Sudan University of Science & Technology
College of Engineering
Electrical Engineering

Design of a Stand-alone Solar PV System
تصميم نظام طاقة شمسية كهروضوئية مستقل

A Project Submitted in Partial Fulfillment for the Requirements of the Degree of B.Sc. (Honors) in Electrical Engineering

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October 2017

الآيـة:

{يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ}

{المجادلة:11}

DEDICATED

To

Our Mothers

Who took care of us all the way this journey

Our Fathers

Who taught us to trust in Allah, believe in hard work and always hope for best

AKNOWLEDGMENT

First we thank god almighty (Allah SWT), the completion of this project could not have been possible without his blessing and assistance.

Then all thanks and appreciation to our supervisor Dr. Nagm Aldeen Abdo Mustafa for his patience and valuable advises.

Lastly thanks to our teachers in electrical engineering school for their effort, without them we wouldn’t be able to reach this far.

Abstract

The frequent power outages from university is delaying learning process and make the environment unsuitable for studying. By using an independent source of supply the frequent power outages are stopped. The independent source of supply chosen is stand-alone solar PV system; because it is practical and available. The solar PV system designed after knowing the value of total consumption demand of the selected loads and the components of the system are selected according to that. Because solar panels are relatively expensive, the load supplied is fans and lights only. Lighting load is rearranged by DIALux program and the type of lights chosen is LED to reduce power consumption.

المستخلص

الانقطاع المتكرر للتيار الكهربائي من الجامعة يتسبب بتأخير عملية التعلم وجعل البيئة غير صالحة للدراسة. باستخدام مصدر مستقل للإمداد تم إيقاف انقطاع التيار الكهربائي المتكرر، والمصدر المستقل للإمداد الي تم اختياره هو نظام الطاقة الشمسية الكهروضوئية المستقل؛ لأنها عملية ومتاحة. تم تصميم النظام بعد معرفة إجمالي استهلاك الطاقة للأحمال المحددة وتم اختيار عناصر النظام وفقا لذلك ايضا. الألواح الشمسية مكلفة نسبيا لذا أخذت أحمال الإضاءة والمراوح فقط في الحسبان. أحمال الإضاءة اعيد ترتيبها حسب برنامج DIALux ونوع الأضواء المختار هو LED من أجل خفض استهلاك الطاقة.

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PV	Photovoltaic
PWM	Pulse Width Modulation
FF	Fill factor
LI	Lithium Ion
LP	Lithium Polymer
LA	Lead-Acid (LA) Battery
MPPT	Maximum Power Point Tracking
LED	Light Emitting Diode
CAD	Computer Aided Design
U0	percentage of lighting uniformity

CHAPTER ONE

INTRODUCTION

1.1 Overview

Energy is the property that must be transferred to an object in order to perform work or to heat the object. It can be converted in form, but not created or destroyed and the SI unit of energy is the joule [1].

There are three main sources of energy, fossil, nuclear and renewable. Fossil and nuclear sources have many negative effects to environment and human health, so the world is moving towards renewable energy sources [2].

Renewable energy is energy that is collected from renewable resources, which are formed due to natural conditions throw human life time on earth, such as solar, wind, rain, tides, waves, geothermal, biomass, ethanol and hydropower ,They are often providing energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services [3,4].

The most common energy source among the renewables is the solar and that is quite obvious because the sun is the biggest source of energy that we know. Solar energy is radiant light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture, molten salt power plants and artificial photosynthesis[5].

The sun radiates (sends out) more energy in one day than the world uses in one year and at a single moment there are $1.74 * 10^{14}$ kilowatts of sun power strikes earth, so roughly one square meter will receive one kilowatt of that energy. There are two ways to benefit from solar energy, photovoltaics and thermal [6].

The potential solar energy that could be used by humans differs from the amount of solar energy present near the surface of the planet because factors such as geography, time variation, cloud cover, and the land available to humans limit the amount of solar energy that we can acquire [7].

1.2 Problem Statement

Electricity is the key to evolution but on the other hand the means of its generation are very harmful to environment and has negative effects on human health, so friendly to environment sources must be used profusely.

There are many problems with the electrical grid, so it is not stable and the interruption of supply are quite often. This unstable situation is delaying learning process by stopping lectures, laboratories and teachers in offices from work.

The distribution of light fixtures is not appropriate, and this makes the environment uncomfortable and may lead to sight problems in a long term.

1.3 Objective

- Study of using solar Photovoltaic (PV) system for the college.
- Decrease the electricity power by using LED lamps for lighting.
- Make the university night lighting depend on solar energy.

1.4 Methodology

- Generating of electrical energy by solar PV system was studied, to solve this problem.
- Distributing of loads was rearranged, lighting load rearranged by using DIALux program.
- University load was calculated after rearranging to estimate the size of the solar plant.
- Redesign outdoor lighting by using DIALux.

1.5 Project Layout

The thesis include five chapters organized as follows Chapter one include overview, Problem statement, Objective, Methodology and Thesis layout, chapter two include Introduction, Types of PV systems, Components of a PV system, Solar cell, Tilt of Solar Panels, External solar cell parameters, Equivalent Circuit, i-v and p-v curves, Batteries, Charge controller, Inverters and ATS, chapter three include Introduction, Case of study, Lighting distribution, DIALux program, System sizing System, System calculation, Assumption and type of component used in project , chapter four include Performance of PV system, Results, Discussions of design lighting load, chapter five include conclusion and recommendation.

CHAPTER TWO

LITRIATURE REVIEW

2.1 Introduction

A solar cell, or photovoltaic cell (PV), is a device that converts light into electric current using the photovoltaic effect, The array of a photovoltaic power system, or PV system, produces direct current (DC) power which fluctuates with the sunlight's intensity, for practical use this usually requires conversion to certain desired voltages or alternating current (AC), through inverters [8,9].

The PV system Operating silently and without any moving parts or environmental emissions, and consists of an arrangement of several components including solar panels to absorb and convert sunlight into electricity, a solar inverter , as well as mounting, cabling and other electrical accessories to set up a working system. It may also use a solar tracking system to improve the system's overall performance and include an integrated battery solution, as prices for storage devices are expected to decline .PV systems range from small, rooftop-mounted or building-integrated systems with capacities from a few to several tens of kilowatts, to large utility-scale power stations of hundreds of megawatts, Many residential PV systems are connected to the grid wherever available, especially in developed countries with large markets. In these grid-connected PV systems, use of energy storage is optional. In certain applications such as satellites, lighthouses, or in developing countries, batteries or additional power generators are often added as back-ups. Such stand-alone power systems permit operations at night and at other times of limited sunlight. Nowadays most PV systems are grid-connected, while off-grid or stand-alone systems only account for a small portion of the market [10, 11].

2.2 Types of PV Systems

PV systems can be very simple, consisting of just a PV module and load, as in the direct powering of a water pump motor, which only needs to operate when the sun shines. However, when for example a whole house should be powered the system must be operational day and night. It also may have to feed both AC and DC loads, have reserve power and may even include a back-up generator. Depending on the system configuration we can distinguish three main types of PV systems [12]:

2.2.1 Stand-alone systems

Stand-alone systems rely on solar power only. These systems can consist of the PV modules and a load only or they can include batteries for energy storage. When using batteries charge regulators are included, which switch off the PV modules when batteries are fully charged, and may switch off the load to prevent the batteries from being discharged below a certain limit. The batteries must have enough capacity to store the energy produced during the day to be used at night and during periods of poor weather. Fig 2.1 shows schematically examples of stand-alone systems [12].

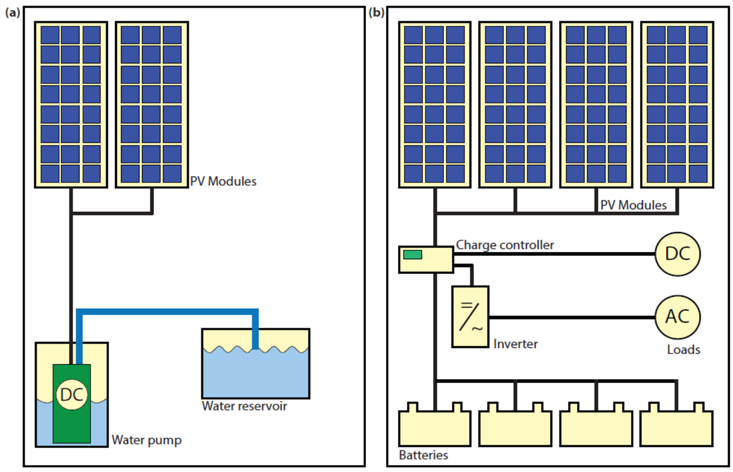

Figure 2.1: Schematic representation of (a) a simple DC PV system to power water pump with no energy storage and (b) a complex PV system including batteries, power conditioners, and both DC and AC load

2.2.2 Grid-connected systems

A grid connected system is connected to a larger independent grid (typically the public electricity grid) and feeds energy directly into the grid. The feeding of electricity into the grid requires the transformation of DC into AC by a special, synchronizing inverter, as illustrated in Fig.2.2, they are connected to the grid via inverters. In small systems as they are installed in residential homes, the inverter is connected to the distribution board, from where the PV-generated power is transferred into the electricity grid or to AC appliances in the house. These systems do not require batteries, since they are connected to the grid, which acts as a buffer into that an oversupply of PV electricity is transported while the grid also supplies the house with electricity in times of insufficient PV power generation. [9]

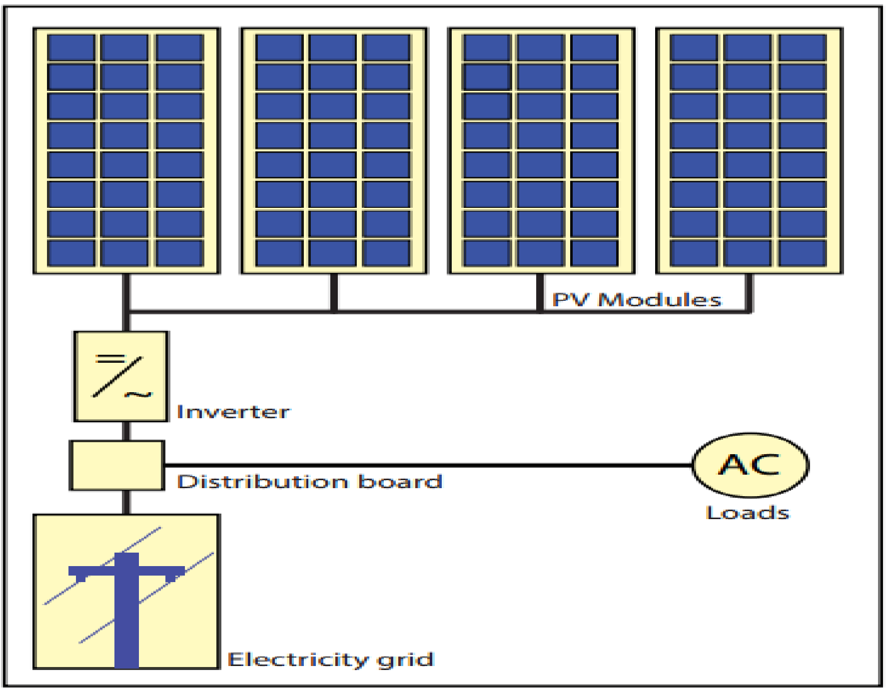

Figure 2.2: Schematic representation of grid connected PV system

2.2.3 Hybrid systems

A hybrid system combines PV with other forms of generation, usually a diesel generator. Biogas is also used. The other form of generation may be a type able to modulate power output as a function of demand. However more than one renewable form of energy may be used e.g. wind. The photovoltaic power generation serves to reduce the consumption of nonrenewable fuel. [11]

A schematic of hybrid system shown in Fig2.3. In order to optimize the different methods of electricity generation, hybrid systems typically require more sophisticated controls than stand-alone or grid-connected PV systems. For example, in the case of an PV/diesel system, the diesel engine must be started when the battery reaches given discharge level and stopped again when battery reaches an adequate state of charge. The back-up generator can be used to recharge batteries only or to supply the load as well. [12]

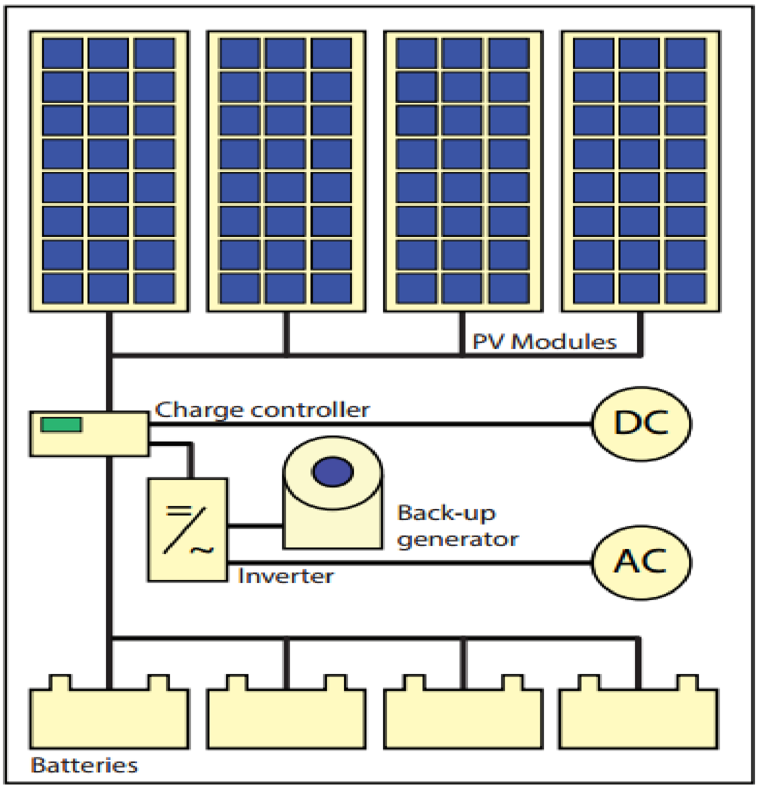

Figure 2.3: Schematic representation of hybrid PV system that has a diesel generator and alternative electricity source

2.3 Components of PV System

Many components are required for a working system; these components are:

• A mounting structure is used to fix the modules and to direct them towards the sun.

• Energy storage is a vital part of stand-alone system because it assures that the system can deliver electricity during the night and in periods of bad weather. Usually, batteries are used as energy storage units.

• DC-DC converters are used to convert the module output, which will have a -variable voltage depending on the time of the day and the weather conditions to a fixed voltage output that can be used to charge a battery or is used as input for an inverter in a grid-connected system.

• Inverters or DC-AC converters are used in grid connected systems to convert the DC electricity originating from the PV modules into AC electricity that can be fed into the electricity grid.

• Cables are used to connect the different components of the PV system with each other and to the electrical load. It is important to choose cables of sufficient thickness in order to minimize resistive losses [12].

2.4 Solar Cell

Any device that directly converts the energy of light into electrical energy through the photovoltaic effect is called solar cell or photovoltaic cell [10].

2.4.1 Formation of solar cell

The overwhelming majority of solar cells are fabricated from silicon with increasing efficiency and lowering cost as the materials range from amorphous (non-crystalline) to polycrystalline to crystalline (single crystal) silicon forms. Unlike batteries or fuel cells, solar cells do not utilize chemical reactions or require fuel to produce electric power and unlike electric generators, they do not have any moving parts [10].

Light enters the device through an optical coating, or antireflection layer that minimizes the loss of light by reflection; it effectively traps the light falling on the solar cell by promoting its transmission to the energy-conversion layers below. The antireflection layer is typically an oxide of silicon, tantalum or titanium that is formed on the cell surface by spin-coating or a vacuum deposition technique, in many such cells the absorber layer and the back junction layer are both made of the same material [10].

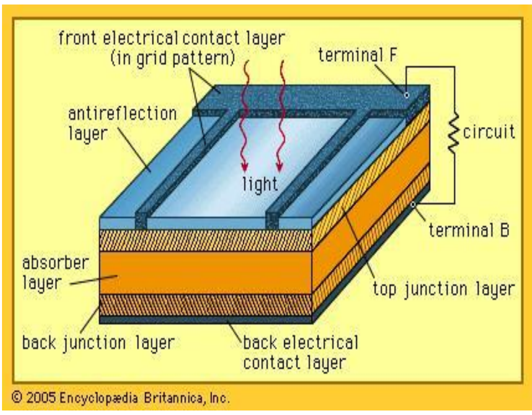

Figure 2.4: A commonly used solar cell structure

The three energy-conversion layers below the antireflection layer are the top junction layer, the absorber layer, which constitutes the core of the device, and the back junction layer. Two additional electrical contact layers are needed to carry the electric current out to an external load and back into the cell, thus completing an electric circuit. The electrical contact layer on the face of the cell where light enters is generally present in some grid pattern and is composed of a good conductor such as a metal. Since metal blocks light, the grid lines are as thin and widely spaced as is possible without impairing collection of the current produced by the cell. The back electrical contact layer has no such diametrically opposed restrictions. It need simply function as an electrical contact and thus covers the entire back surface of the cell structure. Because the back layer also must be a very good electrical conductor it is always made of metal [10].

2.4.2 Module and array

The solar cell is the basic building block of the PV power system. Typically, it’s a few square inches in size and produces about one watt of power. To obtain high power, numerous such cells are connected in series and parallel circuits on a panel (module) area of several square feet/meter, the solar array or panel is defined as a group of several modules electrically connected in series or parallel combination to generate the required current and voltage as shown in figure 2.5 [16].

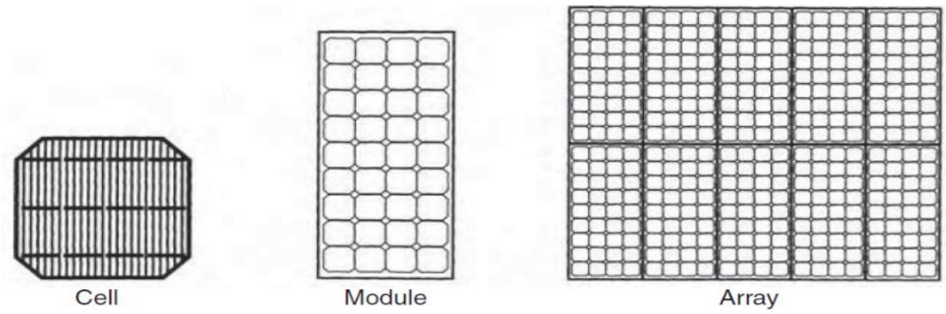

Figure 2.5: Several PV cells make a module, and several modules make an array

2.4.3 Solar module types

There are different types of solar modules:

- Mono-crystalline Silicon

Mono-crystalline solar modules are created using solid silicon, this evident in the silicon wafers that make up the energy-producing part of the module, this occurs due to the manufacturing process of these highly-pure ingots. The wafers are cut out of the cylindrical ingots to make the wafers. They usually have a much more uniform, dark color to them compared to poly-crystalline modules [17].

- Poly-crystalline Silicon

Poly (Multi) crystalline, these modules are manufactured slightly differently than mono-crystalline modules. The silicon is first melted into a rectangular form before the wafers are cut into squares, the wafers have right-angle corners, unlike the mono-crystalline, this is a great indicator of what type of solar module you have, the color is usually lighter and broken up more so than a mono-crystalline solar module [17].

- Thin Film

Thin-Film Solar Cells (TFSC), these modules are manufactured by layering photovoltaic material onto a substrate, the number of layers can vary, the most common photovoltaic materials are categorized by their photovoltaic material such as amorphous Silicon, Cadmium telluride, Copper indium gallium selenide. The comparison between these types shown in table 2.1 [17].

Table 2.1: Comparison between solar modules

Comparison	mono-crystalline	Poly-crystalline	Thin-Film
Efficiency	Typical module Efficiency: 13% - 20%	Typical module Efficiency: 14%-16%	Typical module Efficiency: 6% - 12%
Structure	Formed from single crystal of silicon	Formed from multi crystals of silicon	Formed from amorphous of silicon
Price	More expansive	Expansive	Less expansive
Size per watt	Require least amount of space	Require large surface to get the same power	Require larger surface to obtain the same power

2.5 Tilt of Solar Panels

To get the most from solar panels, we need to point them in the direction that captures the most sun. But there are a number of variables in figuring out the best direction. Panels that track the movement of the sun throughout the day can receive 10% (in winter) to 40% (in summer) more energy than fixed panels [18].

Tilted panels that can be adjusted seasonally can capture more energy during the whole year by adjusting the tilt of the panels according to the season. Table 2.2 shows the effect of adjusting the angle, using a system at 40° latitudes as an example (the comparison would be a little different for different latitudes). Each option is compared with the energy received by the best possible tracker that always keeps the panel pointed directly at the sun [18].

Table 2.2: Effect of adjusting solar panels tilt at 40° latitude

	Fixed	Adj. 2 seasons	Adj. 4 seasons	2-axis tracker
% of optimum	71.1%	75.2%	75.7%	100%

2.6 External Solar Cell Parameters

The main parameters that are used to characterize the performance of solar cells are the peak power Pmax, the short-circuit current density Isc, the open circuit voltage Voc and fill factor FF. These parameters are determined from the illuminated I-V characteristic as illustrated in Fig2.6 [16].

2.6.1 Short circuit current density

The short circuit current Isc is the current that flows through the external circuit when the electrodes of the solar cell are short circuited. The short-circuit current of a solar cell depends on the photon flux density incident on the solar cell, which is determined by the spectrum of the incident light [16].

2.6.2 Open circuit voltage

The open-circuit voltage is the voltage at which no current flows through the external circuit. It is the maximum voltage that a solar cell can deliver. Voc corresponds to the forward bias voltage, at which the dark current compensates the photo current. Voc depends on the photo-generated current density and can be calculated from Eq. (2.6) assuming that the net current is zero, this equation shows that Voc depends on the saturation current of the solar cell and the photo-generated current. While Iph typically has a small variation, the key effect is the saturation current, since this may vary by orders of magnitude [16].

2.6.3 Fill factor

The fill factor is the ratio between the maximum power generated by a solar cell and the product of Voc with Isc [16].

$$Pmax = Imp * Vmp \tag{2.1}$$

$$FF = (Imp*Vmp) / (Isc*Voc) \tag{2.2}$$

Where:

Imp ≡ maximum current of solar cell

Vmp ≡ maximum voltage of solar cell

Isc ≡ short circuit current of solar cell

Voc ≡ open circuit voltage of solar cell

2.7 Equivalent Circuit

The equivalent circuit, Figure 2.6 is represented by a source of electricity in parallel with a diode. This model is not very accurate, but is a simple one, which could yield a general overview of the phenomena inside PV cell [19].

The following assumptions are considered for this model: Rs = 0 and Rsh = ∞, Iph = Isc.

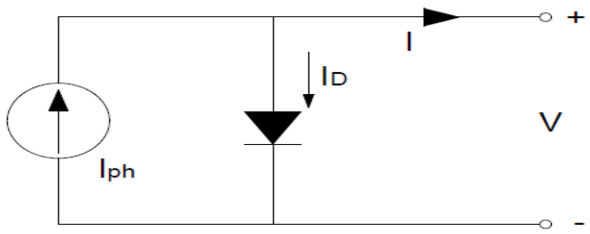

Figure 2.6: Equivalent circuit for ideal model of PV cell.

2.7.1 Simple diode model with Rs

In real operating conditions, there are electric circuits in series with the PV cell that have a certain electric resistance, Rs. This model was developed to model this resistance and it is more accurate than the ideal one, but it is not a comprehensive one [19].

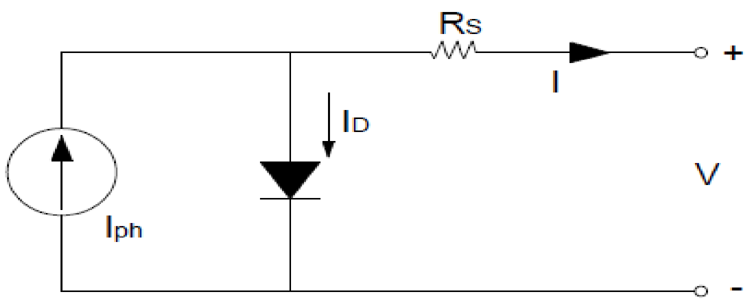

Figure 2.7: Equivalent circuit of PV cell model with Rs.

This circuit is also known as the four parameter model for PV cell.

2.7.2 Simple diode model with Rs and Rsh

The model with Rs and Rsh it is the most spread model for simulating the operation of photovoltaic panels. This model takes into account both series resistance Rs and the other resistance of the PV cell, the shunt one, Rsh. Using this model, the more realistic results are obtained [19].

The value for the output current of the PV cell is determined with the following expression [19]:

$$I = I_{ph} - I_d - I_{sh}, \text{ [A]} \quad (2.3)$$

Where:

I $\equiv$ output current of solar cell

$I_{ph} \equiv$ solar induced current

I_d ≡ Diode current

I_{sh} ≡ Current path through shunt resistance

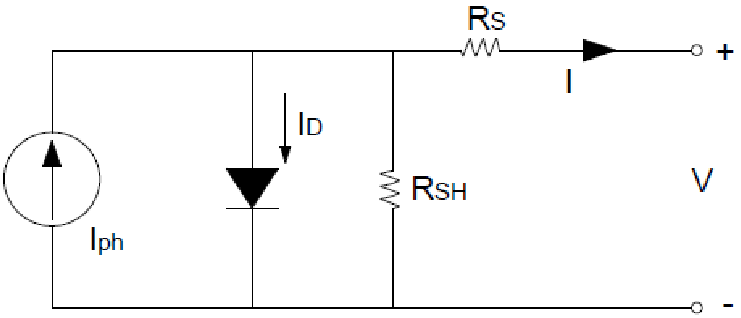

Figure 2.8: Equivalent circuit of PV cell model with Rs and Rsh.

Taking into account the expressions for the Id - Eq. 2.2 and Ish – Eq 2. 3, the Eq.2.1 can be solved. Therefore, the intensity of electric current produced by

Photovoltaic cell to the load has the characteristic equation - Eq2.4.

$$I_d = I_0 * \left(\exp\left[\frac{q(V+R_s I)}{nKT_{op}}\right] - 1\right), [A] \qquad (2.4)$$

$$I_{sh} = \frac{(V+R_s I)}{R_{sh}}, [A], \qquad (2.5)$$

$$I = I_{ph} - I_0[\exp \frac{q(V+R_s I)}{nKT_{op}} - 1] - \frac{(V+R_s I)}{R_{sh}}, [A], \qquad (2.6)$$

Where:

I_0 ≡the measured solar-generated current for the irradiance

n ≡ the quality factor (diode emission coefficient) of the diode

k ≡ Boltzmann constant.

T_{op}≡ operating temperature of the junction, [K]

q ≡ the elementary charge on an electron.

V ≡ voltage across the solar cell electrical ports

Rs ≡ series resistance of solar cell

Rsh ≡ shunt resistance of solar cell

The photovoltaic current Iph could be considered equal to short-circuit current Isc. By applying these assumptions for the standard test conditions, Eq. 2.4 becomes:

$$I=I_{ph}-I_0\,[\exp\frac{q(V+R_sI)}{nKT_{op}} - 1],\ [A] \qquad (2.7)$$

For the same hypothesis, the open circuit voltage of the cell can be determined:

$$V_{oc}\cong \frac{nKT_{op}}{q}\ln\left(\frac{I_{ph}}{I_o}+1\right),\ [V] \qquad (2.8)$$

2.8 I-V and P-V Curves

The electrical characteristic of the PV cell is generally represented by the current vs voltage (I-V) curve. Figure 2.9 shows the I-V characteristic of a PV module under two conditions, in sunlight and in the dark. In the first quadrant, the top left of the I-V curve at zero voltage is called the short-circuit current. This is the current we would measure with output terminals shorted (zero voltage). The bottom right of the curve at zero current is called the open-circuit voltage. This is the voltage we would measure with output terminals open (zero current). In the left-shaded region, the cell works as a constant current source, generating a voltage to match with the load resistance. In the shaded region on the right, the current drops rapidly with a small rise in the voltage. In this region, the cell works like a constant voltage source with an internal resistance. Somewhere in the middle of the two shaded regions, the curve has a knee point, if a voltage is externally applied in the reverse direction, for instance, during a system fault transient, the cell current remains flat, and the power is absorbed by the cell with a negative voltage and positive current. However, beyond a certain negative voltage, the junction breaks down as in a diode, and the current rises to a high value in the dark, the current is zero for any voltage up to the breakdown

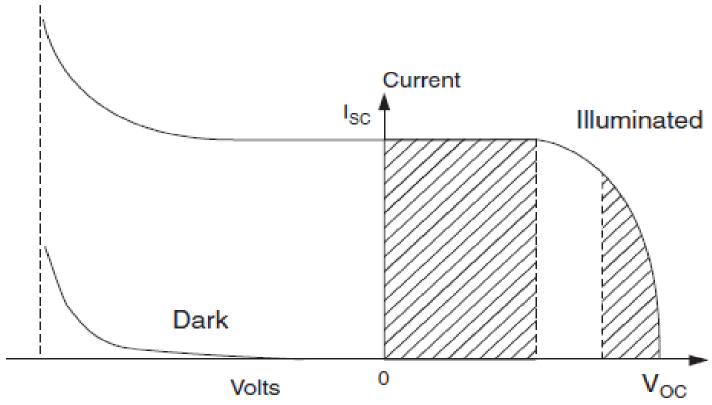

Figure 2.9: Current vs voltage (I-V) characteristic of the PV module

voltage, which is the same as in the illuminated condition.

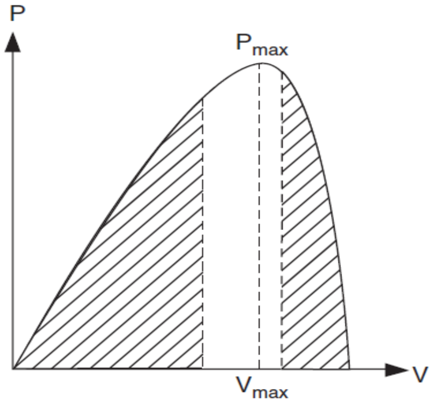

Figure 2.10: Power vs voltage (P-V) characteristic of the PV module in sunlight.

The power output of the panel is the product of the voltage and current outputs and in Figure 2.10 the power is plotted against the voltage. Note that the cell produces no power at zero voltage or zero current, and produces the maximum power at the voltage corresponding to the knee point of the I-V curve. This is why the PV power circuit is always designed to operate close to the knee point with a slight slant on the left-hand side. The PV circuit is modeled approximately as a constant current source in the electrical analysis of the system [16].

2.9 Batteries

PV systems increasingly use rechargeable batteries to store a surplus power to be used later at night. Batteries used for grid storage and also for stabilizing the electrical grid by leveling out peak loads, and play an important role in a smart grid, as they can charge during periods of low demand and feed their stored energy into the grid when demand is high [20].

2.9.1 Battery types

Common battery technologies used in today's PV systems include:

- Lead-Acid (LA) Battery

These batteries are the most commonly used in solar powered systems due to its maturity in technology and low pricing. They can only be used with low depth of discharge (DOD) in order to extend its lifespan. Its DOD ranges from 20%-50%. There are two types of Lead-Acid batteries, i.e. flooded and Valve Regulated Lead Acid (VRLA) batteries which are maintenance free batteries [21].

- Nickel-Cadmium (Ni-Cad) Battery

Nickel-Cadmium (Ni-Cad) batteries are expensive and disposing of Cadmium are hazardous. Even though they have several advantages over Lead-Acid batteries, such as longer life span, and tolerance for higher discharge, Ni-Cd batteries are not commonly used in solar powered systems due to its high cost and limited availability [21].

- Lithium-Ion (LI) or Lithium-Polymer (LP) Battery

Lithium based batteries are considered the future of batteries used in solar powered systems. This is due to a number of factors such as high specific energy, high DOD percentage and higher number of charging cycles. However, due to its higher cost compared to LA type of batteries, they are still not a preferred choice [21].

2.10 Charge Controller

PV systems with an integrated battery solution also need a charge controller, as the varying voltage and current from the solar array requires constant adjustment to prevent damage from overcharging. Basic charge controllers may simply turn the PV panels on and off, or may meter out pulses of energy as needed, a strategy called PWM or pulse-width modulation. More advanced charge controllers will incorporate MPPT logic into their battery charging algorithms. Charge controllers may also divert energy to some purpose other than battery charging. Rather than simply shut off the free PV energy when not needed, a user may choose to heat air or water once the battery is full [22].

2.10.1 Maximum power point tracking (MPPT)

The concept of Maximum power point tracking (MPPT) is very unique to the field of PV Systems and brings a very special application of power electronics to the field of photovoltaics. The concepts discussed in this section are equally valid for cells, modules and arrays, although MPPT usually is employed at PV module/array level. As discussed earlier, the behavior of an illuminated solar cell can be characterized by an I-V curve, the operating point (I, V) corresponds to a point on the power-voltage (P-V) curve, shown in Fig 2.11, for generating the highest power output at a given irradiance and temperature, the operating point should such correspond to the maximum of the (P-V) curve, which is called the maximum power point (MPP). If a PV module (or array) is directly connected to an electrical load, the operating point is dictated by that load. For getting the maximal power out of the module, it thus is imperative to force the module to operate at the maximum power point. The simplest way of forcing the module to operate at the MPP, is either to force the voltage of the PV module to be that at the MPP (called Vmpp) or to regulate the current to be that of the MPP (called Impp) [12].

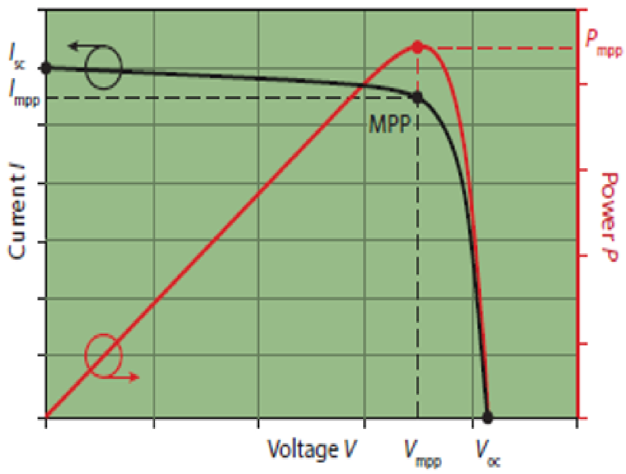

Figure 2.11: A generic I-V curve and the associated P-V curve. The maximum power point (MPP) is indicated

2.11 Inverters

Systems designed to deliver alternating current (AC) such as grid-connected applications need an inverter to convert the direct current (DC) from the solar modules to alternating current (AC). Grid connected inverters must supply AC electricity in sinusoidal form synchronized to the grid frequency, limit feed in voltage to no higher than the grid voltage and disconnect from the grid if the grid voltage is turned off, solar may connect to a string of solar panels. In some installations a solar micro-inverter is connected at each solar panel, for safety reasons a circuit breaker is provided both on the AC and DC side to enable maintenance [23-25].

2.11.1 Stand-alone inverters

Used in isolated systems where the inverter draws its DC energy from batteries charged by photovoltaic arrays. Many stand-alone inverters also incorporate integral battery chargers to replenish the battery from an AC source when available. Normally these do not interface in any way with the utility grid and as such are not required to have anti-islanding protection [26].

2.11.2 Grid-tie inverters

Which match phase with a utility-supplied sine wave. Grid-tie inverters are designed to shut down automatically upon loss of utility supply, for safety reasons. They do not provide backup power during utility outages [26].

2.11.3 Battery backup inverters

Are special inverters which are designed to draw energy from a battery, manage the battery charge via an on board charger, and export excess energy to

the utility grid, these inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding protection [26,27].

2.12 Transfer Switch

A transfer switch is an electrical device that is capable of alternating and transferring a load from one source of power supply to another. The basic function of a transfer switch is to make and break from one source of power supply to another. It can also serve to isolate power sources in the event of over voltage, thus preventing power surge [28].

A manual operation of transfer switch requires the availability of electrical personnel to operate the switch. Thus, it cannot be used in some industrial and commercial applications where absence of power for a certain period of time could have serious implications in terms of life and financial losses due to loss of production, data storage and products. In order to eliminate the time delay between changing over from one source to another, there is therefore a need for an automatic transfer switch. Automatic transfer switch (ATS) serves as an interface between power sources in order to maintain a continuous supply of electricity to the load [29].

CHAPTER THREE

SYSTEM SIZING AND DESIGN

3.1 Introduction

Solar PV system includes different components that should be selected according to system type, site location and applications. The system must be a balanced system and its components wired together to form the entire fully functional system capable of supplying electric power.

The photovoltaic systems are classified according to how the system components are connected to other power sources such as standalone (SA) and utility-interactive (UI) systems. In a stand-alone system the system is designed to operate independent of the electric utility grid, and is generally designed and sized to supply certain DC- and/or AC electrical loads.

3.2 Case of Study

The case under study is designing a solar Photo-Voltaic (PV) system for college's offices, labs and yard. For offices and labs, the system will be designed only for lighting and ventilation, on the other hand the yard PV system will be designed for lighting.

3.3 Lighting

Lighting or illumination is the deliberate use of light to achieve a practical or aesthetic effect. Lighting includes the use of both artificial light sources like lamps and light fixtures, as well as natural illumination by capturing daylight. Proper lighting can enhance task performance, improve the appearance of an area, or have positive psychological effects on occupants [30].

3.3.1 Illuminance

Illuminance is a measure of how much luminous flux (lumens) is spread over a given area and the SI unit of it is (Lux). Luminous flux (lumen) can be said as a measure of the total amount of visible light present, and the luminance as a measure of the intensity of illumination on a surface [31].

One lux is equal to one lumen per square meter:

$$1 \text{ lux} = 1 \text{ lm/m}^2 \qquad (3.1)$$

And then the luminance Ev in lux (lx) is equal to the luminous flux Φ_V in lumens (lm). divided by the surface area A in square meters (m^2) [31].

$$Ev \text{ (lx)} = \Phi_V \text{ (lm)} / A \text{ (m}^2\text{)} \qquad (3.2)$$

3.3.2 Light emitting diode (LED)

LED lamps have been considered as the newest and best environmental lighting method [32]. According to the Energy Saving Trust, LED lamps use only 10% power compared to a standard bulb, where compact fluorescent lamps use 20% and energy saving halogen lamps 70%. The lifetime is also much longer up to 50,000 hours and has low maintenance cost. A downside is still the initial cost, which is higher than that of compact fluorescent lamps [33].

3.3.3 Philips catalogue

A Catalogue is a list of contents of a library or a group of libraries, arranged according to any of various systems. Philips Lighting has a worldwide leading position in developing, producing and selling lamps.

3.3.4 Yards and streets lighting

Lighting of yards and streets depend on vertical light distribution and it is divided into three categories short medium and long. Classification is on the basis of distance from the luminaire to where the beam of maximum candle power strikes the ground in DIALux program all these parameters are taken into account [34].

3.4 Lighting Design Using DIALux

DIALux is a lighting design program used in planning and presentation of projects. This program is used to distribute lighting fixtures in rooms or wide areas. The software is typically used by importing the structural design via CAD files. Then lighting elements are inserted from program's catalogues. The illuminance and luminance produced by each fixture in the space can be calculated. The output is typically a diagram indicating these by means of colors or numbers [35].

3.4.1 Office lighting design

The dimensions of the office are shown below, the Characteristics of lamp used are represented in appendix D.1 and the Characteristics of fan used are represented in appendix D.2.

Height =3m   Width=4m

Length=5m   Area=$20m^2$

The process of simulating the office is represented in appendix B.

Figure 3.1 shape of office after design

3.4.2 Laboratory (Lab) lighting design

The dimensions of the lap are shown below and the Characteristics of lamp used are represented in appendix E.

Height =3m

Width=5m

Length=8m

Area=40m^2

The process of simulating the lab is represented in appendix B.

Figure 3.2: shape of lap after design

3.4.3 College's yard lighting design

The dimensions of College's yard are shown below and the Characteristics of lamp used are represented in appendix F.

Width=400m

Length=500m

Area=$2*10^4$ m^2

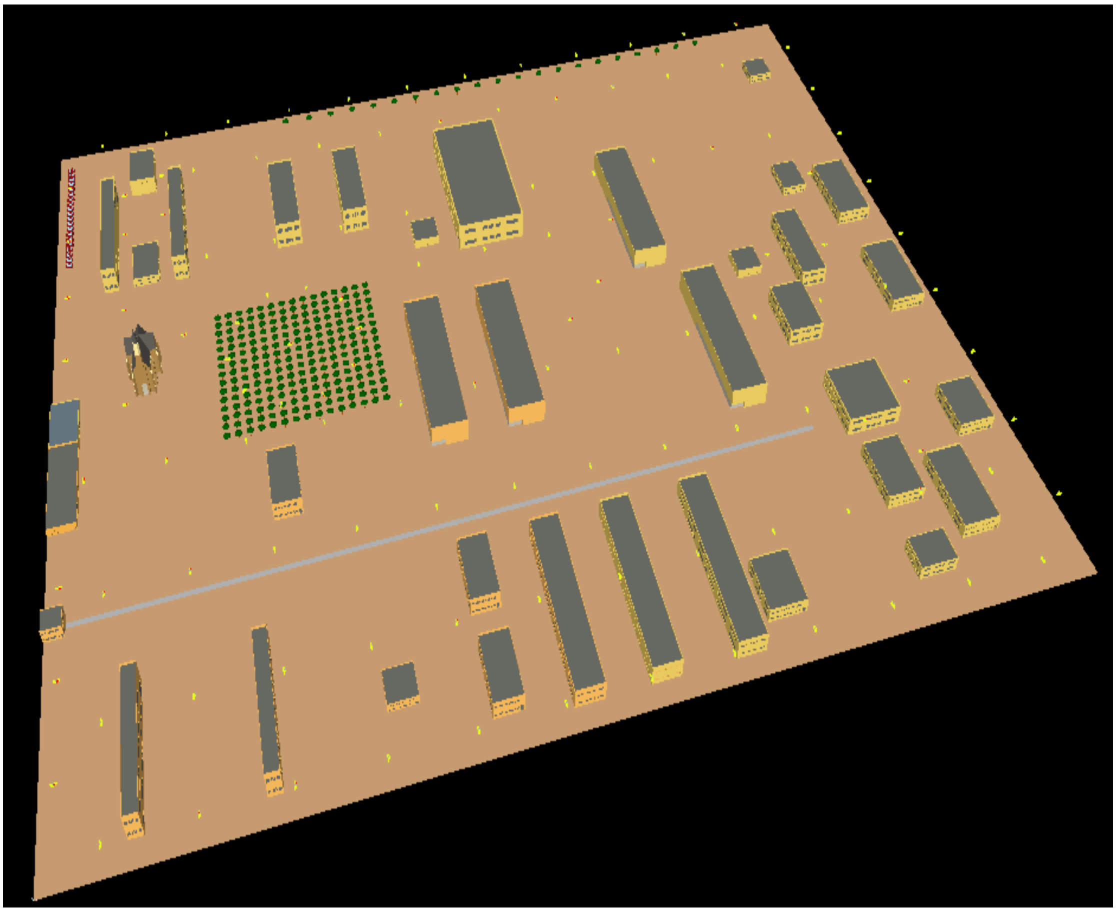

Figure 3.3: Night lighting, yard of SUST-College of engineering

3.5 Determine Power Consumption Demand

The total power or energy consumption of all loads in departments buildings have been calculated in the. The buildings consist of seven departments that need to be supplied by the solar PV system. The types of loads used in the office and lap for each department are lamps and fans only.

3.5.1 Office

The load of the office consists of lamps and fans represented in the table below:

Table 3.1: The daily consumed power for office

Apparatus	Power/unit (watt)	Number of units	Total power(W)	Number of operation hour per day	Total power per day(wh)
Fan	75	2	150	12	1800
Lamp	27.9	9	251.1	12	3013.2
Total ac watts connected			150	Average power	4813.2

3.5.2 Laboratory (Lab)

The load of the lab consists of lamps and fans represented in the table below:

Table 3.2: The daily consumed power for lap

Apparatus	Power/unit (watt)	Number of units	Total power(W)	Number of operation hour per day	Total power per day(wh)
Fan	75	2	150	12	1800
Lamp	17	12	204	12	2448
Total ac watts connected			150	Average power	4248

3.5.3 Dept. of electrical engineering

The department of electrical engineering consists of five offices and three laps:

The average power for all offices = power of one office x number of office

= 4813.2 x 5 = 24066 Wh/day

The average power for all lap = power of lap x number of lap

= 4248 x 3 = 12744 Wh/day

Average power for the department = 24066 + 12744 = 36810 Wh/day

For inverter sizing, the power of devices that may run at the same time must be determined (total ac connected watts). Since the lamps are LED which are DC load the power will be calculated based on fans only because they are AC loads and need an inverter.

ac connected watts for all offices = 150 x number of offices

= 150 x 5 = 750 watt

ac connected watts for all labs = 150 x number of labs

= 150 x 3 = 450 watt

Ac connected watts = 750+450= 1200 watt

3.5.4 Dept. of mechanical engineering

The department of mechanical engineering consists of four offices and two laps:

The average power for all offices = power of office x number of office

= 4813.2 x 4 = 19252.8 Wh/day

The average power for all lap = power of lap x number of lap

= 4248 x 2 = 8496 Wh/day

Average power of the department = 19252.8 + 8496 = 27748.8 Wh/day

ac connected watts for all offices = 150 x number of offices

= 150 x 4= 600 watt

ac connected watts for all labs = 150 x number of labs

= 150 x 2= 300 watt

Ac connected watts = 600+300= 900 watt

3.5.5 Dept. of architecture engineering

The department of architecture engineering consists of three offices and two laps:

The average power for all offices = power of office x number of office

= 4813.2 x 3 = 14439.6 Wh/day

The average power for all lap = power of lap x number of lap

= 4248 x 2 = 8496 Wh/day

Average power of the department= 14439.6 + 8496 = 22935.2 Wh/day

ac connected watts for all offices = 150 x number of offices

= 150 x 3= 450 watt

ac connected watts for all labs = 150 x number of labs

= 150 x 2= 300 watt

Ac connected watts = 450+300= 750 watt

3.5.6 Dept. of civil engineering

The department of architecture engineering consists of five offices and four laps:

The average power for all offices = power of office x number of office

= 4813.2 x 5 = 24066 Wh/day

The average power for all lap = power of lap x number of lap

= 4248 x 4 = 16992 Wh/day

Average power of the department = 24066 + 16992 = 41058 Wh/day

ac connected watts for all offices = 150 x number of offices

= 150 x 5= 750 watt

ac connected watts for all labs = 150 x number of labs

= 150 x 4 = 600 watt

Ac connected watts = 750+600= 1350 watt

3.5.7 Dept. of medical engineering

The department of architecture engineering consists of four offices and four laps:

The average power for all offices = power of office x number of office

= 4813.2 x 4 = 19252.8 Wh/day

The average power for all lap = power of lap x number of lap

= 4248 x 4 = 16992 Wh/day

Average power for the department = 19252.8 + 16992 = 36244.8 Wh/day

ac connected watts for all offices = 150 x number of offices

= 150 x 4= 600 watt

ac connected watts for all labs = 150 x number of labs

= 150 x 4= 600 watt

Ac connected watts = 600+600= 1200 watt

3.5.8 Dept. of survey engineering

The loads of survey engineering department are same as electrical engineering department consists of five offices and three laps:

Average power for the department = 24066 + 12744 = 36810 Wh/day

Ac connected watts = 750+450= 1200 watt

3.5.9 Dept. of general science

The department of architecture engineering consists of four offices:

Average power for all offices = power of office x number of office

= 4813.2 x 4 = 19252.8 Wh/day

Ac connected watts= 150 x number of offices

= 150 x 4= 600 watt

Then the total power of the all departments which consist of seven building will became:

Total average power = 36810 + 27748.8 + 22935.2 + 41058

+ 36244.8 + 36810 + 19252.8

= 220.86 kwh/day

Total ac connected watts = 1200 + 900 + 750 + 1350

+ 1200+ 1200 + 600

= 7200 watt

Calculations can be also done by MATLAB program shown in appendix G.

3.5.10 College's yard

From College's yard lighting design using DIALux the number of poles were found to be 122 pole as shown in appendix C. Each pole has a small solar PV system mounted on top of it (panel, battery, charge controller and LED lamp). The system is identical for each pole so the calculation is held for one pole. The Characteristics of lamp used are represented in appendix F.

The peak power =228 W

Number of hours = 14

The average power =14*228=3.192 KWh/day

3.6 System Sizing

System Sizing is the process of determine the all components needed for constructing of PV system according to types of load in the system. The load of system can be either AC loads or DC loads. The AC loads need an inverter to convert the direct current to alternating current, but the DC loads doesn't need an inverter [36].

3.6.1 Solar array sizing

Before calculating the size of the PV system array there are some variables must be known such as total daily energy in Watt-hours (E), the average sun hour per day $T_{min,}$ and the DC-voltage of the system (Vdc). Once these factors are made available we move to the sizing process. To avoid under sizing, losses must be considered by dividing the total power demand in

Wh/day by the product of efficiencies of all components in the system to get the required energy Er:

$$\text{Er} = \frac{\text{daily average energy consuption}}{\text{product of component's efficiencies}} = \frac{\text{E}}{\eta\text{overall}} \tag{3.3}$$

The daily energy requirement from the solar array can be determined as following:

$$\text{Er} = \frac{\text{E}}{\eta\text{overall}} = \frac{220.86}{0.8} = 276.08\ \text{kwh/day}$$

To obtain the peak power, the previous result is divided by the average sun hours per day for the geographical location T_{min}.

$$\text{Pp} = \frac{\text{daily energy requirement}}{\text{minimum peak sun}-\text{hours per day}} = \frac{\text{Er}}{\text{Tmin}} \tag{3.4}$$

$$\text{Pp} = \frac{\text{Er}}{\text{Tmin}} = \frac{276.08}{6} = 46.01\ \text{kwh/day}$$

The total current needed can be calculated by dividing the peak power by the DC- voltage of the system.

$$I_{DC} = \frac{\text{Peak power}}{\text{System DC volltage}} = \frac{\text{Pp}}{\text{vdc}} \tag{3.5}$$

$$I_{DC} = \frac{\text{Pp}}{\text{vdc}} = \frac{46.01}{24} = 1917\ \text{A}$$

Modules must be connected in series and parallel according to the desired voltage and current of the system.

Number of parallel modules of the system:

$$\text{Np} = \frac{\text{whole module current}}{\text{rated current of one module}} = \frac{I_{dc}}{I_r} \tag{3.6}$$

$$\text{Np} = \frac{I_{dc}}{I_r} = \frac{I_{dc}}{I_{mp}} = \frac{1917}{7.45} = 257.3\ \text{panels}$$

Number of series modules of the system:

$$Ns = \frac{\text{system dc voltage}}{\text{module rated voltage}} = \frac{V_{dc}}{V_r} \quad (3.7)$$

$$Ns = \frac{\text{system dc voltage}}{\text{module rated voltage}} = \frac{V_{dc}}{V_r} = \frac{24}{24} = 1$$

Finally, the total number of modules Nm equals the series modules multiplied by the parallel modules:

$$N_m = N_s * N_p \quad (3.8)$$

$N_m = N_s * N_p$ =258*1=258 panels.

3.6.2 Battery bank sizing

The amount of energy storage required is equal to the multiplication of the total power demand and the number of autonomy days.

$$E_{rough} = E \times D \quad (3.9)$$

$E_{rough} = E \times D = 220.86 * 1 = 220.86$ KWh

For safety, the result obtained is divided by the maximum allowable level of discharge (MDOD) [9]:

$$E_{safe} = \frac{\text{energy storage required}}{\text{maximum depth of discharge}} = \frac{E_{rough}}{MDOD} \quad (3.10)$$

$$E_{safe} = \frac{E_{rough}}{MDOD} = \frac{220.86}{0.8} = 276.08 \text{ KWh}$$

The capacity of the battery bank needed in ampere-hours can be evaluated by dividing the safe energy storage required by the DC voltage of one of the batteries selected.

$$C = \frac{E_{safe}}{V_b} \quad (3.11)$$

$$C = \frac{E_{safe}}{V_b} = \frac{276.08}{12} = 23 \text{ KAh}$$

The battery bank is composed of batteries and the total number of batteries is obtained by dividing the capacity C of the battery bank in ampere-hours by the capacity of one of the battery C_b selected in ampere-hours.

$$N_{batteris} = \frac{C}{C_b} \tag{3.12}$$

$$N_{batteris} = \frac{C}{C_b} = \frac{23}{0.250} = 92 \text{ Batteris}$$

The connection of the battery bank can be then easily figured out. The number of batteries in series equals the DC voltage of the system divided by the voltage rating of one of the batteries selected:

$$N_S = \frac{V_{dc}}{V_b} \tag{3.13}$$

$$N_S = \frac{V_{dc}}{V_b} = \frac{24}{12} = 2$$

Then number of parallel paths Np is obtained by dividing the total number of batteries by the number of batteries connected in series

$$N_P = \frac{N_{battries}}{N_S} \tag{3.14}$$

$$N_P = \frac{N_{battries}}{N_S} = \frac{92}{2} = 46$$

Once the sizing of the battery bank is made available, we proceed to the next system component.

3.6.3 Charge controller sizing

According to its function it controls the flow of current. A good voltage regulator must be able to withstand the maximum current produced by the array as well as the maximum load current. Sizing of the voltage regulator can be obtained by multiplying the short circuit current of the modules connected in parallel by a safety factor F_{safe}. The result gives the rated current of the voltage regulator I:

$I = I_{SC} * N_p * F_{\text{safe}}$ (3.15)

$I = 8.03*258*1.25$

$= 2589.7$ A

The factor of safety is employed to make sure that the regulator handles maximum current produced by the array that could exceed the tabulated value. And to handle a load current more than that planned due to addition of equipment, for instance. In other words, this safety factor allows the system to expand slightly. The number of controller equals the Array short current Amps divided by the Amps for each controller:

$$N_{\text{controller}} = \frac{\text{I}}{\text{Amps each controller}} \quad (3.16)$$

$$N_{\text{controller}} = \frac{\text{I}}{\text{Amps each controller}} = \frac{2589.7}{60}$$

$$= 43.16$$

The number of Charge controllers needed is 44.

3.6.4 Inverter sizing

When sizing the inverter, the power of devices that may run at the same time must be determined as a first step.

Total power of devices run at the same time = Total ac connected loads

= 7200 watt

The inverter needed must be able to handle about 7200 watts at 220-Vac but using one inverter is not practical therefor a 2555 watts inverters is used.

$$Number\ of\ inverters = \frac{\text{Total ac connected loads}}{Inverter\ power} = \frac{7200}{2555} = 2.8$$

The number of inverters needed is 3 inverters.

The process of sizing system components can also be done by using MATLAB program shown in appendix G.

3.6.5 College's yard lighting system sizing

According to DIALux program the height of pole is taken 10 meter and so the effective height of lamp is 9.870 m (this value appear when you insert the height of pole in DIALux)

The daily energy requirement from the solar array can be determined as following:

$$Er = \frac{E}{\eta overall} = \frac{3.192}{0.8} = 3.99 \text{ kwh/day.}$$

Total current needed can be calculated by:

$$I_{DC} = \frac{Pp}{vdc} = \frac{665}{24} = 27.71 \text{ A}$$

Modules must be connected in series and parallel according to meet the desired voltage and current according to:

The number of parallel modules:

$$Np = \frac{I_{dc}}{I_r} = \frac{I_{dc}}{I_{mp}} = \frac{27.71}{7.45} = 3.719 \text{ panels}$$

Approximately 4 panels.

The number of series modules which equals to:

$$Ns = \frac{\text{system dc voltage}}{\text{module rated voltage}} = \frac{V_{dc}}{V_r} = \frac{24}{24} = 1$$

Finally, the total number of modules

$N_m = N_s * N_p$ =4*1=4 panels.

4 panels needed for each pole.

Total average energy use = 3.192 KWh.

E_{rough}=E×D=3.192*1= 3.192 KWh

For Energy safety, $E_{safe} = \frac{E_{rough}}{MDOD} = \frac{3.192}{0.8} = 3.99 KWh$

The capacity of the battery bank needed can be evaluated:

$$C = \frac{E_{safe}}{V_b} = \frac{3.99}{24} = 0.166 \text{ KA.h}$$

The total number of batteries is obtained by

$$N_{batteris} = \frac{C}{C_b} = \frac{166}{250} = 0.665 \text{ Batteris}$$

Approximately one battery

The number of batteries in series equals to:

$$N_S = \frac{V_{dc}}{V_b} = \frac{24}{24} = 1$$

Then number of parallel paths Np is obtained by:

$$N_P = \frac{N_{battries}}{N_S} = \frac{1}{1} = 1$$

The number of batteries needed is, $N_{batteris}$=1 battery. One parallel branches and one series batteries.

$I = I_{SC} * N_p * F_{safe}$ =8.03*4*1.25=40.15 A

$$N_{controller} = \frac{I}{\text{Amps each controller}} = \frac{40.15}{60} = 0.669$$

One controller is needed and connected in parallel.

3.7 Assumption

- Inverter converts DC into AC power with efficiency of about 90%. The overall combined efficiency of inverter and battery will be calculated as shown below:

  Overall efficiency = inverter efficiency × battery efficiency

  = 0.9 × 0.89 = 0.801 = 80%

- Batteries used are lead-acid, they are designed to gradually discharge and recharge 80% of their capacity hundreds of times. Automotive batteries are shallow- cycle batteries and should not be used in PV systems because they are designed to discharge only about 20% of their capacity.
- Operation hours of lights and fan per day = 12 hours/day.
- Operation hours of college's yard lights = 14 hours/day.
- Available sunlight per day is 6 hours (equivalent of peak radiation) include in appendix H.
- Solar irradiance is about 2500 kWh.m^{-2} included in appendix A.
- Fan used has 75 watts

3.8 System Components Description

There are two systems under design, offices and labs of departments buildings and college's yard lighting.

3.8.1 Departments buildings

The select PV panel is (Mitsubishi - MF180UD4, 180- W, 24-V, 7.45-A) and the Specifications are represented in appendix k.

The selected battery is (UB-8D AGM - 250 AH, 12V-DC) and the Specifications are represented in appendix I.

The selected controller is (Xantrex C-60, 24- V, 60-A) the Specifications are represented in appendix J.

The inverter needed must be able to handle about 2555-W at 220-Vac and The selected inverter is (Latronics inverter, LS- 3024, 3000-W, 24-Vdc, 220-Vac) and the Specifications are represented in appendix L.

3.8.2 College’s yard

The components of lighting system mounted on pole are PV module, charge controller, battery and an LED. The specifications of the components are same as used in departments building.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Performance of PV system

The photovoltaics system receives sun light and converts it to electricity (DC current) by the solar panels. The amount of light received by the solar panels is varying during the seasons of the year and that depends on the tilt of the panels, also is varying during the day because of the clouds, so the output DC current is also varying and that is harmful to loads and batteries that receive this current.

The current must be refined to suit the load and protect batteries from damage and that is done by using charge controller which is DC to DC converter. The output of the charge controller is connected directly to batteries and also there are loads receive DC current so they are connected along with the batteries. AC loads can't be connected to charge controller directly because we need to invert the current to AC and that is done by an inverter.

4.2 Results

There are two systems has been designed, offices and labs of departments building and college's yard lighting. The lighting for both systems has been rearranged by using DIALux program.

4.2.1 Results of lighting load design

The lux was measured by DIALux for each system as follows:

- **Office's result**

After design office by DIALux the result will be represented as shown:

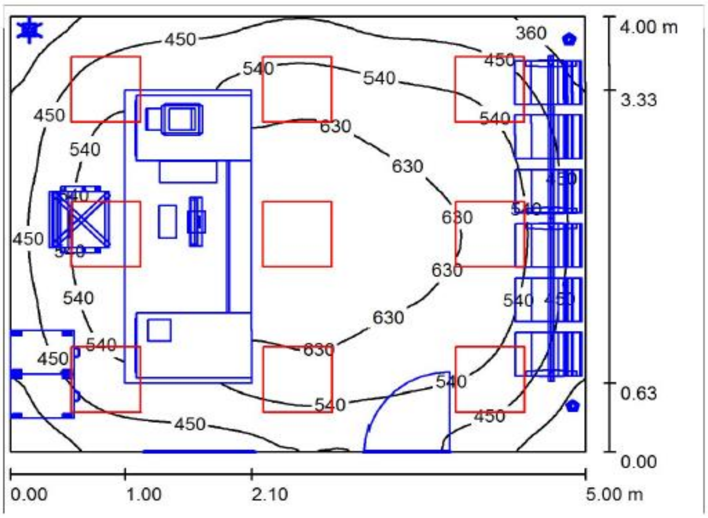

Figure 4.1: Values in Lux, Isolines (E) for office.

Table 4.1: Values in Lux for office.

Surface	P[%]	E_{av}[Lx]	E_{min}[Lx]	E_{max}[Lx]	$U0=E_{min}/E_{av}$
workspace	/	522	283	699	0.541

- **Lab's result**

After design lab by DIALux the result is represented as shown:

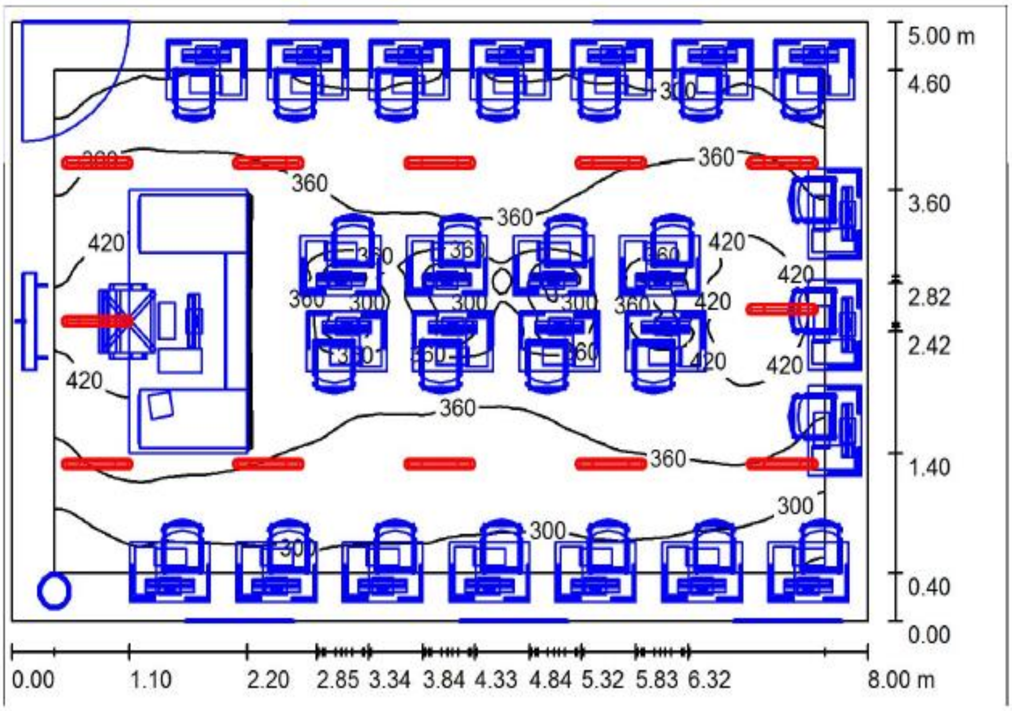

Figure 4.2: Values in Lux, Isolines (E) for lap

Table 4.2: Values in Lux for lap

Surface	P[%]	E_{av}[Lx]	E_{min}[Lx]	E_{max}[Lx]	$U0=E_{min}/E_{av}$
workspace	/	307	166	417	0.542

- **College's yard result**

After designing college yard by DIALux the result is represented as shown:

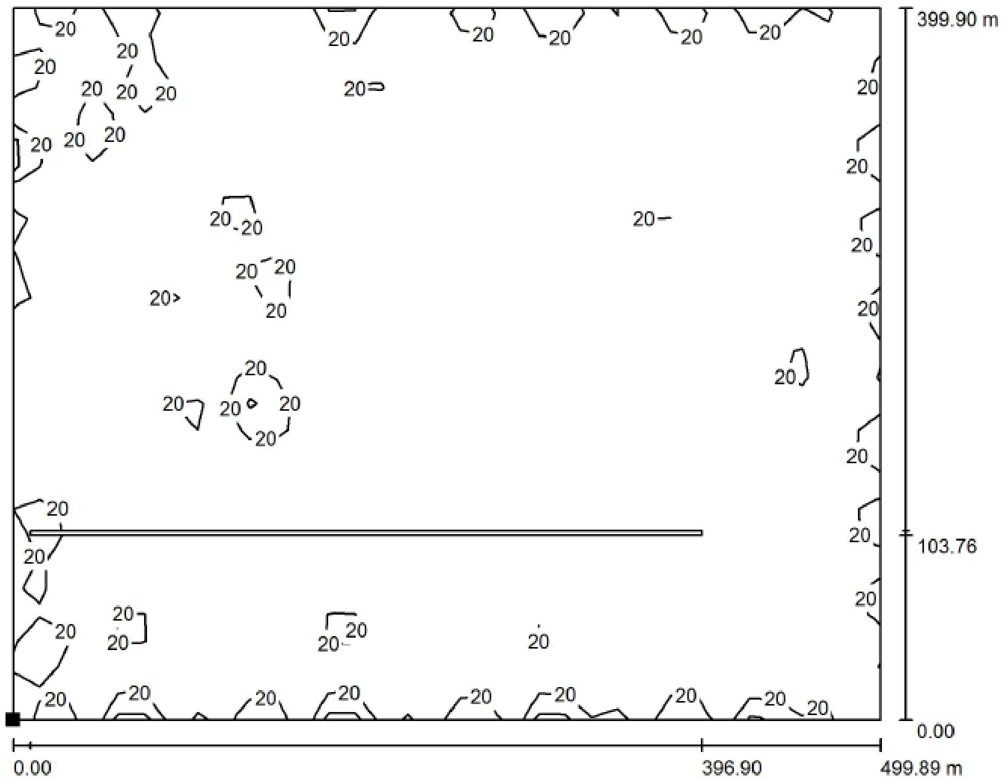

Figure 4.3: Values in Lux, Isolines (E) for university

Table 4.3: Values in Lux for university.

E_{av}[Lx]	E_{min}[Lx]	E_{max}[Lx]	$U0=E_{min}/E_{av}$	E_{min}/E_{max}
9.76	0.000	79	0.000	0.000

4.2.2 Results of PV system design for departments building

The geographical location of Sudan University of science and technology college of engineering, Khartoum, Sudan makes it relatively sun rich region with an average daily irradiance of more than 2500Wh/m^2/day (appendix A). So this project presents an approach for designing solar PV system to supply power to all lecture halls of the university. The summary of the PV system is shown below:

- Total watt hours per day is 276.08KWh/day
- Total number of PV panels required is 258
- Inverter size is 2555 watt
- Battery bank capacity is 23000 Ah
- Charge controller rating is 2589.7 A

4.2.3 Results of PV lighting system design for college's yard

This project presents an approach for designing a solar PV system to power any lighting pole. The summary of the PV system is shown below:

- Total load requirement is 228 W/day
- Total watt hours per day is 3.192 KWh/day
- Total number of PV panels require is 4
- Inverter size is 228W
- Battery capacity is 166 Ah
- Charge controller rating is 40.15 A

4.3 Discussion of Lighting Loads Design

4.3.1 Office lighting design

From table 4.1 it has been found that the average lux for office is 522 lux, the lux of office must be 500 lux but in practice it can be taken plus or minus ten percent. Minimum and maximum lux cannot be controlled because the lux is maximum under the lamp and decrease gradually by the angle of the optical emanation. Uniformity of light E_{min}/E_{max} must be greater than 0.4 and here it is above this value [34].

4.3.2 Lab lighting design

From table 4.2 it has been found that average lux in lab is 307 lux, it must be 300 lux but in practice it can be taken plus or minus ten percent. Minimum and maximum lux cannot be controlled because the lux is maximum under the lamp and decrease gradually by the angle of the optical emanation. Uniformity of light E_{min}/E_{max} must be greater than 0.4 and here it is above this value [34].

4.3.3 College's yard lighting design

From figure 4.3 it has been found that average lux in office is 9.76 lux. The lux in open spaces must be 10 lux but in practice it can be taken plus or minus ten percent. Minimum and maximum lux cannot be controlled because the lux is maximum under the lamp and decrease gradually by the angle of the optical emanation.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Global warming is a serious issue and can destroy our entire plant; the major cause of this problem is CO2 emissions that produced from combustion processes which used by electrical thermal plants to produce electricity and so the usage of renewable resources for electrical energy is becoming a must and not a choice.

After using solar PV system, dependability on grid power has been reduced hence grid health is improved, on the other hand the it demanded the continuity of supply hence smooth learning process.

The environment of the work has been improved thanks to scientific method that used to redistribute the lighting units according to recommended lux for human whether in office or laboratory.

5.2 Recommendation

- There are many lecture halls, many laboratories and workshops need to be supplied with energy to demand continuity of supply.
- Increase PV system efficiency by using sun trackers.
- Connect the PV system to the electrical grid to benefit from surplus power generated by selling it or improving the electrical grid.
- Using automatic transfer switch to make system operation smooth.
- Calculation cost of the system.

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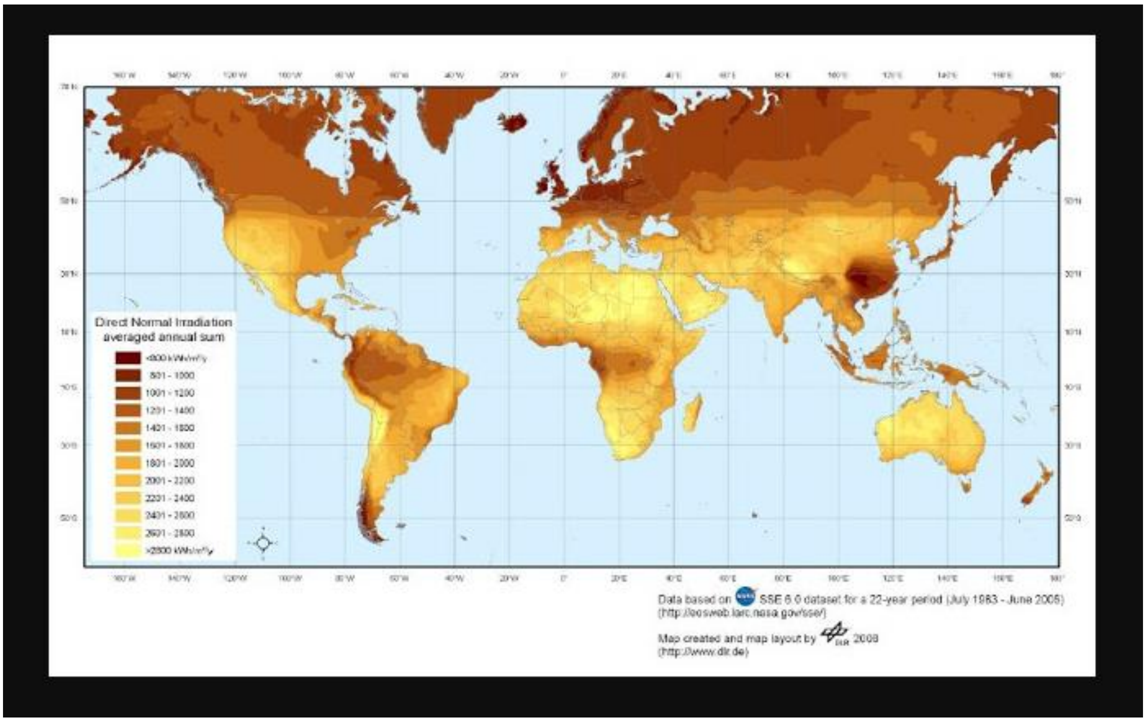
Appendices

APPENDIX A

Sun Radiation in the World

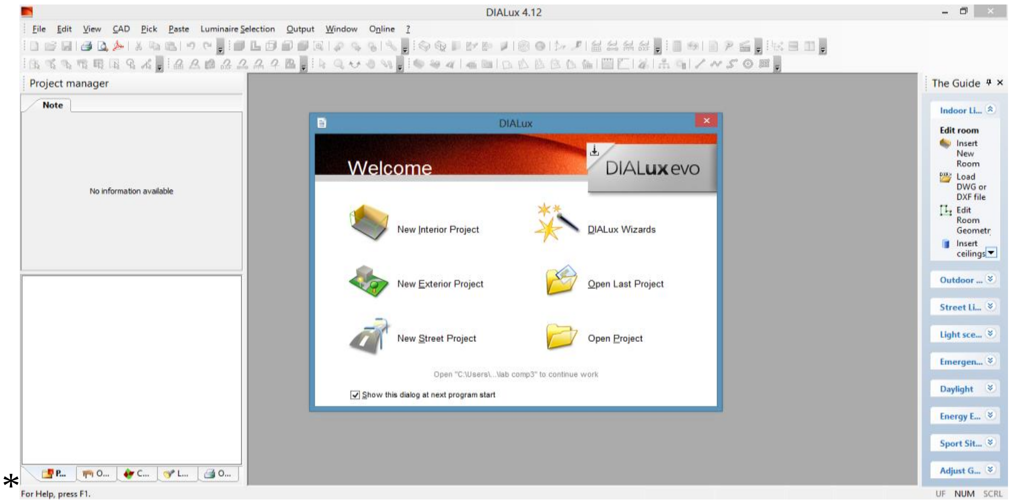


APPENDIX B

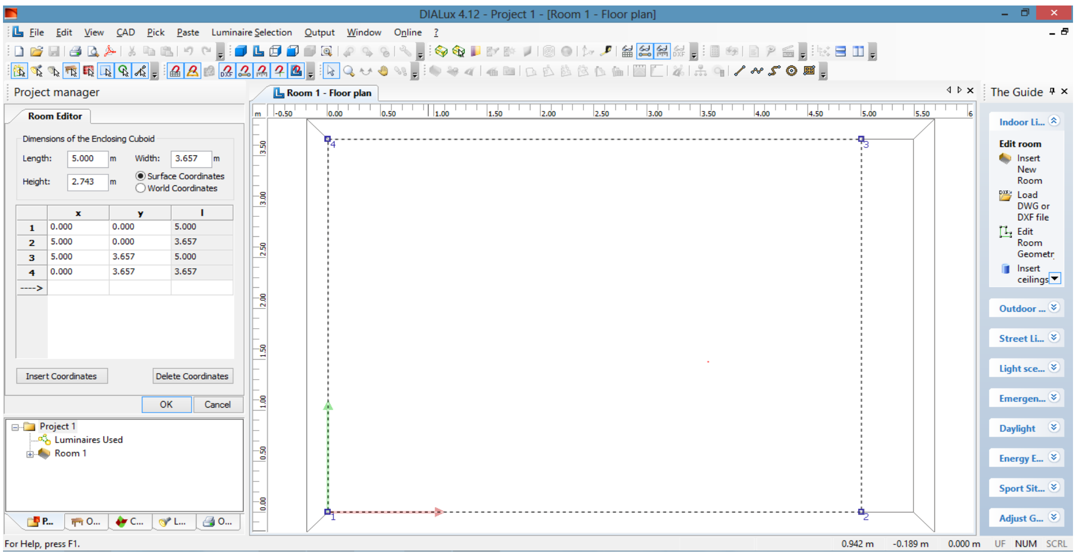
Interior Lighting Design Using DIALux

B.1 Adding a new room

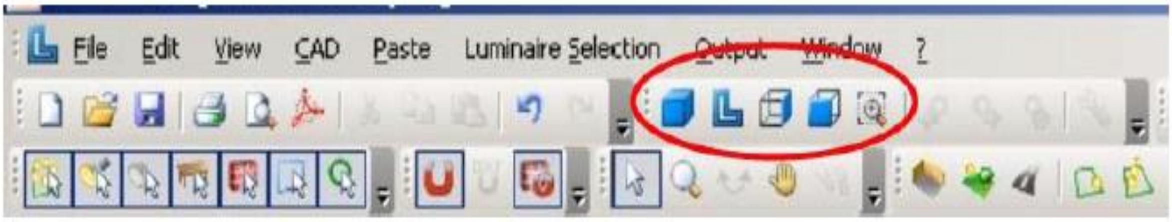
To add a new room, click at new interior project and the room will appear.



B.2 Insert Diminutions:

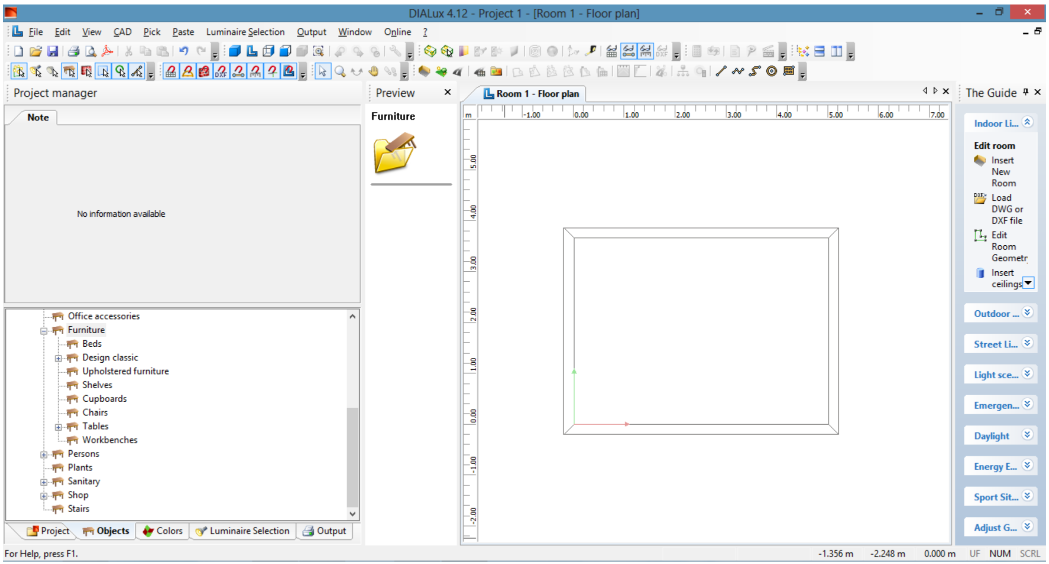


In order to see the 3D view you can use the right mouse button or click on the cube symbol (3D standard view). You can use the double arrow for the rotation of the 3D view.

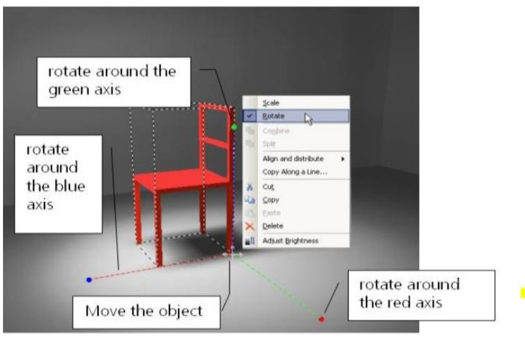


B.3 Adding Furniture:

Furniture can be moved from the furniture to the project (any view) via the mouse using drag and drop, by opening object list as shown:

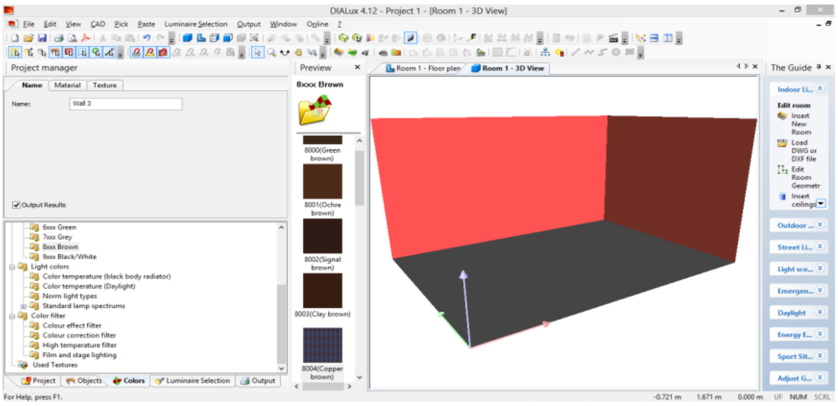


If the Rotate option is activated, the object can be rotated by clicking and rotating the point on the boom. The red rotation point enables a rotation around the red axis, likewise the blue and the green rotation points enable rotations around the blue and green axis respectively. Please keep in mind that the object has its own coordinate system. The object can be moved by clicking and pulling on the arrow cross. Chair can be rotated as shown



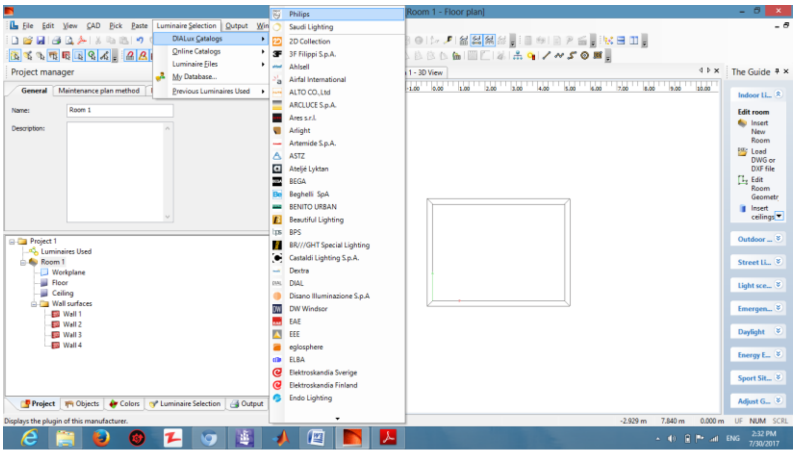
B.4 Coloring:

Click at colors list and drawn it to the wall as shown here

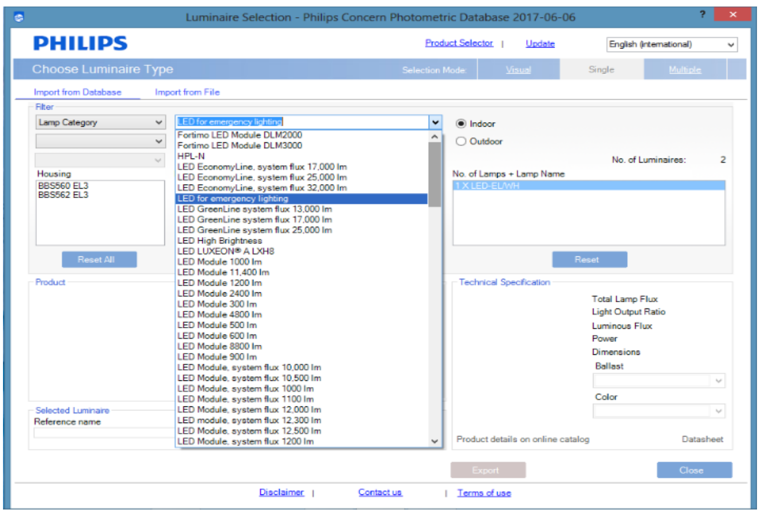


B.5 Adding Luminaries:

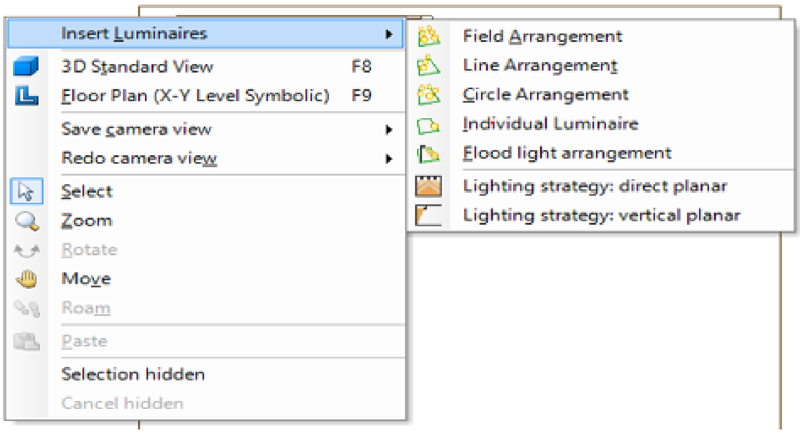
Select lamp from you catalogue as shown



B.6 Lamp Selection from Catalogue:

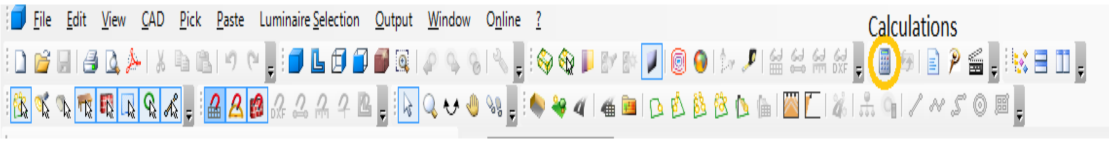


And it can be select lamps from this catalogue and insert lamp in project.



B.7 Calculations:

Click at Calculations figure

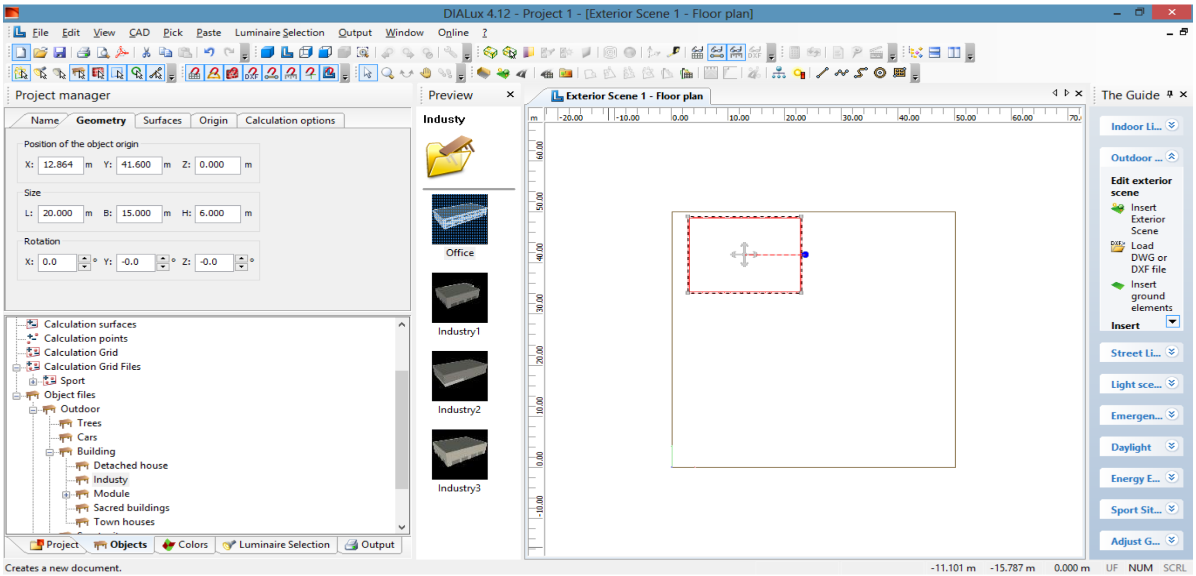


APPENDIX C

Exterior Lighting Design Using DALux

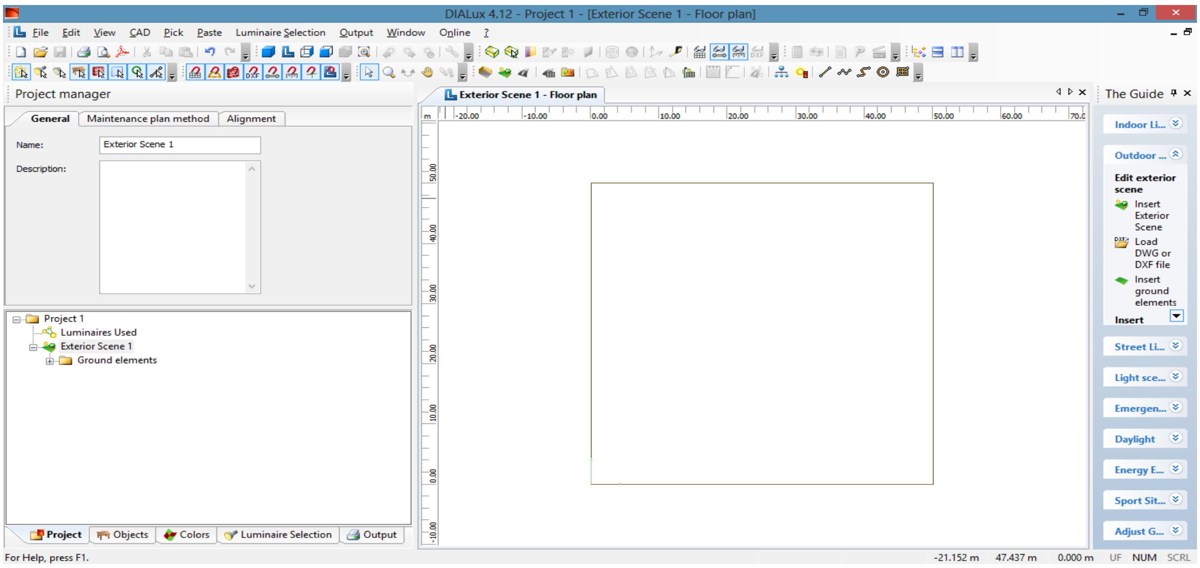
C.1 Insert Building:

Click at object, outdoor, building and select your building



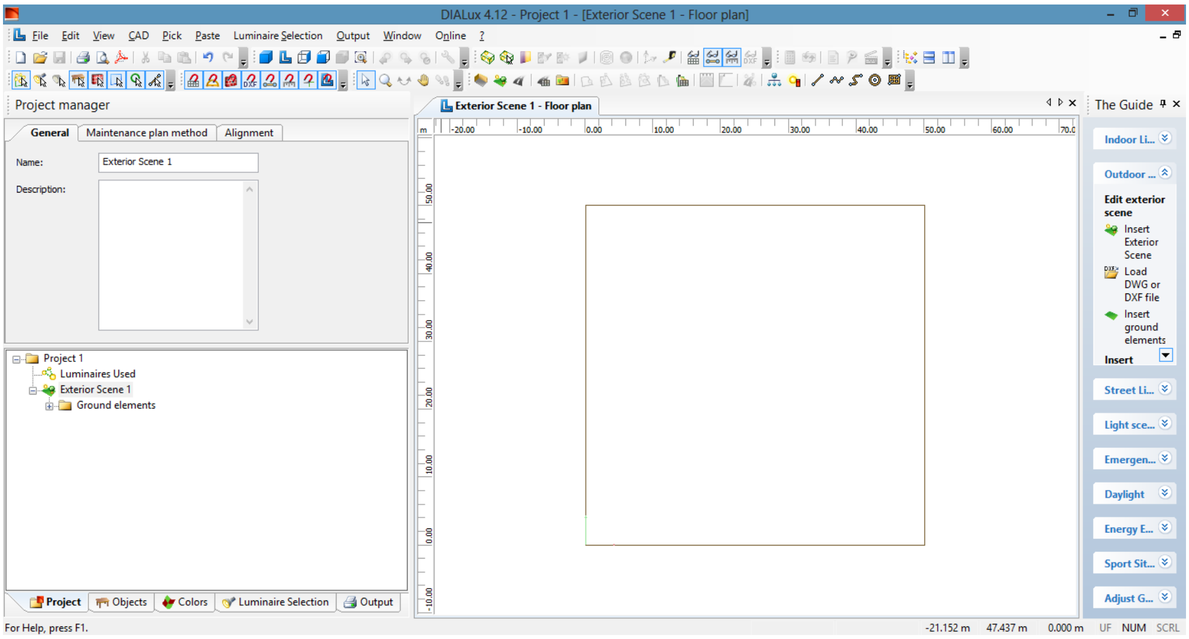
C.2 Insert Dimensions:

By using DIALux after open program and click at exterior project as shown:



C.3 Adding Luminaries:

Lamps can be selected as shown in indoor project and do your calculation.



APPENDIX D

Appendix D.1 Characteristics of Lamp Used in Office

9 Pieces PHILIPS RC088B W60L60 1xLED22S/865, Article No.:

Luminous flux (Luminaire): 2328 lm

Luminous flux (Lamps): 2328 lm

Luminaire Wattage: 27.9 W

Luminaire classification according to CIE: 100

CIE flux code: 53 82 96 100 100

Fitting: 1 x LED22S/865/- (Correction Factor 1.000).

Appendix D.2 Characteristics of fan

Parameter	Smart Saver 50	Ordinary Fan
Power consumption	50 W*	75 W
#Power consumption/day @16hrs/day	800 Wh	1200 Wh
Electricity consumption/month	24 Units	36 Units
Electricity cost/month @ ₹6/- per unit	₹144/-	₹216/-
Electricity cost for 2 years	₹3455/-	₹5180/-

*At 220V, 50Hz. wattage may vary ± 10%.
#Actual savings depend on the usage of fan & cost of electricity.

APPENDIX E

Characterizes of Lamp Used in Lab

12 Pieces PHILIPS WT120C L600 1xLED18S/840

Article No.:

Luminous flux (Luminaire): 1800 lm

Luminous flux (Lamps): 1800 lm

Luminaire Wattage: 17.0 W

Luminaire classification according to CIE: 97

CIE flux code: 48 81 95 97 100

Fitting: 1 x LED18S/840/- (Correction Factor 1.000).

APPENDIX F

Characterizes of Lamp Used in College's Yard

122 Pieces PHILIPS BGP323 T35 1xECO269-3S/740 DM

Article No.: Luminous flux (Luminaire): 25470 lm

Luminous flux (Lamps): 28300 lm

Luminaire Wattage: 228.0 W

Luminaire classification according to CIE: 100

CIE flux code: 42 76 97 100 90

Fitting: 1 x ECO269-3S/740 (Correction Factor 1.000).

APPENDIX G

MATLAB Script for Load Calculation

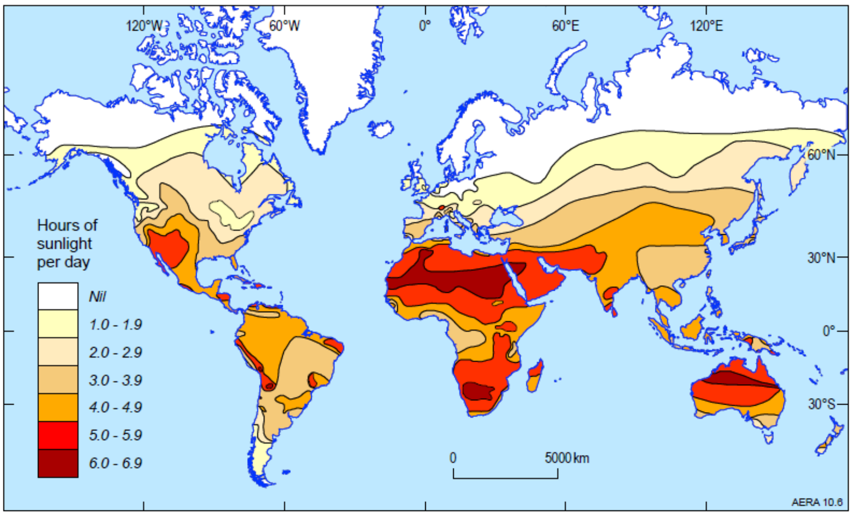
```
clc
s=0;s1=0;
a=input('inter the numbers of office    ');
for i=1:a
    fprintf('office number%8.0f\n',i);
    b=input('inter the numbers of device in this office     ');
        for i1=1:b
    fprintf('device%8.1f power =    ',i1);
    g1=input('');
    fprintf('number of device%8.1f  =    ',i1);
    g2=input('');
    fprintf('operation hour per day%8.1f  =   ',i1);
    g3=input('');
    s=s+g1*g2*g3;
    s1=s1+g1*g2;
end
end
% after that we will divide s/(inverter efficiency)
g4=input('please inter the overall efficiency  as percentage-->');
s2=s/(g4);
s2=1*s2;
g5=input('please inter the sun rise hour per day  -->');
s3=s2/(g5);
g6=input('please inter the power of the cell you need to use it 10-20-100-150 watts etc... -->');
s4=ceil(s3/g6);
```

```
g7=input('please inter the depth of discharge of battery (DOD) as percentage -
->');
g8=input('please inter the battery voltage 12-24 etc... -->');
d=input('inter the numbers of cloady day    ');
s45=s*d;
s5=ceil(s45/(g7*g8));
g9=input('please inter the battery ampere hour -->');
s6=ceil(s5/g9);
fprintf('\n\nresult:-->\n------------------------------------------------\n')
fprintf('you need %8.0f cells\n',s4);
fprintf('Total ampere hour of battery  %8.0f AH\n',s5);
fprintf('Number battery  %8.0f \n',s6);
fprintf('you need inverter above %8.0f watts\n',s1);
fprintf('------------------------------------------------\n')
```

APPENDIX H

Hours of Sunlight per Day

Hours of sunlight per day, during the worst month of the year on an optimally tilted surface Source: Sunrise Technologies2008.



APPENDIX I

TYPE OF BATTERY

	STATE OF CHARGE				
	V open circuit	V open circuit	V open circuit	V open circuit	specific gravity
charge	6-V battery	12-V battery	24-V bank	48-V bank	per cell
100%	6.37	12.73	25.46	50.92	1.277
90%	6.31	12.62	25.24	50.48	1.258
80%	6.25	12.50	25.00	50.00	1.238
70%	6.19	12.37	24.74	49.48	1.217
60%	6.12	12.24	24.48	48.96	1.195
50%	6.05	12.10	24.20	48.40	1.172
40%	5.98	11.96	23.92	47.84	1.148
30%	5.91	11.81	23.62	47.24	1.124
20%	5.83	11.66	23.32	46.64	1.098
10%	5.75	11.51	23.02	46.04	1.073

APPENDIX J

CHARGE CONTROLLER SPECIFICATIONS

Product data sheet
Characteristics

C60
Xantrex C series - charge controller C60 - 12...24V DC - load 60A

Main

Range of product	Xantrex C series
Device short name	C60
Product or component type	Charge controller
Battery voltage	12 V DC 24 V DC

Complementary

Input voltage	<= 55 V DC - open circuit
Load current	60 A at 25 °C
Peak current	85 A
Enclosure type	Ventilated
Enclosure material	Powder coated steel
Device mounting	Wall mounted vertical
Cable entry	3/4" and 1" knock-outs
Height	254 mm
Width	127 mm
Depth	63.5 mm
Product weight	1.4 kg

Environment

AWG gauge	10
Ambient air temperature for operation	0...40 °C
Operating altitude	4572 m
Standards	UL 1741 CSA 22.2 No 107.1-95
Marking	CE

APPENDIX K

PV MODULE SPECIFICATIONS

Specification Sheet

Manufacturer	MITSUBISHI ELECTRIC			
Model name	PV-TD190MF5	PV-TD185MF5	PV-TD180MF5	PV-TD175MF5
Cell type	Polycrystalline Silicon, 156mm x 156mm			
Number of cells	50 cells in a series			
Maximum power rating (Pmax)	190W	185W	180W	175W
Warranted* minimum Pmax	184.3W	179.5W	174.6W	169.8W
Tolerance of maximum power rating	+3 / -3%			
Open circuit voltage (Voc)	30.8V	30.6V	30.4V	30.2V
Short circuit current (Isc)	8.23A	8.13A	8.03A	7.93A
Maximum power voltage (Vmp)	24.7V	24.4V	24.2V	23.9V
Maximum power current (Imp)	7.71A	7.58A	7.45A	7.32A
Normal operating cell temperature (NOCT)	47.5 degree C			
Maximum system voltage	DC 1000V			
Fuse rating	15A			
Dimensions	1658 x 834 x 46mm (65.3 x 32.8 x 1.81 inch)			
Weight	17kg (37.0 lbs)			
Output terminal	(+) 800mm / (-) 1250mm with MC connector (PV-KBT4/6II-UR, P-KST4/6II-UR)			
Module efficiency	13.7%	13.4%	13.0%	12.7%
Packing condition	2 pcs - 1 carton			
Certificate	IEC 61215 edition 2 (static load test 5400 Pa passed), EN 61730, TUV Safety Class II			

APPENDIX L

INVERTER SPECIFICATIONS

Model:	**LS3024**
Voltage:	**24 Volt**
Continuous Rating:	**3000W**
1/2 Hour Rating:	**3700W**
Surge Rating (5 sec):	**9000W**
Battery Voltage Range:	**21 - 34V**
Peak Efficiency:	**93%**
Standby Current:	**50mA**
Weight:	**24kg**
Output Voltage:	**240 Volts AC +/- 4%**
Output Frequency:	**50Hz +/- 0.1%**
Output Waveform:	**True Sine Wave**
Total Harmonic Distortion:	**Less than 4%**
Input Wiring:	**1.5m Leads c/w Lugs**
Output:	**Junction Box**
Chassis:	**Powder Coated Aluminium**
Dimensions (L x W x H):	**370 x 386 x 180mm**