Miniaturized Solar Home System for lighting purpose with Light Emitting Diodes

by

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Date and Place of Birth:
17th December 1972 in Bogra/ Bangladesh

Master Thesis

in the Postgraduate Programme
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Day of Examination:	January 19, 2006.
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Acknowledgements

First, I express my profound gratitude to *Dieter Geyer,* Center for Solar Energy and Hydrogen Research, Baden-Württemberg, Stuttgart and *Dr. Konrad Blum*, Oldenburg University for their professional supervision of my work. Their continuous advice and criticisms have lead to both qualitative and quantitative successful completion of the work. They are highly appreciable for their valuable time spends to read through all the manuscripts during the preparation of this thesis.

I will never forget *Mr. Hans Dieter Mohring* (ZSW) for his valuable advice for light measurement. I am deeply grateful to my colleague *Md Tazmilur Rahman,* has great support to me. I always remember his guidance and advice in all aspects of life.

The good co-operation and solidarity among the members of staff of Institute of physics of Oldenburg University, and Centre for solar Energy and Hydrogen Research (ZSW) Stuttgart, Germany. My special thanks are directed to *Mr. Edu Knagge,* his advice and valuable assistance in all aspects created an attractive and conducive environment for my academic and social activities in Germany.

I gratefully acknowledge to my *parents*, for their love, guidance, advice and prayers. I also like to thanks *Prof. Dr. Abdur Rashid Sharker, Prof. Dr. Sadrul Islam*, *Prof Dr. Mahbubul Alam* and *Dr. Hansjörg Gablar*. I will never forget their love for me.

I express my gratitude to the *Germany Academic Exchange Service (DAAD)* for the scholarship.

My final and special endorsement is directed to my beloved *Sharmin Fatima,* her love, patience, advice, guidance and encouragement are highly valuable and implicate my success in all aspects.

As author, I bear responsibility for all interpretations, opinions and errors in the work.

Zobayer
January16, 2006.

Abstract

Access to electricity in Bangladesh is one of the lowest in the world; coverage today stands around 30% of the total population. However the rural areas of Bangladesh where 76% of population live are seriously deprived of the lighting facilities. This research presents low cost Solar Home System (SHS) using light emitting diodes (LED) as a lighting load for the poor people in the remote and rural areas of Bangladesh

In this research one of the finding is that LED lamps consume very less power and quality of the light is very good. If consider the life it is very cheapest than any other traditional energy saving Compact Fluorescent Lamps (CFL).

Now a day's solar home systems are still expensive because of higher cost of photovoltaic module, using LED the size of the system will be reduced then require less capacity photovoltaic module, which share the maximum cost (65%) of solar home system. Reducing the cost of the modules is clearly very important to make SHS more affordable

The main finding of this research after the economical comparison with the life cycle cost analysis is that the SHS using LED instate of CFL as lighting loads costs will be reduced one third. In addition this new SHS works with very simple charge controller and motorcycle battery instead of solar battery, because of its availability in the remote and rural areas.

Key wards: Light Emitting Diode (LED) and Rural Electrification.

Contents

1.0. INTRODUCTION

Energy is one of the fundamental elements required for overall development of a country. Bangladesh is a country of very low per capita energy consumption. Only 30 % of the total populations have access to the grid and large area is still out of grid coverage. Considering the current pace of grid expansion, it will take several years to cover most of the area in Bangladesh. Moreover there are some remote places like off-shore, river islands and hilly areas where settlements are dispersedly located which are not suitable or cost effective for grid expansion. A low cost Solar Home System (SHS) and using Light Emitting Diode as lighting loads could be the only solution to make energy available there.

This research presents the development of a low cost stand alone Solar Home System (SHS) for lighting purpose, using a small module, locally available motor cycle battery (lead-acid battery), very simple charge controller and very low power consumed Light Emitting Diodes (LED). This report also presents fundamentals of optics, luminary construction with LED, battery selection, and charge control strategies commonly used in small stand-alone SHS, photovoltaic system design and economic analysis.

2.0. OPTICAL FUNDAMENTALS:

2.1. The Spectrum, Human Eye Response

Light is a form of energy. The white light coming from the sun is actually made up of different colours. The human eye responds to light according to the curve shown on Figure 2.1a. The sunlight spectrum (figure 2.1b) lies just outside the human eye response curve (Appendix A: figure A1).

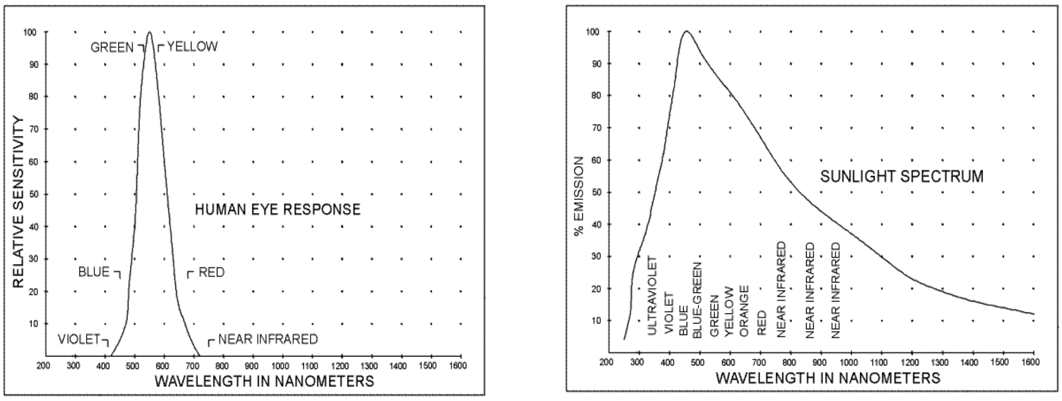


Figure 2.1(a): Human eye response curve. Figure 2.1(b):Sunlight spectrum (Source[3])

2.2. Visible Light:

The lumen (lm) is the photometric equivalent of the watt, 1 watt at 555 nm =683lumens. The human eye can detect a flux of about 10 photons per second at a wavelength of 555 nm; this corresponds to a radiant power of 3.58×10^{-18} W (or J s^{-1}). Similarly, our eye can detect a minimum flux of 214 and 126 photons per second at 450 and 650 nm, respectively (see [6]).

2.3. The Inverse Square Law

The inverse square law defines the relationship between the irradiance from a point source and distance. It states that the intensity per unit area varies in inversely proportional to the square of the distance. (see [6])

$$\mathbf{E = I / d^2} \qquad \mathbf{(2.1)}$$

$$\mathbf{I = Ed^2} \qquad \mathbf{(2.2)}$$

Where:

I= Intensity

E= Irradiance

d= Distance (d>5 times the source diameter)

We can calculate the irradiance at any other distance from the following equation:

$$\mathbf{E_1 d_1^2 = E_2 d_2^2} \qquad \mathbf{(2.3)}$$

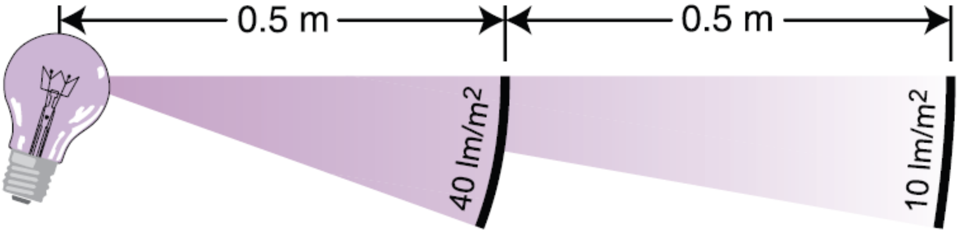


Figure.2.2: Inverse square law. (Source [6])

In figure 2.2 at one meter distance the flux density is 10 lm/m² or 10 lux. Applying inverse square law flux density at half meter distance will be 40 lm/m² or 40 lux.

2.4. Radiant and Luminous Flux:

Radiant flux is a measure of radiometric power. Flux is expressed in watts and is a measure of the rate of energy flow (joules/ second). Photon energy is inversely proportional to wavelength.

Luminous flux is a measure of the power of visible light.

Photopic flux, expressed in lumens, is weighted to match the responsibility of the human eye, which is most sensitive to yellow-green.

Scotopic flux is weighted to the sensitivity of the human eye in the dark adapted state. (See [6])

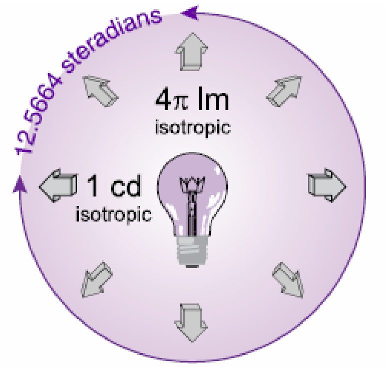


Figure 2.3: Total flux output. (Source [6])

2.5. Irradiance and Illuminance:

Irradiance is a measure of radiometric flux per unit area, or flux density and typically expressed in W/m^2 (watts per square meter).

Illuminance is a measure of photometric flux per unit area, or visible flux density and typically expressed in lux (lumens per square meter) or foot-candles (lumens per square foot).

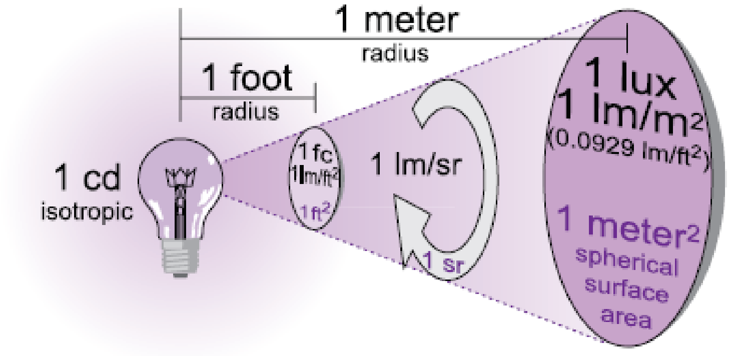


Figure 2.4: Irradiance. (source [6])

In figure 2.4 above, the light source is producing 1 candela. The candela is the base unit in light measurement, and is defined as 1 candela light source emits 1 lumen per steradian in all directions (isotropically).

1 steradian or solid angle has a projected area of 1 square meter at a distance of 1 meter. (see [6])

$$\Omega = A / r^2 \qquad (2.4)$$

Where,

Ω=solid angle or steradian(sr)

A=surface areas(m²)

r=radius (m²)

Therefore, a 1 candela (1 lm/sr) light source will similarly produce 1 lumen per square foot at a distance of 1 foot, and 1 lumen per square meter at 1 meter.

2.6. Radiant and Luminous Intensity:

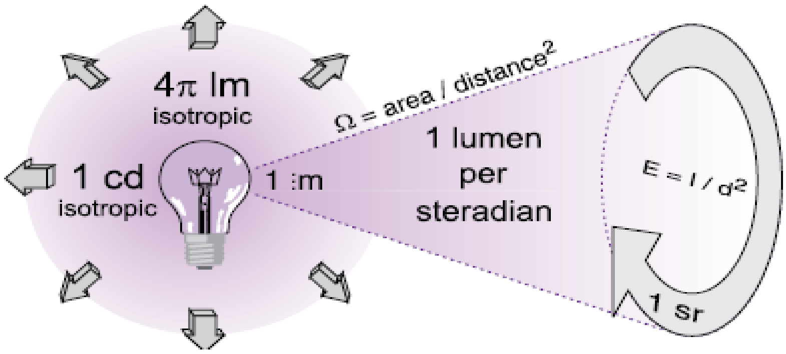


Figure 2.5: Radiant intensity. (source [6])

Radiant Intensity is a measure of radiometric power per unit solid angle, expressed in watts per steradian. Similarly, luminous intensity is a measure of visible power per solid angle, expressed in candela (lumens per steradian) (see [6]). Intensity is related to irradiance by the inverse square law, shown below in an alternate form:

Now $r^2 = A/\Omega$, and substituting in equation (2.2) we get,

$$I = E * A / \Omega \qquad (2.5)$$

where:

I= Intensity

Ω= solid angle or steradian

E= Irradiance

2.7. Flux Density Measurement in Rural Area:

In rural areas people do not have any multimeter and luxmeter for measuring the flux density, but applying local technology rural people can easily find out high flux density lamp. We need only a piece of paper, stands, an optical bench, oil and a dark room. The setting arrangement of the instrument is shown in figure: 2.6.

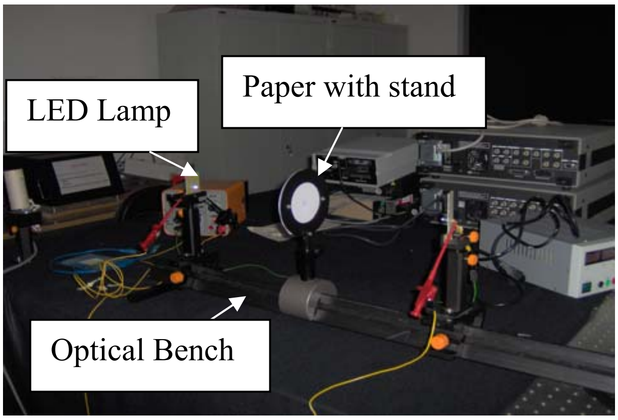


Figure 2.6: high intensity measuring instrument.

Measurement procedures are as follows:

i. Clamp the paper with a stand and put one drop (very small) of oil in the centre of the paper. This point should be transparent.

ii. The paper stand fixes in middle of the optical bench.

iii. Two different LED should be placed both sides of the paper one of them (known intensity) fixed and other one with slide movement on the optical bench. Transparent point and LEDs are in the same axis.

iv. Both LEDs must be powered.

v. Sliding the LED on the optical bench until we can not see the transparent point. This is the distance where the flux density is the same of the two LEDs.

vi. It is necessary to determine each distance from the LED to the paper.

Applying inverse square law [section 2.3], the finding is that the flux density of the long distance LED is higher than the short distance LED.

2.8. Conclusion:

After doing this simple experiment people in rural areas are able to determine the light intensity of a source with a simple comparison against one known source.

3.0. LIGHT EMITTING DIODES (LED):

3.1. LED Circuits:

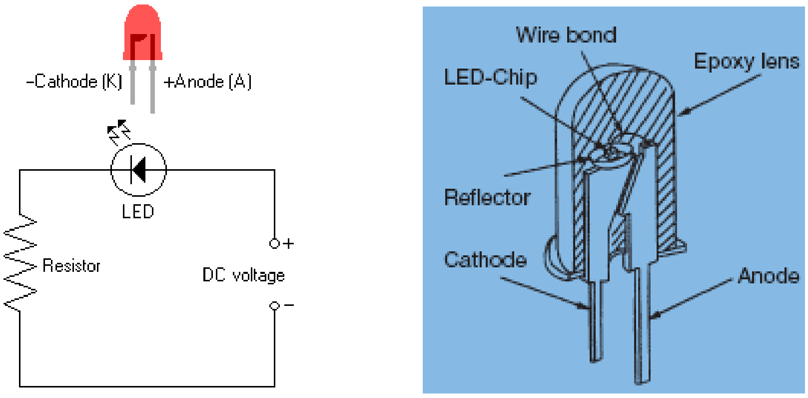


Figure 3.1: LED circuit and components (source [35])

LED has no linear resistance like a resistor does. It has a dynamic resistance that is, its resistance changes depending on how much current passes through on it.

Therefore a LED circuit needs some pre resistance in it, so that it is not a short circuit. Actually we need a very specific amount of resistance. Among the specification for LED, a "maximum forward current" rating is usually given. This is the current that can pass through the LED without damaging, and also the current at which the LED will produce the highest light. A specific value of resistor is needed to obtain this exact current. The maximum forward currents depend furthermore on the ambient temperature.

LED consumes a certain voltage. This is known as the "forward voltage drop", and is usually given with the specifications for that LED. This must be taken into account when calculating the correct value of the resistor to use. (See [2]).

So to drive a LED, it is needed a voltage source and a resistor in series with the LED,

The following equation to determine the needed resistance:

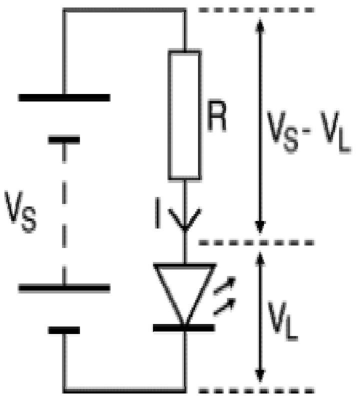


Figure 3.2: Resistance connection of LED circuit

$$\mathbf{R = (V_S - V_{LED}) / I_{LED}} \qquad \mathbf{(3.1)}$$

Here:

V_S = Supply voltage (volts)
V_{LED} = LED voltage (volts)
I_{LED}= LED current (Ampere).

If the calculated value of the resistance is not available, it is advisable to choose the nearest standard resistor value which is greater, so that the current will be a little less than the nominal one. In fact we may choose a greater resistor value to reduce the current (to increase battery life) but this will make the LED less bright.

3.1. General LED Characteristics:

The directional sensitivity indicates a ratio of the LED luminous intensity relative to its axial luminous intensity (= 100%) as viewed from a direction of angle of θ with respect to the light source. The angle at which luminous intensity is exactly 50% of the axial luminous intensity is called a half-value angle θ ½. Luminous intensity on both sides of the axis is expressed as 2θ½ indicating an approximate expanse of luminous intensity. (See ([34])

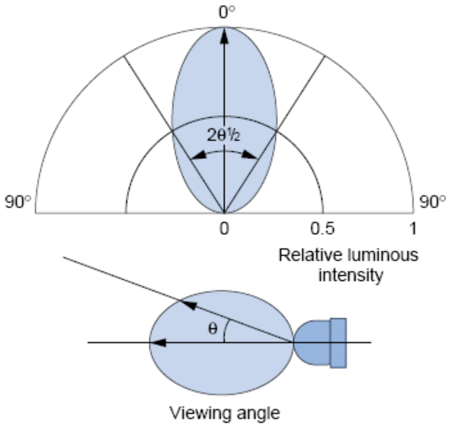


Figure 3.3: relative luminous intensity & viewing angle. (Source [34])

3.2. Colours of LED:

LEDs are available in red, orange, amber, yellow, green, blue and white. Blue and white LEDs are much more expensive than the other colours.

The colour of a LED is determined by the semiconductor material, not by the colouring of the 'package' (the plastic body).

White LED: True white-light-emitting LEDs are not available. Such a device is difficult to build because LEDs typically emit one wavelength. White does not appear in the spectrum of colours; instead, perceiving white requires a mixture of wavelengths.

A trick is employed to make white LEDs. Blue–emitting InGaN base material is covered with a converter material that emits yellow light when stimulated by blue light. The result is a mixture of blue and yellow light that is perceived by the eye as white (figure 3.4). (see [36])

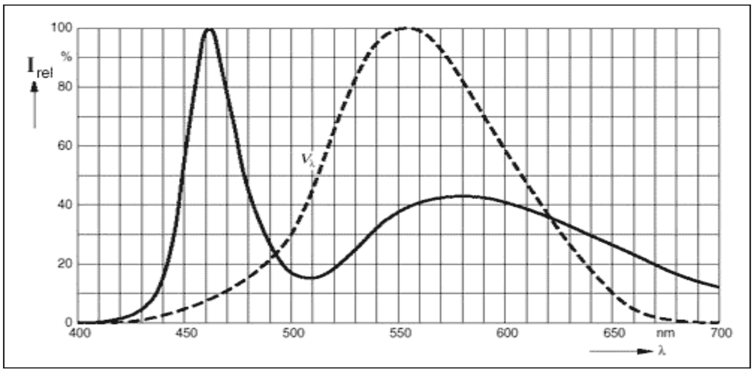


Figure 3.4: The emitted wavelengths of a white LED (solid curve) include peaks in the blue and yellow areas, but are interpreted as white light by the human eye. The relative light sensitivity of a human eye (dotted curve) is shown for comparison (source [36]).

3.3. LED Connection Procedure:

Soldering: For soldering LED on a circuit board, the soldering iron should not exceed 30W in power. The maximum soldering temperature is 300°C for Pb-Sn solder and 350°C for lead free solder for normal lamps. For blue (425nm), and blue-green (525nm) LEDs, the maximum soldering iron temperature is 280°C. We should not place the soldering iron on the component for more than 3 seconds.

After soldering, it must be allowed at least three minutes for the component to cool down at room temperature before further operation.

There must be a minimum of 2mm clearance between the base of the LED lens and the lead bend.

3.3.1. Connecting LEDs in Series:

For several LEDs at the same time it may be possible to connect them in series with a resistor. (Section 3.1) All the LEDs connected in series pass the same current so it is best if they are all the same type. Figure 3.5 shows the series connection of LEDs with the resistor.

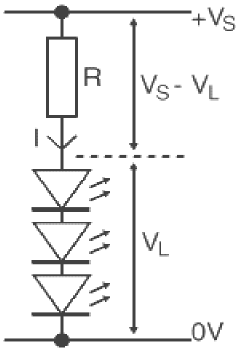


Figure 3.5: Three LED connect in series with a resistance. (Source [13])

3.3.2. Avoid Connecting LEDs in Parallel:

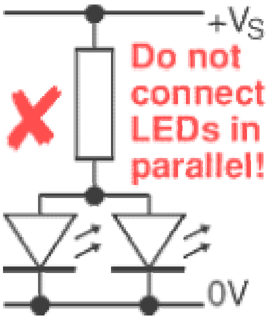


Figure 3.6: Connection LEDs in Parallel. (Source [13])

Figure: 3.6, connection of two LEDs in parallel with just one resistor shared between them is generally not a good idea. If the LEDs require slightly different voltages than the currents through the parallel branches will be unequal and the low voltage LED may be destroyed by the largest current flowing through it.

3.4. Electrical and Luminous Values of the LED:

Supplier's catalogues usually include tables of technical data for components such as LED. The table: 3.1 shows technical data for some 5mm diameter round white LED with diffused packages (plastic bodies) together with the measured values.

Table 3.1: Technical data of different LED. (source: [33])

Colour	**Ø (mm)**	**I_F (mA)**	**V_F (V)**	**Luminous Intensity I (mcd)**	**Viewing angle**	**Cost/LED**
White	5	20mA	3.6V	18000mcd	15°	4.27 €
White	5	20mA	3.2V	10000mcd	20°	0.86€
White	5	20mA	3.6V	6400mcd	30°	3.02€
White	5	20mA	3.6V	2500mcd	50°	2.55€

Here: **I_F**=forward current (mA)

V_F= forward voltage (V)

Ø=diameter (mm)

Table 3.2: Electrical measurement of different colours LEDs

Coloured LED	**Ø (mm)**	**I_F (mA)**	**V_F (V)**
1. White	5	20	3.65
2. Green	5	20	4.35
3. Red	5	20	2.08
4. Yellow	5	20	2.39
5. White	5	20	3.61
6. Green	5	20	4.42
7. Blue	5	20	4.29
8. White	5	20	3.64
9. Red	5	20	2.10

Table 3.2 shows the measured values of forward voltage at constant current obtained for different colours of LEDs available in the markets. Observing the table and found that:

i. Higher forward voltage LEDs are of green and blue, which are 4.35V and 4.29V respectively,

ii. Less forward voltage LEDs are red and yellow which are 2.08V and 2.39V respectively.

iii. Forward voltage of white LED is 3.36V, which is between of them.

4.0. LUMINARIES CONSTRUCTION:

4.1. Design Considerations for Lights:

Lighting is high priority in households. It is important to consider the power of the lighting loads that are used in the solar home system. SHSs are mostly used for lighting, where 12V DC energy efficient CFL lights are commonly used .From my practical experience in the field level of Bangladesh I have found that there are many problems related to this lighting source. Roughly one third of all CFL lamps suffer from early blackening. For early blackening the luminous flux degrades or stops totally very quickly (See [4]) When solar photovoltaic provide the electricity for rural lighting, the high electricity cost per unit stimulates careful consideration in choosing the right type of lamp. LED lamps are the newest addition to the list of energy efficient sources. LED lamp technologies are rapidly progressing and show promise for the future.

4.2. Lamp Characteristics:

Important characteristics of lamps used in lighting are:

- efficacy: lumens per watt
- lumen depreciation
- light colour
- lamp life
- lamp reliability and toughness
- lamp temperature performance
- lamp cost

4.3. Advantages and Disadvantages of LED Lamp:

Advantage of LED lamp:

- Low power consumption
- Long life-high Reliability
- Shock and vibration resistant

- Less heat produce than CFL lamp
- There is no Hg

Disadvantages of LED lamp:

- Limited colour
- Narrow viewing angle
- High cost

4.4. Advantages and Disadvantages of CFL Lamp:

Advantage of CFL lamp:

- Wide viewing angle
- CFL emit light evenly along the entire tube surface
- Low cost
- Available

Disadvantages of CFL lamp:

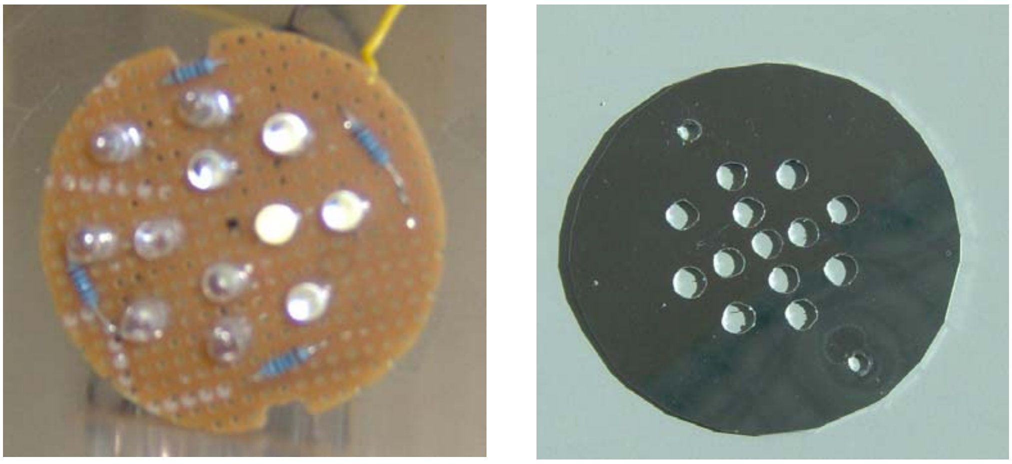
- Power consumption high
- Lamp brightness and glare are relatively low and cause little discomfort
- Limited life
- CFL may produce radio frequency interference.

4.5. Construction of Luminary and Testing:

The idea of the experiment was to determine a comparison of luminous intensity of different types of luminaries composed by LEDs arrays against the viewing angle projected by them. (Appendix A: figureA7-A10) To do so the first step was to purchase from the market different types of LEDs in order to construct the luminary.

The construction of the luminaries is shown in figure 4.1 which illustrates different steps for getting the final assembly. For maximum utilization of power for a lamp, three LEDs were connected with one resistance because source voltage was 12volts and operational voltage of each white LEDs was 3.6 volts; three LEDs in series the total voltage was 10.8 volts so it was necessary to put an extra resistance (section 3.1) to compensate the difference of potential. Different luminaries were constructed with 3 LEDs, 6 LEDs and 12 LEDs.

After the luminaries were constructed, the next step was measuring the luminous intensity of lamps using a luxmeter and compared with each other and also compared with CFL lamp.



LED connection with resistance

Reflector

Lamp setting with reflector

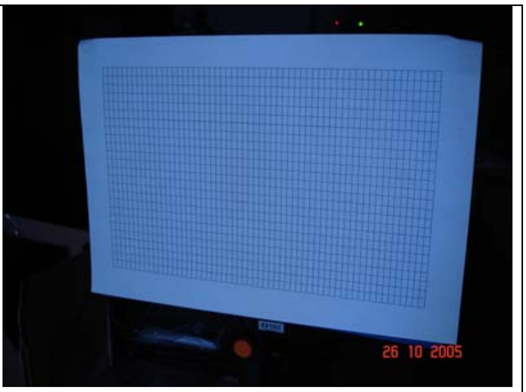
Complete constructed Luminary

Figure 4.1: Construction procedure of LED luminary

The followed criterion to purchase the LEDs was to search from the market those ones which presented a good relationship among price viewing angle and light intensity. In this sense four types of LEDs were tested as it has been shown in (table 3.1) of this research (Appendix A: figures A2-A5). In addition for comparison effects it was also included a CFL lamp (Appendix A: figure A6). The results of the test are shown in Appendix: A (tables A6 - A10). The procedure of testing and results were as follows:

The procedure to take measurements was: at one meter distance from the light source a paper with grid line was fixed and observed it with different LED lamps and CFL lamp.

It was found that the grids were brighter, clearer and equal distributed in the cases of lamp-2. For the other three lamps (lamp-1, lamp-3,and lamp-4) intensity was higher only in the central point of the paper and light was not equal distributed which is shown in Appendix A: figuresA12-A15. For CFL lamp at the same distance we found that the grids were clear and not so much bright. (Appendix A: figure A11) But the whole room was lighted (during experiments) due to its different characteristics. The following figure 4.2 shows the brightness of LED and CFL luminary at 1 meter distance.

	
Figure 4.2a: Brightness of CFL lamp	Figure 4.2b: Brightness of LED (12x10cd) lamp

The best relation price, luminous intensity and viewing angle was obtained for the luminary conformed by 12 LEDs of 10 cd each.

A summary of the comparison is shown in table 4.1 and the selected luminary is indicated by the shadowed column of the table 4.1

This luminary was selected because it is the cheapest one and also provides a good relation light intensity vs. viewing angle. This relation is shown in figure 4.3 for all the luminaries tested.

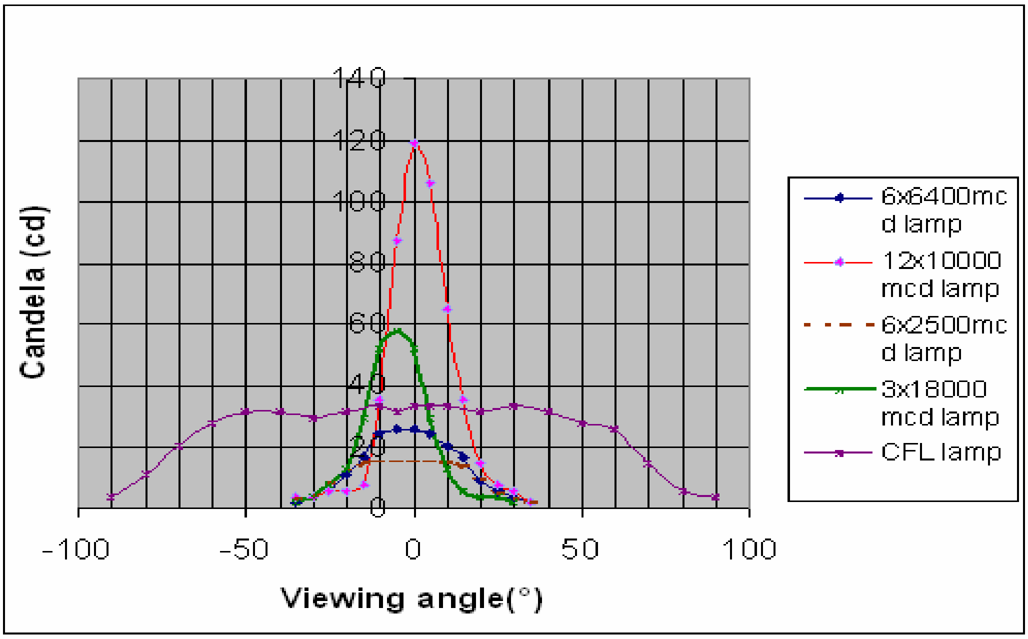


Figure 4.3: Comparison of luminous intensity vs. viewing angles of different LED lamps with CFL lamp

Table 4.1: Compare different characteristics of different LED lamps and CFL lamp

	3x18cd Lamp-1	12x10cd Lamp-2	6x 6.4cd Lamp-3	6x2.5cd Lamp-4	CFL lamp
Luminous intensity of each lamp(cd)	57	119	26.	14	33
Viewing angle of each lamp (°)	20	20	38	50	140
Power (W)	0.3	1.0	0.6	0.4	7
lumen/watt	2388	1495	544	440	60
€/luminary	13	10	19	16	12

It can be also seen that the main advantage of the CFL lamp is that the viewing angle is bigger than all LEDs luminaries tested. Considering the relations costs/luminary and luminous intensity Lamp-2 is the best selection because it is the cheapest one and produces the higher value of luminous intensity.

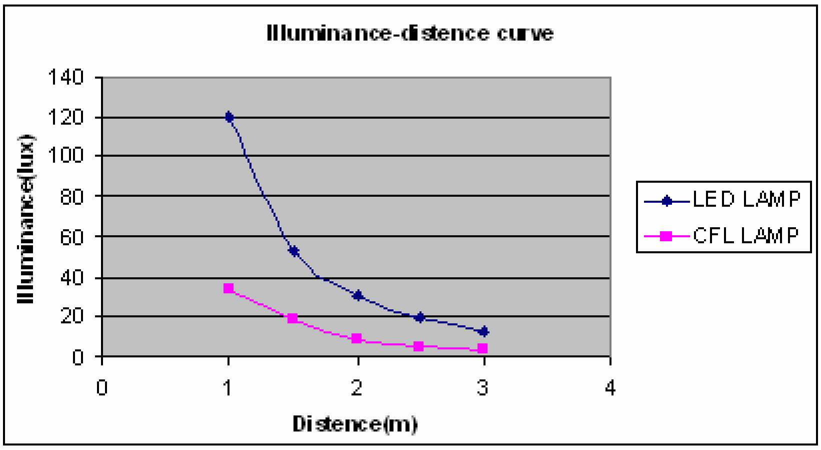


Figure 4.4: Illuminance-distance curve of CFL and LED lamp

Considering illuminance 20 lux as minimum value of visible lighting (for good street light illuminance 20 lux) (see [40]) we can see from the figure 4.4 that the selected LED-2 luminary allows to do this in a larger distance (2.5 m) than the CFL luminary (1.5 m).

4.6. Discussion and Conclusion:

Different types of luminaries were constructed using different numbers of LEDs. Our target was to find out low energy consumption, low cost and high luminous intensity lamp. Observations from the tables 4.1, figures 4.3, 4.4 show that the LED lamp-2 (12 number of 10cd LEDs) presents higher luminous intensity 119cd (1495lumen/watt) and the quality of light was very good.

It can be said that LED luminary is best alternative for lighting compared with CFL luminary since the LED luminary shows the best quality of light and low cost. The only disadvantage of this luminary is that it shows a reduced viewing angle compared with CFL luminary. However the useful life of a LED is much higher (100,000 hrs) than the CFL (6000 hrs) which makes in the long run a suitable option for lighting in poor households.

5.0 COMPONENTS OF SOLAR HOME SYSTEM.

Solar Home System (SHS) generally have a common design and consists of the following components:

1. A PV Generator composed of one or more PV modules, which are interconnected to form a DC power producing unit.
2. A mechanical support structure for the PV generator.
3. A 12V lead acid battery.
4. A charge controller to prevent deepdischarges and overcharges of the battery.
5. Loads.(LED lamps)
6. Wiring (Cable, switches and connection box.)

SHS reliability, in the sense of lack of failures, depends not only on the reliability of the components, but also on some other features of the system which can directly affect the lifetime of batteries and lamps, such as size, the voltage thresholds of the charge controller, the quality of installation, etc. Each component of the system must fulfil similar quality and reliability requirements, because, if there is only one bad component in an otherwise perfect system, this will limit the quality of the whole system.

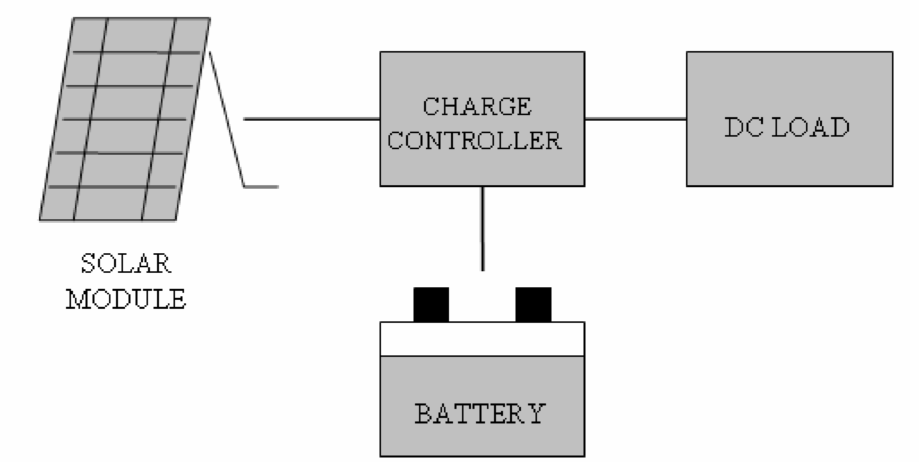


Figure 5.1: Connection of solar photovoltaic home system

The increasing demand for rural electrification favours the continuous use of stand-alone solar home system. The concept and components of stand-alone system depend on demand and application.

Here a stand-alone photovoltaic system consists of 6Wp capacity photovoltaic module, charge controller capacity 12V /10A, and battery capacity 5Ah@10hr, LED lamps (three numbers) each capacity 1 watt and connecting wire.

5.1. Balance of System (BOS):

BOS stands for balance of system, which is used for all non-photovoltaic parts of a PV system. They contribute significantly to the overall system and getting these wrong can seriously damage the system. BOS components can be separated into electrical and mechanical components.

The electrical components are:

- Cables
- Fuses
- Earthing
- Lightning Protection
- Battery
- Charge Regulation

Mechanical components are module support structure and tracing system.

6.0. PV GENERATOR.

6.1. What is Photovoltaic?

Photovoltaic modules generate direct electrical current from sunlight. They consist of solar cells which are connected in series. These cells are encapsulated against environmental influences such as humidity or hail under a cover glass and a stable back sheet.

As long as light is shining on the solar cell, it generates electrical power. When the light stops, the electricity stops. Photovoltaic module is the most reliable components of solar home systems. Photovoltaic modules suitably mounted and electrically connected to from a DC power generating unit.

6.2. Types of Solar Cells

Crystalline silicon:

Crystalline cells have been in service the longest and exhibit outstanding longevity. There are two sub-categories of crystalline cells: Mono crystalline and Multi crystalline. Both of them perform similarly. The principle advantage of mono crystalline cells is their high efficiencies, (Appendix C1) typically around 17%. Multi crystalline cells are slightly less efficient, average efficiencies of around 12%. (See [12])

Amorphous silicon:

Amorphous silicon is a recent technology for solar cells. It is cheaper to produce, but their efficiency is half of the crystalline cells, (Appendix C2) typical efficiencies of around 6%, and they will degrade with use. But they are easier and therefore cheaper to produce. This type of cell produces power in low light situations. The low cost makes them ideally suited for many applications where high efficiency is not required and low cost is important. (See [12]).

Thin Films:

A number of other promising materials such as cadmium telluride (CdTe) and copper indium diselenide (CIS) are now being used for PV modules (see [12]). The attraction of these technologies is that they can be manufactured by relatively inexpensive industrial processes, certainly in comparison to crystalline silicon technologies, yet they typically offer higher module efficiencies than amorphous silicon. (Appendix C3).

6.3. Selection Criteria for PV Modules:

A number of factors should be considered when selecting PV modules for a lighting application. (See [37]) These criteria include:

1. Electrical performance (rated output)
2. Physical properties (e.g., size, weight)
3. Mechanical properties (construction materials, mounting attachment, etc.)
4. Efficiency and surface area requirements for modules
5. Cost, lifetime and warranty.

6.4. Theory behind PV:

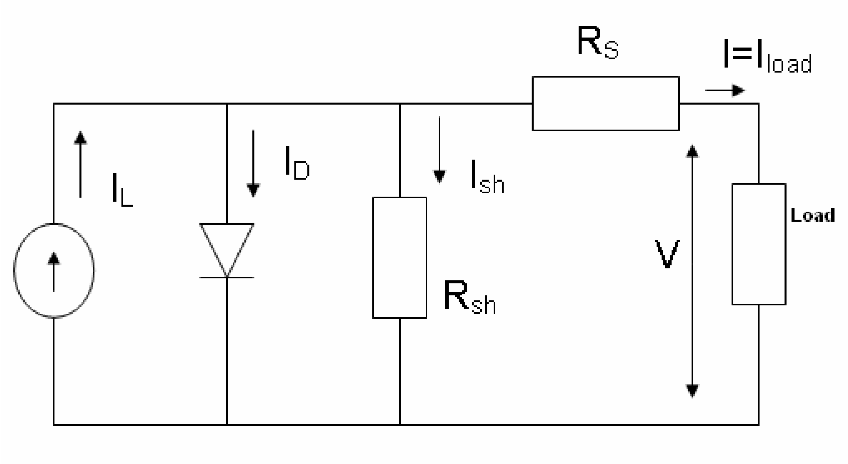


Figure 6.1: the equivalent circuit for a PV generator. (Source [39])

The figure 6.1 is an equivalent circuit that can be used either for an individual cell or for a module consisting of several cells. This circuit requires that five parameters be known: the light current I_L, the diode reverse saturation current Io, the series resistance R_S, the shunt resistance R_{sh}, and a curve fitting parameter **a**. At a fixed temperature and solar radiation, the current-voltage characteristic of this model (see [12]) is given by:

$$I=I_L-I_D-I_{sh}=I_L-Io\{\exp[(V+I.R_S)/a]-1\}-(V+IR_S)/R_{sh} \qquad (6.1)$$

The Power is given by

$$P=VI \qquad (6.2)$$

The power as a function of voltage is shown in figure 6.2. The maximum power that can be obtained corresponds to the rectangle of maximum area under the IV curve. At the maximum power point the power is P_{MPP} the current is I_{MPP} and voltage is V_{MPP},

$$P_{MPP}=I_{MPP}.\,V_{MPP}, \qquad (6.3)$$

At short circuit conditions, the diode current is very small and the light current is equal to the short circuit current.

$$I_L = I_{SC} \qquad (6.4)$$

At open circuit conditions the current is zero and the 1 in equation (6.1) is small compared to the exponential term so that,

$$I_O = I_L . \exp(-V_{OC}/a) \qquad (6.5)$$

The point where modules deliver maximum power is known as maximum power point (MPP). The normalisation of power at MPP to the product of Voc and Isc is called fill factor (FF).

$$FF = P_{MPP} / V_{OC} . I_{SC} \qquad (6.6)$$

Fill factor is an important parameter because it is a measure for the quality of any given module. Typical values are in order of 0.7.

Efficiency of a PV module can be predicted from the efficiency of the individual cells. Efficiency of solar cells is defined as in the following equation:

$$\eta = P_{MPP}/A.G \qquad (6.7)$$

Where, A= the active area of a cell (m^2)

G= the solar irradiation (W/m^2).

P_{MPP} = maximum power point. (W)

The typical conversion efficiencies for most commercially available crystalline silicon modules are now in the range of 11% to 17%.

6.5.0 Characteristics of PV Module:

6.5.1. I-V Characteristics of PV module:

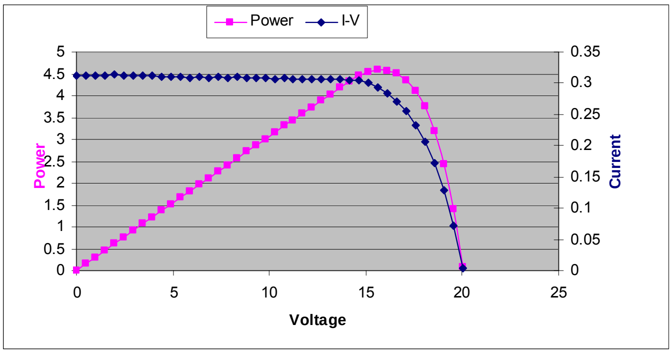


Figure 6.2: I-V and power curve at STC

In the figure 6.2 .shows the reading of the module testing of Standard Test Condition (STC) these being a light intensity equivalent to $1000Wm^{-2}$, a spectral content corresponding to a standard AM1.5 global spectrum and an operating temperature of

25°C. In this figure the measured open circuit voltage is V_{OC}=20.07 volts and the short circuit current is I_{SC}=0.313 amperes. (Appendix C1)

It is found that the output current decreases from maximum to minimum value when the voltage drop across the load is decreased from maximum to minimum value.

6.5.2. P-V Characteristics of PV Module

Figure 6.2 shows the curve of P-V characteristics obtained from the experimental data for the module of PV operated system. The maximum power determined from this figure is 4.59 watts and corresponding maximum power point voltages are recorded as 15.63Volts. The fill factor is found to be about 73.02 % (Appendix C1).

6.5.3 I-V Characteristics of Different Radiation:

Current-voltage curve are shown in the figure 6.3 for the crystalline module operating at approximately fixed temperature and at different radiation levels. For module, the short circuit current increases in proportion to the solar radiation while the open circuit voltage increases logarithmically. The solar PV module is the most reliable component of the SHS. As long as the curved portion of the I-V characteristics does not intersect the current axis. The short circuit current is nearly proportional to the incident radiation.

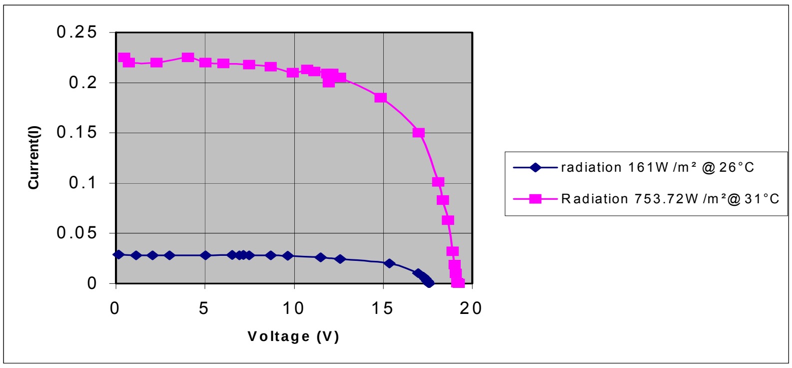


Figure 6.3: I-V Curves of different radiation.

6.5.4. Temperature Effects:

Temperature effect on modules can be critical in some areas. In full sun, the module temperature can increase to 70°C. Normally a quality module has a temperature coefficient of about –2.5mV/ °C/cell. At 70°C a 36-cell module should be able to charge the battery sufficiently. Because a protection diode is connected in series with the module in most systems, the voltage drop across this diode should also be taken into account. (See [38] [5]).

The temperature coefficient increases with a decrease in module quality. After measured a 6Watts module at 25°C (STC) a 36-cell module based on Si-cells. Open circuit voltage is 20.07V. At 70°C this will be 16.02V. That is (70°-25°) x 2.5mV/ °C/cell x 36 cells=4.05V lower.

The figure:6.4 the effect of temperature on a crystalline module I-V Characteristics; Approximately at a fixed radiation (950w/m² to 1000 w/m²) level, increasing temperature from 25°C to 41°C leads to decreased open circuit voltage from 20.07V to 18.68V and slightly increased short circuit current.

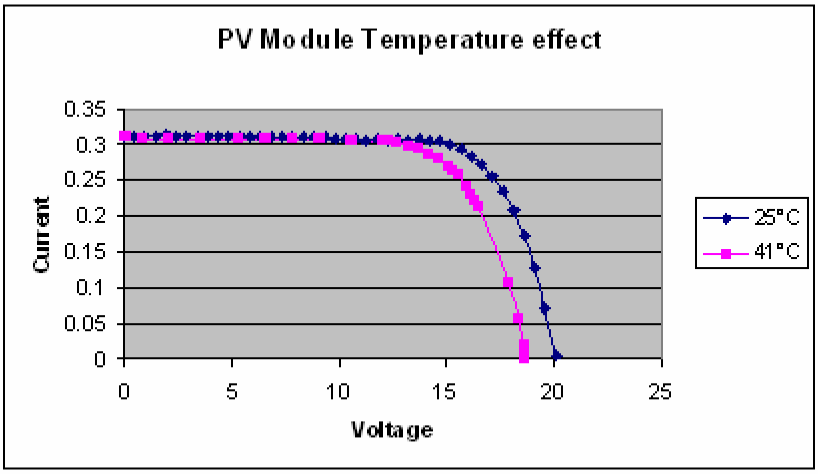


Figure 6.4: I-V Curves of different Temperature.

6.6 Battery Voltage Range:

Battery charging current is sent to battery at the maximum safe rate and it will accept until voltage rises to near (80-90%) full charge level. Charging a battery with PV module, the range of voltages will be 11.5 volts to 14.5 volts is shown in figure.6.5:

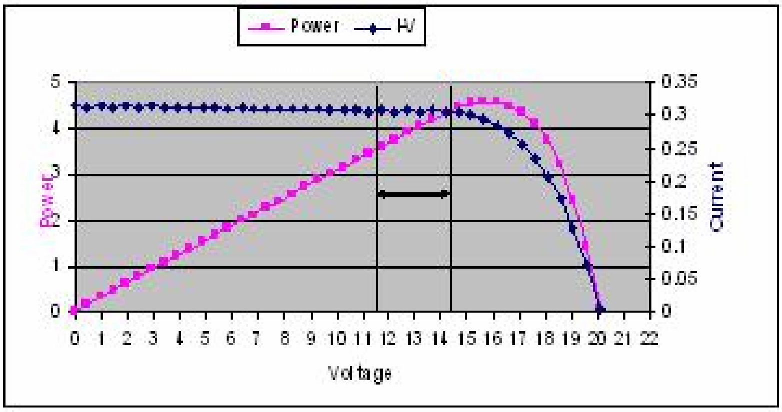


Figure 6.5: Range of battery voltages

6.7 Module Support Structure:

PV module must be placed to receive the most sunlight. Tilt angle should be selected to optimise the energy collection during the worst month, i.e., the month with the lowest ratio of monthly mean daily irradiation to the monthly mean daily load. Generally, constant user load can be assumed. Then, the following formula can be used

$$\textbf{Tilt } (^{o}) = \max \{/\Phi/\pm 10^{o}\} \qquad \textbf{(6.8)}$$

Where, Φ = the latitude of the installation.
This formula leads to a minimum tilt angle of 10^{o}, which is sufficient to allow rainwater to drain off the surface. It may also be useful to note that slight azimuth deviations from south/north (+/-30^{o}) and in the tilt angle (+/-10^{o}) have a relatively small influence on the energy output of a PV module (see [1])
The latitude of Bangladesh between 23°46 N to 25°02 N
Tilt angle (°) = between 33° to35°

Support structures should be able to resist, at least, 10 years of outdoor exposure without appreciable corrosion and must withstand winds of 120 km/h. There are several ways to mount the module - fixed, manual tracking, and automatic tracking. All of these mounting approaches can be placed on the ground or on a roof except for some active trackers which are pole mounted and thus more suited for a ground mount.

We are completely against to manual tracking because it implies a risk of damage to the modules, and a risk of energy lost through poor adjustment.

6.8 Discussion:

Solar radiation and temperature are the two principal factors affecting PV module performance. Peak current and power output are directly proportional to the incident solar radiation.
The module efficiency is related to the total area of the module. The performance of the module is also a function of its operating temperature and hence the rated efficiency is quoted at a standard temperature of 25°C. The module voltage reduces with increasing temperature and although the current increases slightly, the overall effect is for the efficiency to reduce as the temperature rises. The amount of the charges depends on the cell type and structure, with crystalline silicon cells typically losing about 0.4%-0.5% of their output per degree Celsius rise. The operating temperature varies as a function of the climatic conditions of ambient temperature and incident sunlight and also depends on the module design and the module mounting.

7.0 BATTERY.

The most commonly used battery in solar home systems in developing countries is a lead-acid battery which is used in automobiles, because they are relatively inexpensive and available locally. Ideally, solar home systems should use deep-cycle lead-acid batteries that have thicker plates and more electrolyte reserves than automotive batteries and allow for deep discharge without seriously reducing the life of or damaging the battery. In a well-designed solar home system, such batteries can last for more than five years. (See [5])

The primary functions of a storage battery in a PV system are:

1. **Energy storage capacity and autonomy:** to store electrical energy when it is produced by the PV module and to supply energy to electrical loads as needed or on demand.
2. **Voltage and current stabilization:** to supply power to electrical loads at stable voltages and currents
3. **Supply surge currents:** to supply surge or high peak operating currents to electrical loads or appliances.

7.1. Type of Battery:

According to the constructional material there are two types of batteries (see [4]):

1. Lead-Acid battery
2. Nickel-Cadmium battery

Due to the high cost of Nickel Cadmium battery, Lead Acid battery is usually used in SHS, According to the formation; Lead acid battery is again classified as:

1. Sealed battery
2. Flooded battery

Flooded lead Acid battery, depending on their application is classified as:

1. Automotive or SLI battery
2. Industrial Battery

7.2. Lead-Acid Battery:

The Lead-acid battery is the principal battery technology for SHS due to its relative cheapness and wide availability. It does require maintenance and has a finite life depending on construction.

The depth of discharge for lead acid batteries should under no circumstances exceed 80%. When fully discharged a lead-acid cell will have a terminal voltage of 1.9V giving a discharged 12V battery voltage of 11.4 V. and in the fully charge condition the lead-acid cell terminal voltage 2.4V and a fully charge 12V battery will have a voltage 14.4V. Lead acid battery capacity is reduced by 0.8% per ^{0}C below 25^{0}C. (See [29]).

Automotive or Motor cycle Batteries: Starting, lighting and ignition (SLI) battery is a type of lead-acid battery designed primarily for shallow cycle service, most often used for automobile starters. Motor cycle battery is small capacity (4Ah to 14Ah @C10 and 6V to12V)of automobile battery(see[41]) These batteries have a number of thin positive and negative plates per cell, designed to increase the total plate active surface area. The large number of plates per cell allows the battery to deliver high discharge currents for short periods. While they are not designed for long life under deep cycle service, now SLI battery is using for SHS in developing countries. SLI battery provide up to two years of useful service in small SHS. There are three type of SLI battery: Classical SLI battery, Modified SLI battery and Low maintenance SLI Battery. Classical SLI batteries use lead grid alloyed with antimony and require periodic topping up with water. The short lifetimes of automobile batteries can also be compensated to some extent by introducing relatively simple modification to the battery design. The most common modifications are thicker electrode plate and a larger quality of acid solution in the space above the plate. This type of modified SLI batteries are some time marketed as ‘Solar battery’. (See [1])

Industrial battery:

Industrial battery is a type of lead acid battery designed for deep discharge cycle service; Industrial batteries are used where small amount of current is required over a long period of time. These batteries have a fewer number of plates per cell, the plates are much thicker or tubular type and constructed more durably.

These plates are made of antimonies lead placed vertically by a stout integral frame bar at the top and an insulating bar at the bottom. In tubular plate, the lead spines are surrounded by a highly porous, plastic tube, the active mass is located between the lead spine and the tube. The high current capability of this type of electrode is nevertheless limited, because the dimension of the tube can not be reduced. This type of battery usually allows the maximum depth of discharge up to 80% and also having a long life time but too expensive for SHS uses as compared with SLI battery. A particular disadvantage with tubular type solar battery for very small SHS is that they do not readily accept low rates of charge. (See [4], [5])

7.3. Lead-Acid Battery Chemistry:

The basic lead-acid battery cell consists of sets positive and negative plates, divided by separators, and immersed in a case with an electrolyte solution. In a fully charged lead-acid cell, the positive plates are lead dioxide (PbO_2), the negative plates are sponge lead (Pb), and the electrolyte is a diluted sulphuric acid solution. When a battery is connected to an electrical load, current flows from the battery as the active materials are converted to lead sulphate ($PbSO_4$). (See [7])

7.4. Lead-Acid Cell Reaction:

The following equations show the electrochemical reactions for the lead-acid cell. During battery discharge, the directions of the reactions listed goes from left to right. During battery charging, the direction of the reactions is reversed, that is the reactions go from right to left. The elements as well as charge are balanced on both sides of each equation. (see[7])

At the positive plate or electrode:

$PbO_2 + 4H^+ + 2e^- \Leftrightarrow Pb^{2+} + 2H_2O$

$Pb^{2+} + SO_4^{2-} \Leftrightarrow PbSO_4$

At the negative plate or electrode:

$Pb \Leftrightarrow Pb^{2+} + 2e^-$

$Pb^{2+} + SO_4^{2-} \Leftrightarrow PbSO_4$

Overall lead-acid cell reaction:

$PbO_2 + Pb + H_2SO_4 \Leftrightarrow 2PbSO_4 + 2H_2O$

7.5. Which Type of Battery should be Chosen?

In order to maximise the lifetime of lead acid batteries, the following operating conditions must be avoided (see. [1])

High voltages during charging (to prevent against corrosion and loss of water)
Low voltages during discharge (corrosion)
Deep discharge (sulphation, growth of dentrites)
Extended periods without a fully charging (sulphation)
High battery temperatures (all ageing processes are accelerated)
Stratification of the electrolyte (sulphation)
Very low charge currents (sulphation)

Full charging needs high voltages but high voltages accelerate corrosion, so compromises must be found taking into account the particular local conditions: solar radiation, PV module and battery prices, local manufacturing, recycling infrastructure, etc.

To prevent excessive discharge leads to the need to limit the maximum depth of discharge to a certain value, DOD_{MAX}, which is usually ranges from 0.3 to 0.6, but can approach 0.8 according to the type of battery. The supply to the load must be cut when this limit is reached. (See [1])

The available or useful capacity

$$\mathbf{C_U = C_B. DOD_{MAX}} \qquad \mathbf{(7.1)}$$

Where:

C_U =the available or useful capacity,

C_B =nominal capacity,

DOD_{MAX} = maximum depth of discharge

7.6. Battery Charging:

Battery Charging takes place in three basic stages: bulk, absorption and float this idea from [7].

Bulk or Normal Charge: The first stage of battery charging. Current is sent to battery at the maximum safe rate and it will accept until voltage rises to near (80-90%) full charge level. Voltages at this stage typically range from 10.5 volts to 15 volts. There is no "correct" voltage for bulk charging.

Absorption Charge: The 2nd stage of battery charging. When voltage remains constant and current gradually tapers off as internal resistance increases during charging. It is during this stage that the charge controller puts out maximum voltage. Voltages at this stage are typically around 14.2 volts to 15 .5 volts.

Float or Finishing Charge: The 3rd stage of battery charging. After battery reach full charge, charging voltage is reduced to a lower level (typically 12.8V to 13.2V) to reduce gassing and prolong battery life.

Battery charging voltages and currents:

Most flooded battery should be charged at no more than the "C/8" rate for any sustained period. "C/8" is the battery capacity at the 20-hour rate divided by 8. Charging at 15.5volts will give a 100% charge on Lead-Acid batteries. Once the charging voltage reaches 2.583 volts per cell, charging should stop. Flooded battery must bubble (gassing) somewhat to insure a full charge, and to mix the electrolyte. Float voltage for Lead-Acid batteries should be about 2.15volts to 2.23 volts per cell, or about 12.9 volts-13.4 volts for a 12 volts battery. At higher temperatures (over 85°F) this should be reduced to about 2.10 volts per cell.

7.7. Battery Discharging:

Depth of Discharge (DOD): The depth of discharge (DOD) of a battery is defined as the percentage of capacity that has been withdrawn from a battery compared to the total fully charged capacity. The depth of discharge and state of charge of a battery add to 100 percent. (See [7])

Maximum DOD: The maximum percentage that can be withdrawn from a battery is known as its maximum depth of discharge. In SHS, the low voltage load disconnect (LVD) set point of the battery charge controller dictates the maximum DOD limit at a given discharge rate. The maximum DOD should not exceed the values proposed in the table: 7.1.

Table 7.1: Maximum DOD chart of different types of batteries (source [1])

Battery type	**Maximum DOD (%)**	
	Compulsory	Recommended
Industrial (Tubular type)	80	70
SLI		
Classical	50	30
Modified	60	40
Low maintenance	30	20

The maximum DOD is related to the autonomy, in terms of the capacity required to operate the system loads for a given number of days without energy from the PV module.

Average Daily DOD: The average daily depth of discharge is the percentage of the full-rated capacity that is withdrawn from a battery with the average daily load profile.

The average daily DOD is inversely related to autonomy; meaning that systems designed for longer autonomy periods have a lower average daily DOD.

State of Charge (SOC): The state of charge (SOC) is defined as the amount of energy in a battery, expressed as a percentage of the energy stored in a fully charged battery. Discharging a battery results in a decrease in state of charge, while charging results in an increase in state of charge. A battery that is being discharged 75% is said to be at 25% state of charge. The voltages while under charge will not tell us anything, we have to wait at rest for 3 hours or more.

Self Discharge Rate: In a battery put in open-circuit mode for a long lime, the battery undergoes a reduction in state of charge, due to internal mechanisms and losses within the battery. Different battery types have different self discharge rates, the most significant factor being the active materials and grid alloying elements used in the design. Higher temperatures result in higher discharge rates particularly for lead-antimony batteries.

7.8. Battery Maintenances:

There are two common instruments for test a battery for SHS, Hydrometer and Load tester.

Hydrometer: A hydrometer is an instrument used to measure the specific gravity of electrolyte or the ratio of the solution density to the density of water. While the specific gravity of the electrolyte can be estimated from open circuit voltage readings, a hydrometer provides a much more accurate measure. The specific gravity of the electrolyte is related to the battery state of charge in lead- acid battery. In a full charged lead- acid battery, the electrolyte is approximately 36% sulphuric acid by weight or 25% by volume, with the remainder water.

In a fully charged lead-acid battery, the specific gravity of the electrolyte is typically in the range of 1.25gm/cc to 1.28 gm/cc at temperature of 27°C, meaning that the density of the electrolyte is between 1.25 and 1.28 times that of pure water (see [1]). When the battery is discharged, the hydrogen (H^+) and sulphate (SO_4^{2-}) ions from the sulphuric acid solution combine with the active materials in the positive and negative plates to form lead sulphate($PbSO_4$), decreasing the specific gravity of the electrolyte . As the battery is maximum depth of discharge, the sulphuric acid solution becomes diluted until there are no ions left in solution. At this point the battery is fully discharged, and the electrolyte is essentially water with a specific gravity of one.

Load Tester: A battery load tester is an instrument which draws current from a battery with an electrical load and recording the voltage at high discharge rate for short periods. By load tester not only determine the capacity of battery but also determine the general health of battery in a system. Load test data are generally expressed as a discharge current over a specific time period.

7.9. Battery Mounting:

Batteries are mountain a good ventilated room as cool as possible because of extremely corrosive gas and the room should also rain protected but not in living room. Batteries are sometimes left exposed on the ground and accessible to children. The potential dangers (burns from battery acids, shorts, and explosions) highlight the need for a well-designed battery enclosure to maximise safety and minimise maintenance. Some enclosures are made of injection- moulded plastic or Fiberglas, the enclosure contains the battery, battery charge controller, charge indicators and switches. The electronic elements are isolated from the battery, and the battery enclosure has vents to disperse gases and can have channels to divert any acid overflow. There is no exposed wiring and the battery can be checked and filled easily.

7.10 Conclusion

For a small SHS the initial investment cost has to be kept low. In practice the local availability of battery will also be a desired factor. Therefore motor cycle battery is the best and low cost options in Bangladesh where solar battery is not available. A particular disadvantage with tubular type solar battery for SHS is that they do not readily accept low rates of charge. They are also too expensive and are rarely available in the rural markets.

8.0. CHARGE CONTROLLERS

8.1. Introduction:

The primary function of a charge controller in a Solar Home System (SHS) is to maintain the battery at highest possible state of charge, when PV module charges the battery the charge controller protects the battery from overcharge and disconnects the load to prevent deep discharge. Ideally, charge controller directly controls the state of charge of the battery.

Without charge control, the current from the module will flow into a battery proportional to the irradiance, whether the battery needs to be charging or not. If the battery is fully charged, unregulated charging will cause the battery voltage to reach exceedingly high levels, causing severe gassing, electrolyte loss, internal heating and accelerated grid corrosion. Actually charge controller maintains the health and extends the lifetime of the battery.

8.2. Charge Controller Types:

Two basic methods exist for limiting the charging of a battery from a PV module, shunting the module and operating an on-off switching between module and battery.

8.2.1. Shunt Controller:

PV module can be short-circuited without any harm. The ability to short-circuit modules is the basis of operation for shunt controllers. The shunt controller regulates the charging of a battery from the PV module by short-circuiting the module internal to the controller. All shunt controllers must have a blocking diode in series between the battery and the shunt element to prevent the battery from short-circuiting when the module is regulating. Because there is some voltage drop between the module and controller and due to wiring and resistance of the shunt element, the module is never entirely short circuited, resulting in some power dissipation within the controller. For this reason, most shunt controllers require a heat sink to dissipate power, and are generally limited to use in PV systems with module currents less than 20 amps.(see[29])

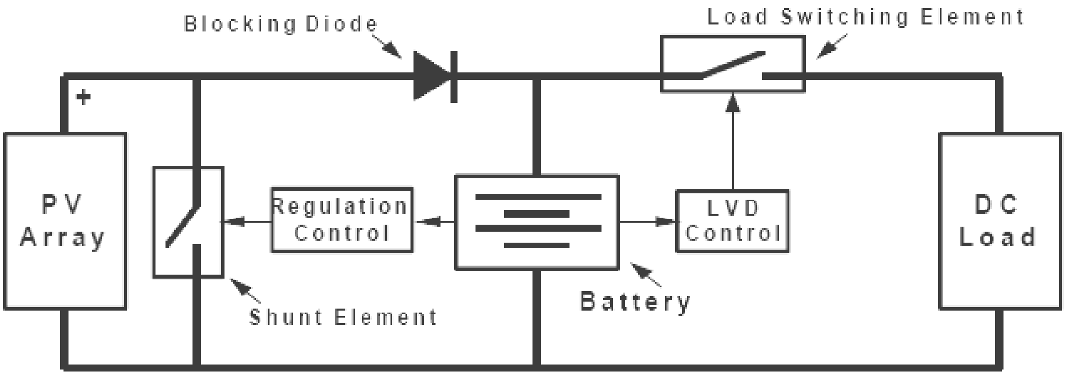


Figure 8.1: Shunt Controller. (Source [7])

8.2.2. Series Controller:

This type of controller works in series between the module and battery, rather than in parallel to the module as for the shunt controller. This type of controller is commonly used in small PV systems. In a series controller, a relay or solid-state switch either opens the circuit between the module and the battery to discontinuing charging, or limits the current in a series-linear manner to hold the battery voltage at a high value. In the simpler series interrupting design, the controller reconnects the module to the battery once the battery falls to the module reconnect voltage set point. As these on-off charge cycles continue, the ‘on’ time becoming shorter and shorter as the battery becomes fully charged. The series controller open-circuits rather than short-circuits the module as in shunt-controllers, no blocking diode is needed to prevent the battery from short-circuiting when the controller regulates (see [29])

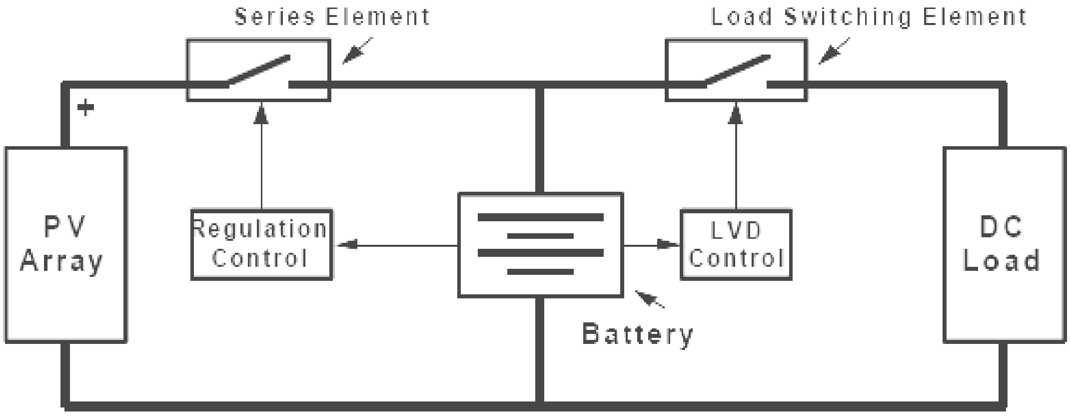


Figure 8.2: Series Controller. (Source [7])

8.3. Functions of Battery Charge Controller:

8.3.1. Overcharge Protection:

A charge controller controls the battery voltage. In a 12 V battery system the voltage vary between 10.5 volts and 14.4 volts, depending on the actual state of charge of the battery, charge current, discharge current, type and age of the battery.

When a normal full loaded battery and no charging or discharging current is flowing than the battery voltage is about 12.4 volts to 12.7 volts, when charging current is flowing the voltages jump to a higher level e.g. 13.7 V (depending on the current), when loads are switched on the voltage drops down to a lower lever e.g. 12.0volts or 11.8 volts (also depending on the current).

The PV module produces energy and the current is flowing into the battery so voltage level increases up to the range of 14.4 volts. Then the over charge protection starts the work.

When the battery voltage level is reached on 14.4 volts, the charge controller is switched off the charging current or reduced it (by pulse wide modulation). Depending on the state of charge of the battery, the level of voltage 14.4 V is a good compromise for fast charging of the battery by a low gassing rate. At the voltage 13.7V there is no gassing at all.(see[1],[7] and [9]).

When charging up to 14.5 volts inside the battery bubbles comes into being and mixes the liquid while moving to the surface. The charge controller charging characteristic is the gassing charge situation the reason for that is the acid inside the battery must be well mixed to increase capacity and lifetime of the battery. The gassing charge program will run if the battery has not been charging since long period or when the battery is deep discharging.

8.3.2. Deep discharge Protection:

When a battery is deeply discharged, the reaction in the battery occurs close to the grids, and weakens the bond between the active materials and the grids. When the battery is deep discharged repeatedly, loss of capacity and life will eventually occur. To protect battery from deep discharge, most charge controllers include an optional feature to disconnect the system loads once the battery reaches a low voltage or low state of charge condition.

If the voltage of the system falls below 11.5 volts for a period of minimum 20 sec than the charge controller will be switched off for minimum 30 seconds. Than all loads which are connected to the controller is off. If the battery voltage increase above

12.5volts for more than 20 seconds than the charge controller will be switched ON the loads again for a minimum time of 30 seconds. The delay of 30 seconds is integrated to protect the system against a swinging situation (See [1], [7], and [9]).

8.4.0. Charge Controller Set Points:

8.4.1. High Voltage Disconnect (HVD) Set Point:

The high voltages disconnect (HVD) set point is one of the key specifications for charge controllers. The voltage regulation set point is the maximum voltage that the charge controller allows the battery to reach, limiting the overcharge of the battery. Once the controller senses that the battery reaches the voltage regulation set point, the controller will either discontinue battery charging or begin to regulate the amount of current delivered to the battery.

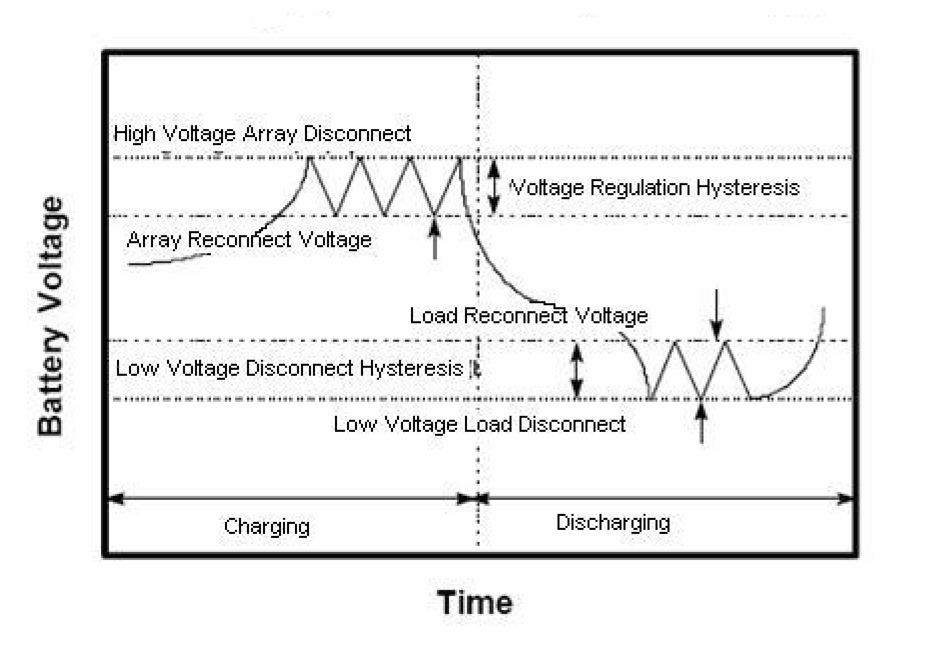


Figure 8.3: Charge controller set points (source [7])

8.4.2. Array Reconnect Voltage (ARV) Set Point:

In interrupting (on-off) type controllers, once the module or array current is disconnected at the voltage regulation set point, the battery voltage will begin to decrease. If the charge and discharge rates are high, the battery voltage will decrease at a greater rate when the battery voltage decreases to a predefined voltage, the module is again reconnected to the battery for charging. This voltage at which the module is reconnected is defined as the array reconnects voltage (ARV) set point.

8.4.3. Voltage Regulation Hysteresis (VRH):

The voltage differences between the high voltages disconnect set point and the array reconnect voltage is often called the voltage regulation hysteresis (VRH). The VRH is a major factor which determines the effectiveness of battery recharging for interrupting (on-off) type controller. If the hysteresis is too big, the module current remains disconnected for long periods, effectively lowering the module energy utilization and making it very difficult to fully recharge the battery. If the regulation hysteresis is too small, the module will cycle on and off rapidly. Most interrupting (on-off) type controllers have hysteresis values between 0.4 and 1.4 volts for nominal 12 volts systems.

8.4.4. Low Voltage Load Disconnect (LVD) Set Point:

Deep discharging the battery can make it susceptible to freezing and shorten its operating life. If battery voltage drops too low, due to prolonged bad weather or certain non-essential loads are connected the charge controller disconnected the load from the battery to prevent further discharge. This can be done using a low voltage load disconnect (LVD) device is connected between the battery and non-essential loads. The LVD is either a relay or a solid-state switch that interrupts the current from the battery to the load,

8.4.5. Load Reconnect Voltage (LRV) Set Point:

The battery voltage at which a controller allows the load to be reconnected to the battery is called the load reconnect voltage (LRV). After the controller disconnects the load from the battery at the LVD set point, the battery voltage rises to its open-circuit voltage. When the PV module connected for charging, the battery voltage rises even more. At some point, the controller senses that the battery voltage and state of charge are high enough to reconnect the load, called the load reconnect voltage set point. LRV should be 0.08 V/cell (or 0.5 V per 12 V) (see [1]) higher than the load-disconnection voltage. Typically LVD set points used in small PV systems are between 12.5 volts and 13.0 volts for most nominal 12 volt lead-acid battery. If the LRV set point is selected too low, the load may be reconnected before the battery has been charged.

8.4.6. Low Voltage Load Disconnect Hysteresis (LVLH):

The voltage difference between the low voltage disconnect set point and the load reconnect voltage is called the low voltage disconnect hysteresis. If the low voltage disconnect hysteresis is too small, the load may cycle on and off rapidly at low battery state-of-charge (SOC), possibly damaging the load or controller, and extending the time it takes to fully charge the battery. If the low voltage disconnect hysteresis is too large the load may remain off for extended periods until the array fully recharges the battery.

8.5. Experiments on Different Charge Controller:

Three different battery charge controller (a) Rahimafrooz charge controller product of Bangladesh, (b) SunOasis charge controller product of China and (c) Steca Charge controller of Germany have been collected and tested. We observed the behaviour of the three different charge controllers.

For this measurement a battery 2.2 Ah @20 hr was connected with Rahimafrooz battery charge controller and the battery were started to charging with a power pack 12V and constant current 200mA. At the beginning the voltage increased. So current was feeding into the battery. And the charge controller did not regulate and all the current was feeding into the battery.

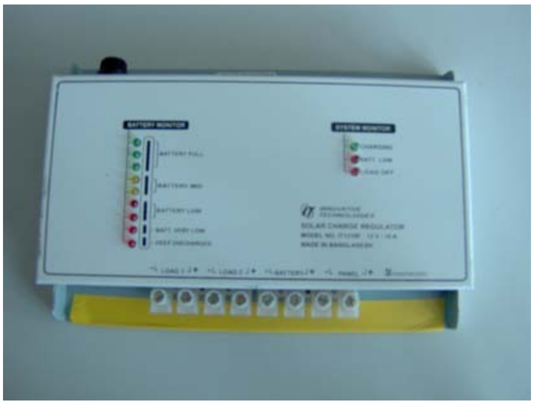


Figure 8.4: Rahimafrooz charge controller

Approximately 75 minutes after the battery voltage was reached the regulation voltage set point (14.48 volts) of the battery charge controller, and the controller began to regulate the current. During regulation, the maximum battery voltage was between 14.4 and 14.5 volts. This maximum battery voltage corresponded to the voltage regulation set point for the battery charge controller. The minimum battery voltage was about 13.94 volts. The fact that the minimum voltage was consistent over the regulation period indicated that the controller was regulating the battery voltage between the voltage regulation and module reconnection set points. This voltage difference 0.54 volt is often referred to as the controller’s hysteresis. The hysteresis is an important specification for a controller and must be selected properly to achieve good module energy utilization and proper battery charging.

Then a load (CFL lamp 12V/ 0.51 A) was connected in the system to start deep discharging process. The battery voltage decreased steadily from 12.8V to 12.18V after one minute the charge controller disconnected the load. It was observed in the oscilloscope that when battery voltage was 11.9V the charge controller disconnected the load. And there was a sharp rise in the battery voltage as it approached to an open-circuit (no load) voltage of about 12.9 volts. This voltage regulation set point might not be perfect for this type of SHS, because this charge controller was made for solar home system whose discharge battery rated at 100 hours discharge rate (see [27]).

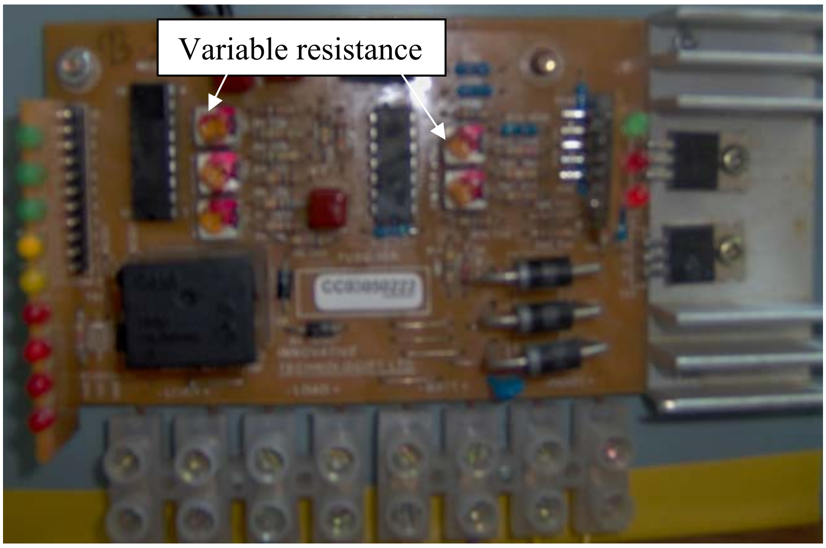


Figure 8.5: Circuit of the Rahimafrooz charge controller

The charge controller cover was removed and found the circuit diagram shown in figure 8.5. It was found that there were five variable resistances, one of them for adjustment high voltages disconnect set point and another one was adjusting for the deep discharge disconnects set point. Again it was connected the load and the battery to the system and adjusting the variable resistance for deep discharge protection with the help of oscilloscope. It was fixed the deep discharge disconnect set point in11.5volts and load reconnection voltage set point in 12.5volts. Observed the behaviour of the charge controller which is shown in figure 8.6:

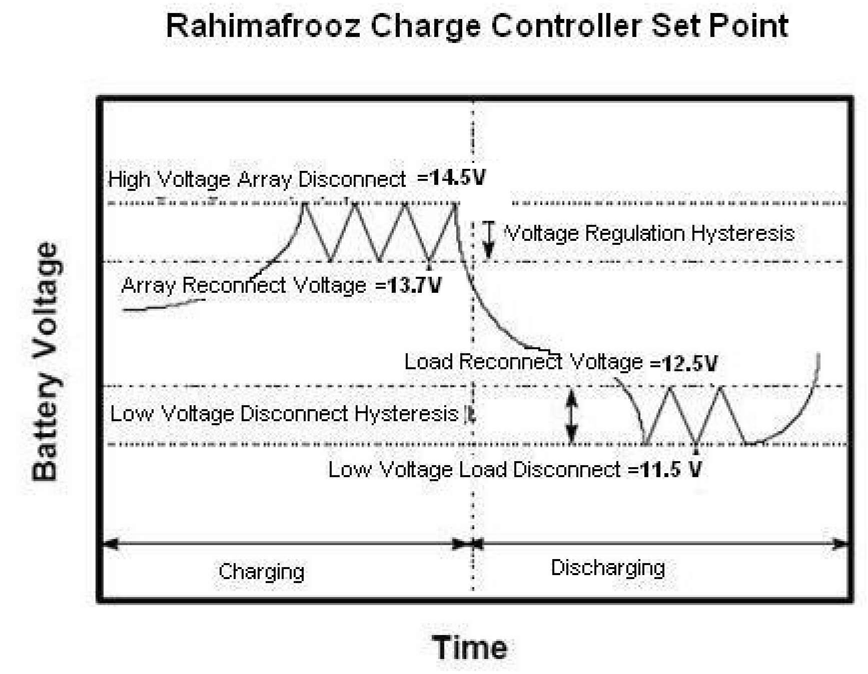


Figure 8.6: Rahimafrooz charge controller set points.

In the oscilloscope it was found the behaviour of overcharge protection curve and deep discharge protection curve for the Rahimafrooz charge controller which is shown in figure 8.7:

Figure 8.7.a: Overcharge protection curve

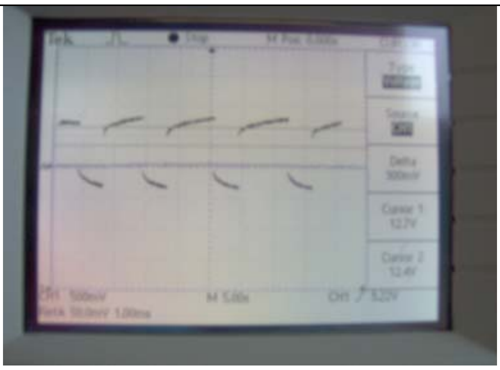


Figure 8.7.b: Deep discharge protection curve

Afterward it was connected the power pack for charging the battery using the same charge controller, it was adjusted the variable resistance with the help of oscilloscope and it was fixed the high voltage disconnection set point in 14.5volts and array reconnection voltage set point in 13.7volts. This charge controller discharged battery at rated 10 hours discharge rate. Then the battery was discharged with the same load (CFL lamp 12V/ 0.51amp) and it was observed that after half an hour battery voltage was 11.5V and the charge controller disconnected the load for save the battery deep discharge.

Another load (LED lamp 12V/ 0.08 amps) was connected in the same system, the battery voltage decreased steadily from about 12.8 volts to 12.5 volts then voltage decreases slowly after 10 hours found that battery voltage was 11.5 volts, the load current was disconnected by the charge controller load regulation circuit. At this point battery current went to zero, and there was a sharp rise in the battery voltage as it approached an open-circuit (no load) voltage of about 12.5 volts.

Then it was observed the behaviour of the other two charge controllers Steca and SunOasis which is shown in figures 8.8, and 8.9, Table 8.1 shows the summarised comparative observation of three different charge controllers.

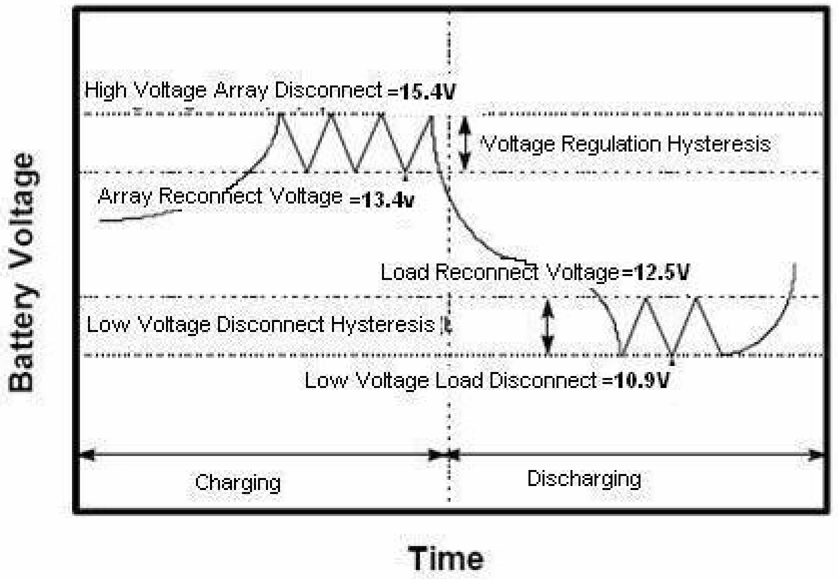


Figure 8.8: Sunosis charge controller set points.

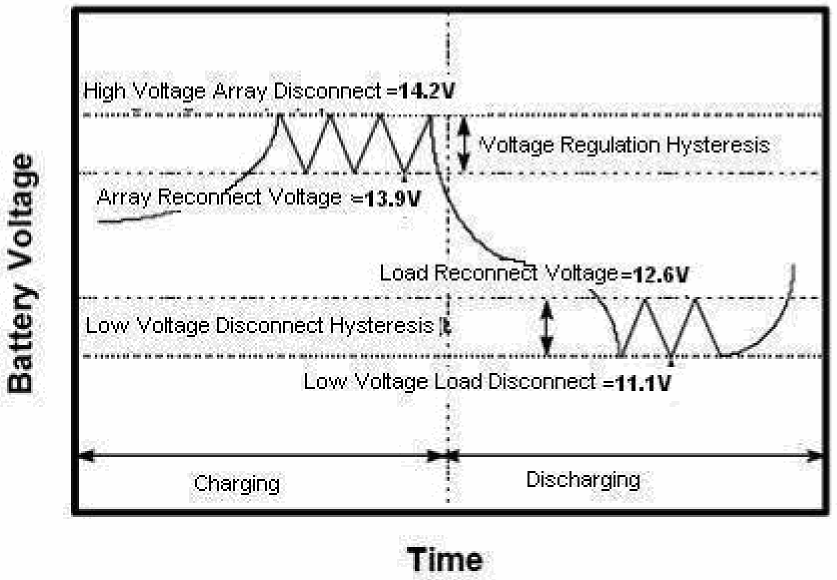


Figure 8.9: Steca charge controller set points.

Table 8.1: Comparative observation of different charge controller set point:

Description	Charge Controller 1	Charge Controller 2	Charge Controller 3
Model	XNY-TZ-12/24/05B	IT1210F.12V/10A	Solsum6.6C
Company	SUNOASIS	Rahimafrooz	Steca
Internal Current Consumption	13mA	5.47mA	4mA
Voltage Regulation	15.4V	14.5V	14.2V
Array reconnect Voltage	13.4V	13.7V	13.9V
Voltage regulation Hysteresis	1.98V	0.80V	0.22V
Load Reconnect Voltage	12.5V	12.5V	12.6V
Low voltage load disconnect voltage	10.9V	11.5V	11.1V
Low voltage disconnect Hysteresis	1.6V	1.0V	1.5V

8.6. Suggestion and Conclusion:

The charge controller prevents SHS for overload or overcharging. For safe and reliable operation, the controller design should include: deep discharge protection.

Low voltage load disconnection voltage should correspond to the maximum depth of discharge values, when the discharge current, in amp, is equal to the daily load consumption, in amp-hours, divided by 5.

Load –reconnection voltage should be 0.08V/ cell (i.e. 0.5V per 12V battery) higher than load disconnection voltage.

Load –disconnection and load-reconnection voltage should be accurate to within ± 1% (± 20mV/cell or ±120mV / battery of 12V) and remain constant over the full range of possible ambient temperature.

Disconnection of the load should be delayed for between 3 and 30 seconds after the load disconnection voltage has been reached.

High voltage disconnect point should lie in the range from 2.3 to 2.4 V/cell (13.8V to 14.4V per 12V battery), at 25°C.

Internal voltage drops between the battery and PV generator terminals of the charge controller must be less than 4% of the nominal voltage (≈ 0.5V for 12V) in the worst operation conditions i.e., with all the loads off and the maximum current from the PV generator.

Internal voltage drops between the battery and load terminals of the charge controller must be less than 4% of the nominal voltage(≈ 0.5V for 12V) in the worst operation conditions, i.e., with all the loads on and the no current from the PV generator.

The upper and lower controlled overcharge voltages should, respectively be 2.5 and 2.25 V/cell (15 V to 13.5V per 12V battery).

Reverse current leakage protection must be provided.

Indicate the battery charge level with a simple LED display. Three indicators are recommended: green for fully charged battery, yellow for a low charge level (pending disconnect), and red for a discharge battery.

Charge controller accounts for only about 5% of the initial investment cost of a typical SHS. However, their impact on the total long term cost of a SHS is much larger than this, because battery can easily become the largest component of the life cycle cost of the system, and the battery lifetime is directly linked to the perfect set points of the charge controller. For this reason, good quality charge controller should be used.

9.0. DIMENSION OF PV-LED LAMP SYSTEM.

To size a solar home system, first calculate the energy demand of the end user. The demanded energy of the system is known then to fulfil those demands and able to dimension of module and battery.

- Determine the average daily electricity demand
- Calculate system losses
- Calculate module wattage
- Determine the battery storage capacity
- The system losses e.g. the cable losses, energy consumption of the charge controller and losses in the battery.

9.1. Proposed Systems:

The system includes:

a. Stand alone Solar Home System (SHS-1) (appliances =3 CFL Lamps)
b. Stand alone Solar Home System (SHS-2) (appliances= 3 LED Lamps)

9.2. Estimating the Load:

Estimating the load, there are only simple calculations involved. The following steps are involved:

- Determine which type of lamp will be used
- Determine the rated power in watts for the lamps
- Estimate the number of hours each day that the item will be in use
- Multiply the rated power for each item with the estimated hours it will be in use to get watt-hours
- Add up the Wh needed for all the items

9.3 Energy Consumptions:

Energy consumption of different loads is shown in table 9.1 below:

Table 9.1:.Energy consumption of different Lamps

Lamps	Rated power (Watt)	Current (Amp)	No of hours/day	Total number of lamp use	Energy /day (Wh/day)
Lamp 1(3x 18 cd)	0.3	0.024	4	3	3.6
Lamp 2(12x 10cd)	1.0	0.090	4	3	13.2
Lamp 3(6x 6.4 cd)	0.56	0.047	4	3	6.72
Lamp 4(6x 2.5 cd)	0.43	0.036	4	3	5.16
CFL lamp	6.38	0.530	4	3	76.56

9.4. Sizing of Battery:

The battery capacity depends largely on how many days of storage capacity is needed. The need for autonomy differs from site to site, since the weather conditions are different.

1. Multiply the daily load with the number of days of the autonomy that is required,
2. Divide this number with the maximum depth of discharge allowed for the battery,

In some PV systems there are need for more than one battery, than the batteries can be connected in parallel to get a greater energy storage capacity.

Option SHS-1:

Appliance is CFL lamps and consider with out autonomy

The system voltage is 12V and the energy demand is 76.56Wh/day.

Energy consumption per day =76.56Wh/12V= 6.38Ah

Battery specification: Motor cycle Battery, (local manufacturer Rahimafrooz Battery Ltd).following types of batteries is available:

1. 12V, capacity 5Ah@C10,
2. 12V, capacity 9Ah@C10,
3. 12V, capacity 14Ah@C10,

The motor cycle battery (SLI) not allowed to be fully discharged; Allowable Maximum Depth of discharge is 50%. (See [1], [41])

Then battery capacity = 6.38Ah/ 0.5= 12.76Ah

Number of Battery

= Calculated battery capacity/rated capacity

=12.76Ah/5Ah= 2.55 ≈ 3 Batteries

Appliance is CFL lamps and considers 3 day autonomy

Then battery capacity = 6.38Ah x 3 day / 0.5= 38.28Ah

Number of Battery

= Calculated battery capacity/rated capacity

=38.28 Ah/5Ah = 7.65 ≈ 8 Batteries

So for this SHS and without autonomy need 3 numbers of 5 Ah motorcycle batteries which are connected in parallel but batteries in parallel connection are not recommended in practical field. Therefore it is a better solution to use single 12V/ 14Ah@C10 motor cycle battery.

If bad weather 3 days then need 8 numbers of 5Ah motor cycle batteries, In that case motor cycle is not suitable better use modified SLI battery(solar battery). So select single 50Ah@20hr solar battery (DOD 80%)

Option SHS-2:

Appliance is LED Lamps and consider with out autonomy

The system voltage is 12V and the energy demand is 13.2 Wh/day using LED lamps.

Energy consumption per day=13.2 Wh/12V=1.1Ah

Battery specification: (already described in option SHS-1)

Then battery capacity = 1.1Ah/ 0.5= 2.2Ah

Number of Battery

= Calculated battery capacity/rated capacity

=2.2Ah/5Ah = 0.44 ≈ 1battery

Appliance is LED lamps and considers 3 day autonomy

Then battery capacity = 1.1Ah x 3 day / 0.5= 6.6Ah

Number of Battery

= Calculated battery capacity/rated capacity

=6.6Ah/5Ah= 1.32 ≈ 2 batteries

So for the SHS without autonomy we need only one 5 Ah motor cycle battery, for bad weather 3 days then need 2 numbers of 5Ah motor cycle batteries, which is connected in parallel but batteries in parallel connection are not recommended in practical field. Therefore, better solution to use single 12V/ 9Ah@C10 motor cycle battery.

9.5. Module Sizing:

To know how to dimension the module size, the solar irradiation data must be available. It is safe to design the system, based on the average daily solar irradiation in the area, where the module is planned to be installed, for the month with the lowest irradiation rate. In Bangladesh the lowest average daily solar irradiation (Appendix A: Table A1) is around 4kW/m²/day.

Our aim for small SHS we used small capacity module.

The specification of 6Wp module is bellow:

Nominal voltage= 12V

Open circuit voltage Voc= 20.07V

Short circuit current I_{SC}=0.313A

P_{MPP}=4.59W

V_{MPP}=15.64V

I_{MPP}=0.294A

Module output = (0.293 A x 6 operating hour) = 1.758Ah

A SHS composed of a PV module whose short circuit current at STC is equal to 0.313 Amps

For SLI Battery CR=30 (Appendix A: table-A11)

The recommended ratios CR = nominal capacity of battery C_B /I_{sc} depend on the battery type

The value of CR must be low enough to ensure that the PV module is able to provide adequate re-charging of the battery. (See [1])

Maximum Battery capacity $\leq$ CR x I_{sc} =30 x 0.313=9.39 Ah

So this module is able to recharge maximum 9.39Ah capacity battery.

Option SHS-1:

Appliance is CFL lamps and consider with out autonomy

If energy demands is 76.56Wh

Then battery capacity = 12.76Ah

Number of module

= Calculated battery capacity/maximum battery capacity

=12.76Ah/9.39Ah= 1.35 ≈ 2 modules

Appliance is CFL lamps and considers 3 days autonomy

Then battery capacity = 12.76Ah x 3 = 38.28Ah

Number of module

= Calculated battery capacity/maximum battery capacity

=38.28Ah/9.39Ah = 4.12 ≈ 5 modules

So for this SHS without autonomy need 2 number of 6Wp module.

If bad weather 3 days then need 5 numbers of 6Wp module,

In that case 6Wp module is not suitable better use single 36Wp.module which can generate the required effect for the SHS.

Option SHS-2:

Appliance is LED lamps and consider with out autonomy

The system voltage is 12V and the energy demand is 13.2 Wh/day

Calculated battery capacity= 2.2Ah

Number of module

= Calculated battery capacity/maximum battery capacity

= 2.2Ah/9.39Ah= 0.23 ≈ 1 module

Appliance is LED lamps and considers 3 days autonomy

Then battery capacity = 6.6Ah

Number of module

= Calculated battery capacity/maximum battery capacity

=6.6Ah/9.39Ah= 0.7 ≈ 1 module

So 6Wp module can generate the require effect for the SHS.

9.6. Charge Controller Energy Consumption:

The charge regulator continuously consumes small amounts of energy, it is between 5mA to 25mA, (table: 8.1)

9.7. Cable Sizing:

The wires must be sized correctly so we can avoid

- Excessive losses in the cables and
- Excessive current going through the cables compared to the safe current capability.

Current carrying capacity (CCC) is a term which refers to the maximum current carrying ability of a conductor most cables that are available commercially can be used in solar home systems wiring, as long as the voltage drop and maximum current is within a specified range. The manufacturers of the cables specify the maximum current carrying capacity of their cables. (See [38])

The losses in the wires are a function of three parameters:

- The conductors cross section in mm^2
- The length of the wire
- The current flow in the wire
- The receptivity in the wire material

The maximum current drawn from the battery can be calculated with the following equation:

$$\mathbf{I = P_{max} / V_n} \qquad \mathbf{(9.1)}$$

Where: Pmax =power drawn from the battery when all loads are operating

Vn =nominal battery voltage.

The voltage drop is given by

$$V = 2LIR/A \qquad \textbf{(9.2)}$$

Where L =length of the wires in metres,

I = current in amperes,

R =receptivity of the wire in $\Omega/m/mm^2$

A=is the cross sectional area of the cable in mm^2.

The most usual material used for SHS wiring is copper, receptivity of copper R =0.01724 $\Omega/\ /m/mm^2$ at 20°C Therefore, when the length of wire, the cross sectional area of the wire and the current are known, the voltage drop can easily be determined. The voltage losses of cables must be less than 3% between PV module and charge controller, less than 1% between battery and charge controller, and less than 5% between the charge controller and load. All of there apply at the maximum current condition. (See [1])

If 3% of voltage losses between PV module and charge controller .

Length of cable =.10 m

Maximum current = 4A.

So cross-section area of cable A = 2LIR/ (V x losses)

$$= \{2\text{x } 10\text{m x } 4\text{A x } 0.01724\ \Omega.\text{mm}^2/\text{m}\}/\{0.03 \text{ x } 12\text{V}\}$$

$$= 3.83\ \text{mm}^2 \approx 4\text{mm}^2$$

If 1% of voltage losses between battery and charge controller.

Length of cable =3 m and

Maximum current = 4A.

So cross-section area of cable A= 2LIR/ (V x losses)

$$= \{2\text{x } 3\text{m x } 4\text{A x } 0.01724\ \Omega.\text{mm}^2/\text{m}\}/\{0.01 \text{ x } 12\text{V}\}$$

$$= 3.44\ \text{mm}^2 \approx 3.5\text{mm}^2$$

If 5% of voltage losses between load and charge controller.

Length of cable = 10 m and

Maximum current = 4A.

So cross-section area of cable A= 2LIR/ (V x losses)

$$= \{2\text{x } 10\text{m x } 4\text{A.x } 0.01724\ \Omega.\text{mm}^2/\text{m}\}/\{0.05 \text{ x } 12\text{V}\}$$

$$= 2.29\ \text{mm}^2 \approx 2.5\ \text{mm}^2.$$

10.0. ECONOMIC ANALYSIS

10.1. Introduction:

The application of small-scale photovoltaic systems is a very recent phenomenon in rural areas of Bangladesh. More than 90% of applications are between 30 Wp to 80 Wp. Lighting is the basic purpose most of the rural households. In case of household they use a photovoltaic system of 36 Wp, which supports 3 CFL lamps for about 4 hours/day this can be replaced by a photovoltaic system of only 6Wp and using 3 LED lamps for four hours/day power supply too. The basic approach of comparison is to estimate the cost of two options over a period of 20 years. The household is spending money to have light in the house. Therefore, Net Present Value (NPV) will be always negative. The negative value indicates expense. So, we will prefer options with smaller value of NPV.

10.2. Theory behind Net Present Value (NPV):

This method is the most logical and the most widely used method for investment decision, especially in case of long-term investment decisions. The basic principal of present value method is the fact that a 'Money today is worth more than a money tomorrow', because the money today can be invested to start earning interest immediately. Thus, the present value of a delayed payoff may be found by multiplying the payoff by a discount factor which is less than one (see [28]).

If C_1 denotes the expected payoff after one year, then

Present Value (PV) = Discount Factor X C_1 (10.1)

The discount factor is expressed as the reciprocal of 1 plus a rate of return:

Discount factor= $1/(1+r)$ (10.2)

Where:

r=rate of return.

The rate of return **r** is the reward that investors demand for accepting a delayed payment. The net present value is found by subtracting the required investment:

NPV = PV- required investment

$=C_0+C_1/(1+r)$ (10.3)

Where C_0 is the initial investment at period 0 (that is today) which is a negative figure and the above formula is valid for an investment of one year duration.

Similarly, for an investment of two years duration

$PV=C_1/(1+r_1)+C_2/(1+r_2)^2$ (10.4)

Where C_1 and C_2 are represent cash flow and r_1 and r_2 are represent discount rates

Then $NPV= C_0+ C_1/ (1+r_1) +C_2/ (1+r_2)^2$ (10.5)

Now extending the formula for an investment of n years we have:

$NPV= C_0+\sum C_n/ (1+r)^n$ (10.6)

Where C_0 is the initial investment and is negative figure.

10.3.0. Financial Analysis:

A family needs three lamps SHS for lighting and reading purpose and using 4 hours/day but the system should be cheapest. We analysis two PV applications were using energy saving CFL lamp system and LED lamp system, for the analysis used cheapest battery like motorcycle battery for storages system, which was available and locally manufactured. Both systems were also design for good weather and bad weather (cloudy/rainy season) because in a country the weather is not same at all the places.

In the investment cost of a standard solar home system, the PV module takes the major share of about 65% of the initial cost, battery takes about 13% and charge controller about 5% and other costs including lighting loads 17%.

10.3.1. Initial Cost and Life Cost Calculation (for bad weather):

Description of SHS-1 & SHS-2:

Table 10.1: Description of two different systems

SHS 1 (CFL Lighting System)		**SHS 2** (LED lighting System)	
Lamp(7W each)	3xCFL lamp	Lamp(1W each)	3xLED lamp
Module (36Wp each)	1module	Module (6Wp each)	1 module
Bad weather(Autonomy days)	3days	Bad weather(Autonomy days)	3 days
Battery 12V, 50Ah@C20 (Solar battery)	1 battery	Battery12V, 9Ah@C10 (motorcycle battery)	1 battery
Operation hour	4hr/day	Operation hour	4 hr/day
Charge Controller	12V/10A	Charge Controller	12V/10A
Life of panel	20 years	Life of panel	20 years
Lamp replacement	every 2 years	Life of LED Lamp	20 years
Battery replacement	every 5 years	Battery replacement	every 2 years
Charge controller replacement	every 10 years	Charge controller replacement	every 10 years

Initial cost calculation of SHS-1 & SHS-2

Table 10.2: Initial cost comparison of SHS-1 and SHS-2
(Consider 3 days autonomy)

SHS-1 (3 CFL lamp)		**SHS-2** (3 LED lamp)	
Component	Cost [Euro]	Component	Cost [Euro]
1 Module (36Wp)	150	1 Module (6 Wp)	25
1 solar battery (50Ah@C20) DOD 80%	56	1 motorcycle battery (9Ah) DOD 50%	12
1 charge controller	15	1 charge controller	15
3 CFL lamp	36	3 LED Lamp	30
Mounting materials, cables.	10	Mounting materials, cables	10
Total costs	267	Total costs	92

Life cycle cost calculation of SHS-1 and SHS-2:

Table 10.3: Comparison Life cycle cost of SHS- and SHS-2.
(Life time 20 years & discount rate of 9 %)

SHS -1 (3 CFL lamp)		**SHS-2** (3 LED lamp)	
Component	Cost [Euro]	Component	Cost [Euro]
1 Module (36Wp)	150	1 Module (6 Wp)	25
4 solar battery DOD 80%	136	10 motorcycle battery DOD 50%	58
2 charge controller	21	2 charge controller	21
30 CFL lamp	174	3 LED Lamp	30
Mounting materials, cables	10	Mounting materials, cables	10
Total costs	491	Total costs	144

Comparison initial cost of SHS-1 and SHS-2:

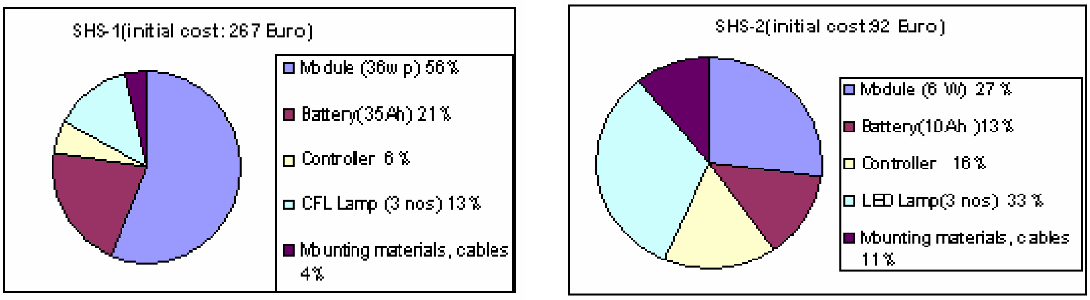


Figure 10.1: Initial cost comparison of two different SHS.

Comparison Life Cycle Cost SHS-1 and SHS-2:

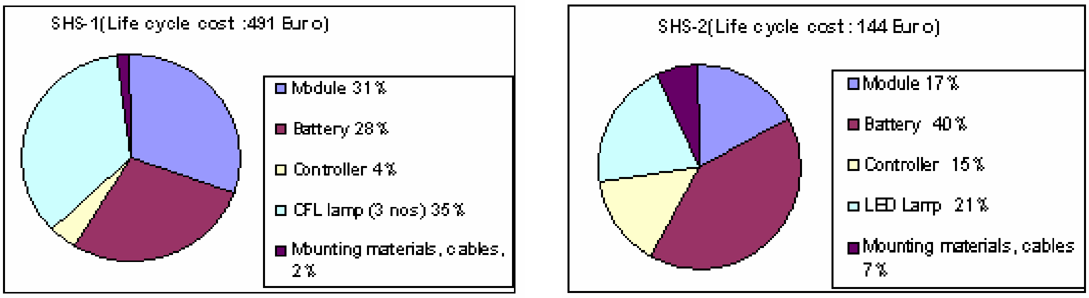


Figure 10.2: Life cycle cost comparison of two different SHSs.

10.3.2. Initial Cost and Life Cost Calculation (for good weather):

Table 10.4: Description of two different systems

SHS 1 (CFL Lighting System)		**SHS 2** (LED lighting System)	
Lamp(7W each)	3xCFL lamp	Lamp(1W each)	3xLED lamp
Module (6Wp each)	2 module	Module (6Wp each)	1 module
Bad weather(Autonomy day)	0 day	Bad weather(Autonomy day)	0 day
Battery 12V, 14Ah@C10 (Motorcycle battery)	1 battery	Battery12V, 5Ah@C10 (Motorcycle battery)	1 battery
Operation hours	4hr/day	Operation hour	4 hr/day
Charge Controller	12V/10A	Charge Controller	12V/10A
Life of panel	20 years	Life of panel	20 years
Lamp replacement	every 2 years	Life of LED Lamp	20 years
Battery replacement	every 2 years	Battery replacement	every 2 years
Charge controller replacement	every 10 years	Charge controller replacement	every 10 years

Initial cost calculation of SHS-1 & SHS-2:

Table 10.5: Initial cost comparison of SHS-1 and SHS-2
(With out autonomy)

SHS -1 (3 CFL lamp)		SHS-2 (3 LED lamp)	
Component	Cost [Euro]	Component	Cost [Euro]
2 Module (6Wp)	50	1 Module (6 Wp)	25
1 Motor cycle battery (14Ah) DOD 50%	18	1 Motor cycle battery (5Ah) DOD 50%	6
1 charge Controller	15	1 charge Controller	15
3 CFL lamp	36	3 LED Lamp	30
Mounting materials, cables &	10	Mounting materials, cables	10
Total costs	129	Total costs	86

Life cycle cost calculation of SHS-1 and SHS-2:

Table 10.6: Life cycle cost comparison of SHS-1 and SHS-2
(Life time 20 years & discount rate of 9 %)

SHS-1(3x CFL lamp)		SHS-2(3 LED lamp)	
Component	Cost [Euro]	Component	Cost [Euro]
2 Module (6Wp)	50	Module (6 Wp)	25
10 Motor cycle batteries (14Ah)DOD 50%	87	10 Motor cycle batteries (5Ah) DOD 50%	31
2 charge Controller	21	2 charge Controller	21
30 CFL lamps	174	3 LED Lamps	30
Mounting materials, cables,	10	Mounting materials, cables	10
Total costs	342	Total costs	117

Comparison initial Cost SHS-1 and SHS-2:

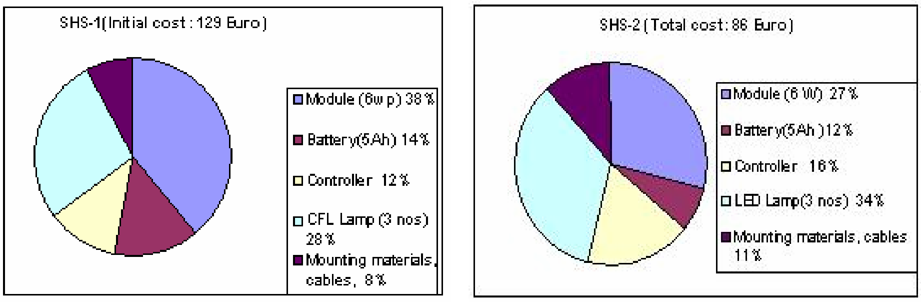


Figure 10.3: Initial cost comparison of two different SHS

Comparison Life Cycle Cost SHS-1 and SHS-2:

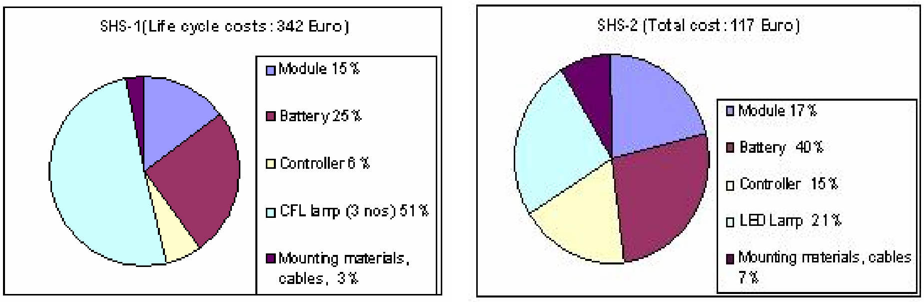


Figure 10.4: Life cycle cost comparison of two different SHS.

10.4. Discussion:

Using CFL lamp in SHS-1, cash flow at the discount rate of 9% and 3 days autonomy , then the PV module contributes 56% of the initial investment cost and the life cycle costs takes up only 31%, where the share of batteries increases from 21% to 28%, which is nearly equal to the life cycle cost of the modules. Over a twenty year period the costs of the battery charge controller remains nearly unchanged at 5% and CFL lamp cost increases from 13% to 35%.

Using LED lamp for SHS-2, the module contributes 27 % of initial investment cost and 17% contributes the life cycle cost. Batteries cost increases from 13% to 40 % and LED lamps cost decrease from 33% to 21%. It is one of the great achievements.

The same systems also design for good weather i.e. do not consider any autonomy days.

SHS-2 design for three days autonomy and with out autonomy ,it is found that both cases the initial cost nearly same which is 92 Euros and 86 Euros and life cycle cost is 144 Euro and 117 Euro respectively.

For considering three days autonomy (for bad weather) ,it is found that the initial cost of SHS-1, is 2.9 times higher than SHS-2 and the life cycle cost of SHS-1 is 3.40 times higher than SHS-2.

For good weather i.e., consider without autonomy, initial cost of SHS-1 is 1.5 times higher than SHS-2 and compare life cycle cost then cost of SHS-1 is 2.91 times higher than SHS-2.

Reducing the cost of the modules is clearly very important to make SHS more affordable. Different components in a solar home system have different life time. Module and LED lamp can last for 20 years or more, but motorcycle battery and CFL lamp usually last for about 2-3 years. The total costs of the different components over a life cycle of 20 years present a different picture than for the initial cost.

11.0. CONCLUSION:

The research presents low cost small stand alone solar home lighting system for poor people in the remote and rural areas of Bangladesh.
This research covers the construction of high luminary intensity, low cost and less power consumption LED luminary. The viewing angle of LED lamp is small; it is the main drawback, which can eliminate by setting LEDs in different position, different angle and using good reflector.

In this research find out and fixed the accurate set points of a simple and low cost charge controller for small SHS Everybody wants good quality charge controller because it is the heart of SHS but most of them do not bother about its voltage control sets point. The set points are most important of charge controller design. If a very sophisticated charge controller is used, but charge control voltage set points are improper selected, no benefit will result from the sophistication, only added expense and performance of battery will suffer the consequence. A relatively simple designed charge controller but the voltage set points adjustment are properly that will work better than an improper voltage set points adjustment sophisticate controller.

For very small SHS motorcycle battery is better .It is usually the cheapest battery and widely available. In the research we do not choose the tubular type solar battery for very small SHS because they do not readily accept low rates of charge. They are also too expensive and are rarely available in the rural markets. Their main drawback of motor cycle battery is their relatively short life time.

The uniformity solar irradiation is not equal in the country and it is elaborated in the monthly average values of the six districts (appendix A: table.A1) given an average values radiation in Bangladesh are in the range 4-5Kwh/m^{2}day. Considering solar irradiation and weather condition we consider two types of SHS (i) for good weather and (ii) for bad weather.
Here, it is described the economic analysis of stand alone Solar Home Lighting system. From the experiment the results of the performance study of a stand alone PV home lighting system, it was found that the PV module can supply power to operate for four hours per day. From the economic analysis of the system it was found that life cycle

cost of the LED lamps system is cheaper than CFL lamp system. by factor three But rural people can not evaluate the product on that basis. Initially LED lamps are expensive than CFL lamp, their concern is with initial costs, they do not bother about life cycle costs.

Solar PV systems are recognised as being technically proven, economically viable and environmentally sounding. There is no doubt the positive role of PV power in improving the quality of life of rural communities must be given a creditable attention.
Actually this PV applications as analysed in this research are suitable for rural people. They should not depend on government subsidy, international donor and financial organization.

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APPENDIX:

1, APPENDIX A

2. APPENDIX B

3. APPENDIX C