PPU College of Engineering and Technology

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Electrical and Computer Engineering Department

Industrial Automation Engineering Program

Graduation Project

GSM Control System of an Open Area Lighting By Using Solar Energy

Project Team

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Des, 2012

ABSTRACT

This project concerns the utilization of generated electrical power from photovoltaic solar panels for street lighting. A deep study have been conducted over system components such as photovoltaic (PV) effect, PV principles, types of photovoltaic cells, advantages and disadvantages of solar cells, characteristic curves of PV modules, specification and types of Batteries and charge controllers.

Lighting concepts, measurements, Lamp types, color temperature, color rendering index, lamp efficacy were studied.

As a case study the lighting of Al- Hesbah Street was executed. It depends on high pressure discharge lamps which are fed from the grid. We found out that the annual cost of consumed electrical energy is high.

Complete new design of Al- Hesbah street lighting was carried out. The design consist of utilization photovoltaic solar modules off-grid system, 24Volt DC light emitting diode fixtures which are controlled and monitored by Global System for Mobile communication (GSM). If Hebron Municipality decided to replace the current existed lighting system with the new one, it will save a lot of money after the completion of payback time which is about six years.

الملخص

يرتبط هذا المشروع بشكل عمليّ مع متطلبات المجتمع المحليّ بوصفه نموذجاً حديثاً وقابلاً للتطبيق والتعميم مُحققا فوائد توليد الطاقة الكهربائية عبر النظام الشمسي الذي يعتمد على الخلايا الضوئية وطرق استغلالها والتحكم بها في إنارة الطرق والأماكن المفتوحة.

ثمّة عدّة مسارات رئيسية للمشروع تطلّبت دراسة عميقة لمكونات النظام ، أهمّها تركيب الخلايا الضوئية ومبادئها العامّة ومنحنياتها الفيزيائية وأنواعها ومزايا استخدامها وعيوبها ذات الصلة إضافةً إلى البطاريات ومواصفاتها وأنواعها وجهاز التحكم الخاص بعملية التفريغ والشحن.

بالإضافة إلى دراسة تفصيلية لمفاهيم الإنارة الكهربائية كشِدّة الإضاءة وتوزيعها في المناطق المفتوحة خاصّةً الشوارع وأنواع المصابيح وكفاءتها الضوئية ودليلي مؤشر اللون والحرارة وسُبل التحكم بالنظام عن طريق الخلايا الضوئية والنظام اللاسلكي GSM.

الدراسة المسحية نفذت لإنارة شارع الحسبة في الخليل الذي يعتمد على مصابيح التفريغ ذات الضغط العالي في إنارته والتي تُغذّى عن طريق الشبكة،وقد تبيَّن من خلال الدراسة أنّ تكلفة إنارته سنويا عالية نسبيا.

من أجل ذلك قمنا بتصميم جديد مُقترح لإنارة هذا الشارع يتسّقُ مع الجدوى الاقتصادية العامة بحيث يعتمد على لوحات الخلايا الضوئية مفصولا عن الشبكة ويستخدم المصابيح الموفرة: LED lamps. والتي يتم التحكم بها ومراقبتها عبر النظام العالمي للاتصالات النقالة GSM.

وإذا ما تبنّت بلدية الخليل هذا التصميم المقترح وقامت بتنفيذه على الأرض ستوفر مصاريف مالية كبيرة وستستعيد مصاريف النظام الكليّة ورأس المال المدفوع بعد ست سنوات حسب الدراسة المقترحة.

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Chapter One

Introduction

1.1 Project Overview

Based on the cooperation efforts between PPU and department of electricity in Hebron municipality, and with the significant progress in the ways of exploiting renewable energy; this project is expected to meet the requirements of solar energy and achieves the objectives of this cooperation.

The solar energy is one of the most important alternatives of renewable energy, and it is essential to intertwined with its scientific sectors. The sunlight is used directly to produce electricity over special solar panels that perform this process using arrays of photovoltaic cells called PV modules.

So, this project is a simple module (prototype) for lighting a DC load, by using solar energy, as shown in Figure 1.1.

Figure1.1 Lighting a DC Load by Solar Energy [1]

1.2 Project Objectives

The main objectives of the project:

- Design and select suitable solar panel, charge controller, battery and spot LEDs light.
- Build a prototype for lighting a street by using solar energy and control it with a wireless technology.
- Propose full design for Al -Hesbah Street lighting.

1.3 Project Importance

1- The solar energy is a renewable environmentally friendly, high reliability, and economic source of lighting, so this project has important role in lighting system by using this type of energy.

2- The Israeli occupation has a fully control on the energy sector in Palestine. This project will reduce the dependency of Palestinians on Israeli economy, if it is applied with a wide range in our land.

3- Creating new job opportunities for Industrial Automation Engineers.

4- Monitoring and controlling the street lighting by wireless technology will save consumed energy.

1.4 Project Contents

This project discusses several important points in designing of a control system of open areas lighting by using solar energy; it is divided into six chapters as follows:

Chapter One: Introduction.
Chapter two: Theoretical Background.
Chapter three: Lighting.
Chapter four: Lighting Control.
Chapter five: Prototype Design and Scaling.
Chapter six: Conclusion and Recommendations.

1.5 Abbreviations

There are some abbreviations that will be used in this project such as:

PV: Photovoltaic.
DC: Direct Current.
GSM: Global System for Mobile Communications.
I_{sc}: Short Circuit Current.
I_{mp}: Max Power Current.
V_{mp}: Max Power Voltage.
V_{oc}: Open Circuit Voltage.

FF: Fill Factor.
Ah: Ampere hour.
W: Watt.
Wh:Watt hour.

1.6 Time Plan

The following table shows the stages of establishing this project.

Table 1.1: Time Plan

Activity	Week Number																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Literature Review	■	■	■	■																										
Theoretical Design				■	■	■	■	■	■																					
Write the documentation									■	■	■	■	■																	
Report													■	■	■															
Collect the Component															■	■	■	■												
Assembly &Electrical Wiring																		■	■	■	■	■								
Test																						■	■	■	■					
Final Test																									■	■	■	■	■	■

1.7 Finance Study

The initial cost of this project is about 4200 NIS, distributed as follows:

Table 1.2: Finance Study

NO.	Material	Price
1	Mono-Crystalline SIEMENS SM55,12V, 55W Photovoltaic	300 NIS
2	Charge Controller 5A 12 Volt	350 NIS
3	Rechargeable Valve Regulated Sealed Battery (REMCO) 12V, 40Ah	From University
4	GSM Controller 94VOE99006 TYPE2B	2000 NIS
5	LED Lamps 15 W,12 V_{DC}	180 NIS
6	Electrical Switch Panel	130 NIS
7	External Frame (Metal Base, Galvanized Metal Posts Battery Box)	950 NIS
8	LDR Photocell, Wires, Accessories	300 NIS
	Total	4200 NIS

CHAPTER

2

Theoretical Background

Chapter Two

Theoretical Background

2.1 Introduction:

As the photovoltaic cell (PV) is clean, reliable, easy to build, and high altitude performance can be used in many applications at a wide community services and industrial companies, it is necessary to have a good knowledge about its historical development, principles, basic materials and methods of operation, this chapter will discuss all of these terms.

By the development of advanced electronic manufacturing, especially semiconductor material and the increasing dependence on renewable energy, the use of (PV) that converts sunlight to electricity became essential and effective.

2.2 Photovoltaic:

A photovoltaic (PV) cell, also known as solar cell, is a semiconductor device that generates electricity when light falls on it.

Photovoltaic (PV) comprises the technology to convert sunlight directly into electricity. The term "photo" means light and "voltaic" electricity. Basically, photovoltaic solar panels create electricity by converting sunlight into energy .The process by which this happen is known as the photovoltaic effect. [2]

2.2.1 PV Principles:

Solar cell or Photovoltaic cell (PV cell), is the device that converts the radiation of the sun to electricity. The sun supplies us a clean and unlimited resource of energy, which help us to relieve the energy crises. Even though it has potential to use as energy source, the approach to efficiently utilize it remains a challenge. To achieve this, researchers have tried to make photovoltaic devices which can utilize the energy from this source. Organic semiconductors are a less expensive alternative to inorganic semiconductors, if low cost processes are used to grow the photovoltaic modules.

Organic semiconductors, dyes, oligomers, polymers are all based on conjugated electrons. A conjugated system is based on an alternation between single and double bonds. The π electrons are more mobile than σ electrons. Therefore, the π electrons can move by hopping from site to site. In case of solar cells these π electrons allow light absorption. Due to this molecular transition happens between π-π^* orbitals which correspond respectively to the Highest Occupied Molecular Orbital (HOMO) and Lowest Unoccupied Molecular Orbital (LUMO) of the molecule.

In organic semiconductors, the intermolecular forces are weak Van der Waals forces and they do not form conduction band and valence band. Therefore, the charge transport proceeds by hopping between localized states rather than transport within a band. This is the main reason for low charge carrier mobility in organic materials compared to inorganic semiconductors. In case of polymers and oligomers, this hopping happens along the conjugated chain and that result into intermolecular charge transport between adjacent polymer chains or molecules which results into lower mobility. Mobility can be improved with the molecular ordering in the films. Therefore, improving ordered structure (columnar liquid crystals, region regular polymers) the mobility can be increased.

The "photovoltaic effect" occurs when photons of light from the sun strike the solar cells; a portion of the energy is absorbed into the silicon, displacing electrons which then begin to flow. In order to harness this flow, the electrons are drawn into a magnetic field generated by positively and negatively charged metal contacts on the top and bottom of the cell, Producing direct current, or DC electricity as shown in (figure 2.1). Using a DC to AC inverter, the DC current is converted to alternating current which can then be used to power electrical appliances.

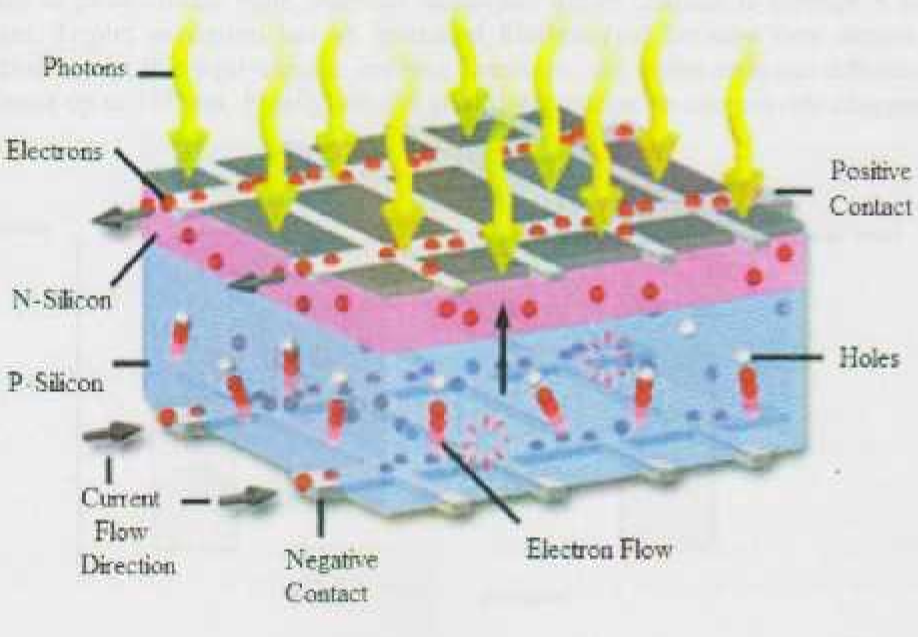

Figure 2.1: Photovoltaic Effect [3]

Generally a solar cell operates through four major steps. The first step is absorption of incident photons, which depends on macroscopic surface property of the material used. After the absorption, it creates the electron hole pair called as excitation. The third step is separation of the electron and hole which is determined by the charge distribution inside the cell. The final step is collection of the charge at respective electrodes which depends upon the Fermi level alignment of the metals with the energy levels of the material. Mainly the efficiency of a solar cell depends on the number of independent charge carriers produced through this procedure. The detailed discussion of these steps is as below.

1. Absorption of Photons and Excitation Generation:

Photons absorption by organic semiconductors produces excitation. In organic materials, the band gap is referred as the difference between energy of lowest unoccupied molecular orbit (LUMO) and highest occupied molecular orbit (HOMO). Extra energy would be wasted in the form of heat. Thus, an efficient solar cell should have a wide absorption spectrum to create as many pairs as possible. Upon light absorption, molecules are excited from the fundamental S0 to the excited state S1 (in the case of singlet transition). Singlet-singlet transitions are very efficient similar to direct transitions in inorganic semiconductors. They have short life time. They can go back to the ground state through luminescence or photon emission. Therefore, luminescence is a loss mechanism in photovoltaic cells. Another excitation decay channel is through a lower triplet state. Triplet excitation has an increased lifetime (μs) because they cannot de-excite radioactively, it is equivalent to indirect transition, and triplet state can diffuse over large distance up to 100 μm. Finally, singlet and triplet excitation can provide charges for PV cells.

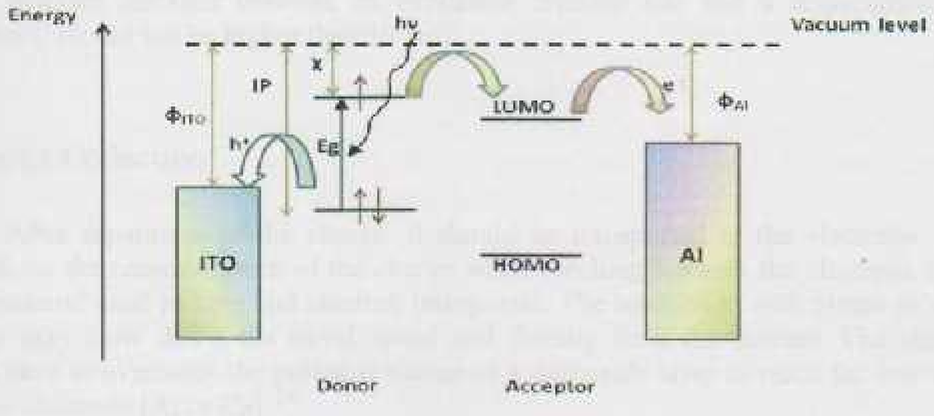

Figure 2.2: Schematic Representation of Operating Principle of Photovoltaic Cell. Electrons are Collected at the Al Electrode and Holes at the ITO Electrode. Φ: Work Function, χ: Electron Affinity, IP: Ionisation Potential, Eg: Optical Band Gap. [4]

2. Excitation Separation:

The separation of excitation is different in various kinds of solar cell materials (semiconductors, dye-sensitized materials, organic polymers). The excitation separation is mainly depends on the binding energy of the electron hole pair. In dye-sensitized materials, the electron is excited to the conducting band, leaving the dye molecule in an ionized state. In other words, the dye sensitized material separates the pair by extracting the hole with electron supplied from the environment.

After photo-excitation of an electron, the electron can jump from the LUMO of the donor (the material with the higher LUMO) to the LUMO of the acceptor. This depends on the potential difference between the ionization potential of the donor and the electron affinity of the acceptor which should be larger than the excitation binding energy as shown in (figure 2.2). However, this process, which is called photo induced charge transfer, can lead to free charges only if the hole remains on the donor due to its higher HOMO level. In contrast, if the HOMO of the acceptor is higher, the excitation transfers itself completely to the material of lower band gap accompanied by energy loss. Excitation can be separated if they meet with electric field within their diffusion range (< 10 nm). When two materials with different work functions were brought into contact, electrons would flow from the one with lower work function to the other until the Fermi surface matches. This builds up an internal field near the contact surfaces.

The difference in electron affinities creates a driving force at the interface between the two materials that is strong enough to separate charge carriers of photo generated excitation. EA and IP of the electron acceptor should be higher than those of the donor. Ideally, all photo excited excitation should reach a dissociation site. As this site may be at the other end of the semiconductor, their diffusion length should be at least equal to the layer thickness, otherwise the holes and electrons will recombine and photons are wasted. Excitation diffusion range in organic materials around 10 nm, which means that the distance between an excitation creation site and a dissociation site (interface), should not be higher than 10 nm.

3. Charge Collection:

After separation of the charge, it should be transported to the electrode. This depends on the recombination of the charge while reaching towards the electrode if the same material used as hole and electron transporter. The interaction with atoms or other charges may slow down the travel speed and thereby limit the current. The charges should have to overcome the potential barrier of a thin oxide layer to reach the low work function electrode (Al or Ca). [4]

2.3 Types of Photovoltaic Cells

2.3.1 Crystalline Silicon Cells:

1. Mono Crystalline Silicon or Single Crystal:

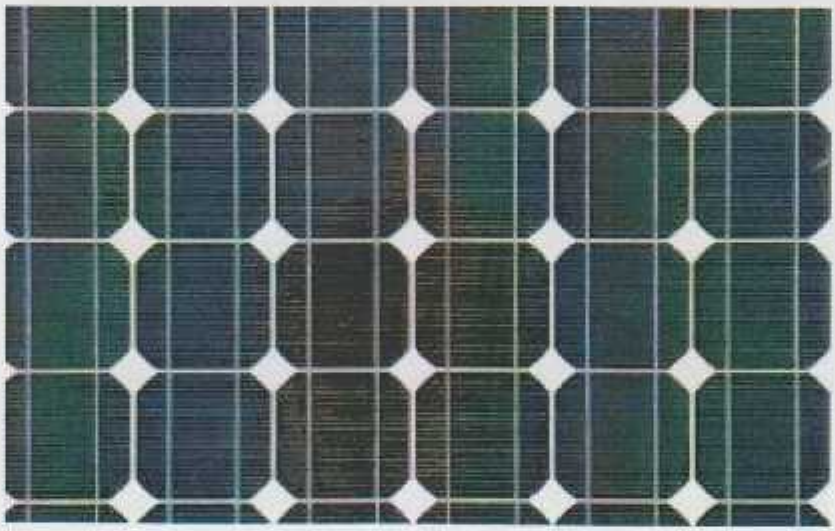

Figure 2.3: Single Crystal [5]

Single crystal silicon cells are the most common in the PV industry. The main technique for producing single-crystal silicon is the czochralski (CZ) method. High purity polycrystalline is melted in a quartz crucible. A single crystal silicon seed is dipped into this molten mass of polycrystalline. As the seed is pulled slowly from the melt, a single-crystal ingot is formed. The ingots are then sawed into thin wafers about 200-400 micrometers thick (1 micrometer – 1/1,000,000 meter). The thin wafers are then polished, doped, coated, interconnected and assembled into modules and arrays as shown in (figure 2.3).

Single crystal silicon has a uniform molecular structure. Compared to non-crystalline materials, its high uniformity results in higher energy conversion efficiency the ratio of electric power produced by the cell to the amount of available sunlight power i.e. power out divided by power in. The higher a PV cell's conversion efficiency, the more electricity it generates for a given area of exposure to the sunlight. The conversion efficiency for single silicon commercial modules ranges between 15-20%. Not only are they energy efficient, single silicon modules are highly reliable for outdoor power applications.

2. Polycrystalline Silicon:

Figure 2.4: Polycrystalline Silicon [6]

Consisting of small grains of single crystal silicon as shown in (figure 2.4), polycrystalline PV cells are less energy efficient than single crystalline silicon PV cells. The grain boundaries in Polycrystalline silicon hinder the flow of electrons and reduce the power output of the cell. The energy conversion efficiency for a commercial module made of Polycrystalline silicon ranges between 10 to 14%.

A common approach to produce polycrystalline silicon PV cells is to slice thin Wafers from blocks of cast polycrystalline silicon. Another more advanced Approach is the "ribbon growth" method in which silicon is grown directly as thin ribbons or sheets with the approach thickness for making PV cells. Since no sawing is needed, the manufacturing cost is lower. The most commercially developed ribbon growth approach is EFG (edge defined film fed growth).

Compared to single crystalline silicon, polycrystalline silicon material is stronger and can be cut into one-third the thickness of single crystal material. It also has slightly lower wafer cost and less strict growth requirements. However, their lower manufacturing cost is offset by the lower cell efficiency.

2.3.2 Thin Film Cells:

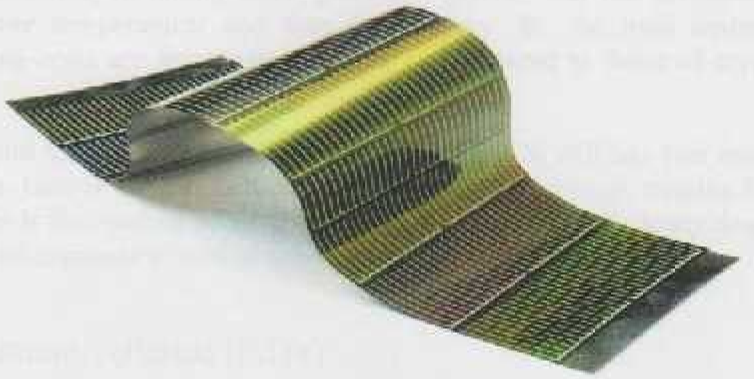

Figure 2.5: Thin Film Cells [7]

In a thin film PV cell, a thin semiconductor layer of PV materials is deposited on low cost supporting layer such as glass, metal or plastic foil as shown in (figure 2.5) Since thin film materials have higher light absorptivity than crystalline materials, the deposited layer of PV materials is extremely thin; from a few micrometers to even less than a micrometer (a single amorphous cell can be as thin as 0.3 micrometers). Thinner layers of material yield significant cost saving. Also, the deposition techniques in which PV materials are sprayed directly onto glass or metal substrate are cheaper. So the manufacturing process is faster, using up less energy and mass production is made easier than the ingot growth approach of crystalline silicon. However, thin film PV cells suffer from poor cell conversion efficiency due to non-single crystal structure, requiring larger array areas and increasing area related costs such as mountings.

Constituting about 4% of total PV module shipments of US4, the PV industry sees great Potentials of thin film technology to achieve low cost PV electricity.

Materials used for thin film PV modules are as follows:

1. Amorphous Silicon (a-Si):

Used mostly in consumer electronic products which require lower power output and cost of production, amorphous silicon has been the dominant thin film PV material since it was first discovered in 1974.

Amorphous silicon is a non-crystalline form of silicon i.e. its silicon atoms are disordered in structure. A significant advantage of a-Si is its high light absorptivity, about 40 times higher than that of single crystal silicon. Therefore only a thin layer of a-Si is sufficient for making PV cells (about 1 micrometer thick as compared to 200 or more micrometers thick for crystalline silicon cells). Also, a-Si can be deposited on various low cost substrates, including steel, glass and plastic, and the manufacturing process requires lower temperatures and thus less energy. So the total material costs and manufacturing costs are lower per unit area as compared to those of crystalline silicon cells.

Despite the promising economic advantages, a-Si still has two major roadblocks to overcome. One is the low cell energy conversion efficiency, ranging between 5-8%, and the other is the outdoor reliability problem in which the efficiency degrades within a few months of exposure to sunlight, losing about 10 to 15%.

2. Cadmium Telluride (CdTe):

As a polycrystalline semiconductor compound made of cadmium and tellurium, CdTe has a high light absorptivity level only about a micrometer thick can absorb %90 of the solar spectrum. Another advantage is that it is relatively easy and cheap to manufacture by processes such as high-rate evaporation, spraying or screen printing. The conversion efficiency for a CdTe commercial module ranging between 6-9%, similar to a-Si.

The instability of cell and module performance is one of the major drawbacks of using CdTe for PV cells. Another disadvantage is that cadmium is a toxic substance. Although very little cadmium is used in CdTe modules, extra precautions have to be taken in manufacturing process.

3. Copper Indium Diselenide (CuInSe2, or CIS):

A polycrystalline semiconductor compound of copper, indium and selnium, CIS has been one of the major research areas in the thin film industry. The reason for it to receive so much attention is that CIS has the highest "research" energy conversion efficiency of 17.7% in 1996 is not only the best among all the existing thin film materials, but also came close to the 18% research efficiency of the polycrystalline silicon PV cells. (A prototype CIS power module has a conversion efficiency ranging between 7.5-9.5%) Being able to deliver such high energy conversion efficiency without suffering from the outdoor degradation problem, CIS has demonstrated that thin film PV cells are a viable and competitive choice for the solar industry in the future.

CIS is also one of the most light-absorbent semiconductors 0.5 micrometers can absorb 90% of the solar spectrum.

CIS is an efficient but complex material. Its complexity makes it difficult to manufacture. Also, safety issues might be another concern in the manufacturing process as it involves hydrogen selenide, an extremely toxic gas. So far, CIS is not commercially available yet although Siemens Solar has plans to commercialize CIS thin film PV modules. [2]

2.3.3 Gallium Arsenide (GaAs):

Figure 2.6: Gallium Arsenide [8]

A compound semiconductor made of two elements: gallium (Ga) and arsenic (As), GaAs has a crystal structure similar to that of silicon as shown in (figure 2.6). An advantage of GaAs is that it has high level of light absorptivity. To absorb the same amount of sun light, GaAs requires only a layer of few micrometers thick while crystalline silicon requires a wafer of about 200-300 micrometers thick.3 Also, GaAs has a much higher energy conversion efficiency than crystal silicon, reaching about 25 to 30%. Its high resistance to heat makes it an ideal choice for concentrator systems in which cell temperatures are high. GaAs is also popular in space applications where strong resistance radiation damage and high cell efficiency are required. The biggest drawback of GaAs PV cells is the high cost of the single crystal substrate that GaAs is grown on. Therefore it is most often used in concentrator systems where only a small area of GaAs cells is needed. [9]

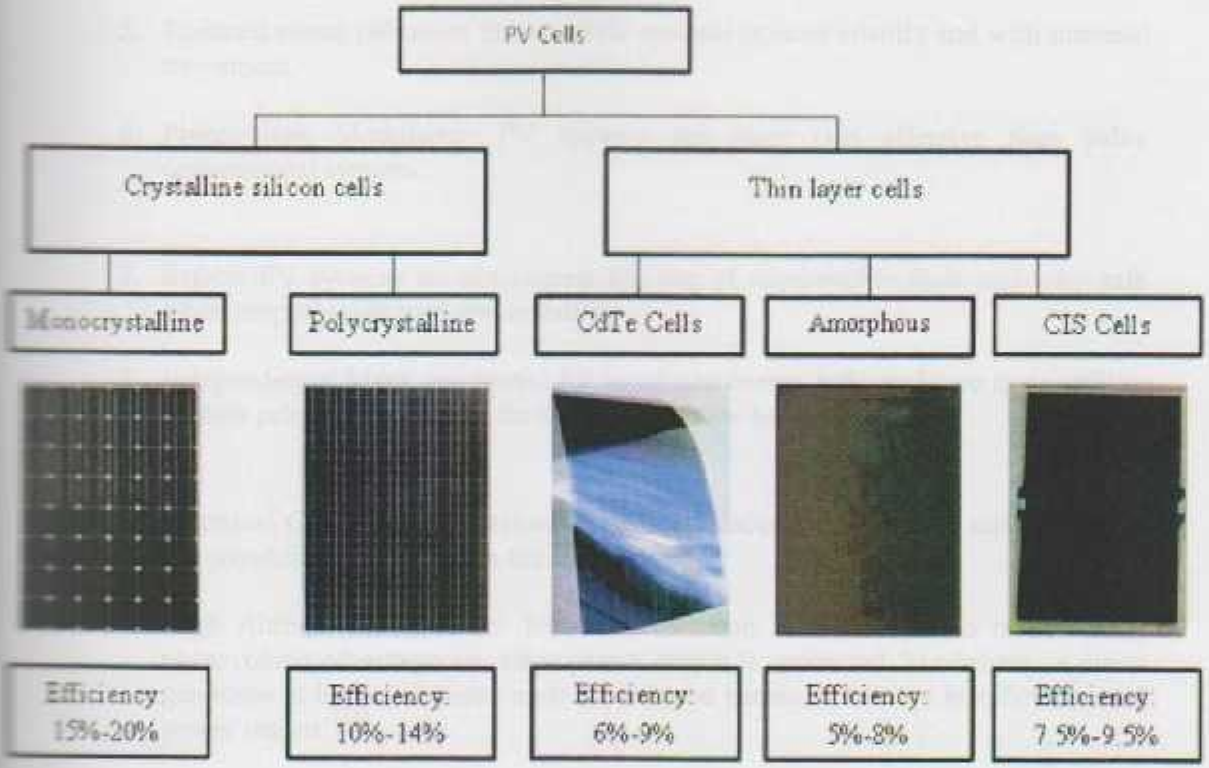

Figure 2.7: Different Types of PV Cells and Their Associated Efficiencies

2.4 Advantages of Solar Cells:

1. Reliability: Even in harsh conditions, photovoltaic systems have proven their reliability .PV arrays prevent costly power failures in situations where continuous operation is critical.

2. Durability: Most PV modules available today show no degradation after ten years of use. It is likely that future modules will produce power for 25 years or more.

3. Low Maintenance Cost: Transporting materials and personnel to remote areas for equipment maintenance or service work is expensive .Since PV systems require only periodic inspection and occasional maintenance, these costs are usually less than with conventionally fueled systems.

4. No Fuel Cost: since no fuel source is required, there are no costs associated with purchasing, storing, or transporting fuel.

5. Reduced sound pollution: photovoltaic systems operate silently and with minimal movement.
6. Photovoltaic Modularity: PV systems are more cost effective than bulky conventional systems.
7. Safety: PV systems do not require the use of combustible fuels and very safe when properly designed and installed.
8. Independence: Many residential PV users cite energy independence from utilities as their primary motivation for adopting the new technology.
9. Electrical Grid Decentralization: Small-scale decentralized power station reduces the possibility of outages on the electric grid.
10. High Altitude Performance .Increased isolation at high altitudes makes using photovoltaic advantageous, since power output is optimized .In contrast , a diesel generator at higher altitudes must be de-rated because of losses in efficiency and power output. [10]

2.5 Disadvantages of Solar Cells:

1. Initial cost: Each PV installation must be evaluated from an economic perspective and compared to existing alternatives. As the initial cost of PV systems decreases and the cost of conventional fuel sources increases, these systems will became more economically competitive.
2. Variability of Available Solar Radiation: Weather can greatly affect the power output of any solar-based energy system. Variations in climate or site conditions require modifications in system design.
3. Energy storage: Some PV systems use batteries for storing energy, increasing the size, cost, and complexity of a system.
4. Efficiency Improvements: A cost effective use of photovoltaic requires a high efficiency approach to energy consumption .This often dictates replacing inefficient appliances. [10]

2.6 Characteristic of PV:

The characteristic of current in amperes versus voltage in volts of a photovoltaic module is shown in (figure 2.8). There is a slight difference between maximum current (I_{mp}) and short circuit current (I_{sc}).

Absorbed current from the solar module is proportional with the sun insolation as it is illustrated in (figure 2.9).

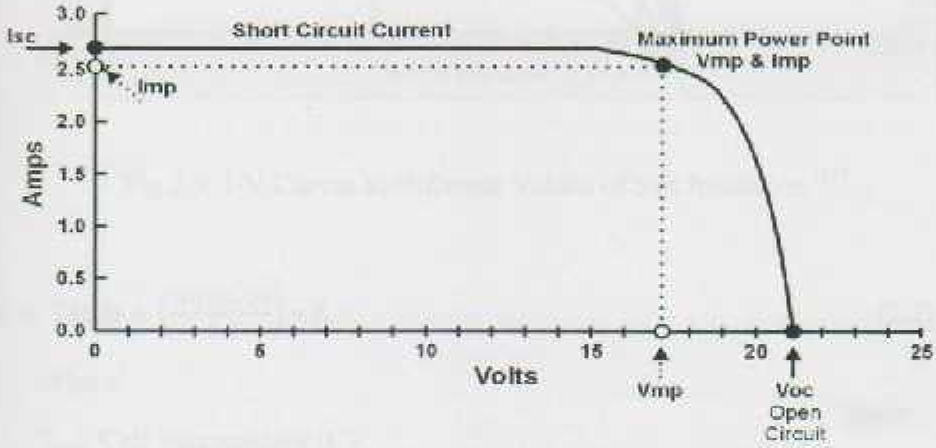

Figure 2.8: I-V Curve [11]

$$Voc = \frac{K*T}{q}\ln(\frac{Ish}{Io} + 1). \tag{2.1}$$

Where:

V_{oc}: Open Circuit Voltage (V).

T: Junction Temperature (k).

K: Boltzmann's Constant 1.381 × 10^−23 J/K.

q: Electron Charge 1.602 × 10^−19 (C).

I_{sh}: Short Circuit Current (A)

Io: Reverse Saturation Current (A). [11]

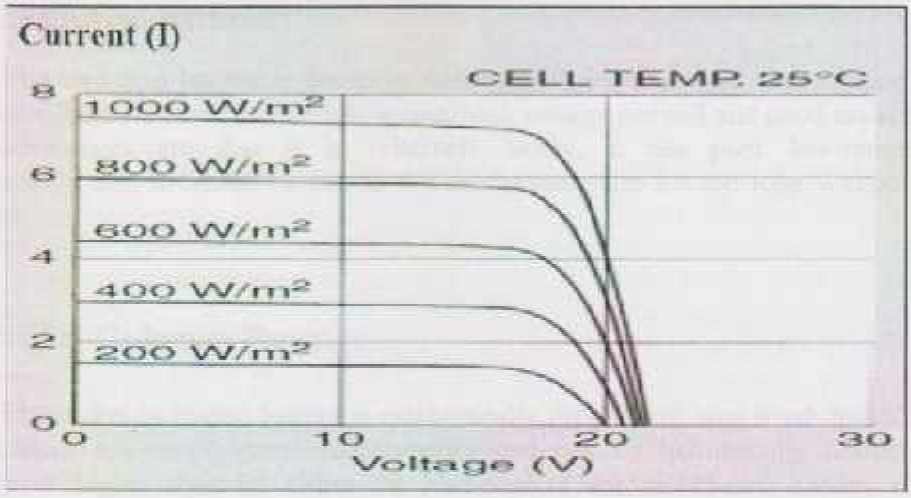

Fig 2.9: I-V Curves at Different Values of Sun Insolation [11]

$$T_{cell} = T_{amb} + \left(\frac{NOTC-20}{0.8}\right) * S. \qquad (2.2)$$

Where:

T_{cell}: Cell Temperature (C).

T_{amb}: Ambient Temperature.

NOCT: Cell Temperature in a Module When Ambient is 20°C

0.8: Radiation.

S: Insolation (KW/m2). [11]

2.7 Batteries:

Batteries in photovoltaic systems are used to store direct current electrical energy in chemical form. This energy can be used later especially at night and during periods of cloudy weather. Batteries can provide a relatively constant source of power when the PV system is producing minimal power during periods of reduced insolation.

They can power the loads when the PV array is disconnected for repair and maintenance. They can provide the necessary surge power to start some kinds of motors.

Five major types of rechargeable batteries are lead-acid, nickel-cadmium; silver-zinc, silver-cadmium and nickel-zinc, and these are discussed in more detail below.

2.7.1 Lead-Acid Batteries:

The lead-acid battery is the most widely used, its main application being in the automotive field. Its advantages are low cost, high voltage per cell and good capacity life. Its disadvantages are that it is relatively heavy, it has poor low-temperature characteristics and it cannot be left in the discharged state for too long without being damaged.

2.7.2 Nickel-Cadmium Batteries:

The nickel-cadmium battery is mechanically rugged and long lived. In addition it has excellent low-temperature characteristics and can be hermetically sealed. Cost, however, is higher than for either the lead-acid or the nickel-zinc battery and, by comparison, its capacity on light drain in terms of watt hours per kilogram is also poorer than for nickel-zinc.

2.7.3 Silver-Zinc Batteries:

Rechargeable silver-zinc batteries can provide higher currents, more level voltage and up to six time's greater watt hour capacity per unit weight and volume than the lead-acid, nickel-zinc and nickel-cadmium storage batteries. Because it is capable of delivering high watt hour capacities at discharge rates less than 30 min, the silver-zinc battery is used extensively for missile and torpedo applications. Its high energy density makes it attractive in electronics indications, satellites and portable equipment where low weight and high performance are prime considerations. It is highly efficient and mechanically rugged, operates over a wide temperature range and offers good shelf life; quick readiness for use and the ability to operate at -40°C without heating are two of the features of this battery. It is available in both high-rate and low-rate cells. Until now the fact that it is more expensive, sensitive to overcharge and has a shorter cycle life than ordinary storage batteries has limited the silver-zinc battery -applications where space and weight are prime .Consecrations. However, long-life silver-zinc batteries have been developed in which some 400 cycles over a period of 30 months' application have been achieved.

2.7.4 Silver-Cadmium Batteries:

The silver-cadmium battery combines the high energy and excellent space and weight characteristic the silver-zinc battery with the long-life, low-rate characteristics and some resistance to overcharge of the nickel-cadmium battery. The battery also provides high efficiency on extended shelf life in charged or uncharged conditions, level voltage and mechanical ruggedness. Watt hour capacity per unit of weight and volume are two to three times greater than those of a comparable nickel-cadmium battery and it has superior charge retention. The silver-cadmium battery promises great weight and space savings and superior life characteristics to those of the nickel-cadmium battery currently used as storage batteries in most satellite programmes.

Today a silver-zinc system offers the greatest available energy density in terms of watt hours per kilogram. There are newer so-called high energy density couples which have been under development for many years; the effective energy density of many of these systems tends to decline as they are developed close to the point of practical utilization. In addition, chronic safety problems have already caused serious difficulties with the lithium systems and are potentially dangerous in others, most of which are high-temperature systems based on volatile materials. The use of silver as a couple obviously increases initial costs (although silver costs are recoverable) when compared to other existing systems such as lead-acid, nickel-cadmium, etc. When space and weight are limiting factors, the silver-zinc system is a very attractive proposition.

Other metal couples that are considered at present to be of great potential are the nickel-hydrogen and nickel-zinc systems. These may be batteries of the future in applications such as utilities load leveling and electric vehicles; the latter type is, in fact, now in commercial production.

2.7.5 Nickel-Zinc Batteries:

With the development of new separators and improved zinc electrodes, the nickel-zinc battery has now become competitive with the more familiar battery systems. It has a good cycle life and has load-voltage characteristics higher than those of the silver-zinc system. The energy per unit of weight and volume are slightly lower than those of the silver-cadmium system. Good capacity retention (up to 6 months) has made the nickel-zinc battery a more direct competitor of the silver-zinc and silver-cadmium systems. Nickel-zinc batteries are not yet available in a sealed form. [12]

2.8 Battery Specifications: [10]

2.8.1 Days of Autonomy Rely On:

Autonomy is the number of days a battery storage system will provide the load without being recharged by the photovoltaic solar panels or another source.

Days of autonomy rely on weather conditions, so the number of non-sun and cloudy days of autonomy. The designer can reduce the number of days of autonomy when adding a hybrid alternative as generator or wind turbine. The days of autonomy affect the size and cost of the solar system.

2.8.2 Battery Capacity:

The capacity of battery is based on the power needed to operate the loads and how much stored energy will be needed to feed the loads when the weather is cloudy.

Battery capacity is affected by load, rate of discharge, depth of discharge, temperature and age.

2.8.3 Rate and Depth of Discharge:

The rate of discharge affects the battery capacity. If it is discharged quickly the capacity is less, but when the battery is discharged slowly the capacity will be greater.

Depth of discharge (DOD) refers to how much capacity will be withdrawn from the battery. Battery life is affected by the depth of discharge as shown in (figure 2.10).

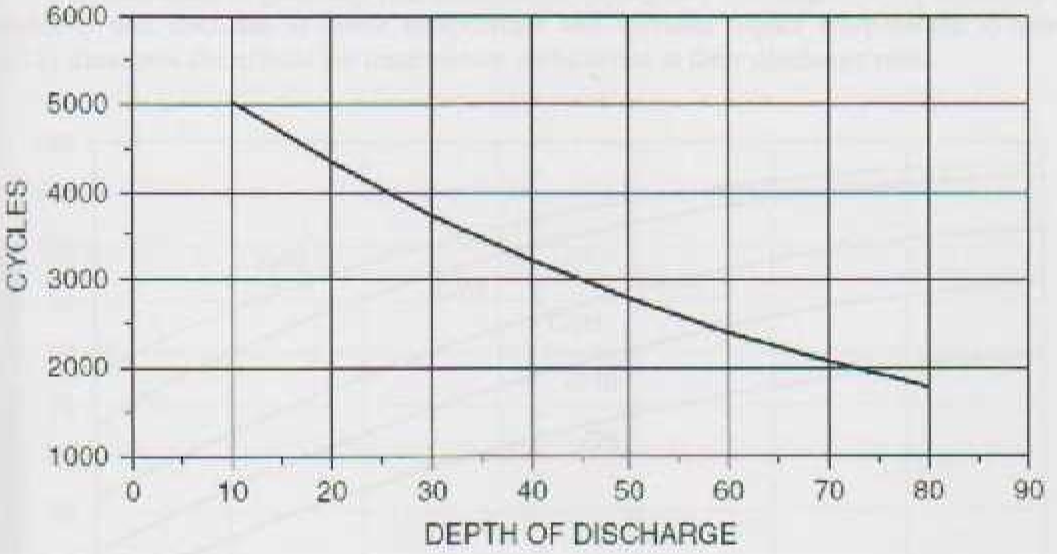

Figure 2.10: Impact of Depth of Discharge on the Number of Cycles [10]

2.8.4 Life Expectancy:

Battery manufactures however specify life expectancy in terms of a quantity of cycle. Batteries lose capacity over time and are considered to be at the end of their life when 20 percent of their original capacity is lost, although they can still be used. When sizing a system initially, this should be considered.

Depth of discharge also refers to the percentage of a battery's rated amp-hours capacity that has been used. Battery life (number of daily cycle) versus depth of discharge (in percent of battery capacity) is shown for a lower cost sealed battery in (figure 2.10).

This is only an estimate. Some batteries are designed to be cycled more than once each day. In addition, batteries degrade over time, affecting life expectancy.

2.8.5 Environment Conditions:

Batteries are sensitive their environment particularly affected by the temperature of that environment. Higher voltaic charge termination points are required to complete charging as a battery's temperature drops (the opposite is true in warmer temperature). Controllers with a temperature compensation features can automatically adjust charge voltage based on a battery's temperature.

Manufactures generally rate batteries at 77 degree F (25 degree C). The battery's capacity will decrease at lower temperature and increase higher temperature. (Figure 2.11) illustrates the effects the temperature on batteries at their discharge rates.

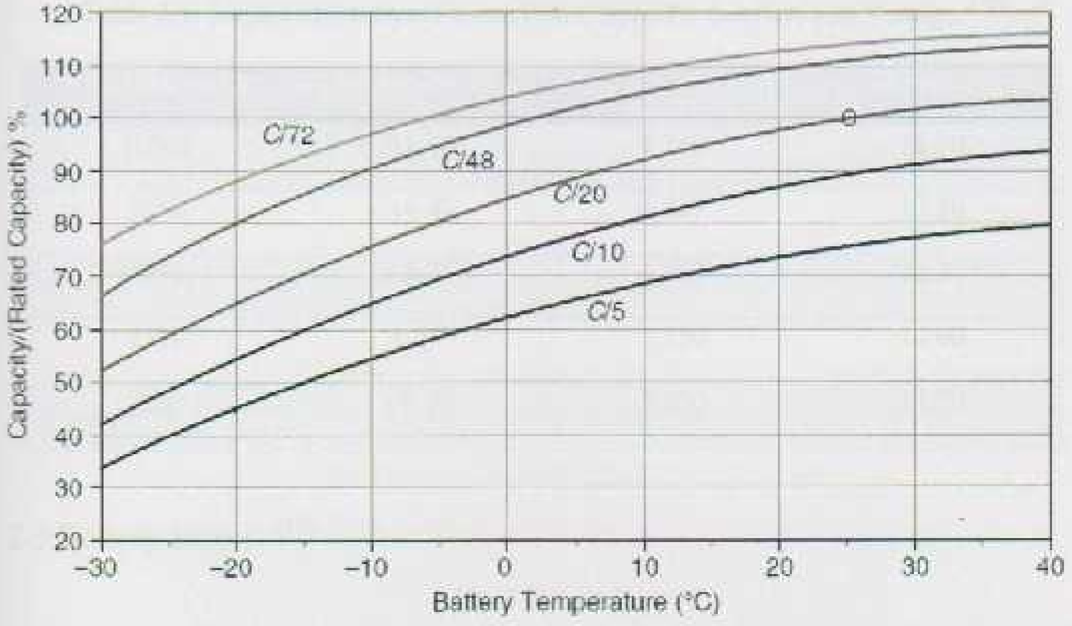

Figure 2.11: Effects of Temperature on Battery Capacity [10]

Even though battery capacity decreases at lower temperature, battery life increases. Likewise, the higher the battery temperature, the shorter the life of the battery.

Regardless of temperature concerns, batteries should be located in a sturdy enclosure (battery box).

Always try to design systems with batteries as near as is safely possible to the loads and the array to minimize wire runs, thereby saving money on materials and reducing voltage drop.

2.8.6 Measuring Battery State of Charge:

A voltmeter or a hydrometer can be used to measure a battery's state of charge. To properly check voltage, the battery should sit at reset for a few hours (disconnect from charging source and loads).Table 2.1 can be used to compare a 12 volt battery's voltage to its state of charge. For a 24 volt system multiply by 2, and for 48 volt system multiply by 4. Can also be used to determine a battery's state of charge by measuring the specific gravity of a cell with a hydrometer.

Table 2.1: Liquid Electrolyte Freeze Point, Specific Gravity, and Voltage. [10]

State Of Charge	Freeze Point	Specific Gravity	Voltage
100%	-71 °F	1.260	12.70
75%	-35 °F	1.237	12.50
50%	-10 °F	1.200	12.30
25%	3 °F	1.150	12.00
0%	17 °F	1.100	11.70

2.9 Battery Safety: [10]

Due to the hazardous materials and chemicals involved, and the amount of electrical energy which they store, batteries are potentially dangerous and must be handled and used with caution. Typical batteries used in stand-alone PV systems can deliver up to several thousand amps under short circuit conditions requiring special precautions. Depending on the size and location of a battery installation, certain safety precautions are be required:

1. Never touch both battery terminals with your bare hands at the same time.
2. Remove rings, watches and dangling jewelry when working with or near batteries. The metal in the jewelry can cause a shock or burn if they contact the battery terminals
3. Only use insulated/non-conducting tools to remove cell caps. Never lay tools or other metal parts on top of a battery.
4. Consider covering battery terminals and connectors if possible with an insulating blanket before overhead inspections or repairs.
5. Ensure charger is turned off before connecting or disconnecting a battery to prevent arcing.
6. Prevent open flames, sparks or electric arcs in battery charging areas.
7. Do not strike the sides of the battery with any spark producing item.
8. Keep tools and other metallic objects away from uncovered batteries.
9. Neutralize static buildup just before working on battery by contacting nearest grounded surface.
10. Ensure battery area ventilation is operating prior to working on.

2.10 Charge Controller:

A Solar Charge Controller (or Regulator) is a device which protects the batteries in a solar electric system from being overcharged or being over discharged.

Figure 2.12: Charge Controller [13]

Overcharged batteries have a much shorter life time than well cared for batteries since the electrolyte is boiled off as gas and lost. Overly discharged (i.e. flat) lead acid batteries become permanently damaged, so a solar charge controller is used to disconnect any load when the battery is discharged down to a safe cut off voltage. [14]

Figure 2.13: Charge Controller Model [15]

(Figures 2.12) and (2.13) show two types of charge controllers. Charge controller is able to handle reverse polarity connection of both the battery and photovoltaic panel. (Figure 2.13) shows the connections of a charge controller.

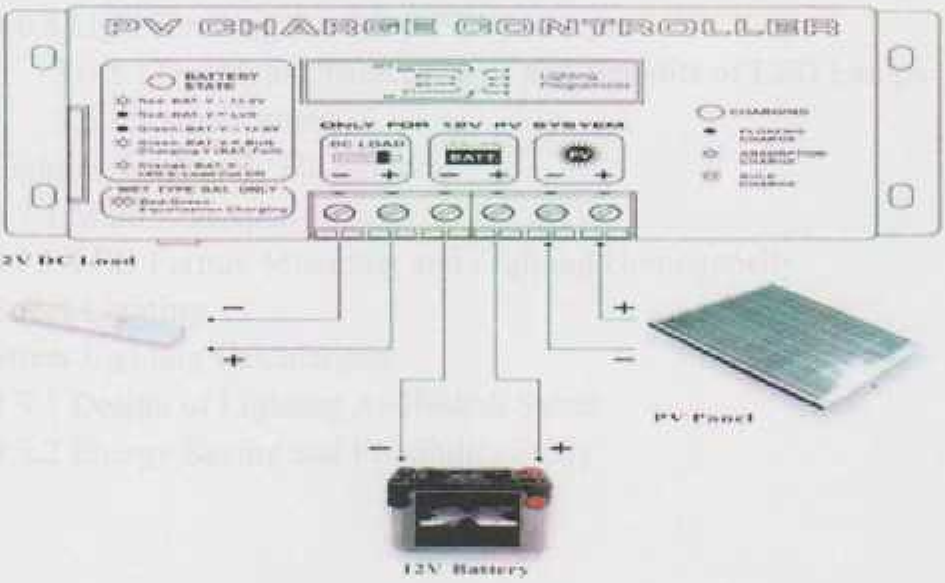

Figure 2.14: The Charge Controller Connections with a Solar System [16]

CHAPTER

3 Lighting

Chapter Three

Lighting

3.1 Introduction:

Lighting is an essential element in most life styles, and electricity or natural day lighting generally provides it.

These lamps can be an appropriate option because they effectively reduce the electrical load requirements of a photovoltaic system. Today, many different light sources are available, which makes choosing the correct energy efficient light source, much more difficult.

A wide variety of attractive, economical lighting options are available in 12V and 24V direct current and 220V alternating current types making photovoltaic powered lighting a feasible choice for many homeowners.

New types of lamps with electrical and light output characteristics far superior to the familiar incandescent and fluorescent lamps further confuse a potential purchaser.

The following sections describe the common lamp types and their efficiencies. LED lights will be considered in our study, design and calculation as an application of Al-Hesbah street lighting. (Figure 3.1) shows atypical street lighting.

Figure 3.1: Street Lighting [17]

3.2 Lighting Concepts and Measurements

1- Luminous Flux (Ø)

It is the rate at which light emitted by a lamp measured in lumen (Lm).

It defines the visible light radiating from a light source in all directions.

2- Luminous Intensity (I)

The luminous intensity is the luminous flux emitted from a point per unit solid angle into a particular direction.

Standard unit of luminous intensity is Candlepower or Candela (cd).

3- Illumination (E)

Illumination is the total amount of visible light illuminating (incident upon) a point on a surface from all directions above the surface.

Standard units for illumination is Lux which is lumens per square meter (Lm/m^2) or foot candle (fc) which is lumens per square foot (Lm/sq.ft).

Foot candle (fc) = 10.764 lux.

Table 3.1: Different Values of Illumination, Different Environments

1 lux	full moon
4-10 lux	street lighting
100-1,000 lux	workspace lighting
10,000 lux	surgery lighting
100,000 lux	plain sunshine

4- Luminance

It is the brightness of a luminous or illuminated surface as perceived by the human eye measured in cd/sq.m or in cd/sq.cm. It expresses the intensity of the light emitted or reflected by a surface per unit area. [18]

3.3 Optical Features of Lighting Units

1- Color Temperature

Color temperature is a simplified way to characterize the spectral properties of a light source.

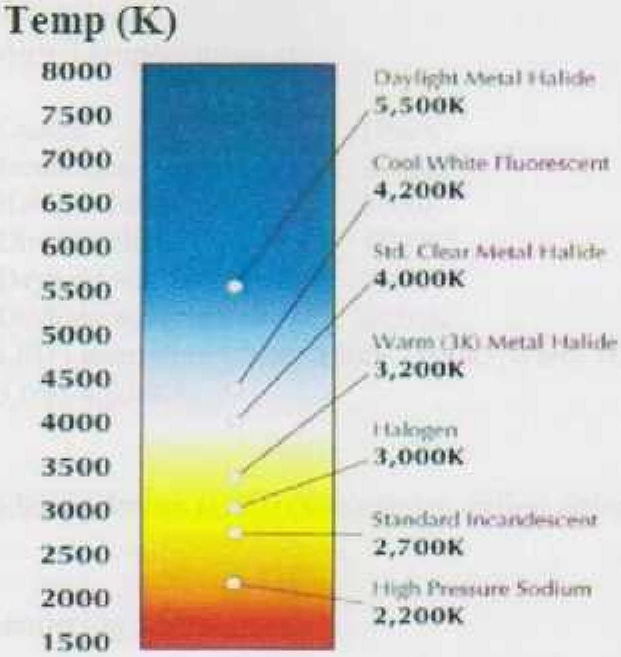

Figure3.2: Color Temperature [19]

Correlated Color Temperature (CCT)

Correlated Color Temperature is a characteristic of visible light that has important applications in lighting, photography and other fields. The color temperature of a light source is the temperature of an ideal black body radiator that radiates light of comparable hue to that of the light source. Color temperature is conventionally stated in the unit of absolute temperature, the Kelvin, having the unit symbol K°.

Color temperatures over 5,000K° are called cool colors (blueish white), while lower color temperatures (2,700–3,000 K°) are called warm colors (yellowish white through red). (Figure 3.2) shows the relation between color and temperature.

Low color temperature implies warmer (more yellow/red) light while high color temperature implies a colder (more blue) light. Daylight has a rather low color temperature near dawn, and a higher one during the day. Therefore it can be useful to install an electrical lighting system that can supply cooler light to supplement daylight when needed, and fill in with warmer light at night.

Standard unit for color temperature is Kelvin (K°).

(The kelvin unit is the basis of all temperature measurement, starting with (0 K°= -273.16 C°) at the absolute zero temperature. The "size" of one kelvin is the same as that of one degree Celsius, and is defined as the fraction 1/273.16 of the thermodynamic temperature of the triple point of water, which positions 0 C° at 273.16 K°).

Some Typical Color Temperatures are:

Candle	1900K°
Incandesce lamp	2700K°
Halogen lamp	3000K°
Direct sunlight	6000K°
Daylight with cloudy sky	7000K°
Daylight with clear sky	20000K°

- LED Lamps Pure White: 5,000~7,000K°,Warm White 3,000~4,000K°

2- Color Rendering Index (CRI) (sometimes called color rendition index)

General Color Rendering Index:

It is the effect of an illuminant on the color appearance of objects compared to a reference source of the same color temperature (ideal or natural light source), so color rendering index is a useful way to determine the quality of a light source. The highest CRI attainable is 100. Typical cool white fluorescent lamps have a CRI of 62. Lamps having rare-earth phosphors are available with a CRI of 80 and above.

In a day lighting context, the color rendering index defines the spectral transmissive quality of glasses or other transparent materials. In this case, values of 95 or better are considered accept.

In other words the color rendering index is the ability of a light source to correctly reproduce the colors of the objects in comparison to an ideal light source as it is illustrated in (figure 3.3).

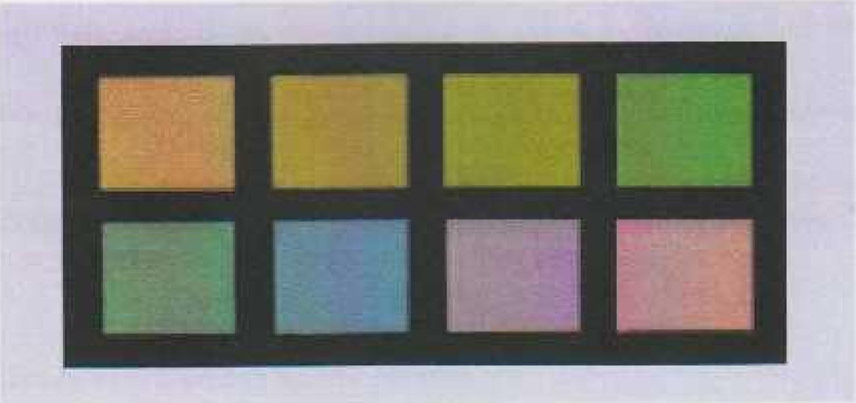

Figure 3.3: Color Rendering Index [20]

The general color rendering index Ra is a measure of the average appearance of eight standardized colors chosen to be of intermediate saturation and spread throughout the range of hues as shown in (figure3.4). If a color rendering index is not qualified as to the color samples used, Ra is assumed. For LED lamps Ra > 75. [18]

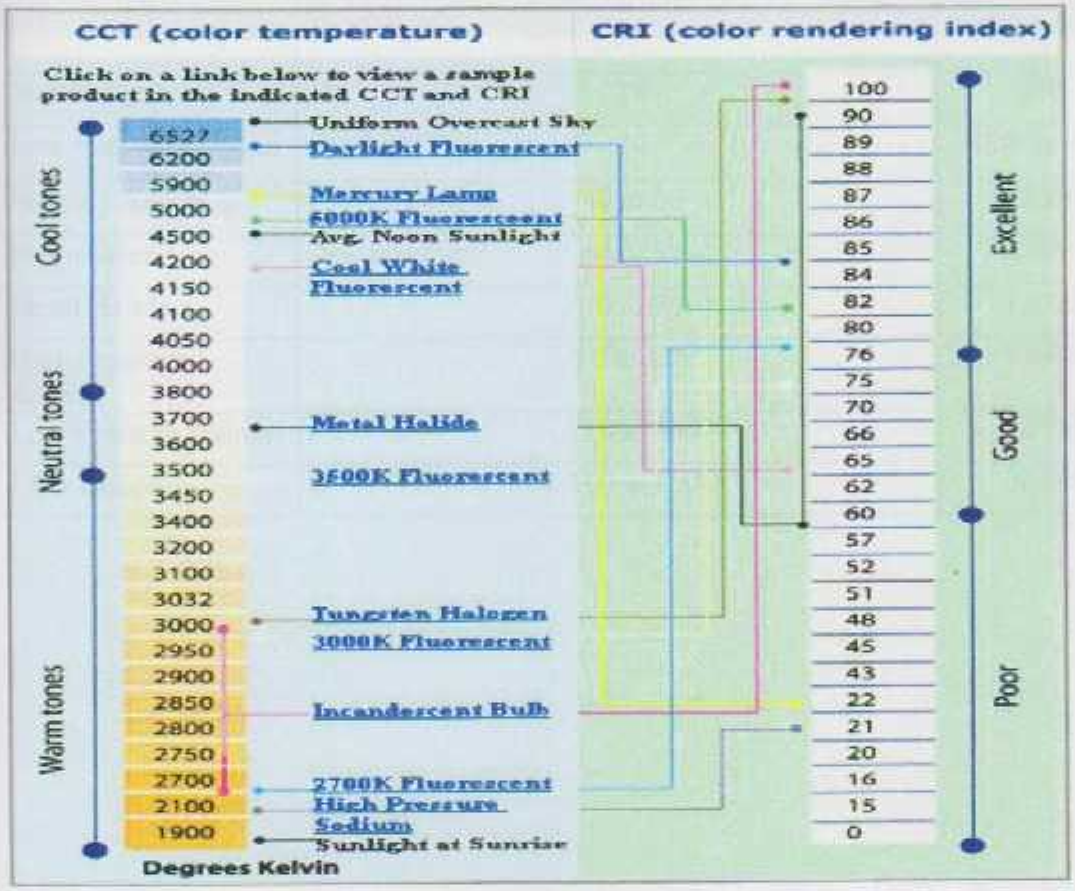

Figure 3.4: Color Temperature and Color Rendering Index [20]

3.4 Lamp Efficacy

When selecting a lamp type, efficacy is an important consideration, but it should not be the only criteria used (Figure 3.5 shows luminous efficacy of different types of lamps) .In most cases, a more efficient light source can be substituted for a less efficient source with little or no loss in visibility or color rendition .The total annual cost savings help to decrease the size of the photovoltaic system.

Lamp efficacy is measured in lumens per watt.

$$\text{Lamp efficacy} = \frac{\text{Luminous flux (lm)}}{\text{Lamp power}} \tag{3.1}$$

Lumens are a measure of the light output from the lamp .If a lamp produces more lumens from each watt of electrical energy input, it is more efficient. [21]

Table 3.2: Typical Efficacy Ranges for the Main Lamp Categories [22]

Lamp Type	Conversion Efficacy (Lumens per Watt)	Life (Hours)
Incandescent	14	800
Low Voltage Halogen	20	2000 to 5000
Mercury Vapor	40 to 60	22000
Fluorescent	64 t0 90	7000
Metal Halide	70 to 90	12000
High Pressure Sodium	90 to 125	25000
Low Pressure Sodium	120 to 200	20000
LED Lamps	100 to 150	50000

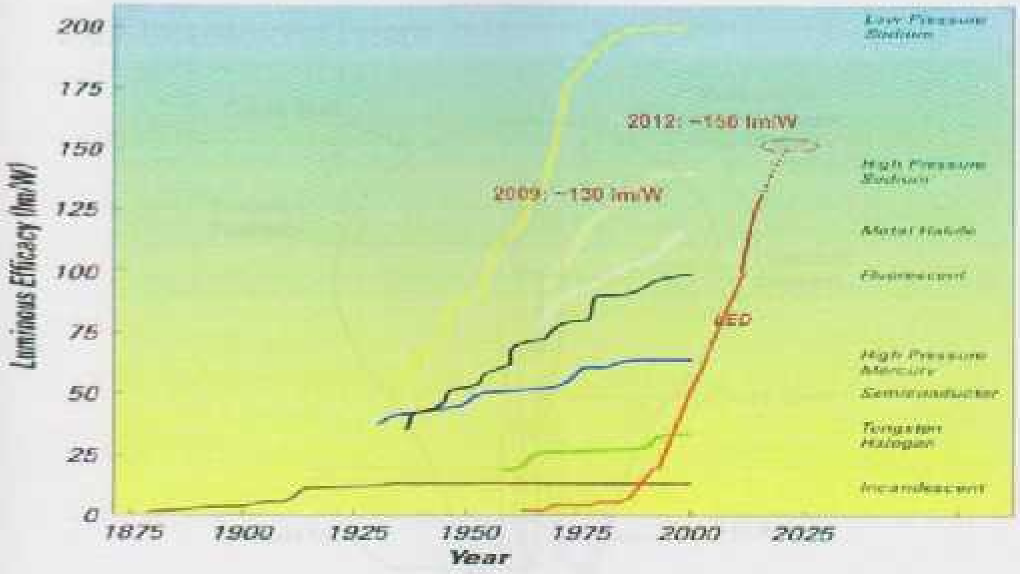

Figure 3.5: LED Luminous Efficacy Compared to Other Light Sources [23]

3.5 Lamp Efficiency

It is the ratio between output power and input power.

$$\text{Lamp Efficiency} = \frac{\text{Output power}}{\text{Input power}} * 100\% \qquad (3.2)$$

Or it is the ratio between lumens emitted by the luminaire and lumens emitted by the light source.

Lamp Efficiency = lumens emitted by the luminaire / lumens emitted by the light source %. [24]

3.6 Lamp Types [18]

The job of a lamp is to convert electrical power (Watts) into light (lumens).

Different lamps do this with varying efficiencies. Lamps are generally divided into the following categories:

3.6.1 Incandescent Lamps

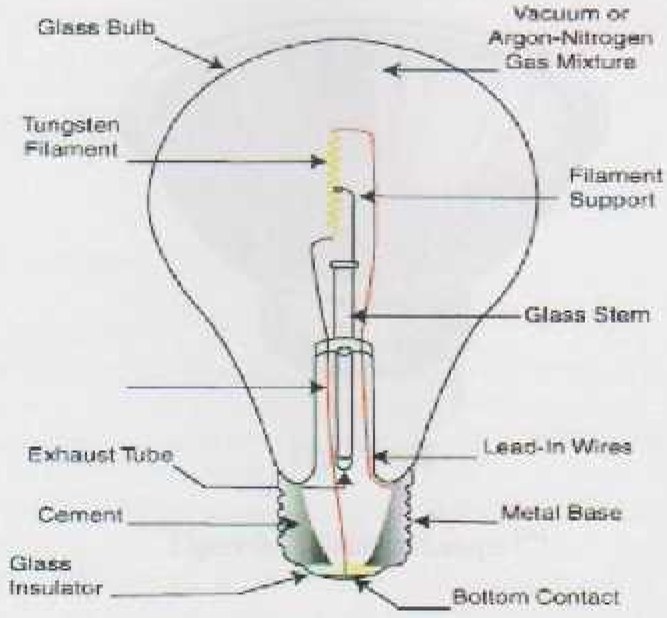

Figure 3.6: Incandescent Lamps [25]

Incandescent Lamps are the most commonly used even though they have the poorest efficiency or lowest lumen per watt ratings. In typical incandescent lamps, electricity is conducted through a filament that resists the flow of electricity, heats up, and glows as shown in (figure 3.6).

The popularity of the Incandescent lamps is due to the simplicity of its use and the low initial cost of both lamps and fixtures.

Incandescent Lamps use the familiar "Edison base" bulb and require no special equipment or ballasts to modify the characteristics of the power supplied to the fixture.

Incandescent Lamps are available in much wattage, both in 220 volt alternating current and 12 volt direct current.

3.6.2 Tungsten Halogen Lamps

Figure 3.7: Halogen Lamps [26]

Like other incandescent lamps, use the tungsten filament as the light source, see (figure3.7). However, these lamps contain a "family of elements" known as halogens. The halogens prevent lamp walls from darkening as quickly as the walls of other in candescent lamps, which keep the light output of tungsten halogen lamp higher for a longer period of time. Halogen lamps are available in low wattages.

3.6.3 Fluorescent Lamps

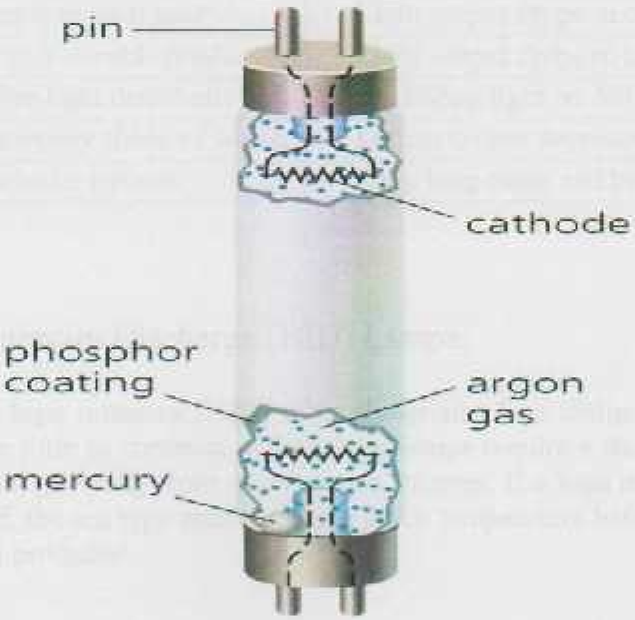

Figure 3.8: Fluorescent Lamps [27]

Are the second most widely used light source .They are found in homes, stores, offices, and industrial plants. These lamps are easily distinguished by their tubular design see (figure 3.8), which can be circular, straight, or bent into an L shape. When operating, an electric arc is drawn along the length of the tube. The ultraviolet light produced by the arc activates a phosphorescent coating on the inside wall of the tube, causing light to be emitted.

3.6.3.1 Construction of the Fluorescent Lamp

The convenience and popularity of the linear fluorescent lamp is underscored by the fact that it accounts for a greater amount of light produced on our planet than any other light source. It achieved this position of dominance by the 1970s and it is estimated that today it accounts for about 80% of the world's artificial light. It can be manufactured in almost any shade of white as well as coloured versions. It offers a low system cost, the lifetime is very long, it is fully dimmable and easy to use, and above all it achieves high luminous efficacies to yield a low cost of operation. The large area of the tube results in a low surface luminance, and it is especially well suited to the efficient and glare-free general illumination of large spaces. In 1980 its position was further strengthened by the introduction of the compact fluorescent lamp. Figure 3.6: illustrates the construction of a typical fluorescent tube.

3.6.3.2 Basic Characteristics

Advantages	Disadvantages
Very high luminous efficacy	Contains toxic mercury vapor
Color rendering is good to excellent	Quite sensitive to ambient temperature
Low cost and simple control gear	Light output drops in cold areas
Long lifetime, highly durable product	Light output drops in hotter luminaires
Even and glare-free light distribution	Flickering light on 50Hz magnetic ballasts
Can produce almost any shade of white	Lumen output decreases through lifetime
Dimmable with special ballasts	Very long tubes can be difficult to handle

3.6.3.3 High Intensity Discharge (HID) Lamps:

The term high intensity (HID) often designates four distinct types of lamps that actually have little in common. All of these lamps require a short period of time to become fully lit, generally from one to seven minutes. If a high intensity discharge lamp is turned off, the arc type must cool to a given temperature before the arc can be restruck and light produced.

These Types of Lamps Include:

- High pressure sodium.
- Low pressure sodium.
- Mercury vapor lamp.
- Metal halide.

3.6.4 High Pressure Sodium Lamps

(HPS) lamps have the highest efficiency of all common in door lamps see (figure 3.9), They produce light when electricity passes through a sodium vapor.

These lamps are constructed using two envelopes: an inner envelope made of a polycrystalline alumina where the arc is struck and protective outer envelope that may be clear or coated.

Since the sodium in the lamp is pressurized, the light produced is not the characteristic bright yellow associated with sodium, but a more "golden white" light.

(HPS) lamps are used widely in street and outdoor lighting.

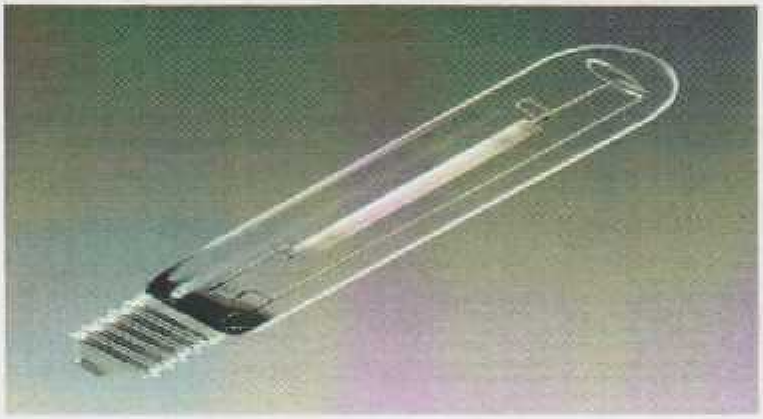

Figure 3.9: High Pressure Sodium Lamps [28]

3.6.5 Low Pressure Sodium Lamps

(LPS) lamps are the most efficient type of lamp, providing up to 183 lumens per watt as shown in (figure 3.10).

Unfortunately, their indoor use is restricted by their monochromatic light output. Reds, blues, and other colors illuminated by an (LPS) light source all appear as tones of gray.

LPS lamps are primarily used for street and highway lighting as well as outdoor area and security lighting. In spite of their high efficacy (60-150 lumens/ watt), their color rendering index (CRI) is very poor.

Figure 3.10: Low Pressure Sodium Lamps [29]

3.6.6 Mercury Vapor Lamps

The Mercury lamp was the first kind of metal vapor light source that was mass produced for general lighting applications, and still today it remains one of the most popular discharge lamps produced globally. In Europe it has fallen out of fashion due to its relative inefficiency and rapid lumen depreciation by contrast with other light sources. However in the Americas and Asian countries its low system cost, long life and high color temperature continue to make it a desirable light source for exterior illumination. (Figure 3.11) illustrates the construction of a typical modern High Pressure Mercury lamp.

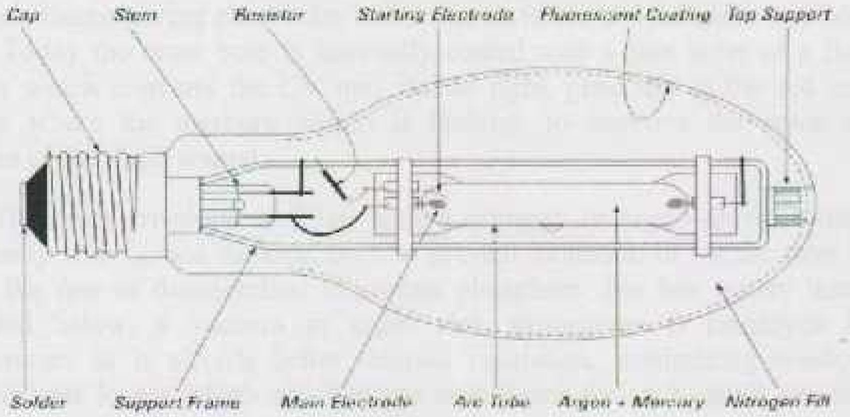

Figure 3.11: Typical High Pressure Mercury Lamp [30]

Produce light when an electrical current passes through a small amount of mercury vapor. The lamp consists of an inner glass envelope where the arc is struck and an outer protective envelope. The mercury vapor lamp, like the fluorescent lamp, requires specially designed ballasts. Special ballasts are also required for dimming mercury vapor lamps.

Lamp Construction

At the heart of the lamp is an arc tube which is fabricated from quartz, with a tungsten electrode disposed at either end. The tube contains a few milligrams of mercury and around 25-50 torr of pure argon as a buffer gas to carry the discharge while the lamp warms up, producing heat to vaporise the mercury and bring it into the discharge.

An auxiliary starting electrode is placed next to one of the main electrodes to facilitate lamp ignition. When the lamp is first energized the full open circuit voltage is applied across the arc tube. The distance between the electrodes is so large that the resulting voltage gradient is not high enough to cause ionization of the gas filling. However the same voltage is also applied between one electrode and the auxiliary via a small resistor. The gap between these electrodes is much smaller, and the voltage gradient is sufficiently high that ionization will occur. A small discharge strikes, the series resistor of 10-30 kW limiting the current flow to about one thousandth of the normal lamp current. Once free electrons, ions and photons have been produced in the arc tube it is then very easy to strike a discharge across the main electrodes. The discharge quickly makes this transition because it can then bypass the starting resistor, and there is no electrical resistance between the main electrodes. Some lamps, particularly high wattage types often include two auxiliary electrodes, one beside each main electrode and connected via a resistor to the opposite end of the arc tube. This is also standard practice in mercury lamps designed for use in colder atmospheres.

Once the lamp has warmed up and the mercury is fully vaporized, the discharge operates in unsaturated mercury vapor at a pressure varying from 18 bar for the smallest types, to 2 bar for the largest. The arc emits the characteristic green, yellow and violet mercury lines and there are also considerable amounts of invisible long-wave ultra violet at 365nm along with a broad range of shorter wavelengths. In the earliest lamps having clear outer bulbs this invisible UV radiation was completely wasted. Today the outer bulb is internally coated with a thin layer of a fluorescent phosphor which converts the UV into visible light, generally at the red end of the spectrum where the mercury output is lacking, to improve the color rendering properties of this light source.

The outer envelope is filled with a nitrogen or argon-nitrogen mixture, or occasionally with carbon dioxide, both to prevent oxidation of the arc tube seals and to slow the rate of deterioration of certain phosphors. For low power lamps of 50 Watts and below, a vacuum or argon rich atmosphere is employed by some manufacturers as it affords better thermal insulation, minimizing conducted and convicted heat losses which can become significant for such small arc tubes, and allowing them to run up to full intensity more quickly. Vacuum or at least reduced gas pressures are also employed in a special range of lamps designed for use in extremely cold atmospheres again the object here is to provide better thermal insulation which allows the arc tube to warm up more rapidly. Heat reflective coatings of platinum or gold are often also applied behind the electrodes of small or cold atmosphere lamps again to minimize heat losses and help them run up more rapidly.

3.6.7 Metal Halide Lamps

Figure 3.12: Metal Halide Lamps [31]

Metal Halide is similar in construction to mercury vapor lamps. These lamps, however, contain a metal halide in the mercury vapor that the electrical energy passes through as shown in (figure 3.12). These lamps are 1.5 to 2 times more efficient than the mercury vapor lamps .Almost all "white light" varieties of metal halide lamps produce a color rendition equal or superior to that of mercury vapor lamps; MH lamps range in size from 175 to 1,500 watts and require specially designed ballasts.

3.6.8 Light Emitting Diodes (LED's) Lamps

Though not yet commonly used in residential applications, the LED (light emitting diode) is worth mentioning as it is used recently in outdoor lighting. In a light emitting diode, the creation of light happens much more efficiently at the molecular level.

Diode is an electronic device which limits the direction that electrons may flow in an electronic circuit. A LED is a special type of diode that has been optimized to release energy in the form of light instead of as heat as in a traditional diode. An unbreakable, crystal clear solid resin encases each LED and makes it nearly indestructible, contributing to the long life of LEDs, which typically last 5 to 10 years of constant use and draw as little as 1/10th to 1/20th the current of an incandescent light bulb producing equivalent lumens.

The main drawback of LED lighting is the quality of the light tends to be a bit too bright and glaring. Current researches is being done to reduce cost, and to improve light quality. Worldwide, LEDs are starting to be used for low wattage PV lighting systems.

Figure 3.13: LED Street Fixture [32]

Light Emitting Diodes (LED's) are used as tiny indicator lamps on electronic equipment. In recent years LED's have become more powerful and more multicolored. They have almost reached a lumen output level that makes it possible to achieve useful output for use in luminaries as it is illustrated in (figure3.13).

3.6.8.1 The Main Characteristics and Benefits of LED Lamps Are:

1. Very long life (20 years in typical application).

2. LED's do not produce light by heating a filament, or by producing an arc. Therefore they generate virtually no heat (compared to an incandescent lamp which wastes more than 50% of the applied energy as heat).

3. Zero Ultra Violet light generated.

4. Lower environmental foot print, mercury, lead or other known disposable hazards.

5. Available to emit Red, Green, Blue, Orange and White light. Color mixing possible for luminaires with Red, Green & Blue LED arrays Lower energy consumption, their efficiency is compatible with other lamps.

6. Very small size enables many LED's be built into an array for increased output.

7. Vibration resistant. With no filament to shake loose, LED's will withstand enormous amounts of vibration.

8. An opportunity to implement programmable controls as they are easily dimmed (from 100% to 15%) by reducing current.

9. Instant start: Unlike sodium lights, LED lights do not require a time delay to reach optimum brightness levels.
10. Night visibility due to higher color rendering, higher color improved temperature and increased Illumination uniformity.

3.6.8.2 Applications

Replacement for dichroic luminaires in areas where low temperature operation is important. For example pavement mounted up-lights that will not cause public liability problems.

Situations where access is difficult. Take advantage of the super long operational life of LED's in situations where replacement of a luminaire would be costly.

Color changing applications. The control of color can be programmed into the combined power supply controller. The controller can accept input from an audio source to pulse the LED's along with the beat.

Garden and street lighting. All of the advantages of LED's can be applied to garden lighting. The extremely low heat generated will not raise the temperature of the luminaire, thus ensuring its watertight seals remain intact for many years.

Energy saving : Older street lights use conventional light bulbs while more modern lights use energy saving Light Emitting Diode (LED) technology. In both cases, street lights need to be durable enough to withstand the elements while continuing to provide light.

3.7 Lighting Uniformly Distribution:

The layout of the luminaires should be designed to ensure the necessary road surface luminance and good visual guidance.

As shown figure (3.14) The Illumination produced at a point P from a single luminaire is given by the formula:

$$E_{hor}=\frac{I\cos^3\gamma}{H^2} \tag{3.3}$$

The process can be repeated for adjacent luminaires and the contributions from all luminaires summed to get the Illumination at that point for the whole lighting installation.

This process can then be repeated over an array of points on the road so as to get the Illumination metrics used for the lighting of conflict areas.

Alternatively, manufacturers often provide a relative isolux diagram, this being the Illumination pattern provided on the road surface by a single luminaire relative to the maximum Illumination and plotted in terms of mounting height. Given a layout of luminaires around a conflict area, the mounting height and information about the maximum Illumination, the overall Illumination pattern can be generated.

3.7.1 Main Concepts

There Are Two Concept Must be Discussed Here:

1- Horizontal Illumination

For horizontal surfaces, the Illumination is calculated by describing the distance (d) between the light source and the calculation point by means of the vertical height (H) of the light source above the surface.

In the (figure3.14) , $H = d \cos\gamma$ or $d = H / \cos\gamma$

So $E_p = \dfrac{I \cos\gamma}{d^2}$ becomes $E_{hor} = \dfrac{I \cos^3\gamma}{H^2}$ (3.4)

This is called the horizontal Illumination at the point.

Figure 3.14: Horizontal Illumination

2- Vertical Illumination

The illumination at the same point P on a vertical facet oriented towards the light source can also be given in function of the height (H) of this source and of the incident angle (γ) of the luminous intensity I as it is illustrated in (figure 3.15).

$$E_v = \frac{I}{d^2} \sin\gamma \tag{3.5}$$

And with: $d = \dfrac{H}{\cos\gamma}$ (3.6)

Becomes: $E_v = \dfrac{I}{H^2}\cos^2\gamma \sin\gamma$ (3.7)

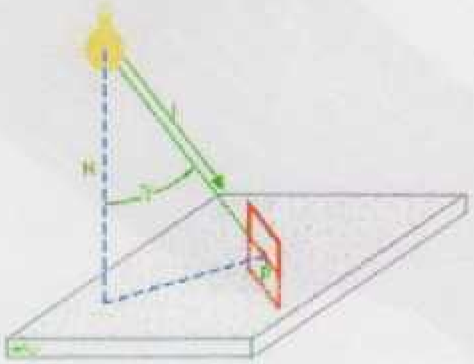

Figure 3.15: Vertical Illumination

3.7.2 LED Fixture Mounting and Lighting Homogeneity

(Figure 3.16) shows the illumination in lux of 48 watt LED luminaire at different hanging heights of the fixture. It is obvious that increasing the height will increase the lightened area, but at the same time the illumination will be decreased. Decreasing the height will decrease the lightened area, but at the same time the illumination will be increased.

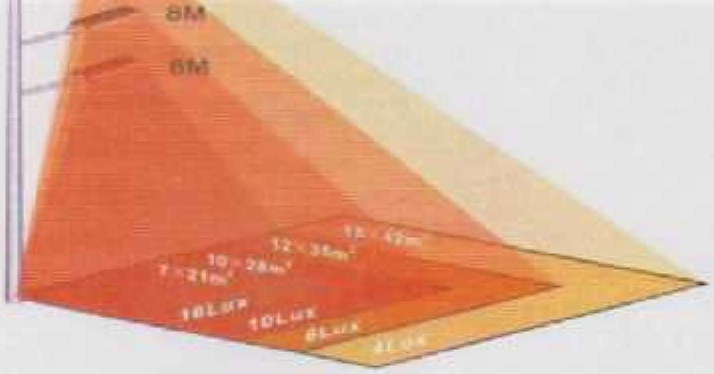

Figure 3.16: Lux Versus Area

Figure 3.16 48watt LED shows street lighting luminaire applied with the best LED light source Cree LED, it attains high illumination efficacy, accelerated by optical lens. The optical lens distribute and focus all the light of every LED onto road with maximum effect and formed a rectangular lighting spot. [33]

Figure 3.17: Another LED Fixture [34]

3.8 Street Lighting

Street lighting is the one of the main lighting studies since its importance to adjust rhythm of life after dark by increasing the human safety and avoiding the accidents on the roads (figure 3.18) shows a typical two twin street lighting.

On the other hand the effective lighting is essential in contemporary cities which need special lighting to achieve to the necessary well-being, that leads us to design and controlling lighting by scientific standards which increase reliability.

Figure 3.18: Street Lighting [35]

Street Lighting Must be Achieve the Following Benefits:

1- Driver Safety

Street lights increase visibility and thus increase road safety for drivers traveling at night. Street lights, for instance, may illuminate an animal in the middle of the road in time for a driver to avoid a collision. In areas where large animals may be on the road, street lights can protect both the life of the animal and that of the driver.

2- Pedestrian Safety

Street lights make it easier to see dangers around you, whether from traffic, people or animals. People who live in rural areas tend to feel safer than people who live in cities, but crime happens everywhere. People are more vulnerable to being victimized when they are out after nightfall in an area so dark that they can't see if someone is lurking nearby, waiting to accost them. And would-be criminals might think twice in well-lighted areas.

3- Increased Nighttime Business

In rural communities, sunlight still dictates many people's schedules: They rise at sunrise to tend to their farms or crops and retire for the day when the sun goes down. This is, to put it simply, bad for business. But people might be lured into coming out at night for everything from shopping to watching a play if the area is well-lighted. A dark area looks deserted; a well-lighted area looks cheery and inviting, so street lights might be good for business. [36]

Components:

1. Post

One component common to all types of street lights is the post, which rises from a base at the ground and supports the lighting element above. Street light posts contain the electrical wiring that connects the lights directly to the electric grid. Some posts also include a service door for gaining access to a street light's control unit and making repairs or adjustments from ground level.

Street lights posts need to be able to withstand ice, wind and rain. Rust resistant metals or a protective coat of paint can help preserve the post against the elements, and metal is by far the most common material for its strength and rigidity.

Some street light posts, such as those in an historic district, may be decorative, while others are simple grey shafts.

2. Bulb

Street light bulbs come in a wide range of styles and sizes. Most conventional street lights use halogen bulbs, which are similar in function and appearance to household incandescent bulbs. These bulbs consist of a vacuum tube with a filament inside and an inert gas (such as halogen) that causes the burned portion of the filament to recollect on the filament wire, extending the life of the bulb. Metal halide bulbs employ similar technology but use even less energy and produce more light.

Fluorescent street light bulbs are fluorescent tubes, which contain a gas that reacts to a current to create illumination. Fluorescent street lights tend to use less energy than other bulbs and cast a greenish light, while halogen bulbs cast a warmer, orange light. Finally, light-emitted diodes, or LEDs, are the most efficient type of street light bulb. LEDs are semiconductors that produce a strong illumination and last much longer than other bulbs.

3. Heat Exchangers

LED street lights include heat exchangers to regulate temperature. These devices moderate the heat that an electrical current produces as it powers the LED. Heat exchangers use the passage of air over a series of fins to keep the lighting element cool and to make sure that the LED is able to produce even light without darker areas or "hot spots" that might otherwise occur.

4. Lens

LED and conventional street lights feature a curved lens that is usually made of heavy-duty glass or, more commonly, plastic. Street light lenses function to magnify the effect of the light inside. They also direct the light downward toward the street for maximum efficiency. Finally, street light lenses protect the delicate lighting elements inside. Fogged, scratched or broken lenses are much easier and cost-effective to replace than entire lighting elements. [37]

3.9 Street Lighting Calculations [38]

3.9.1 Design of the Lighting of Al-Hesbah Street

The design is restricted to the following conditions:

1- Off grid photovoltaic solar energy system.

2- Using LED luminaires (fixtures).

3- Load system is D.C voltage (24 Volt) to decrease the rating of the charge controller and minimize the voltage drop.

4- Each lighting unit is composed from two fixtures erected at the middle of the street (Twin Central).

Effective width of each side of the street varies from 10 to 11 meters

$$H = \left(\frac{2}{3} \text{ to } 1\right) * w. \qquad (3.8)$$

Where:

H: is the height of the post (hanging column) in m.

W: is the effective width of the street in m.

We will select H = 11 meters with an arm of 1.5 m.

The inclination of the fixture is 10 degrees.

Al-Hesbah Street has medium vehicular and pedestrian movement at night, so selecting Illumination value (E) to be 6 lux is enough based on the second classification in the table (3.3).

E = 6 lux.

The existing spacing between two columns (a) is 40 meters.

We will choose the same value (a) in our design in order to use the same posts (columns) if Hebron Municipality decided to exchange its current lighting system with off- grid photovoltaic solar energy system.

a = 40 meters.

Table 3.3: Illumination Design of Roads [39]

Road and Area Classification	Minimum Average Maintained luminance E_{ave} in Lux
Local Residential Roads (Local-Low)	4
Residential Collector Road (Collector-Low)	6
Employment Collector Road (Collector-Low)	6
Arterial Roads (Major-Low)	9
Rural Local Residential (Local-Low)	4
Rural Collector Road (Collector-Low)	6
Low Density Residential	3

$$E_{av} = \frac{n * F_L * \eta_B * LLF}{a * W_{eff}}. \qquad (3.9)$$

E_{av} = Illumination $lumen/m^2$.

n = No. of lamps in the lighting fixture.

F_L = Luminous flux ...lumen.

η_B = Utilization factor.

LLF = Light loss factor.

a = Spacing between column.

W_{eff} = Effective width of the street.

$\eta_B = 0.6.$

$\eta_B = 0.8$ *In LED lamps ...with reflector.*

For Twin Central lighting.

$LLF = LDD*LLD.$

LDD = *luminaire dirt depreciation* $= 0.95.$

LLD: *lamp lumen deperciation* $= 0.85.$

$$F_L = \frac{E*a*W_{eff}}{n*LLF*\eta_B} \qquad (3.10)$$

$$F_L = \frac{6*40*11}{1*0.81*0.8} = 4074\,lumen.$$

$$Lamp\,Rating = \frac{4074\,lumen}{100\,lumen/Watt} = 40\,Watt.$$

For good design and better illumination we will select 48 W luminaire.

P_{load} *for each lighting unit.*

$P_{load} = 2*48 = 96\,Watt.$

The design of Photovoltaic solar energy system:

P_{load} *for each lighting unit.*

$P_{load} = 2*48 = 96\,Watt.$

Table 3.4: Average Night Hours in Hebron from Sunset to Sunrise: [40]

Months	Average Night Hours
January	(13:44+13:33) /2=13:38
February	(13:33+12:23) /2=12:58
March	(12:23+11:40) /2=12:02
April	(11:40+10:25) /2=11:03
May	(10:25+9:46) /2=10:06
June	(9:46+9:40) /2=9:43
July	(9:40+10:08) /2=9:54
August	(10:08+11:00) /2=10:34
September	(11:00+11:58) /2=11:29
October	(11:58+12:56) /2=12:27
November	(12:56+13:36) /2=13:16
December	(13:36+13:42) /2=13:03

Total =140:40 which equals 140+40/60=140.66 h.

Average night hours in Hebron among the year = 140.66/12 = 11.72 h.

Watt hours / night to accommodate system losses:

$$p_{load} = 48 * 2 = 96\,Watt$$

$$Load\,Watthours\ per\ night = 96 * 11.72 = 1125\,Wh$$

$$Wh/night = \frac{load\ Wh}{battery\ efficiency * wiring\ efficiency} \qquad (3.11)$$

$$= \frac{1125}{0.85 * 0.98} = 1350\ Wh.$$

Battery bank size based on depth of discharge and autonomy requirements:

Autonomy=1.7 days

Depth of discharge=60% deep cycle batteries.

$$\text{battery bank size in watt hours} = \frac{[\text{Wh/night}] * \text{autonomy}}{Depth\ of\ discharge} \qquad (3.12)$$

$$= \frac{1350 * 1.7}{0.6} = 3825\,Wh.$$

$$\text{Batteries capacity in amper hours} = \frac{\text{battary size in Wh}}{\text{system voltage}}. \qquad (3.13)$$

24 V dc system will be chosen.

$$\text{Batteries capacity in amper hours} = \frac{3825\,Wh}{24\,V} = 159.37\ Ah \approx 160\ Ah.$$

$$\frac{160\,Ah}{2} = 80\ \text{Ah}\ 24\ \text{V}.$$

We will choose 4 batteries 12V- 80Ah.

Each two batteries are connected in series.

$$Wh\ of\ solar\ panels = \frac{load\ Watt\ h}{total\ efficiency}. \qquad (3.14)$$

$$\eta_{total} = \eta_{battery} * \eta_{wires} * \eta_{charge\,controller} * \eta_{temp.} \tag{3.15}$$

$$\eta_{temp.} = 1 - 0.005(Average\,glass\,temp. - 25)$$
$$= 1 - 0.005(30 - 25) = 0.975.$$

$$\eta_{total} = 0.85 * 0.98 * 0.96 * 0.975 = 0.78.$$

$$Wh\ of\ solar\ panels = \frac{1125}{0.78} = 1442\,Wh.$$

$$Average\ perfect\ sun\ hours = 6.$$

$$Power\ of\ the\ solar\ panels = \frac{Wh\ of\ solar\ panels}{Average\ perfect\ sun\ hours} \tag{3.16}$$

$$= \frac{1442\ Watt/h}{6h} = 240.3\,Watt$$

Each Two 120 Watt 12 volt solar panels will be chosen.
Both of them will connected in series.

The rating of the charge controller = 240.3Watt / 24v = 10 A.
For safe design we will select 15 A charge controller.

3.9.2 Energy Saving and Feasibility Study:

Annual cost of existing high pressure sodium and metal halide fixtures.

Total fixtures= 29*2 = 58.

* Eight fixtures metal halide of AL-Hesbah Entrance at the junction.

* Fifty fixtures high pressure sodium Along the AL-Hesbah Street.

Total power = 58*250W =14500 W = 14.5 KW.

Total hours in a year = 365*11.72 h/night = 4278.

Total annual consumed energy = P*t =14.5 KW *4278 h =62031 KWh.

Total cost = E * unit price=62031KWh *NIS 0.52/KW = NIS 32256.

Annual Total cost in $ =32256 NIS/3.75 NIS/$ =$8601.6.

Total Cost of the proposed system = $52692.

Payback time = $52692/$8601.6 = 6.12 years.

Table 3.5: The Total Cost of Components That Required for Al-Hesbah Street Lighting

Components	$ Cost
Mono Crystalline Silicon Solar Panels	29 * 2 *130 *$1.8 = $13572
Charge Controller 15A 12-24 Volt	26 * 1 * $100 = $ 2600
Sealed Deep Discharge Maintenance Free Batteries 12V 80Ah	29 * 4 * $ 195=$ 22620
GSM Controller	26 * 1 *$ 100 =$2600
48 W 24 V_{DC} LED Street Fixtures	29 * 2 * $ 150 =$ 8700
Accessories (Control Panel, Photocell, Wiring)	26 * 1 * $100 =$ 2600
Total Cost	$ 52692

CHAPTER

4 Lighting Control

Chapter Four

Lighting Control

4.1 Introduction

The principle aim of lighting control is to reduce energy consumption and therefore the cost of annual energy budget.

Different mechanisms of control meet to the desire of human and the operating conditions that required.

Utilizing photocell control enable automatic turning the street light fixtures on at sunset and off at sunrise. It is an efficient, simple, economic and common method of lighting control.

Also, applying a GSM wireless controlling in addition to photocell control will increase the capability of the system by monitoring the state of the light fixtures and controlling the switching. It allows to operate certain lamps and turn off others or to dim the lights when the pedestrian and vehicular movement decreases as shown (figure 4.1)

Figure 4.1: Three Control Modes Using GSM [41]

4.2 Lighting Controls

Lighting control and operation is an important concern when sizing a photovoltaic system since a lower load will reduce the size of the photovoltaic system, and therefore, its cost.

Lighting Controls Include the Following:

4.2.1 Manual Switches

These controls, typified by a wall switch or pull-chain mounted directly on a fixture, are the least expensive and most commonly used controls.

Switching each light separately with a manual switch offers the greatest potential for minimizing energy use, but this method is effective only if people consistently use the switches.

Switches must be conveniently located and easy to use .for example, stairway lights should be switches at the top and bottom of the stairs using three way switches. Standard wall mounted light switches commonly used with 220v alternating current and 12v to 24v direct current systems.

4.2.2 Timers

These controls can be set to automatically turn lights on or off or to limit the time a light will be on ass shown (figure 4.2).You should consider safety when using timers, for example lights should not turn off without warning the occupants first. Timers can require a small amount of additional power for their own operation.

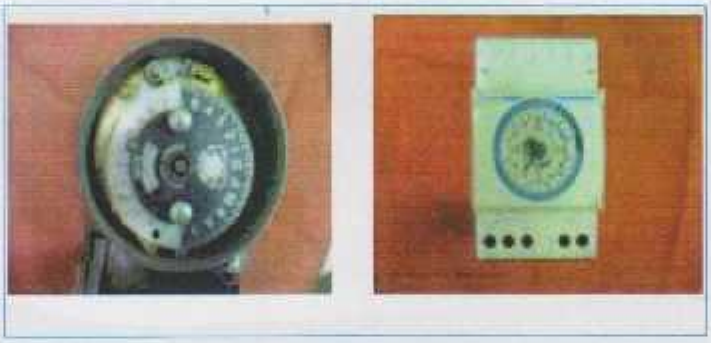

Figure 4.2: Timer [42]

4.2.3 Sensors

Sensors are used when precise control is desired. Sensors activate lights when they detect motion or infrared ray.

4.2.4 Photocells

Security or safety lighting can be controlled by photocells, which are devices that sense light levels .photocells sense a loss of daylight at dusk and activate the light, and conversely, they sense daylight at dawn and turn the light off. Photocells are more dependable than manual switching and more accurate than timers. [43]

4.3 Street Photocell

Figure 4.3: Photocell [44]

24 volt dc battery operated light source, rated at 70 C° to operate in high temperatures near solar modules.

Figure 4.4: Photocell Mounted At the Top of Street Lighting Fixture [45]

Effective lighting plays an important role in keeping streets and roads safe for drivers and pedestrians. Photocell is a sensor that allows to detect light. It is suitable for switching most types of industrial and domestic lighting (e.g. tungsten, fluorescent, discharge or LED lamps). This purpose behind the design of this switch is to have it automatically turn an illuminator on or off, depending on the light conditions. Say, for instance, a photocell switch turns the illuminator on at dusk, and switches it off during the daybreak.

It uses a resistance which is made from cadmium sulphide (CdS) called light dependent resistors (LDR) or photo resistor. It tends to be sensitive to light between 700nm (red) and 500nm (green) light as shown (figure 4.5)

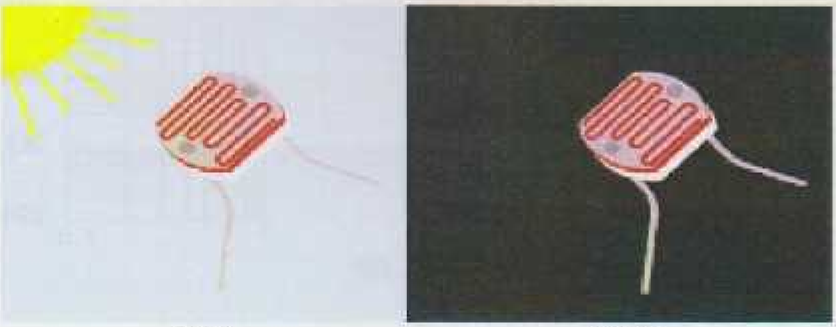
low r
high r

Figure 4.5: Resistance Value (R) of LDR in Day and Night [46]

4.3.1 Light Dependent Resistor

As its name implies, the Light Dependent Resistor (LDR) is made from a piece of exposed semiconductor material such as cadmium sulphide that changes its electrical resistance from several thousand Ohms in the dark to only a few hundred Ohms when light falls upon it by creating hole-electron pairs in the material. The net effect is an improvement in its conductivity with a decrease in resistance for an increase in illumination. Also, photo-resistive cells have a long response time requiring many seconds to respond to a change in the light intensity.

LDR is basically a resistor that changes its resistive value (in ohms) depending on how much light is shining onto the squiggly face. The resistance of the cell when unilluminated (dark resistance) is very high at about 10MΩ's which falls to about 100Ω's when fully illuminated (lit resistance). To increase the dark resistance and therefore reduce the dark current, the resistive path forms a zigzag pattern across the ceramic substrate. The CdS photocell is a very low cost device often used in auto dimming, darkness or twilight detection for turning the street lights ON and OF as shown (figure 4.6).[47]

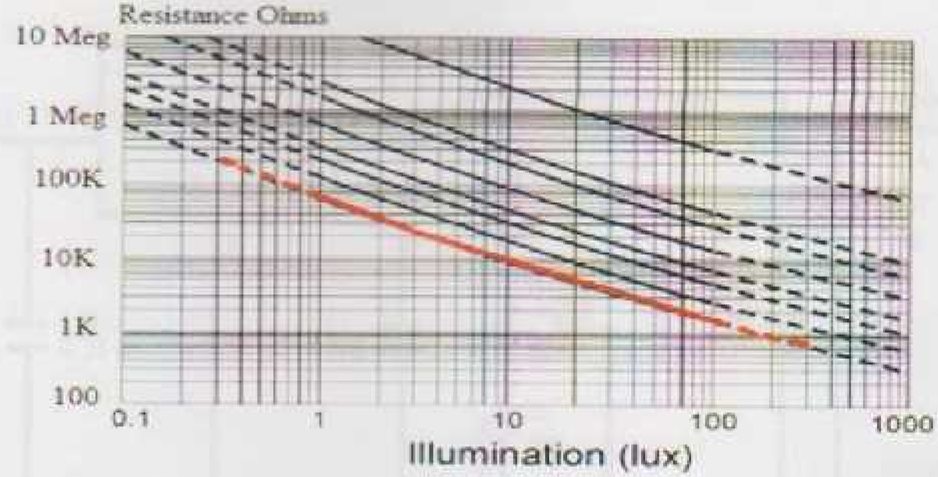

Figure 4.6: Resistance vs. Illumination Graph [47]

4.3.2 Street Light Circuit

The circuit diagram shown in (figure 4.7) presents a street light that automatically switches ON when the night falls and turns OFF when the sun rises. In fact this circuit for implementing any type of automatic night light.

The circuit uses a Light Dependent Resistor (LDR) to sense the light. The collector voltage of Q1 (BC107) is coupled to base of Q2 (SL100). When there is light the resistance of LDR will be low. So the voltage drop across potentiometer R2 will be high .This keeps the transistor Q1 ON. The collector voltage of Q1 (BC107) will be less than 0.2 V which is not sufficient to turn Q2 (SL100) ON. So Q2 will be OFF and so do the relay. The bulbs will remain OFF.

When night falls the resistance of LDR increases to make the voltage across the potentiometer R2 to decrease below 0.6V. This makes transistor Q1 OFF.The collector voltage of Q1 will be high which in turn makes Q2 ON. The relay will be energized and the bulbs will glow. Potentiometer R2 is used to adjust the sensitivity of the circuit. [48]

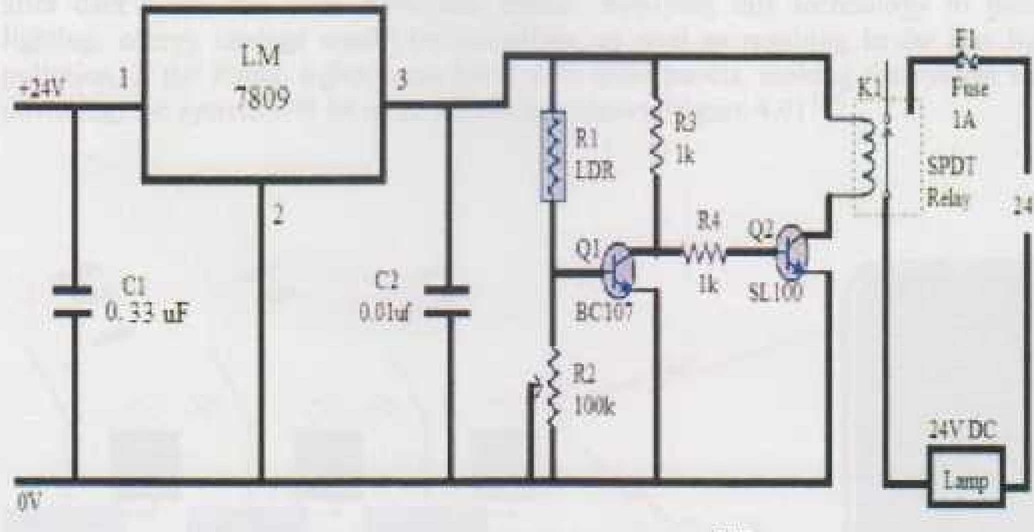

Figure 4.7: 9V Photocell Circuit [48]

4.3.3 Advantages of Using the Photocell Switch:

Photocell switch is a very simple circuit that is efficient enough to provide a very flexible degree of lighting automation and switch lighting safety guidelines that can provide the required ease in operating any lighting system or structure, it has other advantages as follow: [49]

1. Low circuit energy cost.
2. Affordable adjusting system.
3. Automation can be molded in any desired time format and interval.
4. Works in complex light designs.
5. Can work according to the intensity of the available light.
6. Can work in terms of adjusted time.
7. A simple circuit that can be easily linked to any lighting system.

4.4 GSM: (Global System for Mobile Communication)

GSM is an open, digital cellular technology used for transmitting mobile voice and data services. It is a modern method in street lights controlling especially because of its ability to cover long distances. Particularly can be used by the municipalities and remote control centers .The system will communicate via the GSM network to a central computer to determine when the lights should be illuminated, how bright they should be lit based on ambient light levels, and to also dim the lights after dark when the areas have less traffic. Applying this technology to public lighting, energy savings would be incredible, as well as resulting in far less light pollution. If the Public lights were fitted with solar panels, making the system self-powering, the system will be more efficient as shown (figure 4.9) [50]

Figure 4.8: Controlling and Monitoring by GSM [51]

4.4.1 GSM Based Cost Effective Street Lighting Application

Depends on the day light timings the street lights can be controlled by ON, OFF, (Figure 4.10) dimming and staggered with the help of Real Time Clock (RTC). If any over load occurs the load will be cut and the information is transferred through GSM to server. Any disconnect in power the information is sent to server through GSM. If any complaint raised the user needs enter the number in the keypad which will be fixed in the street lamp and the message will be sent to Server through GSM. [52]

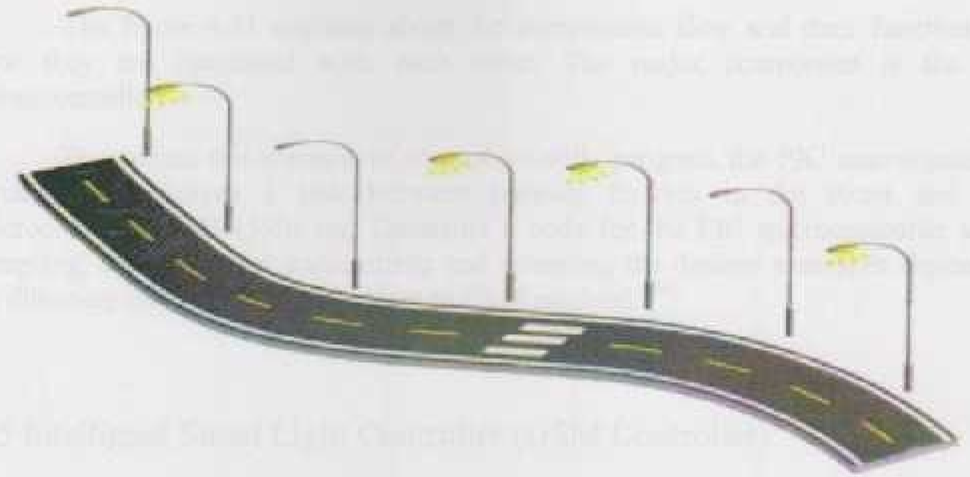

Figure 4.9: Dimming and Staggering Control Modes [53]

4.4.2 PIC Microcontroller

A microcontroller (also microcontroller unit, MCU or μC) is "a small computer on a single integrated circuit consisting of a relatively simple CPU combined with support functions such as a crystal oscillator, timers, watchdog timer, serial and analog I/O etc. Program memory in the form of EEPROM (Electrically Erasable Programmable Read Only Memory) or ROM (Read Only Memory) is also often included on chip, as well as a typically small amount of RAM (Random Access Memory)." [54]

Microcontrollers contain data and program memory, serial and parallel I/O, timers, external and internal interrupts [54], and peripherals. These make them a strong choice when implementing control systems.

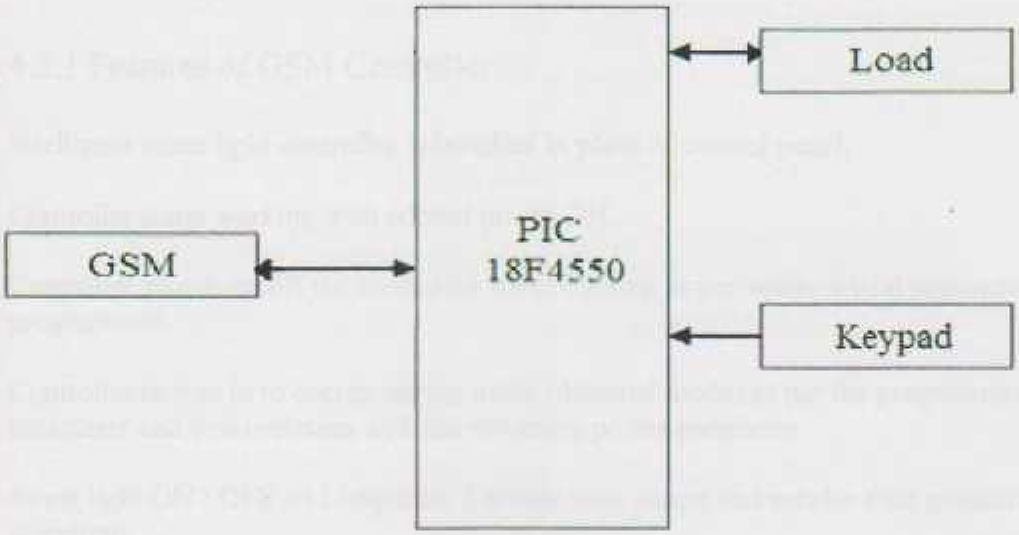

Figure 4.10: PIC Microcontroller [54]

The figure 4.11 explains about the components flow and their function and how they are interfaced with each other. The major component is the PIC microcontroller.

To perform this scenario of control we will program the PIC microcontroller circuit that achieves a link between lighting fixtures in the street and PIC microcontroller (18F4550) and Construct a code for the PIC microcontroller to do sampling, digitizing and transmitting and receiving the desired messages depending on dimming modes and fixture states to GSM modem. [54]

4.5 Intelligent Street Light Controller (GSM Controller)

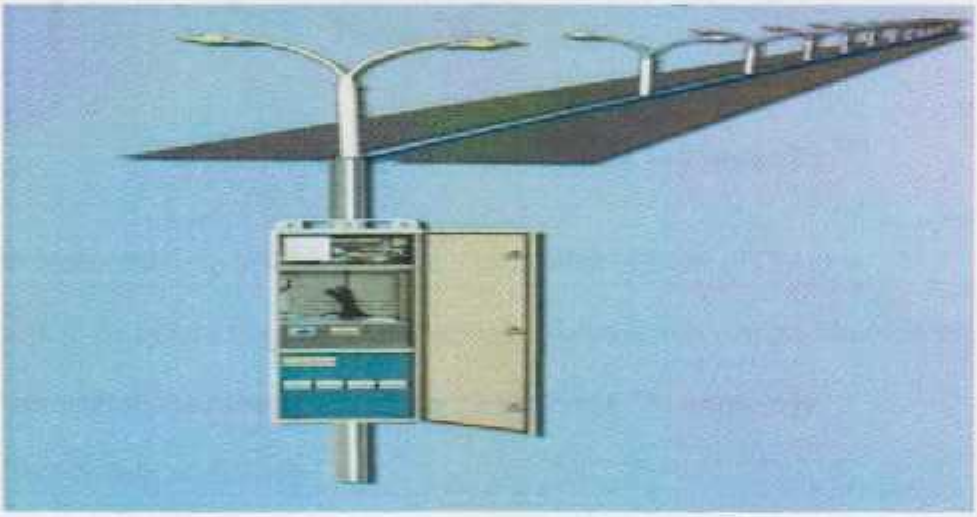

Figure 4.11: GSM Controller in Twin Central Street [55]

4.5.1 Features of GSM Controller:

- Intelligent street light controller is installed in place of control panel.
- Controller starts working with normal power ON.
- Controller switch on/off the connected street lighting as per astronomical parameter programmed.
- Controller moves in to energy saving mode (dimmed mode) as per the programmed parameter and in co-relation with the incoming power parameter.
- Street light ON / OFF on Longitude, Latitude base sunset and sunrise time generation algorithm
- Scrolling display of events which helps to monitoring the systems.

- User friendly key board operation.
- Staggering facility to switch OFF and switch ON lights by late night can save energy when there is no traffics as shown in the (figure 4.13).

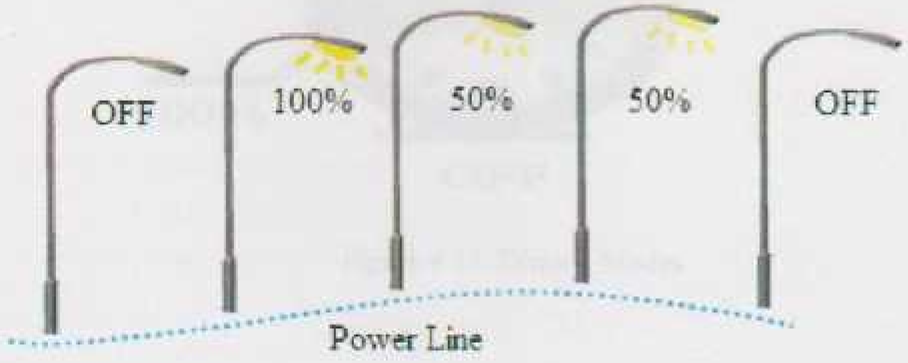

Figure 4.12: Energy Saving by Diming and Staggering [56]

- Put connected lamp in dimmed mode after number of hours of ON time.
- Protects the system from Over voltage, under voltage, over current, Short circuit.
- Communication to central server through low cost GSM technology.
- Effective fault monitoring.
- Helps to decide the preventive maintenance. [57]

4.6 Proposed Control Program for Al-Hesbah Street Lighting

Table 4.1 shows a proposed control program to achieve energy saving in a clear and reasonable way.

Table 4.1: Timing Schedule of Diming Modes

From		Till	Lighting mode
Sunset	to	22:00	100%
22:00	to	24:00	80%
24:00	to	Sunrise	50%
Sunrise	to	Sunset	Off

Figure 4.13: Diming Modes

CHAPTER

5 Prototype Design and Scaling

Chapter Five

Prototype Design and Scaling

5.1 Introduction

In the preceding chapters, the complete construction and principle of operation for each part of GSM Control System of an Open Area Lighting by Using Solar Energy were discussed; this will help to achieve the main goal of this project that is to construct a prototype model after scaling for Al-Hesbah Street.

This chapter talks about the complete design of our prototype model. The designing has passed through several stages such as: selecting the practical components of the overall block diagram, purchasing these components, designing an external frame, mounting the photovoltaic solar panel fixing and connecting it to the charge controller, interfacing GSM with PIC microcontroller, fixing the LED lighting fixtures, studying the scaling specifications of the required components and testing.

5.2 Project Conceptual Design

Three main fields were discussed in our project, solar energy utilization, wireless control system by GSM and using LEDs lamps as a modern way in energy saving.

5.2.1 Block Diagram of the System

The following figure shows the overall block diagram of the street lighting system with its entire requirements.

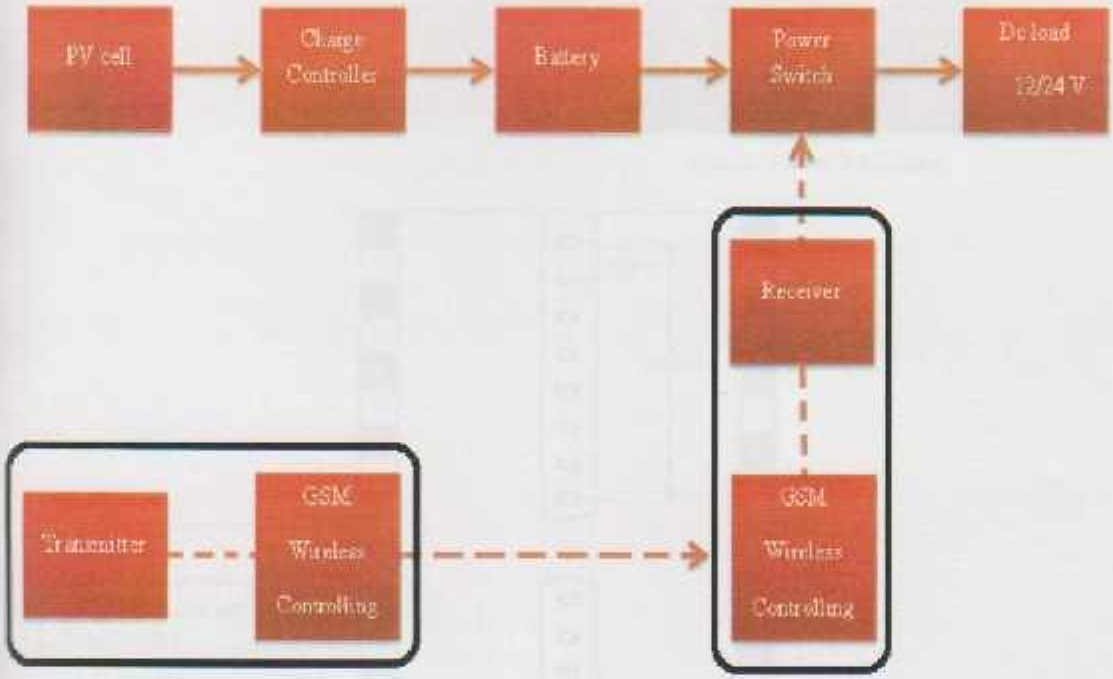

Figure 5.1: Block Diagram of the System

5.3 The Schematic Sketch of the Street

As discussed in chapter three, the following schematic shows the final and most appropriate distribution of the light units in Al-Hesbah Street.

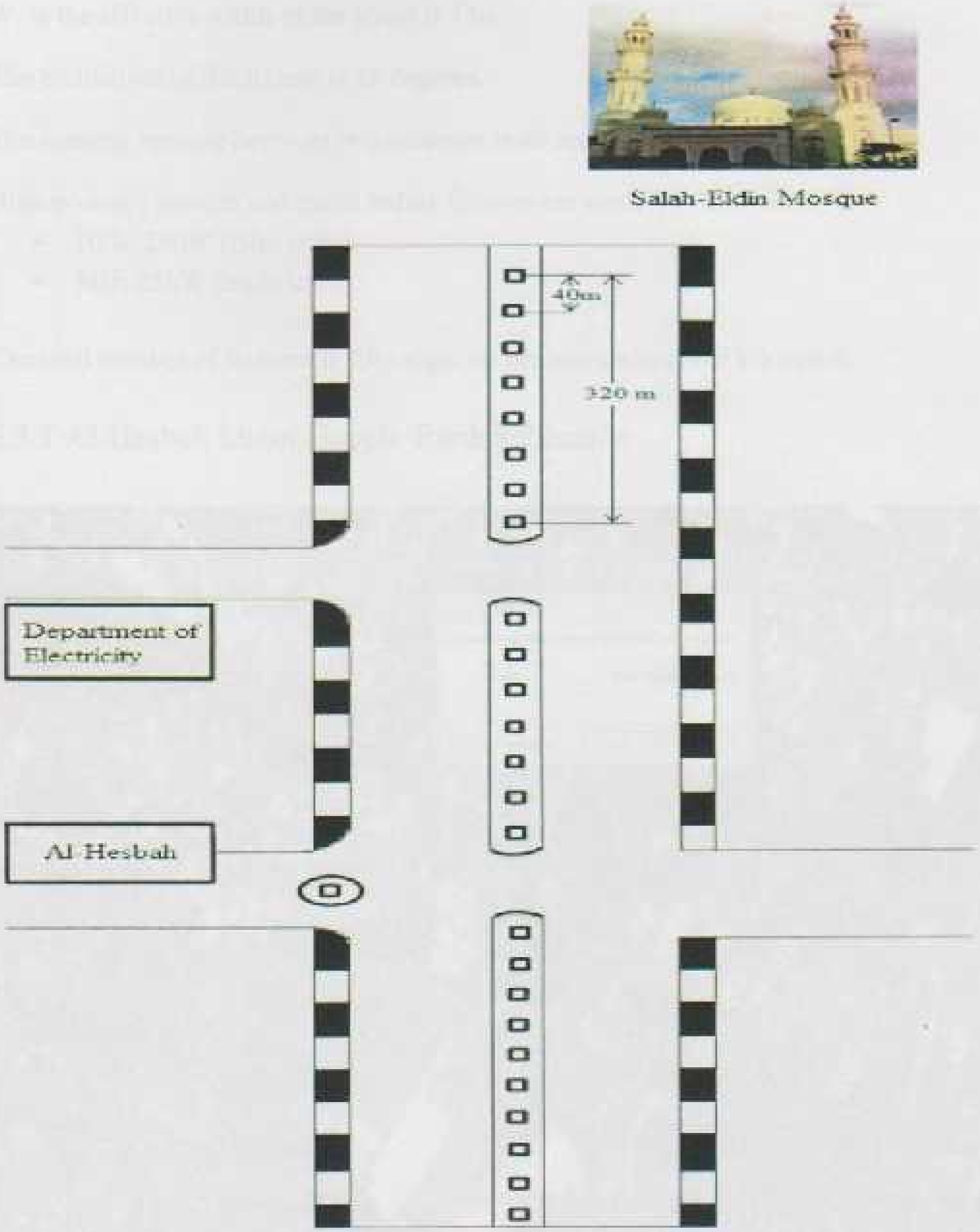

Figure 5.2: Schematic Distribution of Light Units in Al-Hesbah Street

Each lighting unit is composed from two fixtures erected at the middle of the street (Twin Central).

Where:

H: is the height of the post (hanging column) is 11m.

W: is the effective width of the street is 11m.

The inclination of the fixture is 10 degrees.

The existing spacing between two columns is 40 meters.

High pressure sodium and metal halide fixtures are used.

- HPS: 250W (fifty units).
- MH: 250W (eight units).

The total number of fixtures is fifty eight on the street along one kilometer.

5.3.1 Al-Hesbah Street Google Earth Schematic

Figure 5.3: Al-Hesbah Street Google Earth Schematic

5.4 Practical Design and Scaling

5.4.1 Practical Components before Scaling

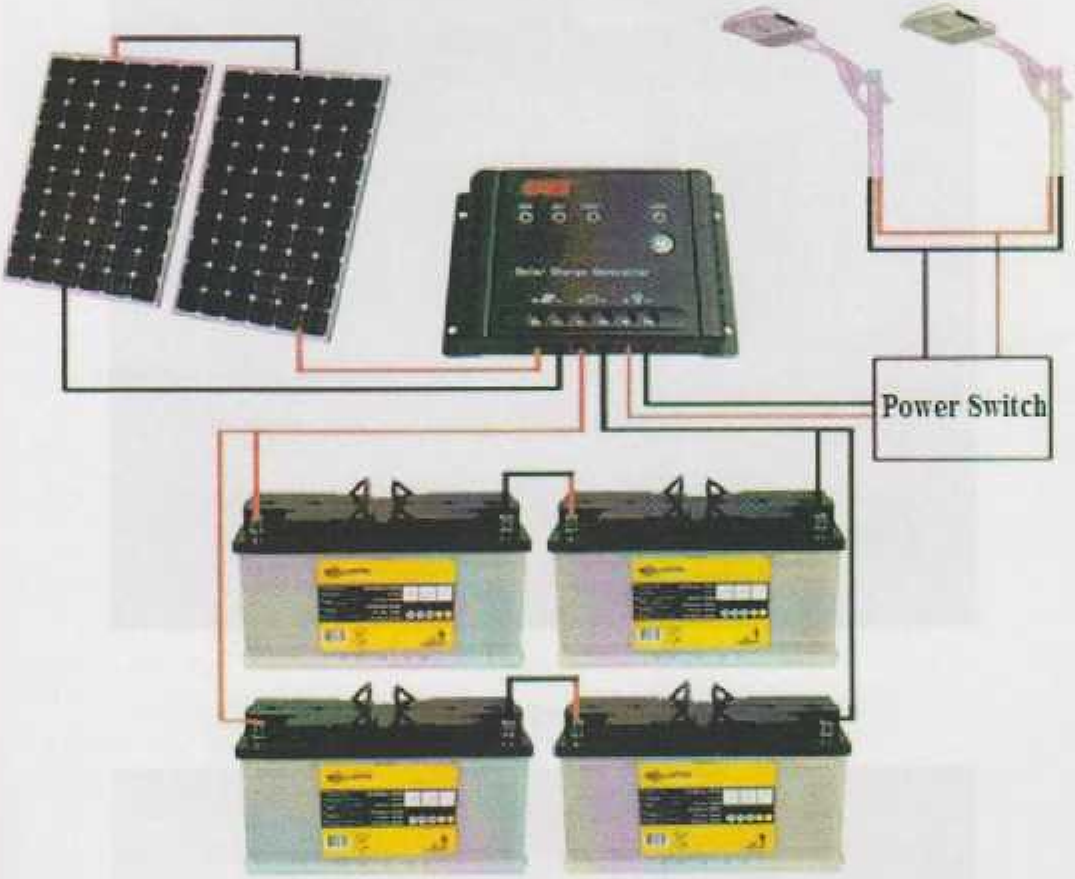

Figure 5.4: Practical Components before Scaling

5.4.2 Practical Prototype after Scaling

Figure 5.5: Practical Prototype after Scaling

Figure 5.6: Overhead Section of the Prototype

Power Switch Consists of:

1- GSM: global system for mobile communications.
2- Photocell sensor.

5.5 The Scaling Specifications

Scaling one sixth of the system (1:6)

1. Load power (LED lamp) 15 W, 12 Volt.
2. Power of the solar panel 55 W_{peak}, 12 Volt.
3. Charge controller 12 Volt, 5A.
4. Battery capacity 12 volt, 40Ah.
5. Assume that the height of the Post (column) is 2m, number of posts after scaling is five, and the span between two posts is 40 cm along 180 cm of overall prototype.

Battery capacity is 160 Ah → at 24V.
Battery capacity is 320 Ah → at 12V.

$$P_{load} = \frac{96\ W}{6} = 16\ W.$$

$$\text{Battary Capacity} = \frac{320}{8} = 40\ W \rightarrow \text{Select } 40\ Ah.$$

$$\text{The Power of PV} = \frac{240}{6} = 40\ W \rightarrow \text{Select } 55\ W.$$

5.5.1The Sketch of the Prototype

Figure 5.7 shows the final schematic of the lighting system with the calculated dimensions according to the international specifications.

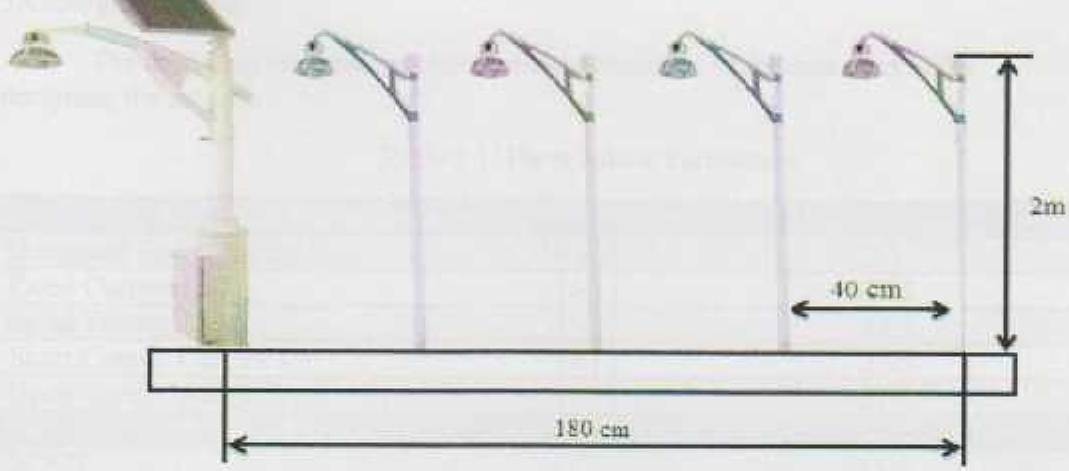

Figure 5.7: The Sketch of the Prototype and its Dimensions

5.6 All Components and Connections

5.6.1 Photovoltaic

Figure 5.8: SIMENS Mono Crystalline Silicon Photovoltaic

We selected a SIMENS mono crystalline silicon photovoltaic panel of type SM55 (M55), 55W, 12V which is fixed on the top of the central lighting post.

As the PV is fixed and there is no tracking system we chose a tilt angle of the solar panel equals the latitude angle of Hebron which is (31.533°). In order to enable the solar panel to collect enough insolation among the year.

The two terminals of the PV are connected to the corresponding terminals in the 5A charge controller.

The following table shows photovoltaic parameters which was used in the designing the module.

Table 5.1: Photovoltaic Parameters

Electrical Parameters		
Maximum Power Rating P_{max}	[W_P]	55
Rated Current I_{MPP}	[A]	3.15
Rated Voltage V_{MPP}	[V]	17.4
Short Circuit Current I_{SC}	[A]	3.45
Open Circuit Voltage V_{OC}	[V]	21.7
Thermal Parameters		
NOCT	[°C]	45±2
Temp. Coefficient: Short Circuit Current		1.2 mA/°C
Temp. Coefficient: Open Circuit Voltage		-0.077 V/°C
Qualification Test Parameters		
Temperature Cycling range	[°C]	-40 to +85
Humidity Freeze, Damp Heat	[%PH]	85
Maximum Permited System Voltage	[V]	600 (1000V per ISPRA)
Wind Loading PSF	[N/m^2]	50[2400]
Maximum Distortion	[°]	1.2
Hailstone Impact	[mm]	25
MPH	[m/s]	V=23
Weight	[Kg]	5.5

5.6.2 Charge Controller

We selected a Teca charge controller, 12V, 5A with three voltage indication voltage lamps (Green 12.8V, Yellow 12.3V, Red 11.8V), (as discussed in chapter three).

Charge controller has two terminals for PV connection, two terminals for battery connection and two terminals for load connection. The rating of the safety fuse is 5A, as shown in the figure (5.9).

Figure 5.9: Teca Charge Controller

5.6.3 Battery

We selected a rechargeable valve regulated (SEALED) battery REMCO.

Figure 5.10: REMCO SEALED Battery

Detailed Battery Description:

1. Sealed Lead Acid Battery maintenance free operation.
2. High quality and high reliability.
3. Low Self discharge characteristic.

The following table shows the specifications of the selected battery

Table 5.2: Sealed Lead Acid Battery

Battery model	RM12-40		
Standard Terminal	Type E		
Dimensions	Length	Width	Height
	18.5 cm	15.5cm	17.2cm
Approx. Weight (±5%)	14.33Kg		
Internal Resistance	Full charged at 25: Approx. 7mOhms		
Self-Discharge	6 Months@25°C		
Charge Voltage (25)	Cycle use		Cycle use
	14.4-14.7 V		13.5-13.8V
Voltage Regulation	3.50- 3.80 V		
Initial Current	12.0 A Max		
Constant Voltage Charge			

A thin metal box was designed for this battery with dimensions (40*17*25) cm (L*W*H), which is suitable for holding the battery and protecting it from out circumstances. As shown in the figure (5.11)

Figure 5.11: Battery box

5.6.4 GSM and PIC Microcontroller

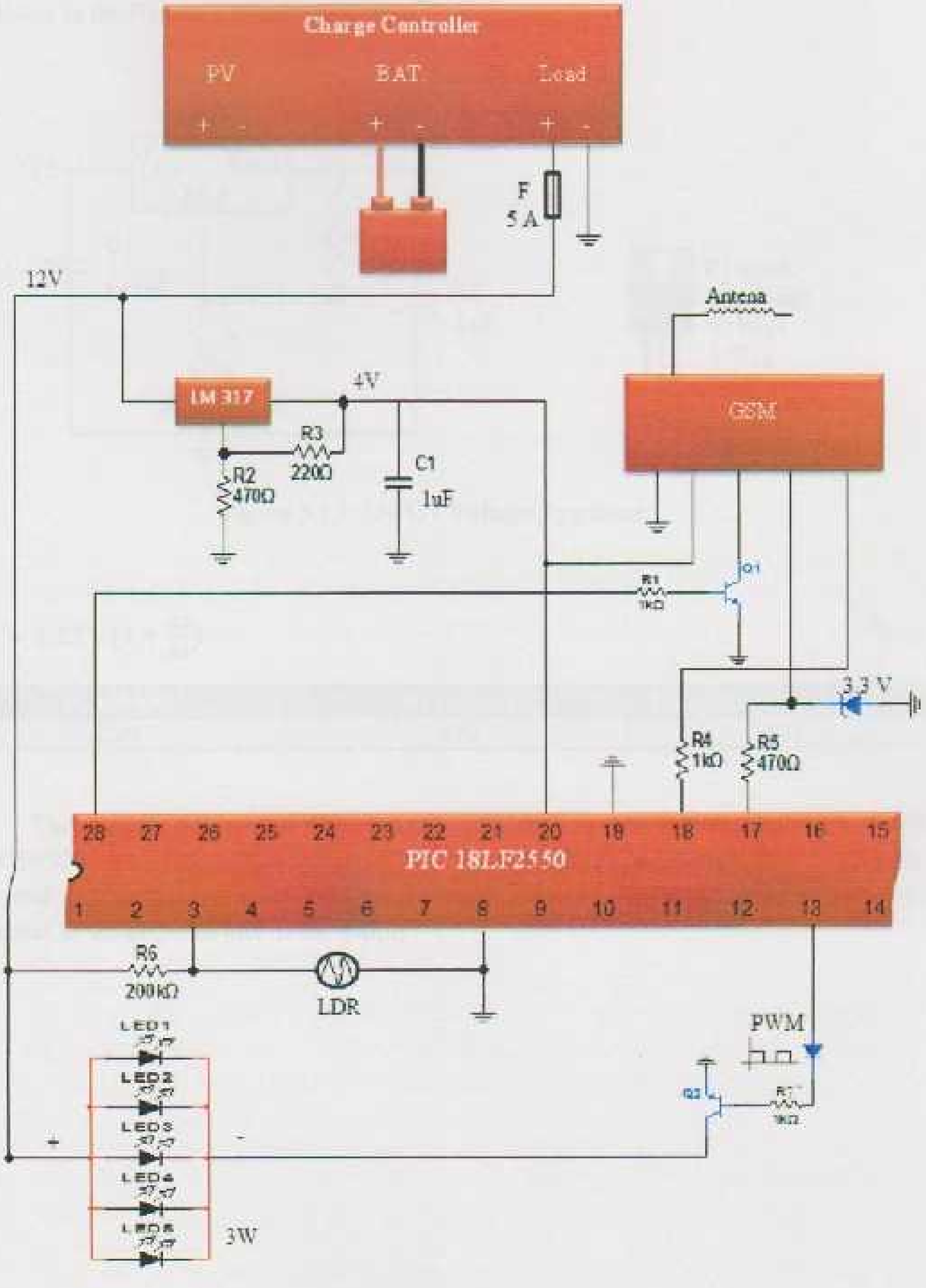

Figure 5.12: Physical Internal Connections of GSM Controller.

12 V DC output of the charge controller is fed to the voltage regulator (LM317) As shown in the figure (5.13).

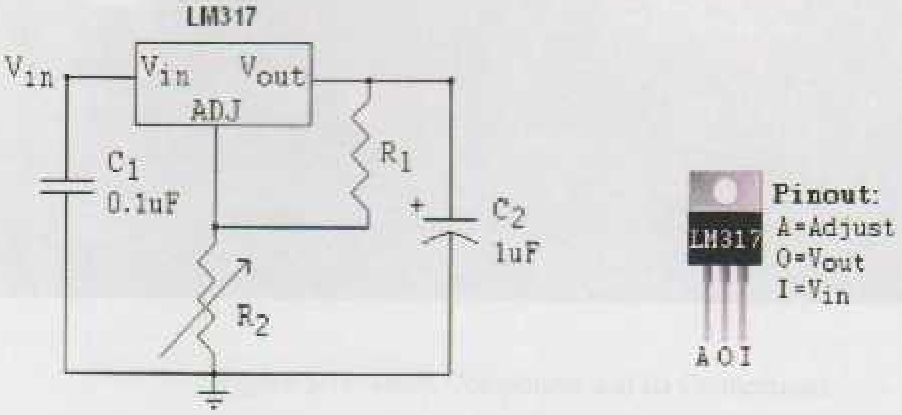

Figure 5.13: LM317 Voltage Regulator

$$V_{Out} = 1.25 * (1 + \frac{R2}{R1}) \quad (5.1)$$

R_1 [ohms]	R_2 [ohms]	Output Voltage [Volts]
220	470	3.92

The output voltage of the voltage regulator is 4V which feeds the GSM 94VOE99006 TYPE2B and the PIC 18LF2550 via pin20 (V_{DD}, Vcc positive supply for logic and I/O pins), Also pin 19 (Vss Ground reference for logic and I/O pins) is connected to the negative line of the supply.

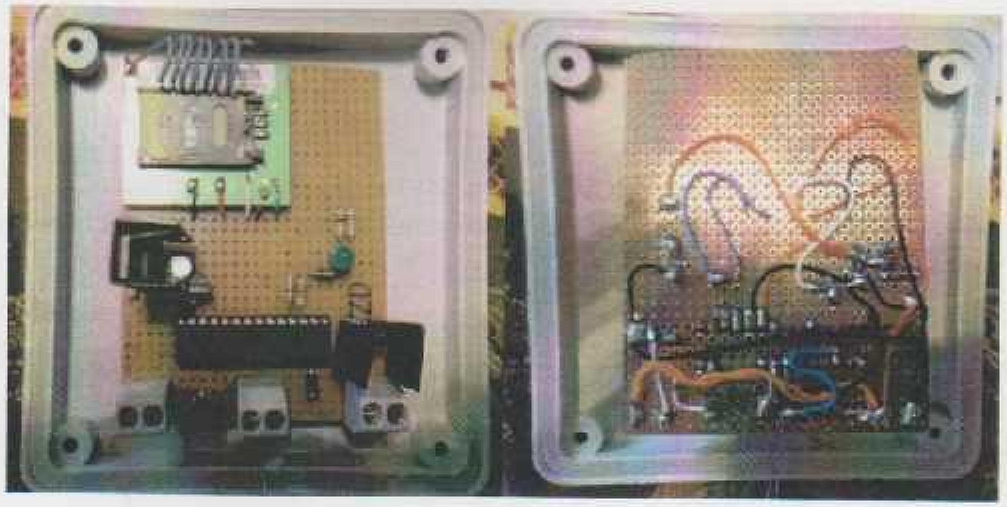

Figure 5.14: GSM Component and Its Connections

The command of the system is accomplished remotely by the text messages which are sent from a mobile phone. The serial number of our JAWWAL SIM is (0592860096). GSM receives the messages through the Antenna and the SIM card. These messages are transferred to the PIC. GSM and the PIC are interfaced through pins 17, 18, 28. (17: transmit output TX), (18: Receive input RX) and pin 28(compatible input RB 7).

Also the impact of the night darkness on the system is included via the Light Dependent Resistor LDR which is connected to the analog input of the PIC via pin 3 (AN1) and pin 8 (ground).

The PIC controls the brightness level of the street lighting fixtures. (100%, 80%, 50% and off operation modes) by pulse width modulation PWM control. As shown in the figure (5.12).

Pin 13 (PWM output) is connected to the base of the NPN power transistor Q2 (TIP41C) through the resistor R7 (1K ohm).The negative terminals of the LED lighting fixtures are connected to the collector of the transistor, meanwhile the positive terminals of the fixtures are connected to the positive line of the 12 v supply voltage.

According to the train of the positive pulses between the base and the emitter, the current will flow to the lighting fixtures through the collector of the power transistor.

When the voltage of the pulses is zero, the voltage on the collector will be high and the voltage on the fixtures will be zero (off mode).

When there is a pulse from PWM between the base and emitter the voltage on the collector will be low (0.2V), the transistor is saturated and the rest of the voltage (12-0.2 – 1.8V) will be on the lighting fixtures.

Controlling the duration of the pulses will affect the average voltage which is applied to the load (LED lighting fixtures).

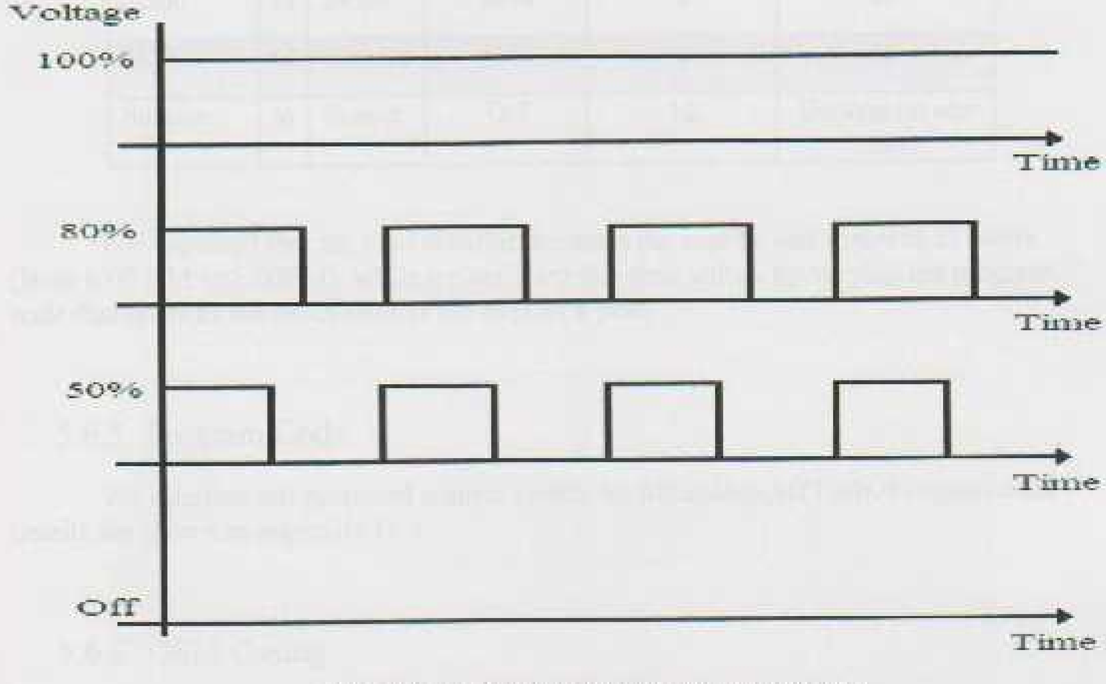

Figure5.15: Pulse Width Modulation Signals

Table (5.3) shows all of the commands that programed in our proposed control system.

Table 5.3: Program Commands

Activated Photocell	
A1	Automatic Sequence Modes
A0	Photocell is Deactivated
B0	Lamps are Off
B1	50% Dimming
B2	80% Dimming
B3	100% Dimming

Table 5.4: Timing Schedule of Diming after Scaling For Automatic Sequence Modes (A1).

From		Till	Lighting mode	Actual Time in the street(hours)	Prototype Time/after scaling(second)
Sunset	to	22:00	100%	4	40
22:00	to	24:00	80%	2	20
24:00	to	Sunrise	50%	6	60
Sunrise	to	Sunset	Off	12	Depend on our test

We Assumed that the time duration between the sunrise and sunset is 12 hours (from 6:00 AM to 6:00PM), while we can vary this time values by varying the program code that satisfies the exact time of the days of a year.

5.6.5 Program Code

We satisfied our proposed control system by Microchip MPLAB. Program code details are shown in appendix D.

5.6.6 GSM Casing

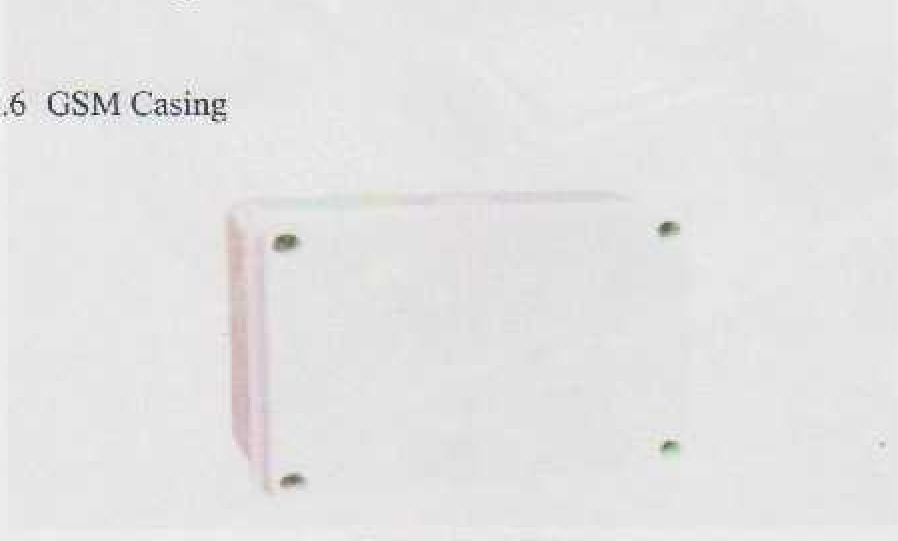

Figure5.16: GSM Casing

We fixed the GSM controller inside a plastic casing and the terminals of LDR photocell are connected with two thin wires from the casing to outside to sense the light existence as shown in the figure(5.16).

5.7 LEDs Lamps

Five LEDs lamps were erected on a small (1\2 inch) galvanized metal tubes with inclined angle, and then they were mounted on the posts.

The total power of these lamps is 15W, 3W each one.

Table 5.5 shows the desired LED specifications which are used in the model.

Table 5.5: LED Specifications

LED Specifications	
Input voltage	12V
Tiny indicator lamps on array	42 LEDs (7*6)
Length/width	13.5 cm/13.5cm
Weight	130g

Figure 5.17: LEDs Lamps

5.8 External Frame

Figure 5.18: Galvanized Metal Posts and Tubes

We constructed five galvanized metal posts, then we fixed them to the base, as shown in the figure (5.18), the height of the post is 2 m, the span between every two posts is 40 cm and the total length of the base is180 cm.

The GSM wireless controller and the charge controller were fixed on a metal panel that mounted inside a (30*40*20 cm) (L*W*H) metal electrical switch board with handgrip for opening and closing its door. As shown in the figures (5.19), (5.20).

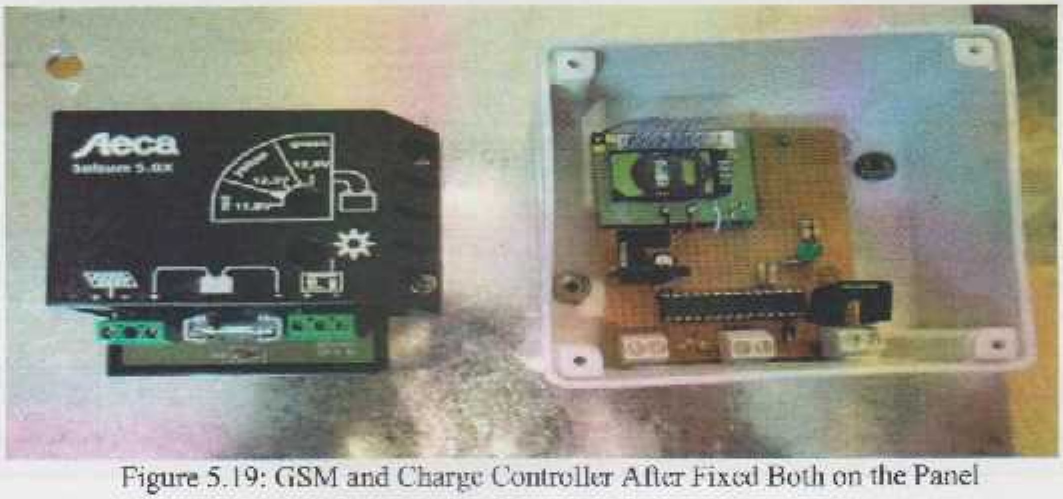

Figure 5.19: GSM and Charge Controller After Fixed Both on the Panel

A voltmeter (0 - 30V) with an (On/Off) switch are flush mounted on the door of the panel to measure the battery voltage.

An independent LED lamp and its Toggle switch also are mounted on the panel to light the surrounding when it is necessary. As shown in the figure (5.20).

Figure 5.20: Electrical Switch Board

5.9 Practical Components

Table 5.6 indicates all the components that we used to build out Prototype completely.

Table 5.6: Overall Prototype Components

Mono-Crystalline SIEMENS SM55, 12V, 55W Photovoltaic
Charge Controller 5A 12 Volt
Rechargeable Valve Regulated Sealed Battery (REMCO) 12V, 40Ah
GSM Controller 94VOE99006 TYPE2B
LED Lamps 15 W,12 V_{DC}
Electrical Switch Panel
External Frame (Metal Base, Galvanized Metal Posts and Tubes, Battery Box)
LDR Photocell, Wires, Accessories

CHAPTER

6 Conclusion and Recommendations

Chapter Six

Conclusion and Recommendations

6.1 Conclusion

The prices of the conventional energy such as coal, oil and gas are permanently increasing. The environmental pollution level when they are used in generating electricity is very high.

Utilizing generated electricity from solar energy is a promising alternative, as it is renewable, eco-friendly and there is a permanent reduction in the cost of its components. It can be applied efficiently in street lighting.

Selecting the lamps of street lighting does not depend only on their electrical power, it must include their efficiency, Illumination efficacy, luminance, correlated color temperature and color rendering index.

The project study of Al-Hesbah Street which is about one kilometer long showed that the annual cost due to electrical lighting energy consumption is about $8600 which is very high amount.

Installing photovoltaic system for Al-Hesbah Street instead of the current existed one is economically successful; the payback time of the project is about six years.

6.2 Challenges

While designing the system, there are many challenges were faced, such as:

1- The project components are expensive.

2- As the system containing programmable device, it wasn't an easy issue to write a complete program for the system to get the optimal results that we reached at the end.

3- It wasn't easy to get all the information about some statistics from the municipality.

6.3 Recommendations

After the great efforts during the last year in constructing the model completely and working perfectly, and because of its high importance for the municipality, we highly recommend the following:

1. Increasing the utilization of electrical energy generated from photovoltaic systems in Palestine.
2. Encouraging Palestinian people and their municipalities to build on-grid photovoltaic system between them which enables the participants to sell their excess needs of electrical energy to the municipality. On grid system saves the cost of the storage batteries which reduces the overall cost of building the solar systems by the people.
3. Manufacturing photovoltaic modules (solar panels) in Palestine.
4. Installing off grid photovoltaic systems for street lighting and remote areas.
5. Replacing the existed discharge lamps used in street lighting fixtures with light emitting diode (LED) lamps.
6. Adopting GSM Wireless controlling of the street lighting by utilizing the Internet and the local cellular communication nets which enables the municipalities to operate and monitor the lighting fixtures in an efficient and economical way.

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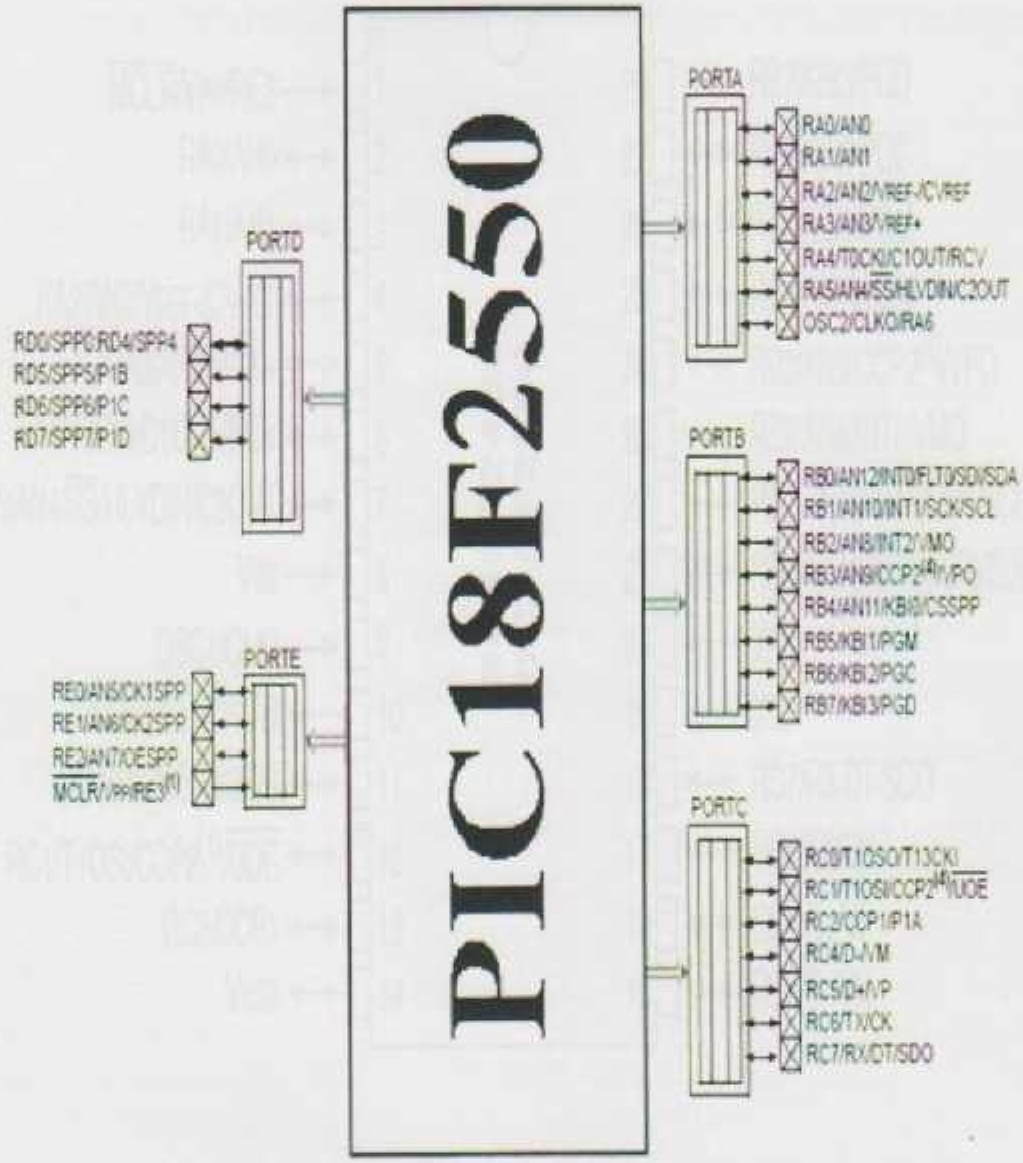
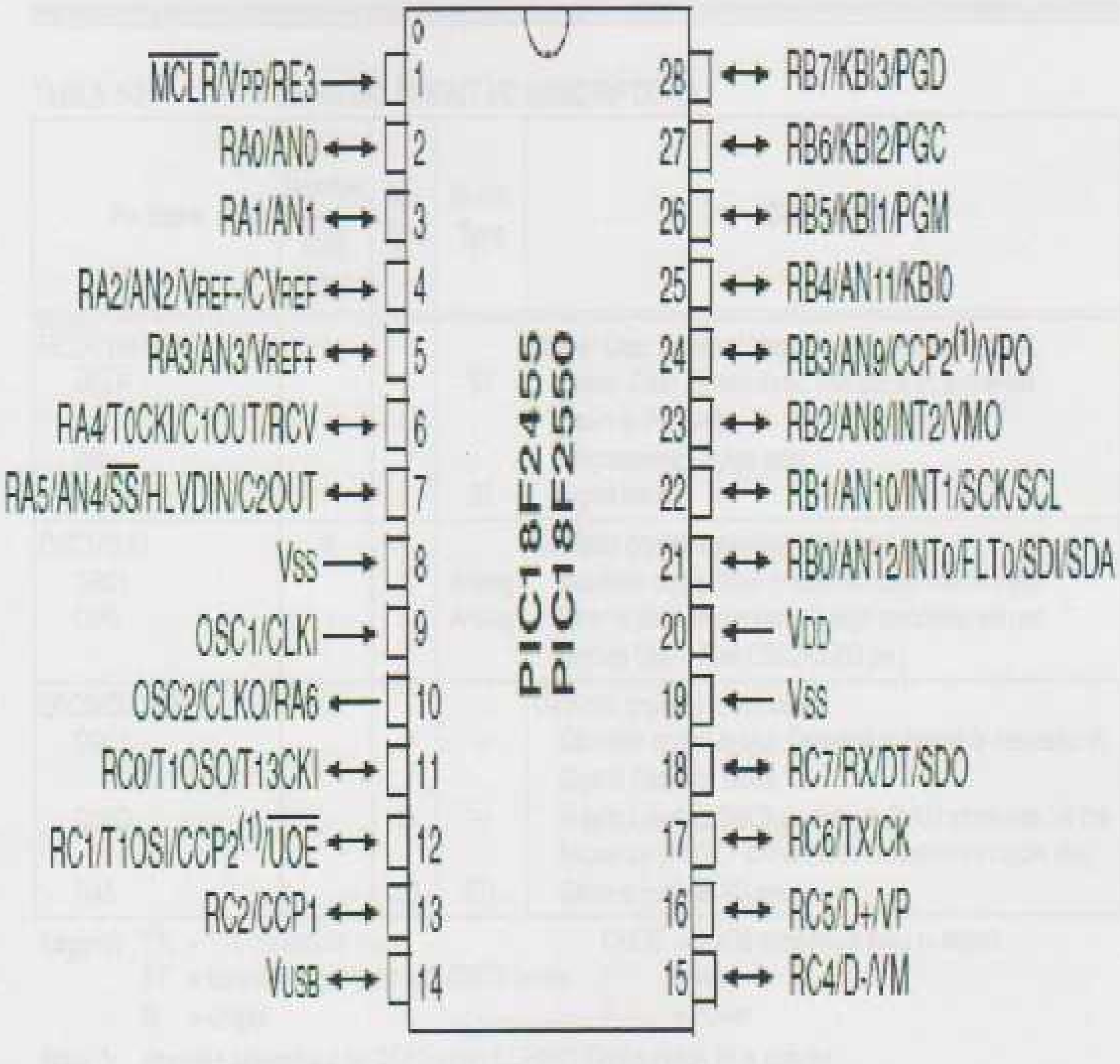
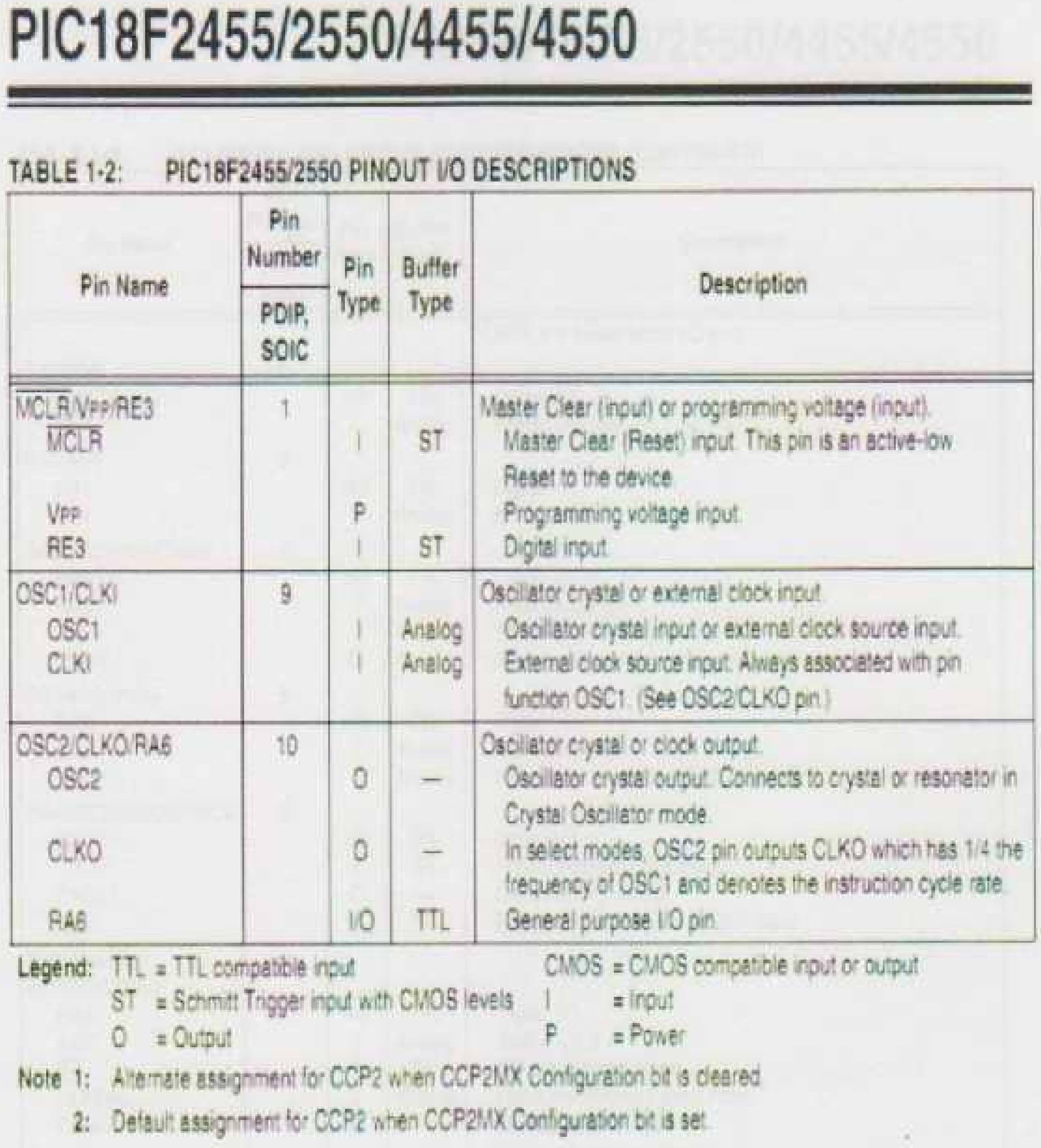
Appendix A (PIC Microcontroller)




PIC18F2455
PIC18F2550
MCLR/VPP/RE3 1
RA0/AN0 2
RA1/AN1 3
RA2/AN2/VREF-/CVREF 4
RA3/AN3/VREF+ 5
RA4/T0CKI/C1OUT/RCV 6
RA5/AN4/SS/HLVDIN/C2OUT 7
VSS 8
OSC1/CLKI 9
OSC2/CLKO/RA6 10
RC0/T1OSO/T13CKI 11
RC1/T1OSI/CCP2(1)/UOE 12
RC2/CCP1 13
VUSB 14
28 RB7/KBI3/PGD
27 RB6/KBI2/PGC
26 RB5/KBI1/PGM
25 RB4/AN11/KBI0
24 RB3/AN9/CCP2(1)/VPO
23 RB2/AN8/INT2/VMO
22 RB1/AN10/INT1/SCK/SCL
21 RB0/AN12/INT0/FLT0/SDI/SDA
20 VDD
19 VSS
18 RC7/RX/DT/SDO
17 RC6/TX/CK
16 RC5/D+/VP
15 RC4/D-/VM



PIC18F2455/2550/4455/4550

TABLE 1-2: PIC18F2455/2550 PINOUT I/O DESCRIPTIONS

Pin Name	Pin Number	Pin Type	Buffer Type	Description
	PDIP, SOIC			
$\overline{\text{MCLR}}/V_{PP}$/RE3	1			Master Clear (input) or programming voltage (input).
$\overline{\text{MCLR}}$		I	ST	Master Clear (Reset) input. This pin is an active-low Reset to the device.
V_{PP}		P		Programming voltage input.
RE3		I	ST	Digital input.
OSC1/CLKI	9			Oscillator crystal or external clock input.
OSC1		I	Analog	Oscillator crystal input or external clock source input.
CLKI		I	Analog	External clock source input. Always associated with pin function OSC1. (See OSC2/CLKO pin.)
OSC2/CLKO/RA6	10			Oscillator crystal or clock output.
OSC2		O	—	Oscillator crystal output. Connects to crystal or resonator in Crystal Oscillator mode.
CLKO		O	—	In select modes, OSC2 pin outputs CLKO which has 1/4 the frequency of OSC1 and denotes the instruction cycle rate.
RA6		I/O	TTL	General purpose I/O pin.

Legend: TTL = TTL compatible input
ST = Schmitt Trigger input with CMOS levels
O = Output
CMOS = CMOS compatible input or output
I = Input
P = Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.

2: Default assignment for CCP2 when CCP2MX Configuration bit is set.

TABLE 1-2: PIC18F2455/2550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number	Pin Type	Buffer Type	Description
	PDIP, SOIC			
				PORTA is a bidirectional I/O port.
RA0/AN0	2			
RA0		I/O	TTL	Digital I/O.
AN0		I	Analog	Analog input 0.
RA1/AN1	3			
RA1		I/O	TTL	Digital I/O.
AN1		I	Analog	Analog input 1.
RA2/AN2/VREF-/CVREF	4			
RA2		I/O	TTL	Digital I/O.
AN2		I	Analog	Analog input 2.
VREF-		I	Analog	A/D reference voltage (low) input.
CVREF		O	Analog	Analog comparator reference output.
RA3/AN3/VREF+	5			
RA3		I/O	TTL	Digital I/O.
AN3		I	Analog	Analog input 3.
VREF+		I	Analog	A/D reference voltage (high) input.
RA4/T0CKI/C1OUT/RCV	6			
RA4		I/O	ST	Digital I/O.
T0CKI		I	ST	Timer0 external clock input.
C1OUT		O	—	Comparator 1 output.
RCV		I	TTL	External USB transceiver RCV input.
RA5/AN4/$\overline{SS}$/HLVDIN/C2OUT	7			
RA5		I/O	TTL	Digital I/O.
AN4		I	Analog	Analog input 4.
$\overline{SS}$		I	TTL	SPI slave select input.
HLVDIN		I	Analog	High/Low-Voltage Detect input.
C2OUT		O	—	Comparator 2 output.
RA6	—	—	—	See the OSC2/CLKO/RA6 pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output
ST = Schmitt Trigger input with CMOS levels; I = Input
O = Output; P = Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.
2: Default assignment for CCP2 when CCP2MX Configuration bit is set.

TABLE 1-2: PIC18F2455/2550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number	Pin Type	Buffer Type	Description
	PDIP, SOIC			
				PORTB is a bidirectional I/O port. PORTB can be software programmed for internal weak pull-ups on all inputs.
RB0/AN12/INT0/FLT0/SDI/SDA	21			
RB0		I/O	TTL	Digital I/O.
AN12		I	Analog	Analog input 12.
INT0		I	ST	External interrupt 0.
FLT0		I	ST	PWM Fault input (CCP1 module).
SDI		I	ST	SPI data in.
SDA		I/O	ST	I²C™ data I/O.
RB1/AN10/INT1/SCK/SCL	22			
RB1		I/O	TTL	Digital I/O.
AN10		I	Analog	Analog input 10.
INT1		I	ST	External interrupt 1.
SCK		I/O	ST	Synchronous serial clock input/output for SPI mode.
SCL		I/O	ST	Synchronous serial clock input/output for I²C mode.
RB2/AN8/INT2/VMO	23			
RB2		I/O	TTL	Digital I/O.
AN8		I	Analog	Analog input 8.
INT2		I	ST	External interrupt 2.
VMO		O	—	External USB transceiver VMO output.
RB3/AN9/CCP2/VPO	24			
RB3		I/O	TTL	Digital I/O.
AN9		I	Analog	Analog input 9.
CCP2(1)		I/O	ST	Capture 2 input/Compare 2 output/PWM 2 output.
VPO		O	—	External USB transceiver VPO output.
RB4/AN11/KBI0	25			
RB4		I/O	TTL	Digital I/O.
AN11		I	Analog	Analog input 11.
KBI0		I	TTL	Interrupt-on-change pin.
RB5/KBI1/PGM	26			
RB5		I/O	TTL	Digital I/O.
KBI1		I	TTL	Interrupt-on-change pin.
PGM		I/O	ST	Low-Voltage ICSP™ Programming enable pin.
RB6/KBI2/PGC	27			
RB6		I/O	TTL	Digital I/O.
KBI2		I	TTL	Interrupt-on-change pin.
PGC		I/O	ST	In-Circuit Debugger and ICSP programming clock pin.
RB7/KBI3/PGD	28			
RB7		I/O	TTL	Digital I/O.
KBI3		I	TTL	Interrupt-on-change pin.
PGD		I/O	ST	In-Circuit Debugger and ICSP programming data pin.

Legend:
TTL = TTL compatible input
ST = Schmitt Trigger input with CMOS levels
O = Output
CMOS = CMOS compatible input or output
I = Input
P = Power

Note 1: Alternate assignment for CCP2 when CCP2MX Configuration bit is cleared.

2: Default assignment for CCP2 when CCP2MX Configuration bit is set.

TABLE 1-2: PIC18F2455/2550 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number	Pin Type	Buffer Type	Description
	PDIP, SOIC			

Appendix B (LM317 Regulator)

LM117, LM317-N

TEXAS INSTRUMENTS

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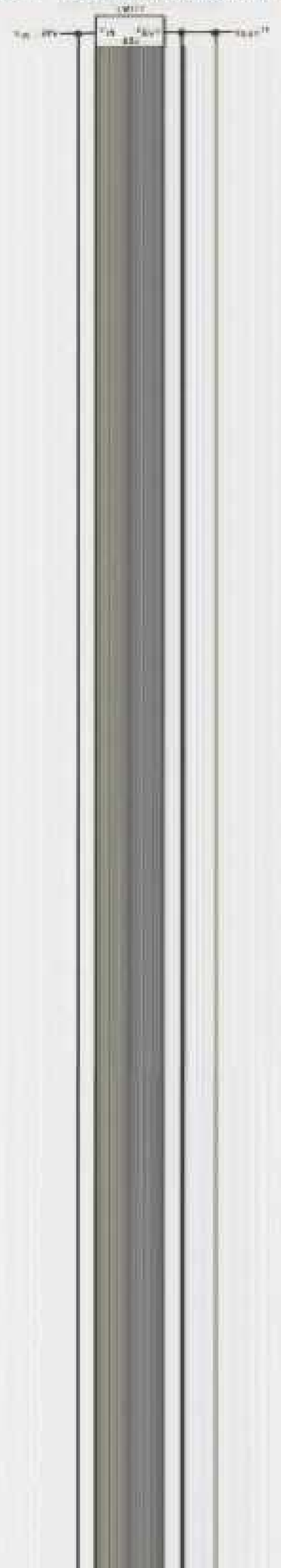
Typical Applications

Figure 1. 1.2V–25V Adjustable Regulator




INPUT
ADJUSTMENT
OUTPUT

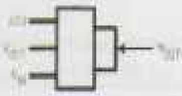


Figure 9. 4-Lead SOT-223 (EMP)

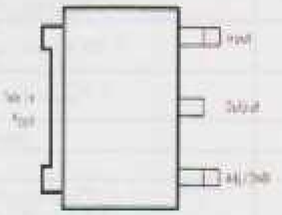


Figure 10. TO-252 (MDT)

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

Absolute Maximum Ratings [1]

Power Dissipation	Internally Limited
Input-Output Voltage Differential	+40V, −0.3V
Storage Temperature	−65°C to +150°C
Lead Temperature	
Metal Package (Soldering, 10 seconds)	300°C
Plastic Package (Soldering, 4 seconds)	260°C
ESD Tolerance [2]	3 kV

[1] Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed.

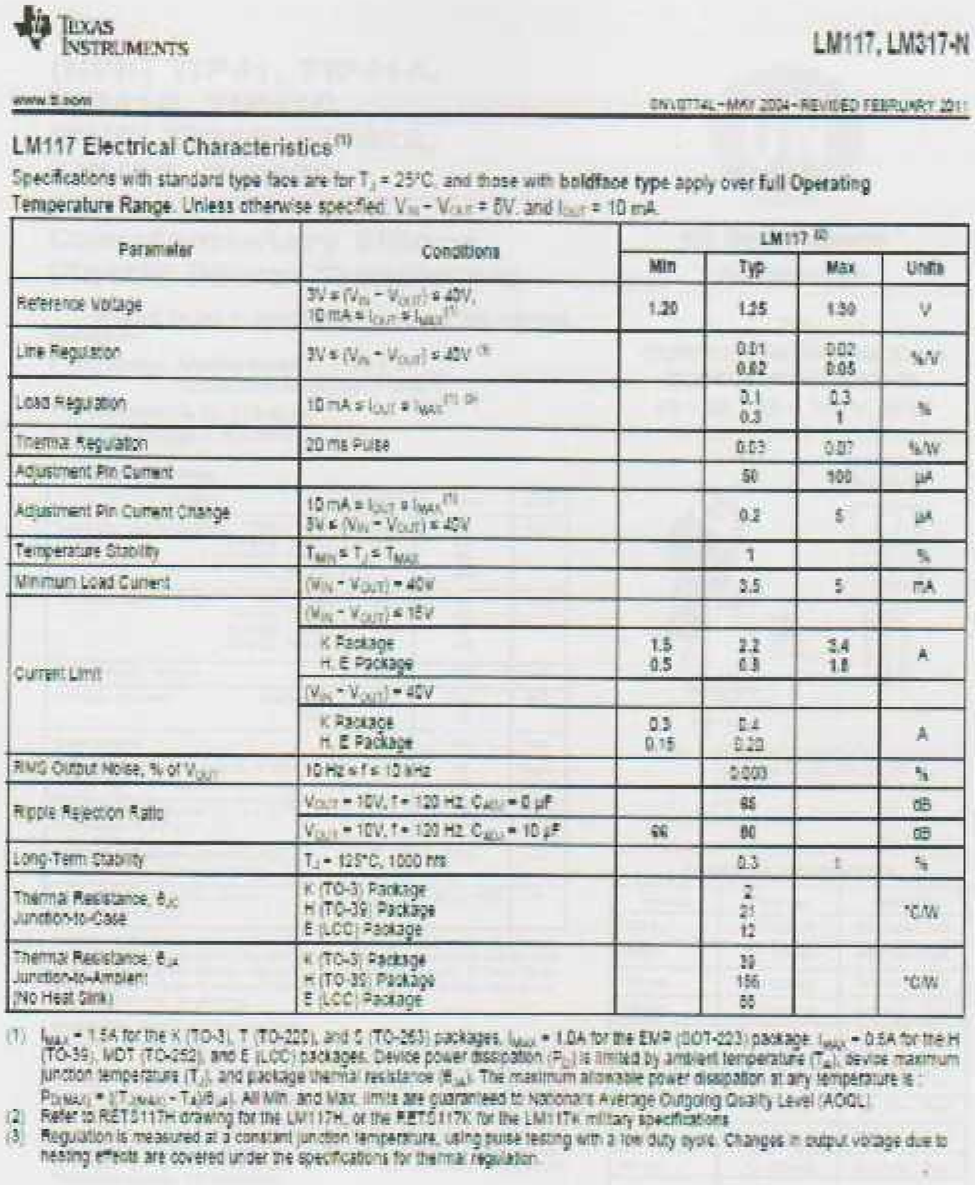
[2] Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Operating Temperature Range

LM117	$-55°C \leq T_J \leq +150°C$
LM317A	$-40°C \leq T_J \leq +125°C$
LM317	$0°C \leq T_J \leq +125°C$

Preconditioning

Thermal Limit Burn-In	All Devices 100%



TEXAS INSTRUMENTS

LM117, LM317-N

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LM117 Electrical Characteristics[1]

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} - V_{OUT}$ = 5V, and I_{OUT} = 10 mA.

Parameter	Conditions	LM117[2]			
		Min	Typ	Max	Units
Reference Voltage	$3V \le (V_{IN} - V_{OUT}) \le 40V$, $10\ mA \le I_{OUT} \le I_{MAX}$[1]	1.20	1.25	1.30	V
Line Regulation	$3V \le (V_{IN} - V_{OUT}) \le 40V$[3]		0.01 **0.02**	0.02 **0.05**	%/V
Load Regulation	$10\ mA \le I_{OUT} \le I_{MAX}$[1][3]		0.1 **0.3**	0.3 **1**	%
Thermal Regulation	20 ms Pulse		0.03	0.07	%/W
Adjustment Pin Current			50	100	μA
Adjustment Pin Current Change	$10\ mA \le I_{OUT} \le I_{MAX}$[1] $3V \le (V_{IN} - V_{OUT}) \le 40V$		0.2	5	μA
Temperature Stability	$T_{MIN} \le T_J \le T_{MAX}$		1		%
Minimum Load Current	$(V_{IN} - V_{OUT}) = 40V$		3.5	5	mA
Current Limit	$(V_{IN} - V_{OUT}) \le 15V$				
	K Package H, E Package	1.5 0.5	2.2 0.8	3.4 1.8	A
	$(V_{IN} - V_{OUT}) = 40V$				
	K Package H, E Package	0.3 0.15	0.4 0.20		A
RMS Output Noise, % of V_{OUT}	$10\ Hz \le f \le 10\ kHz$		0.003		%
Ripple Rejection Ratio	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 0 μF		65		dB
	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 10 μF	66	80		dB
Long-Term Stability	T_J = 125°C, 1000 hrs		0.3	1	%
Thermal Resistance, θ_{JC} Junction-to-Case	K (TO-3) Package H (TO-39) Package E (LCC) Package		2 21 12		°C/W
Thermal Resistance, θ_{JA} Junction-to-Ambient (No Heat Sink)	K (TO-3) Package H (TO-39) Package E (LCC) Package		39 186 88		°C/W

---

(1) I_{MAX} = 1.5A for the K (TO-3), T (TO-220), and S (TO-263) packages. I_{MAX} = 1.0A for the EMP (SOT-223) package. I_{MAX} = 0.5A for the H (TO-39), MDT (TO-252), and E (LCC) packages. Device power dissipation (P_D) is limited by ambient temperature (T_A), device maximum junction temperature (T_J), and package thermal resistance (θ_{JA}). The maximum allowable power dissipation at any temperature is : $P_{D(MAX)} = ((T_{J(MAX)} - T_A)/\theta_{JA})$. All Min. and Max. limits are guaranteed to National's Average Outgoing Quality Level (AOQL).

(2) Refer to RETS117H drawing for the LM117H, or the RETS117K for the LM117K military specifications.

(3) Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.

Appendix C (NPN, TIP41C Transistor)

(NPN) TIP41, TIP41A, TIP41B, TIP41C (PNP) TIP42, TIP42A, TIP42B, TIP42C

Complementary Silicon Plastic Power Transistors

. . . designed for use in general purpose amplifier and switching applications.

- ESD Ratings: Machine Model, C; > 400 V
  Human Body Model, 3B; > 8000 V
- Epoxy Meets UL 94, V−0 @ 1/8″
- Pb−Free Package is Available*

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector−Emitter Voltage TIP41, TIP42 TIP41A, TIP42A TIP41B, TIP42B TIP41C, TIP42C	V_{CEO}	40 60 80 100	Vdc
Collector−Base Voltage TIP41, TIP42 TIP41A, TIP42A TIP41B, TIP42B TIP41C, TIP42C	V_{CB}	40 60 80 100	Vdc
Emitter−Base Voltage	V_{EB}	5.0	Vdc
Collector Current Continuous Peak	I_C	6.0 10	Adc
Base Current	I_B	2.0	Adc
Total Power Dissipation @ T_C = 25°C Derate above 25°C	P_D	65 0.52	Watts W/°C
Total Power Dissipation @ T_A = 25°C Derate above 25°C	P_D	2.0 0.016	Watts W/°C
Unclamped Inductive Load Energy (Note 1)	E	62.5	mJ
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−65 to +150	°C

Maximum ratings are those values beyond which device damage can occur. Maximum ratings applied to the device are individual stress limit values (not normal operating conditions) and are not valid simultaneously. If these limits are exceeded, device functional operation is not implied, damage may occur and reliability may be affected.

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.67	°C/W
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	57	°C/W

1. I_C = 2.5 A, L = 20 mH, P.R.F. = 10 Hz, V_{CC} = 10 V, R_{BE} = 100 Ω

*For additional information on our Pb−Free strategy and soldering details, please download the ON Semiconductor Soldering and Mounting Techniques Reference Manual, SOLDERRM/D.

ON Semiconductor™

http://onsemi.com

6 A
COMPLEMENTARY SILICON POWER TRANSISTORS
40 − 60 − 80 − 100 V, 65 W

MARKING DIAGRAM

AYWW
TIP4xx

STYLE 1:
PIN 1. BASE
2. COLLECTOR
3. EMITTER
4. COLLECTOR

TO−220AB
CASE 221A−09
STYLE 1

xx = Specific Device Code
1, 2, 1A, 1B, 1C, 2A, 2B, 2C
A = Assembly Location
Y = Year
WW = Work Week

ORDERING INFORMATION

Device	Package	Shipping
TIP41	TO−220AB	50 Units / Rail
TIP41A	TO−220AB	50 Units / Rail
TIP41B	TO−220AB	50 Units / Rail
TIP41C	TO−220AB	50 Units / Rail
TIP41CG	TO−220AB (Pb−Free)	50 Units / Rail
TIP42	TO−220AB	50 Units / Rail
TIP42A	TO−220AB	50 Units / Rail
TIP42B	TO−220AB	50 Units / Rail
TIP42C	TO−220AB	50 Units / Rail
TIP42CG	TO−220AB (Pb−Free)	50 Units / Rail

Appendix D Program Code

(NPN) TIP41, TIP41A, TIP41B, TIP41C (PNP) TIP42, TIP42A, TIP42B, TIP42C

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted)

Appendix D (Program Code)

```
//---------PIC18F2550----------
char SMS[160]={0xFF};
char SMSI=0,SMSIX=0;
char gsm_state = 0;
char response_rcvd = 0;
unsigned int sun=0;
char sun_auto=1;
short response = -1;
const GSM_OK   = 1;
const GSM_NEW_SMS =2;
const GSM_SMS=3;

//==================================================
void send_at(const char *s)
{ while(*s){uart1_write(*s++);}
 UART1_Write(0x0D);
}
//==================================================
void deletsmsarry()
{char i=0;for(i=0;i<160;i++){SMS[i]=0xFF;} }
//==================================================
void DELET_SMS()
{
```

```
delay_ms(300);

UART1_Write_text("AT+CMGDA=\"DEL
ALL\"");delay_ms(100);UART1_Write(0x0D);

delay_ms(100);

}

//=====================================================

void NEW_SMS()

{

UART1_Write_text("AT+CMGR=1");UART1_Write(0x0D);

}

//=====================================================

void READ_SMS()

{

delay_ms(500);

DELET_SMS();

delay_ms(500);

if (SMS[0]=='A'&&SMS[1]=='0'){sun_auto=0;}

else if (SMS[0]=='A'&&SMS[1]=='1'){sun_auto=1;}

else if(SMS[0]=='B'&&SMS[1]=='0'){sun_auto=0;PWM1_Set_Duty(0);}

else if(SMS[0]=='B'&&SMS[1]=='1'){sun_auto=0;PWM1_Set_Duty(50);}

else if(SMS[0]=='B'&&SMS[1]=='2'){sun_auto=0;PWM1_Set_Duty(100);}

else if(SMS[0]=='B'&&SMS[1]=='3'){sun_auto=0;PWM1_Set_Duty(255);}

else if(SMS[0]=='B')

{

sun_auto=0;
```

```
PWM1_Set_Duty(255);
delay_ms(5000);
PWM1_Set_Duty(100);
delay_ms(5000);
PWM1_Set_Duty(50);
delay_ms(5000);
PWM1_Set_Duty(0);
}
delay_ms(500);
deletsmsarry();
}
//==================================================
 void setupAT()
 {
 char i=0;
 for(i=0;i<10;i++)
 {
 send_at("AT");
 delay_ms(1000);
 if (response_rcvd==1&&response==GSM_OK) break;
 }
 DELAY_MS(1000);
 response_rcvd=0;
 send_at("ATE0");
 delay_ms(500);
```

```
 send_at("AT+CMGF=1");
 delay_ms(6000);
 send_at("AT+CMGDA=\"DEL ALL\"");
 delay_ms(2000);
 }
//==================================================
 void poweron()
 {
 RB7_Bit=1;
 DELAY_MS(2300);
 RB7_Bit=0;
 DELAY_MS(2000);
 setupAT();
 }
//==================================================
void setup()
{
PIE1.RCIE  = 1;
INTCON.PEIE = 1;
INTCON.GIE  = 1;
//ADCON1 = 15;                    // Configure all ports with analog function as digital
CMCON  = 7;                       // Disable comparators
LATA = 0;
LATB = 0;
LATC = 0;
```

```
TRISA=0xFF;

TRISB=0;

TRISC=0b10000000;

UART1_Init(9600);
```

```
case 20: {if(tmp=='M')gsm_state=30;else gsm_state=0;break;}
case 30: {if(tmp=='T')gsm_state=31;else if(tmp=='G')gsm_state=40;else
gsm_state=0;break;}
case 31: {if(tmp=='I'){response=GSM_NEW_SMS;response_rcvd = 1;gsm_state=0;}else
gsm_state=0;break;}
case 40: {if(tmp=='R')gsm_state=41;else {gsm_state=0;}break;}
case 41: {if(tmp==0x0D)gsm_state=42;else gsm_state=41;break;}
case 42: {if(tmp==0x0A)gsm_state=43;else {gsm_state=0;}break;}
case 43: {if(tmp!=0x0D&&SMSI<30){SMS[SMSI]=tmp;SMSI++;}
else {gsm_state=0;SMSI=0;response=GSM_SMS;response_rcvd = 1;}break;}
default: {gsm_state = 0;break;}}
}}
//==================================================
void main()
{
OSCCON=0x72;
setup();
poweron();
delay_ms(2000);
while(1)
{
sun = ADC_Read(1);
if(sun>950&&sun_auto==1)
{
PWM1_Set_Duty(255);
delay_ms(40000);
```

```
PWM1_Set_Duty(100);
delay_ms(20000);
PWM1_Set_Duty(50);
delay_ms(60000);
PWM1_Set_Duty(0);
}
if (response_rcvd)
{
response_rcvd=0;
if(response==GSM_NEW_SMS){delay_ms(500);NEW_SMS(); }
else if(response==GSM_SMS){delay_ms(500);READ_SMS();}
}
}
}
```