Assessment of Stand-Alone Solar Photovoltaic Power Systems Performance and Reliability for Rural Electrification in Ethiopia

Sebsibie Woldeyes

A Thesis Submitted to
The Center of Energy Technology

Presented in Fulfillment of the Requirements for the Degree of Master of Science (Energy Technology)

Addis Ababa University
Addis Ababa, Ethiopia
May, 2017

Addis Ababa University
Addis Ababa Institute of Technology
School of graduate Studies

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This is to certify that the thesis prepared by Sebsibie Woldeyes, entitled: Assessment of Stand-Alone Solar Photovoltaic Power Systems Performance and Reliability for Rural Electrification in Ethiopia and submitted in partial fulfillment of the requirements for the degree of Master of Science (Energy Technology) complies with regulation of the University and meets the accepted standards with respect to originality and quality.

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Declaration

I, the undersigned, hereby declare that this thesis is my original work. Furthermore, all sources of materials used for the thesis had been duly acknowledged.

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Date: May, 2017

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Dr. Desta Gebeyehu Signature ………………………

Advisor

Acknowledgement

I am greatly indebted to express my sincere gratitude and heartfelt appreciation to my advisor Dr. Desta Gebeyehu, Associate professor of Addis Ababa University for his whole hearted and innovate guidance, even collecting data in Tigray and Amhara regions and persistent encouragement during the period of my work.

Above all, I would like to express my deep sense of gratitude to the Almighty God for giving me the patience, courage and strength during my study.My gratitude also goes to the Ministry of Water, Irrigation and Electricity sponsoring me to attend my Graduate School Program. I have special thanks for Rural Electrification for providing mandatory data and information and AAIT of AAU financing support for the research paper work.

I am also greatly indebted to thank Dr. Jeilu Umer, Addis Ababa University Academic Vice President, Dr. Shimeles Assefa, Ato Elias Tesfaye, W/ro Tsehay G/medihen, Dr. Esayas G/Yohannes, Executive director of Addis Ababa Institute of Technology who provided me moral support during my study period.

I would also like to thank and express my deep regards to AAIT 2014/15 Energy Technology department and friends for their continuous encouragement especially,TeferaArega,senior expert, Daniel Dangiso,Director ,in the Ministry of Water ,irrigation and Electricity and Tami rat Yimer, 2016 ,4th year PhD student in Mechanical Engineering at the AAIT, AAU. Lastly but certainly not the least important, I would like to thank all the people who stood by my side.

Dedication

To those people who live in no access lighting in off- grid rural part of Ethiopia.

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Acronyms

CFL - Compact fluorescent lighting
CRGE - Ethiopia's Climate Resilient Green economy
CUF - Capacity Utilization Factor
DSSC - Dye sensitized solar cell
EREDP - Ethiopia rural energy development and promotion center
EMA - Ethiopia Meteorological Agency
EVA - Ethyl –Vinyl –Acetate
GTZ - Deutsche Gesellschaft für Technische zusammenarbeit
IGAD - Inter-Governmental Authority on Development
LED - Light emitting diode
MoWIE - Ministry of water, irrigation and electric
MPPT - Maximum power point track
MOE - Ministry of education
MOA - Ministry of agriculture
NGOs - Nongovernmental organizations
NASA - National Aeronautics and Space Administration
NREL - National Renewable Energy Laboratory
OPP - Optimum power point
OPVs - Organic photovoltaic cells
REF - Rural Electrification fun
RETs - Renewable energy technologies
SHS - Solar home systems
PV - Photovoltaic
TV - Television
UEAP - Universal Energy Access program
VRLA - Valve Regulated Lead Acid Battery

Symbols

A : total illuminated cross sectional area of the device

AM : Air mass

FF : Fill Factor

g : Gravity 9.8[m/sec^2]

G : Global irradiation[W/m^2]

H_g : global radiation on the horizontal surface at a particular location.

H_c : global radiation per day corresponding to clear sky.

I_{sc} : Short circuit current

L_e : minority carrier diffusion lengths for electron

L_h : minority carrier diffusion lengths for holes

L_h : average length of solar day for a given month calculated/observed.

L_m : length of the longest day in the month.

P_{MP} : Maximum power point

$P_{incident}$: incident light power

I_{Photon} : Photon current

V_{OC} : Open circuit voltage

V_{MP} : Voltage at maximum power point

δ : Declination angle

ω : hour angle

w_s : Sunshine Hour Angle

W : width of the depletion layer

ϕ : latitude of the location.

$\alpha_{1,2}$: average length of solar day for a given month calculated/observed.

η : solar cell conversion efficiency

η_{PV} : Module Efficiency

Abstract

The purpose of this study was focused on assessment of stand-alone solar photovoltaic power systems performance and reliability for rural electrification in Ethiopia. It was conducted to assess and evaluate the data collections which were administered on samples randomly selected sites installed in the Benshangul Gumuz, Tigray, Oromia and Amhara regions of Ethiopia. About ten sample sites were identified for each regions and data gathering were made using solar photovoltaic systems investigation check list (see appendices I -VI) for almost two months. The solar and wind master plan of Ethiopia (used as indicated on the solar radiations data) has a huge solar energy potential for rural electrification through the off-grid system in the samples of randomly selected sites of solar home systems (SHS) and institutional systems (like health post and rural primary schools) in the four regions. The data collected were analyzed using descriptive survey; theoretical, mathematical formulation experimental models, emission reduction analysis and PVsyst software analysis. The analysis and interpretation of data have been made according to the objectives. As can be seen from the investigation of SHS V_{oc} *was decreased by 1.54V (7%),* I_{sc} *whereas decreased by 7.961A (97.3%). Thereby, the output power* $P_{out} = V_{oc} \times I_{sc}$ *was reduced by 4.37W (21.85%) after installation. Similar situations have been observed for institutional systems too. Based on the findings of this study, the performance and the reliability of stand-alone PV power systems were affected by variety of factors, such as failure of the components, system configuration, maximum power point tracking, system orientation, tracking solar panels and the ambient conditions. Moreover, loss of PV systems have been observed everywhere in the sample sites due to an accumulation of dust, failure of system design, high temperature and shading. Some of these factors may not be the cause for a total failure, but still have a de-rating impact on the output power of a PV system. In fact, any parameter that impacts the output power of a PV system causes a de-rating in its nominal generation, and can potentially degrade its capability to supply the load, and that leads to a reliability issue. So, it is critical to adapt standard design practices of mathematical formulations, experimentally and PVsyst methods by numerical simulation to identify the ways to improve performance and reliability of stand-alone PV power systems for further practicality in the country.*

Keywords: Stand-alone, Solar photovoltaic system, Maximum power point tracking, System orientation, Tracking solar panels, Performance, Reliability

Chapter 1: Introduction

Generating electricity from the solar energy makes economic as well as environmental sense; the solar energy is a free, clean and renewable fuel which will never run out. Even though solar energy is free its cost of electricity however, is not free. There is initial capital cost of purchasing photovoltaic's, charge controller, transportation of materials, labor charge, expertise charge, operation and maintenance cost, etc.

According to Jack T Chow, (2010), Solar Home System is being promoted by both government and international organization as a feasible and cost effective alternate for the basic electrification of rural households (Neuwenhout, 2002). A number of successful SHS pilot projects received widespread attention such as Sukatani in Indonesia (Surya, 1992). After these success stories, solar home systems gradually came to be adopted as a viable option for rural electrification. According to estimate by GTZ (Deutsche Gesellschaft für Technische zusammenarbeit). And other institutions, over one millionths have been installed worldwide, the majority in rural areas of Africa, Latin America and Asia (GTZ, 1992). The majority of Ethiopians lives in rural areas where modern energy services are rarely available. The rural electrification fund was working to access lighting together with NGO's and private sectors.

The Rural Electrification Fund was established through a proclamation (No.317/2003) as a permanent financial source by the government of Ethiopia. To provide loan and technical services for rural electrification projects carried out by private operators' and cooperatives and local communalities and more specifically for those projects operating on renewable energy sources. The sources of the fund comprise of the budget allocated by the Government; loans and grants from other Governments; loans and grants form International Financial Institutions; grants from non-Governmental Organizations; and income from other different sources (Source: EREPDC 2010).

Installations of photovoltaic systems have shown high growth rates around the world. Nevertheless, most PV markets need considerable governmental support to reach parity with prevailing electricity supply. On the other side, highly economic but still small PV markets exist in Ethiopia. A sustainable market development of such markets often dominated by small off-grid PV solutions has to consider several key success factors for rural electrification. Similar success patterns have been observed around the world: adequate system design, training of installers and end-users, financing, service and institutional cooperation.

1.1. Background of the Study

Solar Resource Availability

Since Ethiopia is located near the Equator, the solar resource potential is significant. The yearly mean average daily radiation reaching the ground is 5.2 kWh/m^2/day (Stutenbaumer et al.,1999). There are seasonal variations (with a minimum of 4.55 kWh/m^2/day in July to a maximum of 5.55 kWh/m^2/days in February and March) as well as variation with physical locations ranging from 4.25 kWh/m^2/day for south west regions to 6.25 kWh/m^2/day in the north). Further, throughout Ethiopia, the distribution of the global daily radiation around the yearly mean is quite narrow. The average for Ethiopia as a whole indicates that over 90 % of the radiation intensity is within 10 % of the mean value (Master plan Wind and solar FDRE, 2012).

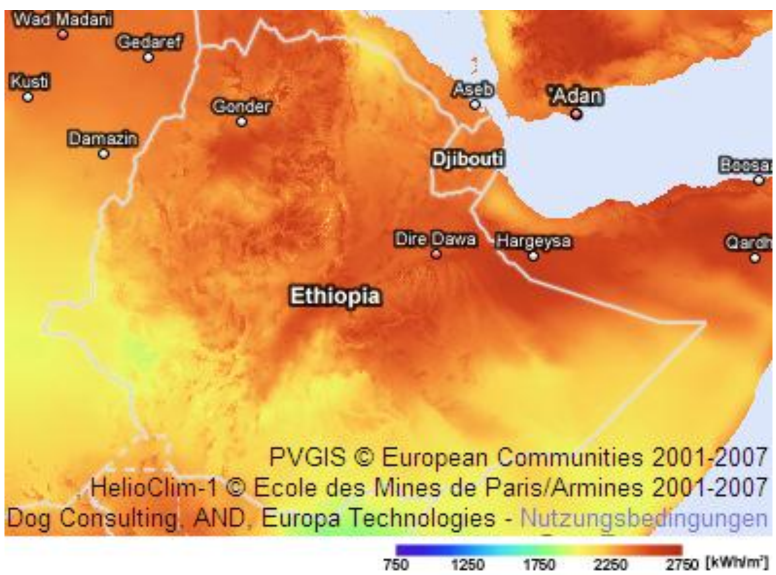


Figure1.1: Global irradiation incident on optimally inclined equator-oriented PV modules in Ethiopia (Master plan report Wind and Solar FDRE, 2012).

Solar Regime

Table 1.1: Statistics of Solar Energy Resource in Different Regions of Ethiopia

Country /state	Area (1,000 km^2)	Average solar radiation flux (W/m^2)	Total regional power (TW)	Average annual solar density ($kW\cdot h/(m^2\cdot a)$)	Average annual total reserve (100,000 TW·h/a)
Amhara	155.0	240.34	37.26	2105.3	3.26
Tigray	50.2	246.48	12.38	2159.1	1.08
Afar	94.1	239.90	22.57	2101.5	1.98
SNNPR	109.9	226.65	24.91	1985.5	2.18
Gambela	24.6	222.48	5.48	1948.9	0.48
Oromiya	320.0	223.96	71.66	1961.9	6.28
Benshagul	49.5	232.52	11.5	2036.9	1.01
Somali	300.3	217.19	65.21	1902.6	5.71
Ethiopia	1,103.6	227.42	**250.98**	**1992.2**	**21.99**

The average solar radiation power and average annual total solar energy of unit area are higher in Tigray, Amhara and Afar (all in North Ethiopia). Generally, solar radiation power density exceeds 230W/m^2 for these regions. For example, solar radiation power density in Tigray exceeds 245W/m^2, and average annual solar density exceeds 2,150 kWh/ ($m^2\cdot a$). However, to consider total solar energy in different regions, it is necessary to consider areas of different regions. Such as, Oromia,Somali and Amhara (Master plan report of wind and solar energy FDRE, 2012).

Solar PV Development in Ethiopia

In Ethiopia, humble beginning was made in the 1980's in the use of solar PV and other RETs. Moreover, the market still can be considered at its early developmental stage. Various groups including Ethio-telecom, NGOs, research institutions, rural schools and clinics and to a lesser extent, private businesses and domestic consumers have been using PV systems for lighting, communication, entertainment and vaccine refrigeration for the past two decades. In the1990s and early 2000, the market for solar PV was mainly a bidding based market for procurements of entire systems, especially SHS by NGOs. Most PV installations in the initial period were either project based or donor-driven, which contributed to the underdevelopment of commercial market in Ethiopia. The market started to develop from 2000 onwards with dissemination of solar equipments under the IGAD (Inter-Governmental Authority on Development) household energy project. The project actively promoted SHS among consumers and the business community. Currently, the total installed capacity of solar PV systems in the country is estimated at about 5.2

MW with almost 70% of the installation being in the telecom sector (EREDPC, 2010). The rest of the systems are in the off-grid sector like, household, small scale business and community systems. Though the commercial market started in early 2000, the annual sales growth was under 5% for almost a decade and a half. However, in the last few years there has been a steady growth averaging 15% to 20% year on year basis as reported by the PV dealers during the survey UNIDO, 2010).

Solar PV Applications

There is a large variety of solar PV products designed to meet the various needs. The applications of solar PV can be of the following modes.

Stand Alone Mode

Stand-alone systems are those with no connection to the utility grid. Stand-alone mode consists of both decentralized/individual systems and centralized/community systems. For example a solar home systems or power pack consists of solar PV modules, battery to store power and a charge controller/ inverter to allow appliances to be powered by solar electricity. Another common example is the solar lantern which is a single light point portable lighting system. Apart from the PV module, it consist of a lamp (LED or CFL), a battery (VRLA type), and electronic components, all placed in a casing, either made of metal, plastic, or fiber glass. Because of its portability, it finds both indoor and outdoor applications. Other common examples of individual systems are solar power packs (including roof top systems), solar pumps, street lights, etc. On the other hand, examples of centralized or community systems are village scale micro power plants, solar charging stations (UNIDPO, 2010).

Grid Connected Mode

Grid connected systems are those which are interconnected with the utility grid. In case of such systems, any electricity generated can be used locally and the surplus electricity is exported to the utility's grid. The utility-grid is used as a back-up supply in place of storage batteries. Common examples of grid connected PV systems are medium and large power plants, urban roof top systems, grid tail end voltage support power plants (Shiraz, 2012).

Some of the Common Applications of Solar PV Relevant to Ethiopian Context are:

- Individual solar home systems and small businesses: lights, TV, radio etc;
- Lighting for Schools, Health post and hostels in remote areas;
- Refrigeration in rural health clinics;
- Battery charging stations in rural areas;
- Water pumping for small-scale irrigation, stock watering, and drinking Water in rural areas;
- Household appliances such as ventilation fans, swamp coolers, televisions, Blenders, stereos, and other appliances; and
- Rural telecommunications by remote relay stations, emergency radios, and cellular telephones; and utility grids that produce utility-or commercial-scale electricity.

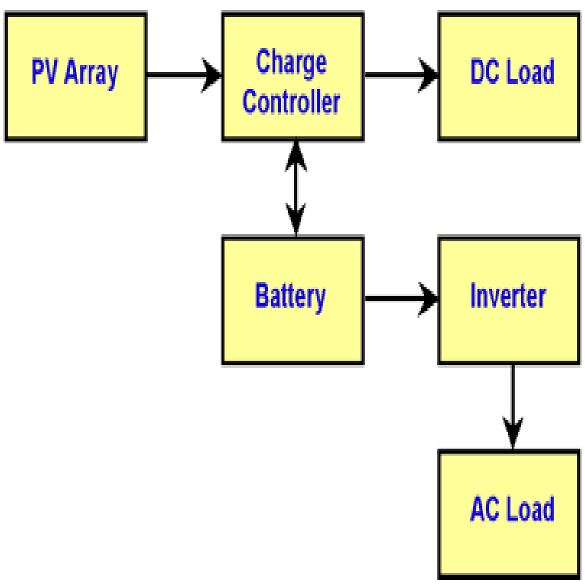


Figure: 1.2 Stand-alone PV power system

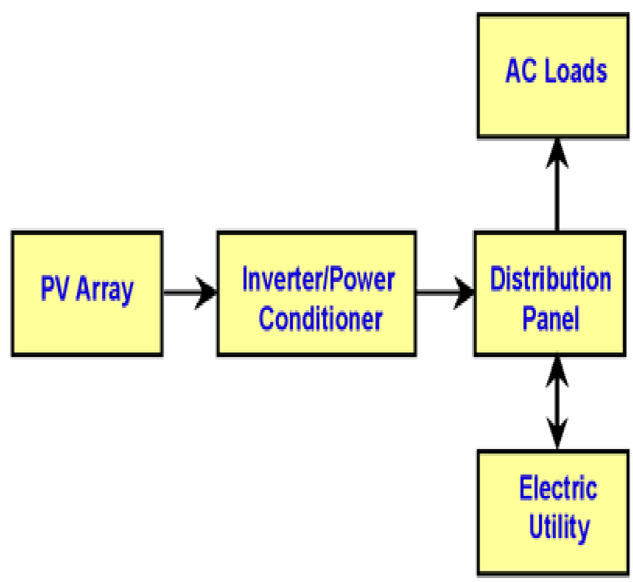


Figure 1.3 Grid- connected PV power system

Performance and reliability of Solar Power Plants

The performance of solar power plants is best defined by the Capacity Utilization Factor (CUF), which is the ratio of the actual electricity output from the plant, to the maximum possible output during the year. The estimated output from the solar power plant depends on the design parameters and can be calculated, using standard software. But since there are several variables which contribute to the final output from a plant, the CUF varies over a wide range. These could be on account of poor selection /quality of panels, degrading of modules at higher temperatures, other design parameters like ohm loss, atmospheric factors such as prolonged cloud cover and mist. It is essential therefore to list the various factors that contribute to plant output variation. The performance of the power plant however depends on several parameters including the site location, solar insolation level; climatic conditions specially temperature, technical losses in cabling, module mismatch, soiling losses, MPPT losses, transformer losses and the inverter losses. There could also be losses due to grid unavailability and the module degradation through aging. Some of these are specified by the manufacturer, such as the dependence of power output on temperature, known as temperature coefficient. The following factors are considered key performance indicators: radiation at the site, losses in PV systems, temperature and climatic conditions, design parameters of the plant, inverter efficiency and module degradation due to aging (CERC, 2011).

In general, reliability is defined as a measure of the ability of a component as well as the power system to deliver electricity to all points of utilization within accepted standards, and in the amount desired, for the given period of time intended, understated operating conditions intended. Indeed, the reliability of PV power systems were affected by variety of factors, such as failure of the components, system configuration, maximum power point tracking, system orientation, tracking solar panels, the ambient conditions, etc.

Monitoring of Photovoltaic Systems: Good Practices and Systematic Analysis Trends in PV System Performance

In reviewing the state of the art in monitoring techniques, the paper highlights the need to track indicators across the whole energy conversion chain, including both capture losses and system losses. The most prominent factors causing reduced Performances are module temperature, dirt, dust and shading, which can account for 70% of all losses in some locations, mismatch and wiring losses, and DC to AC conversion losses. Rapidly detect and diagnose these factors and issues specifically is therefore of key importance in monitoring for optimal performance (EU PVSEC, 2013).

So far, very few solar plants have been installed in Ethiopia and there is no historical practical experience available. Therefore, it is important to investigate the performance of solar power plants. Knowledge about the performance of solar power plants will result correct investment decisions, a better regulatory framework and favorable government policies.

The Literature review discusses the practicality of solar photovoltaic power systems applications using renewable energy source. It is clear from the above discussion that solar energy is becoming an important source of energy all over the World and especially in Ethiopia.

1.2. Statement of the problem

An adequate and reliable power supply system is essential for any developing country like Ethiopia. During the past two decades stand –alone solar photovoltaic power system has been introduced to remote communities in developing countries as a means of remote area electrifications. These are of great importance for Ethiopia especially in the rural communities where there is little or no access to electricity. Indeed, stand-alone solar photovoltaic system can be considered as one of the most promising renewable energy systems. It was adopted globally in meeting basic electricity needs of rural areas that are not connected to the grid. Obviously, stand-alone photovoltaic power systems have been installed in some regions of Ethiopia. Unfortunately, the expectations and degrees of satisfactions of the rural communications, PV systems performance and reliability, care and maintenance issues relating to the photovoltaic systems are not well assessed and investigated carefully and effectively. Hence, this research study is intended to fill this research gap. Therefore, the researcher has investigated the performance and reliability of stand-alone solar PV power systems. In addition, the findings of this study may fill the gap in improving the efficiency and sustainability of solar PV power systems that have to be installed in the near future in our country.

1.3. Objectives

1.3.1. General Objective

The main purpose of this study was focused on the assessment of stand-alone solar photovoltaic power systems performance and reliability for rural electrification in Ethiopia.

1.3.2. Specific Objectives

The study attempted to achieve the following specific objectives.

1. To assess and evaluate the performance and reliability of installed stand-alone photovoltaic power system at different location in Ethiopia.
2. To investigate the solar home systems and institutional solar power systems installed in Ethiopia using appropriate simulation models and tools.
3. To review the system designs, performances and reliability of stand-alone solar photovoltaic power system that can be applied to future projects in the country.
4. To improve the performances and reliabilities of solar home systems and institutional solar Power systems installed in different part of the country.

1.4. Research Question

These research questions have been raised to be investigated in this study

1. How are the performance and reliability of installed stand –alone photovoltaic power systems at different location in Ethiopia?
2. Which factors are affecting the performance of both the solar home systems and institutional solar power systems?
3. Which methods and tools are essential in applying for the the future projects of SHS and Institutional systems?

1.5. Significance of the study

Stand-alone photovoltaic systems have been installed in different regions of Ethiopia but unfortunately, the expected benefits from using the systems have been jeopardized. Therefore, the study was focused on improving installed stand-alone solar photovoltaic power systems. Accordingly, this research study would have the following significance:

- It will help to demonstrate how far the off-grid rural electrification projects have so far benefited the rural communities effectively.
- It will help to investigate the design requirements, PV systems performance and reliability, care and maintenance issues relating to the PV systems.
- It will help to identify key points to improve the current installed solar photovoltaic performance and reliability for brutal electrification in the country in the coming GTP periods.
- It will help indicate methods and solutions for improving the efficiency and practicality of solar photovoltaic power systems, off grid rural electrification, applications in the country in the coming GTP period.

1.6. Outline of the thesis

This study is organized in five chapters. The first chapter contains the introduction of the study, which is background of the study, statement of the problem, objectives of the study, significance of the study and etc. The second chapter explores the theoretical and empirical review of related literatures including the researches made so far. The third chapter deals with research design and methodology, data sources, data collection methods, appropriate data analysis techniques, and software tools. This section also contains all the analysis techniques from load area identification to the mathematical formation and the optimization models. Chapter four discusses the results or findings of the study. Finally, the fifth chapter includes the summary of the findings, conclusions and recommendations.

Chapter 2: Review Literature

2.1. Solar Energy

Solar energy is a free, inconsumable and clean source of energy which is the focus of many recent researches in energy field, many of which are about overcoming the inefficiencies of solar power systems. The interested reader can come up with the idea of how sunlight can be converted to electricity using semiconductors and what are the crucial parameters that can influence the conversion efficiency of photovoltaic systems (S.Mekhilefa et al., 2012).

The energy received from the sun on the earth's surface in one hour equals to the amount of approximately one year energy needs of the earth. Sun acts like a black body radiator with the surface temperature of 5800 K which leads to a 1367 W/m^2 energy density over the atmosphere (Goetzberger A.2003). While designing PV systems, the spectral factor should be studied and taken into consideration. The importance of having a profound knowledge of the sun spectrum lies on the fact that this knowledge can help to understand the effects of atmosphere on the radiation and guides us to select the best materials for solar cells (Gottschalg R., 2003).

2.2. Review of Semiconductor Device Physics of Solar Cells

Solar cell like the crystalline silicon based is a solid-state semiconductor p-n junction device that converts sunlight into direct-current electricity through the principle of photovoltaic effect. The first conventional photovoltaic cells were produced in the late 1950s, and were principally deployed to provide electrical power for orbital satellites.

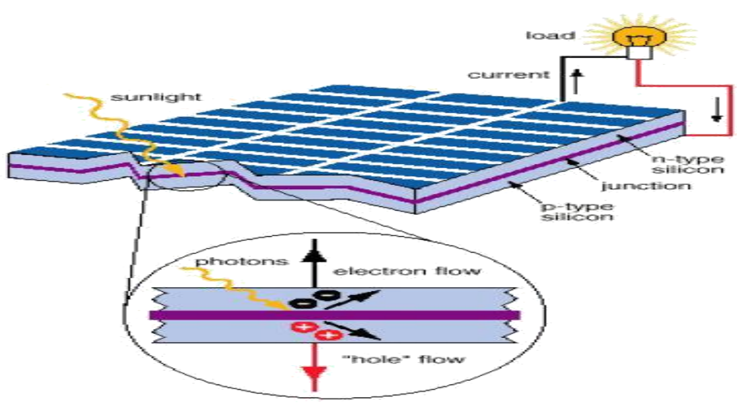


Figure 2.1:.Basic description photovoltaic effects in a solar cell (NASA, 2011).

During this initial deployment, excessive cost of manufacturing and poor efficiency of solar modules were some of the major challenges that limit their competitiveness as a major source for meeting the increasing energy demand that has continued till now. However, recent improvements in design, manufacturing, performance, reduced cost and quality of solar cells and modules have not only opened up the doors for their deployments in applications like powering remote terrestrial applications, rural electrification projects, battery charging for navigational aids, water pumping, telecommunications equipment and critical military installations, but has also propelled solar power system as a competitive means to meeting the ever increasing power need for the world economy.

2.3. P-N Junction

Solar cell is simply a p-n junction device, like a diode that is forward biased with a photo-voltage. Based on this simple definition, it's necessary to review how the p-n junction of a semiconductor diode functions. When a p-type and an n-type (Figure 2.2) semiconductors are interfaced together, p-n junction is formed. The p-n Junction is the region or a boundary that is formed by doping or by epitaxial growth of a layer of crystal doped with one type of dopant on top of a layer of crystal.

These electron and holes migration creates charge imbalance by exposing ionized charges on both sides. The exposed charges would set up an electric field that opposes the natural diffusion tendency of the electron and holes at the junction; this is the behavior of the p-n junction under equilibrium condition.

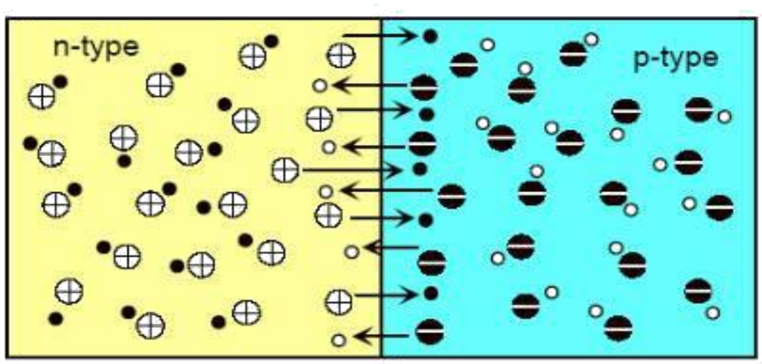


Figure 2.2: Electrons and holes migration at the P-N junction (Henry A., 2013).

Under this condition, there exists within the junction a layer between the p-n junctions that becomes almost completely depleted of mobile charge carriers. This layer/region is called the space-charge region or depleted region and is schematically illustrated in Figure 2.3 below.

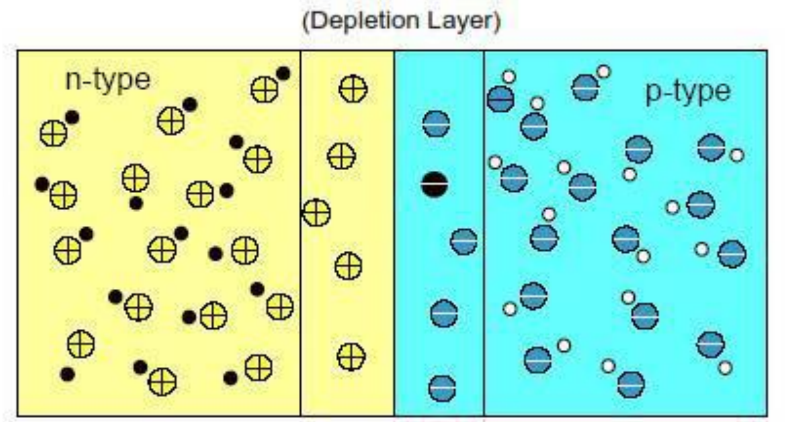


Figure 2.3: PN-junction and depletion region under equilibrium (Green M., 1982).

The characteristic of the deletion layer is that the total amounts of charge on either side of the junction in the depletion region are equal and the net current flow is zero since the drift current and the diffusion charges are equal. Also, the Fermi level is constant during this condition, but the width of the depletion layer can be altered if an external bias is applied. The junction barrier potential becomes increased if reversed biased and becomes narrower if forward biased. Figures 2.4 below shows the energy band diagram at equilibrium, forward bias and reverse bias conditions.

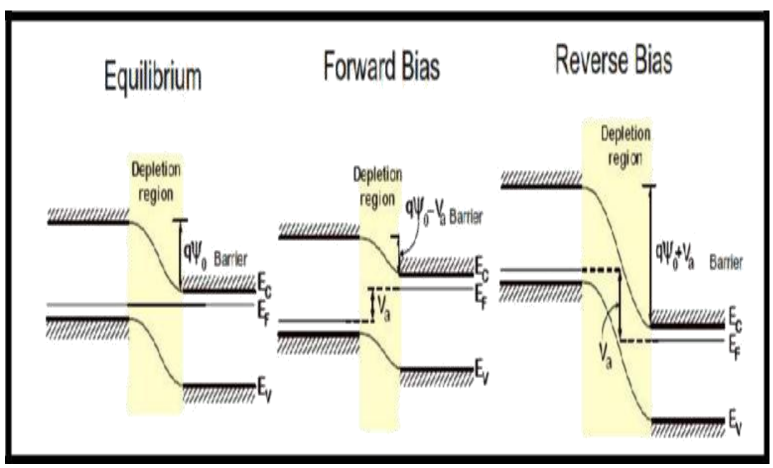


Figure 2.4: Energy Band diagrams of a PN-Junction (Henry A., 2013).

From Figure 2.4 above when no external force like voltage or excess heat or incident light is acting on the junction, electrons in the n-type material closest to the boundary tend to migrate, or diffuse into the p-type material, resulting in the creation of minority positively charged ions in the n-type material and negatively charged minority ions in the p-type material.

The electric field developed by the displaced charges is referred to as the junction built-in potential and the region nearby the p-n junction loses their neutrality forming the depletion layer or space charge region. This is p-n junction in a state of equilibrium. On the other hand ifa voltage is applied across the p-n junction, with the positive terminal connected to the n-type material and the negative terminal connected to the p-type material, the junction is reverse biased; under this condition, the depletion region would further increase as the diffused electrons and holes are pulled further from the boundary and thus increasing the resistance of the material to the flow of current, but there will be a negligible flow of reverse current. The reverse current will remain constant and continue to flow until breakdown voltage is reached. However, if the positive terminal is connected to the p-type region and the negative connected to the n- type material, the junction is forward biased. Now the solar cell operates similar to a forward biased diode.

2.4. Ideal Solar Cell

When a solar cell is illuminated by sun-light, photons energy of the incident light is converted to direct current electricity through the process of photovoltaic effect of the solar cell. Incident light causes electron-hole pairs to be generated in the semiconductor and there is increase in the concentration of minority carriers (electrons in the p-type region and holes in the n-type region) in the depletion region (see Figure 2.5).

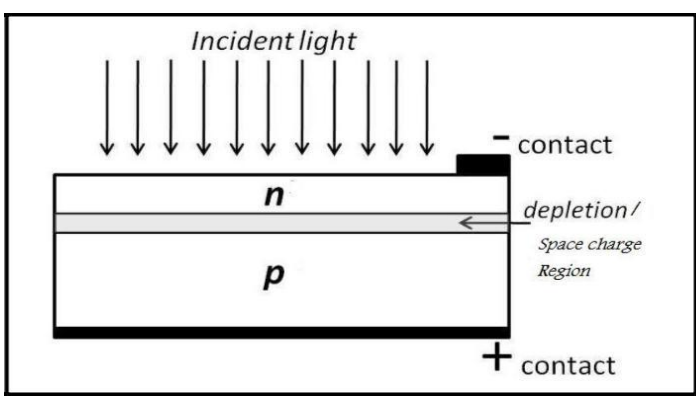


Figure 2.5: Incident light on a typical p-n Solar Cell (Purnomo S.et al., 2011).

If a load is connected between the electrodes of the illuminated p-n junction, some fraction of the photo-generated current will flow through the external circuit. The potential difference between the n-type and p-type regions will be lowered by a voltage drop over the load. Also, the electrostatic potential difference over the depletion region will be decreased which results in an increase of the recombination current.

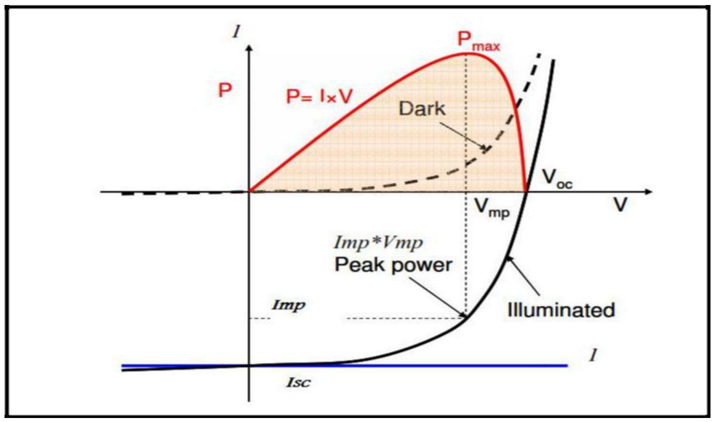


Figure 2.6: I-V characteristic curves of a p-n junction in the dark and under Illumination (Green M., 1982).

The p-n Junction I-V characteristic curve of an ideal diode solar cell is described by the Shockley equation 2.1 below, (Green M., 1982).

$$I = I_{photon} - I_o(e^{\frac{qv}{K_{B}T-1}}) \qquad 2.1$$

The Shockley equation is the fundamental device physics equation which describes the current-voltage behavior of an ideal p-n diode. I_{photon} Is the photo-generated current and is defined by equation 2.2 below **(**Green M., 1982).

$$I_{photon} = qAG(L_e + W + L_h) \qquad 2.2$$

Where L_e and L_h as defined before are the minority carrier diffusion lengths for electron and holes respectively. G is the diode electron-hole pair generation rate, W is the width of the depletion layer and A is the total illuminated cross sectional area of the device. Based on this equation, it can be inferred that only carriers generated in the depletion region and in the regions up to the minority-carrier-diffusion length from the depletion region contributes to the photo-generated current.

2.5. Solar PV Technology

Solar Photovoltaic technology is primarily a solid-state semiconductor based technology, which converts a fraction of the incident solar radiation (photons) into DC (direct current) electricity. PV system can deliver electric energy to a specific appliance and/or to electric grid and because of their flexibility and modularity, the technology can be implemented on virtually any scale, size, connected to the electricity network or used as stand-alone or off grid systems, easily complementing other energy sources. They also offer several advantages such as (I) complementary to other energy resources; both conventional and renewable, (II) flexibility towards implementation and (III) environmental advantages.

A basic PV system comprises PV modules and the BoS (balance of systems) that includes charge controllers, inverters, storage, luminaries, wiring and support structures.

2.5.1. Classification of solar cell technologies

Depending upon the type of absorbing material used, manufacturing technique/process adopted, and type of junction formed etc., the solar cell technologies can be broadly classified as following.

I. First generation

Wafer based crystalline silicon solar cells technologies that are single or Mono-crystalline and Polycrystalline or Multi crystalline silicon solar cell. The silicon wafer-based solar cells are the dominant technology towards commercial production of solar cells accounting for more than 90% of the terrestrial solar cell market. In wafer-based crystalline silicon solar cell technology, crystalline silicon modules are typically produced using the process shown in Figure 2.7.

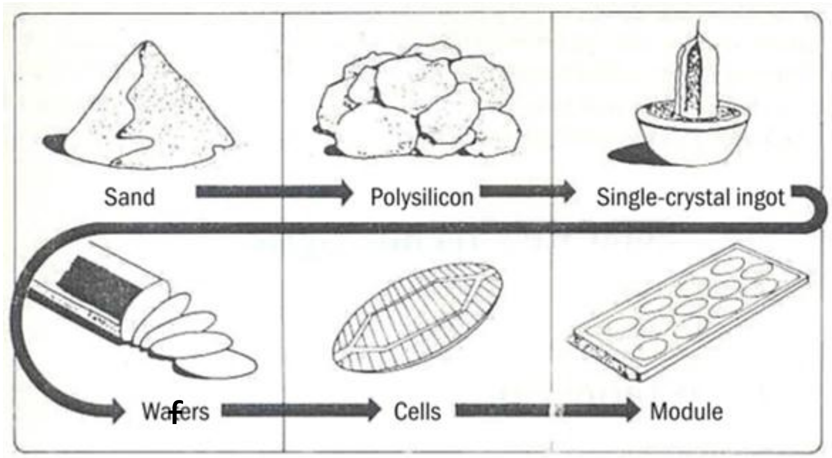
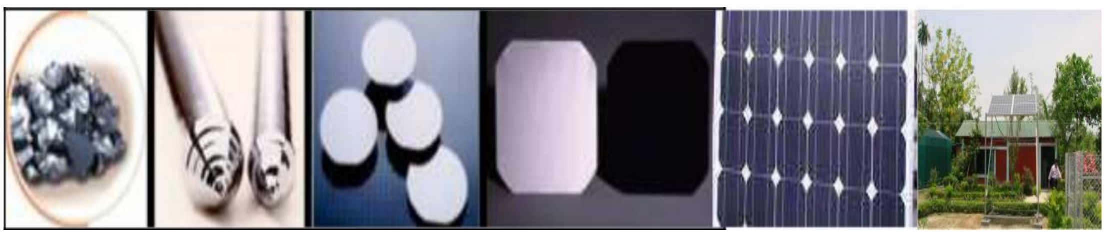


Figure 2.7: Process involved in producing solar cell and module (TERI, 2010).

The complete value chain for the most common c-Si solar PV module manufacturing is shown in Figure 2.8.



Silicon Ingot Wafer PV Cell Module System

Figure 2.8: Value chain in solar PV module production (UNIDO, 2010).

- **Single/mono-crystalline silicon solar cell**

This is the most established and efficient solar cell technologies till date, which have the module efficiency of 15 - 18% at commercial scale production (Figure 2.9). These cells are manufactured from single silicon crystal, by process called Czochralski process. During the manufacturing, single crystal wafers are sliced (approximately 1/3 to 1/2 of a millimeter thick) from a large single crystal ingot which has been grown at around 1400°C.

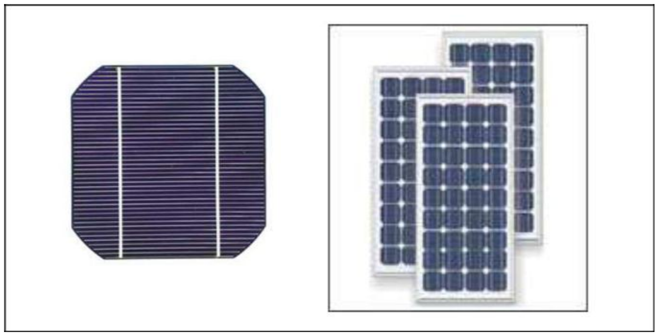


Figure 2.9: Mono-crystalline silicon solar cell and module (UNIDO, 2010)

- **Polycrystalline silicon solar cell (poly-Si or mc-Si)**

Polycrystalline wafers are made by pouring molten silicon into a mould and allowing it to set. It is then sliced into wafers which can be much larger than the single crystal wafers (Figure 2.10). The production of polycrystalline cells is more cost-efficient; however, they are not as efficient as single crystalline cells. These cells have module efficiency of around 12-14%.

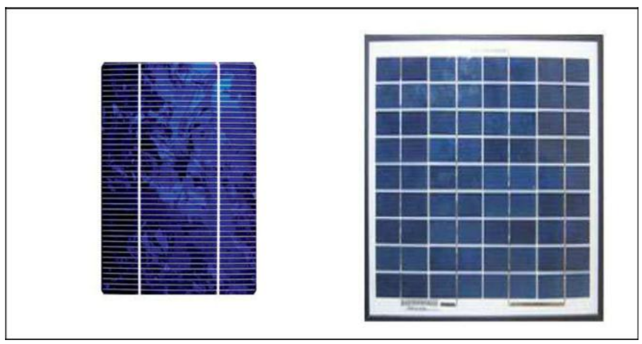


Figure 2.10: Polycrystalline silicon solar cell and module (UNIDO, 2010).

II. Second generation

Thin-film solar cells technologies, which includes, Copper Indium Gallium Diselenide (CIGS), Cadmium Telluride (CdTe), Amorphous Silicon (a-Si), etc. Thin film gained acceptance as a “mainstream” technology during 2006/2007, due partly to manufacturing maturity and lower production costs, and partly to its advantage in terms of silicon feedstock, and now commands 8-9% of the total production of cells.

In thin film solar cell technology, thin layers of semiconductor material are deposited onto a supporting substrate, such as a large sheet of glass. Typically, less than a micron thickness of semiconductor material is required, 100-1000 times less than the thickness of silicon wafer (Figure 2.11). Some of the thin film solar cells in use are: a–Si (amorphous Silicon), Cite

(Cadmium Telluride) CIS, CIGS (Copper Indium Gallium Di-Selenide) thin film crystalline silicon.

Figure 2.11: a-Si and CdTe thin film modules (UNIDO, 2010).

III. New emerging PV technologies

Emerging technologies include thin-film silicon, dye sensitized solar cells; and polymer organic solar cells. Besides crystalline thin-film modules, dye sensitized solar cell (DSSC), organic polymer cells etc. are emerging as new solar cell technologies. Although DSSC is still at the pilot production stage, it is becoming popular because of its potential for high-energy conversion efficiencies at very low cost. In addition, organic solar cells such as polymer organic solar cells have shown the promise of ease of manufacturing at low temperature and at low cost. However, the efficiency as well as the long-term stability has to be improved further in order to compete it with conventional solar cells. Organic photovoltaic cells (OPVs) using carbon Nano-tube are an attractive alternative to traditional silicon-based solar cells because they are inexpensive and can be manufactured more efficiently.

- **3^{rd} Generation Solar Cells**

The third-generation photovoltaic cells are proposed to be very different from the previous semiconductor devices as they do not rely on a traditional p-n junction to separate photo-generated charge carriers.

It has been estimated that 3^{rd} generation solar technologies will achieve higher efficiencies and lower costs than 1^{st} or 2^{nd} generation technologies (Henry A.,2013) Some of these technologies are nanocrystal solar cells, photo-electrochemical cells.

- **4th Generation Solar Cells and Future Trend**

The fourth generation of photovoltaic cells are the hypothetical generation of solar cells; which may consist of composite photovoltaic technology, in which polymers with Nano-particles can be mixed together to make a single multi-spectrum layer. The multi-spectrum layers can be stacked to make multi-spectrum solar cells more efficient and cheaper.

This category of solar cells combined the 3rd generation technologies to form the 4th generation solar cells technology. Example is the nanocrystal/polymer solar cell, a Composite photovoltaic cell technology which combines the elements of the solid state and organic PV cells to form the Hybrid-nanocrystal line oxide polymer composite cell. Although most of these technologies are still in the embryonic development stage, it is predicted that because of the lower cost of material, this type of solar cell would significantly make solar deployment affordable. Another area where Photovoltaic solar cell technology has achieved significant efficiency milestone is in the concentrator solar cell technology. Example is the Multi- junctions (III-Vs) solar cells which has recorded efficiency of greater than 41% (Henry A., 2013). Figure 2.12 below shows best research solar cell efficiency to date, courtesy of NREL (National Renewable Energy Laboratory) and Spectro lab.

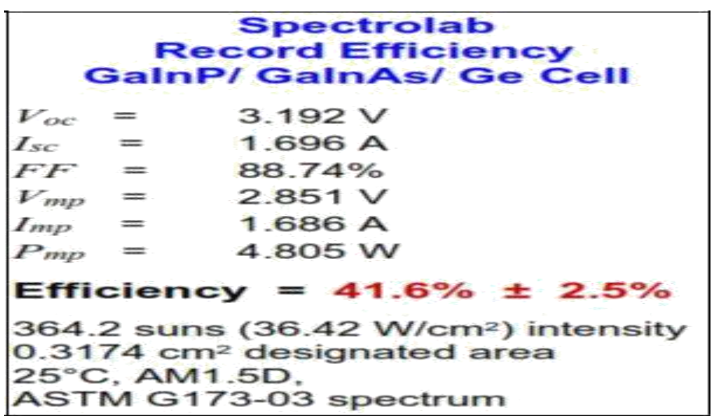


Figure 2.12: Record Efficient concentrator solar cells efficiency 41.6% (Henry A., 2013).

2.5.2. The comparative characteristics of crystalline silicon and thin-film photovoltaic technologies.

The comparative characteristics of crystalline and thin film photovoltaic technologies by different parameters describedin the Table 2.1.

Table 2.1: Detailed Comparison between crystalline and thin-film technology

Parameter	Crystalline Silicon	Thin film
Types of Materials	Mono-crystalline Multi-crystalline	Amorphous silicon (a-Si) Cadmium telluride (CdTe) Copper indium (gallium) Diselenide (CIS or CIGS)
Material Requirement	Requires more material c-Si has been used as light-absorbing semiconductor in Solar cells. To absorb sufficient amount of light, it requires several hundred micron thickness of material	Requires less material The selected materials are all strong light absorbers and only need to be about 1micron thick, so materials costs are significantly reduced
Manufacturing Process	Mono-crystalline is produced by slicing wafers (up to 150mm diameter and 350 microns thick) from a high-Purity single crystal boule. Mono-crystalline silicon, made by sawing a cast block of silicon first into bars And then wafers.	Each of these three is amenable to large area deposition (on to substrates of about 1 meter dimensions) and hence High volume manufacturing. The thin film semiconductor layers are deposited on to either coated glass or stainless Steel sheet.
Power	High power per given area	Low power per given area
Efficiency(Commercial)	11–18%	4.5–6.5%
Effect of Temperature	Effect is more on output power	Effect is less compared to crystalline silicon cells
Shade Tolerance	Low shade tolerant	More shade tolerant
Logistics	Fewer modules - lower shipping cost	More Modules - more shipping cost
Mounting structures Required	Fewer modules- less mounting structures per kWp	More modules- more mounting structures per kWp
Accessories	Requires less junction boxes	Requires more junction boxes
Inverters	High inverter flexibility	Limited inverter flexibility
Cost	High cost per watt	Low cost per watt
Output	Output depends on no. of cells in a 1×1 dimension module	Directly proportion on module dimension
Stabilization	Guaranteed power	It takes 5-6 months to reach a stabilized output
Commercialization	Most matured and commercially established	Very few suppliers

Source: TERI,2010

2.6 .Components of Solar PV System for SHS and Institutional.

Solar home systems and Institutional solar systems like health post and primary schools constitute by the similar solar photovoltaic system components except its size design.

Solar module

The power output of a single solar cell is too low to operate most of the electrical devices. Most single junction solar cells produce a voltage of about 0.5-0.6 V, regardless of the surface area of the cell. Therefore, many cells are connected in series to increase the voltage. The interconnected solar cells are embedded in transparent Ethyl – Vinyl – Acetate (EVA). The solar cells are also extremely fragile. Thus, to protect the series connected solar cells, from damage, they are hermetically sealed between a top layer of glass or clear plastic, and a bottom layer of plastic or combination of plastic and metal. An outer frame is attached to increase the strength and this whole package is called a solar PV module (Figure 2.13). At the back of the module, a junction box is provided to extract electricity. Depending upon the load and battery requirements, the modules are connected in series and or parallel combinations and mounted on a metallic frame. Such aggregates of PV modules or Panels form a solar PV array (Figure 2.14).

The solar PV modules are rated in terms of peak watt (Wp). The solar insolation of a region indicates the total hours for which the rated peak watt from a module can be obtained. The performance parameters are expressed in terms of standard solar conditions: an ambient temperature of 25°C, and an insolation of 1000 Wh/m^2. The power output from a module depends upon the ambient temperature, solar insolation and the location of the site.

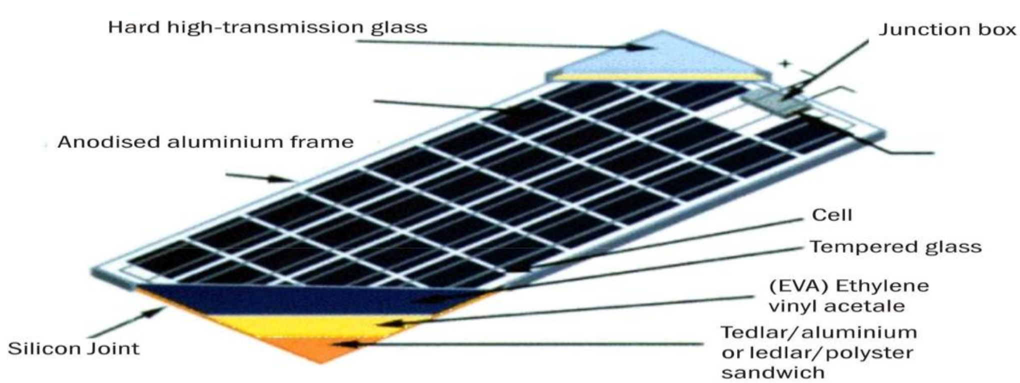


Figure 2.13: View of a solar module (UNIDO, 2010).

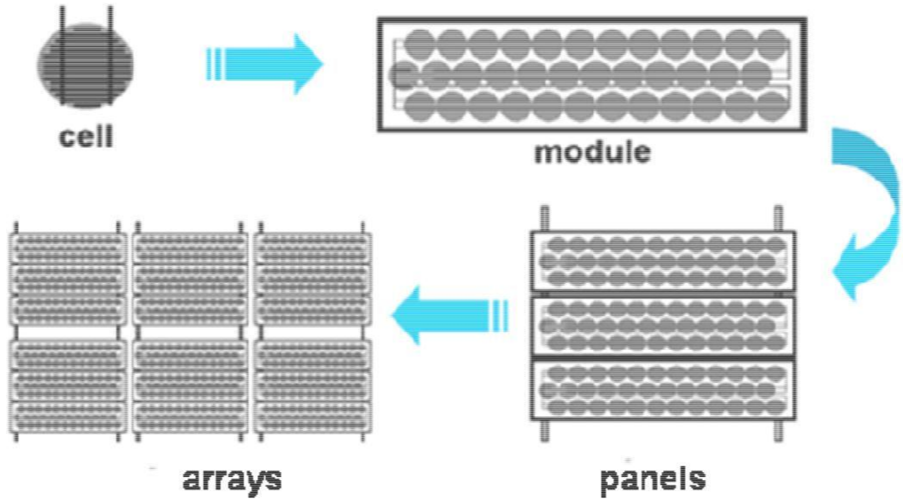


Figure 2.14: View of a solar module and array (UNIDO, 2010).

Balance of Systems

All system components other than PV module are termed as the BoS (balance of systems). This includes storage (battery), charge controllers, inverters (for loads requiring alternating current), luminaries, wiring, conduits, metal structures for mounting the modules, and any additional components that are part of the PV system. The most critical components of the BoS are charge controllers and or inverters and the battery (which acts as the storage device in case of standalone solar PV systems), which are described the following sections.

Battery

The battery stores electricity for use at night or for meeting loads during the day when the modules are not generating sufficient power to meet load requirements. A storage battery is an electrochemical cell which stores energy in chemical bonds. The cell is the basic electrochemical unit in a battery, consisting of a set of positive and negative plates divided by separators, immersed in electrolyte solution and enclosed in a case. In most cases a number of cells are packaged in a single container or sleeve, typically three or six 2V lead acid cells to give a 6V or 12Vbattery. The rated capacity of a cell or battery (in Ah or mAh) is the amount of electricity that it can store (produce) when fully charged under specified conditions. Thus, the total energy of a battery is its capacity, multiplied by its voltage, resulting in a measurement of watt-hours (TERI, 2010).

The three primary functions of a storage battery in a solar PV system are: a) Energy storage capacity and autonomy: to store electrical energy when it is produced by the PV array and to supply energy to electrical loads as needed or on demand. b) Voltage and current stabilization: to supply power to electrical loads at stable voltages and currents, by suppressing or smoothing out transients that may occur in PV systems. c) Supply surge currents: to supply surge or high operating currents to electrical loads or appliances.

Usually, batteries can be divided into the following two types: a) Primary cells or dry batteries: The primary batteries can store and deliver electrical energy, but cannot be recharged. Zinc – carbon and alkaline batteries are typical example of the primary cells. These are not used in PV systems as they cannot be recharged. b) Secondary cells or rechargeable batteries: A secondary battery can store and deliver electrical energy, but can also be recharged by passing a current through it in opposite direction to the discharge current. Common secondary batteries are lead-acid battery and nickel- cadmium batteries (TERI, 2010).

Usually lead-acid, are designed to gradually discharge and recharge 80% of their capacity hundreds of times. Automotive batteries are shallow cycle batteries and should not be used in PV systems because they are designed to discharge only about 20% of their capacity (Sheikh Y. and Ritual J., 2015).

Figure 2.15: Basic Lead-Acid battery FAQ, 2009.

Charge Controllers

The charge controller is the brain of the PV system. The wiring from the solar panels, the batteries, and all of the loads goes through the charge controller. The charge controller manages the flow of electricity from the panels, into and out of the batteries, and to the loads. It has three main functions: a) Protects the battery from over charging, by controlling how the PV panel Charges the battery. b) Protects the battery from discharge, by disconnecting the loads when the battery voltage gets too low. c) Gives information on the state of change of the charge controller.

Fig 2.16: Steca and Morning Star type charge controllers.

Absence of charge controllers in a PV system may result in shortened battery life and decreased load availability.

Shunt regulators

Shunt regulators are typically solid-state. Their primary components are a transistor between the array positive and negative lines, and a blocking diode between the battery positive and the array positive. During normal charging, current flows from the array to the battery. When the battery voltage reaches, the array disconnect setting, the transistor is activated, shorting the array. The battery is prevented from being shorted by the blocking diode. The blocking diode also prevents the current from flowing back into the PV array from the battery during nighttime. When the battery voltage falls to the array reconnect setting, the transistor is released and the current then flows to the battery again as shown in Figure 2.17.

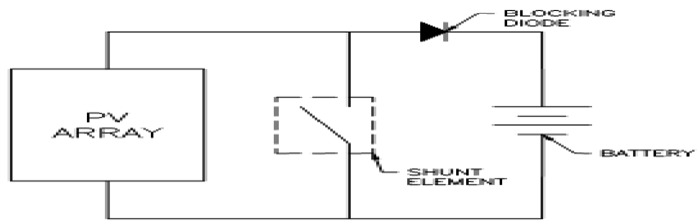


Figure 2.17: Shunt Regulator

This type of charge controller is typically used on smaller low-voltage systems. Although short circuiting the array does not cause damage, there can be large amounts of current flowing through the transistor. The larger the array, the larger the current flowing through the transistor and the larger the amounts of heat the transistor must dissipate. Additionally, voltage drop (loss) occurs across the blocking diode (IEEE, 2007).

Series regulators

Series regulators come in many variations. The basic series regulator consists of a relay (either mechanical or solid-state) between the battery positive conductor and the array positive conductor (for a negatively grounded system), and a voltage comparator. The negative conductors are used for a positively-grounded system. When the battery voltage reaches the array-disconnect setting, the relay is opened, disconnecting the flow of current to the battery. The PV array becomes open-circuited. When the battery voltage falls to the array-reconnect setting, the relay is closed, allowing the current to flow to the battery again as shown in Figure 2.18 (IEEE, 2007).

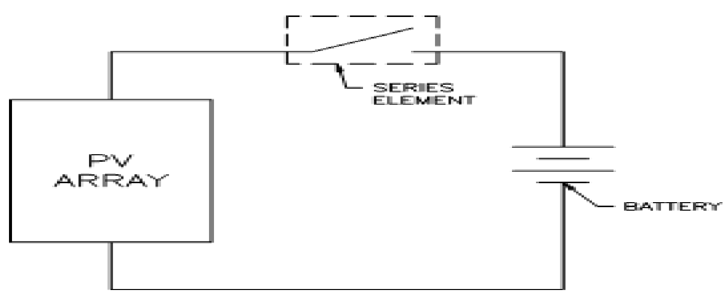


Figure 2.18: Series Regulator

PWM regulators

Pulse width modulated (PWM) regulator is a variation on the series regulator. The PWM regulator is a series regulator with a solid-state switch instead of a relay. With the solid-state switch replacing the relay, the flow of current from the array to the battery can be switched at high speed (frequencies vary with manufacturers, from a few Hz to kHz). By switching the solid-state switch at high speed, the battery charge voltage can be controlled more accurately. Instead of varying the voltage to control battery charging, the PWM regulator varies the amount of the time the solid-state switch is open or closed by modulating the width of the pulse as shown in Figure 2.19.

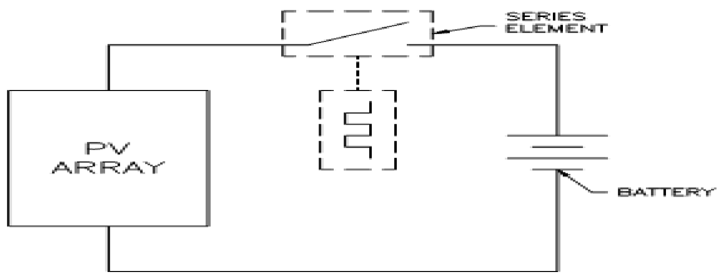


Figure 2.19: PWM Regulator.

PWM charge controllers do not require a diode, as the solid-state switch prevents the current from flowing back to the PV array (IEEE, 2007).

MPPT Controller

The maximum power point tracker (MPPT) charge controller is a variation of the PWM charge controller. The MPPT charge controller as shown in Figure 2.20 adjusts the PWM to allow the PV array voltage to vary from the battery voltage. By varying the array input voltage (while maintaining the battery charge voltage), the maximum output from the PV array can be achieved.

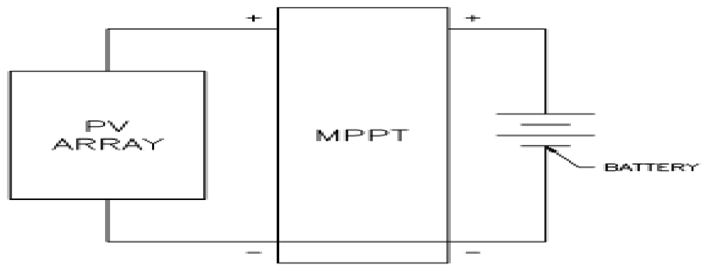


Figure 2.20: MPPT Controllers

The MPPT charge controller is relatively new and has many advantages over other charge regulators. In addition to getting more charge current from the PV array, some MPPT controllers allow the array to operate at a much higher voltage than the battery. This feature can be useful to reduce wire size and voltage drop from the PV array to the controller. Although the MPPT controller can increase the output from the PV array, they typically have greater losses than the other controller types (IEEE, 2007).

Inverter

The electricity produced from the solar home system is D.C. electricity. No A.C appliances can be operated by this type of electricity. In order to operate us need an inverter, which can convert the electricity from the D.C to A.C. Wide range of capacity 100W - 5KW Inexpensive and 10KW–100KW (production by order, expensive). Needs larger PV panels due to low efficiency of AC system compare to DC system.

Figure 2.21: Inverter

Check surge power tolerance: Some appliance such as TV, Fridge requires high current start up. Inverter must have tolerance of this surge current. Example: Rated: 150W (continuous), Surge: 500W (with in one minutes). Choose low self-power consumption and high efficiency type. Sine wave output is ideal. Due to cost limitation, modified sine wave type is common for small applications.

Cables and Accessories: Cables need to be ultra-violet resistant and suitable for outdoor applications. It is very important to keep power losses and voltage drop in the cable to a minimum (Parvathy S. and Jaimol, 2014).

2.7. Description Model

Angstrom's equation *(Renewable and Conventional Energy Technology)* is used to express the average radiation on a horizontal surface in terms of constants α_1, α_2 and the observed values of average length of solar days. The constants α_1, α_2 will be determined for this model based on actual old measurements and equating the data in the Angstrom's equation given as follows:

$$\frac{H_g}{H_c} = \alpha_1 + \alpha_2 (\frac{L_h}{L_m}) \qquad 2.3$$

Where

L_h is the average length of solar day for a given month calculated/observed.

L_m is the length of the longest day in the month.

$\alpha_{1,2}$ are the average length of solar day for a given month calculated/observed.

H_g is the monthly average of daily global radiation on the horizontal surface at a particular location.

H_c is the maximum monthly average of daily global radiation per day corresponding to clear sky.

Values of L_m or Day Length (D_L) is computed from Cooper's formula (solar Energy, 1969) as follows:

$$L_m = (\frac{2}{15}) \qquad 2.4$$

$$w_s = \cos^{-1}(-\tan\phi \tan\delta) \qquad 2.5$$

Where

w_s is the Sunshine Hour Angle

ϕ is the latitude of the location. (Ethiopia)

δ is the solar declination angle, which defined as the angle between the line joining centers of the sun and earth and the equatorial plane. Values of δ are computed from the following relation (Renewable and Conventional Energy Technology),

$$\delta = 232.45\sin(360(\frac{(284+n)}{365})) \qquad 2.6$$

Where

n is the day of the year; it is usually calculated in the 15th of each month.

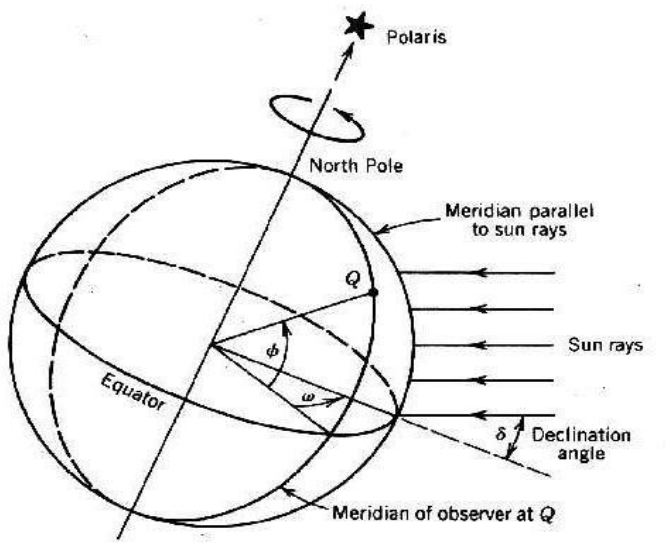


Figure 2.22: Earth-Sun Angles; Latitude (***ϕ***), Declination Angle (***δ***) and Hour Angle (***ω***) (Shadi N. 2010).

Back to equation (2.3), He is replaced with H_o according to changes done on modified Angstrom's Equation for Daily Global Radiation, where H_o is the Daily extra-terrestrial radiation, mean value for the month, which computed by the following relationship in (Renewable and Conventional Energy Technology).

$$H_o = \frac{24}{\pi} I_{sc}(1 + 0.33\cos\frac{360}{365})(\omega s \sin\phi \sin\delta + \cos\phi \cos\delta \sin\omega) \qquad 2.7$$

Where

I_{sc} is the Solar Constant (1353 kW/m^2 = 4870.8 kJ/m^2 .hr)

Using the data of Global Radiation H_g and the average length of solar day L_h around the location of Ethiopia, the regression constants of Angstrom's Equation α_1, α_2 .The Second order polynomial of Angstrom's Equation developed in (Firoz A and Intkhab U., 2004,) is also used in this paper to be modeled for our case.

$$\frac{H_g}{H_o} = \alpha_3 + \alpha_4 (\frac{L_h}{L_m}) + \alpha_5 (\frac{L_h}{L_m})^2 \qquad 2.8$$

Where

$\alpha_3, \alpha_4, \alpha_5$ are the Angstrom's Constants

2.8. Performance of Solar Photovoltaic Power Systems

The performance of solar power plants is best defined by the Capacity Utilization Factor (CUF), which is the ratio of the actual electricity output from the plant, to the maximum possible output during the year. The estimated output from the solar power plant depends on the design parameters and can be calculated, using standard software's. But since there are several variables which contribute to the final output from a plant, the CUF varies over a wide range. These could be on account of poor selection /quality of panels, derating of modules at higher temperatures, other design parameters like ohmic loss, atmospheric factors such as prolonged cloud cover and mist. It is essential therefore to list the various factors that contribute to plant output variation.

2.9 .Reliability of Solar Photovoltaic Power Systems

Reliability engineering is very important in areas of engineering products. According to British Standards, reliability is defined as "the ability of an item to perform a required function understated conditions for a stated period of time". NASA defines reliability as "the probability of device performing adequately for the period of time under the operating conditions encountered".

Reliability, in other words, is the successful operation of the systems. The success of PV systems will be measured by the availability of the power source to the load during its expected life time. Therefore, reliability measurements of photovoltaic systems are usually focused not on cells but on modules and whole systems. Reliability can be improved through fault-tolerant circuit design, which involves using various redundant features in the circuit to control the effect of partial failure on overall module yield and array power degradation. (PVMC, 2014)

Degradation can be controlled by dividing the modules into a number of parallel solar cell networks called branch circuits. This type of design can also improve module losses caused by broken cells and other circuit failures.

Bypass diodes or other corrective measures can mitigate the effects of local cell hot-spots. However, today's component failure rates are low enough that, with multiple-cell interconnects, series/paralleling, and bypass diodes; it is possible to achieve high levels of reliability.

2.10. Factors that Affect Performance and Reliability of Solar Cell

- **Solar Cell Conversion Efficiency** (η)

The conversion efficiency of a typical solar cell is the ratio of the maximum output generated power to the input or incident power. Certain output parameters greatly influence how efficient a solar cell is and are defined as follows.

According to Desta Gebeyehu and K.Leo (2007), the calculation of the overall energy conversion efficiency, η has been performed using the equation

$$\eta = \frac{(V_{oc} \times I_{sc} \times FF)}{P_{inc}} \qquad 2.9$$

Where V_{oc}, I_{sc}, FF and $P_{incident}$ care the open circuit voltage, the short circuit current density, the fill factor and the incident light power on the device as measured by a calibrated reference cell, respectively.

The value of the fill factor of the device is determined, FF from the point $(V_{\max}, I_{\max})$ in the 4th quadrant of the point of the I-V characteristics with the maximum electrical power according to

$$FF = \frac{(V_{\max} \times I_{\max})}{(V_{oc} \times I_{sc})} \qquad 2.10$$

- **Short Circuit Current** (I_{sc})

The short-circuit current (I_{sc}) is the current produced when the positive and negative terminals of the cell are short-circuited, and the voltage between the terminals is zero, which corresponds to a load resistance of zero.

The short-circuit current is dependent on the incident photon flux density and the spectrum of the incident light. The spectrum is standardized to the AM1.5 (see Figure 2.25 and 2.26 below) for standard solar cell parameter measurements. For Ideal solar cell, $I_{sc} = I_{photon}$. And this is the maximum current delivery capacity of the solar cell at any given illumination level. From Figure 2.26, the maximum I_{sc} is found by the integration of the spectrum distributions from low wavelengths up to the maximum wavelength at which electron-hole pairs can be generated for a given semiconductor. The common relationship between the wavelength and the photon energy is $E_{(e_V)} = \frac{1.24}{\lambda}$. Silicon has a band gap of $1.1eV$ and the λ corresponding to this is about $1.13\mu m$. Crystalline silicon solar cell can deliver a maximum of 46mA/cm^2 under an AM 1.5 spectrum (Green M., 1982)

- **Open Circuit Voltage** (V_{oc})

The open-circuit voltage is the maximum voltage at which no current (zero) flows through the external circuit; i.e. when the solar cell terminals are opened or not connected to a load. It is the maximum voltage that a solar cell can deliver under any given illumination. An ideal PN-Junction cell V_{oc} is given as follows in equation 2.11.

$$V_{oc} = \frac{K_{BT}}{q} \ln\left(\frac{I_{photon}}{I_o} + 1\right) \qquad 2.11$$

From this equation, the V_{oc} depends on the photo-generated current density I_{photon} and the saturation current Io. Also since the saturation current depends largely on the recombination in the solar cell, the open circuit voltage is a measure of the recombination in the device. For silicon solar cell, the maximum open circuit voltage is about 700mV.

- **Fill Factor** (FF)

The fill factor is an important parameter for PV cell/module; it represents the area of the largest rectangle, which fits in the I-V curve. The importance of (FF) is linked with the magnitude of the output power. The higher the FF the higher output power. Figure 2.23 illustrates the fill factor which is the ratio between the two rectangular areas and is given by the following formula. The ideal (FF) value is 1 which means that the two rectangles are identical (The Solometric, 2011).

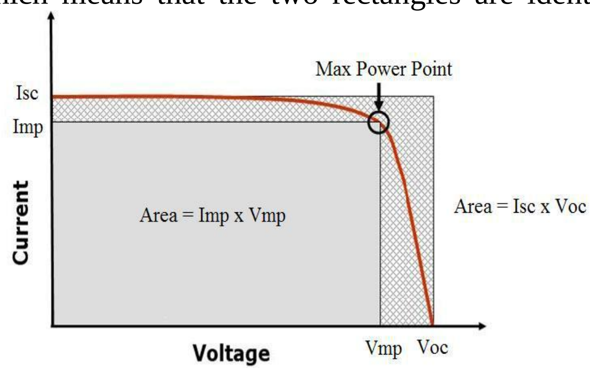


Figure 2.23.: Fill Factor (The Solometric, 2011).

The fill factor FF is the ratio of the maximum power (P_{Mp}) generated by the solar cell to the product of the voltage open circuit V_{oc} and the short circuit current I_{sc}.

$$FF = \frac{P_{MP}}{V_{oc} \times I_{sc}} = \frac{V_{Mp} \times I_{Mp}}{V_{oc} \times I_{sc}} \qquad 2.12$$

From the above set of equations, the solar cell conversion efficiency (η) can be defined as the ratio of the maximum generated power ($P_{Mp} = V_{MP} \times I_{Mp}$) to the input or incident power Pin as given by equation 10 below.

$$\eta = \frac{V_{MP} \times I_{MP}}{P_{inc}} = \frac{V_{oc} \times I_{sc} \times FF}{P_{inc}} \qquad 2.13$$

Pin is the total power of sunlight illumination on the cell. Energy-conversion efficiency of commercially available solar cells typically lies between 10 and 25 % **(**Henry A.et al., 2013). These three-important parameter (V_{oc}, I_{sc} and FF)as described above are the most important factors that determine how efficient a solar cell is and are optimized for efficient solar cell design.

Module Efficiency (η_{PV})

The PV cell/module efficiency is the ability to convert sunlight to electricity. The efficiency is necessary for space constraints such as a roof mounted system. Mathematically, it determines the output power of the module per unit area. The maximum efficiency of the PV module is given by:

$$\eta_{PV_{nax}} = (\frac{V_{mp} \times I_{mp}}{G \times A}) \times 100\% \qquad 2.14$$

Where *G* is global radiation and considered to be 1000 W/m^2 at (STC) and *A* is the Area of the PV module.

Maximum Power (P_{MP})

The Maximum current and voltage of a typical solar cell are represented at the 4th quadrant of the IV characteristic curve of Figure 2.23, the maximum power is the area of the product of the maximum current I_{mp} and Voltage V_{mp} as shown in the equation 2.15 below.

$$P_{MP} = V_{Mp} \times I_{Mp} \qquad 2.15$$

- **Light Energy (Photons) Absorption**

Sunlight is a portion of the electromagnetic radiation (Infrared, Visible and Ultraviolet lights) that is emitted by the Sun. On Earth, sunlight is filtered through the Earth's atmosphere, and is visible as daylight when the sun is above the horizon. The amount of radiant energy received from the sun per unit area per unit time is called Solar Irradiance and it is a function of wavelength at a point outside the Earth’s atmosphere. Solar irradiance is greatest at wavelengths of between 300-800 nm. Figure 2.24 below shows the solar spectrums. The spectrum of the Sun's solar radiation is very closely matches that of a black body with a temperature of about 5,800 deg K. (Henry A., 2013).

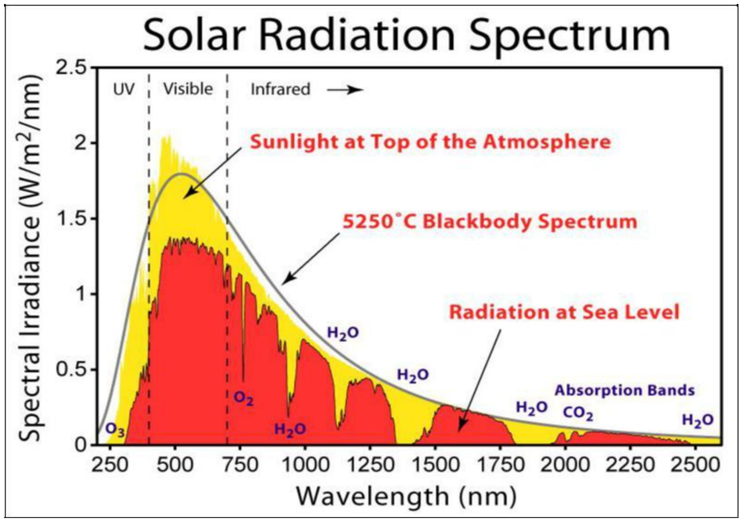


Figure 2.24: Solar radiation spectrums (Henry A., 2013).

The path length of the solar radiation through the Earth's atmosphere in units of Air Mass (AM) increases with the angle from the zenith. For a path length L through the atmosphere and solar radiation incident at angle θ relative to the normal to the Earth's surface, the air mass Coefficient (AM) is;

$$AM = \frac{L}{Lo} \approx \frac{1}{\cos\theta} \qquad 2.16$$

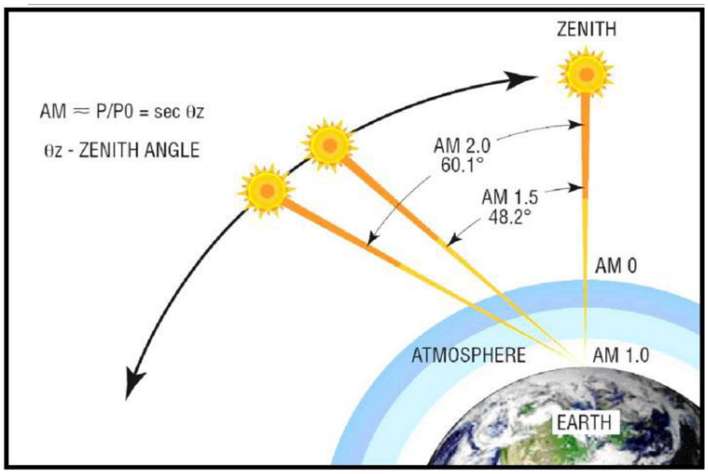


Figure 2.25: Solar Radiation Air Mass standards and corresponding Latitude (Henry A.et al., 2013)

The AM 1.5 spectrum which correspond to Latitude 48.2˚ is the preferred standard spectrum for solar cell efficiency measurements. Where Lo (the zenith path length) is perpendicular to the Earth's surface at sea level and θ is the zenith angle in degrees. The air mass number is dependent on the sun's elevation path through the sky and therefore varies with time of day and with the passing seasons of the year, and also with the latitude of the observer. At the outer space, i.e. beyond our terrestrial environment, the solar spectrum has an Air Mass coefficient of zero (AM 0) it can be seen in Figure 2.25 above and Figure 2.26 below

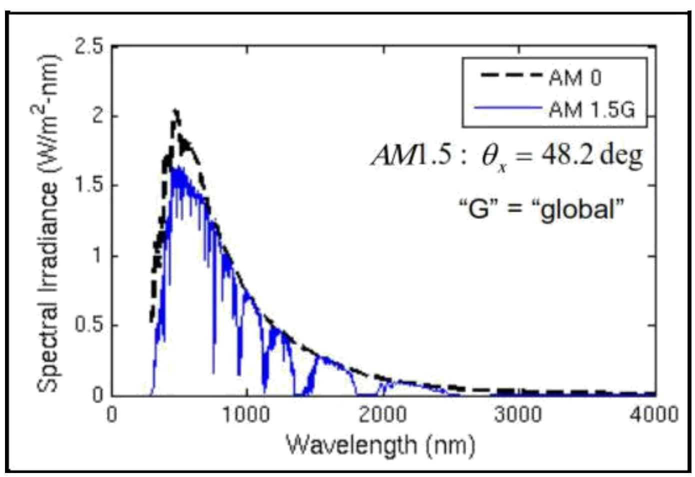


Figure 2.26: Solar Spectrums Terrestrial (Henry A.et al., 2013).

The integrated power of the sun at AM 0 spectrum is 136.6mW/cm^2 (Henry A.et al., 2013).Since the sun's radiation travels through the atmosphere and would encounter various atmospheric diffusion and attenuation, the solar spectrum Air mass coefficient from the surface of the earth atmosphere at typical latitude 48.2° is AM1.5G, the integrated power is reduced approximately to $100mW/cm^2$ (Henry A.et al., 2013).This is the standard power that most solar cells conversion efficiency is measured against. This means for example, if a solar array produces a power output of $15mW/cm^2$, then the conversion efficiency would be 15%.

The question then is how many photons can be absorbed per unit area of solar array? Let us consider silicon cell as example to answer this question; for a Silicon solar cell with energy band gap of $E = 1.1eV$ .Only photons with energy greater than $1.1eV$ and wavelength $\lambda < \lambda_{bandgap}$, about $1.13_{\mu m}$ would be absorbed and the rest will be lost as heat (Purnomo, et al., 2011). Also, even when the incident light with the adequate energy level and wavelength strikes the surface of the cell material, some photons are reflected from the surface of the solar cells; all these leads to reduced efficiency. One way to ensure maximum absorption is through the use of cell material with very low reflective coefficient or placing a thin film anti-reflective coating over cell surface. Another method that can be employed in reducing reflection is using textured surface, in which the direction of reflected light on the textured surface is downward so that reflected photons can be reabsorbed again by the cell, thereby improving the conversion efficiency (Purnomo, et.al, 2011).

- **Losses Due to Parasitic Resistance**

Another source of loss is through parasitic resistance. The equivalent circuit of practical solar cell is shown in the Figure 2.27 below and the ideal diode equation 2.17 as modified below. This is different from the ideal solar cells because of the introduction of series resistance (R_s) which arises from the cell material surface to the contacts. Series resistance is worse at high photo-current. And the Shunt resistance (R_{sh}) arises from the leakage of current around the edges of the device and between contacts of different polarity. It is particularly profound with the cell material of poor rectifying characteristic. The effect of parasitic resistances is that it reduces the area of the maximum power rectangle $(V_{oc}.I_{sc})$ of the IV characteristic curves and hence the efficiency suffers. However, latest cells manufacturing improvement and control of material chemistry has shown significant improvement in achieving optimum cell resistivity and thus improved efficiency (Purnomo, et.al. 2011).

$$I = I_L - I_o(e^{q\frac{(V+IR_s)}{K_{BT-1}}}) - \frac{V \times IR_s}{R_{SH}} \qquad 2.17$$

Equations 2.1 through 2.2, 2.9, 2.10, 2.11, 2.12, 2.13, 2.15,2. 16, and 2.17 (Green M.et al., 1982).

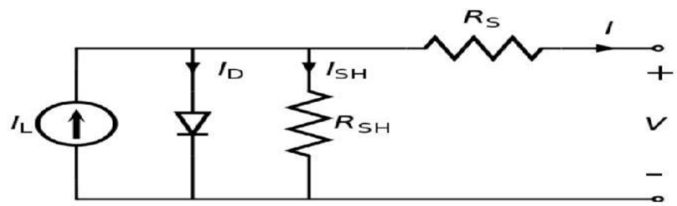


Figure 2.27: Practical solar cell equivalent circuits (Henry A.et.al 2013).

The efficiency of different solar cells with different parameters like fill factor (FF) ,current density (J), open circuit voltage (V_{oc}) upon the space area (A) covered by the panel described the Table 2.3 .

Table 2.2: Different solar cells performance (Green M.et al., 2001).

Cell Type	Area(cm^2)	Voc (V)	Jsc(mA/cm^2)	FF	Efficiency (%)
Crystalline Si	4.0	0.706	42.2	82.8	24.7
Crystalline GaAs	3.9	1.022	28.2	87.1	25.1
Poly-Si	1.1	0.654	38.1	79.5	19.8
a-Si	1.0	0.887	19.4	74.1	12.7
$CuInGaSe_2$	1.0	0.669	35.7	77.0	18.4
CdTe	1.1	0.848	25.9	74.5	16.4

It shows the performance that having highest fill factor of the crystalline attains highest efficiency than the lower fill factor.

- **Irradiation effect**

Photovoltaic output power is affected by incident irradiation. PV module short circuit current (I_{sc}) is linearly proportional to the irradiation, while open circuit voltage (V_{oc}) increases exponentially to the maximum value with increasing the incident irradiation, and it varies slightly with the light intensity ("Electropaedia, Solar Power (Technology and Economics)," 2012). Figure 2.28 describes the relation between Photovoltaic voltage and current with the incident irradiation

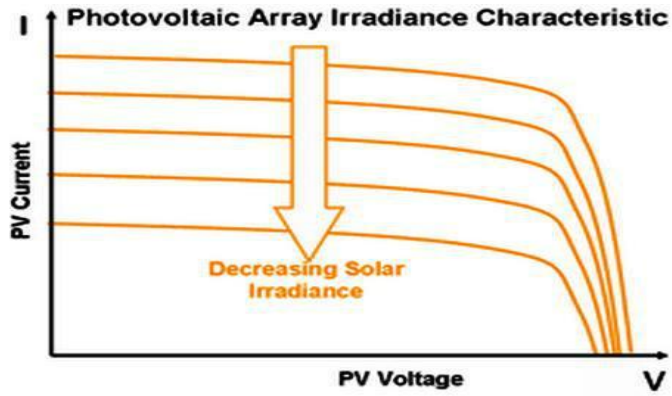


Figure 2.28: Effects of the incident irradiation on module voltage and current ("Electropaedia, Solar Power (Technology and Economics)," 2012).

- **Maximum power point ($_{MPP}$)**

Maximum electrical power of the PV module is equal to the current at maximum power point (I_{MP}) multiplied by the voltage at maximum power point (V_{MP}), which is the maximum possible power at Standard Test Condition (STC). Referring to Figure 2.29, the "knee" of the I-V curve represents the maximum power point (P_{MPP}) of the PV module/system. At this point the maximum electrical power is generated at STC (The Solometric, 2011). The usable electrical output power depends on the PV module efficiency which is related to the module technology and manufacture.

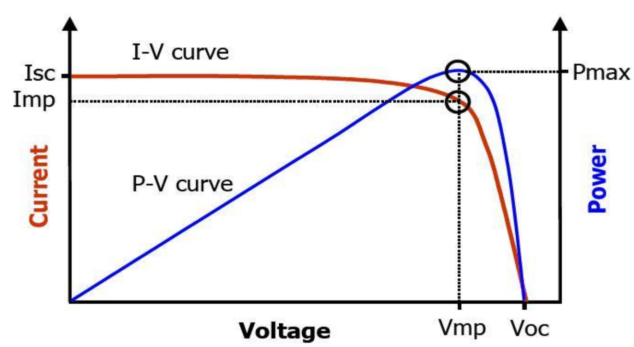


Figure 2.29: Maximum power point (The Solometric, 2011).

2.11. Factors that Affect Performance and Reliability of Solar Photovoltaic Power Systems

The performance of the power plant however depends on several parameters including the site location, solar insulation levels; climatic conditions specially temperature, technical losses in Cabling, module mismatch, soiling losses, MPPT losses, transformer losses and the inverter losses. There could also be losses due to grid unavailability and the module degradation through aging. Some of these are specified by the manufacturer, such as the dependence of power output on temperature, known as temperature coefficient. The following factors are considered key performance and indicators: Radiation at the site, Losses in PV systems, Temperature and climatic conditions, Design parameters of the plant, Inverter efficiency, Module Degradation due to aging and the like. These are covered in detail as follows:

- **Solar radiation**

Solar radiation is a primary driver for many physical, chemical and biological processes on the earth's surface, and complete and accurate solar radiation data at a specific region are of considerable significance for such research and application fields as architecture, industry, agriculture, environment, hydrology, agrology, meteorology, limnology, oceanography and ecology. Besides, solar radiation data are a fundamental input for solar energy applications such as photovoltaic systems for electricity generation, solar collectors for heating, solar air Conditioning climate control in buildings and passive solar devices (Zaharim A. et al., 2009).

12 Several empirical formulae have been developed to calculate the solar radiation using various parameters. Some works used the sunshine duration others used the sunshine duration, relative humidity and temperature, while others used the number of rainy days, sunshine hours and a factor that depends on latitude and altitude (Zaharim A.et al., 2009).

The primary requirement for the design of any solar power project is accurate solar radiation data. It is essential to know the method used for measuring data for accurate design. Data may be instantaneously measured (irradiance) or integrated over a period of time (irradiation) usually one hour or day. Data maybe for beam, diffuse or total radiation, and for a horizontal or inclined surface. It is also important to know the types of measuring instruments used for these measurements (Duffie J. A. and William B., 2006).

All these sources specify global irradiance, measured over one hour periods and averaged over the entire month. The data is available for horizontal surfaces and must be suitably converted for inclined solar collectors. Monthly average daily solar radiation on a horizontal surface is represented as H, and hourly total radiation on a horizontal surface is represented by me. The solar spectrum, or the range of wavelengths received from the Sun are depicted in the figure below. Short wave radiation is received from the Sun, in the range of 0.3 to 3 μm, and long wave radiation (greater than 3 μm) is emitted by the atmosphere, collectors or any other body at ordinary temperatures (Sen, Zekai, 2008). Spectral power density is Energy distribution in KW/m^2μm

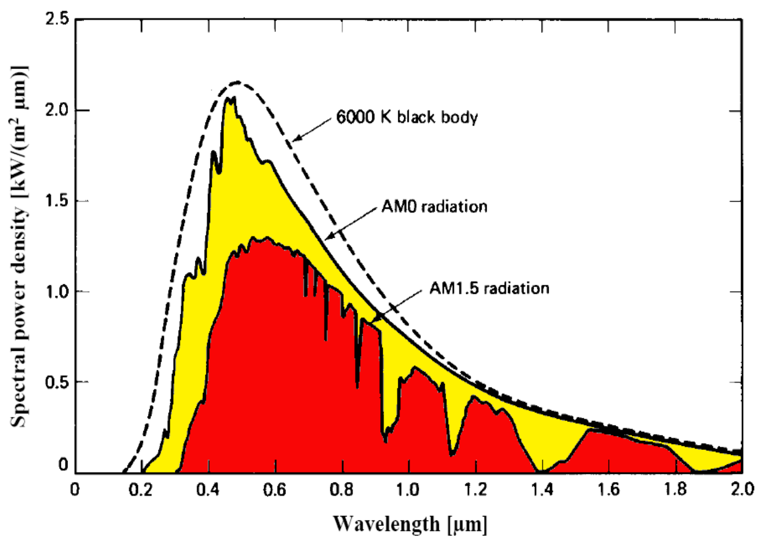


Figure 2.30: Solar spectrum distribution (M. Zeeman, 2011).

- **Measurement of solar radiation**

Measurements may be direct or indirect. Direct methods are those involving the use of devices such as pyrheliometers and pyranometers at radiation stations. Indirect methods use satellite data, the number of sunshine hours, or extrapolation to arrive at values for radiation at a place. The solar radiation data should be measured continuously and accurately over the long term. Unfortunately, in most areas of the world, solar radiation measurements are not easily available due to financial, technical or institutional limitations. Solar radiation is measured using pyrheliometers and pyranometers. Ångström and Thermoelectric Pyrheliometers are used for measurement for direct solar radiation and global solar radiation is measured using the

Thermoelectric Pyranometer.

A Thermoelectric Pyranometer with a shading ring is used for measurement of diffuse radiation. Inverted pyranometers and Sun photometers are used for measuring reflected solar irradiance and solar spectral irradiance and turbidity respectively (IMD Pune, 2010).

- **Sources of radiation data**

Ethiopia is located in Eastern Africa with territory extending from 3 to 15 degrees' North latitude 33 to 48 degrees' East longitude. Thus, Ethiopia possesses quite large and fairly constant solar source spread over the country. Nevertheless, solar energy development in Ethiopia less than 1% (around 6MW). According to the analysis of the national Solar and wind Master Plan developed in Feb, 2012 with the collaboration of Ethiopia and Chinese governments (Ministry of Water and Energy. June 2013, p.4). Ethiopia solar radiation ranges from 4 to 6KWh/ (m^2.a) with an annual total solar energy reserve of 2.199 million TWh. (Figure 2.31).

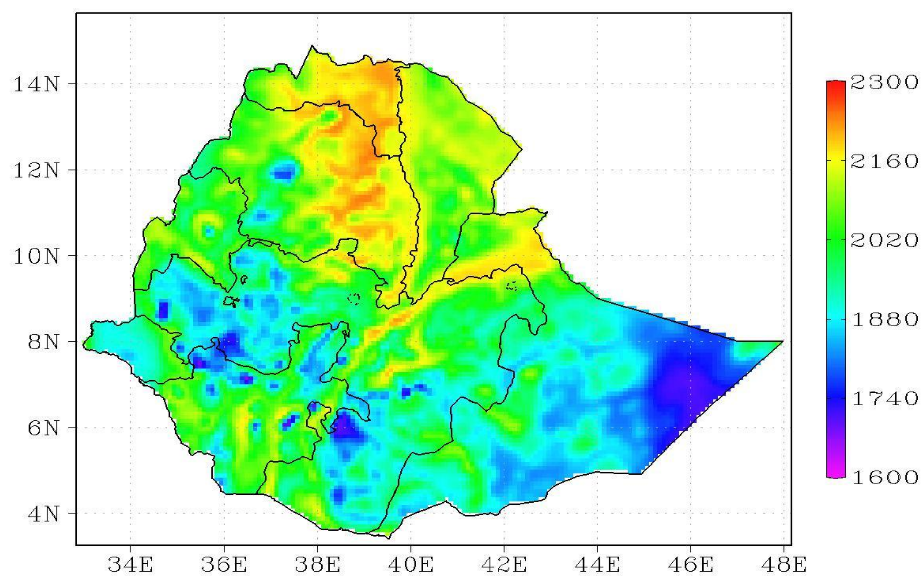


Figure 2.31: Source: Solar and Wind Master plan report 2013.

According to the standard of Chinese meteorological industry *Assessment Method for Solar Energy Resources* (QX/T 89-2008), annual total solar radiation in any region of the country reaches class "very rich" (1400 kW·h/ (m^2·a) ≤annual total solar radiation≤ 1750 kW·h/ (m^2·a)) or "richest" (annual total solar radiation≥1750 kW·h/ (m^2·a)). (Figure 2.32)

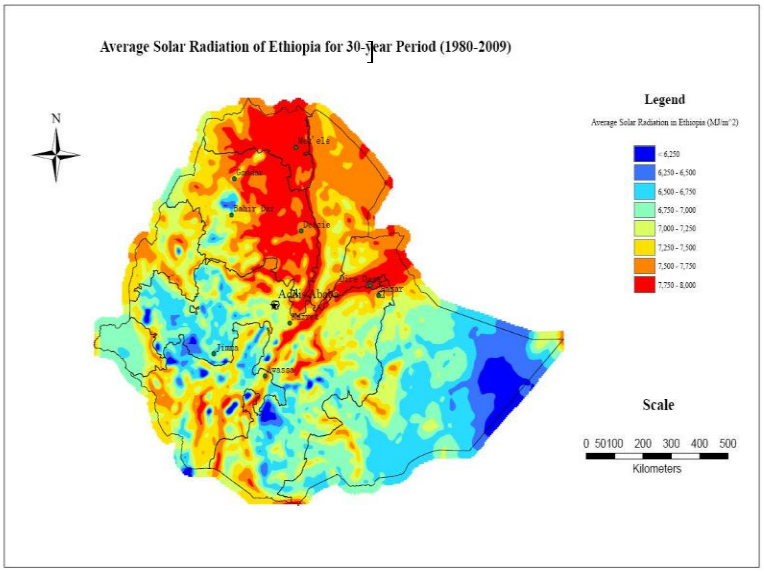


Figure 2.32: Source: solar and Wind Master plan report 2013.

Solar energy development in Ethiopia is for application of lighting and powering water pumps in rural areas and water heating in major cities and these account for only around 6MW. In remote telecom installations, solar PV is used.

Table 2.3: presents the list of recommended sites for short term solar PV power development by the governments of Ethiopia.

No	Name	Capacity (MW)	Area (Km^2)	Region
1	Debere Berhan PV power station	10	0.39	Amhara
2	Metahara PV power station	50	1.6	Oromyia
3	Dera solar energy PV power station	60	1.59	Oromiya
	Total	120	3.58	

- **Losses in PV Solar systems**

The estimated system losses are all the losses in the system, which cause the power actually delivered, or to the electricity grid to be lower than the power produced by the PV modules. There are several causes for this loss, such as losses in cables, power inverters, dirt (sometimes snow) on the Modules, ambient temperature, soiling, shading, varying insolation levels and so on. While designing a PV system, all possible losses have to be taken into consideration.

Reflection losses

PV module power ratings are determined at standard test conditions, which require perpendicular incident light. Under field conditions larger incidence angles occur, resulting in higher reflection losses than accounted for in the nominal power rating. Calculations show that for modules faced towards the equator, and with a tilt angle equal to the latitude, yearly reflection losses relative to STC are about 1%.

Soiling

Soiling of solar panels can occur as a result of dust and dirt accumulation. In most cases, the material is washed off the panel surface by rainfall; however, dirt like bird droppings may stay even after heavy rains. The most critical part of a module is the lower edge. Especially with rather low inclinations, soiling at the edge of the frame occurs. By often repeated water collection in the shallow puddle between frame and glass and consecutive evaporation dirt accumulates. Once it causes shading of the cells, this dirt reduces the available power from a module. The losses are generally 1%; however, the power is restored if the modules are cleaned.

Mismatch effects

Mismatch losses are caused by the interconnection of solar modules in series and parallel. The modules which do not have identical properties or which experience different conditions from one another. Mismatch losses are a serious problem in PV modules and arrays because the output of the entire PV array under worst case conditions is determined by the solar module with the lowest output. Therefore, the selection of modules becomes quite important in overall performance of the plant.

Temperature effect

Module performance is generally rated under Standard Test Condition (STC): irradiance of 1,000 W/m², solar spectrum of AM 1.5 and module temperature at 25°C. All electrical parameters of solar module depend on temperature. The module output decreases with increase in temperature. Module temperature is highly affected by ambient temperature. Short circuit current increases slightly when the PV module temperature increases more than the Standard Test Condition (STC) temperature, which is 25°C. However, open circuit voltage is enormously affected when the module temperature exceeds 25^{o}C. In other words, the increasing current is proportionally lower than the decreasing voltage. Therefore, the output power of the PV module is reduced (Electropaedia, 2012). Figure 2.41 explains the relation between module temperature with voltage and current.

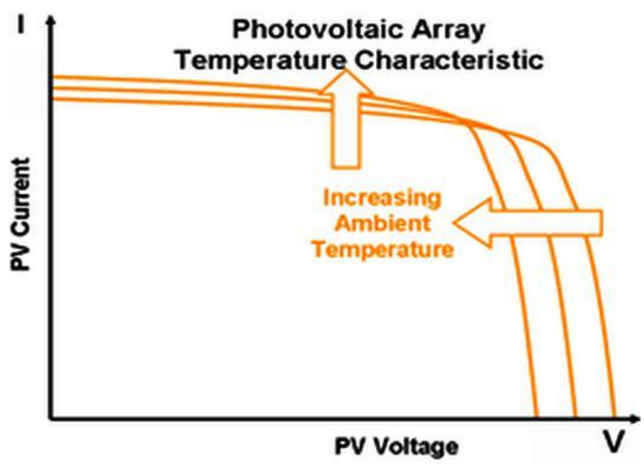


Figure 2.33.: Effect of ambient temperature on module voltage and current. ("Electropaedia", 2012).

The loss of power as defined by Temperature coefficients. This effect can be seen in the sample V-I characteristics, obtained from the specification sheet for commercially available module. The temperature coefficient represents the change in power output with different temperatures. Typical values of temperature coefficient γ for crystalline silicon are as follows:

$\gamma(P_{mpp})$ Typical values for crystalline modules is -0.4 to 0.45%/K

$\gamma(P_{mpp})$ Typical values for amorphous modules is -0.2 to 0.23%/K

$\gamma(P_{mpp})$ Typical values for CdTe modules is -0.24 to 0.25%/K

Note: Therefore, thin film modules will certainly give higher performance at elevated temperature when compared to crystalline silicon.

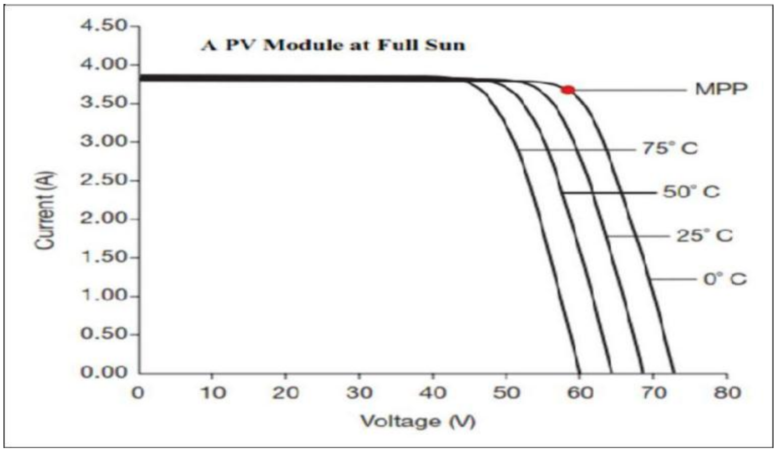


Figure 2.34: MPP with different temperature. (Henry A., 2013).

Inverter efficiency

A solar PV inverter is a type of electrical inverter that is made to change the direct current (DC) electricity from a photovoltaic array into alternating current (AC) for use with home appliances or to be fed into the utility grid. These inverters may be stand-alone inverters, which are used in isolated systems, or grid tie inverters which are used to connect the power plant to the grid. The efficiency of an inverter has to do with how well it converts the DC voltage into AC. The currently available grid connected inverters have efficiencies of 96 to 98.5%, and hence choosing the correct inverter is crucial to the design process. There are less efficient inverters below 95% also available. Inverters are also much less efficient when used at the low end of their maximum power. Most inverters are most efficient in the 30% to 90% power range.

Solar Plant design

There are two key parameters that govern the design; 1) solar resource (energy supply) and 2) electricity usage (energy demand). The fundamental design objective is to ensure that the supply meets the demand, under various environmental and cost constraints and uncertainties in both the energy supply and demand, and also to maximize component lifespan. It is important for the two key parameters to be determined and/or estimated as accurately as possible for ideal system performance. The basic design goal is to properly size the solar panel and the battery (or battery bank) so that the loads can be powered up 90%-99.99% of the time (Shepperd and Richards, 1993).

Maximum Power Point Tracking (MPPT) Losses

Power output of a solar PV module changes with change in direction of sun, changes in solar insolation level and with varying temperature. The PV (power vs. voltage) curve of the module there is a single maximum of power. That is there exists a peak power corresponding to a particular voltage and current. Since the module efficiency is low it is desirable to operate the module at the peak power point so that the maximum power can be delivered to the load under varying temperature and insolation conditions. Hence maximization of power improves the utilization of the solar PV module. A maximum power point tracker (MPPT) is used for extracting the maximum power from the solar PV module and transferring that power to the load. A dc/dc converter (step up/step down) serves the purpose of transferring maximum power from the solar PV module to the load. Maximum power point tracking is used to ensure that the panel output is always achieved at the maximum power point. Using MPPT significantly increases the output from the solar power plant. As depicted in the V-I curve for the monocrystalline solar module below; the maximum power point is achieved at the intersection of the current and voltage curves at a particular value of irradiation.

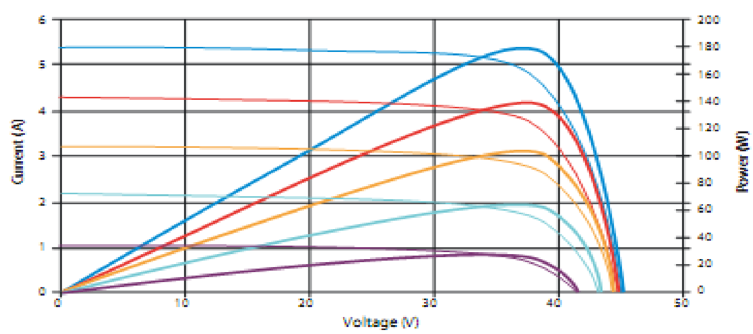


Figure 2.35: Maximum Power Point Tracking

There are losses in the cabling, transformer, inverter and transmission systems, which are easy to determine in most cases.

The Maximum power point tracking (MPPT) feature that allows an inverter to remain on the ever-moving maximum power point (MPP) of a PV array is called maximum power point tracking (MPPT).As discussed in the section of the solar cell device physics, the IV characteristic curve of PV modules includes the short-circuit current value (I_{sc}) at 0 V Dc, the open-circuit voltage (V_{oc}) value at 0 A_and a "knee", the point where maximum power point (MPP) is found on the curve, this is the location on the IV curve where the voltage multiplied by the current yields the highest value of power. Figure 2.34 shows the MPP for a module at full sun at various temperature conditions. As cell temperature increases, voltage decreases and module conversion efficiency suffers. Other than temperature, module performance is also affected by sun irradiance. When sun is full i.e. at irradiance of $1000W/m^2$, module current is highest and when there is less sunlight, module current decreases and so is conversion efficiency. Since sunlight intensity and module or cell temperature vary substantially throughout the day and the year, array MPP (current and voltage) also varies accordingly. The ability of an inverter to accommodate these environmental variations and optimize its performance to meet grid criteria and other regulatory standards (NEC, IEEE and UL etc) at all the time of operation is achieved largely due to effective maximum power point tracking feature.

Orientation and Optimum Tilt angle

The performance of photovoltaic (PV) modules and systems is affected by the orientation and tilt angle. As these parameters determine the amount of solar radiation received by the surface of a PV module in a particular region. Normally the region that lies in the northern hemisphere the panel installed on these building should be facing south or facing the equator and for southern hemisphere facing the north tilt from horizontal at an angle approximately equal to the site latitude. So that maximum irradiance captured. Panel will collect solar radiation more. Efficiently where the sun rays are perpendicular to the panel surface.

The solar array faces south (or north in the southern hemisphere) and is usually tilted at an angle to the horizontal approximately equal to the latitude of the site plus or minus 15^0 C depending on the application. This maximizes the solar energy collected during the year and reduces excess solar energy collected in the summer.

Types of Solar Panel Mountings

Research shows that there are three types of solar panel mountings. These are fixed, adjustable, and tracking. The fixed solar panel mounting system is completely stationary. This is the simplest and cheapest type of solar panel. Example: All the SHS and Institutional installed in the fixed solar panel.

The adjustable solar panel mounting system includes adjusting the angle of inclination of the solar panel mount two or more times a year to account for the lower angle of the sun in the winter season. This system is more expensive than the fixed mount but it increases the solar panel power output by approximate lately 25%, thus making it more efficient.

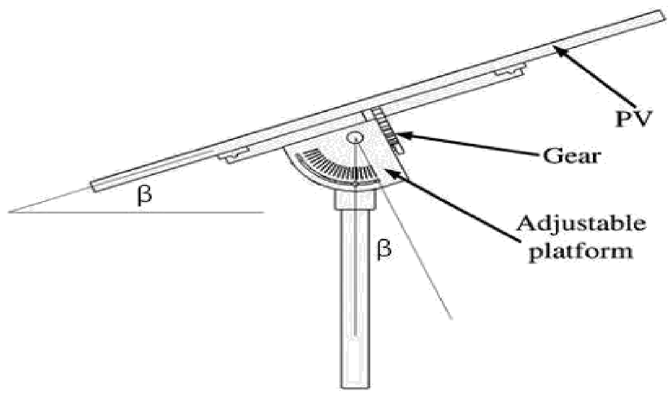


Figure 2.36.: Adjustable Solar Panel Mount

The tracking solar panel mounting system is the most expensive of the three types of mounting. It tracks and follows the path of the sun (east to west) during the day as well as the seasonal declination movement of the sun. The tracking solar panel output increases by approximately 25% - 30%. It cannot be denied that this type of mounting is the most efficient in producing the greatest amount of solar power.

Figure 2.37: Tracking Solar Panel Mount

Solar Array Mounting and Tracking

The conversion efficiency of a solar panel is directly proportional to the amount of direct solar irradiance that is absorbed. Irradiance is the amount of solar radiation that strikes the surface of a solar cell or panel and it is expressed in kW/m^2. The irradiance multiply by time is a measure of solar insolation. The peak sun hours is the number of hours per day when the solar insolation =1kw/m$^{2/}$/d. Apart from the effect of atmospheric attenuations, solar energy absorption is also affected by the earth's distance from the sun and the earth tilt angle with respect to the sun. The angle between the true south and the point on the horizon directly below the sun is the Azimuth angle, measured in degrees east or west of true south. For south facing locations in the northern hemisphere, the default value is an azimuth angle of 180°. Increasing the azimuth angle maximizes afternoon energy production. For a fixed PV array, the azimuth angle is the angle clockwise from true north that the PV array faces and for a single axis tracking system, the azimuth angle is the angle clockwise from true north of the axis of rotation. The azimuth angle is not applicable for dual axis solar tracking PV arrays (Henry A., 2013).

Table 2.4: Azimuth Angle by heading (en.wikipedia.org/wiki/Azimuth, 2012).

Azimuth Angles by Heading	
Heading	Azimuth Angle (°)
N	0 or 360
NE	45
E	90
SE	135
S	180
SW	225
W	270
NW	315

The sun's height above the horizon is its altitude and it changes based on time and season of the year. Based on the sun's altitude changes, the tilt angle of a solar module with respect to the sun must be carefully considered during module or array installations. The general practice for fixed array is that the tilt angle be equal to the latitude, for providence Ethiopia, the latitude is extending from 3 to 15 degrees' North latitude 33 to 48 degrees' East longitude. For better absorption, it is recommended that the tilt angle be adjusted to Latitude + 15˚ during winter and Latitude - 15˚ during summer.

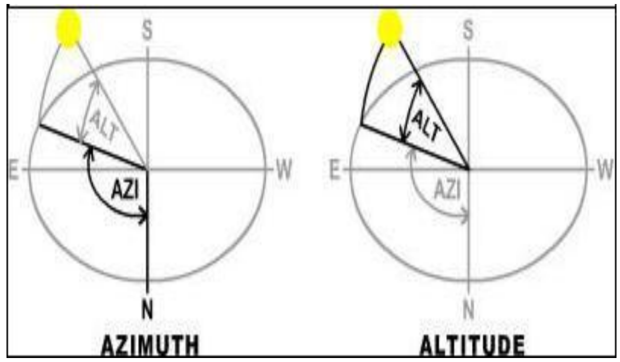


Figure 2.38.: Sun's position; Azimuth and Altitude (Henry A., 2013).

Several factors must be considered when determining the use of trackers. Some of these include: the solar technology being used, the amount of direct solar irradiation available and the cost to install and maintain the trackers among others.

Types of tracker

Trackers can be categorized by the complexity of operation and sophistication. There are two major groups; Active and passive Trackers. Passive trackers are without motor. Active trackers are motorized and can be sub-categorized into single axis and dual axis trackers:

Single axis**:** Solar trackers can either have a horizontal or a vertical axis. The horizontal type is used in tropical regions where the sun gets very high at noon, but the days are short. The vertical type is used in high latitudes where the sun does not get very high, but summer days can be very long. In concentrated solar power applications, single axis trackers are used with parabolic and linear Fresnel mirror designs.

Dual axis**:** The Dual axis solar trackers have both a horizontal and a vertical axis and thus they can track the sun's apparent motion virtually at any angle. A dual axis tracker maximizes the total power output of solar array by keeping the panels in direct sunlight for the maximum number of hours per day.

Tracker Components

A typical solar tracking system consist of mechanical parts like the linear actuator with integrated dc or ac motor and gear and an electronic part like motor drive and controller, sun sensor and power supply. Based on complexity of design and accuracy of tracking, there might be more additional components than those mentioned above. For example, The AZ125 Wattsun dual tracker shown in Figure 2.36 below can move up to 270˚ in the horizontal direction and up to 75˚ vertical (Henry A.,2013).

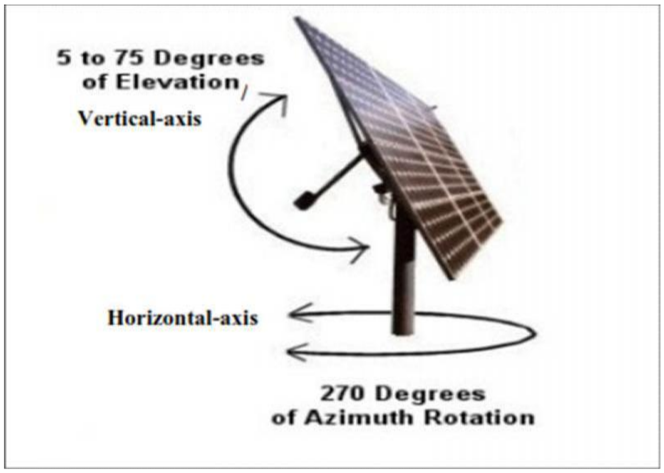


Figure 2.39: a 2-Axis Tracking system (Henry A., 2013).

Module Degradation

Degradation (or aging) of the PV module has a key role for decreasing the output power among its life time, and it differs from technology to another. It is important factor for the investors whom interested in Photovoltaic field. In this section degradation from PV performance point of view is considered based on the previous researches on this field (Laith Sa'd Basha, 2012).

Degradation generally is caused by UV absorption near the top of silicon surface for crystalline silicon based technology, many other factors such as lamination disintegration of backing material, bubbling at solder spots, and fissures in backing material, module delaminating, solder-joint degradation, hot spots, encapsulate, discoloration, mechanical damage and cell degradation. NREL3 Laboratory grouped the degradation into 5 categories. Degradation of packaging materials, Loss of adhesion, Degradation of cell/module interconnects, Degradation caused by moisture intrusion and Degradation of the semiconductor device (Laith Sa'd Basha, March, 2012).

To estimate the lifetime from degradation, standard tests called ‘Type Approval Tests’ have been introduced by the International Electro Technical Commission (IEC). These are essentially accelerated test procedures based on accelerated climatic testing. However, there is still some uncertainty as to whether these accelerated tests can accurately simulate real time long term exposure. The IEA guidelines recommended life expectancy used in life cycle assessment studies of photovoltaic components and systems as follows:

Modules lifetime: 30 years for mature module technologies (e.g. glass-tedlar encapsulation), life expectancy may be lower for foil-only encapsulation;

Inverters: 15 years for small size plants (residential PV); 30 years with 10% of part replacement every 10 yrs (parts need to be specified) for large size plants utility PV, (Mason et al., 2006).

Structure: 30 years for roof-top and façades and between 30 to 60 years for ground mount installations on metal supports. Sensitivity analyses should be carried out by varying the service life of ground mount supporting structures within the time span indicated.

Cabling: 30 years

2.12. Lighting Options in Ethiopia

Lighting sources in Ethiopia can be divided between grid-connection, kerosene (and other traditional methods), modern off-grid technologies, and PV-battery based systems. Urban zones rely on an existing grid network, while in rural areas most lighting products are powered usingkerosene fuel and conventional thermal generation. With 84 percent of Ethiopians living in rural areas, this represents more than 70 million people (15 million households) who do not have access to electricity. This study also estimated that even with tremendous investments to rapidly scale up grid connection in Ethiopia, more than 12 million families will still be living without electricity by 2025. For basic energy services like lighting, these families will continue to rely on carbon dioxide (CO_2)-emitting, hazardous, and unhealthy traditional lighting sources such as kerosene, fuel wood, and candles. The latest census data (2004) indicated that about 80 percent of households in rural towns and villages rely on kerosene for lighting, compared to 23 percent of urban dwellers. Moreover, 18 percent of rural families use firewood as their primary source for lighting.

Existing solar companies in Ethiopia

Existing solar companies are few, with less than 15 PV equipment suppliers in Ethiopia. However, only five or six company's supply 90 percent of the market. The other suppliers sell PV systems along with many other products, with the solar business accounting for less than 5 percent of their annual turnover.10 While the private sector is the sole supplier of PV systems in the commercial market, it relies heavily on tenders from the public sector—REF, non-government organizations (NGOs), and foreign aid missions. Only a few companies like Direct Solar, Ethio-Dutch Business, and ever bright sell off-grid lighting products to consumers. Many other small electronic shops offer only small LED lighting products as off-grid lighting technology options (Lighting Africa Policy Report, 2011).

Where is the Off-Grid Market Going?

Lighting Africa Report ,2012, approach to make high market, to educate the population about the performance of the devices off-grid lighting market in non-grid connected areas or cannot afford connection fees. Even in electrified areas.

The low electrification rate in the country outlines the importance of creating a modern off-grid market in Ethiopia, where a large proportion of the population lives in non - grid connected areas or cannot afforded connection fees. In addition, it is also essential to highlight that poor electricity distribution in electrified zones brings about a subsequent need for modern off-lighting products even in electrified areas. The assumptions used are based on an urban electrification scenario that considers an annual increase of two percent between 2010 and 2020 and one percent between 2020 and 2025. Considering the current low rural electrification rate and the ambitious UAEP, aggressive rural grid connection efforts were assumed with annual rural electrification rate of 25 percent between 2020 and 2025. Based on the aforementioned assumptions and the population growth rate, it is projected that overall access to electricity (grid connection) could reach 54 percent by 2025, with 100 percent households electrified in urban areas and almost 45percent in rural areas (see Fig .39).

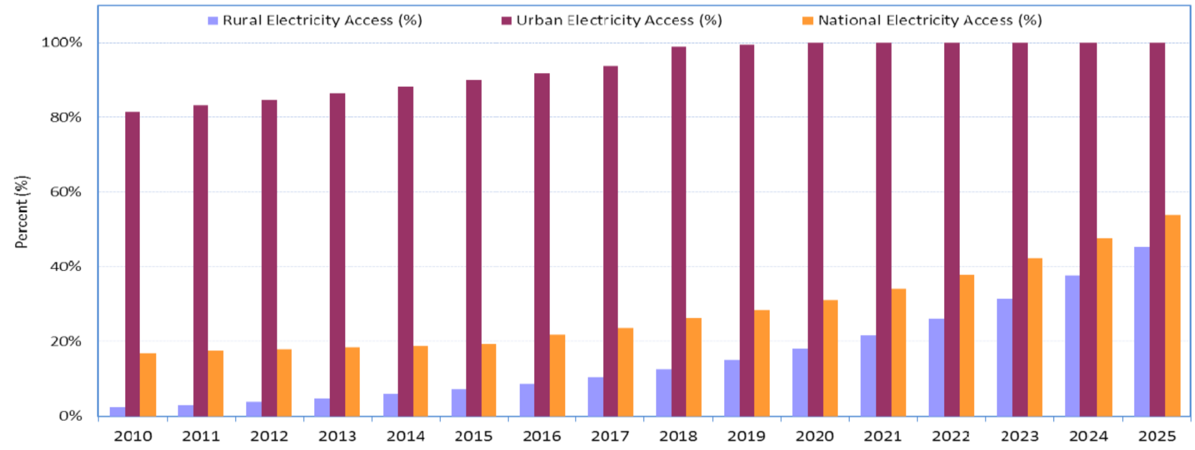


Figure 2.40: Modeled growth of electricity access in Ethiopia by 2025- Ethiopia (Lighting Africa, 2011, Policy Report Note Ethiopia).

2.13. Emissions Reduction

Utilizing solar power can save people from fossil fuel dependence. Fossil fuels are not only nonrenewable but are also the main source of carbon dioxide emissions, the primary greenhouse gas in the atmosphere. Thus, solar power systems have an impact of reducing co_2 emissions to the atmosphere.

Ethiopia's emission rate compared to any developing countries shows low level. In comparison to Sub-Saharan Africa countries, Ethiopia's energy related CO_2 emission per person is still very low whereas they have grown over the period of 2000 and 2010, to the transport sector growth which leads to an increase of imports of petroleum products. Ethiopia's CO_2 emission per capita was 0.06 tons in 2010 and 0.27 Kg of CO_2 per US dollar using 2005 prices (GDP using market exchange rates) (IEA,2012). However, conventional economic development would project environmental impact. The country's emissions are expected to grow rapidly since more carbon intensive fuels are being applied in the growing economic sectors (Dereje A., 2014).

Energy related CO_2 emissions have grown between 2000 and 2010 and the specific CO_2 emissions per capita actually increased from 0.05 metric tons per capita to 0.06 metric tons per capita of the same period. Based on the peak in 2009, an increase of 4.55 % was recorded (IEA, 2012).

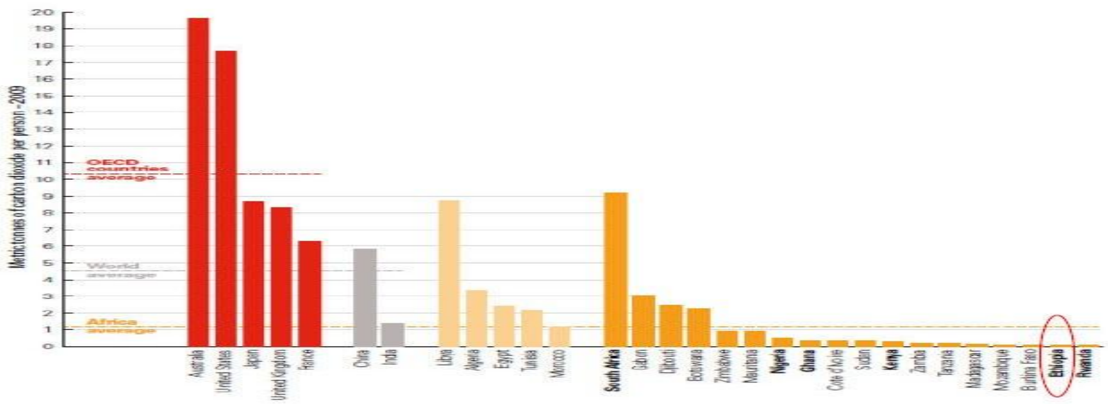


Figure 2-41: presents Ethiopia's energy related CO_2 emissions (metric tons per capita) in the year 2009, in comparison to World, OECD countries and sub-Saharan Africa countries. (IEA, 2012).

2.14. Socio-Economic Developments

Energy is arguably an important element in the development process. It has been argued that without energy, it is almost impossible to attain sustainable development. "Since access to modern energy lies at the heart of human development, it is evident that in order to meet the MDGs (Millennium Development Goals), substantial improvements are needed in the type of energy services that the poor have access to", GNESD (2007).

Energy is surely an important aspect of socio-economic development that touches almost every sphere of human life, and an essential requirement for human development. Improved household energy technologies for the very poor can prevent almost 2 million deaths a year attributed to indoor air pollution from solid fuel use WHO and UNDP (2009).

Chapter 3: Methodology

Site Identification

The sampling method used on survey data was simple random sampling selected stand –alone photovoltaic systems about 10 of each SHS and institutional systems - health post and primary schools from randomly selected regions of Tigray, Amhara, Oromia and Benshangul gumuz evaluated to determine their systems performance and reliabilities of off grid rural electrification components.

Random sampling mean every member of the judgmental sampling the standalone photovoltaic power system will select on the strength of their experience of the phenomena under the study.

Data collection Methods

Primary Sources

Primary data had been collected by observation and field investigation method was a planned visit using standard structured type check list format of the specification, orientation, wiring system, and the like of institutional and solar home systems installed in different randomly selected regions of the country was made in order to get valuable information. For this researcher, the concerned stand-alone photovoltaic power system was visited and obtained information directly and study real situations.

Secondary sources

Under the secondary source of data , conducted information and data from a wide variety of sources has been used on different documents of off- grid rural electrification components, specification of Energy access projects and some other related source ,which includes, theoretical knowledge of solar energy technology, for solar PV power plants available in standard literature, data for solar radiation has been analyzed from sources such as Master Plan Report of Wind and Solar Energy in the Federal Democratic Republic of Ethiopia,2012,data collected from REF under MoWIE and Meteonorm.

Beginning phase: Desk study

Collection of secondary data and information from Literature, Preparation for data collection from the off grid rural electrification projects. Site identification of Tigray, Amhara, Oromya, Benshangul gumuz. sample randomly selected sites of SHS and Institutional.

Investigation phase: field study

Investigating about 10 of each SHS and Institutional systems from each randomly selected regions. Comparison made in terms of the design and the specification between the installed and the data of off grid rural electrification projects at hand. Investigation of the specification, orientation, wiring system, and the like of institutional and solar home systems of photovoltaic systems installed in different regions of the country. Households and institutions had been consulted to search opinions on solar Photovoltaic power system applications.

Data Analysis Methods

Once the investigation would complete, expected to collect from the field and secondary sources, cross checked, verified, analyzed and interpreted data theory on the basis of the problem and form generalizations, principles and using appropriate theories. Tasks or exercises are given to enable to make discoveries. Analysis of photovoltaic system performance (System efficiency) and reliability assessment using parameters, algorithms to track the maximum power point have been developed., using different models for PV system (PV sizing, wiring, charge controller, inverters etc).The performance methods is verified through Models and experiments and PVsyst software.

3.1 Data Gathering Method and Identified Sites of the Rural Electrification.

This study was conducted to assess and evaluate the performance and reliability of installed stand-alone photovoltaic power system at different location in Ethiopia. Data collection was administered on sample randomly selected sites installed in four regions of Ethiopia. About ten sample sites were identified for each regions and data gathering were made using solar photovoltaic systems investigation check list (See appendices I -VI).

The data collections and investigation works from sample randomly selected sites of Tigray and Amhara region rural villages were done 28/07/08 up to 22/08/08 E.C. In addition to sample sites of Benshangul Gumuz, Oromia and some part of Amhara from 28/08/08 up to 24/09/08 E.C.

Most of SHS and institutional like health post and primary schools were installed by the support of REF together with Poly Technology International China, Angelique International India, Lucky Export Trade International,India,Communications and Accessories Company (CAA) International Germany, 2009–2010 and Zhiangue International China, 2014/15). (See table 3.1) the distribution of SHS and institutional solar photovoltaic systems in some selected regions by the support of REF together with governmental and non-governmental companies in Ethiopia summarizes in the Table 3.1.

Table 3.1: Distribution of SHS and Institutional Solar photovoltaic system by region.

No	Region	Number of Health post by Lucky Export Trade Int.India.	Number of Primary schools by Zhiangue Holly Int china. (Agent, Acme Eng.Plc)	Number of SHS by Poly Tech.Int. China (Agent Gedion General Trade Plc, Addis Ababa, Ethiopia)	Number of SHS by CCE Oasis Tech. corporation China. (Agent Electrical engineering system PLc, Addis Ababa, Ethiopia)	Zhiangue Holly Int china. (Agent Gedion General Trade Plc, Addis Ababa, Ethiopia) 2016
1	Amhara	84	-	5678	2654	-
2	Benshangul G.	7	27	1315	494	1080
3	Tigray	24	40	2167	1217	-
4	Oromia	115	-	11,681	2861	-
	Total	230	67	20,841	7226	1080

In this study the researcher was used purposive and random sampling technique to determine the sample size as shown in the table 3.2 below.

Table 3.2: Solar photovoltaic power systems Installed in four samples randomly selected regions of Ethiopia.

No	Region	No of SHS	No of Primary School	No of Health post
1	Benshangul Gumuz	10	5	7 – See Appendices
2	Amhara	10	11 – See Appendices	10
3	Tigray	11	10	10 – See Appendices
4	Oromia region	10 –See Appendices	No Primary sch.	10

The geographical location of the Benshangul Gumuz region is at 11° 0’ 0 N Latitude and 35°30’ 0 Longitude makes high sun-rich region with an average annual solar density 2036.9 (kW·h/(m2·a) (Solar and wind master plan report of Ethiopia,2012).The average annual temperature reaches from 20 - 25^{0}C. During the hottest months (January - May) it reaches a 28 - 34^{0}C. The annual minimum and maximum mean temperature registered at Asosa for the last 26 years is 12.4^{0}C and 27.8^{0}C respectively. This implies that solar energy systems would be very efficient in this part of the country. Peoples are living at different village collectively, it is convenient for solar energy technology disseminations.

The geographical location of the Amhara region is at 9°-14° N and 36°-40°E in Ethiopia's Northwest. The annual mean temperature for most parts of the region lies between 15°C - 21°C. It makes a relatively sun-rich region with an average annual solar density 2105.3(kW·h/(m^2·a) (Solar and wind master plan report of Ethiopia ,2012). The sample sites are sparsely scattered and the system cannot be monitored or investigated at the same time. It has difficulties in disseminating the solar systems.

The geographical location of the Tigray region is at Latitude 14° 10' 0 N and Longitude38° 49' 59 E. The annual mean temperature for most parts of the region lies between 15°C - 21°C.It makes a relatively sun-rich region with an average annual solar density 2159.1(kW·h/(m^2·a) (Solar and wind master plan report of Ethiopia ,2012). This implies that solar energy systems would be very efficient in this part of the country. The sample sites are sparsely scattered the system cannot be monitored or investigated at the same time. It has difficulties in disseminating the solar systems.

The geographical location of Oromia region is at 8° 00' 00" N Latitude and: 39° 00' 00" Longitude E. It makes high sun-rich region with an average annual solar density 1961.9(kW•h/(m^2•a) (Solar and wind master plan report of Ethiopia ,2012). The dry climate is characterized by annual mean temperature of 27°C to 39°C, hot semi-arid climate mean annual temperature varies between 18°Cand 27°C. The sites are sparsely scattered the system cannot be monitored or investigated at the same time.

3.2 Stand-Alone PV Systems

The main components in a Stand-alone PV system (Reddy,2010) for solar home systems and institutional are shown in figure 3.1 and 3.2 using DC system installation and DC and AC system installation respectively.

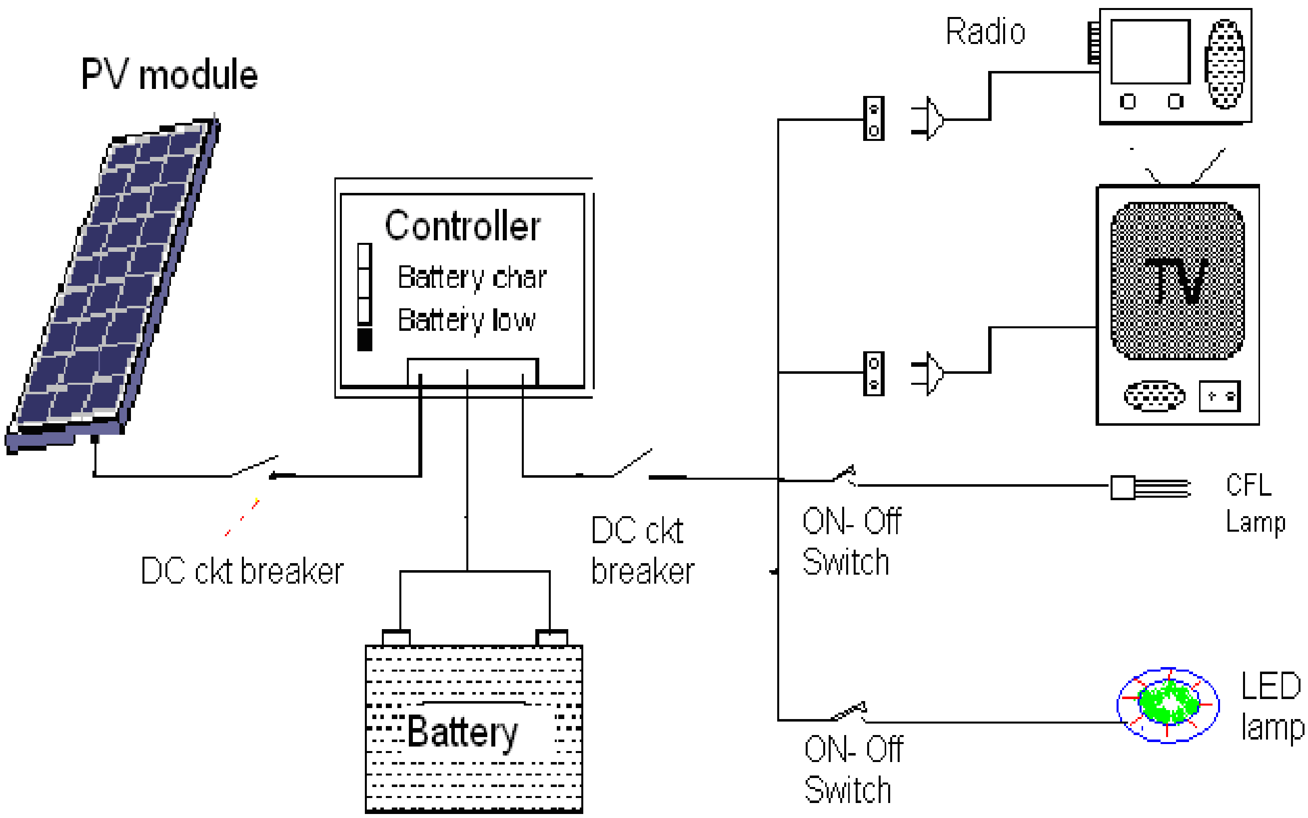


Figure 3.1 : Solar home system with no inverter (only DC system).

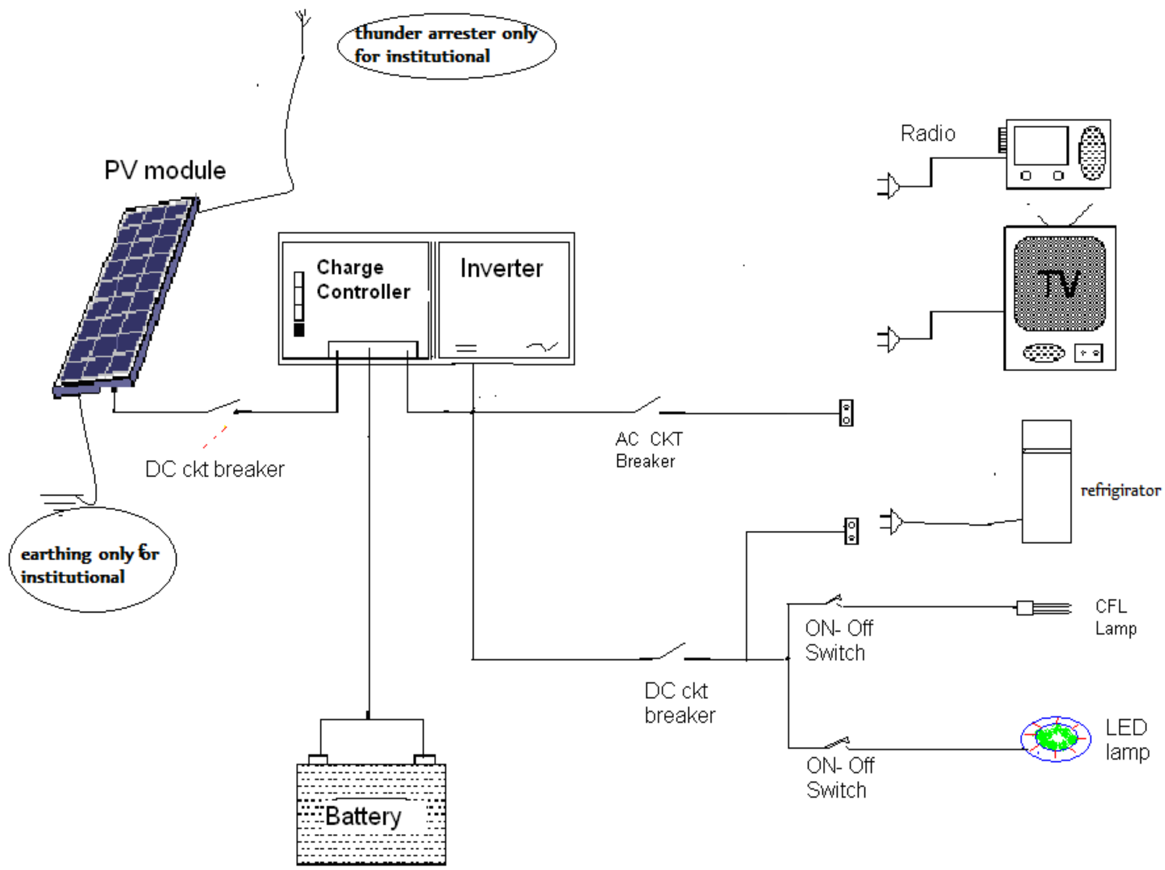


Figure 3.2: AC and DC system installation for household and institutional.

3.3. Status of Solar Home Systems

3.3.1Investigation of SHS at the Sample Randomly Selected Sample Site in Oromia Region.

Ato Dibaba Mideksa (in S.W. Shoa zone, Tolie, Kusti Areda leqa woreda, Adami Gotu kebele), has used 100Wp solar home system. However, the main Sockets was burnt completely and the PV system is not working anymore as shown in the figure 3.3. So, the main cabinet has to be changed.

Figure 3.3: SHS in Oromia region.

Measurements of PV module V_{oc}, I_{sc}, battery voltage status, inverter cum charge controller, wiring and casing, socket and bulb were carried out using a multimeter. Whereas radiation, temperature, humidity was not measured and the equipments were not in hand, but the radiation even in the cloud is insignificant with it indicated on Master plan report that 4kwh/m^2 to 6kwh/m^2 as the data taken.

Comparison of the standard specification with the measured performance of the module. described in the Table 3.3.

Table 3.3: Specification and performances comparing with measured performance of module.

Polycrystalline module Performance at 25^{0}c		Measured performance at local Time: 11:30	
			Decreased by
V_{oc}	21.5V	19.96V	7%
I_{sc}	8.818A	0.219A	97.3%
P_{max}	17Wp	4.37W	21.85%
Peak power	2×50=100Wp		
Battery status	12V	4.15V	

As can be seen from the investigation that V_{oc} is decreased by 1.54V (7%), I_{sc} is decreased by 7.961A (97.3%). so that, the output power $P_{out} = V_{oc} \times I_{sc}$ decreases to 4.37W (21.85%) after installed. While measurements are taken, the panel were covered by dirt and dusts, most panels not orientated to south and tilted at different angles. Hundred percent of sample randomly selected ten solar home systems shows different value and the performance of the solar photovoltaic power systems decreases or varies by certain parameters (see appendices I - VI).

The measurement as described above and observation has made in the sample randomly selected ten SHS of installations, most of the system are Polycrystalline PV, 8Wps to 130Wps solar photovoltaic power systems, while they start use of the system before the battery is fully charged creates problems on an inverter. As observed the PV systems the performance standard decreases starting from the selection of PV module level, orientations, tilt angle, tracking and lose in the PV Systems due to temperature, aging, dust lose in the wire within three years. It is supported by available literatures while analyzing the data.

3.3.2. Investigation of SHS at the Randomly Selected Site at Benshangul Gumuz Region

In the same manner, the measurement as described above and observation has made in the sample randomly selected ten SHS of installations in this site the output power also decreases. Most of the system are Polycrystalline PV 8Wps to 100Wps solar photovoltaic power systems. While they start use the system before the battery is fully charged creates problems on an inverter and on the systems. The performance standard decreases starting from the selection of PV module level, orientations, tilt angle and tracking and lose in the PV systems due to temperature, aging, dust, lose in the wire within three years (see appendices I - VI). It is supported by available literatures while analyzing the data.

3.3.3. Investigation of SHS at the Randomly Selected Site at Amhara Region

The measurement as described 3.3.1 above and observation has made in the sample randomly selected ten SHS of installations in this site the output power also decreases. Most of the system are Polycrystalline PV 8Wps to 100Wps solar photovoltaic power systems. While they start use the system before the battery is fully charged creates problems on an inverter and on the systems. The performance standard decreases starting from the selection of PV module level, orientations, tilt angle and tracking and lose in the PV systems due to temperature, aging, dust, lose in the wire within three years (see appendices I - VI). It is supported by available literatures while analyzing the data.

3.3.4. Investigation of SHS at the Randomly Selected Site at Tigray Region

The measurement as described 3.3.1 above and observation has made in the sample randomly selected ten SHS of installations in this site the output power also decreases. Most of the system are Polycrystalline PV 8Wps to 100Wps solar photovoltaic power systems. While they start use the system before the battery is fully charged creates problems on an inverter and on the systems. The performance standard decreases starting from the selection of PV module level, orientations, tilt angle and tracking, and lose in the PV systems due to temperature, aging, dust, wire lose within three years (see appendices I - VI). It is supported by available literatures while analyzing the data.

3.3.5. Comparison Solar Home System Performances between Four Regions.

The SHS in the four regions has the same nature of installation design, orientation, tilt angles and fixed tracking systems and the problems observed in the solar photovoltaic power systems performances. The solar PV systems mainly cater to households'. The major demand in the SHS is for providing lighting, powering TV sets and music systems, charging mobile phones, and for solar lanterns. Although in some cases of the systems ranges small scale businesses and shops etc. do buy larger systems, the typical capacity for majority of the systems ranges from 20Wps to 80Wps. The demand for SHS and solar lanterns is mainly from the cash crop growing areas as reported by the EREDPC (Ethiopian Rural Energy Development and Promotion Centre). One of the key driving forces for the PV market in this sector seems to be because of the financial support from REF, NGOs and international donors.

Expertise in the North shoa and Tigray explained that solar systems above 60Wp like 100Wp ,130Wp was expected to apply for TV and refrigerator but used only for mobile charger and radio but not functional for these devices that may be due to design criteria. There is also shortage of standardized solar system supply with governmental and non-governmental companies.

The energy process owners were raised some question in the Oromia, Benshangul Gumuz, North Shoa that so many solar energy technologies are installed by unknown organization and available on the black markets, how it disseminates to the rural villages that are not confirmed the energy office or responsible office? Who is responsible for these great problems which are not stated on the energy policy that give mandates about solar energy technology regulations and monitoring its dissemination and quality that are installed and bought rural people and sold by unprofessional people?

The failure of the components of the SHS by region according to the installed company described in the table 3.4 .

Table 3.4: Compare solar home system performances between four regions -Poly Tech's PV program Failure or Defects.

Regions	No of SHS	System type	Charge controller	Inverter Failures	Installation Errors (not modeled)
Benshagul G	10	100Wps		1	
Amraha	10	130Wps	1	-	-
Tigray	11	-	-	-	-
Oromia.	10 -Appen.data	-	-	-	-
Total	41		1	1	-

In the Benshangul Gumuz and Amhara region some of the photovoltaic power systems shows inverter failure and has effects on the performance of the systems.

3.4 Solar Home Systems (SHS) in Ethiopia

REF has installed many SHS together with NGO's and private sectors as indicated in the table below, but few in comparison to the number of rural people in Ethiopia since 2009. It is reported that with growing telecommunication coverage, a micro system with a single light point and a mobile phone charger is also in high demand in rural areas. The growing demand from this market is due to the growing rural income over the past few years. Capacity building and awareness raising projects by GTZ and international NGOs such as Solar Energy Foundation and Plan International seems to have created the demand for SHS in rural households and businesses (UNIDPO,2010).

The SHS of different watt peaks installed in the country by solar energy foundation described the table 3.5.

Table 3.5: Solar home systems installed by solar energy foundation.

PV systems	Distribution	Households	PV demand	Market for optimized systems	
[Wp]	[%]	[MWp]	[million]	[mETB]	[m€]
2	20%	2	4	600	43
10	20%	2	20	3,000	214
20	30%	3	60	9,000	643
50	20%	2	100	15,000	1,071
100	10%	1	100	15,000	1,071
total	100%	10	284	42,600	3,043

Source: Solar home systems installed by solar energy foundation 2009.

As it indicates on the table 3.5 above 20Wps was installed higher than other systems and there Was high demand in million) of SHS.

Table 3.4 shows 25,000 plus 3,800 is equal to 28,800 Solar Home System Installed by Poly Technology Inc, China (agent based in Addis Ababa, Gedeon general Trade plc) 2012 – 2014, 11,488 SHS by CCE Oasis Technology corporation China (agent, Amare, Electrical engineering system Plc., Addis Ababa, 2015 in Ethiopia and 4, 004 SHS by Holly international Int China totally which is equal to 44,227. The solar home system installed in Ethiopia described by watt peaks system in the table 3.6.

Table 3.6: Solar home systems installed by Ministry of water, irrigation and electricity facilitated by REF by watt Peaks(Wps).

No	System Type	Lamps	Amount	Total Wps
1	8Wp	2 – LED	9725	77800
2	10Wp	4 – LED	10,277	100,277
3	20Wp	4 – LED	4,867	97,340
4	40Wp	4 –LED	2,653	106,120
5	60Wp	4- LED	5,107	306,420
6	75Wp	4- LED	5,025	376,875
7	80Wp	6 – LED	2,413	433,040
8	100Wp	8 – LED	2,875	287,500
9	130Wp	10 – LED	1,285	167,050
		Total	44,227	1,952,372

Source: REF, Ministry of Water, irrigation and Electricity, 2015.

So that, it can be seen from the above table 3.6 that the solar home systems of 8Wps and 10Wps are highly disseminated to the country than the other systems listed.

The cumulative SHS installed by different stakeholders in the country since 2009. Indicates in the table 3.7.

Table 3.7: Ethiopian cumulated rural electrification of Solar Home Systems by different stakeholders since 2009.

Type	No of Systems	Installed company	Year	Remark
SHS	1950	REF	2010	40Wps- 70Wps
SHS & lamps and Mobile Charging capacity	70 systems, free of charges (2 system in each of 35 Woredas)	Vera Int.Bussiness PLC, Addis Ababa Ethiopia	2014/15	
SHS	1132	Lydetco PLC, Addis Ababa, Ethiopia	2010	Facilitated by REF
Solar Lantern	Above 70,000	Vera plc	2010-2012	
SHS and Lanters	15,248	Stiftung,solar energy foundation	2005-2011	About 940,000 people who have profiled from our work since 2005.
SHS	11,000	Beta engineering plc, Addis Ababa, Ethiopia	2012	
SHS	25,000 + 3,735 =28,735	Poly Technology China Inc. China. Agent Gedion General Trade Plaudits Ababa, Ethiopia.	2014/15	Facilitated by REF and
SHS	1,000	HOAREC (Horn of Africa Regional Environment Centre and Network	2014/15	
SHS	2,207 sold	GIZ		
	600 small-scale efficient cooking stoves	“		In 310 district 0f 7 regions.
	Close to 75,000 of Mirt, IRS and Tikikle	“		
	23,388solarlantern			
	4 - pilot project of Micro-hydro power	“		SNNPR 127Kw
SHS	11,488	CCE Oasis Technology corporation China. Agent (Amare) Electrical engineering system PLc, Addis Ababa	2015	Almost all installed.
SHS	4004	ZHiange Holly International		
Solar Lanters	8000	ZHiange Holly International		
Total	Above 65,359			Excluding,LantersCookin GstovesMicrohydropower

As can be seen from the table 3.7 above it is estimated that more than 65,000 SHS were installed in the country by different governmental and non-governmental companies.

3.5 Status of Institutional Solar Photovoltaic Power Systems.

3.5.1 Status of Primary School's Photovoltaic Power Systems.

3.5.1.1 Investigation of Primary Schools Solar PV System at the Randomly Selected Sample Sites Amhara Region.

Among the measurement taken from installed system in West Gojam, Gonji Woreda, Gonji Kebele, Gonji primary school ,200Wp DC system installed by Communications and Accessories Agency, Germany (CAA) ,2010 as shown in figure 3.4.

Figure 3.4: Gonji Primary School in Amhara region.

The comparison of the standard specification and the measured value of the performance of the module that are installed in the sample selected sites described in the Table 3.8.

Table 3.8: Specification and measured performance of the module.

<table>
<tr><td colspan="4">All technical data standard test condition–AM=1.5,1-1000w/m^2, T=25^{o}c.</td><td colspan="2">Measured performance at local Time 4:45</td></tr>
<tr><td colspan="2">1</td><td colspan="2">2</td><td colspan="2"></td></tr>
<tr><td colspan="2">Solar Module Type TsM-75M</td><td>-</td><td>-</td><td>-</td><td>Decreased by</td></tr>
<tr><td>Peack power</td><td>75W×4=300Wp</td><td>Peack power</td><td>50Wp×4=200Wp</td><td></td><td></td></tr>
<tr><td>Voc</td><td>21.7V</td><td>Voc</td><td>21.63V</td><td>19.70V</td><td>13.8%</td></tr>
<tr><td>Isc</td><td>4.93A</td><td>Isc</td><td>3.12A</td><td>0.216A</td><td>95%</td></tr>
<tr><td>Imax</td><td>4.36A</td><td>Imax</td><td>2.91A</td><td>-</td><td>-</td></tr>
<tr><td>Vmax</td><td>17.2v</td><td>Vmax</td><td>17.2 V</td><td>0 .0003V</td><td>-</td></tr>
<tr><td>Operating temp</td><td>-40^{o}c - 85^{o}c</td><td>Field wiring 90^{o}c– 2.5mm^2</td><td>Field wiring 90^{o}c – 2.5mm^2</td><td>Charge controller 00.0V</td><td>-</td></tr>
</table>

Source: 1). REF, Installed 300Wps by Zhiang Holley International Int (Agent China Acme Engineering and Plc.in Ethiopia), 2014/15. 2).REF, Installed 200Wps by Company name CAA (communication and Accessories Agency, Germany, 2009/2010.

As can be seen in the above table 3.8 the system is out of use and dismantled by some unknown case and even the battery status was measured and reads almost dead about 0.003V.The V_{oc} of the panel was decreased by about 13.8% and Its Isc decreased by 95%.

The measurement as described above and observation has made in the sample randomly selected 11(see appendix) Primary school's installations, most of the system are Polycrystalline PV 200Wps and 300Wps solar photovoltaic power systems. As observed on the installation sites the systems performance standard decreases starting from the selection of PV module level orientations, tilt angle and tracking and, lose in the PV systems due to temperature, aging, dust, lose in the wire within three years. It is supported by available literatures while analyzing the data.

3.5.1.2 Investigation of Primary Schools Solar PV System at the Randomly Selected in Benshangul Gumuz Region.

Similarly, the measurement as described above and observation has made in the sample randomly selected five primary Schools installations are investigated. Most of the system are Polycrystalline PV200Wps and 300Wps solar photovoltaic power systems ,and the systems the performance standard decreases starting from the selection of PV module level, orientations, tilt angle and tracking and lose in the PV systems due to temperature ,aging ,dust , lose wire within three years. It is supported by available literatures while analyzing the data.

3.5.1.3 .Investigation of Primary Schools Solar PV System at the Randomly Selected at Tigray Region.

In the same way that, the measurement as described above and observation has made in the sampling randomly selected ten primary schools installations, most of the system are Polycrystalline PV, 200Wps and solar photovoltaic power systems, and the systems performance standard decreases starting from the selection of PV module level orientations, tilt angle and tracking and, lose in the PV systems Such as temperature, aging, dust, lose wire within three years. It is supported by available literatures while analyzing the data.

3.5.1.4 .Investigation of Primary Schools solar PV system at the randomly selected at Oromia region.

No primary schools were observed that are installed by the mentioned companies (REF) during investigations.

3.5.1.5.Comparison of Primary Schools Solar PV System Performances between Four Regions.

The primary schools in the four regions have the same nature of installation design, the problems observed on the orientation, tilt angles, and in the solar photovoltaic power systems performances. The solar PV systems mainly cater to households. The major demand is SHS for providing lighting, powering TV sets and music systems, and charging mobile phones, and for solar lanterns. Although in some cases of the systems ranges small scale businesses and shops etc. do buy larger systems, the typical capacity for majority of the systems ranges from 20Wp to 80 Wp. The demand for SHS and solar lanterns is mainly from the cash crop growing areas as reported by the EREDPC (Ethiopian Rural Energy Development and Promotion Centre). One of the key driving forces for the PV market in this sector seems to be because of the financial support from REF, NGOs and international donors.

The failure of the components of the primary schools solar photovoltaic system by region according to the installed company describes by comparing in the the Table 3.9.

Table 3.9: Comparison Primary Schools solar system performances between four regions -ACME's PV Program Failures or Defects.

Regions	No of Sch.	System type	Charge controller	Inverter Failures	Installation Errors (not modeled)
Benshabgul G.	5	-	-	-	-
Amhara	11 Appen.data	300Wps	-	1	-
Tigray	10	300Wps	-	2	-
Oromia	No Primary sch.		-	-	-
Total	26		-	3	-

As it described on the table 3.9 in the Amhara and Tigray region primary schools some of the photovoltaic power systems shows inverter failure and has effects on the performance of the systems.

3.5.2 Status of Health Post Solar Photovoltaic Power Systems

3.5.2.1 Investigation of Health Post Solar PV Systems Randomly Selected Sites in Benshangul Gumuz Region.

As described below measurement were taken from one of the Benshangul Gumuz region, Bambasi woreda, Sheh Bergush health post installed by Lucky Export Indian $75wp \times 8 = 600wp$ system in 2010.G.C, the system was not operating, the inverter has no output and, it has to be changed,

Figure 3.5: Sheh Bergush in Benshangle Gumuz region

In the table 3.10 described the comparison of the standard specification and the measured value of the performance of the module that are installed in the sample selected sites.

Table 3.10 Specification and performance of the module.

All technical data standard test condition AM=1.5,1-1000w/m^2, T=25^{o}c				Measured performance at local Time 4:45	
1		2			Decreased by
Peack power	75Wp × 8-600W	Peack power	60Wp × 6=360Wp		
Voc	21V	Voc	21.8V	19.35V	7.85%
Isc	4.6A	Isc	3.9A	0.234A	94.9%
Imax	4.26A	Imax	3.5A	-	-
Vmax	17.6V	Vmax	17V	Inverter Input 13.02V	-
Maximum charging current	50A	Minimum by pass diode	6Amp	Battery 13.21V	-
Max Voltage	17V – 140 V	-	-	Charge controller 12.9V	-
DC start voltage	17V	-	-	-	-
Minimum by pass diode	8Amp	-	-	-	-
Inverter (CC) efficiency	95.5%	-	-	Inverter output zero	-

Source 1). REF, Installed 600Wps by Lucky Export Inc. Indian 2013/14. 2). REF, Installed 360Wps by Angelique Int.Indian 2009/2010.

So, that, compare and contrast the performance at the manufacturer and the measured values observed at the site, V_{oc} is decreased by1.65V (7.85%), I_{sc} is decreased by 4.366A (94.9%) so that the output power $P_{\max} = V_{oc} \times I_{sc}$ decreases by 6.98W after installed. All or hundred percent of sample randomly selected seven solar home systems shows different value and the performance of the solar photovoltaic power systems decreases /varies by certain parameters (see appendices I - VI).

Similarly, the measurement as described above and observation has made in the sample randomly selected and only seven health posts were installed by Lucky Export International and investigated that most of the system are Polycrystalline PV 600Wps solar photovoltaic power systems. As observed on the installation sites the systems performance standard decreases starting from the selection of PV module level, orientations, tilt angle and tracking and, lose in the PV systems due to temperature, aging, dust, wire lose within three years. It is supported by available literatures while analyzing the data.

3.5.2.2 Investigation of Health post solar PV systems randomly selected sites at Amhara region.

The measurement as described above and observation has made in the sample randomly selected 10 Health post installations and most of the system are Polycrystalline PV, 360Wps and 600Wps solar photovoltaic power systems. As observed the systems performance standard decreases starting from the selection of PV module level, orientations, tilt angle and tracking and, lose in the PV systems due to temperature, aging, dust, wire lose within three years. It is supported by available literatures while analyzing the data.

3.5.2.3 Investigation of Health post solar PV systems randomly selected sites at Tigray region

In the Central zone, Merebleke woreda, Adifetaw health post, 600Wps solar photovoltaic system installed by Lucky Export, Indian. They use for lighting, mobile charging and sometimes for microscope in health centers.

Figure 3.6: Adifetaw Health post in Tigray region . Inverter output is zero

The comparison of the standard specification and the measured value of the performance of the module that are installed in the sample selected sites described in the Table 3.11.

Table 3.11: Specification and performance of the module.

All technical data standard test condition AM=1.5,1-1000w/m^2, T=25^{o}c		Measured performance at local Time 4:45	
Peack power	75Wp ×8- 600W	Decreased by	
Voc	21V	18.9V	2.1(10%)
Isc	4.6A	0.209A	4.391(95%)
Pout	96.6W	3.95	92.65 (95.9%)
Inverter (CC) efficiency	95.5%	Inverter output = 0V (the fuse of the inverter is burnt out.)	

Source: REF, Installed by Lucky Export Inc. Indian ,2013/14.

As it is compared and contrast the performance at the manufacturer and the measured values observed at the site V_{oc} decreased by 2.1V (10%), I_{sc} is decreased by 4.391A (95%) so that the output power $P_{out} = V_{oc} \times I_{sc}$ decreases by 9.22W after installed. All or hundred percent of sample randomly selected ten health posts performance decreased (see appendices I-VI). Shows different value and the performance of the solar photovoltaic power systems decreases /varies by certain parameters.

The measurement as described above and observation has made in the sample randomly selected seven health posts installation and most of the systems are Polycrystalline PV 600Wps and the solar photovoltaic power systems. While they start use the system before the battery is fully charged and creates problems on an inverter and the systems performance standard decreases starting from the selection of PV module level, orientations, tilt angle and tracking and, lose in PV systems due to temperature, aging, dust,wire lose within three years. It is supported by available literatures while analyzing the data.

3.5.2.4 Investigation of Health Post Solar PV Systems Randomly Selected Sites at Oromia Region

Mango health post shown in figure 3.7 below is one of the sample randomly selected solar photovoltaic $75wp \times 8 = 600wp$ system site in West Shoa zone, Tokee Kutayee (Bsabichi-Babo golo) Woreda, installed by Lucky Export Indian in 2010. G.C.

All the system is designed and installed for bulbs, sockets etc, of AC output. The Inverter is not working (does not convert AC–DC). Needs to use VDL (Veterinary diagnosis laboratory), Microscope, refrigerator for syringes, TV, used to apply centrifuge (a device that used to test blood & urine shown in figure 3.7) but not applied. The system gives only light.

Centrifuge

Figure 3.7: Mango health post in Oromia region.

The comparison of the standard specification and the measured value of the performance of the module that are installed in the sample selected sites described in the Table 3.12.

Table 3.12: Specification and performance of the module.

All technical data standard test condition AM=1.5,1-1000w/m^2, T=25^{o}c		Measured performance at local Time 6:30	
Peack power	75Wp × 8- 600W	Decreased by	
Voc	21V	18.56V	2.44V (11.61%)
Isc	4.6A	0.211A	4.389VA (95.4%)
Inverter (CC) efficiency	95.5%	Inverter output = 0V (the fuse of the inverter is burnt out.)	

Source: REF, Installed by Lucky Export Inc. Indian 2013/14.

The manufacturer and the measured values observed at the site, from the investigation V_{oc} was decreased by 2.44V (10%), I_{sc} was decreased by 4.389A (95%) so that the output power $P_{out} = V_{oc} \times I_{sc}$ decreases by 10.70W after installed. All or hundred percent of randomly selected seven health posts performance decreased. Shows different value and the performance of the solar photovoltaic power systems decreases /varies by certain parameters.

The measurement as described above and observation has made in the sampling randomly selected ten health posts installations and most of the system is Polycrystalline PV 600Wps solar photovoltaic power systems. While they start use of the system before the battery is fully charged creates problems on an inverter and the systems the performance standard decreases starting from the selection of PV module level, orientations, tilt angle and tracking and lose in systems due to temperature, aging, dust, wire lose within three years. It is described by available literatures while analyzing the data.

3.5.2.5 Comparison of Health Posts Solar PV Systems Performances between Four Regions.

The health posts in the four regions have the same nature of installation design, orientation,tilt angles, and the problems observed in the solar photovoltaic power systems performances.

Table 3.13 Comparison of Health post solar system performances between regions Lucky Export's PV Program Failures

Regions	No of HP	System type	Charge controller	Inverter Failures	Installation Errors (not modeled)
Benshangul G.	7 App. data	600Wps	7	7	-
Amhara	10	600Wps	3	3	-
Tigray	10 App. data	600Wps	10	10	-
Oromia	10	600Wp	3	3	-
Total	47		23	23	

Among the observed 47 health posts of 23 Charge controllers and Inverters each are not functioning and the battery has beeping sound problems. The solar PV systems mainly cater to health pots. The major demand health posts is for providing lighting for women during birth, powering TV sets, refrigerators for medicines and syringes, music systems, charging mobile phones, and for solar lanterns., the typical capacity for majority of the systems ranges from 360Wps to 600Wps.One of the key driving forces for the PV market in this sector seems to be because of the financial support from REF, NGOs and international donors.

3.6 Off-Grid institutional systems.

Off-grid institutional systems provide beneficial services to communities by increasing access to health, education and water or any other socially productive use in communities. The demand from health institutions and schools are entirely dependent on external support from government programs or NGO initiatives. The systems in this sector include SHS for institutional lighting, PV powered pumps, market lighting, vaccine refrigerators and ICT power (such as radio transmitter, computer kiosk etc.). The total installed solar PV capacity in off grid institutional systems including health institutions, schools, and water supply systems is reported to be more than 500kWp (GTZ 2009). REF is supporting installation of systems and has tendered out 300 solar PV systems for the health clinics (360Wp/system) and rural schools (200Wp/system) during 2009-10. Similarly, GTZ International is also implementing a project of electrification of schools and health centers (to keep fridges working to maintain vaccines) in the north-eastern region of the country. Further, it is becoming a trend for the religious institutions to install solar PV systems to power their sound systems and musical instruments. An 80Wp system has been a typical size for rural religious institutions (UNIDO,2010).

Table 3.14 and 3.15 gives the above all information on the installed solar photovoltaic power systems in the country by different stakeholders till 2017

Table 3.14: Installed Primary Schools by different stockholders in rural part of Ethiopia since 2009.

Type	No of Systems	Installed company	Year	Remark
Village school	35	Stiftung, solar energy foundation	2005- 2011	
Primary Schools	100	Communications and accessories company (CAA) Inc Germany	2009 - 2010	REF 200Wp/system
Rural primary schools	270	Zhiangue Holly Int china Acme plc agent ()	2014/15	REF 360Wp/systems
Primary schools and Health post	110	ZTE	2015	Grant 720Wps/system
Total	515			

Table 3.15 : Installed Health posts by different stockholders in rural part of Ethiopia since 2009.

Type	No of Systems	Installed company	Year	Remark
Rural health clinics with Solar refrigerators for cooking medicine	54	Stiftung,solar energy foundation	2005- 2011	
Health posts	300	Angelique India Inc,India	2009-2010	Facilitated by REF-360wp/system
Rural health post	345	Lucky Export Int India.	2013/14 It is under problem	Facilitated by REF-600wp/system
Rural health post	131+11	GIZ		237Kw
Rural primary schools	1109	Zhiangue Holly Int china Acme plc agent	2014	MOH/300Wps
Rural primary schools	300	Zhiangue Holly Int china Acme plc agent	2014	MOH/3KW
Health post	4000	ACME Engineering Plc.	2015/16	Supported By MOH,450Wp/ systems
Health post, Primary schools and FTC in four Developing regions	24	REF, zhiange, Holly Int china	2016	
Total	6360			

GTZ (2009) report indicates 500KWp institutional PV were installed in Primary schools and health post. NOTE: - There are Photovoltaics’ systems done by NGO’s and relevant companies not mentioned in the data above.

Chapter 4: Data Analysis and Discussion

This chapter deals with the presentation and analysis of the data gathered from randomly selected sample sites in four regions of Ethiopia during two months of study. The data collected were analyzed using descriptive survey; theoretical, mathematical formulation experimental models and PVsyst software analysis were used.

4.1. Performance and Reliability Analysis of Solar Photovoltaic (PV) Power Systems for the Selected Sample Site

The data were measured from the solar photovoltaic systems installed for solar home systems of 8Wps,10Wps,20Wps,40Wps,60Wps,75Wps,80Wps,100Wps and 130Wps and institutional systems 200Wps,300Wps ,360Wps and 600Wps for the sample selected sites in four regions of Ethiopia.

The performance of the system after it has been installed varies/decreases by some affecting factors in comparison to before installation, the measurement of the PV module V_{oc} and I_{sc} decreases moreover the product, the output power i.e. $P_{out} = V_{oc} \times I_{sc}$ of the system also decreases thus the performance of the solar photovoltaic power system and its reliability also decreases. This is due to the selection of the module, orientation, tilt angle and tracking and Lose in the PV systems. The study described and analyzed some of affecting factors among the mentioned parameters.

In the selection of the panel, PV module efficiency has to be considered.

4.2 Efficiency of PV Module

Selection of module performance was determined by its efficiency. The array is characterized by its average efficiency, η_p which is a function of average module temperature T_c

$$\eta_p = \eta_r \left[1 - \beta_p (T_c - T_r)\right] \qquad 4.1$$

the average module temperature (Tc) can be obtained from the mean monthly ambient temperature (Ta) through Evans' formula (4.2).

$$T_c - T_a = [219 - 832\bar{K}_T]\frac{NOCT - 2}{800} \quad 4.2$$

Table 4. 1 PV Module Characteristics for Standard Technology

PV module	η_r (%)	$NOCT(^0C)$	$\beta_p(\%/^0C)$
Mono silicon	13.0	45	0.4
a-SI (amorphous silicon)	5.0	50	0.11
cadet (cadmium telluride)	7.0	46	0.24
CIS (copper indium diselenide)	7.5	47	0.46

Equation (4.2) is valid when the array's tilt is optimal which is latitude minus declination. If the angle differs from the optimum, the right side of equation (4.2) has to be multiplied by a correction factor C_f defined by:

$$C_f = 1 - 1.17 \times 10^{-4}(Z_M - \beta)^2 \quad 4.3$$

$$Z_m = \phi - \delta \quad 4.4$$

η_r =PV module efficiency at reference temperature T_r, δ = declination angle

$NOCT$ = nominal operating cell temperature, $\bar{K}_T$ = monthly clearance index

β_p = the temperature coefficient for module efficiency, ϕ = Latitude angle

The design of solar PV system can be analyzing by the mathematical formulations as follows:

4.3. Analyzing the Design of SHS Solar PV System

Determining the power consumption demand the panel, inverter, battery and solar charge controller sizing will be analyzing.

Table 4.2: Demand applications

No	Appliance	Watt (W)	Daily use/hour	Daily Energy
1	21’’ color Television	60	2	120
2	Radio / Caste player	15	3	45
3	Lamp 3 (Bed room)	11	2	22
4	Lamp 2 (Kitchen room)	11	2	22
5	Lamp 1 (Salon)	11	3	33
	Total	105		228 Wh/day

4.3.1. Determine power consumption demands

Household daily energy demand is Calculated from the total appliance use = (60x2) + (15x3) + (11x2) + (11x2) +11x3) =228Wh/day,

Total PV panel energy needed =228x1.3=296.3Wh/day.

4.3.2. Size the PV panel

Total Wp of PV panel capacity needed = 296.3/3.4 = 87.14Wp, Number of PV panels needed = 87.14/50 =1.74modules, Actual requirement =2 modules.

So this system should be powered by at least 2 modules of 50Wp PV module.

4.3.3. Inverter sizing.

Total Watt of all appliances = 60W+15W+11W+11W+11W = 105W. For safety, the inverter Should be considered 25%- 30% bigger size**.** The inverter size should be about 150W greater.

4.3.4. Battery sizing.

Total appliance use = (60 x 2 + 15 x 3 +11 x 2 + 11 x 2 + 11 x 3) = 228 Wh/day Nominal battery voltage =12V, Day of autonomy =3days.

Battery capacity $= \frac{(60W \times 2) + (15 \times 3) + (11W \times 2) + (11W \times 2) + (11W \times 3)}{(0.85 + 0.6 = 12)} \times 3 = 111.76Ah.$ Total

Ampere- hours required. So the battery should be rated 12 V 120 Ah for 3 day autonomy.

4.3.5. Solar charge controller sizing

PV module specification: P_m =50W, Vm =16.7Vd, I_m = 6.6A, Voc =20.7, I_{sc} =7.5A, Solar Charge controller rating = (2 string x 7.5) x1.3 = 19.5A .So, the solar charge controller should be rated 20A at 12V or greater.

4.4. Electrical Accessories

Installation of PV panel requires the following accessory parts: All wiring to loads must be connected through the charge controller; Wire from solar panel – charge controller; Wire from charge controller – battery; Wire from charge regulator – charges, Lights, radio, etc Key of charges control; Switches and Radio connections.

4.4.1. Selection of Cable

The solar system is a limited capacity system. The voltage drop/ system loss in a solar system should not exceed 2%. Appropriate cable should be used to reduce the loss of voltage and to make the system. work with optimum efficiency.

For instances: - a solar panel that puts out 7A of current on a 12V system, in Good sun. (the current value can be found by reading the short circuit current, or I_{sc} on the label on the back of the panel.) The distance between the panel and the controller is 8 meters which is used to determine the proper wire size.

For 2% voltage drop, of the 7A until you reach a distance of 8 meters or longer. The has a wire size of 10 mm^2. If 5% voltage of the 7A is applied, it gives a wire size of 4 mm^2. In this case, since 10 mm^2 wire is not readily available in most places, a 4 mm^2 wire is taken which causes 5% voltage drop. But here, it would close to the limit with 4mm^2 wire, and if the distance would be a bit longer than 8 meters, should use the next larger size wire of 6 mm^2. Stranded and flexible insulated copper wiring must be used. Minimum acceptable cross-sections of the wire in each of the following sub-circuits are shown in the table 4.7 as follows:

Table 4.3 Minimum wiring specification for wiring circuits

	< 40Wp	>40 Wp and < 75 Wp	> 75 Wp and < 220 Wp	≥ 220 Wp
From PV module to charge controller	AWG#12 (4 mm²)	AWG#10 (6 mm²)	AWG#6 (16 mm²)	AWG#5 (25 mm²)
From charge controller to battery	AWG#12 (4 mm²)	AWG#10 (6 mm²)	AWG#6 (16 mm²)	AWG#5 (25 mm²)
From charge controller to loads	AWG#14 (2.5 mm²)	AWG#14 (2.5 mm²)	AWG#14 (2.5 mm²)	AWG#14 (2.5 mm²)

Source: Communications and Accessories (CAA), geramny.2010: Measured in American Wire Gauge (AWG#).

As can be shown depending upon the size of the panel from 40Wp and above 220Wp the wiring size of PV module to charge controller, charge controller to battery and charge controller to loads are specified in the table 4.3 above.

4.5. Analyzing the Design of Off-Grid Primary Schools Solar PV system

Determining the power consumption demand the panel, inverter, battery and solar charge controller sizing will be analyzing. Table 4.4 describes load for designing the solar photovoltaic systems as discussed Chapter 3.the case of Zhiange Holly International (ACME Eng. Trade Plc) primary schools PV program.

Table 4.4.: Approach for deciding the load and designing for primary schools.

Description	No of Rooms	Load (W)	Bulb(W)	Loads(W)	Use hours/day	Watt hr
Director office	1	3	3	3	4	12
Class rooms	2	3	6	6	4	24
store	1	3	3	3	4	12
Outside light	2	3	6	6	12	72
Radio/Tape	1	25		25	8	200
TV	1	50		50	8	400
Sub total						720
	No of Rooms	No of Lantern/room	Lantern size (W)	Charging time/day	Watt hr	
For class rooms	5	2	7	4	280	280
Sub total						1000

System descriptions: 4x75 = 300Wp crystalline module. 4x100AH sealed and deep cycle maintenance free solar batter ,20A charge controller, 300Watts continuous power of pure sine wave inverter, 3W LED lamps.

4.5.1. Determine power consumption demands

The primary school daily energy demand is: Total appliance use=(3W x 4hrs) + (6W x4hrs) +(3 W x 4hrs)x(6Wx12hr)+(25Wx8hr)+(50Wx8hr)+(5Wx2hr)+(7W x4hr) = 1000Wh/day .

Total PV panels energy needed =1,000x1.3=1,300Wh/day.

4.5.2. Size of the Panel

Total Wp of PV panel capacity needed =1,300/3.4 =397Wp, Number of PV panel needed=397/75=5 module, Actual requirements =5 modules**.** So, this system should be powered by at least 5 modules of 75 Wp PV modules.

4.5.3. Inverter Sizing

Total Watt of all appliances = (1x3) +(2x3) +(1x3)+ (2x3)+(1x25)+(1x50)+(5x2x7)= 163W

For safety, the inverter should be considered 25-30% bigger size. The inverter size should be about 210W or greater.

4.5.4. Battery sizing

Total appliance use =(3Wx4hr)+(6Wx4hr)+(3Wx4hr)+(6Wx12hr)+(25Wx8hr)+(50Wx8) + (5Wx2hr)+ (7Wx4hr) =1,000Wh/day, Nominal battery voltage=12V, Days of autonomy = 3 days.the battery capacity = $\frac{1.000Wh/day}{(0,85\times 0.6\times 12)}\times 3 = 490.19Ah.$ Total Ampere hour required 490.19Ah.So, the battery should be rated 12V 500Ah for 3 days' autonomy.

4.5.5. Solar charge controller sizing

PV Module specification of Hinge Holly International int. china for primary schools is P_m = 75 W_p, V_m = 17.2 Vdc ,I_m = 6.6 A, V_{oc} = 21.5 A, Isc= 0.818 A .Solar charge Controller rating = (5 strings x 6.6 A) x 1.3 = 42.9 A. So the solar charge controller should be rated 50A at 12 V or greater.

4.6. Analyzing the Design of Off-Grid Health Post Solar PV System.

Determining the power consumption demand the panel, inverter, battery and solar charge controller sizing will be analyzing .Table 4.5 Describes desired applications for health posts as discussed Chapter 3.the case of Lucky Export Int. PV program.

Table 4.5: Desired applications for health posts.

Description	No of units	Load s(W)	Use hours/day	Watt hr
Patient waiting room lighting	1	11	5	55
Treatment room lighting	1	11	5	55
Delivery room lighting	1	8	4	32
Vaccine store lighting	1	8	3	24
Outdoor lighting	1	11	12	132
Toilet lighting	1	8	4	24
Vaccine Refrigerator	1	200	10	2000
TV	1	60	6	360
Tape/Radio	1	30	4	120
Energy consumption/day(Wh)				2865

System descriptions : 8 × 75 =600Wps crystalline module,8 × 100AH sealed and deep cycle maintenance free solar battery,50A charge controller chum,500watts continuous power of pure sine wave inverter,11W and 8W CFL lamps, Then

4.6.1. Determine Power Consumption Demands

The health post daily energy demand is total appliance use=(11Wx5hr) +(11Wx5hr)+(8Wx4hr) +(8Wx4hr)+(8Wx3hr)+(11Wx12hr)+(8Wx4hr)+(200wx10hr)+(60Wx6hr)+(30Wx4hr)=2865W h/day,Total PV panels energy needed=2865x1.3=2203.84Wh/day.

4.6.2. Size the PV panel

Total Wp of PV panel capacity needed =2203.84/3.4 = 684.19 Wp, Number of PV panels needed = 684.19 /75= 8.64 modules. Actual requirement = 9 modules. So this system should be powered by at least 9 modules of 75Wp PV module.

4.6.3. Inverter sizing

Total Watt of all appliances = 11W+11W+8W+8W+11W+8W+200W+60W+30 W= 347W.

For safety, the inverter should be powered by at least 9 modules of 75Wp PV module. considered 25-30% bigger size.ie 433.75 and 451.13. The inverter size should be about 500W or greater.

4.6.4. Battery sizing

Total appliances use = 2865wh/day, Nominal battery voltage = 12 V, Days of autonomy = 3days, Battery capacity $= \frac{2865 Wh/day}{(0.85 \times 0.6 \times 12)} \times 3 = 1404.41 Ah.$ Total Ampere hour required 1404. 41Ah.So, the battery should be rated 12V 1500Ah for 3 days autonomy.

4.6.5. Solar charge controller sizing

PV Module specification of Lucky Export trade int china for health post. Peack power is 75Wpx8 = 600W, V_{oc} = 21V , I_{sc} = 4.6A , I_{max} = 4.26A ,V_{max} = 17.6 ,Maximum charging current = 50A , Inverter (CC) efficiency = 95.5% ,Solar charge controller rating = (9 strings x 4.6A) x 1.3 = 53.82 A .So the solar charge controller should be rated 60 A at 12 V or greater.

4.7. Experimental Methods Orientation of Solar PV System and Tilted Angle

Tilt angle obtain maximum sunlight, a PV module has to face to the sun. Ideally, PV module should track to the sun. However tracking system is expensive and not economical for SHS. Therefore, a PV module is fixed at an optimum tilt angle. Solar radiation changed daily and monthly so that using tilt angle targeted to worst month would be a better solution.

However, this method requires actual record of solar radiation throughout the year. This study recommends a simple method tilt angle is the latitude plus 5^0 to 10^0 and round it to 5^0 steps. If the latitude is around 10^0 or less, there is another factor of loss … dust. PV modules should have some tilt angle to avoid accumulation of dust on its surface and to get maximum power point tracking. This study recommends 15^0 as a minimum tilt angle (Shiota A., 2000).

Orientations

Towards to equator. North for south hemisphere. And south for north hemisphere. Tilt angle should be Latitude + 5^0 to 10^0 .Therefore ,Ethiopia is located at the north of the equator and the panel orientation should be to south , then the tilt angle of the panel at Benshangul gumuz has to be latitude 11° 0' 0 N+ 5^0 to 10^0 is between 15^0 to 21^0 ,at Oromia latitude 8° 00' 00" N + 5^0 to 10^0 is between 13^0 to 18^0,at Amhara region latitude 9°-14° N + 5^0 to 10^0 is between 14^0 to 19^0 and at Tigray region latitude 14° 10' 0 N+5^0 to 10^0 is between is19^0 to 24^0 (Shiota A.,2000) .

4.8 Experimental model: PV system in parallel and in series.

Stand-alone photovoltaic system for Home lighting - the experiment made on two different 25Wp of panel in series and in parallel Voc and Isc determines the efficiency of the module at the same conditions.

Figure 4.2: Experimental PV System in parallel and in series

.

Table 4.6: The measurement value of Voc and Isc on two 25Wps panels in parallel at the same conditions.

No	Voc	Isc	Power(W)
1	0	2.64	0
2	20.04	0.77	15.43
3	19.83	0.9	17.84
4	19.3	1.24	23.93
5	18.55	1.61	29.86
6	16.97	2.15	**36.48**
7	12.01	2.53	30.3
8	6.71	2.58	17.3
9	1.4	2.59	3.6
10	21.36	0	0

Table 4.7: The measurement value of Voc and Isc on two 25Wps panels in Series at the same conditions.

No	Voc	Isc	Power(W)
1	0	3.18	0
2	10.17	0.4	4.06
3	10.11	0.57	5.76
4	10.00	0.9	9
5	09.08	1.39	12.62
6	08.48	3.38	1.62
7	08.45	3.60	**30**
8	08.74	2.81	24.56
9	09.01	1.02	9.19
10	10.29	0	0

As it is calculated the Pmax output of the panels in parallel has higher than in series, this implies that it is advantageous if the panels connected in parallel than in series. The overall generation of power is enhanced by more than 20% adopting parallel connected SPV vis-à-vis the SPV connected in series (Ashok T., 2012). Less effected by shading effects: Just 10% shading of a solar array (due to falling leafs etc.) can lead to a 50% decline in efficiency and even total system shutdown, if connected in series. This loss can totally be avoided in parallel connected SPV.

4.9. Mismatch Effects

Mismatch losses are caused by the interconnection of solar modules in series and parallel. The modules which do not have identical properties or which experience\different conditions from one another. Mismatch losses are a serious problem in PV modules and arrays because the output of the entire PV array under worst case conditions is determined by the solar module with the lowest output. Therefore, the selection of modules becomes quite important in overall performance of the plant (Ashish V.2015).

4.10. Increasing the Performance and Reliability by a Tracking System

The tracking device for solar cell with a sensor which is composed of four photo-resistors surrounding a sunshade to represent east, west, south and north. The resistance of photo-resistor will vary under solar irradiance such that the position of the sun can be determined by comparing circuit based on which the AC motor can be driven to allow perpendicular incident angle of sunlight onto the solar cell. This way the solar illumination can be improved and power generation efficiency can be enhanced. The tracking system is shown as (Figure 3.8). The daily improving power producing is calculated by Equation (4.5). (Exclude the power used of the tracking device).

$$E_{improved} = \sum_{i-6}^{17} (V_{batt} \times I_{charg})_{tracking} - (V_{batt} \times I_{chag})_{non-tracking} W \qquad 4.5$$

Using the table shown below

$$26.08\% = \frac{(280.05W - 222.12W)}{222.12W} \times 100\% \qquad 4.6$$

The energy generation efficiency is increased 26.08% every day, shown as equation (4.6).Although the tracking device of solar photovoltaic system increases 26.08% of energy generation efficiency, it must base on a shining day. If it is a windy day, the tracking device must be stop. The wind will damage the tracking device.

Table 4.8: The power producing from the non-tracking solar photovoltaic system.

Time	Non-tracking illumination	Vpv (V)	Vbatt. (V)	Ichag (A)	Pnon-tracking (W)
6	11.46	14.27	13.66	0.32	4.37
7	25.56	14.86	13.7	0.65	8.91
8	42.4	15.26	13.82	1.31	18.10
9	62.5	15.42	14.29	1.55	22.15
10	70.97	16.15	14.82	1.65	24.45
11	79.11	16.15	14.86	1.74	25.86
12	82.36	16.82	14.92	1.84	27.45
13	77.23	15.76	14.35	1.84	26.40
14	65.05	16.36	14.82	1.71	25.34
15	49.28	16.08	14.72	1.34	19.72
16	30.98	15.9	14.65	1.02	14.94
17	13.37	14.72	13.78	0.32	4.41
Total power producing from non-tracking device (W):					222.12

Data resources: solarpv.itri.org.tw, Green Energy and Environment Research Laboratories of Industrial Technology Research Institute (ITRI).

Table 4.9: The power producing from the tracking solar photovoltaic system

Time	Tracking illumination	Vpv	Vbatt. (V)	Ichag (A)	Ptracking (W)
6	42.45	15.07	13.77	1.25	17.21
7	48.77	15.23	13.84	1.38	19.10
8	54.27	15.36	14.02	1.48	20.75
9	68.47	15.96	14.44	1.67	24.11
10	75.55	16.33	14.86	1.74	25.86
11	80.97	16.31	14.93	1.8	26.87
12	84.42	16.88	15.11	1.85	27.95
13	81.96	16.1	14.76	1.86	27.45
14	74.1	16.16	14.72	1.76	25.91
15	71.66	16.43	14.99	1.63	24.43
16	66.33	16.27	14.84	1.52	22.56
Total power producing from tracking device (W):					280.05

Data resources: solar pv.itri.org.tw,Green Energy and Environment Research Laboratories of Industrial Technology Research Institute (ITRI).

4.11. Dust/Dirt Analysis

Sometimes there is a thick layer of dust accumulated on the surface of PV panel it significantly affects the performance of the PV modules. A dust layer of 4 grams per square meter can decrease solar power conversion by 40 percent (Ashok T., 2012). Literature review indicates the efficiency of PV panels with surface fouling is 7.5% while with the surface cleaning is 9.3%.(Subhash K., Dr. Tarlochan k**.,**et.al 2014).The dust may be acidic or alkaline thus causes the corrosion of the glass cover of the module. It is defined that in the same light intensity ambient condition, the fouling PV panel and clean PV panel power generation efficiency ratio is the PV fouling coefficient that is

$$\alpha = \frac{\eta_2}{\eta_1}, \tag{4.7}$$

Where α , is the PV fouling coefficient, η_2 is efficiency of fouling PV panel and η_1 is efficiency of clean PV panel.

The PV fouling coefficient (α) is higher in the dust and it is lower without in the dust surface, the rain will also help to decrease the PV fouling.

It has been analyzed from the data that the power output before cleaning is lower than after cleaning i.e. the measurement indicates after installed it's covered by dirt or dust. For instance, form Table 3.3 V_{oc} decreased by 7% and I_{sc} decreased by 97.3% i.e. the power output decreases to at least 21.3 %. (See appendices I - VI).

A dust layer of 4 grams per square meter can decrease solar power conversion by 40 percent.

4.12. Emissions Reduction Analysis

The installed solar photovoltaic power systems were significant for the globe in reducing emission and creating climate resilient green economy. Since CO_2 has a global effect, these systems and sinks could be anywhere in the world and claims to these reductions can be secured by obtaining emission reduction credits (ERC's) through this and other institutions.

According to CO_2 reduction and parameter for currently installed systems type 60Wps unit Photovoltaic's costs about USD 529.9.80 have emission reduction of 0. 37tons CO_2/year and 1Wps unit costs 8.83USD and costs 0.88 (USD) per ton CO_2 emission (International Carbon Bank and Exchange, carbon reduction calculator). One tone of carbon is equivalent to 0.37 tons of carbon dioxide. According to the information data collected in the chapter 3 can see that

A.In the table 3.15 the installed 300 health post of 360Wp/system will have that 108,000Wp/60Wps equal to 1800 times 0.37ton/yr is 666.0 ton CO_2/year emission were reduced.

B.Form table 3.14 the installed 100 primary schools of 200Wp/system will have that 20,000Wp/60Wps equal to 333.33 times 0.37ton CO_2/yr is 123.33ton CO_2/year emission were reduced.

C. In the table table 3.14 the installed 270 primary schools of 360Wp/system will have that 97200Wps/60Wps equal to 1620 times 0.37ton CO_2/yr is 599.4 ton CO_2/year emission were reduced.

D.From table 3.6 the installed 44,227 solar home systems a total watt peak of 1,952,372Wps/60Wp equal to 32,539.53 times 0.37 ton CO_2/year is 12,553.45ton CO_2/year emission were reduced.

Therefore a total of 13,942.18 ton CO_2/year emissions could reduce and its cost estimated about 12,219.11USD /year from the installed solar photovoltaic power systems in the country till the study is hand over.

4.13. PVsyst Software – Simulation.

PVsyst: Among the various software programs, PVsyst simulation software is the most popular. This software gives the detailed performance of the PV plants under operating as well as non-uniform operating conditions. It can be also used to investigate different loads on the system, to estimate the size of the system, to determine the optimal size of the panel, and to assess the energy production in the system. It can evaluate hourly, monthly as well as yearly energy production and performance. It also performs economic evaluation of the PV system at the design stage itself. Its application performs a detailed simulation and shading analysis according to many variables. PVsyst also considers the shading of a diffuse radiation. The limitation of the software is that it can compute only a single layer of PV module (Mahendra L., 2010). This means that if there are two layers of PV modules, one above the other, the software has no provision or option to compute the solar energy.

Figure 4.3: PVsyst: Screen shot.

Project: For the stand-alone PV system, the basic parameters required for modeling are the following - PV component database includes open circuit voltage, short circuit current, shunt as well as series resistances and a set of constants, inverter database consists of required voltage and power ratings, geographical site information includes latitude, longitude, altitude etc, and monthly meteorological data for horizontal global irradiance and temperature. In the present study, the meteorological data is acquired from Meteonorm version 6.1.0.23, a comprehensive climatological database for solar energy applications.

4.13.1. Temperature Effect Analysis

When the temperature of a photovoltaic module is increased, the efficiency drops. This can typically result in an efficiency drop off of 0.5% per °C increase in the cell operating temperature. The operating temperature is increased because a large part of the solar radiation is not converted to electricity but is absorbed by the panel as heat (Penick, T.et al., 1998).

Figure 4.4 shows the graphics of module efficiency made with PVsyst software. The software provides information on the operation of PV. It has a database of the main PV components marketed (Ali Najah et al., 2015).

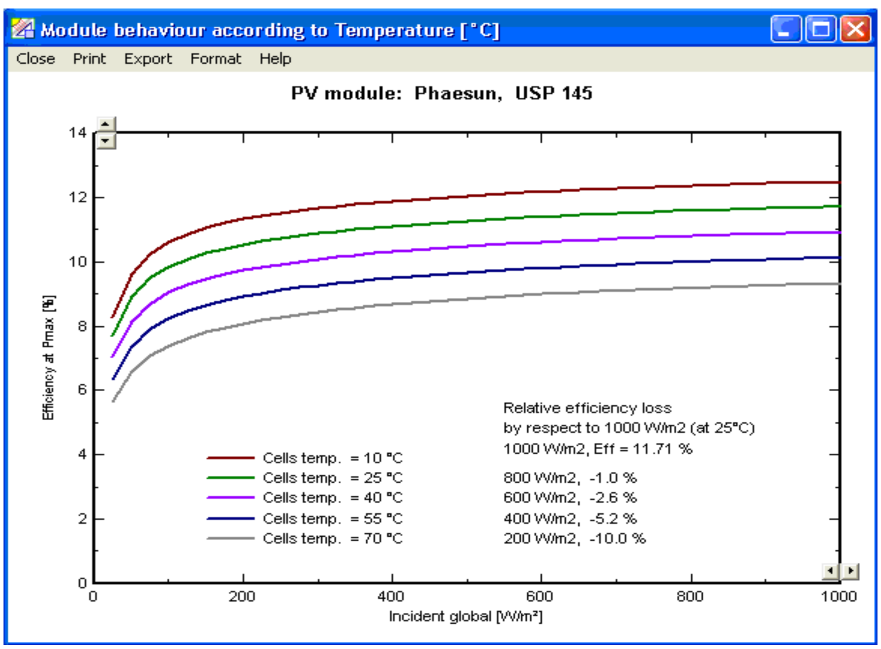


Figure 4.4: PV Modules Efficiency for Different Temperatures.

Location: In the project part, the geographic location defined is Ethiopia. PVsyst includes its own solar data for some locations. In the figure 4.5 shown solar hourly data for Benshangul Gumuz region. Metro for Ethiopia, reference year.

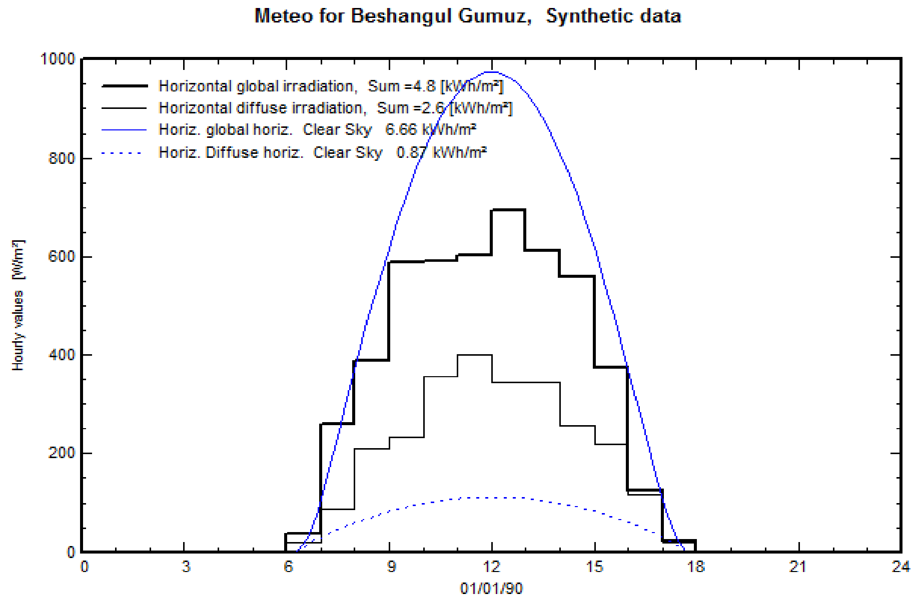


Figure 4.5: Graphs of metro hourly data for Benshangul Gumuz Region.

As shown the horizontal global irradiation in Benshangul region is 4.8KWh/m^2, and horizontal global Clear sky is 6.25KWh/m^2. Solar irradiance is higher at noon than other metro hours. In the figure 4.6 shown solar monthly data for Tigray region.

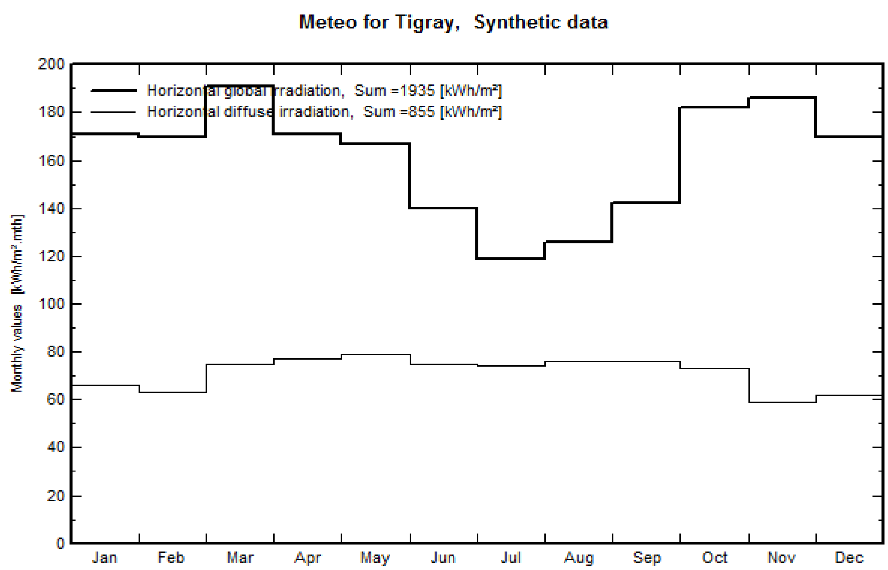


Figure 4.6 Graphs of metro monthly data for Tigray region.

As can be seen from figure 4.6 maximum solar irradiance can be attained starting from the middle of February to the middle of March and starting from in the middle of September to the middle of November. Minimum starting from in the middle of June to September.

4.13.2. Orientation

In the orientation part, the panels are facing (south for this study case), and the angle the panels will form with the ground (the inclination or tilt angle) are set. The energy usage between winter time and summer time is big, otherwise at this latitude, the solar resource gap between winter and summer is not that big. That is the reason why the inclination needs to be optimized for the summer months. Here the plane tilt is about 300 and azimuth is about 200.

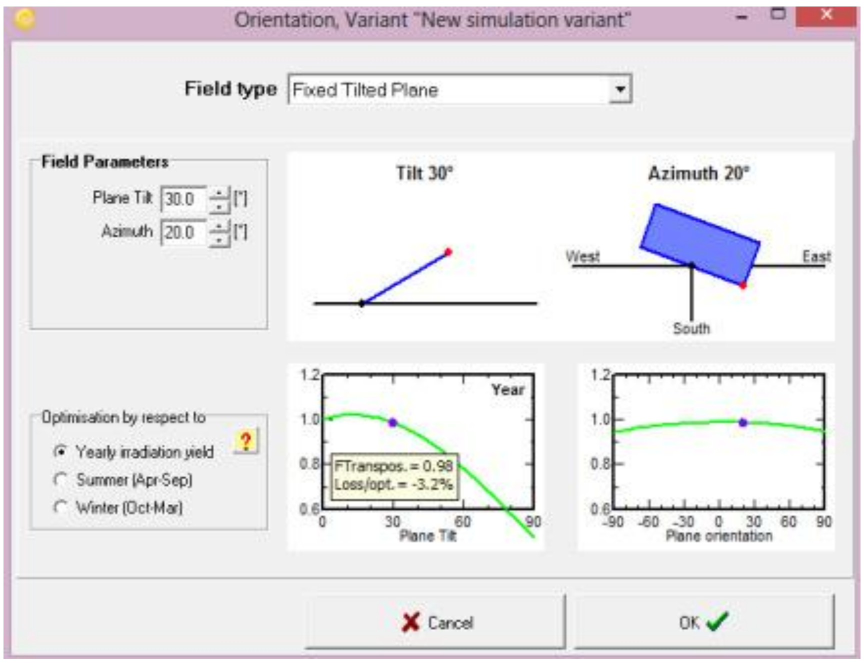


Figure 4.7: Tilting and orientation of PV panel.

4.13.3. Shading analysis

It was observed that area of the shade had significant effect on the PV characteristics as well as power output. The shade produced by the cable had minimum effect on the power output whereas that produced by the building model had the maximum effect (SathyaNarayana P., et al., 2015).

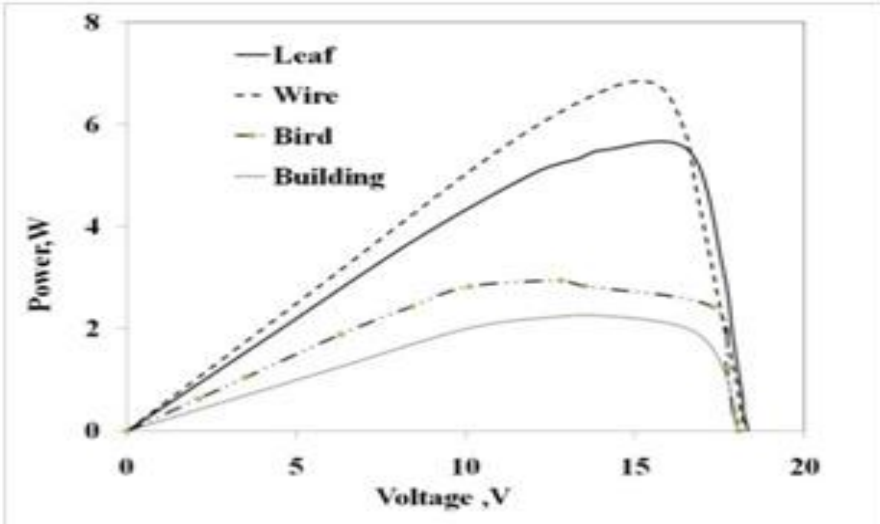


Figure 4.8: P-V characteristics of the module under non-uniform shading.

If the shade covered one complete cell area of the panel, then the power output completely vanished.

4.14. Techno-Economic Analysis of SHS Installed by Poly Technologies inc, China by lot.

Table 4.10 System type and description with the respective number of users by LOT and cost of PV systems.

System Type	System Size	LOT 1	Each system cost in Birr	LOT 2	Each system cost in Birr	LOT 3	Each system cost in Birr
1	8Wp	292	3,702.02	230	3,691.47	1571	3,765.75
2	10Wp	213	4,275.13	109	4,263.13	1269	4,347.41
3	20Wp	114	5,599.91	85	5,582.31	412	5,705.69
4	40Wp	135	8,167.95	76	8,140.65	229	8,332.73
5	60Wp	176	11,774.26	297	11,737.66	292	11,995.24
6	75Wp	339	12,994.75	725	12,952.75	23	13,248.43
7	80Wp	93	14,693.21	184	14,633.91	90	15,051.19
8	100Wp	56	17,023.89	99	16,964.09	49	17,384.37
9	130Wp	209	19,295.6	34	19,231.8	74	19,680.38
	Total	1627	97,526.72	1839	97,197.77	4009	99,511.19

Source: REF, MoWIE, Some of the price as per system type by their Lot REF/2012.

25,000 SHS were installed in 2012 to 2014 under Ministry of water, irrigation and energy named REF rural electrification fund. Thus the rural society initially affords 5% down payment and the payback will processed through their cooperative and will collect by developmental Bank of Ethiopia to The world bank within 5 (five) years.

Whereas, the institutional Solar photovoltaic systems like health post are installed by the support getting from World Bank grants it costs about Birr 75,000.

4.15. Techno-Economic Analysis Options

Today, in investments of solar systems not only consider cost of it, but also consider its benefits. Despite all the issues, one can find some of location in country that using solar energy is economical. For example, in remote areas using of Photovoltaic cell is appropriate. Ethiopia being landlocked country, most of the equipment comes by air. In case of any shipment through sea, inland transport from Djibouti to Addis Ababa contributes 6-8% of the c.i.f price. Though currently there is no import/customs duty, there is still no a surtax 10%) on the systems and an additional VAT (value added tax) of 15% by agreement or the company include in the sell price. Retail margins vary from 15% to 40%, with large variations between different dealers, thereby contributing to the different pricing of the products for the end user. Thus, the final prices of the solar PV modules, when reaches the local market, sell for up to US$4.5 – US$ 7/Wp (ETB 60 –95/) (Jalal Addin Sadri, 2012).

Table 4.11 Price of typical solar PV components (as on March 2010)

Items	Price (in US $)
c-Si PV module (purchase cost in its country of origin)	US $ 2.5 – 3.5 / Wp
c-Si PV module (average retail cost in Addis Ababa considering different capacity of module incl smaller capacity size module)	US $ 4.5 – 7/Wp
Typical 50 Wp solar PV module in Addis Ababa	US $ 225 - US $ 300
Typical charge controller (depending on capacity)	US $ 30 - US $ 50
Solar lanterns depending on model and illumination	US $ 35 - US $ 110
Gelled battery (depending on capacity)	US $ 150 -US $ 300

Note: All prices mentioned here are approximations, indicated by the respondents during the survey.

With regard to the cost of the complete systems with say 3-4 lamps, provision for powering TV and small appliance, the price is ETB 250-300 /Wp (US $ 18 -22/Wp). Individually, the price of a 50Wp PV module ranges between ETB 3000 to ETB 4200 (US$ 225 to US$ 300) excluding the cost of installation and commissioning. The price of a charge controller ranges between ETB 400 to ETB 700 (US $ 30 to US $ 50) depending on the capacity (such as 6 amp, 8 amp etc). The cost of the solar lanterns ranges between ETB 500 to ETB 1500 (US$ 37 to US $ 110) depending on the model, illumination level, country of import and quality. Mostly gelled batteries are used in the country and are available at a cost of about ETB 2000 to ETB 4000 (US $ 150 to US $ 300) depending on the capacity whereas the cost of a 70 Ah the VRLA battery range between ETB 2500 to ETB 3000 (US $ 185 to US $ 225) (Jalal A. ,2012).

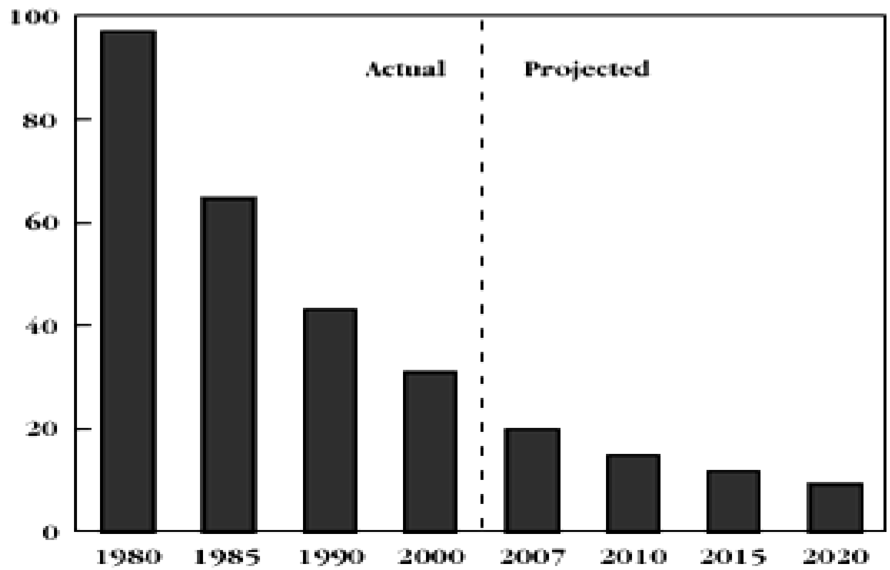


Figure 4.9: Trend of cost reduction for PV systems from 1980 to 2020.

Simply So, comparing the price of fuel used by the off-grid rural household per liter is an average Birr15.00/day, while used for a month is 15x30 is equals to Birr 450.Thus yearly consumption may take a minimum of Birr 5,400.If they have an access of a solar photovoltaic power system one can save money, uses for long period of time free from CO_2 emissions.

Chapter 5: Conclusion and Recommendations

This study was designed to examine and improve stand-alone solar photovoltaic power systems performance and reliability for the rural electrification of Ethiopia. The study was conducted to assess and evaluate and the data collection were administered on sample randomly selected sites installed in the Benshangul gumuz, Tigray, Oromiya and Amhara regions of Ethiopia. About ten sample sites were identified for each regions and data gathering were made using solar photovoltaic systems investigation check list (See appendices I -VI). The solar and wind master plan of Ethiopia used as indicated the solar radiations data , has a huge solar energy potential for rural electrification through the off-grid system in the sample randomly selected sites of solar home systems (SHS) and institutional like health post and rural primary schools in the four regions. The data gathered from randomly selected sample sites in four regions of Ethiopia for almost during the two months of study. The data collected were analyzed using descriptive survey; theoretical, mathematical formulation experimental models, emission reduction analysis and PVsyst software analysis were used.

The major findings of the study were summarized as follows.

- The solar radiations is indicated on the solar and wind master plan of Ethiopia, has a huge solar energy potential for rural electrification through the off grid system in the sample randomly selected sites of the four regions.
- The output power that obtained by measuring Voc and Isc of the systems indicates that the performance of the solar photovoltaic systems has been determines.
- It has been observed that most of the systems are installed by flat plate polycrystalline modules.
- The orientations of the module were not stricted to south, fixed tracking systems and most of the system not tilted about 15^0 .
- Lose in PV systems were observed due to, system design, efficiency of the modules with temperature, accumulation of dirt/ dust, shading by nearby trees, objects etc.

5.1. Conclusion

Based on the findings as it has been analyzed in the previous chapters the performance of the system after it has been installed varies/decreases by some affecting factors in comparison with before installation, the measurement of the PV module Voc and Isc that determines of the output power (Pout =Voc x Isc) of the system also reduced thus the performance of the solar photovoltaic power system and its reliability also reduced.

Amongst different factors affecting to improve stand-alone solar photovoltaic systems performances and reliability of rural electrifications some of them are described as follows:

1. As Ethiopia is located near the equator, the solar resource potential is significant. The yearly mean average daily radiation reaching the ground is 5.2KWh/m^2/day (Stutenbaumer et al., 1999).It also analyzed by PVsyst model.
2. Most of the systems are installed by flat plat polycrystalline of efficiency around 12-14% which is lower efficiency than other crystalline module. As it was calculated the open circuit voltage (Voc) and short circuit current (Isc) of SHS reduced, which implies the output power (P_{out}) output of the system performances changing or reduced taking an average range from 21.85% to 95 % in each the four regions in the three years of utility.
3. The orientation is not strict to south and the tilt angle is not considered the latitude of the location. For example, Benshangul gumuz has latitude 11° 0’ 0 N+ 5^0 to 10^0, the tilt angle has been between 16^0 to 21^0 , in Oromia , latitude 8° 00' 00'' N + 5^0 to 10^0 is between 13^0 to 18^0, in Amhara region, latitude 9°-14° N + 5^0 to 10^0 is between 14^0 to 19^0 and Tigray region , latitude 14° 10’ 0 N+5^0 to 10^0 is between is19^0 to 24^0 . Increasing the Performance and Reliability by a Tracking solar panel System. The energy generation efficiency is increased 26.08% every day, shown as equation (4.6).Although the tracking device of solar photovoltaic system increases 26.08% of energy generation efficiency, it must base on a shining day. If it is a windy day, the tracking device must be stop. The wind will damage the tracking device.
4. Lose in PV systems due to system design, efficiency of the modules with temperature, accumulation of dirt/smog power reducing effects of array shading by trees, nearby buildings, etc,the efficiency of inverter, Cable thickness and reliability

A. Regarding the system design for the primary schools were used 12V,400Ah Battery it has to be rated 12V, 500 Ah for 3-day autonomy, 20A charge controller has to be rated 60 A at 12 V or greater. For the health posts in the system design from the load requirements this system should be powered by at least 9 modules of 75Wp rather than 8modules of 75Wps, the solar charge controller should be MPPT type and rated 60 A at 12 V or greater instead of 50A charge controller as well as the battery should be rated 12 V 1500 Ah or 15 for 3-day autonomy.
B. As indicates the temperature of the module rises and for every degree in temperature rise in temperature output efficiency reduced by 0.5% (Penick, T.et al., 1998).
C. Most PV systems are covered by dust or dirt thus a dust layer of 4 grams per square meter can decrease solar power conversion by 40 percent (Ashok T., 2012). From Table 3.2 Voc decreased by 7% and Isc decreased by 97.3% i.e. the power output decreases to at least 21.3 %.((see also appendices I- VI). Sometimes there is a thick layer of dust accumulated on the surface of PV panel it significantly affects the performance of the PV modules. Literature review indicates the efficiency of PV panels with surface fouling is 7.5% while with the surface cleaning is 9.3 %.(Subhash K., Dr. Tarlochan k., et.al 2014).

D. Most modern MPPT devices have conversion efficiency close to 92-97%. These controllers are based on control algorithms using artificial intelligence techniques such as artificial neural networks (Ionel L. and Florin R.,2014).The overall generation of power is enhanced by more than 20% adopting parallel connected SPV compared with the SPV connected in series (Ashok T. ,2012).
E. Wiring size should determined by the watt peak (Wp) of the module, for instance from PV module to charge controller 4 mm² (AWG#12), from charge controller to battery 4 mm² (AWG#12) and from charge controller to loads 2.5 mm² (AWG#14).It different for different WPs of modules (see table 4.3).
F. Improvement in efficiency brought by parallel wiring may also reduce requirements of sizing of batteries as state of charge of batteries will improve. Less effected by shading effects, just 10% shading of a solar array (due to falling leafs etc.) can lead to a 50% decline in efficiency and even total system shutdown, if connected in series. This loss can totally be avoided in parallel connected solar photovoltaics.

So that these are some important factor that significantly affects the performance of solar PVsystems.As compared to other research paper this paper gives information's on comparisons of performances of stand-alone photovoltaic power systems in the four regions of Ethiopia.

5.2. Recommendation

The findings of the study reveal that advanced models are better than the methods that used to enhance performances and reliability of the solar photovoltaic power systems. A few suggestions are put forward for improving the performance and reliability of stand-alone solar photovoltaic power systems for rural electrification.

- Since in the selection of PV modules, thin film modules will certainly give higher performance at elevated or high temperature when compared to crystalline silicon. Mono crystalline is the most established and efficient solar cell technologies which have the module efficiency of 15 - 18%, than polycrystalline. Moreover, concentrator solar cells are the best for performance of the solar PV system.
- The orientation and tilt angle of the panel has to be depending on the latitude of the location.
- The solar cell with a tracking device improved efficiency than fixed once.
- Cleaning of solar panel can increase the performance of the system.
- Modules connected in Parallel may be deployed to get highest power generation than in series and the mismatch also affects the performance of the system.
- MPPT charge controller is recommended for efficient performance solar device.
- Higher performance can be attained by a good solar photovoltaic system design.
- Most installations needs maintenance and replacement of battery, inverter, charge controllers and the like that are placed without function.
- It helps to reduce emission of carbon.
- Stakeholders should be encouraged to use these methods in solar photovoltaic power

systems.

As indicated on the lighting Africa report, about 84 present of Ethiopians are living without modern light, SHS and institutional solar systems are very essential for rural electrifications at least for lighting and mobile charging sustainably. There are, however, formidable challenges like low purchasing power of the rural people; needs subsidy. The solar dealers are free from tax to import the solar devices from abroad, unfavorable public attitude towards the private sector besides quality monitoring and regulations that work against development and distribution of renewable energy technologies. Maximum effort must be exerted to change the prevailing attitude and so that the energy policy has to address and should reach the rural electrification early period.

It hoped that present study will open door for further research in the area of solar photovoltaic power systems in different rural regions of the country.

References

Ashok Tiwari, 2012, Methodology to maximize the efficiency of Solar Photovoltaic energy Sources and to reduce the OPEX of telecommunication infrastructure for rural Communications in developing countries, Mumbai, India.

Ashish Verma and Shivya Singhal, January 30, 2015, Solar PV Performance Parameter and Recommendation for Optimization of Performance in Large Scale Grid Connected Solar PV Plant—Case Study, India.

A.M.Reis,N.T.Coleman,M.W.Marshal,P.A.Lehman,and C.E.Chamberlin,May 2002"Comparison of PV Module Performance before and after 11 years of field exposure", Proceedings of the 29th IEEE Photovovoltaic's Specialists Conference New Orleans, Louisiana.

Ali Najah Al-Shamani, Shikha Yadav and Rituraj Jalan, May 2015, Design & Sizing of Stand-Alone Solar Power Systems A house Iraq, Vol. 2, Special Issue 1.

CERIC, February, 2011, Performance of solar power plants, New Delhi.

Ching-Lung Lin, August, 2015, Case Study of Solar Power Producing Efficiency from a Photovoltaic System, Hsin-Chu, Taiwan.

Cooper, P.I. "Digital simulation of transient solar still process," Solar Energy, 1969, Vol. 12.

Desta Gebeyehu and K.Leo, Organic Thin-film; Next Generation Law-Cost Photovoltaic Applications, Journal of Ethiopian Engineers and architects, vol.24, 2007, 59-65.

Dereje Azemraw Senshaw (April, 2014), Modeling and Analysis of Long-Term Energy Scenarios for Sustainable Strategies of Ethiopia, Flensburg, Germany.

Duffie John A, William Beckman A, "Solar Engineering of Thermal Processes, 3rd Edition, 2006, John Wiley and Sons Inc, pages 3 – 138.

Ewan D. Dunlop, David Halton, 2006, “The Performance of Crystalline Silicon Photovoltaic Solar Modules after 22 Years of Continuous Outdoor Exposure”, Prog. Photovoltaic: Res. Appl.; 14:53–64.

"Electropaedia, Solar Power (Technology and Economics),"Woodban Communications Ltd, Jan 2012. [Online].Available: http://www.mpoweruk.com/solar_power.html.

EU PVSEC 28th, Sep 30-Oct 4 2013, Monitoring of photovoltaic systems: good practices and Systematic Analysis Trends in PV System Performance, Paris, Frances.

EREDPC, 2007. Solar and Wind Energy Utilization and Project Development Scenarios Final Report; Addis Ababa: Ethiopian Rural Energy Development and Promotion Centre

Fraunhofer Institute: Module Power Evaluation Report, commissioned by Schott Solar AG.

Firoz Ahmad, Intkhab Ulfat. “Empirical Models for the correlation of Monthly Average Daily Global Solar Radiation with Hours of Sunshine on a Horizontal Surface at Karachi, Pakistan. Karachi”, Turk J Phys, Pakistan, 2004, Vol. 28.

Getachew Bekele,2009,Study Into The Potential And Feasibility of A Standalone Solarwind Hybrid Electric Energy Supply System,For Application In Ethiopia, Stockholm .

Green Martin A. Solar Cells; Operating Principles, Technology, and System Applications, Prentice-Hall Inc, 1982 pp xii and pp 62-184.

Goetzberger A, Hebling C, Schock HW. Photovoltaic materials: history, status and outlook. Materials Science and Engineering R: Reports 2003; 40(1):1–46.

Gottschalg R, Infield D, Kearney M. 2003; Experimental study of variations of the solar Spectrum of relevance to thin film solar cells. Solar Energy Materials and Solar Cells.

GTZ, 2009. Target Market Analysis: Ethiopia's Solar Energy market; Berlin: German Technical Cooperation.

GNESD (2007). Reaching the millennium development goals and beyond: access to modern forms of energy are prerequisites. Global Network on Energy for Sustainable Development.

Henry A.Aribisala, 2013, Improving the Efficiency of Solar Photovoltaic Power System, University of Rhode Island.

Ionel Laurentiu Alboteanu1, Florin Ravigan, Volume 1, 2014, Methods for Increasing Energy Efficiency of Photovoltaic Systems.

IMD Pune website, http://www.imdpune.gov.in/, accessed on 20th June 2010.

IEEE, 2007, IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stand-Alone Photovoltaic (PV) Systems, IEEE STD 1013-2007.

International Energy Agency (IEA) statistics (2012):Co_2 emission from fuel combustion high lights, Paris, France.

Jack.T.Chow,Assessment of Solar Home System for rural isolated rural Community's in Vanuatu using project life cycle/Sustainability Frame Work, Michigan Technological University, 2010.

Jalal Addin Sadri a, b, PayamHooshmand, © 2012, A Survey Study on Hybrid Photovoltaic System: Technical and Economical Approach, Text Road Publication.

Lighting Africa Policy Report: Ethiopia, March 2011, Policy. Report Note Ethiopia.

LathSa'd Basha, March, 2012, Analysis and evaluation tools development of photovoltaic modules and system performance under Jordanian and German climatic conditions.

Mason, J.E., et al., Energy Payback and Life-cycle CO2 Emissions of the BOS in an Optimized 3.5 MW PV Installation. Progress in Photovoltaic's: Research and Applications, 2006. 14: p. 179-190.

Mahindra Lalwani, D.P. Kothari and Mool Singh, 2010, Investigation of Solar Photovoltaic Simulation Software's, Indian Institute of Technology, Delhi, India.

M.Zeman, February, 2012"Solar Cells. Chapter 2: Solar Radiation, "Delft University of Technology Master Plan Report of Wind and Solar Energy in the Federal Democratic Republic of Ethiopia.

NASA (2011). How do photovoltaic's work. http://science.nasa.gov/science-news/science-at-nasa/2002/solar cells/. Accessed on 2011-02-01.

PVMC, Photovotaic Performance Monitoring Center, Universiti Technology MARA, Malaysia, 2014.

Parvathy S. and Jaimol, 2014, Thomas Performance Analysis of Stand-alone PV Systems Under Non-Uniform Operating Conditions Using PVsyst.

Penick, T.and Bill Louk: Photovoltaic Power Generation, December 4, 1998.

Performance of Solar Power Plants in India, Central Electricity Regulatory Commission, February, 2011 New Delhi.

Purnomo Sidi Priambodo, Nji Raden Poespawati and Djoko Hartanto (2011). Solar Cell, Solar Cells – Silicon Wafer-Based Technologies, Prof. Leonid A. Kosyachenko (Ed.), ISBN: 978-953-307-747-5, InTech, Available from:

http://www.intechopen.com/books/solar-cells-silicon-wafer-based-technologies/solar- Cell Date accessed: 2/27/13.

Stutenbaumer U and Negash T and Abdi A, 1999. Performance of small scale photovoltaic Systems and their potential for rural electrification in Ethiopia.

Sen, Zekai, 2008, solar energy fundamentals and modeling techniques: atmosphere, environment, Climate change and renewable energy, Springer, pp 44-70.

Shepperd, L., & Richards, E. (1993). Solar photovoltaic's for development applications. Sandia National Labs.

Shiota Akio, 2000, Solar home systems Hand book, JICA, Japan.

Shiraz University, May,2012, Performance Evaluation of Sun TrackingPhotovoltaic Systems in Canada,20thAnnual International Conference on Mechanical Engineering, Shiraz, Iran.

Shikha Yadav and Rituraj Jalan, May 2015,Design and Simulation of Small Power Stand Alone Solar Photovoltaic Energy System for Residential unit, India.

S.Mekhilefa R.Saidurb, M.Kamali, 22 March 2012, Effect of dust, humidity and air velocity on efficiency of photovoltaic cells solar energy, sarvestanib.

Shadi N.AlBarqouni, 2010, Re-Evaluation and Re-Design Stand-Alone PV Solar Lighting Projects in Gaza Strip, Palestine. The Islamic University of Gaza, Palestine.

Sathyanarayana P., Rajkiran Ballal, Lakshmi Sagar P.S., Girish Kumar, 2015, Effect of Shading on the Performance of Solar PV Panel SDM Institute of Technology, Ujire, India.

Surya, P. R. (1992). Rural electrification by PV solar home systems, Sukatani, West Java, Indonesia 1988-1992. Jakarta.

Subhash Kumar, Dr. Tarlochan kaur, November 2014, Solar PV Performance-Issues and Challenges, PEC University of Technology, Chandigarh, India.

The Solometric, Guide to Interpreting I-V curve Measurements of PV “Array“. http://www.solometric.com, March, 2011.

TERI (The Energy and Resources Institute), September 2010, Working Paper Study on Local Manufacturing of Renewable Energy Technology Components in East Africa, India.

Reddy, P. J. (2010). Science and Technology of Photovoltaic’s. BS Publications, Kundl Haryana, India. ISBN: 9789350437438. Renewable and Conventional Energy Technology.

UNDP. “World Energy Assessment*”,* United Nations Development Programme, New York, 2009, 92-1-126126-0, 2009.

UNIDO, 2010, Study on Local Manufacturing of Renewable Energy Technology Components in East Africa.

Zaharim Azami, Razali Ahmad Mahir, Gim Tee Pei, Sopian Kamaruzzaman“Time Series Analysis of Solar Radiation Data in the Tropics”, European Journal of Scientific Research, Vol.25 No.4 (2009), pp.672-678.

Appendices

Appendix I: Description of SHS Site Installation Investigation check list

Region …………Zone ………………Name of Co-operative……………….. Date …………………….

User name :		Sign :
S.No	**Main Check Points**	**Observation**
1	**PV area visual Investigation**	
a.	Is the PV module tight or loose	
b.	Is the cable connection tight or looses	
c.	Shading on the PV module	
d.	Does the PV module face to south & tilt by 15^0	
e.	PV module support structure	
2	**Main Cabinet area visual Investigation**	
a.	Is cable connection tight or loose	
b.	Is the cabinet at a place out of reach of direct sun rays and fire?	
c.	Ventilation at the cabinet area	
d.	Is the content of main cabinet proper (Battery, Charge controller, Breaker and Inverters for PLS- 60-H and above)?	
3.	**Installation of visual Investigation**	
a.	Is cable alignment proper?	
b.	Is the cable connection loose or tight	
4.	**Inverter(PLS-60- tp PLS-130-H) visual monitoring**	
a.	Is it functional at the time of visit?	
b.	Cable connection tight or loose	
5.	**Electrical appliances**	
a.	How many sockets are there?	
b.	Are all sockets are functional?	
c.	How many lamps are there?	
d.	Are all lamps are functional?	
e.	Are mobile Chargers are functional?	
6.	**Roof Installation of PV module**	
a.	Is appropriate sealing made for every roof penetration	
c.	Is the support structure and roof are tightly fixed	
d.	Is the module at appropriate direction & no fear of damage of the panel by wind	
7.	Is training provided properly to the user (if not give it during monitoring)	
	Monitoring :- Time :	Panel Voc-…………. Battery voltage status: Isc - ………. Charge controller Vcc-……Inverter & AC

		wire V …..

Appendix II: Description of Institutional Site Installation Investigation check list

Region ………………… Zone ……………………Name of Health post /Primary school… …………… Date ……………..

S.No	Main Check Points	Observation
1.	PV Module	
a.	Has it been fixed properly with roof?	
b.	Has it been made leak proof against rain?	
c.	Direction of orientation of tilting angle proper?	
d.	Has it been cleaned after installation?	
e.	Has it been observed against possible shadow from surrounding?	
f.	Wiring from Module to Earth pit & to metal box properly installed?	
2.	Distribution board	
a.	Has it been fixed properly with wall?	
b.	Is the distance b/n DB & Inverter cum Charge controller as per drawing?	
c.	Is the alignment OK?	
d.	Has it been cleaned after installation?	
e.	Has it been observed against possible damage from surrounding?	
f.	Are the connection OK?	
3.	Inverter cum charge controller	
a.	Has it been fixed properly with wall?	
b.	Has it been connected securely with wires?	
c.	Has it been cleaned after installation?	
d.	Has it been observed against possible damage from surroundings?	
e.	Wiring from DB to Inverter (DC) & Inverter to DB (AC) is properly done?	
4.	Battery -Battery State of Charge (Vbat)	
a.	Has it been placed properly with battery box?	
b.	Has it been connected securely with wires?	
c.	Is the battery wiring OK & as per drawing?	
d.	Has it been cleaned after installation?	
e.	Has it been observed against possible damage from surroundings?	
f.	Wiring from charge controller & Battery properly installed or done?	
g.	Has it been placed in ventilated place?	
5.	Socket & Bulb	
a.	Has it been fixed properly with wall?	
b.	Has it been connected securely with wires?	
c.	Has it been cleaned after installation?	
d.	Has it been observed against possible damage from	

	surroundings	
e.	Wiring from DB to Socket & bulb is properly installed?	
f.	Bulb must be placed at 1900mm from floor?	
6.	Wiring & Casing	
a.	Has it been fixed properly with wall?	
b.	Is the alignment correct with reference to wall & floor?	
c.	Are the saddles at proper distance?	
d.	Has it been cleaned after installation?	
e.	Has it been observed against possible damage from surroundings?	
	Other Observation: Time :	Panel : Battery voltage Status…………… Voc -…………… Isc-………………

General:

S.No	Main Check Points	Observation
a.	Stickers have been fixed properly & at proper location?	
b.	Has training been conducted for Health post officials & the PAC been taken	
c.	Has operational manuals been given to Health post officials /Primary Schools?	
d.	Has photographs been taken of installation?	
e.	Material Handling Over certificate taken?	
f.	Has do & don't Explain proper?	
g.	Is this system aesthetically OK?	
h.	Has been made clear after installation?	
I.	Has wall repaired & painted after installation?	

Appendix III: Description of SHS Installation Site Investigation, among randomly selected 10 SHS in each of four regions as an Example in Oromia region.

No	Woreda	Owner of SHS	Installed by(Company)	Maximum Power(The system type)	Year of Installation	Problems observed during investigation	Maintenance	The current status	Performance of panel & battery
4. Oromia Region	1.W.Shoa .,Dendi Woreda	1. Ato Teshome Dibaba.	“	75Wp	Feb. 24,2013	-.Covered by dust - Not oriented to the South.	-The system is operating -green all signals. . Performance at 25^0c -Imax-3.48A -Vmax-21.5V -Voc -17.5V -Isc -3.78A -Peak power-75W Local Time :7:30 Panel With dust cover Voc-19.39V -Isc-0.231A Panel after cleaning Voc- 13.72V -Isc- 0.154A -Battery status- 13.85V -Charge controller voltage-13.24V		
	2.W.Shoa , Dendi Woreda	Ato Bekele Feyisa	“	60Wp	Feb. 24,2013	- Covered by dust - Not oriented to the South.	-The system is operating -green all signals. . Performance at 25^0c -Imax-3.48A -Vmax-21.5V -Voc -17.5V -Isc -3.78A -Peak power-60W Local Time :7:30 Panel With dust cover Voc-18.91V -Isc-0.208A Panel after cleaning Voc-13.72V -Isc-0.154A -Battery status- 13.67V -Charge controller voltage-13.12V		
	3.W.Shoa	Ato							

	.,Dendi Woreda	**Kuma Feyissa**	**“**	**75Wp**	**Feb. 24,2013**	**-. Coverd by dust**	**-The system is operating** **-green all signals.** **.** **<u>Performance at 25^{0}c</u>** **-Imax-3.48A** **-Vmax-21.5V** **-Voc -17.5V** **-Isc -3.78A** **-Peak power-75W** **<u>Local Time :7:30</u>** **<u>Panel With dust cover</u>** **Voc-19.24V** **-Isc-0.229A** **<u>Panel after cleaning</u>** **Voc- 13.72V** **-Isc- 0.154A** **-Battery status- 13.68V** **-Charge controller voltage-13.21V**
	4.W.Shoa .,Dendi Woreda	**Ato Lemma Gottie** **Pictured No- 1436- 1439**	**“**	**75Wp**	**Feb. 24,2013**	**-. Covered by dust**	**-The system is operating** **-green all signals.** **-Philips TV 38W –power AC properly uses 1hr- day time.** **2hr – night time** **Can use Solar TV-15Wp** **.** **<u>Performance at 25^{0}c</u>** **-Imax-3.48A** **-Vmax-21.5V** **-Voc -17.5V** **-Isc -3.78A** **-Peak power-75W** **<u>Local Time :11:35</u>** **<u>Panel With dust cover</u>** **Voc-18.77V** **-Isc-0.225A** **<u>Panel after cleaning</u>** **Voc- 13.72V** **-Isc- 0.154A** **-Battery status- 12.83V** **-Charge controller voltage-13.11V**
	5.W.Shoa .,Dendi Woreda	**Ato Geleta Regassa.**	**“**	**75Wp**	**Feb. 24,2013**	**-. Covered by dust**	**-The system is operating** **-green all signals.** **-** **.** **<u>Performance at 25^{0}c</u>** **-Imax-3.48A** **-Vmax-21.5V**

							-Voc -17.5V -Isc -3.78A -Peak power-75W <u>Local Time :11:35</u> <u>Panel With dust cover</u> Voc-17.96V -Isc-0.210A <u>Panel after cleaning</u> Voc- 13.72V -Isc- 0.154A -Battery status- 12.84V -Charge controller voltage-13.06V
	6.W.Shoa , Dendi Woreda	**Ato Lemmu Regassa**	“	**60Wp**	**Feb. 24,2013**	**-. Covered by dust**	**-The system is operating -green all signals. . <u>Performance at 25^{0}c</u> -Imax-3.48A -Vmax-21.5V -Voc -17.5V -Isc -3.78A -Peak power-60W <u>Local Time :11:55</u> <u>Panel With dust cover</u> Voc-17.25V -Isc-0.190A <u>Panel after cleaning</u> Voc-17.72V -Isc-0.195A -Battery status- 13.24V -Charge controller voltage-13.10V**
	7.W.Shoa , Dendi Woreda	**Ato Taffa Gnikola**	“	**60Wp**	**Feb. 24,2013**	**-. Covered by dust**	**-The system is operating -green all signals. -Uses Redio . <u>Performance at 25^{0}c</u> -Imax-3.48A -Vmax-21.5V -Voc -17.5V -Isc -3.78A -Peak power-60W <u>Local Time :11:55</u> <u>Panel With dust cover</u> Voc-17.31V -Isc-0.191A <u>Panel after cleaning</u> Voc-17.72V -Isc-0.195A**

							-Battery status- 13.01V -Charge controller voltage-13.10V
	8.S.W.Shoa,Wolliso- Adami Gotu Woreda	Ato Abera Mirkana	"	10Wp	Feb. 24,2015	- Demand was not recoreded correctly as the individual need. -The system is not enough for the house hold being very large. -Covered by dust	-The system is operating Performance at 25^0c -Imax-0.58A -Vmax-17.5V -Voc -21.5V -Isc -0.64A -Max System voltage-1000V -Peak power-10W Local Time :11:00 Panel With dust cover -Voc-19.85V -Isc-0.236A -Battery status- 13.14V. -Charge controller voltage-12.94V.
	9.N.Shoa ,Wolliso Adami Gotu	Ato Haile Bekele	"	100Wp	"	It was started blinking at the moments of measurement taken by multimeter & the bulbs ceased giving light. -After some 3hr starts light .it was cloudy time. - Covered by dust	-The system is operating Performance at 25^0c -Voc -21.5V -Isc -8;18A -Peak power-20W Local Time :11:30 -Voc-118:05V -Isc-0.33A -Battery status- 13.15V
	10.S.W.Shoa ,TOLIE, Kusti Areda leqa kebeleAdami Gotu	Ato Chaka Mideksa Pictured No-1444-1449	"	100Wp	"	- Covered by dust	-The system is Operating. -Uses LED 15.6Wp,3.3A SUNRANSFER -TV Performance at 25^0c -Voc -21.5V -Isc -8.18A -Peak power-20W Local Time :11:30 -Voc-19.96V -Isc-0.219A -Battery status- 13.10V
	11.S.W.Shoa ,TOLIE, Kusti Areda leqa kebeleAdami Gotu	Ato Dibaba Mideksa Pictured No-1450-1455	"	100Wp	"	-The main Cabinet & the main Sockets has to be changed. -Covered by dust	-The system is not Operating. -Main socket burnt Performance at 25^0c -Voc -21.5V -Isc -8.18A -Peak power-20W

							<u>Local Time :11:30</u> **-Voc-19.96V** **-Isc-0.219A** **-Battery status- 4.15V**

Appendix IV : Health post Solar photovoltaic systems installations site Investigation in Tigray region

No	Woreda	Name of Health post	Installed by(Company)	Maximum power (The system Type)	Year of Installed	Problems observed during investigation	Maintenance	The current status	Performance of panel & battery
3. Tigray Region	**1.South East zone,Doga Temben Woreda**	**Aregen health post.**	**Lucky Export Indian**	**75Wp × 8=600Wp**	**2010 .G.C**	**-Inverter switch will not be off & on.** **-Inverter has to be changed, no out put** **-Charge controller** **-All has to be changed. Panels surface were covered by dust.** **-**	**-The system gives light only** **- Uses Ac socket charger of the system** **<u>Measured performance</u>** **- Local Time :2:50** **<u>Panel With dust cover</u>** **- Voc-18.9V** **- Isc-0.209A** **<u>Panel Without dust cover</u>** **Voc-19.9V** **Isc- 0.211A** **- Battery status- 13.73V** **- Charge controller reading- 12.82V** **Inverter Input =12.57V** **Inverter Output =0(zero)**		
	2.Southern zone,ofla Woreda	**May Maido health post?**	**Lucky Export Indian**	**75Wp × 8=600Wp**	**2010 .G.C**	**Covered by dust**	**-The system gives light only** **- Uses Ac socket charger of the system**		
	3.Southern zone, Alagie Woreda	**Qilma Health post.**	**Lucky Export Indian**	**75Wp × 8=600Wp**	**2010 .G.C**	**Covered by dust**	**-The system gives light only** **- Uses Ac socket charger of the system**		
	4.Western zone, Tsegedie Woreda	**Mekeze Health post.**	**Lucky Export Indian**	**75Wp × 8 =600Wp**	**2010 .G.C**	**Covered by dust**	**-The system gives light only** **- Uses Ac socket charger of the system**		
	5.Central zone, Merebleke Woreda	**Adifetaw Health post**	**Lucky Export Indian**	**75Wp × 8=600Wp**	**2010 .G.C**	**Covered by dust**	**-The system gives light only** **- Uses Ac socket charger of the system** **<u>Measured performance</u>** **Local Time :5:00** **<u>Panel With dust cover</u>** **- Voc-18.4V** **- Isc-0.201A** **<u>Panel Without dust cover</u>** **Voc-19.0V** **Isc- 0.210A** **Battery status- 13.55V** **Charge controller**		

							reading- 12.82V Inverter Input =12.57V Inverter Output =0(zero)
	6.Central zone, Kola Tembein Woreda	Agimera Health post.	Lucky Export Indian	75Wp × 8=600Wp	2010 .G.C	Covered by dust	-The system gives light only - Uses Ac socket charger of the system
	7.Central zone, were Lekie Woreda	Golagn Health post.	Lucky Export Indian	75Wp × 8=600Wp	2010 .G.C	Covered by dust	-The system gives light only - Uses Ac socket charger of the system
	8.Central zone, Saesie Tseadamba Woreda	Edega rebu Health post.	Lucky Export Indian	75Wp × 8=600Wp	2010 .G.C	Covered by dust	-The system gives light only - Uses Ac socket charger of the system
	9.N.West zone, Tselemti Woreda	Fiyel Wuha Health post.	Lucky Export Indian	75Wp × 8=600Wp	2010 .G.C	Covered by dust	-The system gives light only - Uses Ac socket charger of the system
	10.N.West zone, asegede Tsimbela Woreda	Maibel Health post.	Lucky Export Indian	75Wp × 8=600Wp	2010 .G.C	Covered by dust	-The system gives light only - Uses Ac socket charger of the system
	11.Western zone, Raya Alamata Woreda	Tsetserah /Dogyat Health post.		450Wp	2016 .G.C	Covered by dust	-The system is operating -Light -Mobile charger Lp-solar Inverter-600V Charge controller-45A/12Vdc Vmp-35V Battery- 600AH/12VDc Local time:-7:30 Voc- 20.2V Isc-3.8A Battery status-13.7V

Appendix V.Primary Schools Solar photovoltaic systems installations site Investigation in Amhara region

No	Woreda	Name of Primary School	Installed by(Company)	Maximum Power(The system Type)	Year of Installed	Problems observed during investigation	Maintenance	The current status	Performance of panel & battery
2. A m	1. South Wollo, Dessie	Cherecha primary school.	"	"	" Not Installed at the sit		" No		

ha ra Re gio n	**zuria.**				**acc.to the Ref list.**	**measurement**
	2.North shoa,Mida Woreda Weremo	**Behera primary school 08/09/08 E.C**	"	"	" **-Gird already reached to the village** **-It was raining.** **- Covered by dust**	" **<u>Measured performance</u>** **- Local Time :10:02** **- Voc-13.03V** **- Isc-0.15A** **- Battery status- 12.98V** **- Charge controller reading- 13.12V**
	3.North shoa,Merhabetie Woreda	**Zeyita primary school 08/09/08 E.C**	**CAA-200Wp-DC System**	"	" **-The system is DC** **-But they connect an Inverter of 600VA to use computer, costs 7740Birr** **-Which is high inverter size for the panel?** **-The charge controller signal shows red thus it should disconnect the system from the charge controller & the battery & has to stay until the panel collects photon to show green light.** **-It was Cloudy time. Temperature 58OF**	" **<u>Measured performance</u>** **- Local Time :1:45** **- Voc-19.85V** **- Isc-0.22A** **- Battery status- 10.49V** **- Charge controller reading- 12.42V**
	4.South wollo,Woreda - Legehida	**Siba-primary school 08/09/08 E.C**	"	"	" **-The system is dismantled & moves to another block to new construction.** **-Thus, installed by themselves & only 2 bulbs gives light.** **-No mobile charger, The sockets are simply**	" **<u>Measured performance</u>** **- Local Time :11:03** **- Voc-15.21V** **- Isc-0.175A** **- Battery status- 13.8V** **- Charge controller reading- 13.52V**

					put in one place but it works.	
	5. South Wollo, Delanta Woreda.	Tsehay Mewcha primary school 08/09/08 E.C	CAA-200Wp-DC System	"	" - Covered by dust	" DC system Measured performance - Local Time :4:35 - Voc-20.56V - Isc-0.228A - Battery status- 13.58V - Charge controller reading- 13.86V
	6. North Wollo, Dawint Woreda.	Chet 2ndary & primary school 08/09/08 E.C	CAA-200Wp-DC System	"	" -The system is Ok, bulbs are not functional. Uses grid electric. -Shadow casts on panel. -Training is not provided.	" DC system Measured performance - Local Time :9:15 - Voc-20.43V - Isc-0.277A - Battery status- 13.58V - Charge controller reading- 13.86V
	7. Bahir Dar Admin.Bahir Dar Woreda. kebele 011.	Bahir dar poly technology 12/08/08 E.C	Zhiang – Holley International Int China (Agent – ACME ENGINEERING AND PLC, in Ethiopia.	"	" -The system is Ok, bulbs are not functional. Uses grid electric. -Shadow casts on panel. -Training is not provided. - Covered by dust	" DC system Measured performance - Local Time :12:30 Panel With dust cover Voc-13.33V -Isc-0.145A Panel after cleaning Voc-14.27V -Isc-0.165A -Battery status- 13.39V -Charge controller voltage-13.5V
	8. W.Gojjam, Gonji Woreda. Gonji kebele.	Gonji Primary school 12/08/08 E.C. Photographed-captured see folder Whole	- CAA-200Wp-DC System	"	" -The system is not functional.-The system is dismantled. -Now start using grid electric. - Covered by dust	" DC system Measured performance - Local Time :5:30 Voc-19.70V Isc-0.216A -Battery status- -0003.0V=0V -Charge controller voltage-00.0V

		system is dismantled.				
	9. W.Gojjam, Degadamot Woreda.	Arefa Debtera primary school Pictured No-1482-1492	CAA-200Wp-DC System	"	" All 13-lanterns are not working. - Covered by dust	" DC system **Measured performance** - Local Time :6:30 - Voc-18.83V - Isc-0.232A - Battery status- 13.65V - Charge controller reading- 13.88V
	10. E.Gojjam, Bibugn Woreda.	Debre Mechanis t/Mehal meda - primary school 30/08/08	CAA-200Wp-DC System	"	" All 13-lanterns are not working. -Needs more than 6 bulbs, TV, & Refrigerator application.	" DC system **Measured performance** - Local Time :6:05 - Voc-19.60V - Isc-0.198A - Battery status- 13.56V - Charge controller reading- 13.92V
	11Awi, Banja Woreda.	Sankit/Lideta primary school 01/09/08	CAA-200Wp-DC System	"	" All 13-lanterns are not working. -Needs more than 6 bulbs, TV, & Refrigerator application. -Shading casts on the panel. -Start using grid electric.	" DC system **Measured performance** - Local Time :7:15 - Voc-13.69V - Isc-0.150A - Battery status- 13.62V - Charge controller reading- 13.78V

Appendix VI A .Health post Solar photovoltaic systems installations site Investigation in Benshangul Gumuz region

No	Woreda	Name of Health post	Installed by(Company)	Maximum power (The system Type)	Year of Installed	Problems observed during investigation	Maintenance	The current status	Performance of panel & battery
1. Benshangul Gumuz	1.Bambasi woreda-	Sheh Bergush Health Post	Lucky Export Indian	75Wp × 8=600Wp	2010 .G.C	-The whole system is Not operating. -Inverter has to be	-The system is not operating - Uses Ac socket charger **Measured performance**		

Region		Photographed.				Changed, no output. - Need to use water Boiler. -175Wp SIBIR refrigerator were working for some $1^{1/2}$ year by the system but now totally ceased. -Covered by dust	- Local Time :4:45 - Voc-19.35V - Isc-0.234A - Battery status- 13.21V - Charge controller reading- 12.9V Inverter Input =13.02V Inverter Output =0(zero)
	2.Assosa worked-	Sherkole fundu Health Post Photographed.	Lucky Export Indian	75Wp × 8=600Wp	2010 .G.C	-One panel among the eight is cracked & it is out of use. - The battery status indicates that the wires, the charge controller & Inverters as well as the the bulbs & breakers are already out of function. i.e. –no photovoltaic (voltage & current comes from the panel to the system. -The whole system is Not operating. -Inverter has to be Changed, no output. - Need to use water Boiler. -175Wp SIBIR refrigerator were not working by the system.	-The system is not operating - Uses Ac socket charger Measured performance - Local Time :7:50 - Voc-18:89V - Isc-0.27A - Battery status- 13.55V - Charge controller reading- 12.64V Inverter Input =12.65V Inverter Output =0(zero)
	3.Wonbera woreda-	Muze Health Post	Lucky Export Indian	75Wp × 8=600Wp	2010 .G.C	-The whole system is Not operating. -Inverter has to be changed, no out put -Charge controller Has to be changed... - Need to use water Boiler. - Covered by dust	-The system is not operating - Uses Ac socket charger Measured performance - Local Time :5:20 - Voc-19.65V - Isc-0.263A - Battery status- 13.24V - Charge controller reading- 12.78V Inverter Input =13.00V Inverter Output =0(zero)
	4.Guba woreda-	Ayishmeshimesh Health Post	Lucky Export Indian	75Wp × 8=600Wp	2010 .G.C	-The whole system is not operating. -Inverter has to be changed, no out put -Charge controller has to be changed. - Need to use water Boiler. - Covered by dust	-The system is not operating - Uses Ac socket charger Measured performance - Local Time :8:15 - Voc-19.72V - Isc-0.276A - Battery status- 13.06V - Charge controller reading- 12.78V Inverter Input =12.98V Inverter Output =0(zero)
	5.Yasso woreda-	Timijo Mitie Health Post	Lucky Export Indian	75Wp × 8=600Wp	2010 .G.C	-The whole system is not operating. -Inverter has to be changed, no out put	-The system is not operating - Uses Ac socket charger of the system Measured performance

						-Charge controller has to be changed. -- Covered by dust	**- Local Time :3:45 - Voc-19.14V - Isc-0.228A - Battery status- 13.01V - Charge controller reading- 12.67V Inverter Input =12.69V Inverter Output =0(zero)**
	6.Kokeb woreda-	**Kokeb Health Post**	**Lucky Export Indian**	**75Wp × 8=600Wp**	**2010 .G.C**	**-The whole system is not operating. -Inverter has to be changed, no out put -Charge controller has to be changed. -- Covered by dust**	**-The system is not operating - Uses Ac socket charger of the system <u>Measured performance</u> - Local Time :6:25 - Voc-19.04V - Isc-0.214A - Battery status- 13.10V - Charge controller reading- 12.80V Inverter Input =12.71V Inverter Output =0(zero)**
	7.Ode Baldigilu woreda-	**Bediessa Health Post**	**Lucky Export Indian**	**75Wp × 8=600Wp**	**2010 .G.C**	**-The whole system is not operating. -Inverter has to be changed, no out put -Charge controller has to be changed. -- Covered by dust**	**- Uses Ac socket charger of the system <u>Measured performance</u> - Local Time :10:20 - Voc-19.22V - Isc-0.230A - Battery status- 13.31V - Charge controller reading- 12.88V Inverter Input =12.77V Inverter Output =0(zero)**