIS_TYPE fis_gMFI7Coeff1[] = { 0, 0, 0.5 };

FIS_TYPE fis_gMFI7Coeff2[] = { 0.5, 1, 1 };

FIS_TYPE* fis_gMFI7Coeff[] = { fis_gMFI7Coeff1, fis_gMFI7Coeff2 };
```

```
FIS_TYPE** fis_gMFICoeff[] = { fis_gMFI0Coeff, fis_gMFI1Coeff, fis_gMFI2Coeff, fis_gMFI3Coeff, fis_gMFI4Coeff, fis_gMFI5Coeff, fis_gMFI6Coeff, fis_gMFI7Coeff };


// Coefficients for the Input Member Functions
FIS_TYPE fis_gMFO0Coeff1[] = { 0, 0, 0.5 };
FIS_TYPE fis_gMFO0Coeff2[] = { 0.5, 1, 1 };
FIS_TYPE* fis_gMFO0Coeff[] = { fis_gMFO0Coeff1, fis_gMFO0Coeff2 };
FIS_TYPE fis_gMFO1Coeff1[] = { 0, 0, 0.5 };
FIS_TYPE fis_gMFO1Coeff2[] = { 0.5, 1, 1 };
FIS_TYPE* fis_gMFO1Coeff[] = { fis_gMFO1Coeff1, fis_gMFO1Coeff2 };
FIS_TYPE fis_gMFO2Coeff1[] = { 0, 0, 0.5 };
FIS_TYPE fis_gMFO2Coeff2[] = { 0.5, 1, 1 };
FIS_TYPE* fis_gMFO2Coeff[] = { fis_gMFO2Coeff1, fis_gMFO2Coeff2 };
FIS_TYPE fis_gMFO3Coeff1[] = { 0, 0, 0.5 };
FIS_TYPE fis_gMFO3Coeff2[] = { 0.5, 1, 1 };
FIS_TYPE* fis_gMFO3Coeff[] = { fis_gMFO3Coeff1, fis_gMFO3Coeff2 };
FIS_TYPE** fis_gMFOCoeff[] = { fis_gMFO0Coeff, fis_gMFO1Coeff, fis_gMFO2Coeff, fis_gMFO3Coeff };


// Input membership function set
int fis_gMFI0[] = { 0, 0, 0, 0 };
int fis_gMFI1[] = { 1, 1 };
int fis_gMFI2[] = { 1, 1 };
```

```
int fis_gMFI3[] = { 1, 1 };

int fis_gMFI4[] = { 1, 1 };

int fis_gMFI5[] = { 1, 1 };

int fis_gMFI6[] = { 1, 1 };

int fis_gMFI7[] = { 1, 1 };

int* fis_gMFI[] = { fis_gMFI0, fis_gMFI1, fis_gMFI2, fis_gMFI3, fis_gMFI4, fis_gMFI5,
fis_gMFI6, fis_gMFI7};


// Output membership function set

int fis_gMFO0[] = { 1, 1 };

int fis_gMFO1[] = { 1, 1 };

int fis_gMFO2[] = { 1, 1 };

int fis_gMFO3[] = { 1, 1 };

int* fis_gMFO[] = { fis_gMFO0, fis_gMFO1, fis_gMFO2, fis_gMFO3};


// Rule Weights

FIS_TYPE fis_gRWeight[] = { 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
1 };


// Rule Type

int fis_gRType[] = { 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,
1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1 };
```

```
// Rule Inputs

int fis_gRI0[] = { 1, 0, 0, 0, 1, 0, 0, 0 };

int fis_gRI1[] = { 1, 1, 0, 0, 0, 0, 0, 0 };

int fis_gRI2[] = { 1, 0, 1, 0, 0, 0, 0, 0 };

int fis_gRI3[] = { 1, 0, 0, 2, 0, 0, 0, 0 };

int fis_gRI4[] = { 1, 0, 0, 0, 2, 0, 0, 0 };

int fis_gRI5[] = { 1, 2, 0, 0, 0, 2, 0, 0 };

int fis_gRI6[] = { 1, 0, 2, 0, 0, 0, 2, 0 };

int fis_gRI7[] = { 1, 0, 0, 0, 2, 0, 0, 2 };

int fis_gRI8[] = { 1, 2, 2, 0, 2, 2, 2, 1 };

int fis_gRI9[] = { 2, 0, 2, 0, 0, 0, 0, 0 };

int fis_gRI10[] = { 2, 0, 0, 2, 0, 0, 0, 0 };

int fis_gRI11[] = { 2, 0, 0, 0, 2, 0, 0, 0 };

int fis_gRI12[] = { 2, 2, 1, 0, 0, 2, 1, 0 };

int fis_gRI13[] = { 2, 1, 2, 0, 0, 1, 2, 0 };

int fis_gRI14[] = { 2, 0, 0, 0, 2, 0, 0, 2 };

int fis_gRI15[] = { 2, 2, 2, 0, 0, 2, 2, 0 };

int fis_gRI16[] = { 2, 1, 0, 0, 0, 0, 0, 0 };

int fis_gRI17[] = { 2, 0, 0, 0, 1, 0, 0, 0 };

int fis_gRI18[] = { 2, 0, 1, 0, 0, 0, 0, 0 };

int fis_gRI19[] = { 2, 0, 0, 1, 0, 0, 0, 0 };

int fis_gRI20[] = { 2, 2, 0, 0, 0, 0, 0, 0 };

int fis_gRI21[] = { 3, 2, 0, 0, 0, 0, 0, 0 };
```

```
int fis_gRI22[] = { 3, 0, 2, 0, 0, 0, 0, 0 };

int fis_gRI23[] = { 3, 0, 0, 2, 0, 0, 0, 0 };

int fis_gRI24[] = { 3, 0, 0, 0, 2, 0, 0, 0 };

int fis_gRI25[] = { 3, 0, 0, 0, 2, 0, 0, 2 };

int fis_gRI26[] = { 3, 2, 1, 0, 0, 2, 1, 0 };

int fis_gRI27[] = { 3, 1, 2, 0, 0, 1, 2, 0 };

int fis_gRI28[] = { 3, 2, 2, 0, 0, 2, 2, 0 };

int fis_gRI29[] = { 3, 0, 0, 0, 1, 0, 0, 0 };

int fis_gRI30[] = { 3, 0, 0, 1, 0, 0, 0, 0 };

int fis_gRI31[] = { 3, 0, 1, 0, 0, 0, 0, 0 };

int fis_gRI32[] = { 3, 1, 0, 0, 0, 0, 0, 0 };

int fis_gRI33[] = { 3, 2, 2, 2, 2, 2, 2, 2 };

int fis_gRI34[] = { 3, 2, 2, 2, 2, 2, 2, 1 };

int fis_gRI35[] = { 3, 2, 2, 2, 2, 1, 2, 1 };

int fis_gRI36[] = { 3, 2, 2, 2, 2, 1, 2, 2 };

int fis_gRI37[] = { 3, 2, 2, 1, 2, 2, 2, 2 };

int fis_gRI38[] = { 3, 2, 2, 1, 2, 2, 2, 1 };

int fis_gRI39[] = { 3, 2, 2, 1, 2, 1, 2, 1 };

int fis_gRI40[] = { 3, 2, 2, 2, 2, 1, 1, 1 };

int fis_gRI41[] = { 3, 2, 2, 2, 2, 1, 1, 2 };

int fis_gRI42[] = { 3, 2, 2, 2, 0, 1, 1, 0 };

int fis_gRI43[] = { 3, 2, 2, 2, 0, 1, 2, 0 };

int fis_gRI44[] = { 3, 1, 2, 2, 0, 1, 2, 0 };
```

```
int fis_gRI45[] = { 4, 2, 0, 0, 0, 0, 0, 0 };

int fis_gRI46[] = { 4, 0, 2, 0, 0, 0, 0, 0 };

int fis_gRI47[] = { 4, 0, 0, 2, 0, 0, 0, 0 };

int fis_gRI48[] = { 4, 0, 0, 0, 2, 0, 0, 0 };

int fis_gRI49[] = { 4, 0, 0, 0, 2, 0, 0, 2 };

int fis_gRI50[] = { 4, 2, 1, 0, 0, 2, 1, 0 };

int fis_gRI51[] = { 4, 1, 2, 0, 0, 1, 2, 0 };

int fis_gRI52[] = { 4, 2, 2, 0, 0, 2, 2, 0 };

int fis_gRI53[] = { 4, 2, 2, 2, 2, 2, 2, 2 };

int fis_gRI54[] = { 4, 2, 2, 2, 2, 2, 2, 1 };

int fis_gRI55[] = { 4, 2, 2, 2, 2, 1, 2, 1 };

int fis_gRI56[] = { 4, 1, 2, 2, 2, 1, 2, 1 };

int fis_gRI57[] = { 4, 1, 2, 2, 1, 1, 2, 1 };

int fis_gRI58[] = { 4, 2, 2, 2, 1, 1, 2, 1 };

int fis_gRI59[] = { 4, 2, 2, 2, 1, 1, 1, 1 };

int fis_gRI60[] = { 4, 2, 2, 2, 2, 1, 1, 1 };

int fis_gRI61[] = { 4, 2, 2, 2, 2, 1, 1, 2 };

int fis_gRI62[] = { 4, 2, 2, 2, 2, 1, 2, 2 };

int fis_gRI63[] = { 4, 1, 2, 2, 2, 1, 2, 2 };

int* fis_gRI[] = { fis_gRI0, fis_gRI1, fis_gRI2, fis_gRI3, fis_gRI4, fis_gRI5, fis_gRI6, fis_gRI7, fis_gRI8, fis_gRI9, fis_gRI10, fis_gRI11, fis_gRI12, fis_gRI13, fis_gRI14, fis_gRI15, fis_gRI16, fis_gRI17, fis_gRI18, fis_gRI19, fis_gRI20, fis_gRI21, fis_gRI22, fis_gRI23, fis_gRI24, fis_gRI25, fis_gRI26, fis_gRI27, fis_gRI28, fis_gRI29, fis_gRI30, fis_gRI31, fis_gRI32, fis_gRI33, fis_gRI34, fis_gRI35, fis_gRI36, fis_gRI37, fis_gRI38,
```

```
fis_gRI39, fis_gRI40, fis_gRI41, fis_gRI42, fis_gRI43, fis_gRI44, fis_gRI45, fis_gRI46,
fis_gRI47, fis_gRI48, fis_gRI49, fis_gRI50, fis_gRI51, fis_gRI52, fis_gRI53, fis_gRI54,
fis_gRI55, fis_gRI56, fis_gRI57, fis_gRI58, fis_gRI59, fis_gRI60, fis_gRI61, fis_gRI62,
fis_gRI63 };

// Rule Outputs
int fis_gRO0[] = { 0, 0, 0, 1 };
int fis_gRO1[] = { 1, 0, 0, 0 };
int fis_gRO2[] = { 0, 1, 0, 0 };
int fis_gRO3[] = { 0, 0, 1, 0 };
int fis_gRO4[] = { 0, 0, 0, 2 };
int fis_gRO5[] = { 2, 0, 0, 0 };
int fis_gRO6[] = { 0, 2, 0, 0 };
int fis_gRO7[] = { 0, 0, 0, 2 };
int fis_gRO8[] = { 2, 2, 0, 1 };
int fis_gRO9[] = { 0, 1, 0, 0 };
int fis_gRO10[] = { 0, 0, 1, 0 };
int fis_gRO11[] = { 0, 0, 0, 2 };
int fis_gRO12[] = { 2, 1, 0, 0 };
int fis_gRO13[] = { 1, 2, 0, 0 };
int fis_gRO14[] = { 0, 0, 0, 2 };
int fis_gRO15[] = { 2, 2, 0, 0 };
int fis_gRO16[] = { 1, 0, 0, 0 };
```

```
int fis_gRO17[] = { 0, 0, 0, 1 };

int fis_gRO18[] = { 0, 1, 0, 0 };

int fis_gRO19[] = { 0, 0, 1, 0 };

int fis_gRO20[] = { 2, 0, 0, 0 };

int fis_gRO21[] = { 2, 0, 0, 0 };

int fis_gRO22[] = { 0, 2, 0, 0 };

int fis_gRO23[] = { 0, 0, 2, 0 };

int fis_gRO24[] = { 0, 0, 0, 2 };

int fis_gRO25[] = { 0, 0, 0, 2 };

int fis_gRO26[] = { 2, 1, 0, 0 };

int fis_gRO27[] = { 1, 2, 0, 0 };

int fis_gRO28[] = { 2, 2, 0, 0 };

int fis_gRO29[] = { 0, 0, 0, 1 };

int fis_gRO30[] = { 0, 0, 1, 0 };

int fis_gRO31[] = { 0, 1, 0, 0 };

int fis_gRO32[] = { 1, 0, 0, 0 };

int fis_gRO33[] = { 2, 2, 1, 2 };

int fis_gRO34[] = { 2, 2, 1, 1 };

int fis_gRO35[] = { 2, 2, 1, 1 };

int fis_gRO36[] = { 1, 2, 1, 2 };

int fis_gRO37[] = { 2, 2, 1, 2 };

int fis_gRO38[] = { 2, 2, 1, 1 };

int fis_gRO39[] = { 1, 2, 1, 2 };
```

```
int fis_gRO40[] = { 1, 1, 2, 2 };

int fis_gRO41[] = { 1, 1, 2, 2 };

int fis_gRO42[] = { 1, 1, 2, 1 };

int fis_gRO43[] = { 1, 2, 1, 1 };

int fis_gRO44[] = { 1, 2, 1, 1 };

int fis_gRO45[] = { 2, 0, 0, 0 };

int fis_gRO46[] = { 0, 2, 0, 0 };

int fis_gRO47[] = { 0, 0, 2, 0 };

int fis_gRO48[] = { 0, 0, 0, 2 };

int fis_gRO49[] = { 0, 0, 0, 2 };

int fis_gRO50[] = { 2, 1, 0, 0 };

int fis_gRO51[] = { 1, 2, 0, 0 };

int fis_gRO52[] = { 2, 2, 0, 0 };

int fis_gRO53[] = { 2, 2, 1, 2 };

int fis_gRO54[] = { 2, 2, 1, 2 };

int fis_gRO55[] = { 2, 2, 1, 2 };

int fis_gRO56[] = { 1, 2, 1, 2 };

int fis_gRO57[] = { 1, 2, 2, 1 };

int fis_gRO58[] = { 2, 2, 1, 1 };

int fis_gRO59[] = { 2, 1, 2, 1 };

int fis_gRO60[] = { 2, 1, 2, 2 };

int fis_gRO61[] = { 2, 1, 2, 2 };

int fis_gRO62[] = { 2, 2, 1, 2 };
```

```
int fis_gRO63[] = { 1, 2, 1, 2 };

int* fis_gRO[] = { fis_gRO0, fis_gRO1, fis_gRO2, fis_gRO3, fis_gRO4, fis_gRO5, fis_gRO6, fis_gRO7, fis_gRO8, fis_gRO9, fis_gRO10, fis_gRO11, fis_gRO12, fis_gRO13, fis_gRO14, fis_gRO15, fis_gRO16, fis_gRO17, fis_gRO18, fis_gRO19, fis_gRO20, fis_gRO21, fis_gRO22, fis_gRO23, fis_gRO24, fis_gRO25, fis_gRO26, fis_gRO27, fis_gRO28, fis_gRO29, fis_gRO30, fis_gRO31, fis_gRO32, fis_gRO33, fis_gRO34, fis_gRO35, fis_gRO36, fis_gRO37, fis_gRO38, fis_gRO39, fis_gRO40, fis_gRO41, fis_gRO42, fis_gRO43, fis_gRO44, fis_gRO45, fis_gRO46, fis_gRO47, fis_gRO48, fis_gRO49, fis_gRO50, fis_gRO51, fis_gRO52, fis_gRO53, fis_gRO54, fis_gRO55, fis_gRO56, fis_gRO57, fis_gRO58, fis_gRO59, fis_gRO60, fis_gRO61, fis_gRO62, fis_gRO63 };


// Input range Min

FIS_TYPE fis_gIMin[] = { 0, 0, 0, 0, 0, 0, 0, 0 };


// Input range Max

FIS_TYPE fis_gIMax[] = { 17, 1, 1, 1, 1, 1, 1, 1 };


// Output range Min

FIS_TYPE fis_gOMin[] = { 0, 0, 0, 0 };

FIS_TYPE fis_gOMax[] = { 1, 1, 1, 1 };


FIS_TYPE fis_MF_out(FIS_TYPE** fuzzyRuleSet, FIS_TYPE x, int o)

{

   FIS_TYPE mfOut;

   int r;
```

```
    for (r = 0; r < fis_gcR; ++r)
    {
        int index = fis_gRO[r][o];
        if (index > 0)
        {
            index = index - 1;
            mfOut = (fis_gMF[fis_gMFO[o][index]])(x, fis_gMFOCoeff[o][index]);
        }
        else if (index < 0)
        {
            index = -index - 1;
            mfOut = 1 - (fis_gMF[fis_gMFO[o][index]])(x, fis_gMFOCoeff[o][index]);
        }
        else
        {
            mfOut = 0;
        }

        fuzzyRuleSet[0][r] = fis_min(mfOut, fuzzyRuleSet[1][r]);
    }
    return fis_array_operation(fuzzyRuleSet[0], fis_gcR, fis_max);
}
```

```
FIS_TYPE fis_defuzz_centroid(FIS_TYPE** fuzzyRuleSet, int o)
{
    FIS_TYPE step = (fis_gOMax[o] - fis_gOMin[o]) / (FIS_RESOLUSION - 1);
    FIS_TYPE area = 0;
    FIS_TYPE momentum = 0;
    FIS_TYPE dist, slice;
    int i;

    // calculate the area under the curve formed by the MF outputs
    for (i = 0; i < FIS_RESOLUSION; ++i){
        dist = fis_gOMin[o] + (step * i);
        slice = step * fis_MF_out(fuzzyRuleSet, dist, o);
        area += slice;
        momentum += slice*dist;
    }

    return ((area == 0) ? ((fis_gOMax[o] + fis_gOMin[o]) / 2) : (momentum / area));
}

void fis_evaluate()
{
    FIS_TYPE fuzzyInput0[] = { 0, 0, 0, 0 };
```

```
FIS_TYPE fuzzyInput1[] = { 0, 0 };

FIS_TYPE fuzzyInput2[] = { 0, 0 };

FIS_TYPE fuzzyInput3[] = { 0, 0 };

FIS_TYPE fuzzyInput4[] = { 0, 0 };

FIS_TYPE fuzzyInput5[] = { 0, 0 };

FIS_TYPE fuzzyInput6[] = { 0, 0 };

FIS_TYPE fuzzyInput7[] = { 0, 0 };

FIS_TYPE* fuzzyInput[fis_gcI] = { fuzzyInput0, fuzzyInput1, fuzzyInput2, fuzzyInput3, fuzzyInput4, fuzzyInput5, fuzzyInput6, fuzzyInput7, };

FIS_TYPE fuzzyOutput0[] = { 0, 0 };

FIS_TYPE fuzzyOutput1[] = { 0, 0 };

FIS_TYPE fuzzyOutput2[] = { 0, 0 };

FIS_TYPE fuzzyOutput3[] = { 0, 0 };

FIS_TYPE* fuzzyOutput[fis_gcO] = { fuzzyOutput0, fuzzyOutput1, fuzzyOutput2, fuzzyOutput3, };

FIS_TYPE fuzzyRules[fis_gcR] = { 0 };

FIS_TYPE fuzzyFires[fis_gcR] = { 0 };

FIS_TYPE* fuzzyRuleSet[] = { fuzzyRules, fuzzyFires };

FIS_TYPE sW = 0;


// Transforming input to fuzzy Input

int i, j, r, o;

for (i = 0; i < fis_gcI; ++i)
```

```
{
    for (j = 0; j < fis_gIMFCount[i]; ++j)
    {
        fuzzyInput[i][j] =
            (fis_gMF[fis_gMFI[i][j]])(g_fisInput[i], fis_gMFICoeff[i][j]);
    }
}

int index = 0;
for (r = 0; r < fis_gcR; ++r)
{
    if (fis_gRType[r] == 1)
    {
        fuzzyFires[r] = FIS_MAX;
        for (i = 0; i < fis_gcI; ++i)
        {
            index = fis_gRI[r][i];
            if (index > 0)
                fuzzyFires[r] = fis_min(fuzzyFires[r], fuzzyInput[i][index - 1]);
            else if (index < 0)
                fuzzyFires[r] = fis_min(fuzzyFires[r], 1 - fuzzyInput[i][-index - 1]);
            else
                fuzzyFires[r] = fis_min(fuzzyFires[r], 1);
```

```
        }
    }
    else
    {
        fuzzyFires[r] = FIS_MIN;
        for (i = 0; i < fis_gcI; ++i)
        {
            index = fis_gRI[r][i];
            if (index > 0)
                fuzzyFires[r] = fis_max(fuzzyFires[r], fuzzyInput[i][index - 1]);
            else if (index < 0)
                fuzzyFires[r] = fis_max(fuzzyFires[r], 1 - fuzzyInput[i][-index - 1]);
            else
                fuzzyFires[r] = fis_max(fuzzyFires[r], 0);
        }
    }

    fuzzyFires[r] = fis_gRWeight[r] * fuzzyFires[r];
    sW += fuzzyFires[r];
}

if (sW == 0)
{
```

```
        for (o = 0; o < fis_gcO; ++o)
        {
            g_fisOutput[o] = ((fis_gOMax[o] + fis_gOMin[o]) / 2);
        }
    }
    else
    {
        for (o = 0; o < fis_gcO; ++o)
        {
            g_fisOutput[o] = fis_defuzz_centroid(fuzzyRuleSet, o);
        }
    }
}
```

Bibliography

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