بسم الله الرحمن الرحيم

جامعة بوليتكنك فلسطين

Hybrid system for electrical generation and wastewater treatment using Photovoltaic and Fuel Cells

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Abstract

Water and energy security continue to be primary threats to our lifestyle. The need of alternate eco-friendly fuel to generate electricity and recycle wastewater is increasing rapidly with the depletion of non-renewable electrical energy resources and scarcity of water. This study represents the importance and the necessity of increasing the efficiency of clean processes that treat the wastewater. Furthermore, generating electricity by environmental methods and focusing on solutions for remote areas that suffer from limited electrical and sewage networks were presented in a modern technique of treatment and generation the power. This study provides a power management and generation strategy for solar and fuel cells system for houses in Hebron City with a simulation of the system. The design was developed to meet total electrical load demand without need of grid connection. The models of simulation facilitate more understanding of the system. Thus the electrical components of the system, like photovoltaic panel, PEM fuel cell, electrolyzer, control management of hybrid system are modeled as a Simulink blocks by using matlab simulation program. The simulation show performance of electrical devices and load during the day. Also show the amount of hydrogen produce and consume during the 24 hours. A prototype design of MFC is applied. However, double chambered Microbial Fuel Cells (MFC) prototype in batch and semi-batch conditions was used to treat the house greywater and to generate some electricity. Chemical oxygen demand removal efficiency achieved in batch and semi-batch was 45.29%, 55.37% respectively and 61%, 75% for dissolved solids removal. The performance of the MFC decreased, when the wastewater concentration was decreased. Thus, MFC can provide cleared water and the maximum current obtained from grey wastewater was 0.73mA. Then this water can be electrolyzed by excess power from PV panels into Hydrogen and Oxygen. Hydrogen will be used to generate the electricity by Fuel cell. Thus the recycling water cover the demand of water by electrolyzer, also feed water for irrigation around the home.

الإهداء

إلى العظيمة التي أفنت حياتها من أجلنا . . إلى من مهدت طريقنا لنصل إلى ما نحن عليه الآن . . إلى من ترى نجاحها بنجاحنا

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إلى الذين وهبونا الحياة والأمل والنشأة على شغف الاطلاع والمعرفة

إلى إخوتنا وأخواتنا . . . أنتم القناديل المضيئة في ليالينا

إلى الرجل الذي وهبني حياته، وشدّ على يدي وأنا أحبو أول خطوة لي في حياتي ،

إلى الرجل الذي كان يرى بي دوماً ما لا يراه أحد . وينتشلني كلما سقطت لأعود من جديد . . .

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إلى مصدر قوتي و ملهمي ، للرجل الذي عانا وتحمل شقاء وتعب الأيام ليعطيني كل ما أحتاجه ، ، للذي لولاه بعد فضل الله ما صرت هنا ، ، فها أنا ابنتك وصلت لما أردت ان أكون منذ صغري ، ، إليك والدي الحبيب

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نهدي هذا العمل . . . والله وليّ التوفيق.

الشكر

أعوامٌ قد قضيناها وسرنا بها خطوة بخطوة، أشخاصٌ كانوا معنا ولا زالوا . شجعونا بحبٍّ و أمل ، أعادونا للصواب كلّما حدنا عنه وكانوا هم القدوة المختارة ، و الإلهام المقدّم .

واليوم ونحن نخطو خطواتنا قبل الأخيرة في حياتنا الجامعية نتقدم لهم بما في الكون من كلمات شكرٍ وتقدير، و لهفات حبٍّ و عرفان .

فأرقّ الشكر بدايةً لجامعتنا التي احتضنتنا دوماً . التي رسمت لنا خطوات الحياة و أساس كل علم، فمنها كان الإبداع .

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List of Abbreviations

AC: Alternating Current

AF: Air Flow

AM: After Midday

BEAMR: Bio-Electrochemically Assisted Microbial Reactor

BOD: Biological Oxygen Demand

COD: Chemical Oxygen Demand

DC: Direct Current

DHI: Diffuse Horizontal Irradiance

DNI: Direct Normal Irradiance

EC: Electrical Conductivity

GHI: Global Horizontal Irradiation

GMR*: Geobacter- metallireducens bacteria*

GSR: Geobacter-Sulfurreducens Bacteria

GW: Gigawatts

GWhs: Gigawatt Hours

L/p/d: Litter Per Capita Per Day

LISF: Low Income Single Family

µA: Micro-Ampere

MFC: Microbial Fuel Cell

ML-MFC: Mediator Less And Membrane Less Microbial Fuel Cell

MPPT: Maximum Power Point Tracking

NiMH: Nickel Metal Hydride

NOCT: Nominal Operating Cell Temperature

PEA: Palestinian Energy Authority

P_{el}: Rated Power Of The Electrolyzer.

PEM: Proton Exchange Membrane

$P_{L,min:}$ Minimum Of The Clinic Load.

PM: Before Midday

PMS: Power Management Strategy

P_{PV}: Output Power Of PV Modules.

PV: Photo Voltaic

Q: Flow

Redox: Reduction Oxidation Reaction

RFR: *Rhodoferax-ferrireducens bacteria*

SCMFC: Single Chamber Microbial Fuel Cell

SF: Single Family

SOFC: Solid-Oxide Fuel Cell

SS: Suspended Solids

TDS: Total Dissolved Solid

TKN: Total Kjehldahl Nitrogen

TSS: Total Suspended Solid

UPS: Uninterrupted Power Supplies

Chapter One

Introduction

1.1 Introduction

The problems of fossil-fuel depletion, environmental pollution, water shortage and security demand of energy and related services, to meet social and economic development and improve human welfare and health are tending intensive efforts towards more sustainable technologies whether in wastewater treatment or energy service.

Global warming, fuel sources depletion and pollution of water, lead to search about a suitable ways to treat wastewater and generate energy by using renewable sources that is described as clean and environmentally friendly, and exploit the consuming products to recycle by environmentally friendly ways, to obtain our needs of energy and water without the aggravation of previous problems.

Hybrid system is generally the best way. This project aims to design a prototype of MFC and simulation a hybrid system of (PV with fuel cell). In this system, treating the wastewater can lead to recycle the water and generate electricity, in order to achieve the house needs of energy and recycle its wastewater.

1.2 Project Overview

The sun is the main source of energy on earth. Most of the energy we use has undergone several transformations before it is finally applied. Mainly at specific areas such as the Mediterranean have high solar insulation (the total energy per unit area received from the sun).

Photovoltaic (PV) or solar cells refers to the creation of voltage from light. A solar cell is a converter which transforms the light energy into electrical energy. A cell does not store any energy, so when the source of light (typically the sun) is removed, electrical current stopped. If electricity is needed in the night, a storage device batteries or (electrolyser complement by fuel cell as way that use in this project) must be included in the circuit. There are many materials that can be used to make solar cells, but the most common one is the silicon element. The conversion operations occur immediately at any time there is light falling on the surface of a cell, and the output of the cell is proportional to the input light.

There is a need to store excess energy during the day to meet the needs load of energy during the full day. The most popular storage solution uses battery arrays, but they are expensive to install, require the maintenance, suffer from self-discharge, have toxic substances inside and have a limited life cycle, so we use another solution of environmental storage by using fuel cell.

At the beginning of the 21st century, fuel cells appear poised to meet the power needs of a variety of applications. Fuel cells are a mean of converting a fuel to electrical energy using an electrochemical membrane. The most popular to date has been the proton exchange hydrogen fuel cell. It takes two molecules of hydrogen and one molecule of oxygen and produces two molecules of water leaving behind four spare electrons to generate an electrical current. In terms of the energy value of the hydrogen, the theoretically conversion process is around 83% efficient. Fuel cell systems are available to meet the needs of applications ranging from portable electronics to utility power plants.

Whereas we must have a source of hydrogen, PV provides electricity to the load, and the excess of energy used to produce hydrogen using the electrolyser which split the solution to its atoms to store hydrogen in a tank and this hydrogen is used by fuel cell units to produce energy in the absence of solar energy.

The desire to recover clean water, energy and useful resources all over the world is increasing strongly today, taking into account the need of source of water in this project, and because wastewater treatment is energy intensive and require high investment and operating cost, the project aims to recycle house greywater and use it as a source of fuel in microbial fuel cell technique.Wastewater treatment has traditionally been an energy intensive process, consuming between 950 and 2850 kJ/m^3 of wastewater treated[1].

A microbial fuel cell (MFC) is a bio-electrochemical device that mainly consist of anode , cathode, proton exchange membrane and external circuit , the anode host bacteria and organic material which is anaerobic, while the cathode host conductive salt water solution, it has the ability to convert organic substrates directly into electrical energy. Microbial fuel cell technology can use bacterium already present in wastewater as catalysts to generate electricity while simultaneously treating wastewater. The process summarize as bacteria create proton and electron(oxidation), the electron put out of solution and the electrode conduct through the external circuit, the proton travel through the proton exchange membrane or a salt bridge to make the electrons at the cathodes .

Greywater is the wastewater that is generated from homes and commercial buildings through the use of water for laundry, dishes, or for bathing. Greywater differs from black water which is wastewater used in toilets and designated for sewage systems. After recycling greywater, it can be used for a variety of purposes such as irrigation or toilet flushing.

In summary, Although the main source of energy is sunlight that found naturally during day, PV system could generate DC power, and it is convert by using inverter to AC to feeding a load. On other side, the greywater coming out of the house wastewater will be treated using microbial fuel cell technology, and it is characterize by generating some of additional power. We store the over flow energy through day to use it at the absence of sunlight, a traditional way to store it is by lithium-ion or lead-acid batteries but they are expensive, have short life time and toxic substances inside. So we use environmentally friendly way by using electrolyzer to separate water molecules from the water, which treated by microbial fuel cell to get pure hydrogen and store it in the tank. Then, at afternoon, we can use the storage hydrogen to generate DC power by PEM fuel cell. The result is we will have the ability to feed the house of energy all time of day. The importance of the theoretical study is study the behavior of hybrid system.

1.3 Problem Statement

1.3.1 Project main question

This project is intend to demonstrate the creation of an environmentally friendly form of energy production and wastewater treatment.

This research project answered this question:

Can hybrid system of solar-PEM fuel cell with treatment home's wastewater by microbial fuel cell, be used to generate enough energy to home which is separated from the grid?

1.3.2 Project sub questions

1. How can MFCs aid in wastewater treatment ?

2. How many power values PV, PEM fuel cell, electrolyzer panels needed to feed our case in the system ?
3. What are the challenges faced the system?
4. What is the relationship between wastewater concentration and treatment efficiency ?
5. How can use mathematical equations of photovoltaic panel, PEM fuel cell, electrolyzer use to build modeling as a simulation blocks by matlab program?

1.4 Aim of Project

The current project aims to provide energy to domestic areas using green method which reduces the pollutants emissions produced by traditional energy production technologies, for example, coal and gas. In addition, this project reduces the water pollutants by supplying the system by treated water.

1.5 Objectives

The project targets the following specific objectives:

1. To design a hybrid system of PV with fuel cells to treat wastewater and generate electricity.
2. To determine the efficiency of designed prototype and test generated water quality.
3. Evaluate the possibilities of MFCs application in wastewater treatment technologies and generate an electricity.
4. To develop a simulation model for system and evaluate it .
5. To determine the optimum condition for running MFC .

1.6 Significance of Study

The importance of this study comes from the society increasingly awareness that wastewater could be a source of energy rather than waste. Moreover, the large number of people who lives in areas that are not yet connected to utility lines (Electricity or water), led to shift in the ways of handling with wastewater and energy resource recovering technologies. Hence, that it is the first time of this hybrid system implementation in Palestine.

1.7 Construction of the thesis

The thesis consists of the five chapters :

Chapter 1 Chapter 1 Provides an introduction to the hybrid system of the Photovoltaic and Fuel Cells , the project objectives and the significant of this study .

Chapter 2 Include a literature review for each part in this project , such as Photovoltaic , PEMFC, electrolyser , MFC and greywater .

Chapter 3 Describe the project block diagram with load profile and design for electrical and water consumption with sizing the system .

Chapter 4 In this part of project the electrical components of the system, like photovoltaic panel, PEM fuel cell, electrolyzer, control management of hybrid system are modeled as a Simulink blocks by using matlab simulation program.

Chapter 5 Design and experimental results conducted in the laboratory and analysis foe batch and semi batch conditions in the prototype .

1.8 Budget

The total estimated cost for implementing this project is estimated at 101$ as detailed in Table (1.1) below.

Table 1. 1 The total estimated cost for implementing the project.

Number	Item	Quantity	Total Cost
1	Cell Electrodes	12	8$
2	Silicon	2	8$
3	Pump	1	$5
4	Tank	4	10$
5	Salt bridge membrane	1	7 $
6	Cables	4m	8 $

7	Pipes	5m	15$
8	Paraffin	100 ml	20 $
9	Stand with valves	1	20$

1.9 Plan of Action

The action plan for this study during the first semester is shown in Table 1.2, and the action plan for the next semester was shown in Table 1.3.

Table 1. 2 Plan of action for first semester.

Date **Task**	1st Month				2nd Month				3rd Month				4th Month			
	Wk$_1$	Wk$_2$	Wk$_3$	Wk$_4$	Wk$_1$	Wk$_2$	Wk$_3$	Wk$_4$	Wk$_1$	Wk$_2$	Wk$_3$	Wk$_4$	Wk$_1$	Wk$_2$	Wk$_3$	Wk$_4$
Identification of Project Idea	■	■														
Literature Review			■	■	■	■	■	■								
Data collection					■	■	■	■	■	■	■	■				
Data Analysis							■	■	■	■	■	■	■	■		
Building MFC prototype of Design							■	■	■	■	■					
setup project design											■	■	■	■		
Documentation						■	■	■	■	■	■	■	■	■	■	
Presentation of First Semester																■

Table 1. 3 Plan of action for the next semester.

TASKS	1st Month				2nd Month				3rd Month				4th Month			
	Wk$_1$	Wk$_2$	Wk$_3$	Wk$_4$	Wk$_1$	Wk$_2$	Wk$_3$	Wk$_4$	Wk$_1$	Wk$_2$	Wk$_3$	Wk$_4$	Wk$_1$	Wk$_2$	Wk$_3$	Wk$_4$
Simulation of Hybrid system				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
Experimental investigation				🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
Data analysis							🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
Obtaining final results							🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
Documentation						🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
Presentation of second Semester															🟦	🟦

Chapter Two

Literature Review

2.1 Introduction

Using MFC in treatment wastewater and hybrid system of PV and PEM fuel cell with electrolyser has been studied by several researchers in the literature review, in which they provide the relevant information related to the technology and will give the reader an understanding of the design, function, important and potential use.

The global warming problem due to increasing of greenhouse gases, such as carbon dioxide emissions from burning fossil fuels or from deforestation, and the limitations of global resources of clean water, fossil and nuclear fuel has required an instant search to reduce pollutant emissions and utilize the world's available energy and water resources more efficiently which has led to increase more attention towards alternative environmental friendly solutions for clean energy and water resources. It is also important to find alternative sources which can make substantial cuts in these emissions in the near term. In order to further understand and evaluate the prerequisites for sustainable and energy, water saving systems to meet the continuously increasing demand of power supply and water resources [2, 3].

Water scarcity already affects every continent, almost one-fifth of the world's population lives in areas of physical scarcity, and 500 million people are approaching this situation. Another one quarter of the world's population, faces economic water shortage. While there remains 18% of the world's population without access to electricity. However, traditional grid connection is not a practical or economic solution for a substantial proportion of rural population, the off grid home system attractive is the way forward for rural electrification [4, 5].

The models of simulation facilitate more understanding of the system whereas does not need to perform experimental tests. Based on the amount of information available on system can build generic models able to emulate the behavior of any system. Simulation model of PV, PEM fuel cell, electrolyzer was realized in the Matlab-Simulink environment.

A possible solution for stand-alone power generation is to use a hybrid energy system in parallel with new technologies, such as hydrogen technology for storage energy. Renewable energy sources (solar, wind, hydrogen, etc.) are attracting more attention as alternative sources to traditional fuel. The microbial fuel cell technology represent a new form of renewable energy, which transform the organic matter into electricity while treating the wastewater. Most of people live in villages that are not yet connected to utility lines. These villages are the largest potential market for stand-alone hybrid systems for meeting their energy needs [2, 3, 6].

2.2 Photo voltaic (PV) system

The most popular usage of renewable source is Photovoltaic; PV uses the chemical-electrical interaction between light radiation and a semiconductor to obtain DC electricity. PV power generation systems are considered a proper solution for small applications in sunny areas and are among the most promising renewable energy technology solutions. Power generation from solar PV has long been seen as a clean sustainable energy technology that uses upon the planets. The most plentiful and widely distributed renewable energy source is the sun.

The amount of energy that can be produce is directly dependent on the sunshine intensity. Thus, as with many other renewable energy technologies, PV has a seasonal fluctuation in electricity production with the peak in summer. Fluctuation of weather conditions, including clouds and rainfall, effect on the amount of electricity that can be acquired. Although PV devices can operate along all seasons, whereas PV is capable of producing electricity even these weather conditions albeit at a reduced rate. Also During the day, electricity production varies from dawn to dusk peaking during midday, PV provides electricity to the load and the excess of energy feeds storage system [7].

PV system has many strength points, including the high reliability and long lifetimes (power output warranties from PV panels now commonly for 25 years), automatic operation with very low maintenance requirements, no fuel required (no additional costs for fuel), range of system sizes as application dictates, environmental impact low compared with conventional energy sources, the user is less affected by rising prices for other energy sources, and the solar system is an easily visible sign of a high level of responsibility, environmental awareness and commitment.

On the other hand, it has some weaknesses, such as its performance depends on sunshine levels and local weather conditions, Storage/back-up usually required due to fluctuating nature of sunshine levels or no power production at night, high capital investment costs, and use of toxic materials in some PV panels.

However, PV power generation systems are still among the most promising renewable energy technology solutions especially for small-scale generation of electricity in off grid remote rural areas, as compared with other renewable technologies, which often operate at large systems to achieve high efficiency. PV modules have many types like Mono-crystalline silicon, Poly-crystalline silicon cells, thin film solar cells and multiple junction cells. At PV system, it is hoped further improvements in efficiencies and technologies will bring the cost down over the next 5 to 10 years, though for several markets, PV is already competitive, in particular for small-scale generation of electricity in off grid remote rural areas [8].

2.3 Storage system

One of the main problems in electrical systems, are energy storage process. Grid independent electric power systems using renewable power sources (such as solar, wind, and hydrogen technology) generate intermittently variable power that is nature of renewable generation. Such systems typically like solar system require both a large energy storage capacity and a backup generator because the sun is not always able to totally cover energy demand. There are a few options currently available for storage of electricity which generate by PV system [9, 10].

2.3.1 Battery

The most popular storage solution uses battery arrays. These are generally suited as small scale localized back up, such as for uninterrupted power supplies (UPS) for key installations or delicate equipment such as hospitals or computer servers. Large arrays of nickel metal hydride (NiMH) batteries have been used for grid backup for isolated communities. Practical choices for continuous feeding of power is a deep-cycle lead acid batteries for storage plus an engine generator. While batteries can achieve high energy storage efficiencies near 80%, the battery/generator combination is quite expensive (first cost plus maintenance costs).

In addition, current generators using internal combustion technology are highly polluting, noisy, and have low fuel efficiencies. However, these are expensive to install, require the maintenance and monitoring of many cells, they can also suffer from self-discharge, have toxic substances inside and a limited cycle life [9].

2.3.2 Fuel cell

Another storage solution uses fuel cells. The basic principle of the fuel cell is convert chemical energy into electrical and thermal energy. Fuel cells produce electricity from an electrochemical reaction between hydrogen and oxygen. It is classified as power generator because it can operate continuously, if fuel and oxidant are supplied. Promising applications for fuel cells include portable power, transportation, building cogeneration, and distributed power for utilities. For portable power, a fuel cell coupled with a fuel container can offer a higher energy storage density and more convenience than conventional battery systems. A fuel cell system includes a fuel processor and subsystems to manage air, water, thermal energy and power. Fuel Cell saves fuel and it is efficient, cleaner for the environment and reliable for power production. Whereas it can generate electricity from clean sources to power loads located in inaccessible or remote areas [11, 12].

In this case, we should find a source of feeding Hydrogen to fuel cell, and that is by using electrolyser, one of the chief advantages of electrolysis is its ability to apply at a great range of scales. One of uses in off-grid or localized power generation, where it is a key component to enable smart, secure and flexible distributed energy systems that include renewables such as solar and wind power. However, these sources provide a variable output, which is difficult for the electricity grid to accept while maintaining its stability, and this places a real and fundamental limit on how much of this energy can currently be incorporate into the supply. This limit can be circumvent if the renewable energy can be stored at times of excess generation energy.

In many cases electrolysis can be the crucial missing link, electrolysis uses an electric current to split water into hydrogen and oxygen gases. Using clean electricity to drive water electrolysis and produce hydrogen in large quantities as an energy storage. In fact, it is one of the most viable options available to us for large scale renewable energy storage.

Hydrogen can be produce by electrolysis driven by either distributed renewables or grid electricity and then stored. From there, it can used as fuel to cover demand electricity or combined heat and power generation, or it be used in other ways as a vehicle fuel, or supplied to industry [13].

Hydrogen produced via electrolysis by passing electricity through two electrodes in water. The water molecule was split and produces oxygen gas at the anode and hydrogen gas at the cathode via the following reaction: $H_2O \rightarrow \frac{1}{2} O_2 + H_2$.

The electrolyser stack uses DC electricity, so feeding it by the PV array which also produces DC is better than use grid which is AC electricity, because the converting from Ac to Dc by rectifier get losses of energy. Using direct PV to electrolysis leads to eliminate some of power electronics and could make electrolysis system economical. PV provides electricity to the load or the excess of energy produce hydrogen by the electrolyser. This hydrogen is used by Fuel cell units to produce energy in absence of solar energy (night for example) [14, 15].

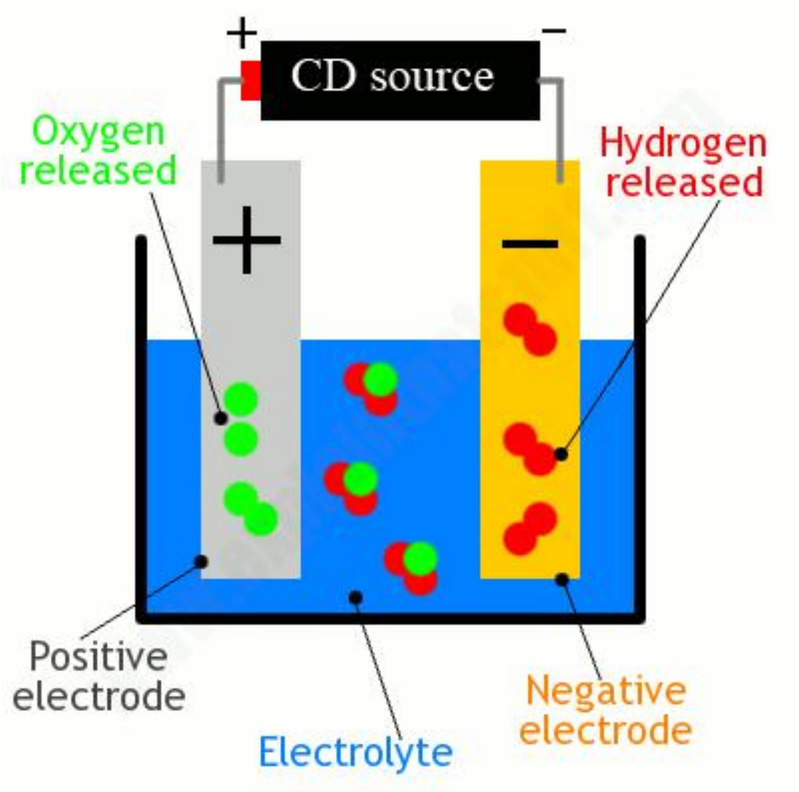

Figure 2. 1: Basic configuration of an electrolyzer**[16].**

The various fuel types also try to play to the strengths of fuel cells in different ways. The proton exchange membrane (PEM) fuel cell capitalizes on the essential simplicity of the fuel cell. The electrolyte is a solid polymer in which protons are moveable.

These cells run at quite low temperatures, so the problem of slow reaction rates is addressed by using sophisticated catalysts and electrodes, so platinum is used as catalyst, the problem of hydrogen supply is addressed, pure hydrogen must be used.

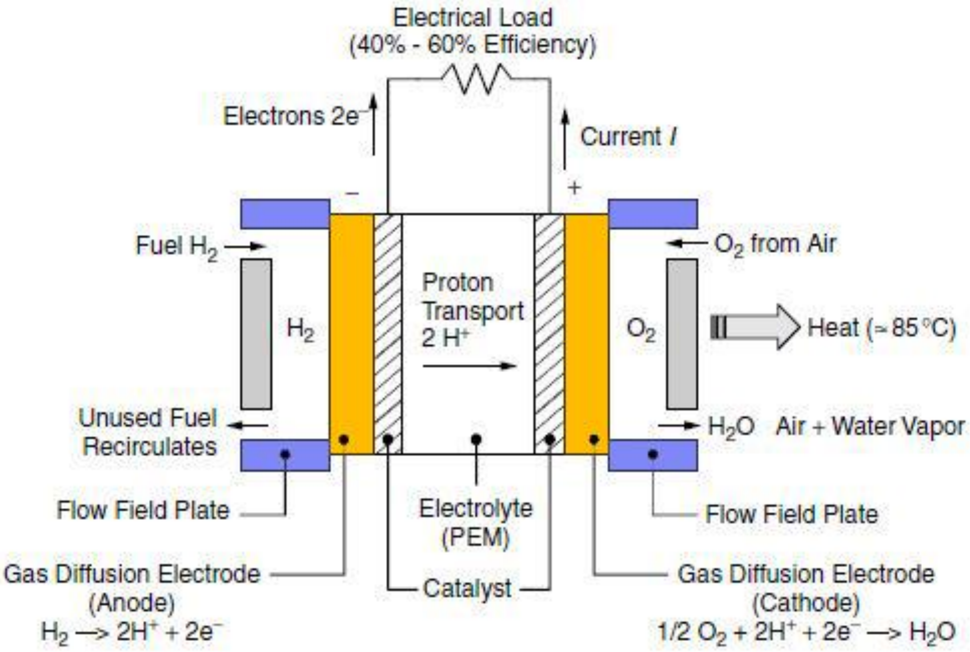

Figure2. 2:Configuration of a proton-exchange membrane (PEM) fuel cell [17].

The fuel cell shown in Fig.2.1.is described by the following pair of half-cell reactions:

Anode: $H_2 \rightarrow 2H^+ + 2e^-$ (2.2)

Cathode: $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$ (2.3)

When combined equations (2.2) and (2.3) result in the same equation that we would write for ordinary combustion of hydrogen: $H_2 + \frac{1}{2} O2 \rightarrow H_2O$ (2.4)

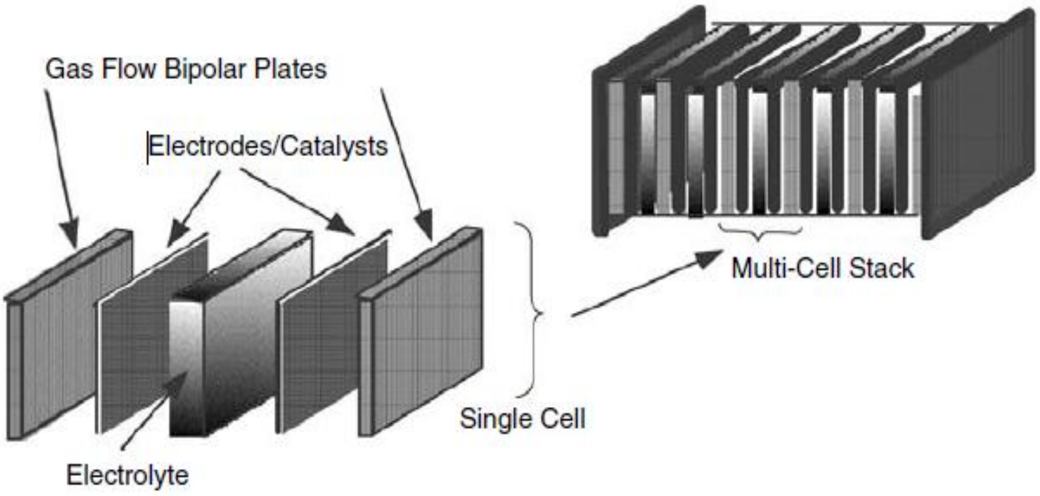

Figure2. 3:Multicell stack made up of multiple cells increases the voltage [17].

In fact, the membranes used in PEM fuel cells can be use in low temperature electrolyzers. Similarly, solid-oxide electrolytes can be use for high temperature electrolysis.

A sketch of an electrolysis cell that uses a proton exchange membrane is shown in Fig.2.3. Water introduced into the oxygen side of the cell dissociates into protons, electrons and oxygen. The oxygen is liberated, the protons pass through the membrane, and the electrons take the external path through the power source to reach the cathode where they reunite with protons to form hydrogen gas.

Overall efficiency can be as high as 85%. Hydrogen produced by electrolysis has the advantage of being highly purified. When the electricity for electrolysis is generate using a renewable energy system, such as wind, hydro, or photovoltaic power, hydrogen is produced without emission of any greenhouse gases.

When the resulting hydrogen is subsequently converted back to electricity using fuel cells, the ultimate goals of carbon-free electricity, available whenever it is needed, whether or not the sun is shining or the wind is blowing, without depleting scarce nonrenewable resources, can become an achievable reality.

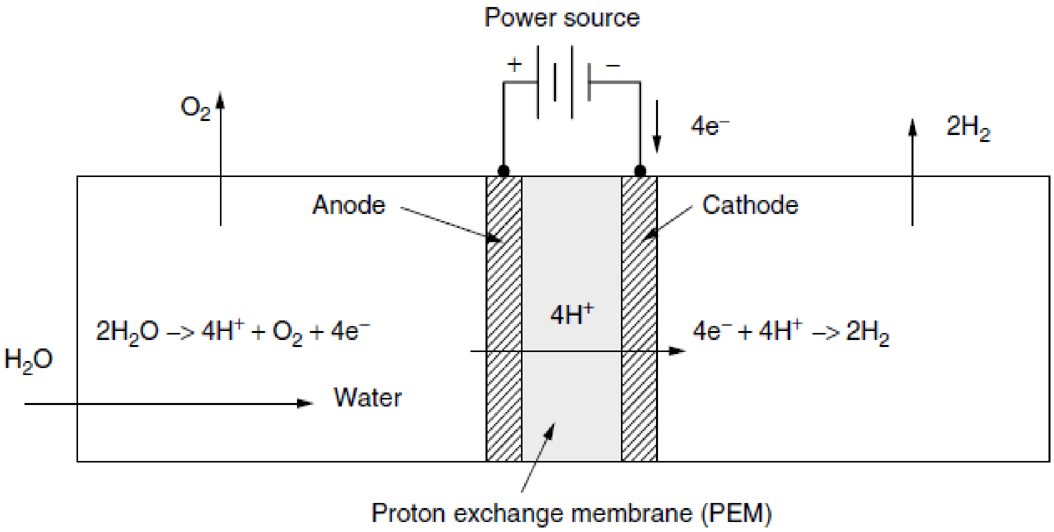

Figure2.4:A proton exchange membrane used to electrolyze water [17].

Another solution of storage energy using a reversible solid-oxide fuel cell (SOFC)/electrolyzer system which able to store electrical energy that generated from renewable sources (e.g. solar or wind energy) by producing hydrogen at projected round-trip efficiencies over 80% and it is providing backup power generated from propane at efficiencies over 60%. According to the cost which is the major barrier to the practical use of systems in this type, there is currently many experiments and researches focused on this technology and to make total system capital and operating costs are be lower than an equivalent lead-acid battery with a backup generator system [10].

2.4 Treatment of Greywater

Palestine is actually very rich in water resources, but Israeli violations of the human right to water and sanitation are preventing Palestinians from having sufficient access to clean water and adequate sanitation, Household water consumption of Palestinians connected to a network is less than half the World Health Organization’s minimum recommended daily allowance and 1/6 of Israeli occupation household consumption, the Average net consumption at the household level after losses from the network was 50 liters per person per day [18].

2.4.1 Greywater -definitions and characteristics:

2.4.1.1 Definitions

Greywater is wastewater from kitchen contains food residues, high amount of oil and fat. It is high in nutrient and suspended solid, dishwasher greywater may be very alkaline show high SS and salt concentration. Baths is regarded as the least contaminated greywater source within a household, it may thus be contaminated with pathogenic microorganisms, showers, hand basins, washing machines, dishwashers and laundries which contain high concentrations of chemical from soap powders such as Na, P, N_2 as well as bleaches, SS and possibly oils, paints and non-biodegradable fibers from clothing.

The greywater management including wastewater from bath, laundry and kitchen but excluding toilet wastewater is important, especially where inadequate wastewater management has a detrimental impact on public health and the environment. Although, greywater is less polluted than industrial wastewater, it still contain very high levels of pathogenic microorganisms, which cause diseases, suspended solids like soap, oil and detergents. Greywater composition and volume are both differ according to climate, social status and cultural habits [19].

Greywater can treated using varies traditionally ways, a MFC is a new technology used to both treat wastewater and generate electricity. A common greywater treatment technologies with exclusive description, Pros and Cons of them was describe in the table below:

Table 2. 1 Common greywater treatment technologies[3].

Treatment Technology	Description	Pros	Cons
Disinfection	Chlorine, ozone, or ultraviolet light can all be used to disinfect greywater.	Highly effective in killing bacteria. Operated low operator skill requirement.	Chlorine and ozone can create toxic byproducts.

Activated carbon filter	It used to remove organic compounds and/or extracting free chlorine from water .These filters are widely used to adsorb odorous or colored substances from gases or liquids.	Simple operation, activated carbon is particularly good at trapping organic chemicals, as well as inorganic compounds like chlorine.	High capital cost, many other chemicals are not attracted to carbon. This means that an activated carbon filter will only remove certain impurities.
Sand filter	Beds of sand or in some cases coarse bark or mulch which trap and adsorb contaminants as greywater flows through.	Simple operation, low maintenance, low operation costs.	High capital cost, reduces pathogens but does not eliminate them, subject to clogging and flooding if overloaded.
Aerobic biological treatment	Air is bubbled to transfer oxygen from the air into the greywater. Bacteria present consume the dissolved oxygen and digest the organic contaminants, reducing the concentration of contaminants.	High degree of operations flexibility to accommodate greywater of varying qualities and quantities, allows treated water to be stored indefinitely.	High capital cost, high operating cost, complex operational requirements, does not remove all pathogens.

Membrane bioreactor	Uses aerobic biological treatment and filtration to encourage consumption of organic contaminants and filtration of all pathogens.	Highly effective, high degree of operations flexibility to accommodate greywater of varying qualities and quantities, allows treated water to be stored indefinitely.	High capital cost, high operating cost, complex operational requirements.

2.4.1.2 Greywater characteristics :

The characteristics of grey wastewater depend firstly on the quality of the water supply, secondly on the type of distribution net for both drinking water and the grey wastewater (leaching from piping, chemical and biological processes in the biofilm on the piping walls) and thirdly from the activities in the household. The compounds present in the water vary from source to source, where the lifestyles, customs, installations and use of chemical household products will be of importance.

Physical parameters of relevance are temperature, colour, turbidity and content of suspended solids.

Greywater temperature is often higher than that of the water supply and varies within a range of 18–30 C^o Due to use of warm water for personal hygiene and discharge of cooking water. While Food, oil and soil particles from kitchen sinks or hair and fibers from laundry can lead to high suspended solids content in greywater.

Suspended solids concentrations in greywater range from 50–300 mg/l, but can be as high as 1500 mg/l. In a case of pH and alkalinity, pH is in the range of 6.5–8.4. Greywater also contains salts, indicated as electrical conductivity that measure the ions dissolved in greywater. The electrical conductivity (EC) of greywater is typically in the range of 300-1500 µs/cm but can be as high as 2700 in Palestine.

The biological and chemical oxygen demand are parameters to measure the organic pollution in water. COD describes the amount of oxygen required to oxidize all organic matter found in greywater while BOD describes biological oxidation through bacteria within a certain time span. The main groups of organic substances found in wastewater comprise proteins, carbohydrates, fats and oils.

The BOD and COD concentrations in greywater strongly depend on the amount of water and products used in the household. In Palestine, average BOD was as high as 590 mg/l and exceeded 2,000 mg/l in isolated and finally Greywater normally contains low levels of nutrients compared to toilet wastewater [19] Appendix B shows the Greywater characteristic in Palestine.

Greywater can be reuse for purposes that does not require potable water – such as landscaping, agriculture, or for flushing toilets – thereby reducing potable water use. Greywater can also be allow to seep into the ground to recharge aquifers and reduce the volume of wastewater needing to be treated. Greywater is often, but not always, treated before it is reuse, and the degree of treatment can vary widely. Greywater may contain many of the same contaminants as raw sewage, but generally in lower concentrations. For example, greywater can contain fecal coliforms and nutrients including nitrogen and phosphorus.

Table 2. 2 Common greywater contaminants [3]**.**

Greywater Source	Possible Contents
Automatic clothes washer	Suspended solids (dirt, lint), organic material, oil and grease, sodium, nitrates and phosphates (from detergent), increased salinity and pH bleach.
Automatic dishwasher	Organic material and suspended solids (from food), bacteria, increased salinity, pH, fat, oil, grease and detergent.
Bath tub and shower	Bacteria, hair, organic material, suspended solids (skin, particles, lint), oil, grease, soap and detergent residue.
Sinks, including kitchen	Bacteria, organic matter and suspended solids (food particles), fat, oil, grease, soap and detergent residue.

The generated amount of greywater greatly varies as a function of the dynamics of the household water consumption in low-income areas with water scarcity and rudimentary forms of water supply can be as low as 20–30 liters per person per day. A household member in a richer area with piped water may generated several hundred liters per day. A typical greywater amount of 90–120 l/p/d with piped water in house without water shortage, A greywater volumes in Palestine (l/p/d) was 30 for kitchen, 55 for shower bath and 13 for laundry. While in the southern towns, supply to 16% of people living in connected households is less than 20 liters [19].

2.4.2 Microbial Fuel Cell technology

The need of alternative eco-friendly fuel is increasing quickly with the decrease of non-renewable energy resources. One of the alternative of fossil fuels could be MFCs to overcome energy crisis and global warming, Microbial fuel cells represent a new form of renewable energy, which transform the organic matter into electricity with bacteria's present in wastewater while treating the wastewater, these technology was able to treat domestic and dairy wastewater, the microorganisms that found in the wastewater are for electricity generation and removing COD and TDS [20, 21].

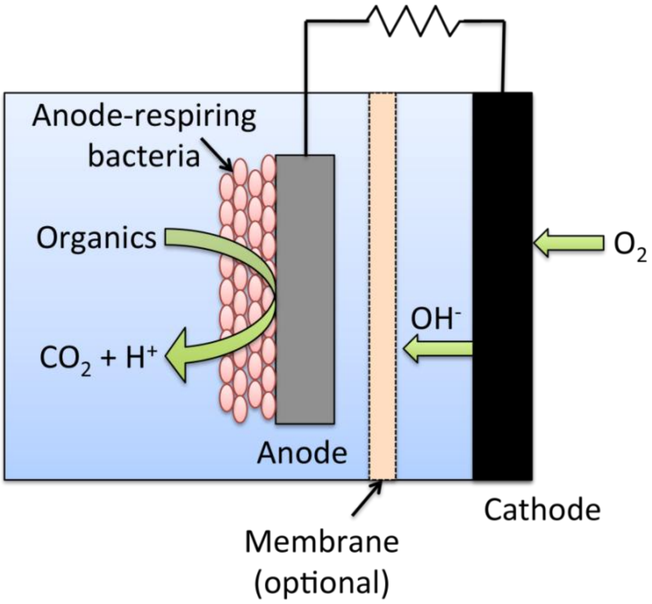

Figure2. 5 Schemed diagram of MFC Technology[22].

MFC represents a new type of renewable energetic resource by producing electricity from what is considered as waste .In this technology, it is possible to use bacterium which already present in the wastewater as something used to motivate to produce electricity, while treating wastewater at the same time although MFCs produce a lower amount from energy than hydrogen fuel cells, making combination from both electricity production and wastewater which is treated would reduce the cost of treating primary effluent wastewater [20, 23].

Bacteria used in MFC either require direct contact with the solid electron acceptor and therefore cannot form a biofilm or presence in a soluble electron shuttle which is a compound carries electrons from the bacteria by diffusive transport to the surface of the metal oxide (or electrode) and is able to react with it and discharging its electrons. This compound in its oxidized state then diffuses back to the cells, which should be able to use the same compound repeatedly. Bacteria are known to produce compounds, which act as electron shuttles, including melanin, phenazines, flavones, and quinines or the third mechanism proposes a solid component, which is part of the extracellular biofilm matrix and is conductive for electron transfer from the bacteria to the solid surface [20].

MFCs have advantages over other technologies used for generating energy from organic matter. First, the direct conversion of substrate into electricity permits high conversion efficiencies. Second, they operate efficiently at ambient temperature, including low temperatures. Third, they do not require the treatment of biogas generated in the cell. Fourth, they do not require additional energy to aerate the cathode, given that it can be aerate passively. Fifth, they have the potential for application in remote areas without electrical infrastructure making them an additional renewable energy option to meet global energy requirements. Finally, MFCs involve an anaerobic process, and bacterial biomass production will therefore be reduce compared to that of an aerobic system. Estimated cell yield from a MFC process is in the order of Yx/s=0.16 g-COD-cell/g-COD. This is about 40% of the value produced by an aerobic process of Yx/s=0.4 g-COD-cell/g-COD. Although, MFCs produce less amount of energy than hydrogen fuel cells and it is a combination of both wastewater treatment and electricity generation which would reduce the cost of wastewater's treatment [18].

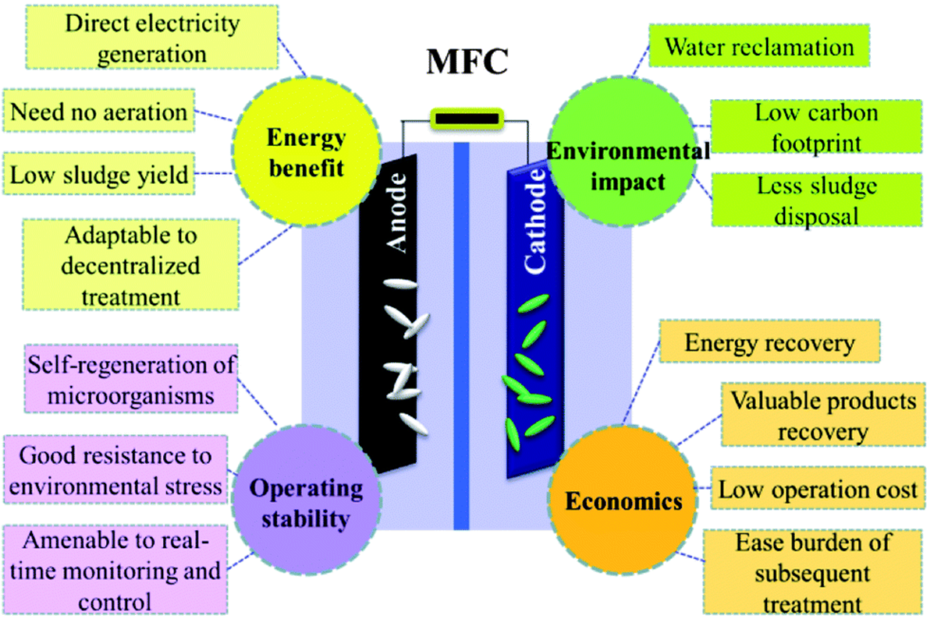

Figure 2. 6 Potential benefits of MFCs for energy, environmental, operational and economic sustainability [24].

MFC has benefits of producing less sludge compared to the applied activated sludge treatment process in current wastewater treatment plants. In most wastewater treatment plants the sludge which produced by aerobic process in the second treatment process needs a special process in order to treat it. The aeration process consume more energy even the most reports show that more than 60% of the total energy consumption around the world used in wastewater treatment plant is for aeration. Through applying MFCs , the energies' consumption can be decreased and the energy consumption will be reduced [25].

MFC uses bacteria to motivate the conversion of organic matter into electricity through transferring electrons to a develop circuit. Microorganisms can transfer electrons to the anode electrons through three ways: firstly, exogenous mediators (ones external to the cell) like potassium ferricyanide, neutral red and thionine. Secondly, through using mediators produced by the bacteria. Thirdly, by direct transfer of electrons from the respiratory enzymes to the electrode. All of these mediators can transfer electrons from the chain of respiratory by entering the outer cell membrane and then it became reduced, after that leaving in a reduced state to shuttle the electron to the electrode. *Shewanella- utrefaciens, Geobacter-*

Sulfurreducens,Geobacter-Metallic-Reducensand Rhodoferax-Ferrireducons bacteria have been shown to produce electricity in a mediator less MFC.

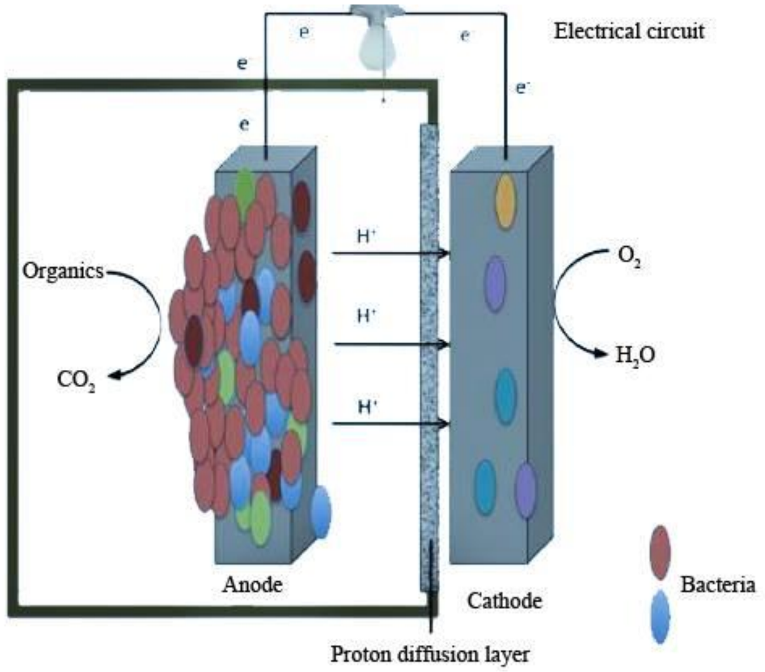

Figure 2.7 Microbial fuel cell component[26].

Bacteria present in the mediator less MFCs have electrochemically redox enzymes on their outer membranes, which transfer the electrons to external materials; therefore, they do not require exogenous chemicals in order to accomplish electron transfer in to electrode. When these bacteria oxidize, the organic matter present in the wastewater and the electron is shuttled to the electrode also the protons produced diffuse through the water to the electrode (counter electrode) giving the particular some of positive characteristics. Oxygen, the hydrogen protons, and the electron that is connected by a circuit from the anode to the cathode, are then catalytically combined with a platinum catalyst to form water at the cathode [23, 27].

In current producing biofilms bacterial cells conduct electron transfer using membrane bound cytochromes. The bacterial cells use a long range network capable of conducting electron flow from the farthest cells to the closest ones to the anode. Oxidation of the organic substrate leads to a high concentration of protons under the biofilm mass where it is highest towards the anode [27].

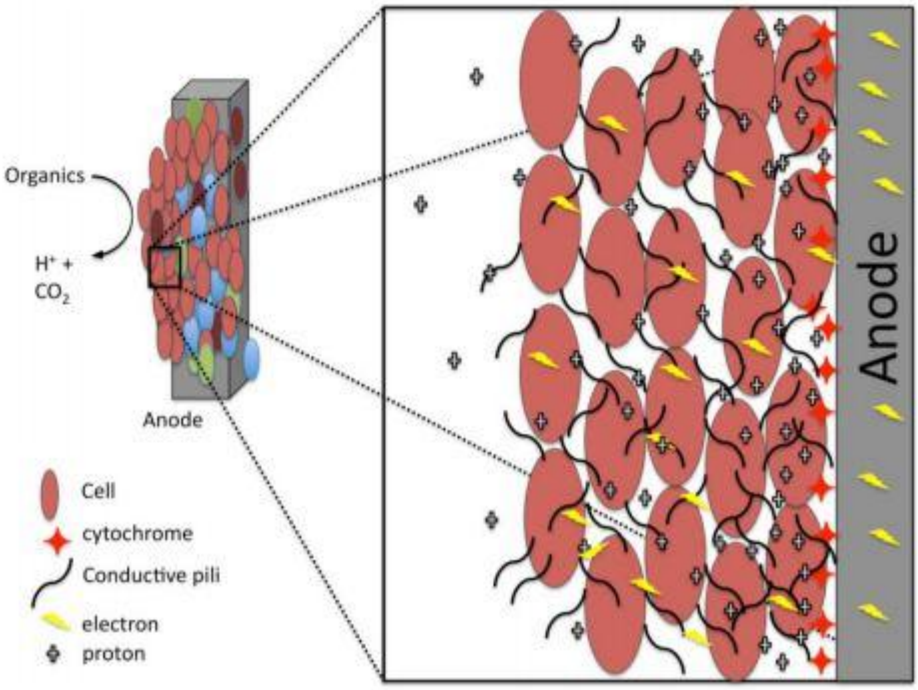

Figure 2.8 The process of bacteria cells in the anode[26].

The bacteria destroyed the organic matter and release energy, this bacteria have the ability to produce electricity then transfer the electron efficiently to the anode they are called "exoelectrogens", this kind is the most appropriate one to operate in MFC because of their ability to transfer the electrons [28].

There is a compression between three types of MFC process, which includes the batch mode (SS), a continuous flow of influent with ferricyanide (PF) as the oxidizing agent and continuous flow of influent with O_2 (PU) as an agent of oxidizing. Electricity generation in the highest quantity was achieved by using the continuous flow mode with ferricyanide (0.8330 V) it is followed by the continuous flow mode with O_2 (0.5890 V) and finally the batch mode (0.352 V). On the top of that, carbon removal in the highest efficiently also achieved by the continuous flow mode in a mount near to 87% then it is followed by the continuous flow mode 51% and finally the batch mode 46%.

Moreover, the continuous flow mode produced the highest efficiency of N removal (63%), followed by the continuous flow mode (54%) and finally the batch mode (27%). The efficiency of COD removal for the three systems was (86.69%) is the PF, (51.28%) in PU system and (46.15%) for SS system. As a result, the use of ferricyanide as the oxidizing agent enhance the removal rate by 35.41 % for the PF when it is compared with PU system while the percentage of N components removed is higher for PF [27, 29].

The effect of distance between the electrodes and total surface area of anode on producing electricity was evaluate under the external resistance variable. At the lower spacing between both the electrodes and lesser surface area of the anode the max power density was nearly 10.9 and 10.13 mw\m^2 respectively [29].

By using Gore-Tex such a proton exchange membrane and loose-weave carbon fiber cloth like the anode in MFC design, The cell was able to produce voltages between 0.4-0.5 V when it tended and shaken suddenly also 0.5-0.6 V in batch fed [30].

2.5 Statistic

To achieve the goal of designing the hybrid system in this project, the needed data was collected according to a house located in south of Hebron city, which is low-income single family consists of 6 members.

2.5.1 Electrical Energy

Solar PV is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity. More than 100 countries use solar PV. Installations may be ground-mounted or built into the roof or walls of a building.

At the end of 2014, worldwide installed PV capacity increased to at least 177 gigawatts (GW), sufficient to supply 1 percent of global electricity demands. China, followed by Japan and the United States, is the fastest growing market, while Germany remains the world's largest producer [31].

Palestine depends on electricity and energy produced directly from petroleum and natural gas, as an energy sources to supply its needs. The energy sector suffers firstly by a lack of local traditional energy sources such as natural gas and fossil fuels, which are used to generate electricity, and secondly by a lack of ability to utilize available resources. The only domestic producer of electricity is a power plant in Gaza, which has a very low production capacity, so the electricity sector in Palestine has been considered as both inefficient and costly, where the prices are high compared to neighboring areas.

The most of Palestine’s energy consumption is imported. In 2012, 91% of the total 5370.4 gigawatt hours (GWh) of available electricity in Palestine was imported, (2.3%) is imported electricity from Egypt, (1.6%) from Jordan , and (96.1٪) is from Israel occupation, locally produced electricity accounts are less than 10% of the total supply, so Israel occupation has the control over electricity prices. This has a negative effect on the electricity sector and economy in Palestine. Day by day the ratio of imported to domestically produced electricity has increased, that mean growing of energy insecurity, so most of motivating towards starting to depend on solar energy to generate electrical power.

Considering these drags, while efforts tend to using PV systems to reduce the aggravation of these drags, which can improve energy security in Palestine, whereas 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.day, so solar energy is very suitable in Palestine because of a high average of number of sunny days.

Whereas Palestinian Energy Authority (PEA) in 2012 published the ‘General Renewable Energy Strategy’ that encourage households to use PV systems for their homes, where it leads to reach 5% of the total domestic electricity expected consumption will be generated using renewable sources specially solar energy by 2020 [32].

The angle of PV panels must be positioned to receive the maximum amount of solar radiation throughout the year. For cost reasons panels are often installed at a fixed angle, instead of following the sun’s movement in the sky. Global Horizontal Irradiation (GHI) is considered as solar climate reference that shown in (Fig.2.9).

The most important parameter for PV potential evaluation is the global horizontal irradiance (GHI) falling onto the Earth’s surface consists of the diffuse horizontal irradiance (DHI) from the sky and the direct normal irradiance (DNI) from the sun.

Whereas Hebron have high GHI, where values can reach up to 2000 kWh/m2 and the suitable angle to receive the maximum amount of solar radiation is 31°.

$$GHI = DHI + DNI*Cos(\theta) \tag{2.1}$$

Where θ is the solar zenith angle (vertically above the location is 0°, horizontal is90°).

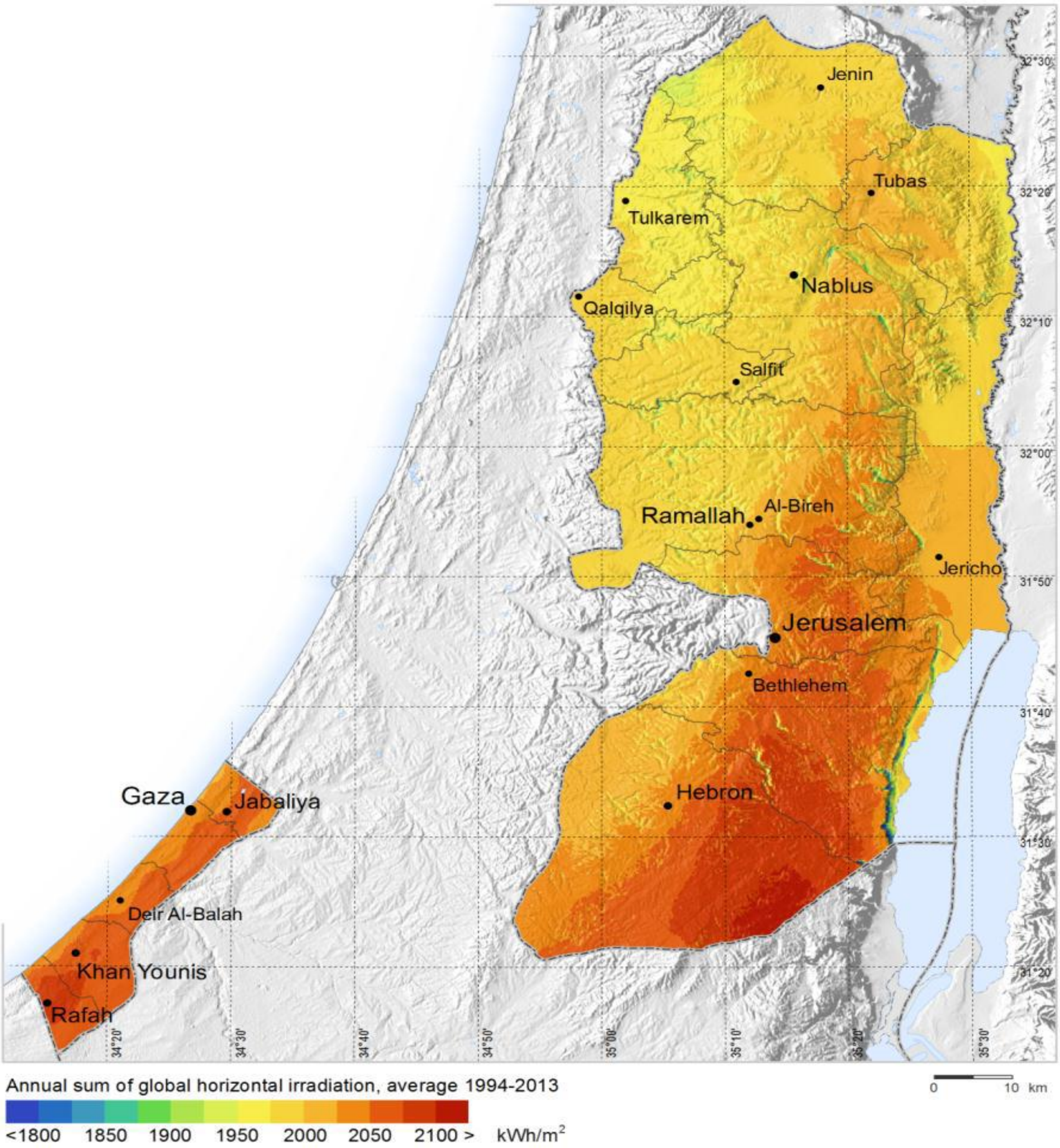

Figure 2.9 Global Horizontal Irradiation - long-term yearly average. Period 1994-2013 [30].

Comparison monthly values of GHI minimum and maximum in Gaza, Hebron, Jericho, Nablus and Ramallah was shown in Figure 2.10. It shows sunny months (from April to September) which have high values of irradiation. Whereas the months between (October to march) have less values of irradiation [30].

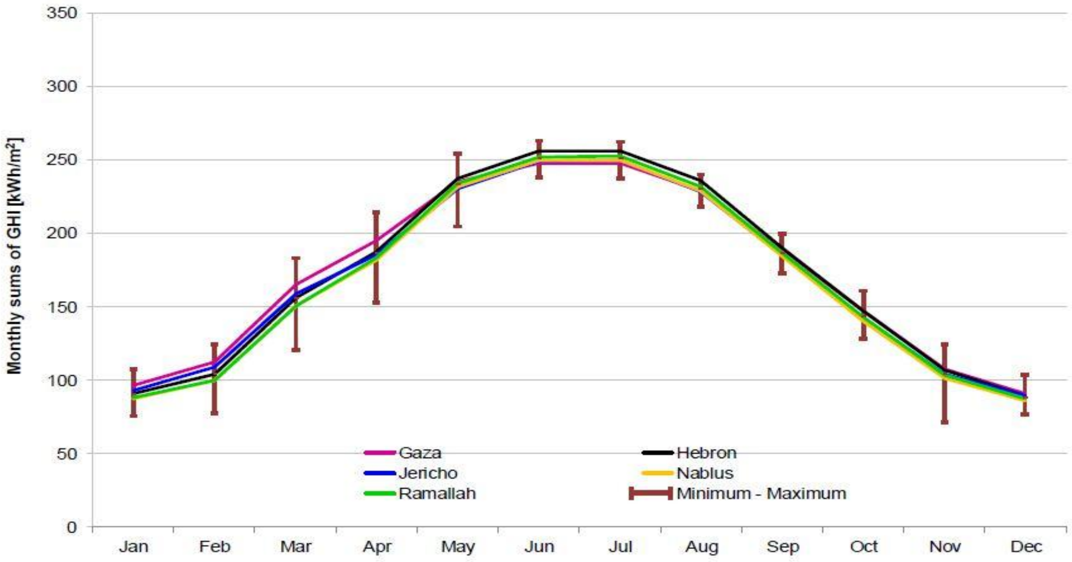

Figure2.10 Global Horizontal Irradiation - long-term monthly averages, minimum and maximum at selected sites [30].

The average household electricity consumption in the Palestinian during July 2008 was 271 KWh, it reached 301 KWh in the Middle of the West Bank and did not exceed 229 KWh in the North of WB. The average was about 282 KWh in urban localities and 226 KWh in rural localities. The average per capita electricity consumption in the Palestinian during July 2008 was 46.7 KWh. The household electricity consumption in Hebron for 12 months in 2016 as shown in Figure 2.11 [33].

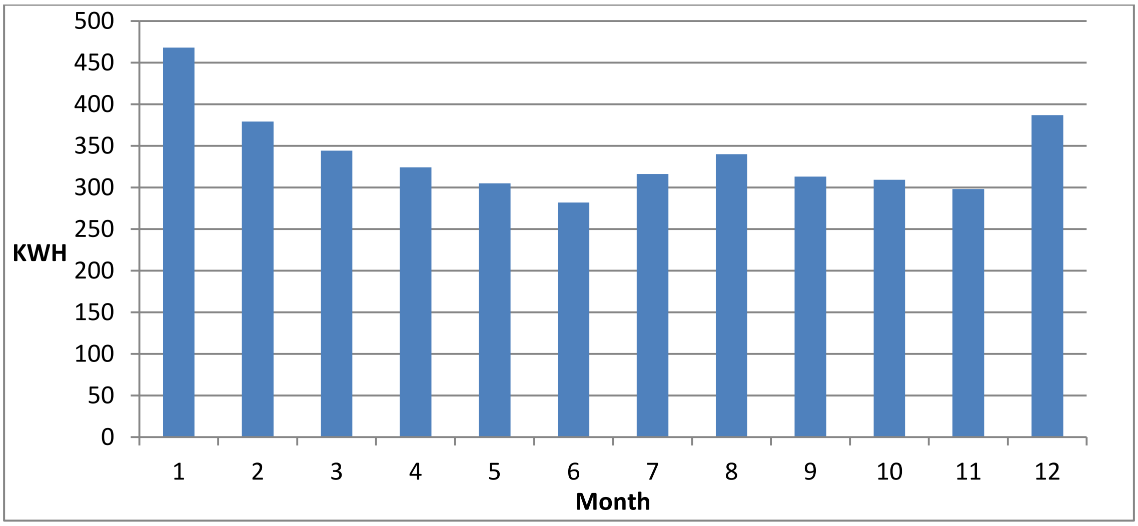

Figure2.11 The average household electricity consumption in Hebron (kWh) [33].

2.5.2 Wastewater

Greywater generally refers to the wastewater generated from household uses like bathing and washing clothes. This wastewater is distinguishe from more heavily contaminated “black water” from toilets. In many utility systems around the world, greywater is combined with black water in a single domestic wastewater stream. Yet, greywater can be of far higher quality than black water because of its low level of contamination and higher potential for reuse. When greywater is reused either onsite or nearby, it has the potential to reduce the demand for new water supply, reduce the energy and carbon footprint of water services and meet a wide range of social and economic needs. In particular, the reuse of greywater can help reduce demand for more costly high-quality potable water [3].

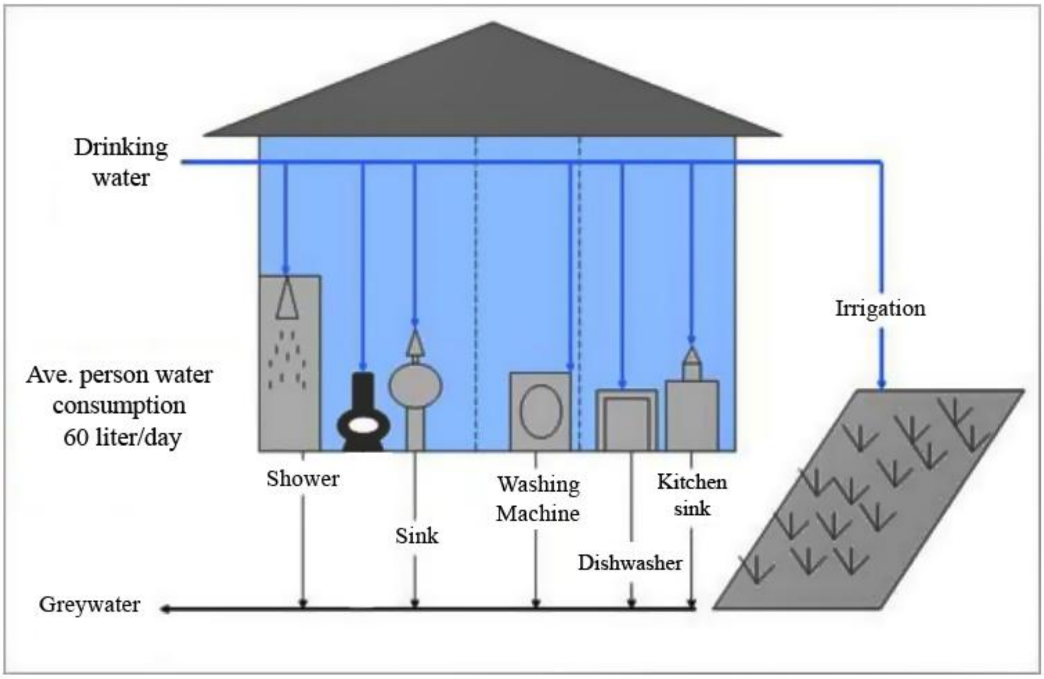

Figure2.12 Typical household water infrastructure and consumption in Hebron [3].

The generated amount of greywater greatly varies as a function of the dynamics of the household water consumption in low-income areas with water scarcity. The rudimentary forms of water supply can be as low as 20 –30 liters per person per day. A household member in a richer area with piped water may generate several hundred liters per day, a typical greywater amount of 90–120 l/p/d with piped water in house without water shortage. A greywater volume in Palestine (l/p/d) was 30 for kitchen, 55 for shower bath and 13 for laundry.

While 65% of wastewater in a household is greywater. Bathrooms contribute up to 60% of grey's water production. The least amount of greywater comes from kitchen. Appendix A shows supply and consumed quantities, population total losses, daily allocation and defect in domestic supply in west bank in 2015 [19].

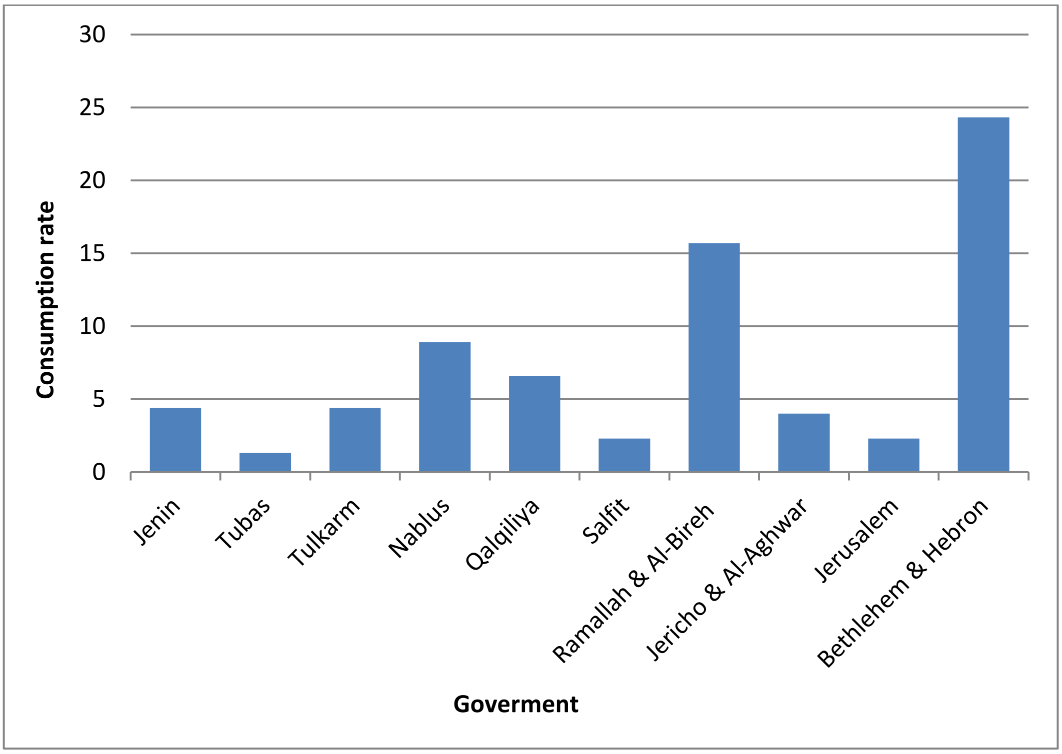

Figure 2.13: Typical household water consumption in West Bank [34].

Chapter Three

Load Profile And Design System

3.1 Block Diagram of system

In this project as shown in figure 3.1, the system utilizes photovoltaic (PV) as the primary power generator, PEMFC as the secondary backup power generator, electrolyzer (to produce hydrogen and storage in tank to store any excess power) and the MCF to treat greywater with some additional power generated. The advantage of the proposed system is that, in addition to being environmentally friendly, decreasing noise and carbon footprint.

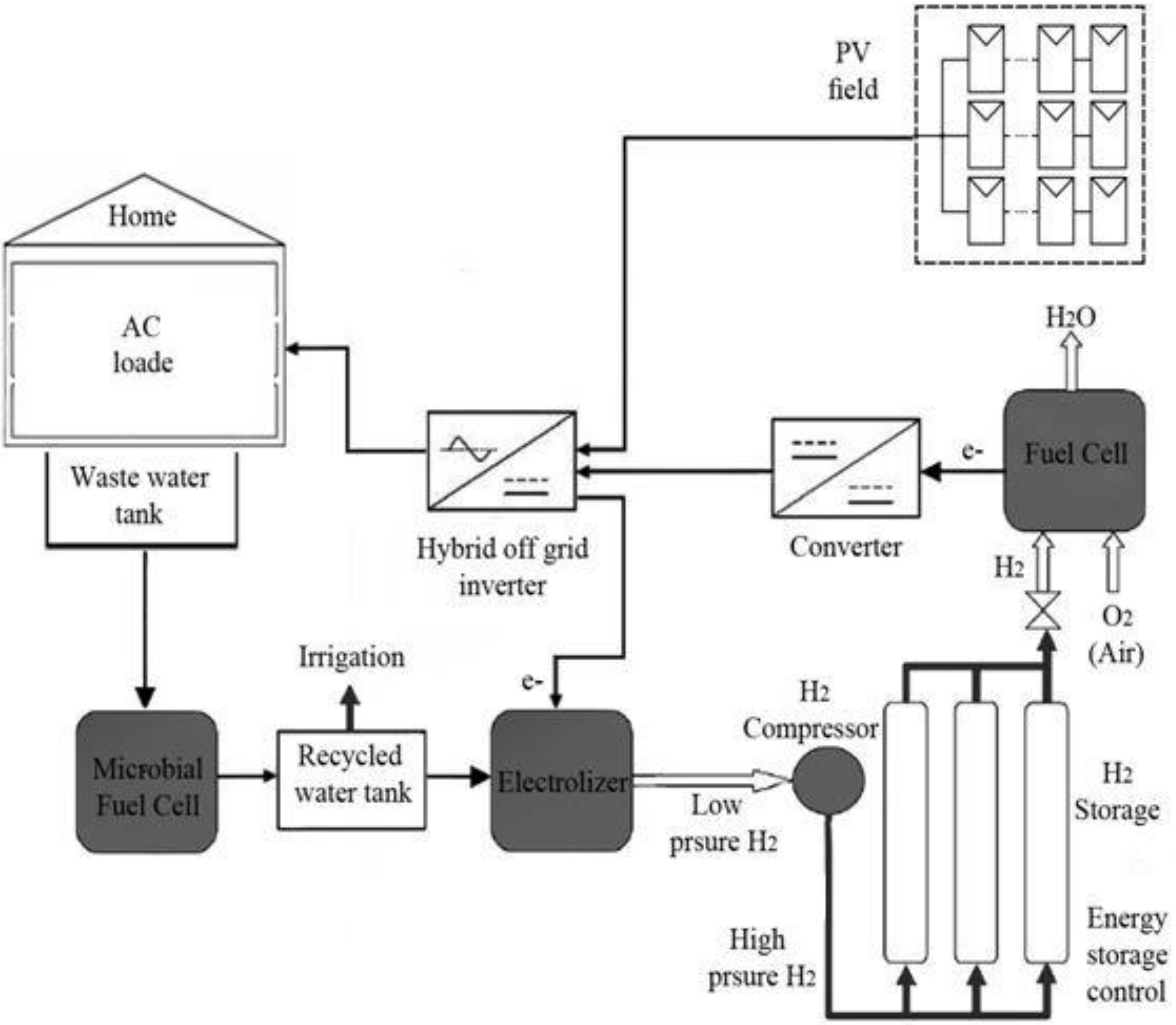

Figure 3.1: System Block Diagram.

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3.2 Load profile

3.2.1 Load profile of Electrical consumption

When the grid is not nearby, electricity becomes much more valuable with the extra cost and complexity of a self-sufficient, stand-alone power system can provide enormous benefit.

We have limited solutions, one of that, the competition with the cost of bringing the grid to the site, which may run many thousands of dollars per mile. Instead of use utility power, use a PV–fuel cell off grid system.

Sizing of a PV system means determining how much energy is required to run the system and how many PV modules are needed to generate it. A PV system has to generate enough energy to cover the energy consumption of the loads (lights, appliances, equipment) and energy used by the system itself.

The design process for stand-alone systems begins with an estimate of the loads that are to be provided. To achieve reduction in electricity consumption, it is vital to have current information about household electricity use. This allows to draw user behavior profile and it is important to implement the measures associated with energy efficiency improvements in households.

The project data was collected according to a house located in south of Hebron city, consist of six person with total area of 160 m^2 and Latitude of +31.54(31°32'24"N) and +35.09 (35°05'24"E) Longitude.

Power needed by a load, as well as energy required over time by that load, is important for system sizing. In the simplest case, energy (watt-hours or Kilowatt-hours) is just the product of some nominal power rating of the device multiplied by the hours that is used. Appendix C lists example of power used by a number of household electrical loads.

Some of these are simply watts of power, which can be multiplied by hours of use to get watt-hours of energy, often power values can get from device nameplate, but some loads calculate by ways that is more complicated, for example, an amplifier needs more power when the volume is increased and many appliances, such as refrigerators and washing machines, use different amount during using different portions of the operating cycle. Refrigerator are also unusual since they are always turn on, but their power varies throughout the day so we estimate average usage that it be at full power for 16% through a day. Many of the devices listed in the consumer electronics category show power while they are being used (active) and power consumed the rest of the time (standby), both of which must be considered when determining energy consumption.

After knowing the number of hours of use each appliance can calculate the energy consumption of each of them and the sum of these is the energy consumption through a day of the month. January and July was chosen as the two months were peak consumption of electric power through a year.

$$E=P*T \tag{3.1}$$

P: power consumption (kW).

E: energy consumption (kWh).

T: The period of time that the appliance was operate (hour).

Table 3. 1: The average daily energy consumption for household appliances in January

#	Appliance	Quantity	Power rating (W)	Operating time (h/day)	Energy Consumption (Wh/day)	Percentage
1	**Refrigerator 22 cu.ft**	1	300	3.8	1140	6.9%
2	**Microwave**	1	800	1.5	800	4.8%
3	**Heater**	1	750	7	5250	31.8%
4	**Fluorescent lamp**	10	35	7	2450	14.8%
5	**Iron**	1	1000	0.5	500	3.0%
6	**Hair Dryer**	1	1000	0.3	300	1.8%
7	**Washing Machine**	1	500	1.5	500	3.0%

8	**Computer active mood**	1	44	3	132	0.8%
9	**Computer Standby mood**	1	3	21	63	0.4%
10	**Satellite receiver active mood**	1	17	4	68	0.4%
11	**Satellite receiver Standby mood**	1	16	20	320	1.9%
12	**TV 39 in active mood**	1	142	4	568	3.4%
13	**TV 39 in Standby mood**	1	3.5	20	70	0.4%
14	**Phone**	2	4	2	16	0.1%
15	**Laptop computer**	2	20	5	200	1.2%
16	**Radio**	1	75	2	150	0.9%
17	**Fan**	2	300	0	0	0%
18	**water heater**	1	1000	4	4000	24.2%
	sum				16972	100%

Table 3. 2: The average daily energy consumption for household appliances in July.

#	Appliance	Quantity	Power rating (W)	Operating time (h/day)	Energy Consumption (Wh/day)	Percentage
1	**Refrigerator 22 cu.ft**	1	300	3.8	1140	9.2%
2	**Microwave**	1	800	1.5	1200	9.7%
3	**Heater**	1	750	0	0	0%

4	**Fluorescent lamp**	10	35	6	2100	17.0%
5	**Iron**	1	1000	0.5	500	4.0%
6	**Hair Dryer**	1	1000	0.5	500	4.0%
7	**Washing Machine**	1	500	1	750	6.1%
8	**Computer active mood**	1	44	3	132	1.1%
9	**Computer Standby mood**	1	3	21	63	0.5%
10	**Satellite receiver active mood**	1	17	4	68	0.5%
11	**Satellite receiver Standby mood**	1	16	20	320	2.6%
12	**TV 39 in active mood**	1	142	4	568	4.6%
13	**TV 39 in Standby mood**	1	3.5	20	70	0.6%
14	**Phone**	2	4	2	16	0.1%
15	**Laptop computer**	2	20	5	200	1.6%
16	**Radio**	1	75	2	150	1.2%
17	**Fan**	2	300	6	3600	29.1%
18	**water heater**	1	1000	1	1000	8.1%
	sum				12377	100%

According to the figure (3.2), we find that the amount of energy consumed in the winter more than the summer, and this is due to several reasons. This causes by increased use some of the equipment such as water heating, electric heater, increase the period running lights and weather conditions that may prevent exit persons of the household which leading to run for a longer period of devices.

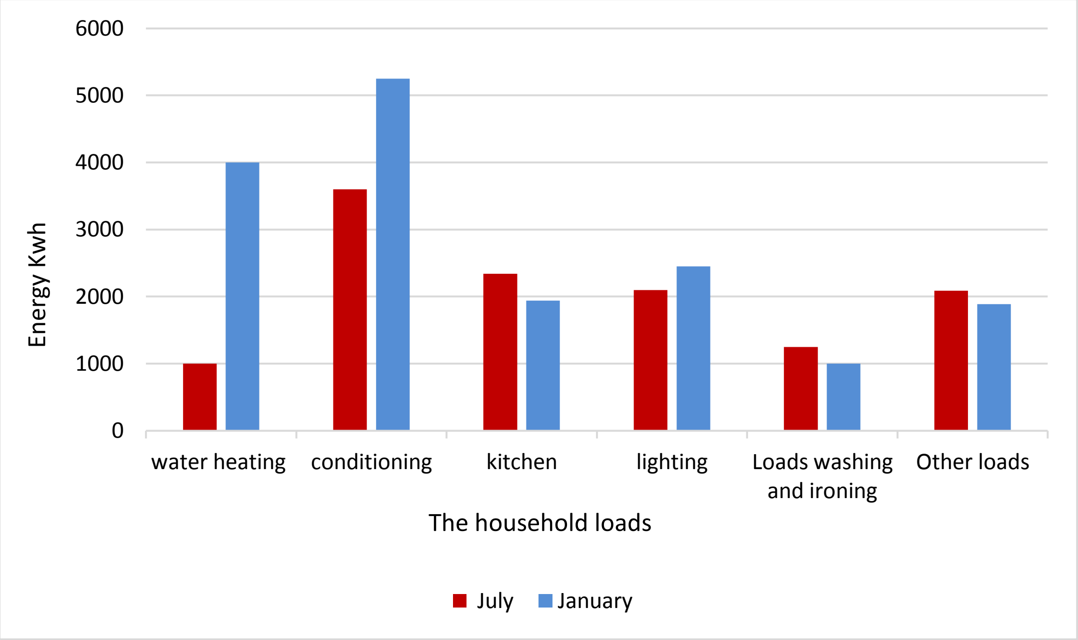

Figure3.2: The Comparison of proportion of major household loads between winter and summer.

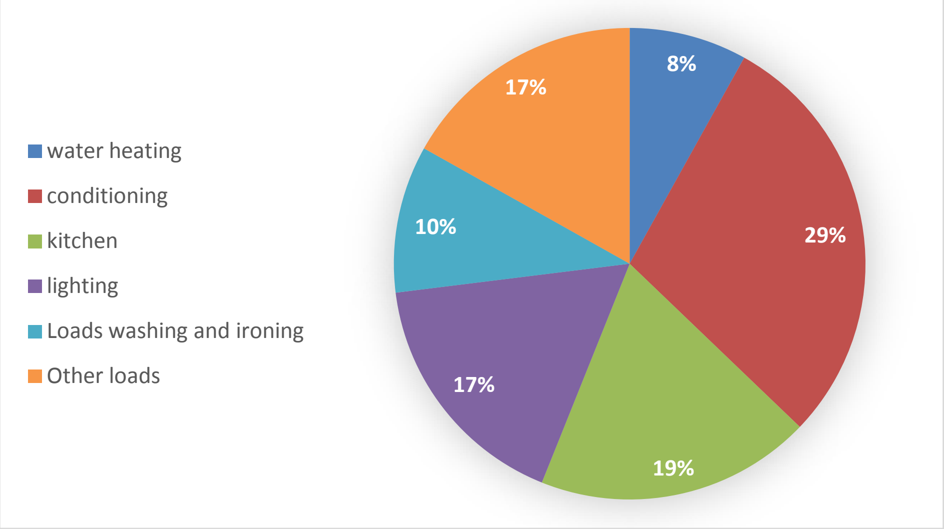

Figure3.3: The proportion of major household loads per day in summer.

The charts (3.3, 3.4) appear the following:

- The proportion of energy consumption for air conditioning and water heating loads are higher in the winter than the summer (which uses a fan and an electric heater not electric air conditioner).
- The proportion of energy consumption per the following activates (loads of washing and ironing equipment, kitchen equipment and lighting equipment) are almost equal during the two seasons.

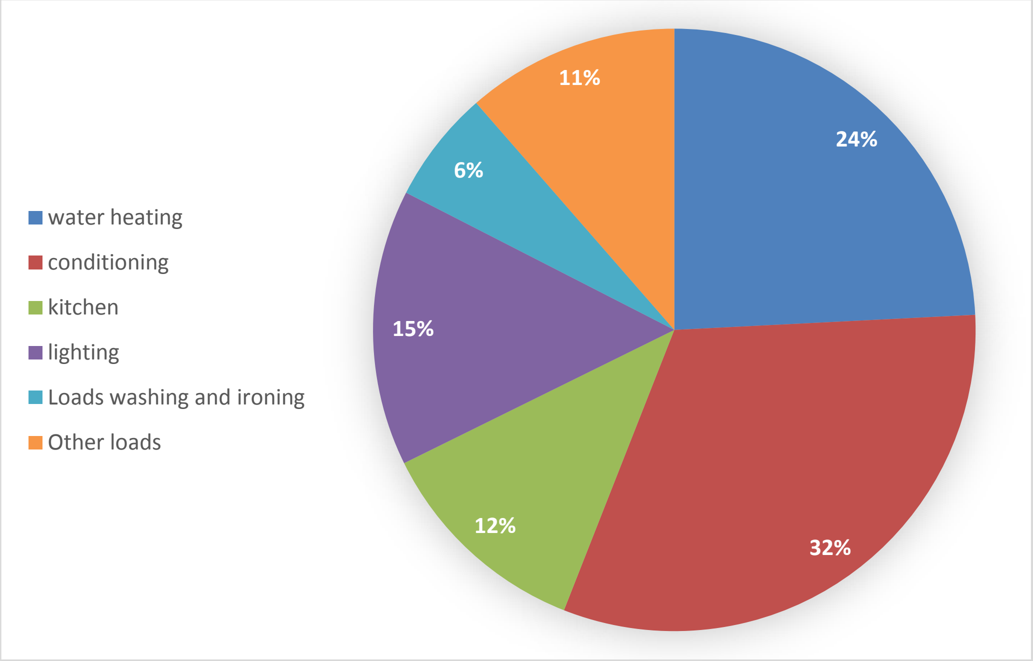

Figure3.4: The proportion of major household loads per day in winter.

The year is divided into two main seasons summer and winter, the notes by drawing energy consumption curve (day / month during the year) figure (3.5), There are two peak of energy consumption during the year, one in the middle of winter (P1) in the month of January and February, second peak in the middle of the summer (P2) in July.

In addition, it is noted the most less energy consumption periods during the year (L1, L2) and they are in May and October. The total consumption of 12 months is 4116 kWh/year.

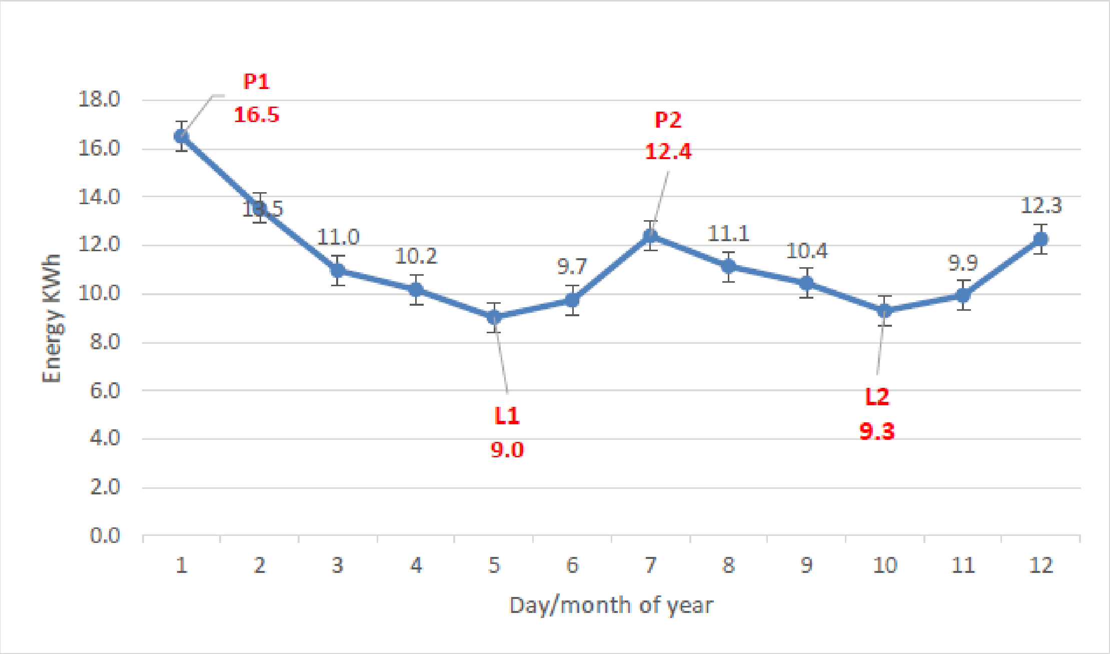

Figure3.5: The curve day/month during the year [35].

3.2.2 Load Profile of Water Consumption

Embedded energy in water refers to the amount of energy that is used to collect, convey, treat, and distribute a unit of water to end-users. The amount of energy that is used to collect and transport used water for treatment prior to safe discharge of the effluent in accordance with regulatory rules.

A little information is currently available that can describe the consumption patterns of water consumption rate at any given time or over the course of a given day, week, month or season. For indoor water use, the proportions of demands by various water demand profile categories are comparable.

The hourly water use profile data was collected to characterize and quantify the relationships between water and energy use by water and wastewater agencies and to determine the range of magnitudes and key drivers of embedded energy in water.

Single-family household indoor water-use had two peaks during the day, one at 7:00 AM and one at 7:00 PM. Low-income single-family households also had two distinguishable peaks in the daily water use: The first, one hour later than single-family homes, at 8:00 AM and the second at 8:00 PM, an hour later than Single-family homes. Neither of these groups peaks coincides with the peak energy demand. Appendix D shows the essentially identical patterns of peak indoor water demand for single-family and low-income single-family homes. Single-family homes use slightly more water prior to the peak, while the low-income Single-family homes use slightly more water after the peak.

The goal of analyses hourly Single-family household water use is to provide accurate and current water demand profiles for various categories. Table (3.5) shows the indoor single-family and low-income single-family category hourly water use profile data in tabular format as percentages of total indoor water use. The daily water consumption per unit area, summarized by days is shown below for residential buildings.

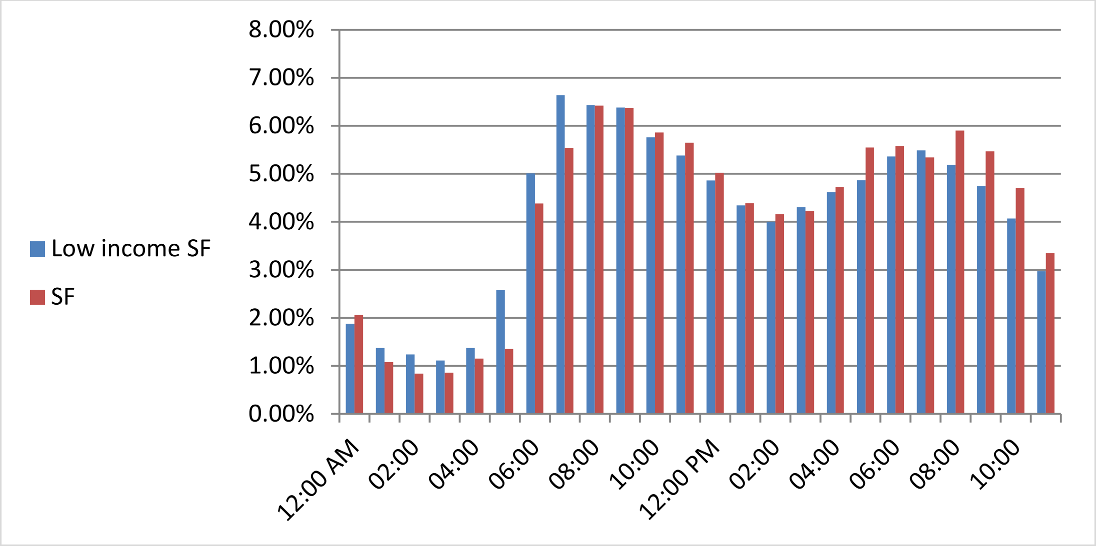

Figure3.6: Hourly Water Demand – SF and LI.SF Indoor.

Water consumption data and load profiles of major household appliances are crucial elements for demand response studies. Here, discusses load profiles of major household appliances in Palestine, including baths, showers, toilets, clothes washers, dish washers and faucet.

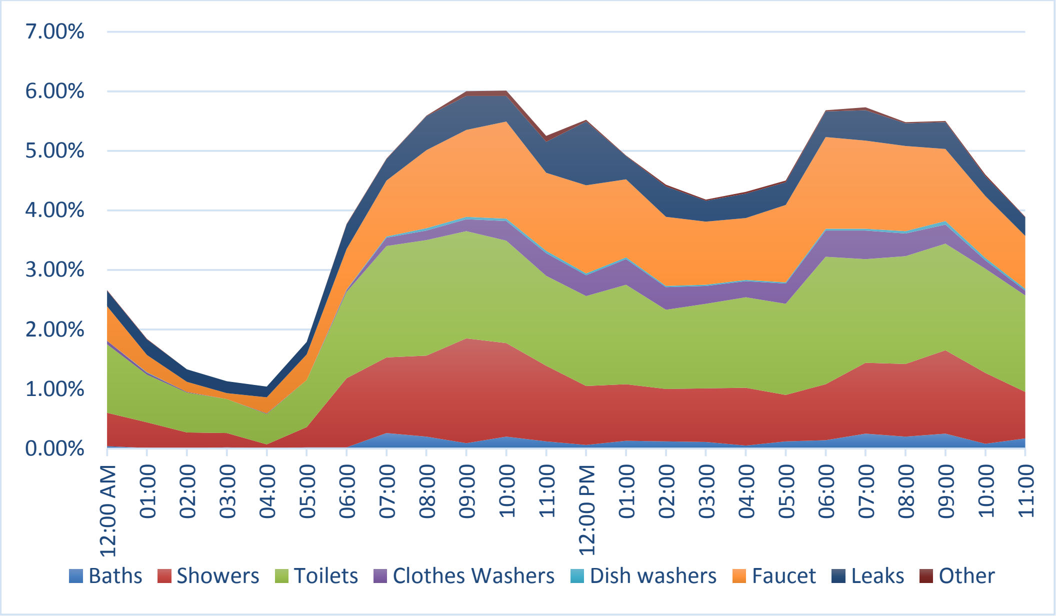

Figure 3.7: Disaggregated Hourly Water Demand activities – LI.SF Indoor.

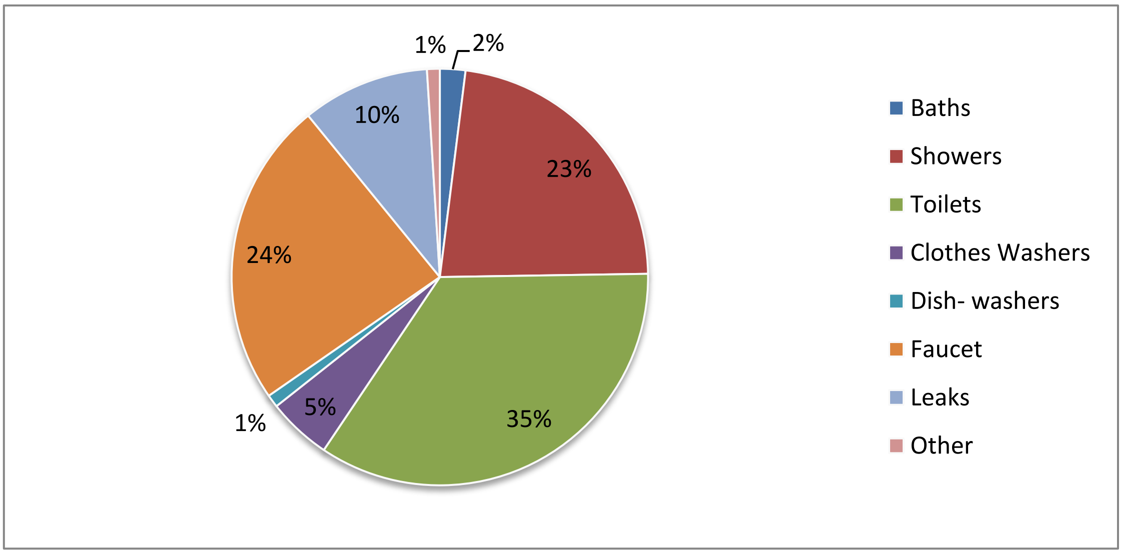

Figure3.8 :Total Disaggregated Hourly Water Demand Activities.

3.3 PV-PEM fuel cell system sizing and Design

3.3.1 Solar radiation

The geographical location of Palestine is within a considerably high solar radiation. The daily average of solar radiation in Palestine amount to 5.401 kWh/m2 per day.

Table 3.3: Monthly global solar insolation at Hebron [36].

Month	**Solar insolation (kwh/m2)**
January	3.097
February	3.607
March	4.735
April	5.322
May	7.052
June	7.48
July	7.65
August	7.19
September	6.44
October	5.35
November	4.1
December	2.835
Average insolation	**5.401 (KWh/m2)**

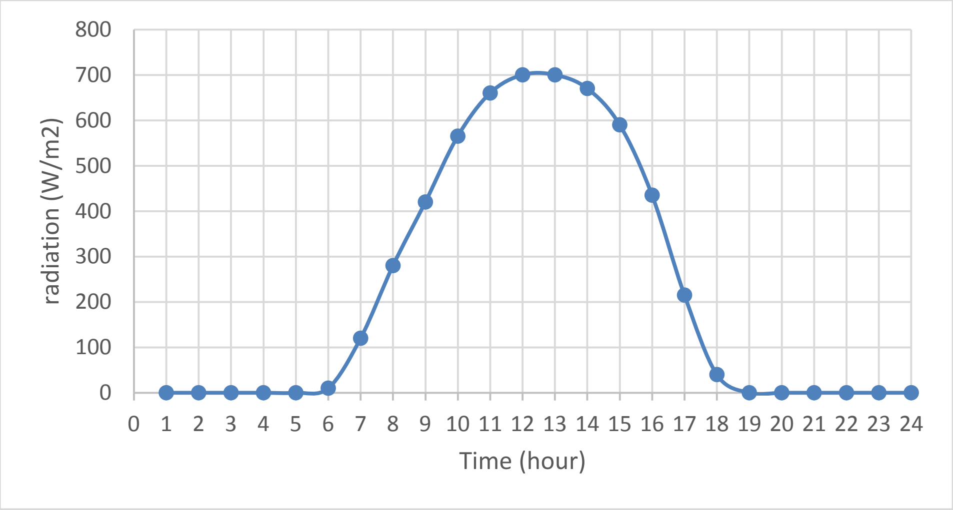

Figure 3.9: Solar radiation pattern per day at April [37].

3.3.2 Sizing the PV generator

The important parameters for system sizing are the average daily solar radiation energy and the load consumption. The total consumption of 12 months is 4116 kWh/year as in the Figure (3.5). Moreover, the average number of hours at peak sun daily for Hebron city is 5.4 hour/day.

The modules PV are Polycrystalline Silicon with an efficiency of about 15.9%. The PV system generate electricity to the house via an off Grid Hybrid Solar Inverter with efficiency of 93%.

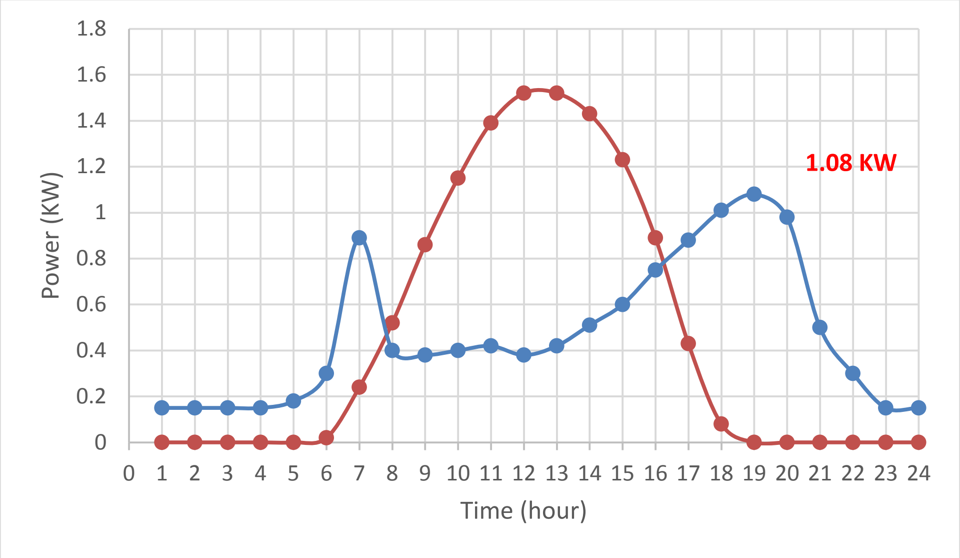

Figure 3.10: The load demand and the output power of the PV generator.

According to figure3.13. The day is classified into four periods for operating the system:

1- Morning (5:00 - 8:00): During this period the sun rise and the solar radiation will increase slowly and the PV panels do not cover demand of consumption so the PEM fuel cell will operate to provide the needed of power.

2- (8:00 - 16:20): the solar radiation will increase to reach its maximum values at midday, after that will decrease. During this period, no need for PEM fuel cell because the power output from the PV panels can meet the load demand and the excess power use to produce hydrogen by electrolyzer.

3- Sunset (16:20 - 18:30): in this period of day the sundown and the solar radiation will decrease slowly therefor the PV panels do not cover demand of consumption so the PEM fuel cell will operate to provide the needed of power.

4- Night: During the time (18:30 - 5:00): where no sunlight exists, the PV power output is zero. The fuel cell must give the required power to meet the load demands.

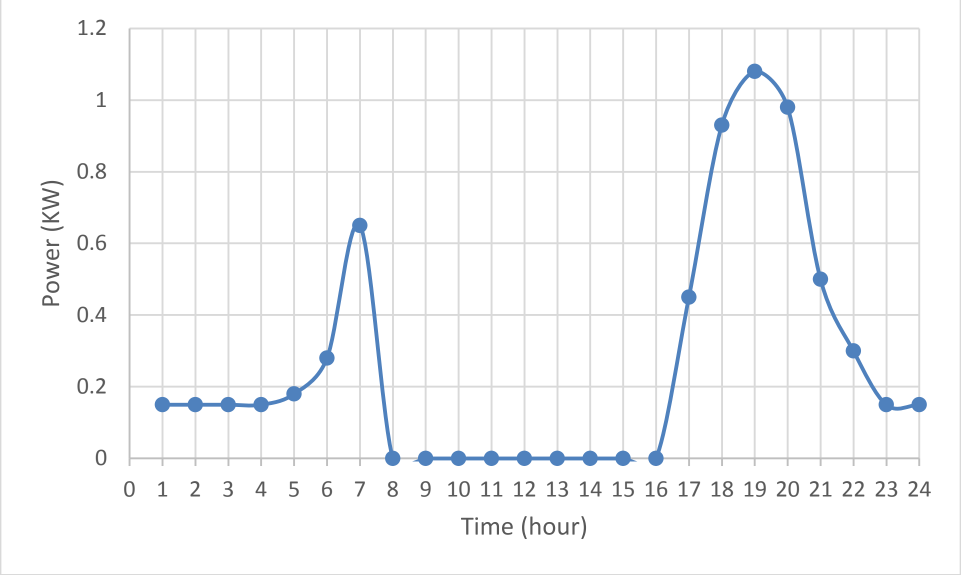

Figure 3.11: The demand load after provides of PV modules.

To determine the size of the PV modules during the day is divided into two periods, first the covered section of consumption which provide by the PV, which equals 43.6% of all consumption all day long as in the figure (3.10), and have conversion efficiency value differs from the conversion efficiency in the absence of the power generated by the PV, where this section equals 56.4% of all consumption all day long, as in the figure (3.11) where it is taken into consideration efficiency of both PEM fuel cell and electrolyzer.

Power Loss at % $\left(\frac{\Delta P}{°\mathrm{C}}\right)$ = 0.48% per degree above 25C° (Appendix F)

NOCT = 50° (Appendix F)

$$\mathrm{T_{CELL}} = \mathrm{T_{amp}} + \frac{\mathrm{NOCT}-20}{0.8} * 1\ \mathrm{SUN} \tag{3.1}$$

$$T_{CELL} = 20° + \frac{50°-20°}{0.8} * 1\ SUN = 57.5°\mathrm{C}$$

$$P_{\underset{PTC}{dc}} = 1KW * (1 - \% \left(\frac{\Delta P}{℃}\right) * (T_{cell} - 25°) = 0.844kw \quad (3.2)$$

$$\eta_{temp} = \frac{P_{\underset{PTC}{dc}}}{1kw} = \frac{0.844kw}{1kw} = 0.844 \quad (3.3)$$

$\eta_{\text{mismatching}}$ = 97% (Appendix F)

η_{inverter} = 93% (Appendix G)

$\eta_{\text{dirty collectors}}$ = 96% [37]

η_{fc} = 56% (Appendix H)

η_{ele} = 85% (Appendix I)

The conversion efficiency in the covered section of consumption by the PV is:

$$\boldsymbol{\eta}_{\textbf{conversion 1}} = \boldsymbol{\eta}_{\textbf{dirty collectors}} * \boldsymbol{\eta}_{\textbf{mismatching}} * \boldsymbol{\eta}_{\textbf{inverter}} * \boldsymbol{\eta}_{\textbf{temp}} \quad (3.4)$$

$$\eta_{\text{conversion 1}} = 0.96 * 0.97 * 0.93 * 0.844 = 73.09\%$$

The conversion efficiency in the absence section of the power generated by the PV is:

$$\boldsymbol{\eta}_{\textbf{conversion 2}} = \boldsymbol{\eta}_{\textbf{dirty collectors}} * \boldsymbol{\eta}_{\textbf{mismatching}} * \boldsymbol{\eta}_{\textbf{inverter}} * \boldsymbol{\eta}_{\textbf{temp}} * \boldsymbol{\eta}_{\textbf{FC}} * \boldsymbol{\eta}_{\textbf{ele}}$$

$$\eta_{\text{conversion 2}} = 0.96 * 0.97 * 0.93 * 0.844 * 0.56 * 0.85 = 34.79\%$$

Energy (KWh/year) =Pac (KW) * CF * 8760 h/yr (3.5)

$$Capacity\ factor\ (CF) = \frac{(\frac{h}{day} of "peak\ sun"}{24 \frac{\text{h}}{\text{day}}} = \frac{5.401}{24} = 0.2251 \quad (3.6)$$

$$P_{ac} = \frac{energy\left(\frac{KWhr}{year}\right)}{cf * 8760 \frac{\text{h}}{\text{yr}}} = \frac{4116}{0.2251 * 8760} = 2.0874\ KW_{AC}$$

$$P_{dc\,1} = \frac{P_{ac}}{\eta_{\text{conversion 1}}} * 43.6\% = \frac{2.0874kw}{73.09\%} * 43.6\% = 1.245\ KW_{Peak(DC)} \quad (3.7)$$

$$P_{dc\,2} = \frac{P_{ac}}{\eta_{\text{conversion 2}}} * 56.4\% = \frac{2.0874kw}{34.79\%} * 56.4\% = 3.384\ KW_{Peak(DC)}$$

$P_{dc\,total} = P_{dc\,1} + P_{dc\,2}$ = 1.245 + 3.384 = 4.629 $KW_{Peak(DC)}$

$\eta_{pv} = 15.7\%\ datasheet$

$$number\ of\ PV\ panels = \frac{P_{DC\,(PV)}}{P_{panel}} = \frac{4.629k}{260} = 17.804\ \cong 18\,panels \qquad (3.8)$$

$$P_{\underset{STC}{dc}} = \frac{1kw}{m^2} at\ 1\ sun * Area * \eta_{pv} \qquad (3.9)$$

$$Area\ of\ PV = \frac{4.456kw}{\frac{1kw}{m^2}{*}0.159} = 28.03\ m^2$$

The system consist three strings connect with inerter by three Links of MPPT. Each string have 6 panels, which each 2 panels connect parallel, and the three pairs connect series.

3.3.3 Sizing of the PEM Fuel Cell

The PEM fuel cell supply is required when there is not enough solar radiation and in the night. Its power can be calculated according to the maximum load required.

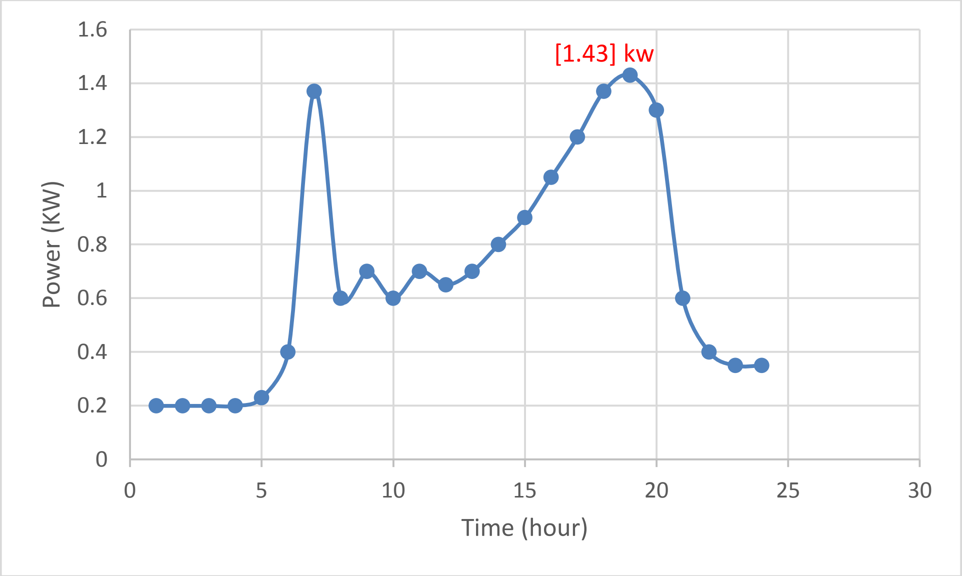

Figure 3.12: Behavior of maximum consumption load pattern per day in the year.

Based on the highest daily consumption during the year is in January which equal 1430 watt as appearance in figure (3.8), therefore we choose the rated power for PEM fuel cell = 1500 watts with efficiency = 56%, taking into consideration the increase of consumption in the future. Where need three fuel cell 500 watt, connect them in series, start up battery 13.5V and converter to step up voltage for inverter.

3.3.4 Sizing an Electrolyzer

The rated power of the electrolyzers can be calculated by the equation (3.10):

$$P_{el} = P_{PV} - P_{L,min} \quad (3.10)$$

P_{el} : rated power of the electrolyzer.

P_{PV}: output power of PV modules.

$P_{L,min}$: minimum power of the load.

$P_{el} = 1832 – 370 = 1462$ watt

Where the maximum power from PV in the year at June, it is equal 1836 watt, minimum consumption equal 370 watt. Therefor we will choose electrolyzer of 1500 watt.

3.3.5 Power management

The most important in the system is ability to manage operation of PEM fuel cells and electrolyzer, which coordinate the changes load of house by time. PV operate throughout the presence of the radiation, but dealing with of the excess or missing power led to operate PEM fuel cells or electrolyzer by power management strategy.

The adopted PMS is must be built to provide the operating modes under variable weather conditions to cover the consumption demand all time and the logical block diagram is shown in figure (3.13).

The PV modules provides the necessary power to meet the total load demand, and the excess power from the PV modules will provides the electrolyzer to produce the hydrogen when $P_{PV} > P_{Load}$, but if $P_{PV} < P_{Load}$ then is necessary run PEM fuel cells to provide load of enough power that make power difference between solar and load equal zero.

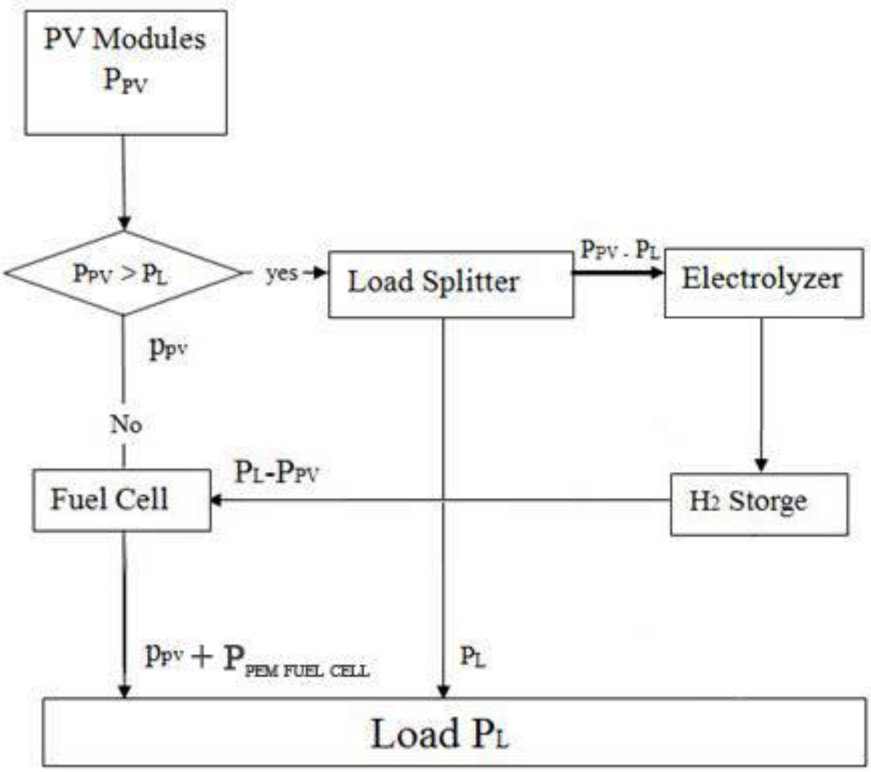

Figure 3.13: Logical block diagram for PMS [11].

3.4 Microbial Fuel Cell design

3.4.1 Over view

The Annual energy used for the water infrastructure was 5-6% of all electricity generated and (0.12 to 1-2 kWh/m^3) for Wastewater treatment.

Because of the low initial cost, low operating costs, and low power output associated with an MFC, the main market of it is people who live or work in areas without access to conventional means of power production and clean water, but still have need of small amounts of electrical power for applications with safety water for use.

This project use natural resources (mainly sun and water) to create sustainable, environment friendly energy for use in areas suffering of water shortage and when the energy is not readily or economically available. The Wastewater used was collected from a house contain 6 person located in south of Hebron, the samples was only greywater.

The Fuel Cell is one of the electrochemical devices which are capable to produce electricity directly from chemical energy. Microbial Fuel Cells are those which diverse chemically as bacteria that powered the cells and drawn worldwide interest as a direct electricity generation from organic material like wastewater. It use bacteria to catalyze the conversion of organic material to electricity. Bacteria generate electrons and protons in anode from oxidized substances and electrons are transferred through an external circuit.

Here protons diffuse through the solution to the cathode and electrons combine with protons and oxygen and form water. Some factors affecting the performance of MFC such as Solution conductivity, Electrode spacing, batch and continuous flow, hydraulic retention time and Cathode material.

In wastewater treatment system MFCs can convert 1 kg of chemical oxygen demand (COD) to 4 kWh, but with anaerobic digestion 1 kg of COD could be converted to roughly 1 kWh , The average power density of MFCs is about 40 W/m^3 [38].

3.4.2 Microbial Fuel Cell, component and process

Microbial Fuel Cells comprised with an anode and a cathode, these are separated by a proton exchange membrane (PEM). In anode compartment electron donors are oxidized by bacteria and produce free electrons and protons and bacteria transfer’s electrons to anode which are insoluble electron acceptor. After deposition of electrons on anode these transfer to cathode through an external circuit (electricity production) and protons travel through wastewater and PEM. At the end protons and electrons travel to cathode where oxygen reduces to produce water, in most MFCs the electrons that reach the cathode combine with protons that diffuse from the anode through a separator and oxygen provided from air; the resulting product is water.

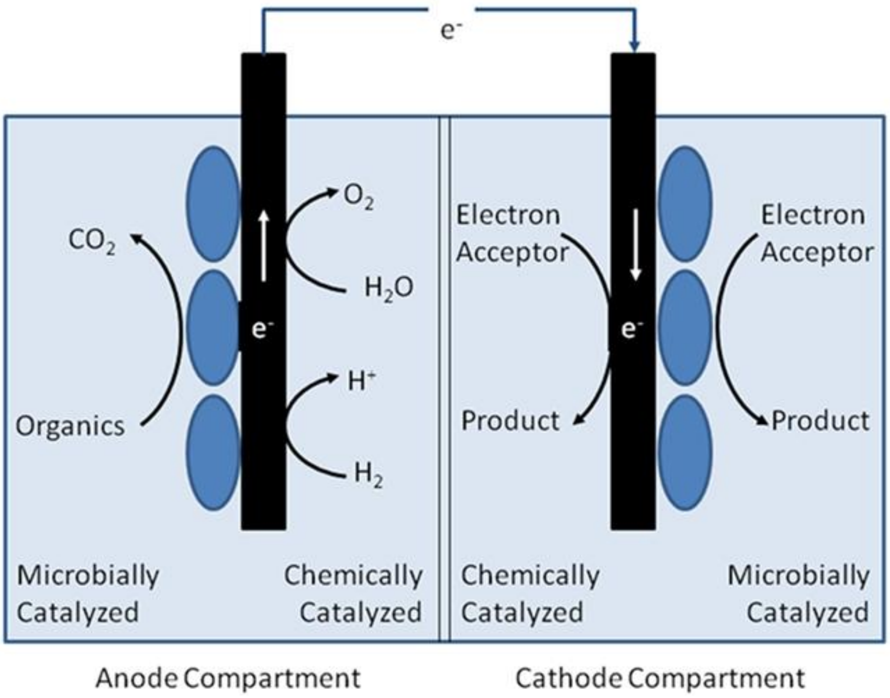

Figure 3.14: Model for Microbial Fuel Cells catalyzed [39].

The situation occurs where bacteria can feed food. Bacteria create oxygen lacking situation which helpful for them to grow in slow, oxygen act as electron acceptor. Electrons from any bio available molecules are taken by bacteria and transfers through a metabolic pathway in a way that electron may use as electricity supply in a cell. Here oxygen act as driving force within this system.

The *Geobacter-sulfurreducens* bacteria (GSR) is the most effective bacteria used in term of its price, power, accessibility and needing of caring, *Geobacter-metallireducens*(GMR) and *Rhodoferax-ferrireducens*(RFR) are followed it respectively .

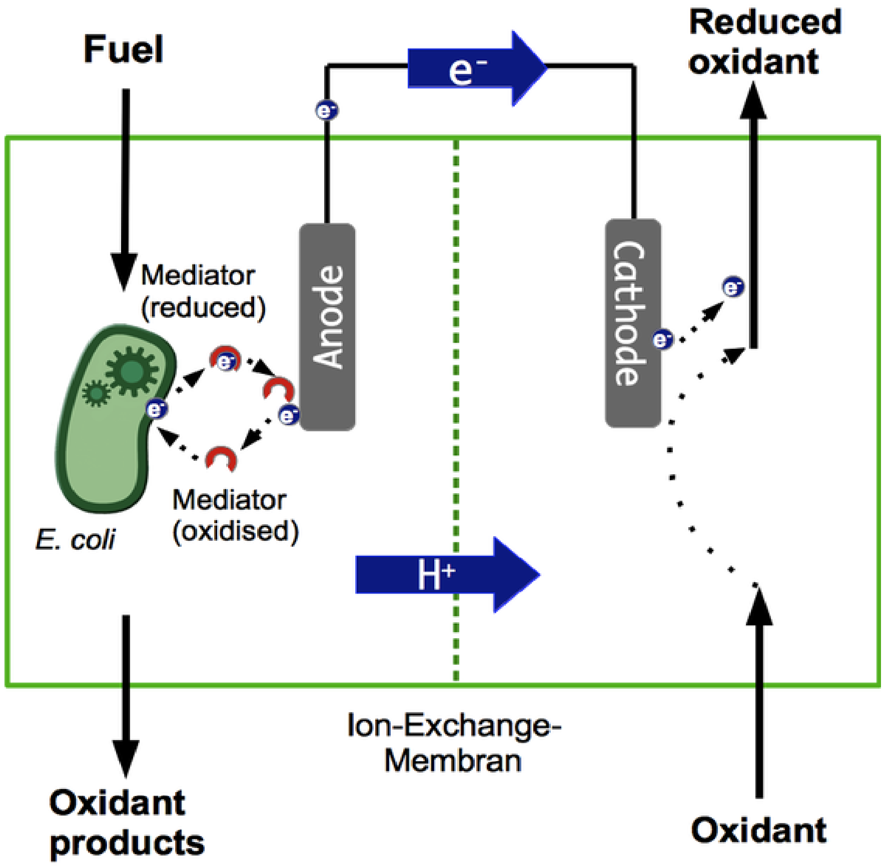

Figure 3.15: Schematic illustration of the general microbial fuel cell functional principle, and the flow of charged species during operation [40].

3.4.3 Types of MFC

Types of MFCs include bio-electrochemically assisted microbial reactor BEAMR, single chamber microbial fuel cell, conventional two-chamber, a flat plate MFC, single chamber air cathode system ,salt bridge MFC and MFC with cells joined in series. An exclusive summery for each type with schematic view are shown in figures below :

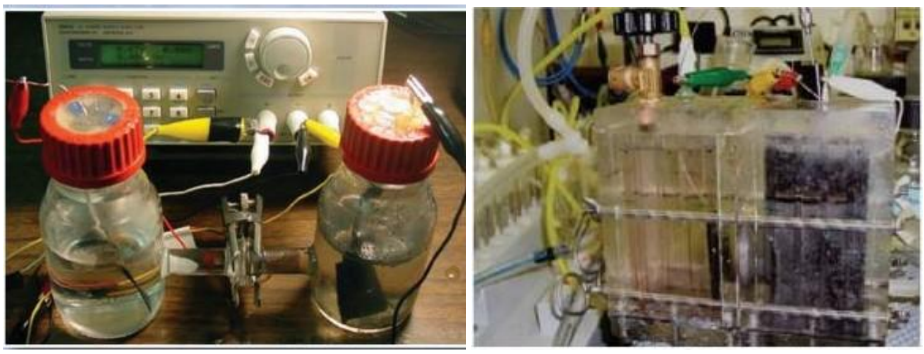

Figure 3.16: The BEAMR MFC [41].

The BEAMR process is a two-chambered system that produces pure hydrogen gas. The power generated by the bacteria in the anode is supplemented with a slight voltage, producing hydrogen gas in the cathode chamber (on left).

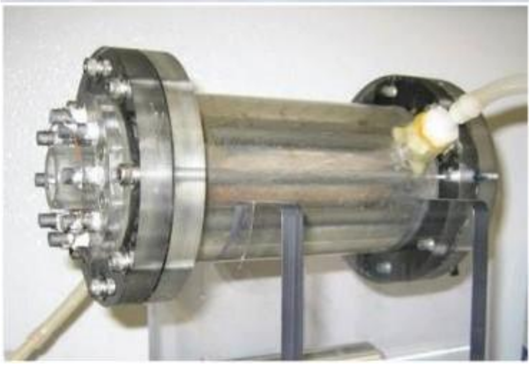

Figure 3.17: Single chamber MFC [42].

The design of single chamber microbial fuel cell (MFC). This MFC was used to show how electricity could be continuously produced from wastewater. The central cathode tube running down the center, surrounded by graphite rods (anodes).

Figure 3.18: The conventional H-design MFC [41].

The conventional MFC with two-chamber, as the "H-design" MFC. As shown, both the anode and cathode chambers can be gas exposed, the anode chamber with anaerobic conditions where the bacteria grow, the other with air to provide oxygen in solution (cathode). A proton exchange membrane is clamped between the ends of the tubes to allow passage of protons (H+) and to limit exchange of substrate from the anode to cathode chamber, and oxygen from the cathode to anode chamber.

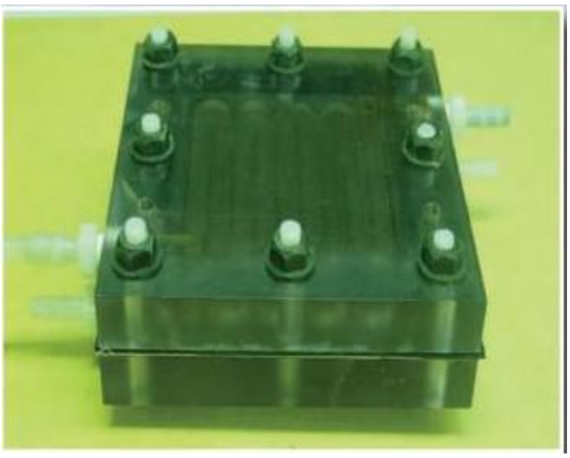

Figure 3.19: The flat plate MFC [42].

The flat plate MFC that operates in continuous flow mode and it is a lot like a conventional hydrogen fuel cell. This MFC has a proton exchange membrane sandwiched between two electrodes such as carbon paper. Channels are drilled so that the flow follows a serpentine path through the system.

Figure 3.20: A single chamber air cathode system [41].

A single chamber air cathode system which is the most commonly used MFC. The cathode was exposed to air on one side and water on the other side (inside). There is no proton exchange membrane. The anode, where the bacteria grow, is on the opposite side but is sealed so that air cannot enter. This type of cell is a relatively new invention. The first idea of it was formed in 1911, and the first design was conceived in 1977.

Figure 3.21: A salt bridge MFC [41].

A very early MFC design which is the salt bridge MFC, it is very inexpensive to make. Protons are conducted between the two chambers via a salt bridge consisting of a glass tube filled with salty agar.

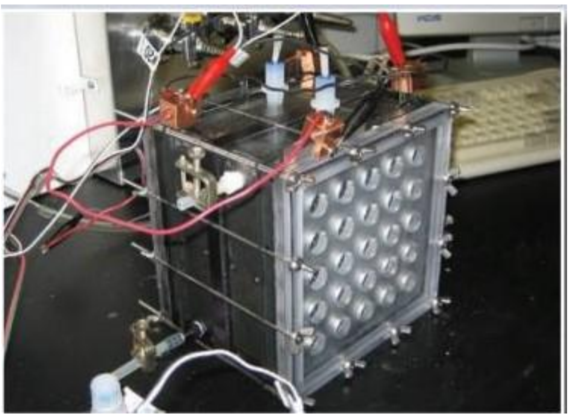

Figure 3.22: MFC with cells joined in series [41].

A MFC with two cells joined in series with granules material (usually graphite) in each anode chamber, this system can produces 2000 µW/m^2 of power.

3.4.4 MFC Redox reaction

The salt bridge allows current to flow of hydrogen ions in a circuit. The anode of the microbial fuel cell depends on a potential that causes the current to flow, and therefore, the oxidation reaction in its chamber is also dependent on a potential. In this case, the potential element is the cathode in the chamber filled with oxygenated water, because it helps to complete a reduction reaction in that chamber. Oxidation and reduction reactions always have to occur together (called a redox reaction), and in a microbial fuel cell, they are absolutely necessary. Electrons emitted by an oxidation reaction must be accepted by atoms or ions of another substance.

During the first oxidation reaction, which takes place in the wastewater filled container on the anode, the bacteria consume organic material for energy and water. They then yield carbon dioxide, positive hydrogen ions, and electrons. The positive hydrogen ions and the electrons are attracted to compounds in the second container and will take part in a reduction reaction. The electrons travel up to the cathode in the second container. The positive hydrogen ions make their way across the salt bridge to the second container. This is here the second part of the redox reaction takes place.

During the reduction reaction, the positive hydrogen ions combine with the electrons left over from the oxidation reaction and oxygen from within the water to yield water. The redox reaction ends here. Therefore, the lifetime of the microbial fuel cell is limited by the lifetime of the bacteria within the sample of wastewater.

The anaerobic process equation in the anode reaction was:

$$\text{BOD} + \text{biomass} \longrightarrow CO_2 + H^+ + e^- \tag{3.11}$$

While the aerobic process equation in the cathode reaction was:

$$O_2 + H^+ + e^- \longrightarrow H_2O \tag{3.12}$$

The aquarium pump provides extra oxygen to the reaction yielding water. Because the bacteria are not exposed to oxygen, they produce carbon dioxide, protons, and electrons instead of carbon dioxide and water.

Bacteria need energy to survive, Bacteria get this energy in a two-step process. The first step requires the removal of electrons from some source of organic matter (oxidation), and the second step consists of giving those electrons to something that will accept them (reduction), such as oxygen. The electrons then move across a wire under a load (resistor) to the cathode where they combine with protons and oxygen to form water. When these electrons flow from the anode to the cathode, they generate the current and voltage to make electricity.

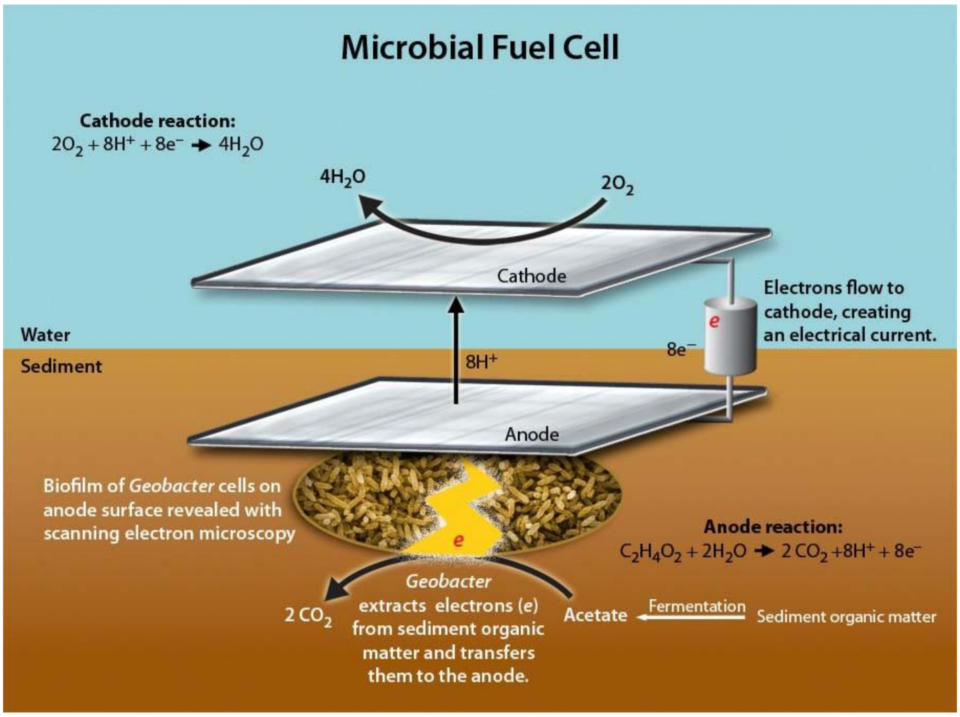

Figure 3.23: MFC Redox reaction [43].

Chapter Four

Modeling And Simulation

4.1 Introduction

The models of simulation facilitate more understanding of the system whereas does not need to perform experimental tests. Based on the amount of information available on system can build generic models able to emulate the behavior of any system. Simulation model of PV, PEM fuel cell, electrolyzer was realized in the Matlab-Simulink environment.

In this part of project the electrical components of the system, like photovoltaic panel, PEM fuel cell, electrolyzer, control management of hybrid system are modeled as a Simulink blocks by using matlab simulation program. All of the models are based on physical and chemical principles so they are based on mathematical equations. The models have been designed to be as general as possible. Simulink offers the advantage of buildings hierarchical models, namely to have the possibility to view the system at different levels. Thus each block can contain other blocks, other levels.

4.2 Photovoltaic (PV) system

4.2.1 Mathematical model for a photovoltaic module

A solar cell is basically a p-n junction fabricated in a thin wafer of semiconductor. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor creates some electron-hole pairs proportional to the incident irradiation[44]. The equivalent circuit of a PV cell is as shown in Figure 4.1.

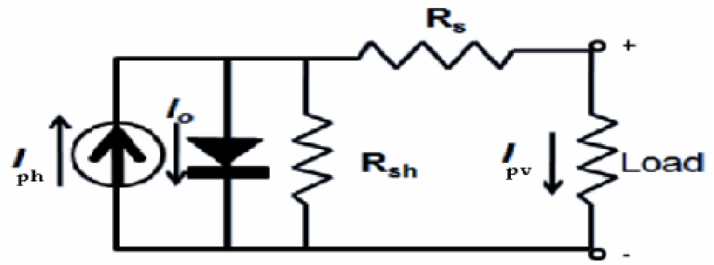

Figure 4.1: PV cell modeled as diode circuit [44].

The current source I_{ph} represents the cell photocurrent. R_{sh} and Rs are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of R_{sh} is very large and that of Rs is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in a parallel-series configuration to form PV arrays.

The photovoltaic panel can be modeled mathematically as given in equations (4.1)-(4.4).

Module photo-current:

$$I_{Ph} = [I_{SCr} + K_i\,(T\text{-}298)] * \lambda \backslash 1000 \qquad (4.1)$$

Module reverse saturation current - I_{rs}:

$$I_{rs} = I_{SCr} / [\,exp(qV_{OC} / N_S\, kAT) - 1\,] \qquad (4.2)$$

The module saturation current I0 varies with the cell temperature, which is given by

$$I_0 = I_{rs}\,[\frac{T}{Tr}]^3\, exp\,[\frac{q * E_{g0}^{1}}{Bk}] \qquad (4.3)$$

The current output of PV module is (4)

$$I_{rs} = I_{SCr} / [\,exp(qV_{OC} / N_S\, kAT) - 1\,] \qquad (4.4)$$

Where Vpv = Voc,

4.2.2 Step by step procedure for simulink modeling of PV module

A model of PV module with moderate complexity that includes the temperature independence of the photocurrent source, the saturation current of the diode, and a series resistance is considered based on the Shockley diode equation.

Being illuminated with radiation of sunlight, PV cell converts part of the photovoltaic potential directly into electricity with both I-V and P-V output characteristics.

Using the equations given in previous section, simulink modeling is done in the following steps:

Step 1:

Subsystem 1 is shown in Figure 4.2. This model converts the module operating temperature given in degrees Celsius to Kelvin and we used these equations:

TaK = 273 + Top (operation Temp)

TrK=273 + 25 (Ref Temp)

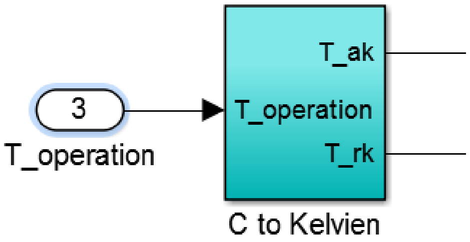

Figure 4.2: Subsystem 1.

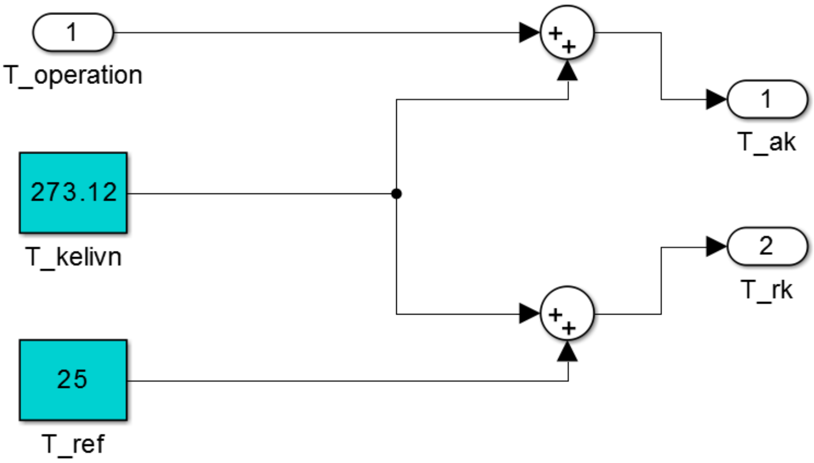

Figure 4.3: Circuit under subsystem 1.

Step 2:

Subsystem 2 is shown in Figure 4.4. This model simulation for equation 1, and takes following inputs:

Irradiation – (G / 1000) 1 kW/ m2 = 1.

Module operating temperature T_{aK} = 30 to 70 C °

Module reference temperature T_{rK} = 25 C °.

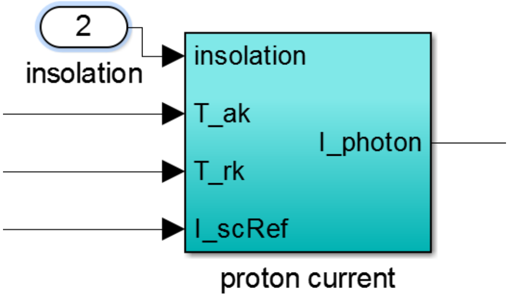

Figure 4.4: Subsystem 2

This model to find light generated photon current of PV module. Figure 4.5 gives the circuit under subsystem.

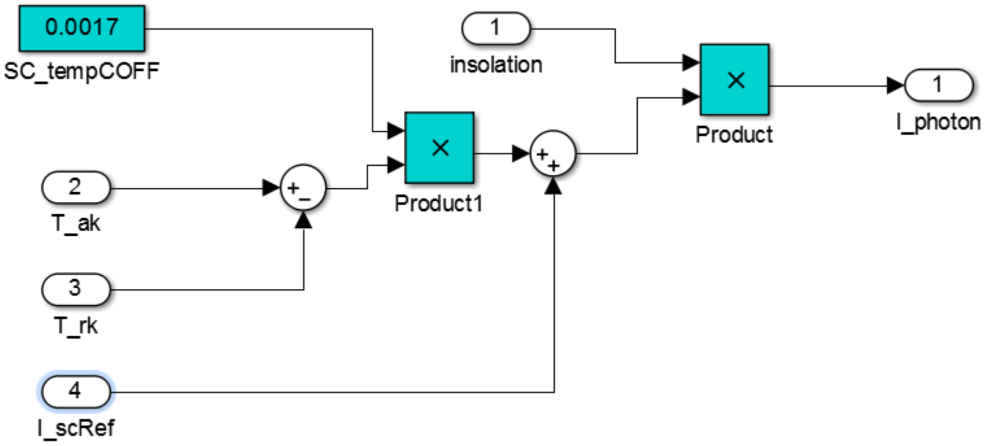

Figure 4.5: Circuit under subsystem 2.

Step 3:

Subsystem 3 is shown in Figure 4.6. This model simulation for equation 2, takes Module reference temperature TrK= 25 C ° as input.

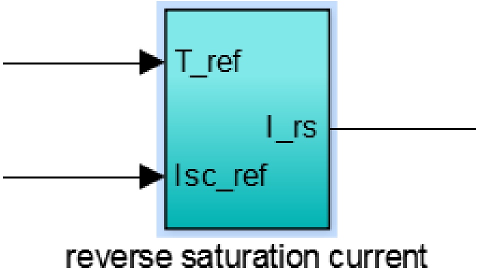

Figure 4.6: Subsystem 3.

Using equation 2, the reverse saturation current of the diode is calculated in subsystem 3. Figure 4.7 gives the circuit under subsystem 3.

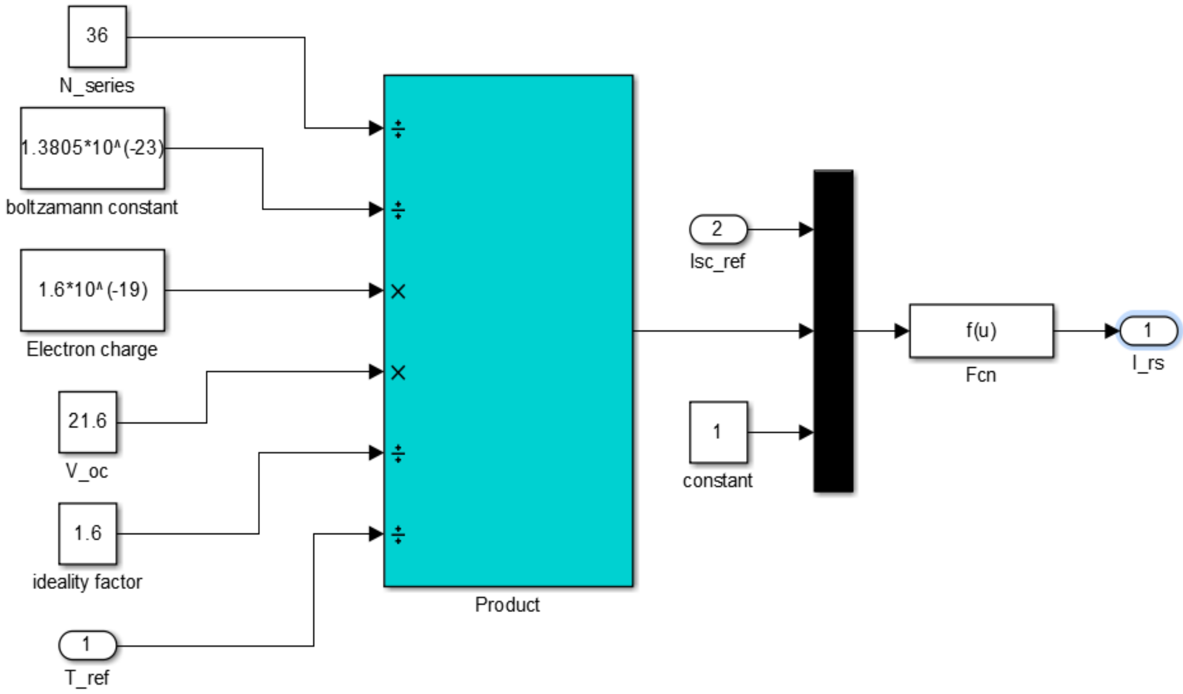

Figure 4.7: Circuit under subsystem 3.

Step 4:

Subsystem 4 is shown in Figure 4.8.

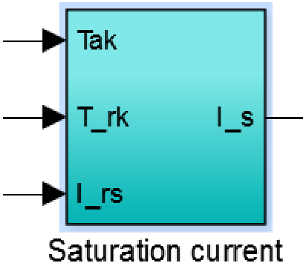

Figure 4.8: Subsystem 4.

This model takes reverse saturation current I_{rs}, Module reference temperature T_{rK} = 25 C° and Module operating temperature T_{aK} as input and calculates module saturation current. Figure 4.9 gives the circuit under subsystem 4.

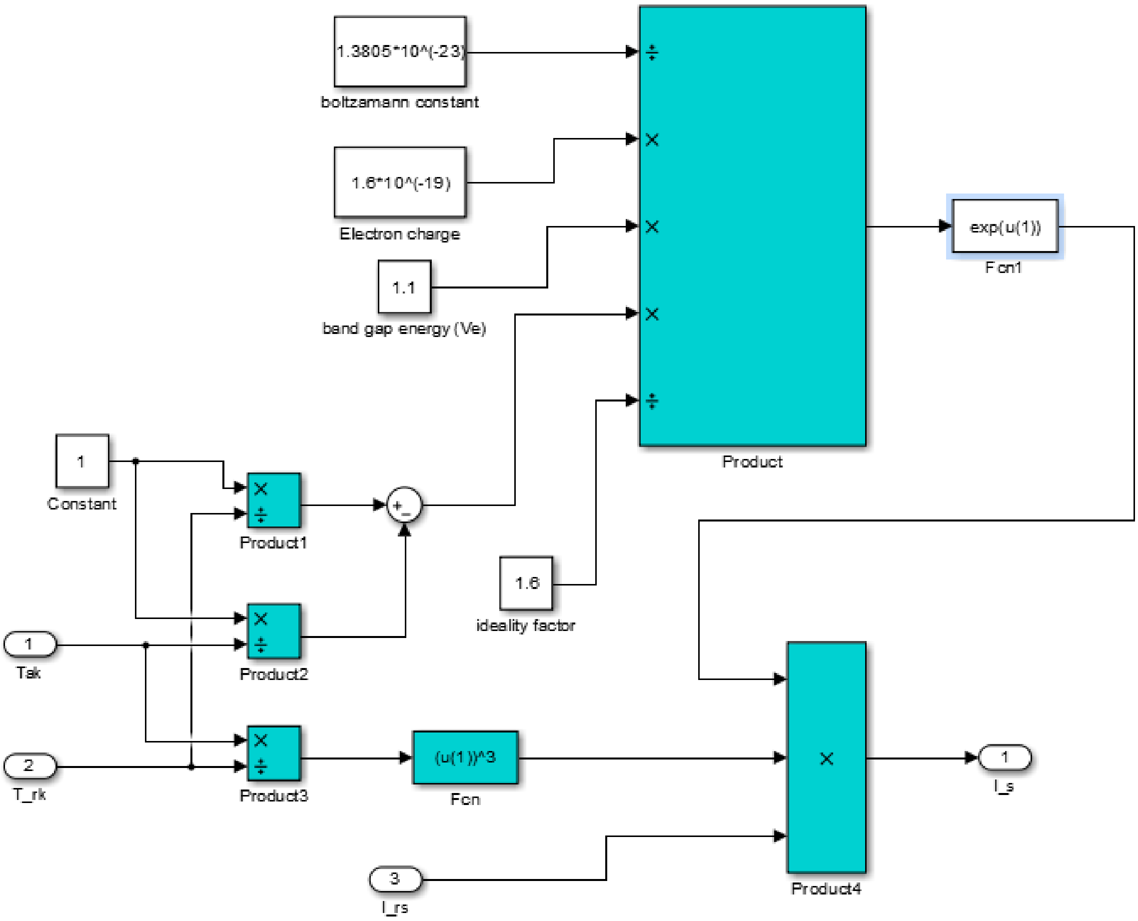

Figure 4.9: Circuit under subsystem 4.

Step 5:

Subsystem 5 is shown in Figure 10.

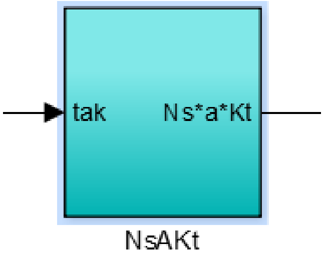

Figure 4. 10: Subsystem 5.

This model takes operating temperature in Kelvin T_{aK} and calculates the product NsAkT, the denominator of the exponential function in equation (4). Figure 4.11 gives the circuit under subsystem 5.

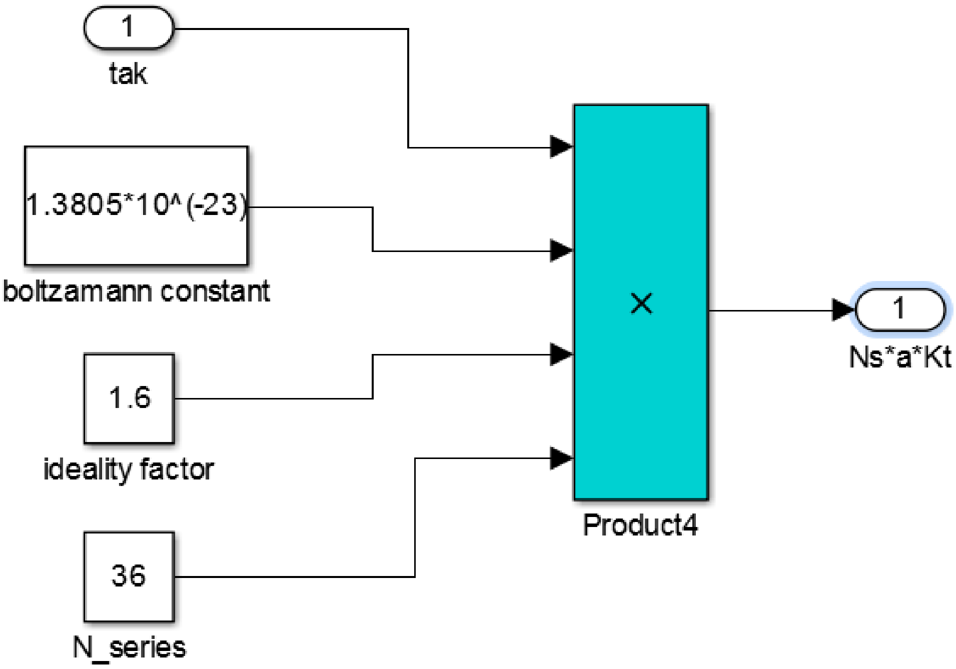

Figure 4.11: Circuit under subsystem 5.

Step 6:

Subsystem 6 is shown in Figure 4.12.

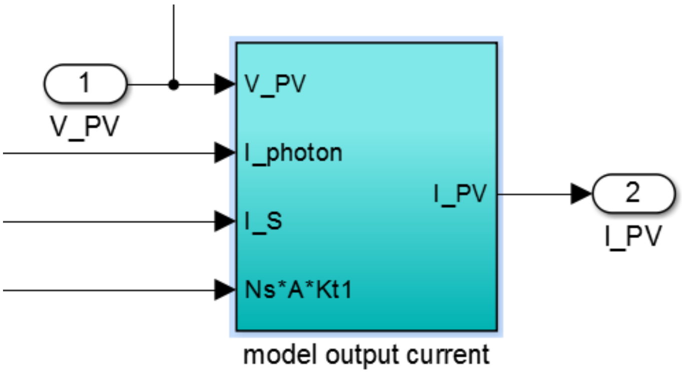

Figure 4.12: Subsystem 6.

This model executes the function given by the equation (4). Figure 4.13 gives the circuit under subsystem 6.

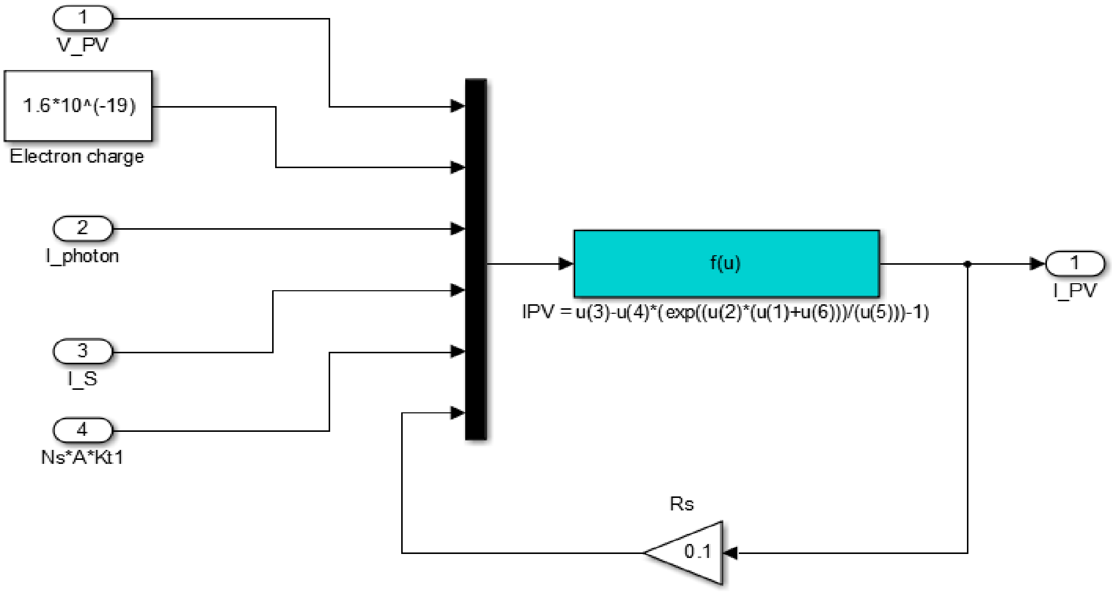

Figure 4.13: Circuit under subsystem 6.

Step 7:

All above six models are interconnected as given in Figure 4.14.

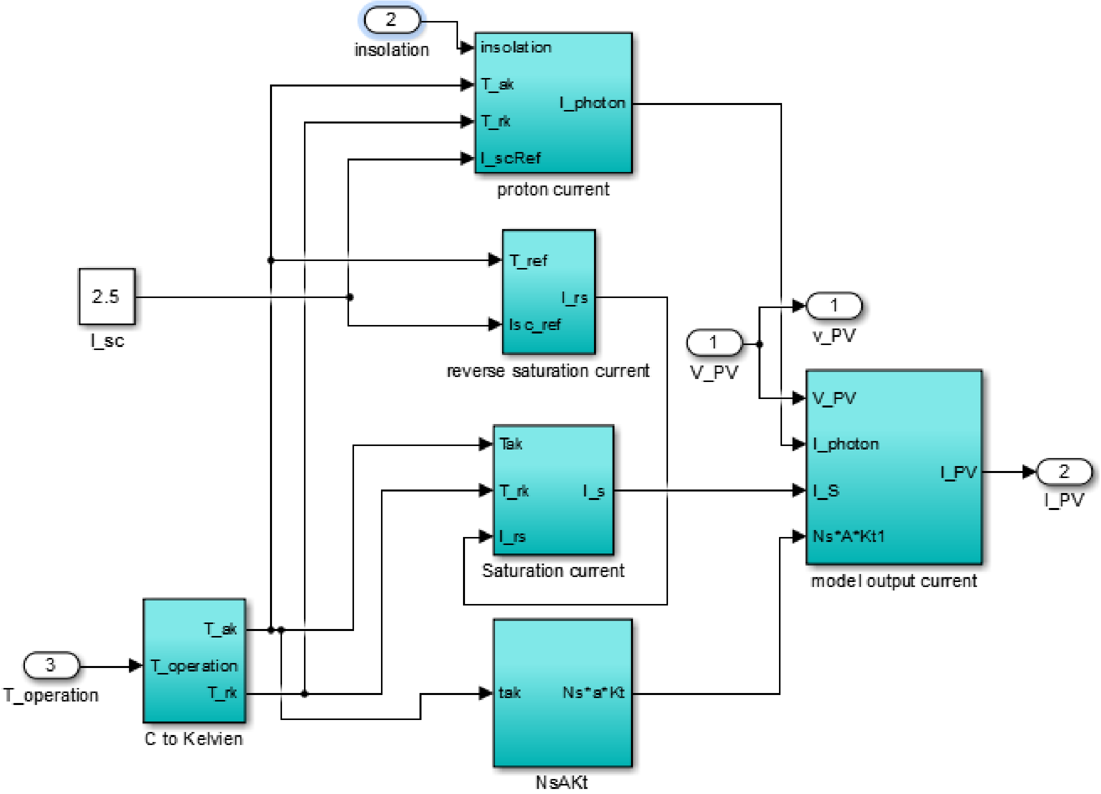

Figure 4.14: Interconnection of all six subsystems.

The final model is shown in Figure 4.15. The workspace is added to measure I_{pv}, V_{pv}, P_{pv} in this model. The time tout is stored in workspace with scope model can be used to plot graph.

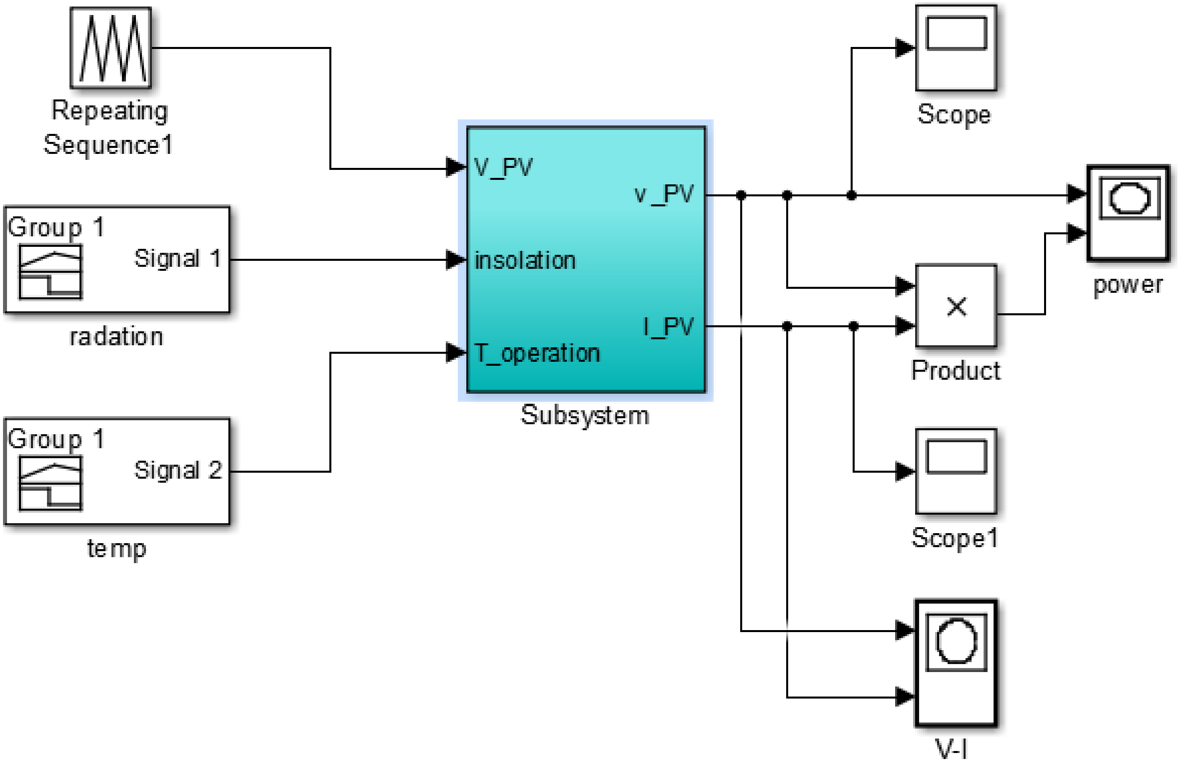

Figure 4.15: Simulink model of PV module.

The final model takes irradiation, operating temperature in Celsius and module voltage as input and gives the output current I_{pv} and output voltage V_{pv}.

Matlab code for plotting XY graph is given below:

plot (V_{pv}, I_{pv})

plot (V_{pv}, P_{pv})

4.2.3 Performance Estimation

In Figure 4.16, the input irradiation is shown. Between 0 and 1 s, the irradiation is 300W/m2, between 1 and 2 s it is 700 W/m, while from 2 s onwards it is 1000W/m2.

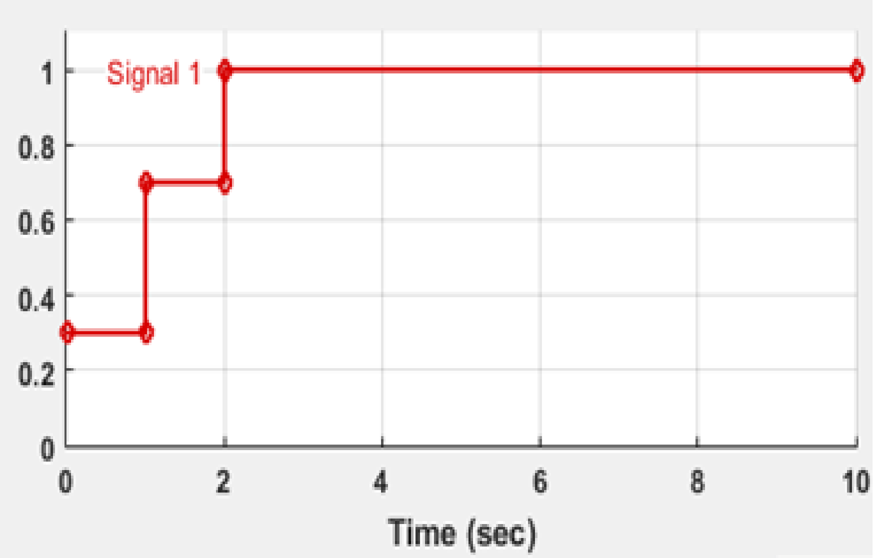

Figure 4.16: Input – Time varying irradiation - 1000*(W/m^2**)**.

In Figure 4.17 the input temperature is shown which is constant at 25 C°.

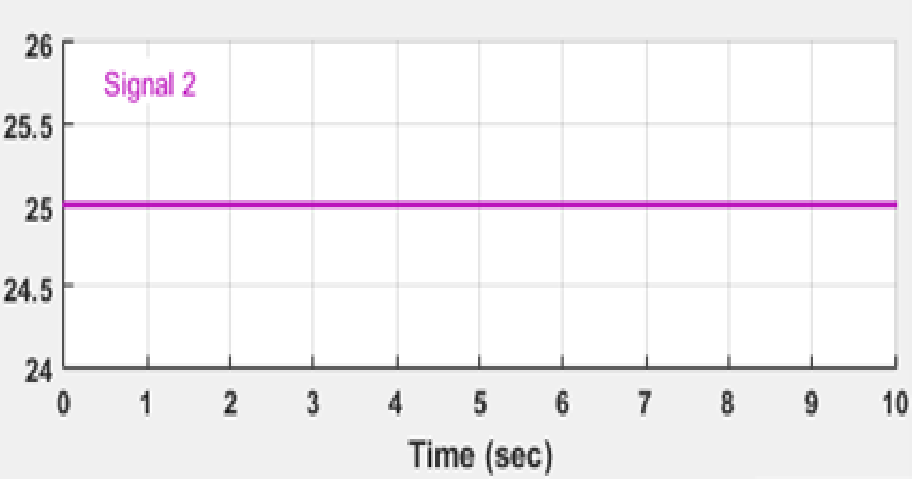

Figure 4.17: Input - Constant temperature – 25 C°.

The I-V output characteristics of PV module with varying irradiation at constant temperature are shown in Figure 4.18.

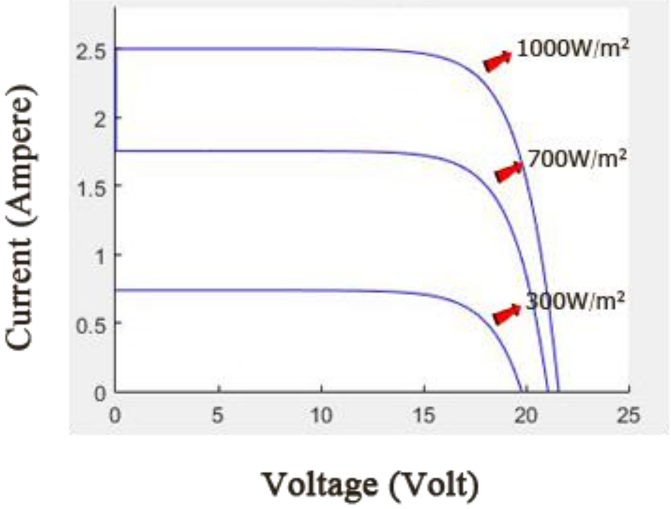

Figure 4. 18: Output – I-V characteristics with varying irradiation.

The P-V output characteristics of PV module with varying irradiation at constant temperature are shown in Figure 4.19.

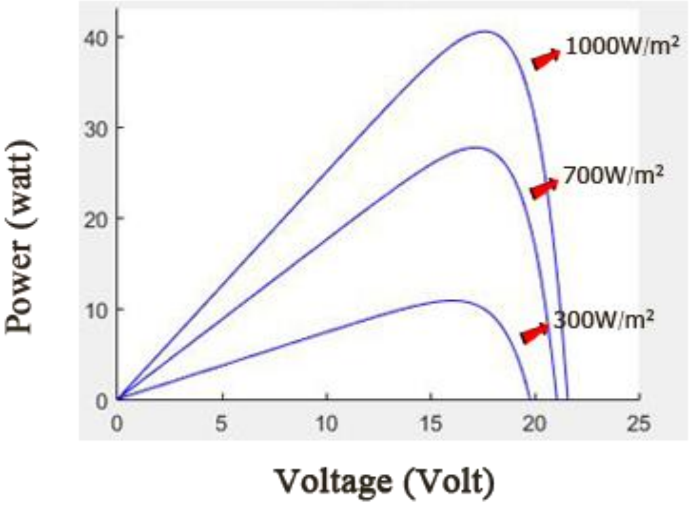

Figure 4.19: Output – P-V characteristics with varying irradiation.

When the irradiation increases:

- The current output increases
- The voltage output also increases.

This results in net increase in power output with increase in irradiation at constant temperature.

I-V and P-V Characteristics under constant irradiation with varying temperature are obtained in Figures 4.20 to 4.23. In Figure 4.21 the time varying temperature signal is shown. Between 0 and 1 second, the temperature of 25 C° is applied and it is increased to 45 and 75C°.

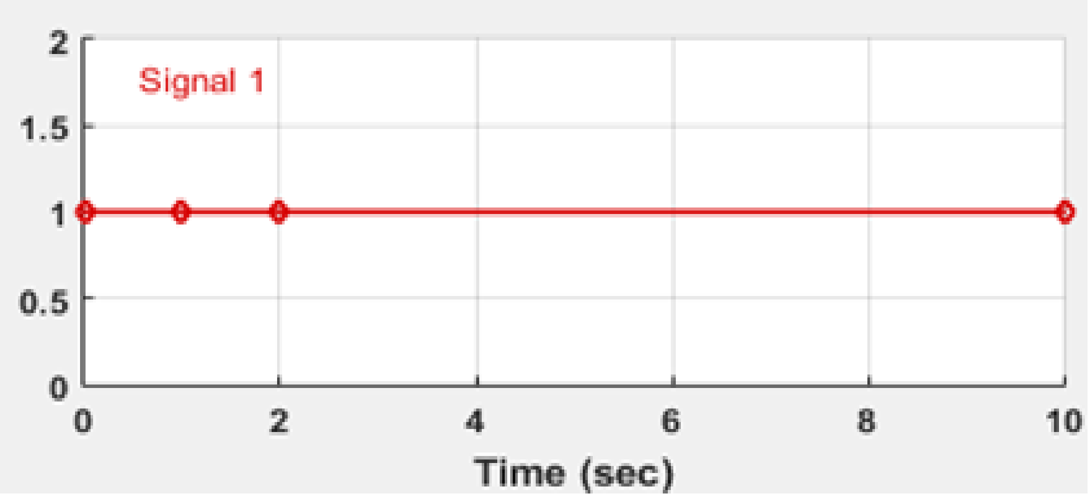

Figure 4.20: Input – Constant irradiation of 1000W/m2.

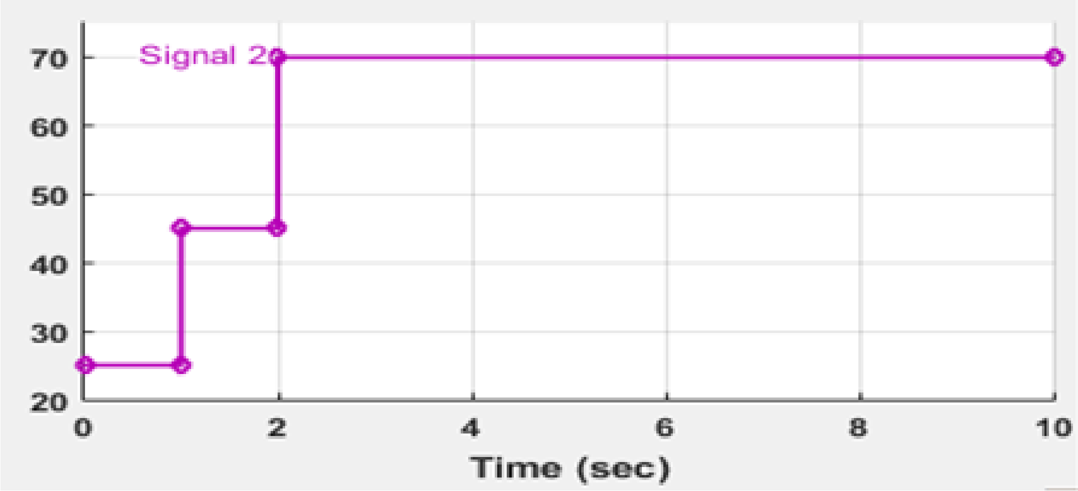

Figure 4.21: Input – Time varying temperature (**C**°).

The I-V output characteristics of PV module with varying temperature at constant irradiation of 1000W/m2 are shown in Figure 4.22.

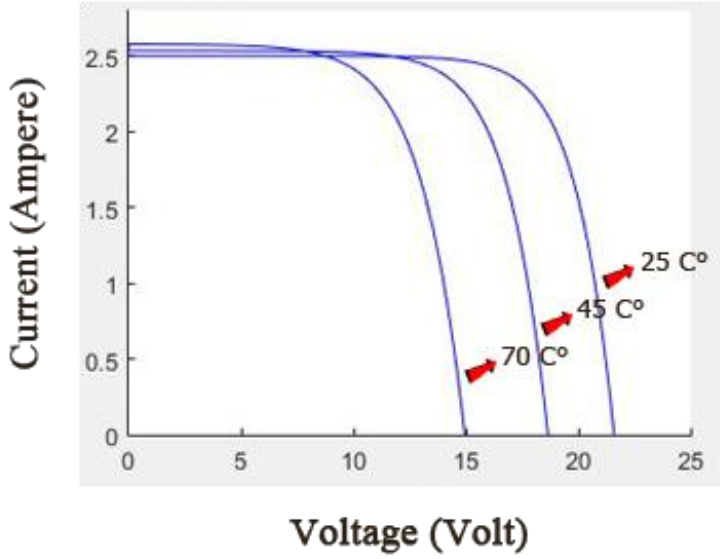

Figure 4.22: Output – I-V characteristics with varying temperature.

The P-V output characteristics of PV module with varying temperature at constant irradiation are shown in Figure 4.23.

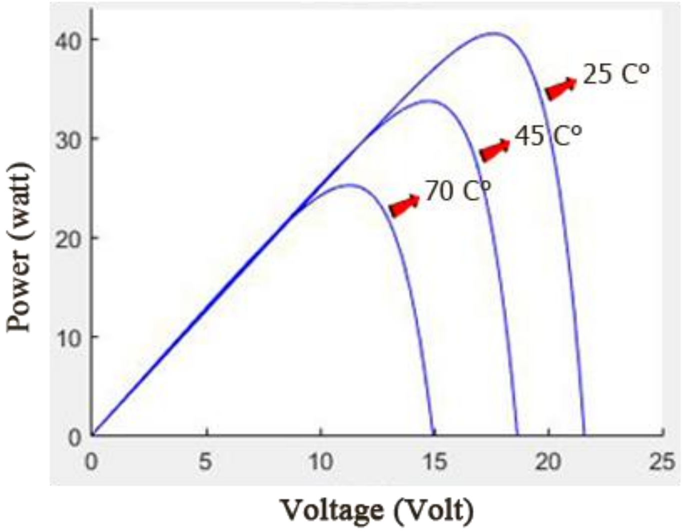

Figure 4.23: Output – P-V characteristics with varying temperature.

When the operating temperature increases:

- The current output increases marginally
- But the voltage output decreases drastically
- Results in net reduction in power output with rise in temperature

4.3 PEM Fuel Cell

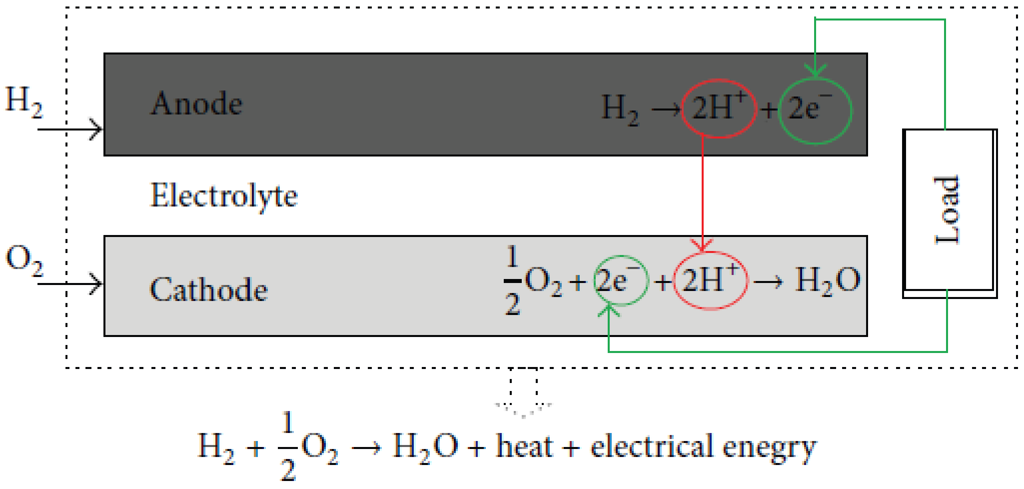

Figure 4.24: Cross-sectional view of a PEM Fuel Cell[45].

The amount of hydrogen and oxygen consumed in the fuel cell depends upon the input and output flow rates and the current drawn out of the fuel cell; it also depends upon the volume of electrodes[45].

The different partials pressures can be given as:

$$PH_2 = \frac{1\frac{1}{KH2}}{\tau H2*S+1} * (\dot{m}_{H2-}^{in} 2 * K_r * I) \tag{4.5}$$

$$PO_2 = \frac{1\frac{1}{KO2}}{\tau O2*S+1} * (\dot{m}_{O2}^{in} - * K_r * I) \tag{4.6}$$

$$PH_2O = \frac{1\frac{1}{KH2O}}{\tau H2O*S+1} * (2 * K_r * I) \tag{4.7}$$

The thermodynamic potential E is given by:

$$E = [E_0 + \frac{R*T}{2*F} * log (\frac{PH2* P_{O2}^{0.5}}{P\ H2O})] \tag{4.8}$$

The ohmic voltage loss in the fuel cell is given by:

$$\eta_{ohmic} = I * R_{int} \tag{4.9}$$

The parametric equation for the over-voltage due to activation resistance is given as:

$$\eta_{act} = B * \log (C * I) \qquad (4.10)$$

The output voltage of the cell can be determinated from the combined effect of thermodynamics, mass transport, kinetics, and ohmic resistance, it is defined as:

$$V = E - \eta_{act} - \eta_{ohmic} \qquad (4.11)$$

The fuel cell power is a function of the current and voltage; it is given as follows:

$$P = V_{stack} * I \qquad (4.12)$$

From the various equations and the values from appendix H , we carried out a model of a fuel cell using Matlab Simulink, as it is shown below:

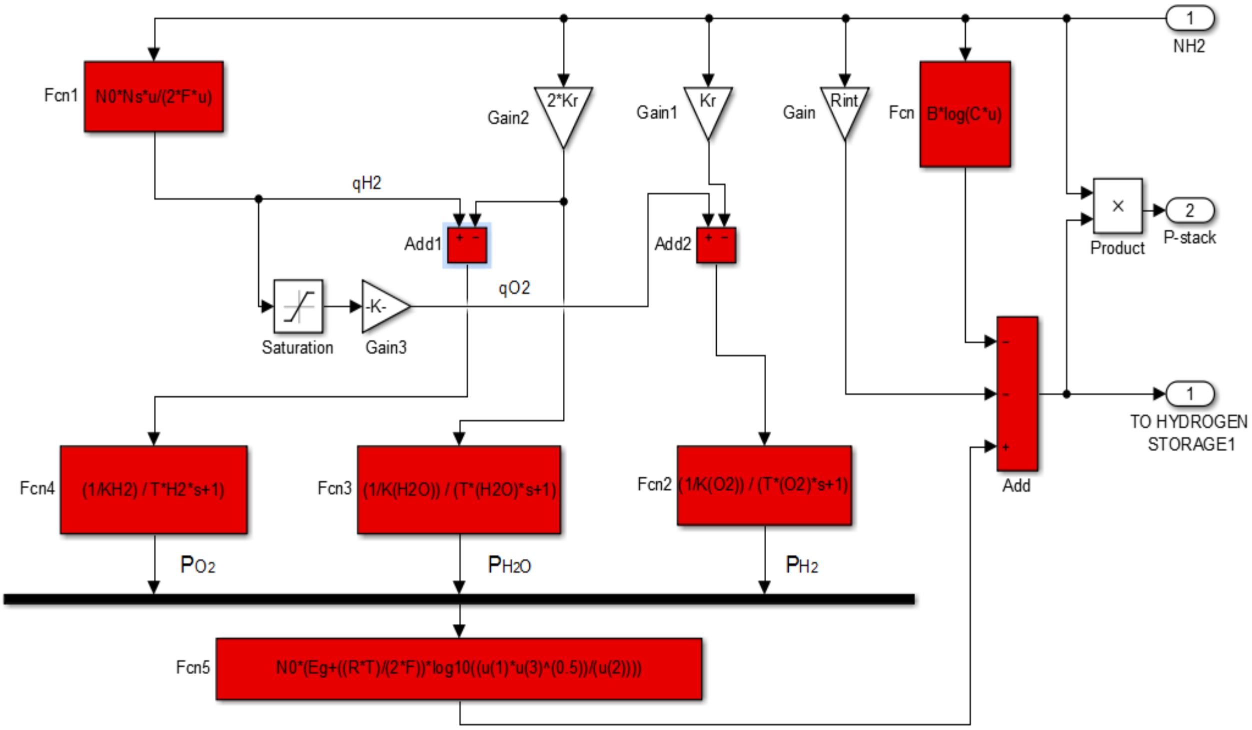

Figure 4.25: Fuel cell model.

4.4 Electrolyzer

An electrolyzer is a well known electrochemical device utilizing electrical current to decompose water into hydrogen and oxygen. It consists of several electrolyzer cells connected in series. The current in comparison to voltage feature of an electrolyzer depends on its working temperature according to Faraday's law, the production rate of hydrogen in an electrolyzer cell is directly proportional to the transfer rate of electrons at the electrodes, which in turn is equivalent to the electrical current in the circuit expressed in the following equation[46].

According to Faraday law, the production rate of hydrogen is directly proportional to the electrical current in the equivalent electrolyser circuit that given as:

$$N\,H_2 = \frac{\eta F * nC * ie}{2 * F} \tag{4.13}$$

Where ie is the electrolyzer current, nc is the number of electrolyzer cells in series and ηF is the Faraday efficiency which is the ratio between the actual and th eatrical amount of hydrogen produced in the electrolyzer. In general, it is assumed to be more than 99%. The Faraday efficiency is expressed by

$$\eta_F = 96.5 * exp\,(\frac{0.09}{ie} - \frac{75.5}{i_e^2}\,) \tag{4.14}$$

According to the Eqs (4.13) and (4.14), a simple electrolyzer model is developed using simulink, which is illustrated in figure 4.26.

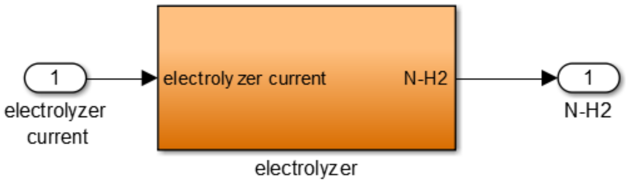

Figure 4.26: Electrolyzer subsystem.

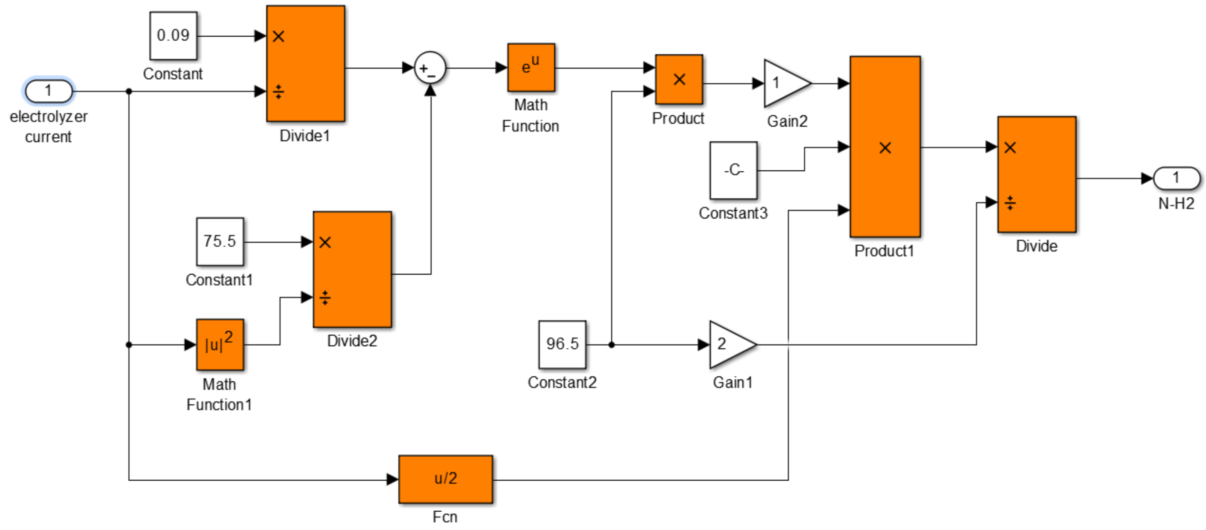

Figure 4.27: Electrolyzer model.

4.5 Hybrid System

The ability to manage operation of PV, PEM fuel cells and electrolyzer is the most important in the system, which coordinate the changes load of house by time. PV operate throughout the presence of the radiation, but dealing with of the excess or missing power led to operate PEM fuel cells or electrolyzer by power management strategy that done by MATLAB Function. The PV modules provides the necessary power to meet the total load demand, and the excess power from the PV modules will provides the electrolyzer to produce the hydrogen when $P_{PV} > P_{Load}$, but if $P_{PV} < P_{Load}$ then is necessary run PEM fuel cells to provide load of enough power to meet load demand. The manage operation of hybrid system as shown in Figure 4.28.

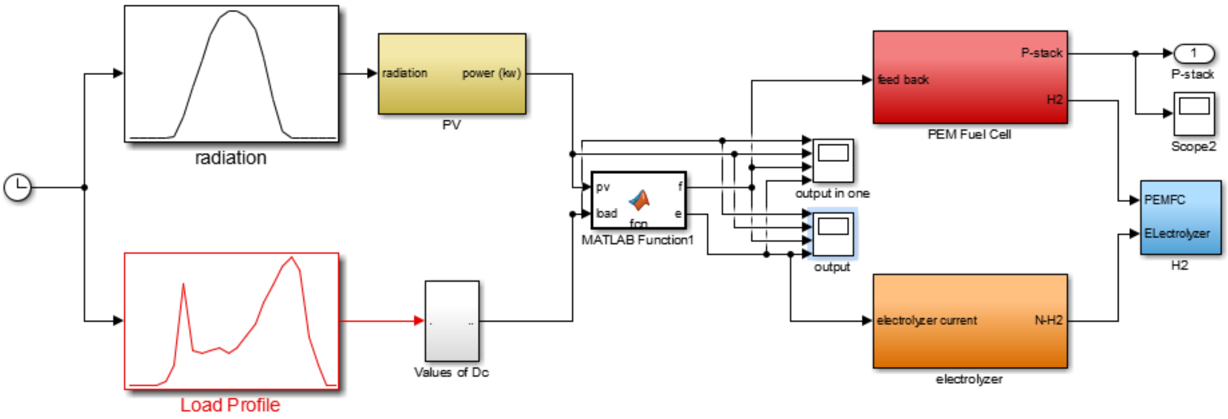

Figure 4. 28 : The manage operation of hybrid system of PV,PEM Fuel Cell and electrolyzer.

case 1: morning (5:00 AM - 8:00 AM)

In this period of day the sun rise slowly and the solar radiation will increase slowly and the PEM fuel cell will operate partially to provide the lack of energy, because PV panels do not cover all demand of consumption as shown in Figure 4.29.

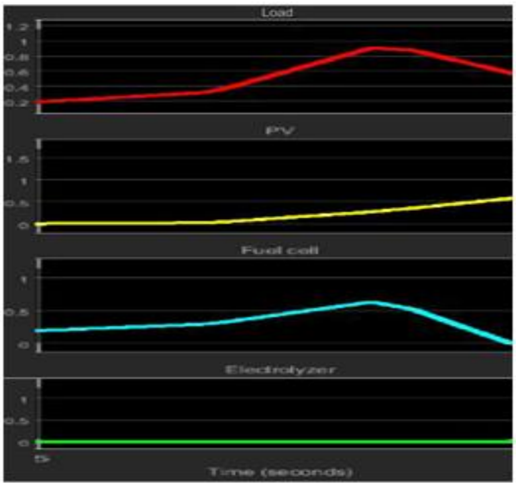

Figure 4.29: PV,PEM Fuel Cell, load, electrolyzer during the morning.

Case 2: (8:00 AM - 8:00 PM)

In this period of day the solar radiation will increase to reach its maximum values. Thus the power output from PV panels cover the load demand until the solar radiation decreases at sunset. Then PEM fuel cell still shutdown and work partially when sunset, but the excess of power from PV panels supply to electrolyzer to produce hydrogen as shown in Figure 4.30.

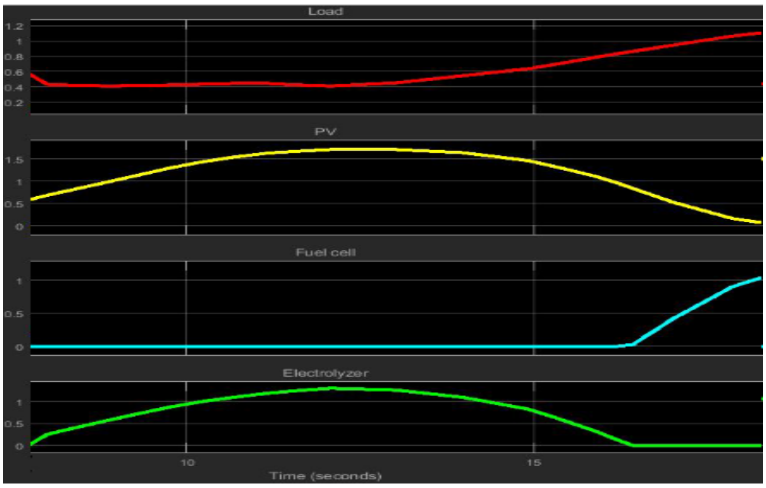

Figure 4.30: PV,PEM Fuel Cell, load, electrolyzer during the (8:00 AM - 8:00 PM).

Case 3: (8:00 PM - 5:00 AM)

During this period the solar radiation is zero so the power output from PV panels is zero. Thus the demand load totally in this period is covered by PEM fuel cell until sunrise as shown in Figure 4.31.

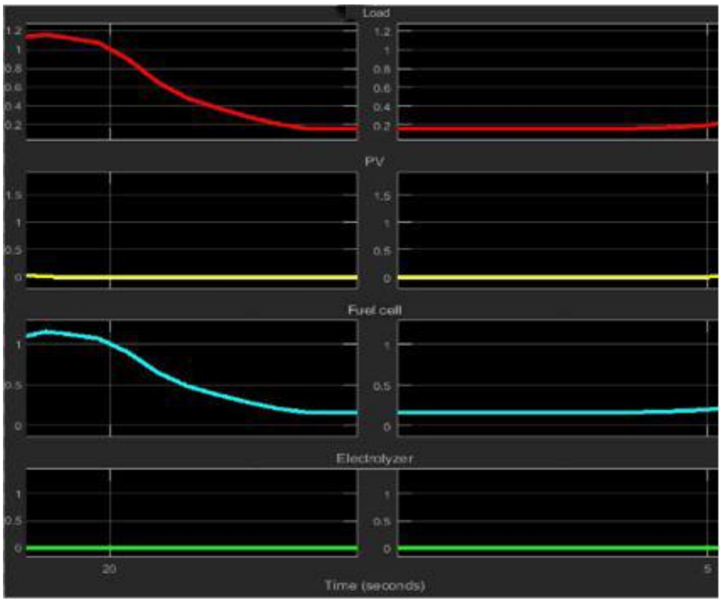

Figure 4.31: PV,PEM Fuel Cell, load, electrolyzer during the evening (8:00 PM - 5:00 AM).

The hybrid of PV, PEM fuel cells and electrolyzer in this system coordinate to the changes load of house during the day as shown in Figure 4.32.

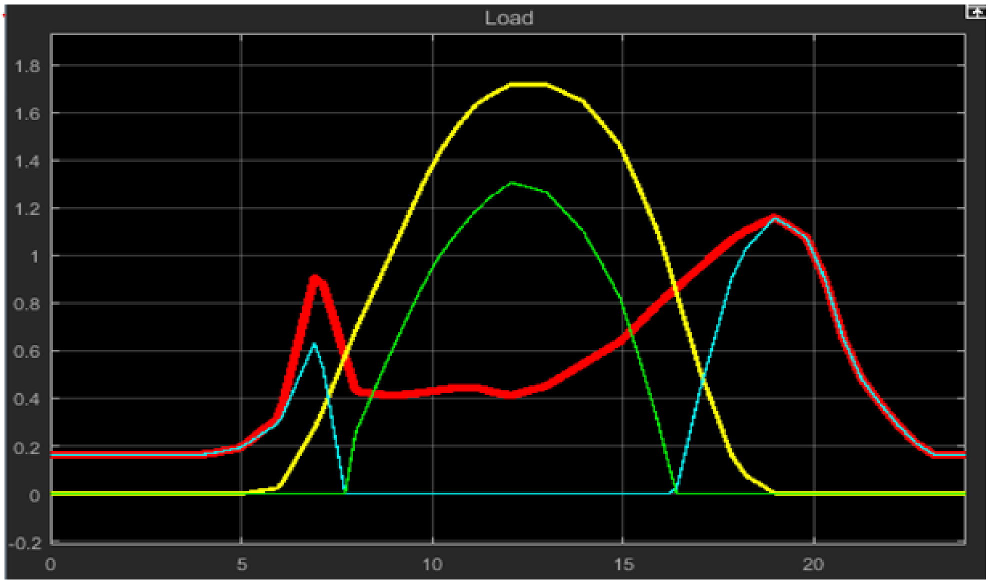

Figure 4. 32: PV,PEM Fuel Cell, load, electrolyzer during the day.

Fuel of electrolyzer is water, Figure 4.33 show the amount of water consumed by electrolyzer. The excess of power from PV panels supply to electrolyzer to produce hydrogen (Kmol/s) as shown in Figure 4.34. Amount of hydrogen consumed by PEM fuel cell as shown in Figure 4.35.

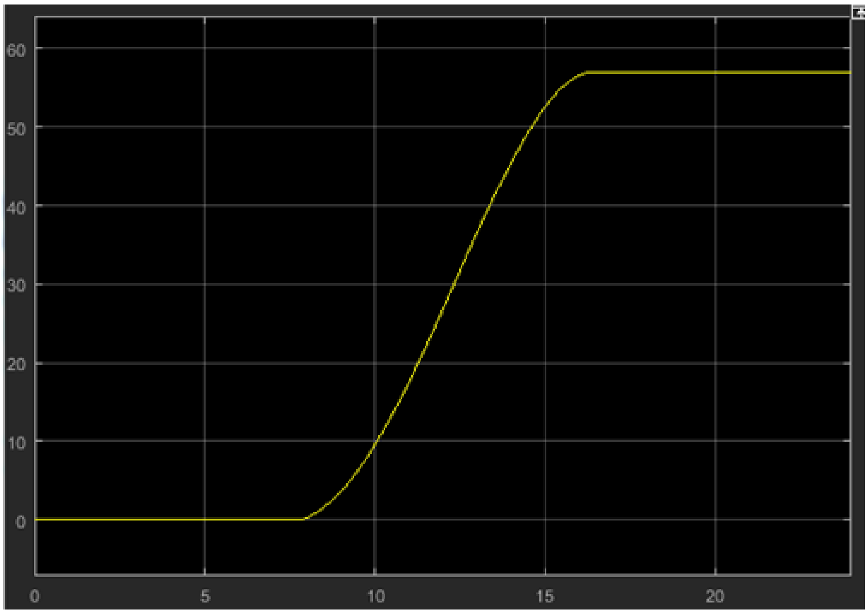

Figure 4.33: Amount of water consumed by electrolyzer.

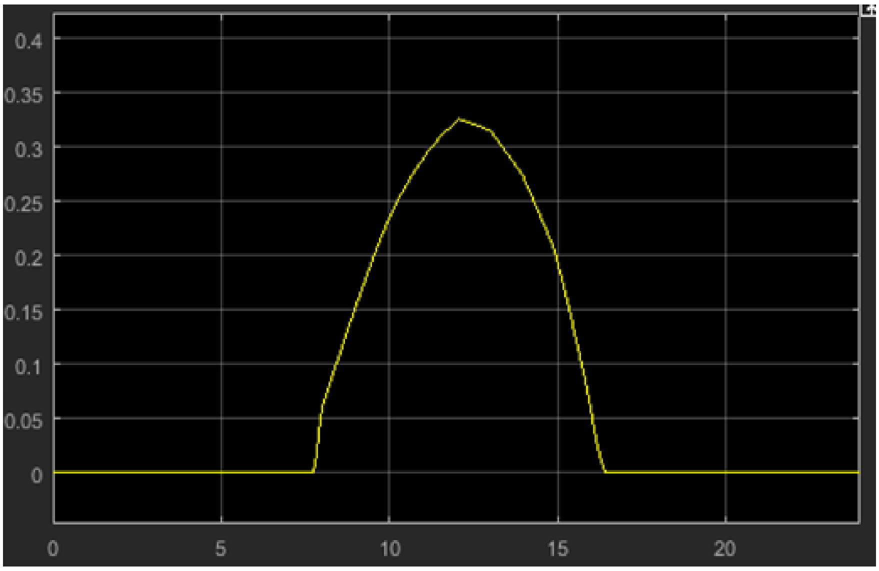

Figure 4.34: production of H2 (kmol/s) by electrolyzer.

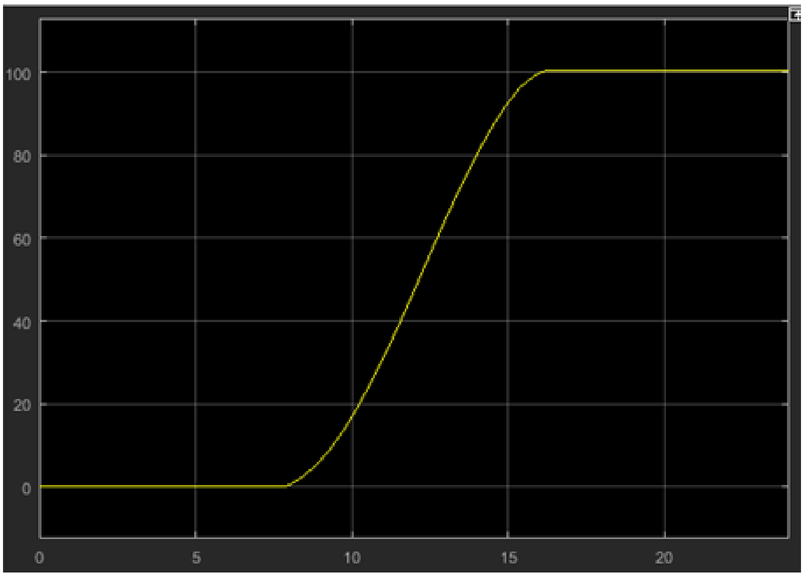

Figure 4.35: Amount of hydrogen produced by electrolyzer.

Fuel of PEM fuel cell is hydrogen, Figure 4.36 show the amount of hydrogen consumed by PEM fuel cell. The PEM fuel cell will operate partially to provide the lack of energy, because PV panels do not cover all demand of consumption, but sometimes the all demand load is covered by PEM fuel cell as shown in Figure 4.37.

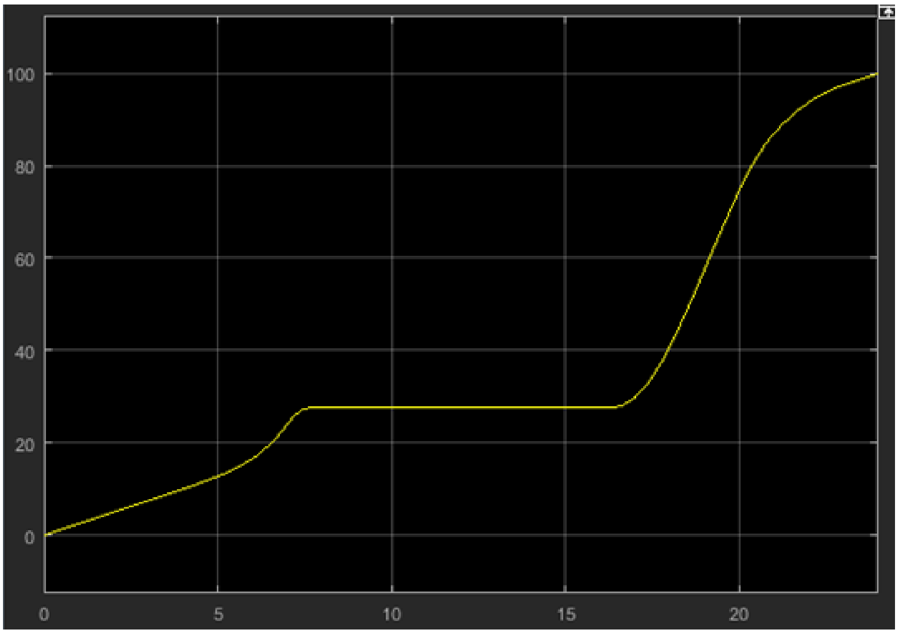

Figure 4. 36: Amount of hydrogen Consumed by PEM fuel cell.

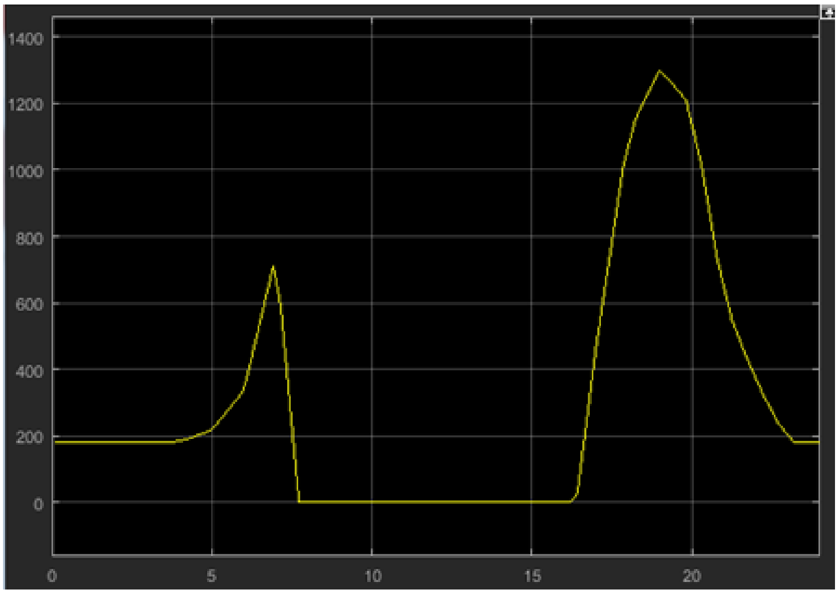

Figure 4.37: Power produced (watt) by the PEMFC.

Chapter Five

Microbial Fuel Cell Experimental Procedure And Results

5.1 Introduction

This research is based on scientific experimental approach . This approach is based on using COD and TDS tests as a tool to investigate the effectiveness of using MFC for wastewater treatment . A double chambered MFC was fabricated , batch and semi-batch condition was operated in order to test the samples. The reactor was fabricated using non-reactive plastic containers with total volume of 3 liters . The wastewater sample used in design prototype was obtained from a house contain 6 person. The project was conducted by feeding different strengths of grey wastewater (100% strength without any dilution, 75% strengths by diluting with 25 % distilled water) , the limitation faced this system and the recommendation as future work for the way for scaling up the MFC was shown in details .

5.2 Characteristics of Greywater samples

The wastewater sample used in design prototype was obtained from a kitchen in house contain 6 person, A main tests include COD TDS and current was measured to the sample from input tank after the set up in different conditions . The obtained tests result for the samples used was plotted as a curves.

For original sample, both in batch and semi-batch conditions , the original sample was filtrated and testes include pH , TDS , COD , BOD_5 and current was listed in table 5.1

Table5.1: Greywater original sample characteristics.

Value / Characteristic	Batch condition	Semi-batch (100 % concentrated)	Semi-batch (75 % concentrated)
pH (alkaline)	7.6	7.4	7.9
Color	Grayish	Grayish	Grayish
Total Dissolved solid (mg/l)	9010	9760	7400
BOD_5 (mg/l)	235.384	2368.92	1641.8

COD (mg/l)	3744	3872	2680
Current (mA)	0.28	0.31	0.18

5.3 Design and Fabrication of MFC

This research is based on scientific experimental approach . This approach is based on using COD and TDS tests as a tool to investigate the effectiveness of using MFC for wastewater treatment, Appendix K and L shows the steps for Standard Procedure . Batch and semi-batch experiments were performed to test the percent removal of organic matter (COD reduction) and TDS in domestic wastewater. The following subsections describe materials and equipments used and experimental procedure and results.

A double chambered MFC was fabricated. The reactor was fabricated using non-reactive plastic containers with total volume of 3 liters and the working volume was 2.8 L. Six graphite rods from pencils were used as both anode and cathode materials. The arrangement of graphite rods (35mm in length & 6mm in diameter) was made in such a way as to provide the maximum surface area for the development of biofilm on anode.

The electrodes were connected using copper wire. The anode and the cathode chambers were separated by agar salt bridge, the salt bridge consist of 10 % agar in 0.1 morality of NaCl poured into 100 ml plastic pipe to make a gel, allows for hydrogen protons yielded by the bacteria to pass through. The length and diameter of the agar salt bridge is 100mm and 60mm respectively. The electrodes were placed in the chambers, then were sealed, made airtight and were checked for water leakages.

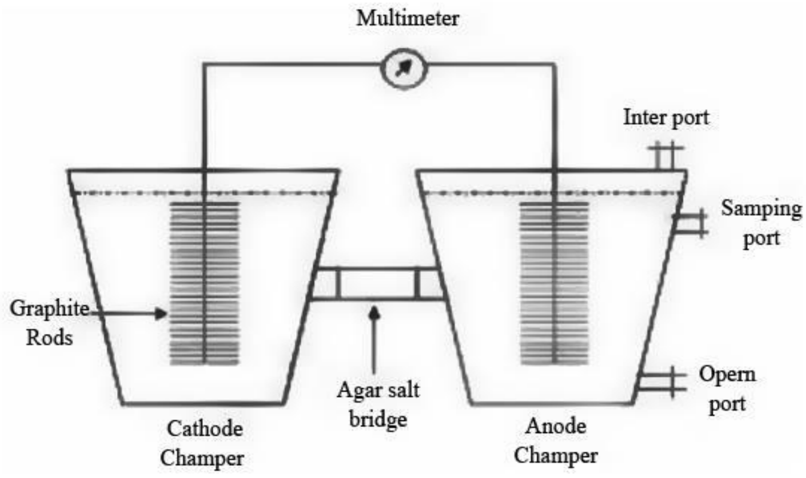

Figure5.1:Double Chamber MFC[21].

The batch conditions, operated for one week without greywater change or sludge removal; because the sludge does not reach unacceptable volume to need re-entering it , two sample is taken every day; the first sample at 9 A.M and 3 P.M for the second one ,and the samples was treated (colour and content are indicators).

The anaerobic digesters generally worked with a hydraulic retention time in a range of 20–40 days and an organic loading rate of some 1 kg VS/m3reactor day[47].

For the upcoming work, nitrogen gas is requires for semi-batch operation to ensure the absence of oxygen (anaerobic conditions) , but the nitrogen is not available now, so another solution should be selected and some errors may exist.

The next operation condition was semi-batch, some problems were faced, starting from the control of flow reach the anaerobic tank, then the isolation of small tank to distinguish anaerobic circumstances; in order to decrease errors. To isolate the tank; three materials were tested in order to use the best one; Paraffin, hydraulic gas and oil mineral.

The numerous methods that have been suggested for cultivating the obligately anaerobic bacteria involve was reduction of oxygen tension or maintenance of reduced oxygen tension.

The reduction of oxygen tension may achieved by biological reduction (as aerobe-anaerobic symbiosis , symbiotic in medium , symbiotic in air chamber or using of animal and plant tissues) , chemical reduction (such as agents in air chamber , catalytic ignition or hydrogen and residual oxygen , reduction by phosphorus , iron compounds or by alkaline pyro-gallol) or physical reduction (using boiling , evacuation or used an inert gases) , while the maintenance of reduced oxygen tension can be achieved by portion of medium sealed off , deep medium seals , insoluble liquid seals or mechanical seals . on the other hand , using an air chamber sealed and fusion of glass outlet are also using to maintenance the oxygen tensions . Insoluble liquid seals as oils, greases, and waxes have been used in the form of oil several research[48].

At the meeting of bacteriologists ,we search about the development of the growth of anaerobic organisms in suitable media which were covered by a layer of solid paraffin which can defined as Soft colourless, tasteless, odourless, water insoluble, solidsubstance not easily acted upon by reagents, consisting of a mixture ofhydrocarb ons chiefly of the alkane series, obtained from crude petroleum it is one of the higher members of the alkane series, solid at ordinarytemperatures, with boiling points inthe range 150°–300°C and It has a density of around 0.8 g/cm^3.

Research found that the addition of from 25 to 50 per cent. of fluid paraffin makes the sealing more perfect by preventing in the act of cooling the retraction of paraffin from the sides of the tubes, tanks or flasks. To drive all air from the culture media it is only necessary to heat the flasks, tanks or tubes in the autoclave. The oxygen thus driven out is reabsorbed through the semisolid-paraffin layer only to a very slight degree, if at all[49].

So , With adding a Paraffin over the liquid culture we can create an microaerophilic environment. However, Paraffin was the best isolating material to create anaerobic circumstances, and it was used.

Paraffin was chosen as the best isolating material To run the prototype in a semi-batch condition , and based on tests, , but it was hard to control the flow between feeding tank and anaerobic tank. The capacity of treated tank was 3 litres, and 530 ml/hr was the least flow achieved , taken in to account the effect of variety surface area and height, different tubes and valves were tested. Injecting tube(IV intravenous line with regulator to decrease the flow more and more were used, the minimum flow were obtained was 25 ml/hour, equal to 600 ml/day, this lead the project team to change the treated water in anaerobic tank manually and retained it batch to the feed tank to complete 10 days operation in this case.

The obtained wastewater samples are diluted. For each sample, the obtained 2.5 mL volume is mixed with a volume of 1.5 mL of digestion solution (standard potassium dichromate solution) and 3.5 mL of sulfuric acid reagent. COD test vessels are digested at 150 ^{o}C for 120 minutes. Then, the resulting digested solution is titrated using standard Ferrous Ammonium Sulfate (FAS), using Freon indicator until the end point is reached (color change from blue to orange or brown).

COD values are obtained from the following mass balance equation:

$$\text{COD as mg/L} = \frac{(A-B)\times 8000\times M}{V_S} \tag{5.1}$$

Where A is the volume of FAS used for blank sample (mL), B is the volume of FAS used for the wastewater sample (mL), M is the molarity of FAS, V_S is the volume of sample in ml (2.5 mL). The value (8000) is the miliequivalent weight of oxygen.
The efficiency of the adsorption process is obtained from the percentage COD and TDS reduction, as given by the following equation:

$$\text{Percentage removal of COD} = \frac{COD_o - COD_t}{COD_o} \times 100\% \tag{5.2}$$

$$\text{Percentage removal of TDS} = \frac{TDS_o - TDS_t}{TDS_o} \times 100\% \tag{5.3}$$

Values of BOD are estimated from COD values according to the following equation[50].

$$BOD = 0.61COD + 7 \tag{5.4}$$

While the TDS of water is directly related to the conductivity of dissolved ionized solids in the water. Ions from the dissolved solids create the ability for water to conduct an electrical current.TDS analyzers based on conductivity provide a quick accurate value of the TDS , the high values of the samples was due to lake in water resources and high salt content in the water in general .

EC can be converted to TDS using the following calculation:
TDS (ppm) = C * EC (µS/cm), C is a constant may be within the range of 0.5-0.7, a typical value of 0.5 is used in groundwater while 0.64 value was used for wastewater[51].

5.4 Operation and Monitoring

The project was conducted by feeding different strengths of grey wastewater (100% strength without any dilution, 75% strengths by diluting with 25 % distilled water).

The anode chamber (anaerobic chamber) was filled with wastewater and the cathode chamber (aerobic chamber where oxygen was used as electron acceptor) was filled with 1 molar of NaCl solution. The internal wiring of anode and cathode was connected to a multimeter (Model No. GDM-8034) to complete the circuit. The entire setup was left for 1 hr for stabilization and the reading in the multimeter was noted down every 24 h for month of operation.

Water to be treated in semi-batch condition was fed to a tank containing Paraffin in the highest layer to prevent oxygen from entering the tank and so, creating anaerobic circumstances, one sample each 24 hour for 20 days was taken to analysed in both 100 % and 75 % concentrated greywater in semi-batch .The MFCs were continuously monitored during experiment and readings were taken one time at a day. On the other hand , twice reading at a day were taken in the batch operation conditions.

5.5 Limitations of the hybrid system

Considering that the carbon removal from wastewater is crucial because carbon compounds are the main energy source for the microorganisms. Additionally, nitrogen removal from wastewater is an important component of treatment because high nitrogen contents in the wastewater can cause a bad smell. Nitrogen removal has been difficult to achieve in single-process systems. Therefore, the relationship between the electricity generation of a MFC with the rate of nitrogen and carbon removal described as, The rate of bio-energy generation is highly affected by the biological activities of the microorganisms in the anodic chamber. In addition, several other physical factors of the MFC design can also affect the rate of bio-energy generation such as the size of the electrode being used, the mode of the anodic process, the distance between the two electrodes and the components of the electrolyte in the cathode chamber [27].

High temperatures may be unfavourable since they favour microbial growth and could in supersaturated waters, induce precipitation . Food particles and raw animal fluids from kitchen sinks and soil particles, hair and fibres from laundry wastewater are examples of sources of solid material in the grey wastewater.

There still be great challenges to achieve the envisioned advantages of the hybrid processes and to realize their practical implementation. First of all, the high cost, low power density of MFCs and difficulty for reactor scaling-up have been and will continue to be primary barriers for practical implementation of both MFCs and such a hybrid process.

Although better overall performances in economics and energy production can be expected in a MFC-centered hybrid system, the ultimate success of this system would still heavily rely on further breakthroughs of MFC technology. Because of the offsetting effects of other treatment steps, the improvement in power density and economics of MFCs to achieve self-balanced treatment could be less as compared to that of advancing MFC technology alone, thereby making such hybrid systems more feasible to be realized.

5.6 Obtained Results

The double chambered MFC was run. The MFC was operated by feeding greywater with different concentrations separately. The effect of wastewater concentration on COD and TDS removal efficiency and current generation was observed.

5.6.1 Last semester data

In last semester the system design as a preliminary results was batch, and it was operate for 10 days, 5 morning samples was taken (a sample every 2 days),

Appendix M shows the COD and TDS values , COD and TDS was tested for all samples, the results showed that the removal efficiency was about 73% for COD and 60% for TDS. But these results were not accurate due to human error, there was two errors should be considered; the first one is that the samples should be refrigerate instead of using it after 10 days of storage in wrong circumstances since The samples should have been stored at 4 °C to avoid bacterial and fungal overgrowth, and the second one is that the amount of used sulfuric acid should be 2 drops for each liter to store the samples. So the removal occurred in the experiment was due both self-digestive and the system removal .

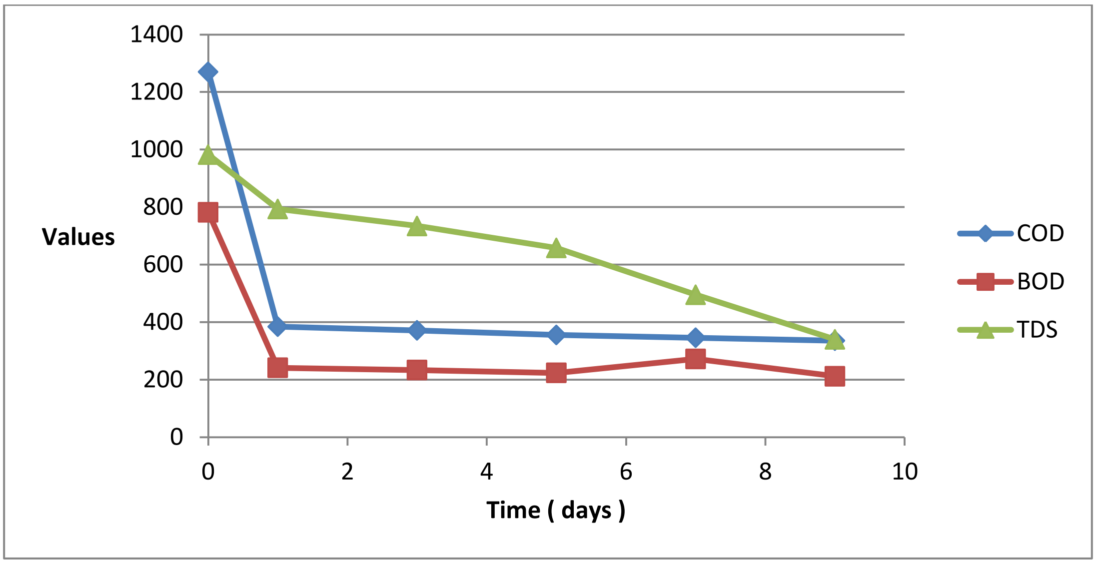

Figure5.2: COD, TDS and BOD vs. Time.

Figure (5.2) illustrate the relation between COD, TDS and BOD with time which obtained in the last semester , However, BOD did not tested, it is calculated from COD using equation (5.4) , the figure shows the decreasing in COD and TDS with time during batch operation for 10 days, but these results are incorrect as explained previously.

5.6.2 Batch Conditions

The obtained COD and TDS data are plotted as a function of time in batch (week , twice/day) first at 9 am , sec at 3 pm with 100 % concentration greywater , with maximum current obtained was 0.73 mA, the obtained values for COD and TDS was shown in Appendix N.

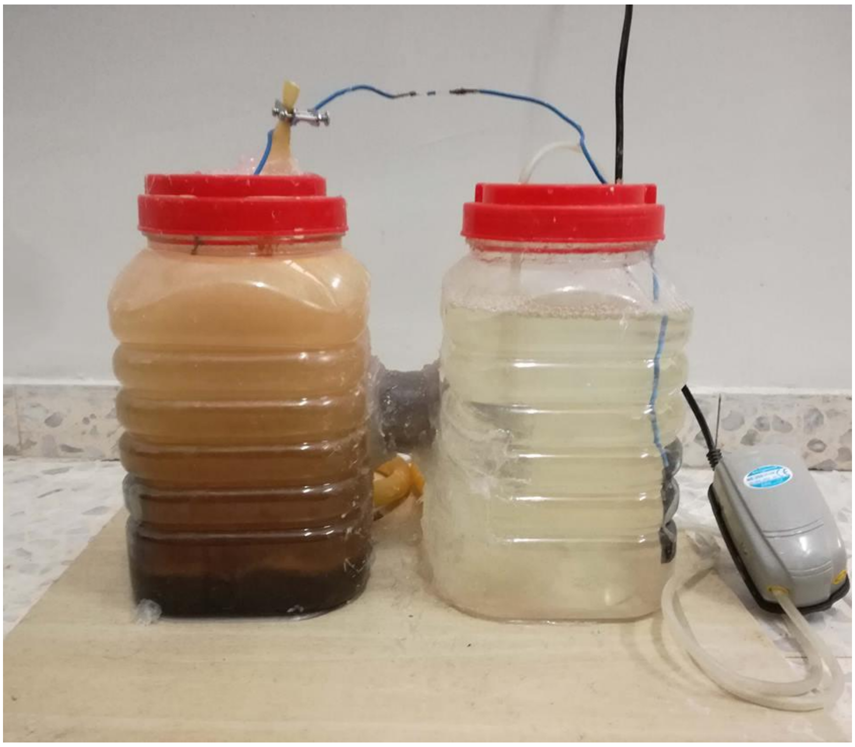

Figure5.3: Prototype after running in batch condition.

The percentage removal of COD was calculated and a plot of COD % removal and TDS % virus time is shown in Figures (5.4 and 5.5).

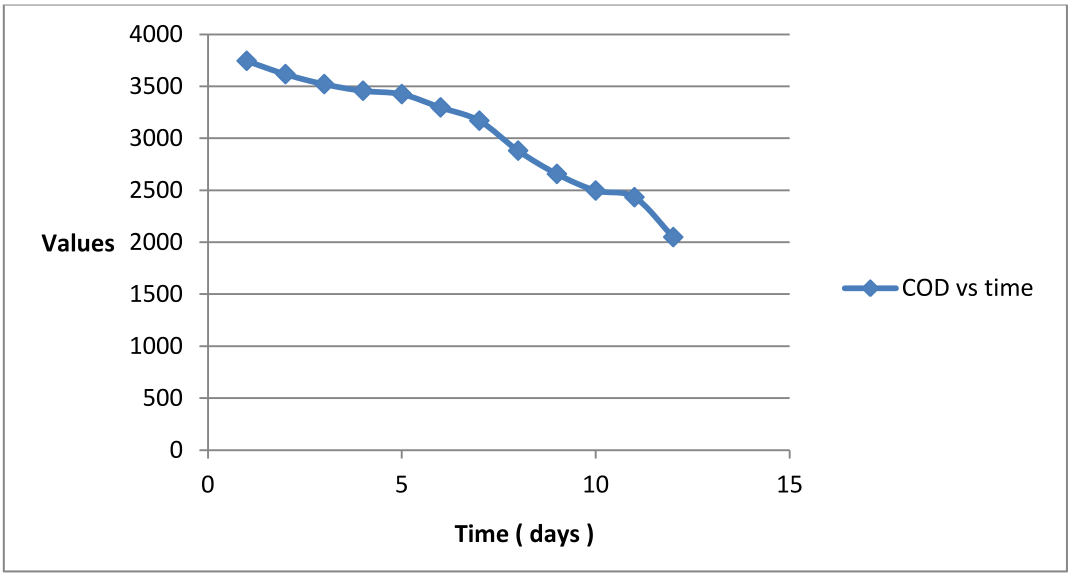

Figure5.4: COD vs. Time.

Figure(5.4) shows COD removal vs. time, it illustrates the decreasing in COD removal with time, however, the objective of the designed technique is to removal of organics from water using bacteria from the sludge.

Since the samples timing was not equal, the results shows that the additional COD removal, was differs from day and night, the first and second samples have 6 hours for treatment in the equipment, but the third and fourth samples have 18 ho.urs, and this is the reason of different results from day to night.

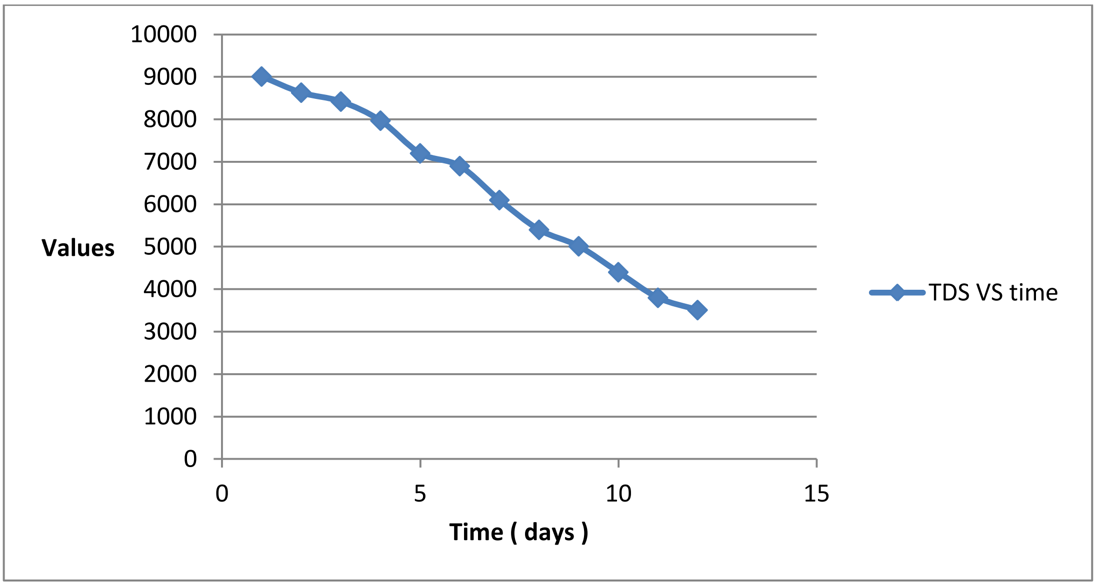

Figure 5.5: TDS vs. Time.

Figure (5.5) shows the TDS vs. time, TDS decrease with time, and this corresponds to the objective of treatment equipment.

5.6.3 Semi-Batch Conditions

5.6.3.1 (100 %) Greywater concentration

The obtained COD and TDS data are plotted as a function of time in semi-batch (10 days/ one per a day) at 9 am with 100 % concentrated greywater , with maximum current obtained was 0.56 mA, the obtained values for COD and TDS was shown in Appendix O.

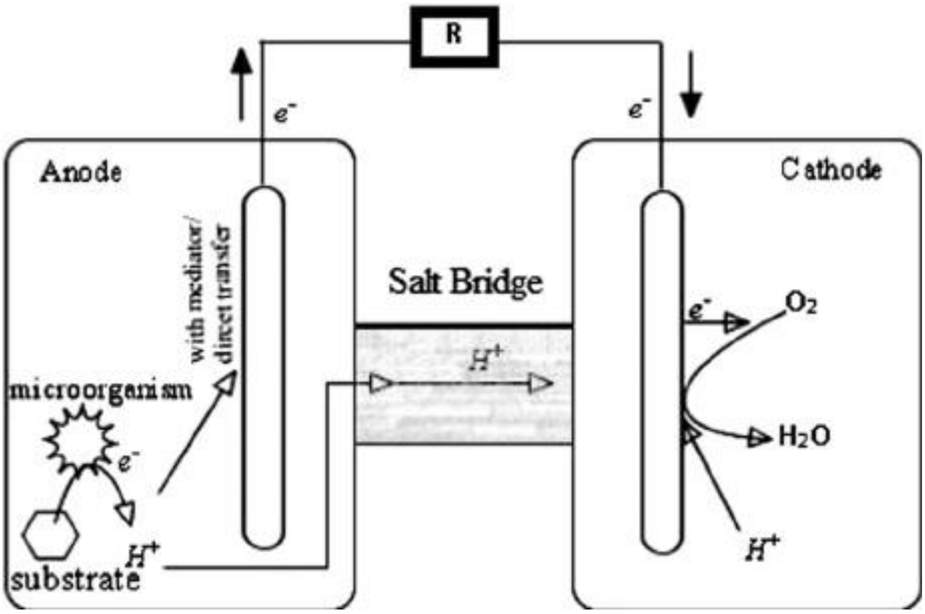

Figure 5.6: Schematic diagrame of MFC[52].

Figure 5.7: MFC prototype after finishing operated days.

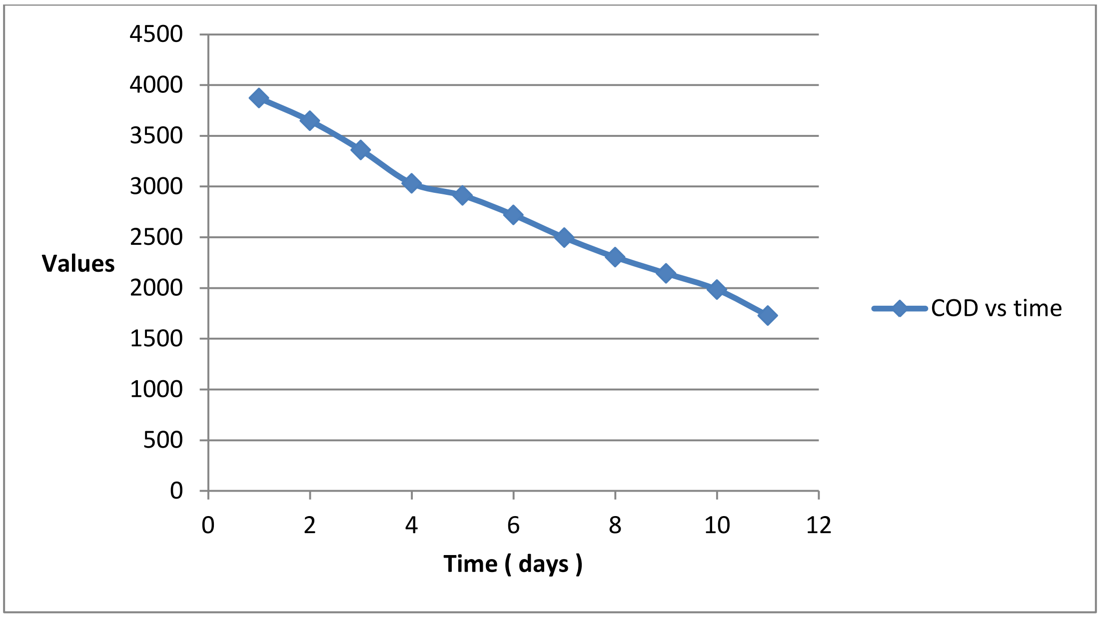

Figure 5.8: COD vis Time in semi batch with 100 % concentrated .

Figure(5.8) shows COD removal vs. time, it illustrates the decreasing in COD removal with time , while Figure (5.9) shows the TDS vs. time, TDS decrease with time, and this corresponds to the objective of treatment equipment.

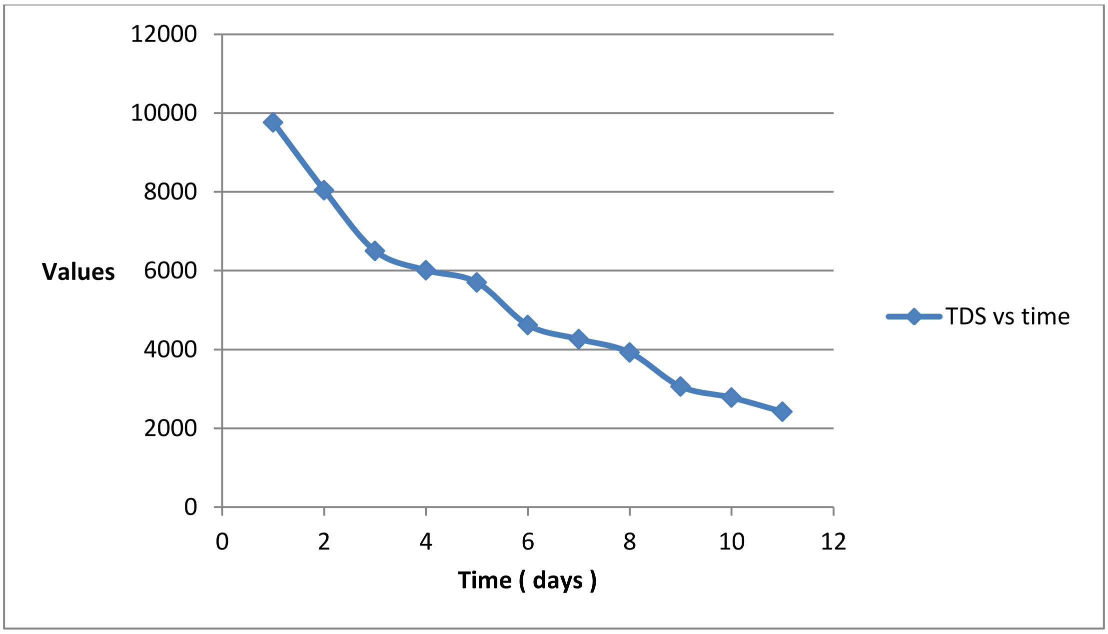

Figure5.9: TDS vis Time in semi batch with 100 % concentrated .

5.6.3.2 (75 %) Greywater concentration

The device running using 75 % greywater with 25 % dilution , the obtained COD and TDS data shown in Appendix P , figures (5.10 and 5.11) shows the decreasing in both Chemical oxygen demand and total dissolved solids in samples after treatment , the maximum power obtained was 0.24 mA .

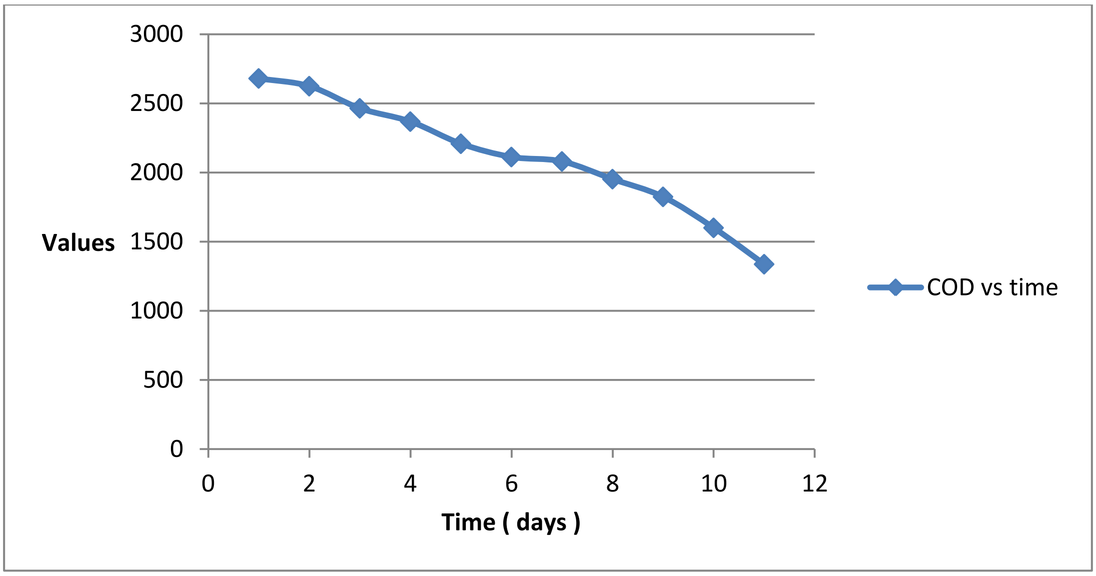

Figure 5.10: COD vis Time in semi batch with 75 % concentrated .

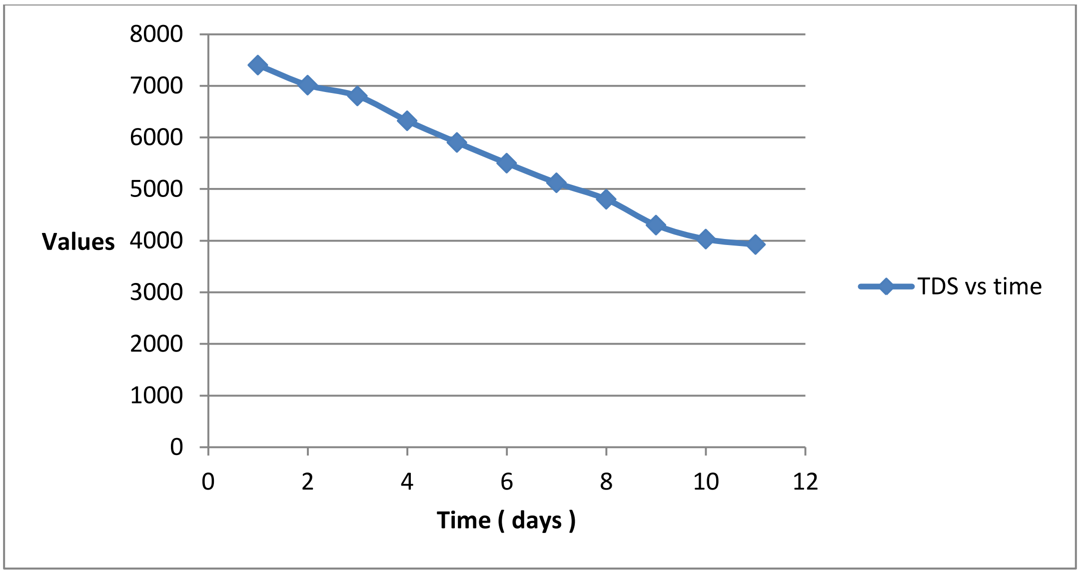

Figure 5.11: TDS vis Time in semi batch with 75 % concentrated .

5.7 Discussion

The obtained COD , TDS and BOD of domestic wastewater samples treated using MFC device is illustrated in Figures (5.2, 5.4, 5.5, 5.8 – 5.11). They indicates a continuous removal of organic pollutants while the electrical current was in mille Ampere due to small prototype.

The original sample of grey water was diluted 1/100 after filtration it , and the other sample was diluted 1/50 .
Aerobic tank was containing 1M NaCl salt : 1L water, water concentration raised due to interaction between hydrogen ions (from salt bridge) and oxygen ions (from the pump).

However, the organic matter in wastewater is essentially free. As long as COD removal is accomplished, by electricity generation or other methods, the goal of wastewater treatment is achieved.

5.7.1 COD Removal Efficiency

During operation, the MFC was continuously monitored for waste (as COD) removal to enumerate the potential of fuel cell to act as wastewater treatment unit. Both batch and semi-batch condition showed its potential for COD removal indicating the function of microbes, present in wastewaters in metabolizing the carbon source as electron donors. It is evident from experimental data that current generation and COD removal showed relative compatibility. Continuous COD removal was observed in MFC during all operation days .while in the batch the greywater concentration was 100 % , the semi-batch was initially full strength wastewater used in the anodic chamber, and then it was replaced by 75% concentrations. Experimental data indicated that COD removal efficiency was decreased with the decrease of wastewater concentration from 100% to 75%. The COD removal efficiency using grey wastewater at 100%, 75% wastewater concentrations were ٤٥,٢٩ % in batch and 55.37 % , 50.12% respectively in semi batch .This relative slow COD removal was possibly due to less availability of biodegradable substrate in 75% than that of full strength wastewater leading to competitive inhibition in microorganisms.

COD removal and power were a function of hydraulic retention times (there are a proportional relation) of the wastewater in the reactor. COD removal increased with HRT increased until reach 33 hours in the operation . A large percent of the COD removal was not associated with power generation. While the Current generation was controlled by the efficiency of the cathode.

It appears that substantial losses of COD resulted from passive oxygen transport into the reactor by diffusion across the proton exchange membrane. COD reduction due to passive oxygen transfer may actually be beneficial when compared to the high cost of forced-air oxygen transfer using blowers in wastewater treatment systems such as activated sludge. Graphite rods have been the most popular type of anode as they provide good electrical conductivity and chemical stability whilst being inexpensive[1].

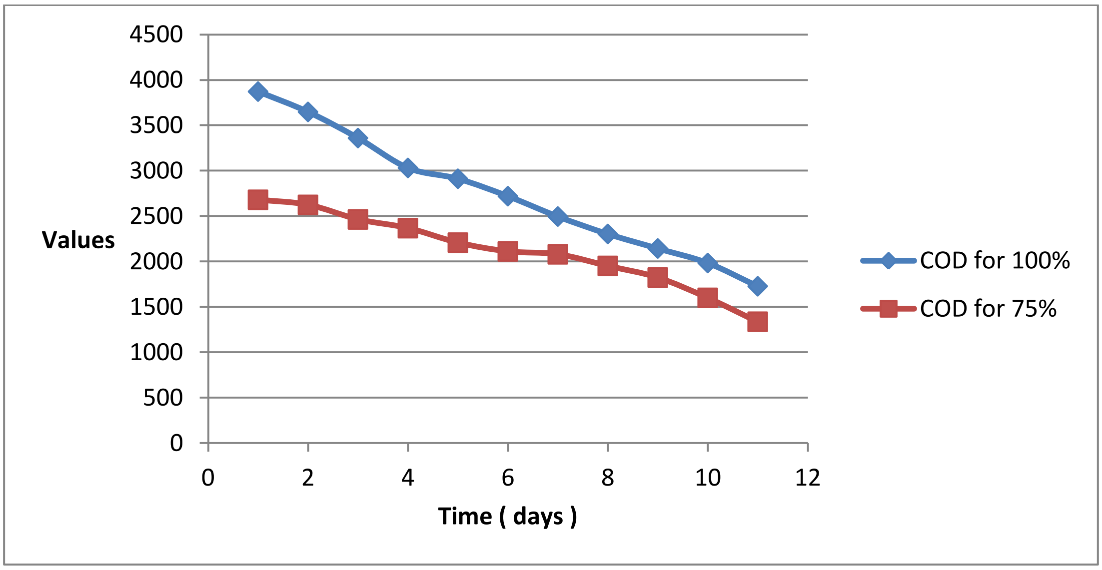

Figure 5.12: Comparison between COD in different greywater concentrations.

5.7.2 Dissolved Solids Removal Efficiency

The MFC showed its potential for dissolved Solids removal. Initially full strength greywater was used in the anodic chamber, and then it was replaced by 75% wastewater concentrations.. Experimental data indicated that dissolved removal efficiency was decreased with the decrease of wastewater concentration. The dissolved solids removal efficiency in batch was 61% , while at 100%, 75% wastewater concentrations in semi-batch were 75%, 47.02% respectively.

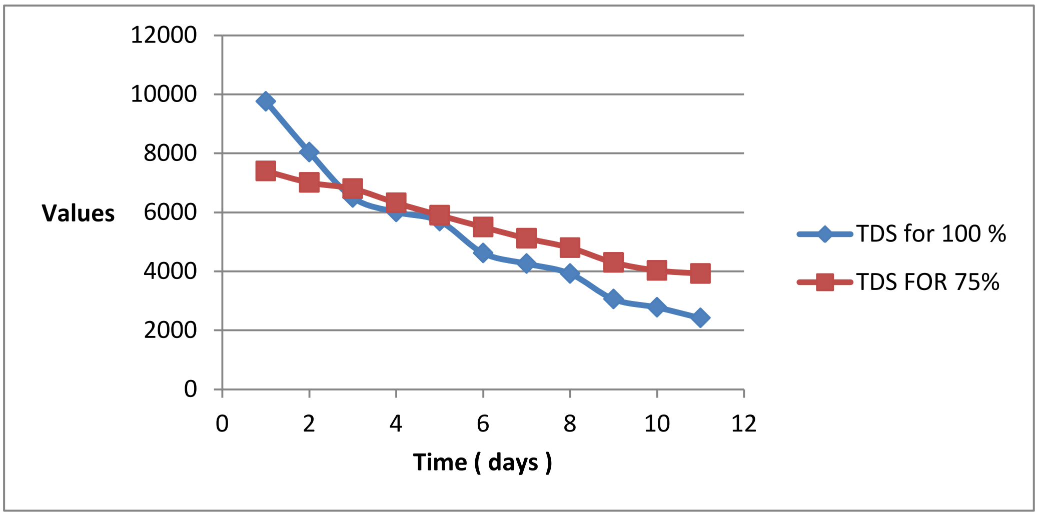

Figure 5.13: Comparison between TDS in different greywater concentrations.

5.8 The way forward scaling up MFCs to a practical level

With the high energy potential of wastewater, there is significant benefit in harnessing this power during treatment. Microbial Fuel Cell (MFC) technology allows electricity generation while simultaneously treating wastewater. Microbial fuel cells use electrochemically active bacteria to oxidize substrates and separate protons from electrons.

To make MFCs suitable for real-world applications, system scaling up would be inevitable. This requires not only increasing the reactor size and treatment capacity to a practical level, but also achieving levels of useful energy. Although a neutral or positive energy balance has been theoretically demonstrated, there has not been an actual operation of energetically self-sustained MFCs for wastewater treatment [24].

Traditional methods of wastewater treatment are energy intensive, often consuming between 950 and 2850 kJ/m^3 of water treated[1].

Therefore, the biggest challenge of MFCs designed for wastewater treatment application is how to simultaneously scale up the reactor size and energy output. The specific limitations associated with system scaling up include high internal resistance, pH buffering, high material cost, and low efficiency of mixed culture biofilm on an electrode.

On the other hand, the sustainable wastewater treatment is a fascinating concept which promises to partially address the multiple challenges of energy shortage, resource depletion and environmental pollution. It is widely accepted that a sustainable treatment process should strive for: neural-energy operation, balanced investment and economic output, stable treatment performance, high effluent quality to meet water reclamation and reuse requirement, less resource consumption, a low environmental footprint, and good social equity. It is essentially difficult to simultaneously meet all these criteria with the existing technologies and/or single treatment technology. The MFC technology, although still at its infancy, might bring in new opportunities because of its many unique features (Figure 5.14).

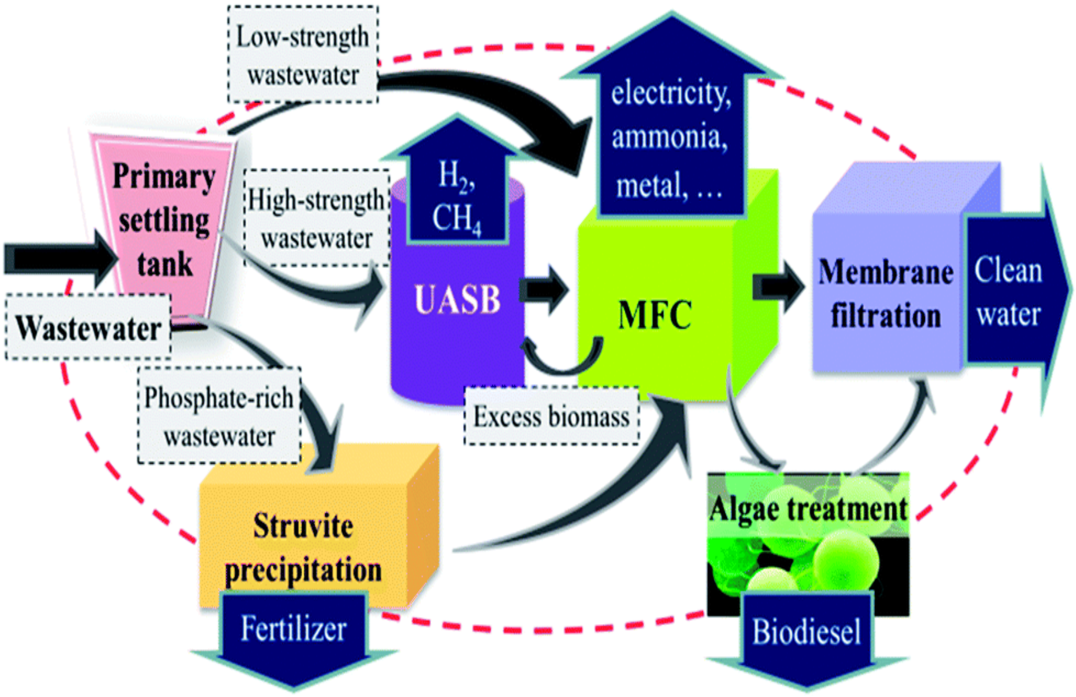

Figure 5.14: Process flow of a hypothetical MFC-centered hybrid process for wastewater refinery [24].

Conclusion

The project demonstrated that microbial fuel cell technology was able to treat greywater successfully, and microorganisms present in the wastewater are responsible for electricity generation and COD & TDS removal. The performance of MFCs decreased with the decrease in the wastewater concentration. MFC technology may provide a new method to offset wastewater treatment plant in term of operating cost, making wastewater treatment more affordable for developing and developed nations. Thus, the combination of wastewater treatment along with electricity production may help in saving money as a cost of wastewater. On the other hand, the project study the possibility of meeting consumption demand for house in Hebron City by using hybrid system PV with PEM fuel cell and electrolyzer. Where the system was design to meet the needs of the house of continuously electricity throughout the year, without connect it on grid. MFC technology can be applied as a renewable energy source with applications in wastewater treatment, water quality monitoring and power generation. It is can provide clean, safe, and quiet performance. For power generation, it was found that the highest load consumption for the house was in January and then in July. Therefore, the system needs 18 PV panels of 260 watt, 3 PEM fuel cells of 500 watt, an electrolyzer of 1500 watt and hybrid inverter of 5kw. The models of simulation facilitate more understanding of the system. The ability to manage operation of PV, PEM fuel cells and electrolyzer is the most important in the system, which coordinate the changes load during the 24 hours in day. Thus the electrical components of the system and the control management of hybrid system are modeled as a Simulink blocks by using matlab simulation program. Also show the amount of hydrogen produce and consume during the 24 hours whereas the highest value of production hydrogen by electrolyzer is 0.34 kmol H_2/s from electrolyze recycling water using excess power from PV panels. the addition of recycling water use for irrigation. Hydrogen will be used to generate the electricity by PEM Fuel cell. Thus meet the total electrical load demand without need of grid connection.

Appendix A

Needed, Supply and Consumed Quantities, Population and Deficit in Domestic Supply in the West Bank[34].

Governorate	Needed Quantities of Water(2)	Water Supply for Domestic Sector (million m^3)	Water Consumed for Domestic Sector (million m3)	Deficit Domestic Supply (million m3)	Actual Deficit for Domestic Need (million m3)
Jenin	16.8	6.4	4.4	10.4	12.4
Tubas	3.5	2	1.3	1.5	2.2
Tulkarm	9.9	7.1	4.4	2.8	5.5
Nablus	20.6	12	8.9	8.6	11.7
Qalqiliya	6	8.6	6.6	-2.6	-0.6
Salfit	3.8	3.1	2.3	0.7	1.5
Ramallah & Al-Bireh	18.8	22.5	15.7	-3.7	3.1
Jericho & Al-Aghwar	2.8	5.9	4	-3.1	-1.2
Jerusalem	8.6	0	2.3	8.6	6.3
Bethlehem & Hebron	49.8	35.2	24.3	14.6	25.5

Appendix B

Greywater characteristic in Palestine [29].

Parameter	Range of values
Flow Q[l/p/d]	50
PH	6.7-8.35
EC(ms/cm)	1585
COD(mg/l)	1270
BOD(mg/l)	590
TSS	1396
NH4-N	3.8
PO4-P	4.4
Na+	87-248
Fecal coli.	$3.1*10^4$

Appendix C

Power Requirements of Typical Loads [17].

Appliance	Power(watt)
Kitchen Appliances	
Refrigerator: ac EnergyStar, 14 cu. ft	300 W, 1080 Wh/day
Refrigerator: ac EnergyStar, 19 cu. ft	300 W, 1140 Wh/day

Refrigerator: dc Sun Frost, 12 cu. ft	58 W, 560 Wh/day
Freezer: ac 7.5 cu. ft	300 W, 540 Wh/day
Freezer: dc Sun Frost, 10 cu. ft	88 W, 880 Wh/day
Dishwasher: cool dry	700 W
Microwave oven	750–1100 W
Coffeemaker (warming)	600 W
Toaster	800–1400 W
General Household	
Clothes washer: vertical axis	500 W
Clothes washer: horizontal axis	250 W
Furnace fan: 1/4 hp	600 W
Furnace fan: 1/3 hp	700 W
Ceiling fan	65–175 W
Whole house fan	240–750 W
Air conditioner: window, 10,000 Btu	1200 W
Heater (portable)	1200–1875 W
Fluorescent lamp	35 W
Clothes iron	1000–1800 W
Electric clock	4 W
Consumer Electronics	
TV: >39-in. (active/standby)	142/3.5 W
TV: 25 to 27-in. color (active/standby)	90/4.9 W
TV: 19 to 20-in. color (active/standby)	68/5.1 W
Analog cable box (active/standby)	12/11 W
Satellite receiver (active/standby)	17/16 W
VCR (active/standby)	17/5.9 W
Component stereo (active/standby)	44/3 W
Compact stereo (active/standby)	22/9.8 W
Cordless phone	4 W
Computer, desktop (active/standby)	44/3 W
Laptop compute	20 W

Appendix D

Aggregated Hourly Water Demand – Single-family and Low-income Single-family Indoor[53].

Hour	SF % of Total Daily Indoor Water Use	LI.SF % of Total Daily Indoor Water Use	Hour	SF % of Total Daily Indoor Water Use	LI.SF % of Total Daily Indoor Water Use
12:00 AM	1.88%	2.06%	1:00	4.34%	4.39%
1:00	1.37%	1.08%	**Total Before Peak**	**54%**	**51%**
2:00	1.24%	0.84%	2:00	4.00%	4.16%
3:00	1.11%	0.86%	3:00	4.31%	4.23%
4:00	1.37%	1.15%	4:00	4.62%	4.73%
5:00	2.58%	1.35%	**Total During Peak**	**13%**	**13%**
6:00	5.01%	4.38%	5:00	4.87%	5.55%
7:00	6.64%	5.54%	6:00	5.36%	5.58%
8:00	6.43%	6.42%	7:00	5.49%	5.34%
9:00	6.38%	6.37%	8:00	5.19%	5.90%
10:00	5.76%	5.86%	9:00	4.75%	5.47%
11:00	5.38%	5.65%	10:00	4.07%	4.71%
12:00 PM	4.86%	5.02%	11:00	2.97%	3.35%
			Total After Peak	**33%**	**36%**

Appendix E

Disaggregated Hourly Water Demand activities - Low-income Single-family Indoor[34].

Hour	Baths	Showers	Toilets	Clothes Washers	Dish-washers	Faucet	Leaks	Other	Total
12 AM	0.04%	0.56%	1.15%	0.06%	0.00%	0.58%	0.26%	0.01%	3%
1:00	0.01%	0.43%	0.80%	0.03%	0.01%	0.29%	0.26%	0.01%	2%
2:00	0.00%	0.27%	0.67%	0.01%	0.00%	0.17%	0.21%	0.00%	1%
3:00	0.02%	0.24%	0.57%	0.00%	0.00%	0.10%	0.20%	0.00%	1%
4:00	0.00%	0.07%	0.51%	0.01%	0.00%	0.27%	0.18%	0.00%	1%
5:00	0.02%	0.34%	0.79%	0.00%	0.00%	0.43%	0.21%	0.00%	2%
6:00	0.02%	1.16%	1.45%	0.03%	0.01%	0.68%	0.41%	0.01%	4%
7:00	0.26%	1.27%	1.87%	0.14%	0.02%	0.94%	0.36%	0.01%	5%
8:00	0.20%	1.36%	1.94%	0.16%	0.04%	1.31%	0.57%	0.01%	6%
9:00	0.09%	1.76%	1.80%	0.20%	0.04%	1.46%	0.57%	0.08%	6%
10:00	0.20%	1.57%	1.72%	0.33%	0.04%	1.63%	0.43%	0.09%	6%
11:00	0.12%	1.27%	1.51%	0.38%	0.04%	1.31%	0.52%	0.10%	5%
12 PM	0.06%	0.99%	1.51%	0.35%	0.03%	1.48%	1.07%	0.03%	6%
1:00	0.13%	0.95%	1.67%	0.43%	0.03%	1.31%	0.39%	0.01%	5%
2:00	0.12%	0.88%	1.33%	0.38%	0.02%	1.16%	0.51%	0.03%	4%
3:00	0.11%	0.90%	1.42%	0.30%	0.02%	1.06%	0.35%	0.02%	4%
4:00	0.05%	0.97%	1.52%	0.27%	0.02%	1.04%	0.41%	0.03%	4%
5:00	0.12%	0.78%	1.53%	0.34%	0.02%	1.30%	0.38%	0.03%	4%
6:00	0.14%	0.94%	2.14%	0.44%	0.03%	1.54%	0.43%	0.02%	6%
7:00	0.25%	1.19%	1.74%	0.48%	0.03%	1.48%	0.51%	0.05%	6%
8:00	0.20%	1.22%	1.81%	0.38%	0.04%	1.43%	0.38%	0.02%	5%
9:00	0.25%	1.40%	1.79%	0.32%	0.06%	1.21%	0.45%	0.02%	6%
10:00	0.08%	1.19%	1.75%	0.14%	0.04%	1.04%	0.33%	0.03%	5%
11:00	0.17%	0.78%	1.62%	0.08%	0.03%	0.89%	0.31%	0.01%	4%
Total	2%	23%	35%	5%	1%	24%	10%	1%	100%

Appendix F

PV panel Specifications.[54].

Parameter	Nominal Value
STC Power Rating	260W
Peak Efficiency	15.9%
Vmp	8.25A
Imp	31.5V
Isc	8.74A
Voc	37.5V
NOCT	50°C
Temp. Coefficient of Power	0.48%/K
Mismatching Efficiency	97%

Appendix G

Off grid hybrid solar single phase inverter with MPPT solar [55].

Parameter	Nominal Value
Rated Output Power	5Kw
Nominal Voltage	220/230/240v AC
Solar controller	4 MPPT 40AMP
Input voltage	52v-88v
Noise	<40dB
Transfer Efficiency	93%

Appendix H

PEM Fuel Cell Specifications[56].

Parameter	Nominal Value
Number of Cells	30
Rated Power	500W (600W Peak)
Rated Performance	0 - 33.5A @ 18V
External Temperature	5 - 35˚C (41 - 95˚F)
Reactants	Hydrogen and Air
Max Stack Temperature	65˚C (149˚F)
Hydrogen Pressure	7.2 - 9.4 PSI
Hydrogen Flow Rate at Max Output	6.25 L/min
Efficiency of System	56% (Peak)
External Power Supply	13.5V (Start Up Battery)

Appendix I

PEM Electrolyzer Specifications[57].

Model	Unit	1800
Cells	-	4
Active Area per Cell	cm^2	50
H2 Production	std cc/min	180 - 1800
O2 Production	std cc/min	90 - 900

Current	A	6 - 60
Operating Voltage @ 40A	V	8
H2 Output Pressure (Max)	barg (psig)	20 (300)
O2 Output Pressure	-	Ambient (Nominal)
Operating Temperature	“C	20 - 55
Mass	Kg	3

Appendix J

Standard COD Test Procedure

The desired reagents and their production will be described below:

1- Standard potassium dichromate digestion 0.0166 M: 500ml of distilled water will be added to 4.903 g $K_2Cr_2O_7$ that is dried previously at 150 ^{o}C for 2 hours, and 167 ml conc. H_2SO_4 , 33.3 g $HgSO_4$ will be added. Dissolve them and cool to room temp and dilute to 1000 mL .

2- Sulfuric acid reagent.

3- Freon indicator solution: dilute it by a factor of 5. This indicator is used to indicate change in oxidation – reduction potential of the solution.

4- Standard ferrous ammonium sulfate titrate (FAS), nearly 39.2g of $Fe(NH_4)_2(SO_4)_2 .9H_2O$ in distilled water are dissolved. Add 20 ml conc. H_2SO_4 cool and dilute to 1000 ml. Standardized solution daily against standard $K_2Cr_2O_7$ digestion solution as follows: Pipe 5 ml digestion solution into small beaker. Add 10 ml reagent water to substitute for sample. Cool to room temperature and add 1 to 2 drops diluted Freon indicator and titrate with FAS.

5- Wash culture tubes and caps with 20% H_2SO_4 before using to prevent contamination.

6- Place sample in culture tube or ampoule and add digestion solution. Carefully run sulfuric acid reagent down inside of vessel so an acid layer is formed under the sample-digestion solution layer and tightly cap tubes or seal ampoules, and invert each several times to mix completely.

7- Place tubes or ampoules in block digester preheated to 150 ^{o}C and reflux for 2 h behind a protective shield.

8- Cool to room temperature and place vessels in test tube rack. Some mercuric sulfate may precipitate out but this will not affect the analysis.

9- Add 0.05 to 0.10 ml (1 to 2 drops) Freon indicator and stir rapidly on magnetic stirrer while titrating with standardized 0.10M FAS .The end point is sharp color change from blue to orange.

Appendix K

Standard TDS Test Procedure :

- **Total solid**

1. Ignite the clean evaporating dishes in the muffle furnace for 30 min at 550 c and cool it
2. Note down the empty weight (w1)
3. Pour 50 ml of the water sample in the beaker
4. Put the beaker in the oven and maintained it at 103-105c and dry it for 1 hr.
5. Allow the beaker to cool before weighting it
6. Weight the beaker (w2)
7. Calculate it TS(mg/l)= $\frac{(\mathrm{w2}) - (\mathrm{w1})}{\text{sample volume}} * 100\%$

- **Total suspended solid**

1. Weight the filter paper (w1).
2. Filter a 50 ml of the sample after dilute it (1ml of waste water with 49ml distilled water)
3. Dry the filter paper in the oven at 103-105c for 1 hr.
4. Wight the filter paper after draying(w1) .
5. Calculate it TSS(mg/l)= $\frac{(\mathrm{w2}) - (\mathrm{w1})}{\text{sample volume}} * 100\%$

- **Total dissolved solid**

1. Take 30 ml of the filtered sample above.
2. Make the same procedure for TS determination.

Appendix L

Last semester values

Sample number	COD	BOD	TDS
Original sample	1270	781.7	982.4
1	384	241.24	793.2
2	371.2	233.4	734.1
3	355.2	223.6	657.9
4	345.6	271.8	495.0
5	335.36	211.5	339.91

Appendix M

Result from Batch condition.

Sample number	FAS ml	TDS mg/l	COD mg/l
Original	2.3	9010	3744
1	2.7	8630	3616
2	3	8420	3520
3	3.2	7970	3456
4	3.3	7200	3424
5	3.7	6900	3296
6	4.1	6100	3168
7	5	5400	2880
8	5.7	5012	2656
9	6.2	4401	2496
10	6.4	3799	2432
11	7.6	3510	2048
	Removal efficiency %	61%	45.29

Appendix N

Result from semi-batch condition , 75 % concentration .

Sample number	FAS	COD	TDS
Original	1.5 for original sample	3872	9760
1	2.2	3648	8040
2	3.1	3360	6500
3	3.9	3031	6010
4	4.5	2912	5701
5	5.1	2720	4620
6	5.8	2496	4262
7	6.4	2304	3924
8	6.9	2144	3060
9	7.4	1984	2780
10	8.2	1728	2421
	Removal efficiency %	55.37%	75%

Appendix O

Result from semi-batch condition , 100 % concentration .

Sample number	FAS	COD	TDS
1	5.2	2680	7400
2	5.4	2624	7011
3	5.9	2464	6802
4	6.2	2368	6321
5	6.7	2208	5901
6	7	2112	5500
7	7.1	2080	5120
8	7.5	1952	4800
9	7.9	1824	4300
10	8.6	1600	4029
11	9.42	1337	3924
	Removal efficiency %	50.12	47.02

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