ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF MULTIDISCIPLINARY
CENTER OF RENEWABLE ENERGY

Performance Evaluation of Solar Photovoltaic Power Supply System the Case of Ethiopian Civil Aviation, Arbaminch site

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Energy Technology

By Mesfin Behailu

Thesis Advisor: Kamil Dino Adem (PhD)

December, 2021

CERTIFICATION

I, the undersigned, certify that I read and hear by recommend for the acceptance by Addis Ababa University, Addis Ababa Institute of Technology, Center of Renewable Energy a thesis entitled “Performance Evaluation of Solar Photovoltaic Power Supply System the Case of Ethiopian Civil Aviation, Arbaminch site”. This certificate used as a partial fulfillment of the requirement for the degree of Master of Science in energy technology.

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Date ____________________

DECLARATION

I, Mesfin Behailu, declare that this thesis is the result of my own work and that all source and material used for this thesis have been duly acknowledged. This thesis is submitted in partial fulfillment of the requirement for master's degree in energy technology at Addis Ababa University and to be made available at the university's library under the role of the library. I confidently declare that this thesis has not been submitted to any other institutions anywhere for the award of any academic degree, diploma, or certificate.

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PERFORMANCE EVALUTION OF SOLAR PHOTOVOLTICE POWER SULLPY SYSTEM THE CASE OF ETHIOPIAN CIVIL AVIATION

By

Mesfin Behailu

Approved by Board of Examiners

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Mesfin Behailu

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ACRONYMS AND ABBREVIATION

AC	Alternate Current
ADS-B	Automatic Dependent Surveillance-Broadcast
AGL	Air field Ground Lighting
AGM	Adsorbed Glass Mat
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
ATM	Air Traffic Management
ATS	Automatic Transfer Switch
AWG	American Wire Gage
BTS	Telecom Base Transmission Stations
GaAs	Gallium Arsenide
CdTe	Cadmium Telluride
CNS	Communication Navigation and Surveillance
CIGS	Copper Indium Gallium Selenide
CIS	Copper Indium Selenide
CSP	Concentrate Solar Power
DC	Direct Current
ECAA	Ethiopian Civil Aviation Authority
EREDPC	Ethiopian Rural Energy Development and Promotion Centre
ETC	Ethiopian Telecommunication Corporation
FAA	Federal Aviation Administration
FF	Fill Factor
GI	Global Irradiance in the array plane (W/m^2)
GIS	Geographic Information System
GSTC	Global irradiance at Standard Test Conditions (W/m^2)
GWh	Gega Watt hour
HERIC	Highly Efficient and Reliable Inverter Concept
HI	Global Irradiation in the plane of the array (kWh/m^2)
ICAO	The International Civil Aviation Organization
IEC	International Electrotechnical Commission
IEA	International Energy Agency

KVA	Kilo Volt Ampere
LCoE	Levelized Cost of Energy
MPPT	Maximum Power Point Tracking
NEC	National Electrical Code
NOCT	Nominal Operating Cell Temperature
VRLA	Valve regulated lead acid cells
NREL	National Renewable Energy Laboratory
NASA	National Aeronautics and Space
PLC	Programmable Logic Control
PR	Performance Ratio
PV	Photovoltaic
REF	Rural Electrification Fund
RMIS	Reference Meteorological Irradiance System
SOC	State-Of-Charge
STC	Standard Test Condition
SRRL	Solar Radiation Research Laboratory
UPS	Uninterruptable Power Supply
UV	Ultra Violet
VHF	Very High Frequency
VRLA	Valve Regulated Lead-Acid
VSAT	Very Small Aperture Terminal
Voc	Open circuit voltage
Isc	Short circuit current
Pm	Maximum power voltage
Imp	Maximum power current
YA	Array yield (h / d)
EA,d	Array output Energy per day (kWh)
Po	Nominal Power or module Power at STC (kW)
Euse	Useful Energy supplied by the system (kWh)
Yf	Final yield (h / d)
Euse, PV, day	Direct PV energy contribution to Euse (kWh)
FA	Fraction of total system input energy contributed by PV Array

Ein	Total system Input Energy (kWh)
η_{tot}	Over all PV plant efficiency
$\eta_{A,mean}$	Mean Array Efficiency
ES,A	Total Solar Energy on Array plane (kWh)
Y_r	Reference yield (h / d)
Lc	Array Capture Losses (h / d)
Ls	System Losses (h / d)

ABSTRACT

The research work targeted on performance evaluation of power generated from solar source in the case of Ethiopian Civil Aviation Authority, at a specific location of Arbaminch, southern Ethiopia. All the Authority electronic equipment that are used for communication, demands a reliable and stable source of electrical energy to function. Especially ground to air and air to ground radio voice and signal communication requires the highest level of power quality and security. Hence, the quest for obtaining this source of energy from different means is mandatory. The communication equipments are installed at remote areas, on top of mountains, to avoid communication obstacles and to attain quality signal strength, where there is no reliable conventional power supply. But today other forms of energy are being harnessed, so as to convert to electrical energy, solar energy. The solar Arrays of Arbaminch were faded, shaded with dust and tree as a result the PV arrays can’t deliver the required power in order to charge solar batteries, so that the batteries frequently discharged and eventually discarded before the service year. Twelve solar batteries each 2V/3266AH was purchased with more than one million birr and installed for Arbaminch solar site. The performance evaluation was made on panels, storage battery, solar charger, inverter and the connecting cable. The evaluation were done based on the literature review of similar plants, actual site observation, technical and meteorological data collected, then the measurement and the PVsyst software result were compared and discussed. PV power supply system performance losses were considered. Effect of temperature, shad and dust, improper sizing, tilt angle, and effect of irradiance were considered. Based on the name plate data of the component the total power generated from the PV Array were 2.72kW before loss and minimum energy 13kWh/day with inverter and charge controller power capacity of 3kW but only 0.56kW were supplied to the load and the rest wasted. The PV syst simulation results are indicator parameters whether the PV can charge the battery effectively or not. Based on other countries, the expected performance Ratio (PR) value were more than 0.7 but in the case of Arbaminch the Ratio achieved were below 0.5 and this shows that there is a minimum loss of 0.2 (20%). Moreover, the fill factor value obtained 0.62 but the expected value is 0.8 and more, this shows that there is a loss. The optimal power sources interfacing mechanism and the best performance up grading means in terms of technical and economical benefits was recommended.

Keywords: Performance Ratio, Degraded PV Modules, Fill Factor, Temperature, Shad.

CHAPTER ONE

INTRODUCTION

1.1. Background

Solar photovoltaic system or solar power system is one of renewable energy which uses PV cells to convert sunlight into electricity. The generated electricity can be used directly or stored, fed as an off grid or into the grid line while combined with other electricity sources. Solar PV system is a reliable and clean source of electricity that can be used for wide range of applications. ECAA established by regulations and rules which are approved by the country proclamation for controlling and regulating the civil air craft's, operators, air lines and air ports. ICAO and FAA are the licensing and grading organization based on internationally approved annexes and check lists. One of the major criteria for licensing based on annex 10 volume 1071 is the availability of reliable and stable electrical power supply and Doc 9988 presents the basket of measures that member States can consider for reducing CO_2 emissions and environmental pollution from civil aviation. One big opportunity for the member States to achieve their environmental and carbon emissions reduction objectives is through the use of renewable energy (ICAO 2017). The authority installed high raised antennas with voice and signal communication radios and related facilities, having a dedicated frequency band width rented from Ethio Telecom.

The communication equipments are installed on top of high mountains at different regions of the country to avoid any air craft communication barriers and obstacles. Air navigation equipments installed on top of nearby mountains. Due to the absence, frequent black out and voltage drops, the Authority does not relies on commercial power supply as a result besides the PV power two or more diesel generators and UPS were installed at each site. Generators demand continuous fuel supply and regular maintenance. Mostly stations are working 24 hours unmanned and diesel generators are not recommended. It is possible to say that PV power supply woks good than any other sources. This paper deals with the basic issues of PV power supply performance evaluation in the case of Ethiopian civil aviation, Arbaminch site. The loads are working with AC and DC supply, if AC loads are used, means the system requires inverter to convert. A photovoltaic power system mainly consists of a PV array, battery and elements for power conditioning.

The PV system performance depends on the local climate, orientation, inclination and the efficiency of the array, the battery, the inverter and charge controller performance.

Mostly the storage device is a battery, the battery bank stores energy when the power supplied by the modules exceeds the battery voltage and releases it back when the PV supply is insufficient.

A wide variety of tools exist for the analysis and dimensioning of both Grid connected and stand-alone photovoltaic systems. System designers and installers use simpler tools for optimal sizing the PV system. Software tools related to photovoltaic systems can be classified into pre-feasibility analysis, sizing, and simulation. PV syst is a dedicated PC software package for PV systems. The software were developed by the University of Geneva (HemanthBabu et al. 2019). After defining the location and loads, the user selects different components from a product database and then the software automatically calculate the size of the PV system (Ahmed 2014). Performance affecting parameters such as solar irradiance, ambient temperature, PV module temperature, array tilt angle were analyzed. In addition to these different yields, ratios, factors, module and system efficiencies and various losses were considered in this thesis.

1.2. Problem of the Statement

Ethiopian civil aviation authority installed radio, radar and navigational aid equipments that are used for air craft communication purpose, the electrical power were supplied mostly from solar arrays and diesel generators. More than two generators were installed at each site; most of these generators are unserviceable due to technical problems. The solar PV power supply system has also performance degrade. The performance problem of Arbaminch PV power supply are the PV arrays were fade (discolored), shaded with tree and dust, the Array tilt angle were below the standard, as a result the arrays were unable to provide the desired output power to charge the solar batteries. If batteries not sufficiently charged will never deliver the required amount of power to the load, then considered as dead and rejected with in short period before its life time. The Arbaminch, OPZV2, solar batteries are expected to work for more than 10 years but ECAA replaces it almost every 3 years, moreover the replaced batteries are purchased randomly, not based on design analysis. Recently twelve batteries were purchased with 50,000 Euro to replace Arbaminch site solar batteries. Secondly the generated total power from the solar were 2.72kW with loss and 2.2kW if loss considered, but only 0.56kW were supplied to the radios and the radar loads are not connected to the solar PV and this is loss of power. As per the interview made with the ECAA air navigation officer, most of the controversy with the air lines and air craft operators were made due to communication equipment failure or burn caused by electrical power fluctuation and interruption. Any communication interruption or failure, costs a series economical and human life loss.

1.3. Research objectives

1.3.1. General objective

The general objective of this study is to evaluate the performance of stand-alone PV solar power supply the case of Ethiopian civil aviation authority, Arbaminch site though identification of performance affecting factors, then recommending the performance upgrading means

1.3.2. Specific objective

- To examine the technical conditions of standalone PV solar power supply of ECAA, at Arbaminch site
- To show why PV power supply selected over the other sources
- To evaluate the effect of performance affecting factors using PV syst software
- To make comparison between the existing PV power of Arbaminch and the analytical values
- To identify performance upgrading means and its benefit for Arbaminch solar PV power

1.4. Research questions

- Why PV power supply selected?
- Does the collected solar meteorological and technical data's of the site enough to run the software for the desired output?
- Does the performance of the existing system compatible with the actual values?
- What are the technical failures affecting the efficiency of PV power supply of Arbaminch
- Is there a possibility to upgrade the effectiveness of the existing system?

1.5. Significance of the study

Reliable and stable power supply availability is a serious mandatory prerequisite for licensing any civil aviation organization. Starting from departure preparation, up to the arrival destination continuous ground to air craft and air craft to ground communication were performed via the communication equipments. Almost all communication equipments of the organization are installed, where there is no reliable commercial power supply, for this ECAA installed diesel generators and solar power supply. Analyzing, optimizing and upgrading the performance of solar PV power supply are a big deal. The application of optimized system avoids poor performance and minimize equipment and installation cost. ICAO amended carbon free aviation on document number 9988.This study is useful for further study on degradation and performance analysis of PV power supply. The authority invests lots of local and foreign currency on solar PV panels, charge controllers, inverters and batteries, while purchasing every two and three years and this thesis will help to identify the case for performance losses and reduces frequent purchase of solar materials. In this thesis the case of battery sulfating and performance degrade were identified and solution recommended. If the authority implement the recommendation of this thesis for each solar site, the efficiency of the solar PV, the batteries and related component will increase, as a result reduces solar equipment purchase, farther more the unused solar power can be supplied to some of the radar loads efficiently. This thesis provides optimal interface /connection approach of solar and generator power supply. There will be chance for redesigning including the radar loads and for reusing the newly installed OPZV batteries. The issue raised and the findings recommended are highly applicable for similar ECAA sites such as Gore, Gode, Mekelle and Diredawa solar PV plants.

1.6. Limitations

The limitation of this work, the PV component was out date and some of the technical specification was not available in the PV syst tool kit. If I-V curve tracer were available to measure the individual current and voltage, temperature, V_{oc}, I_{sc}, P_{max} of the PV module would be best. The annual meteorological data of the site were not proper to change it in to graphs. I was unable to take repeated measurement of solar power component while disconnecting since the system were active and frequent interruption were not allowed.

1.7. Organization of the research

The structure of this research was organized as follows: chapter one deals with the introduction of the research which includes background of the research, problem of statement, significance and objective of the research. Chapter two describes literature review. Chapter three discusses about the materials and methods that were used in the research include measured and recorded value analysis. On chapter four the PV syst output table and graphs with simulation results and discussion were done finally the last chapter describes about conclusions and recommendations for future implementation.

CHAPTER TWO

LITERATURE REVIEW

2.1. Energy and Development

The rapid population growth in the developing countries has kept the per capita energy demand and consumption high compared with that of the less population. Development without Industrialization is impossible and industries require reliable supply of energy. The developed countries average energy consumption per person is higher than that of the developing countries. In industrialized countries, people use four to five times more than the world average and nine times more than the average for the developing countries (B.Tech 2020), this shows that developed countries contributes the higher amount of air pollution to the rest of the world. The hidden agenda of the current and the next generation war and challenges targeted on energy demand and supply. Despite the energy potential available to our door the current implementation of solar energy is less than 5% globally. There are countries that are taking action to switch from using fossil fuels to solar. These countries form a pool called the G-20 countries and they have taken the global leadership position to adopt renewable resources of energy. The Government of Germany is one of the G-20 countries that switched its energy demand to approximately 38% to solar, and targeted to go completely stop dependency on nuclear power and replace it with solar by the year 2050. Similarly, many countries have an abundant solar potential and can take a lesson from Germany to switch their energy demand to solar (Khamisani 2017).

2.2. Renewable Energy and International Civil Aviation Organization (ICAO)

Education and awareness is very important indeed in aviation. There are many airline customers who have never thought that airports and flying as environmental problems. European aviation start charge of some fee aimed at reducing air pollution from this sector. The objective of this reduction is to reduce the impact of aviation on climate change, destruction of the ozone layer, acidification and ground level ozone formation (smog) (Whitelegg 2000). ICAO and its States of member are working together to develop Action Plans to Reduce Emissions of CO_2 from the International Aviation. Making effort to investigate for the institutional and financial resources necessary to develop and implement their action plans of environmental pollution.

Some States are also endeavor to establish or improve their national regulatory and policy frameworks which is necessary to encourage lower carbon technology deployment. The Organization has developed Doc 9988, Action Plans on CO_2 Emissions Reduction Activities Guidance to the States. As of Nov, 2017, 105 States representatives, which is more than 90.1 per cent of them, are willingly submitted their Action Plans. One of the important opportunities for member States to perform their CO_2 emissions reduction and environmental objectives is through the use of renewable energy. Resolution A39-2 shows the determination of State members to perform continuous leadership in limiting or reducing its emissions that contribute to global climate change (Whitelegg 2000). Immediate action is required to address the challenges of climate change, local air quality and aviation noise. Such effects are anticipated /expected/ to grow as the demand for air transportation grows. And hence, these will become fundamental constraints on the growth of air transportation in 21st century, if proper measures are not taken immediately (Golui, et al 2020). Aviation sectors are working on improving fuel efficiency by 2 % per annum and keeping the net carbon emissions from 2020 at the same level, as agreed at the 37th Assembly in 2010. Global aspiration /goal /for aviation in light of the 2°C and 1.5°C temperature goals of the Paris Agreement.

An ambitious work programmed for capacity building and assistance to States in the development and implementation of their action plans to reduce emissions. capacity-building and assistance for project implementation, in cooperation with the United Nations Development Program (UNDP), with financing from the Global Environment Facility (GEF).The International Energy Agency (IEA) stated that renewable power accounted for more than half of the world's additional electricity capacity in 2015 as the result of supportive government policies and sharp cost reductions. It is clear that civil aviation authority should serve as the agency that provides leadership and guidance role to all airports. The airport more over when considering renewable energy projects at airports, the civil aviation authority could participate in technical assistance programs' to build their internal capacity for evaluating opportunities and renewable energy resources appropriate to the specific conditions of the air ports. The ICAO-EU assistance project is supporting the design and construction of a solar PV facility to generate electricity in Mombasa, Kenya, the project includes a 500 kW solar project (ICAO, 2017).

Fig.2.1 and Fig.2.2 below shows exemplary experience how air ports are implementing policies related to Climate change and environmental protection. Almost all the roofs area is covered with poly crystalline PV arrays.

Fig.2.1. The first in African, airport Solar project, at George in South Africa (ICAO 2017)

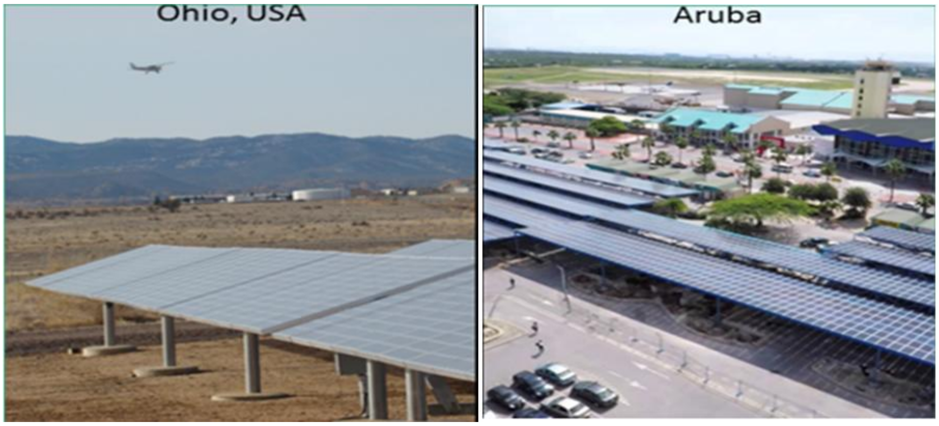


Fig.2.2. Examples of solar PV at different airports (ICAO 2017)

Improving the environmental performance of aviation is a big challenge that all relevant stakeholders are expected to take very seriously. ICAO in fulfilling its duties has two major goals targeted at limiting and reducing environmental effects;

1) The number of people significantly affected by the noise from aircraft and generators

2) The impact of aviation greenhouse gas emissions on the global climate (ICAO group 2019). In the case of civil aviation basket of measures has been identified, and out of this improved use of communication, navigation and surveillance/air transport management (CNS/ATM) to reduce fuel burn from generators is the basic objective which is similar to the objective of this thesis.

2.3. Electric power: Short Scenario of Ethiopia

The solar resource is virtually unlimited but the conversion of solar energy into usable form is inefficient and expensive to be commercially viable. But steps are being taken globally to make solar energy systems commercially, economically & technically viable. Furthermore, the reliable solar energy needs to be complemented by storage device to accommodate the daily and seasonal solar radiation variations. The geographical location of Ethiopia is quite favorable for implementation of solar power technologies. Since Ethiopia is located near to the equator, it has significant potential to explore solar energy. The annual average irradiance of the country is estimated to be 5.2 kWh/m^2/day with seasonal variations that range between the minimum of 4.5 kWh/m^2/day in July and a maximum of 5.9 kWh/m^2/day in March (A. D. Hailu and Kumsa 2020). It is observed that there is a huge renewable energy potential in Ethiopia which is underutilization, and can be used as a major energy resource for the rural community. Over half of the population is geographically located close to the electricity grid, but the actual interconnection rate is just nearly 25%, and the per capita domestic consumption of electricity is less than 100 kWh per Annam. Moreover, traditional biomass for household cooking accounts for 89% of total domestic energy consumption with poor conversion mechanisms, but this trend needs to be reversed since Ethiopia will continue to use up unsustainable levels of natural resources (due to its expanding population). Unless the country explores energy in new ways of generating (not only just electricity) and new means (technology) of using energy resources it will be risky.

The rural electrification fund (REF) under the Ethiopian Rural Energy Development and Promotion Centre (EREDPC) brought new opportunities for Renewable Energy Technologies (RETs) particularly solar PV and mini and micro hydro power development in the country. Knowing of the inherent limitations of grid-based rural electrification, the GoE has launched the Rural Electrification Fund to electrify off-grid rural areas. The two significant components of the REF initiatives are promotion and support to mini-grids and solar PV for institutions such as health and education. For a mini-off grid initial budget of about 29 million Euros were designed to finance about 180- 200 projects, with majority of renewable energy projects, i.e., mini and micro hydro, and solar PV. The project was targeted at providing electricity to 150,000 households, for inhabitants of 750,000.

The solar PV component, which had a budget of about 1.9 million Euros, was designed to support the installation for 1000 selected clinics and schools (Shanko and Efficiency 2015a). Ethiopia has abundant potential of renewable energy resources ,estimated to over 60,000 MW of electric power from hydroelectric, wind, solar and geothermal sources (Nigussie et al. 2017).

Based on the massive clean energy reserves, Ethiopia can become a cornerstone of the regional power market of the East Africa Power Pool (EAPP).A large scale of expansion and generation capacity is also driven by the GoE, targeted at to become a power export hub of East Africa, while also scaling-up its domestic power supply. Besides the domestic network expansion, in the coming years the exports of electricity to Sudan, Djibouti, and Kenya could boost the country's export revenue potential, and estimated to be as much as $500 million USD, per annum, by the end of the decade. In 2020, Ethiopia could achieve revenue from power export as much as it does from domestic sources. The generated revenue currency could be used for continued cross-subsidies demand of domestic consumers partly. Currently the country earns about 80 million dollars of revenue annually from selling about 100 MW of energy to Sudan and 80 MW of energy to Djibouti (Shanko, et al 2015). Eritrea is also at the verge to buy the hydropower from Ethiopia and in place Ethiopia, the land locked country will use port Aseb from Eritrea. If attention given to the country electricity deficiency, it would play a major role in improving the life quality of rural communities.

It is advisable to use integration of mini hydro, wind and solar power for rural community of Ethiopia. The huge bio mass capacity of the country left without conversion technology and highly abused while implementing in a traditional way of conversion. Performance evaluation and auditing is applicable to every resources based on criteria's. The Ethiopian civil aviation and Ethio telecom communication equipments are considered as a standalone off grid electrification and can use solar power comfortably since their loads are of minimum power rating and located far from the grid.

2.4. Ethiopian Civil Aviation and Telecom

Civil aviation and telecommunication has similarity that their antennas and communication apparatuses are mostly located on top of mountains, where there is no reliable commercial power, as a result both companies are using sola power.

The Ethio telecom sector is one of the fastest growing and largest PV market access perhaps in the whole of Eastern Africa. In 2005 a total installed capacity stood at around 3MWp which constituted over 70 % of the total market share in the country. In rural Ethiopia over 18,000 villages are known to exist. The program targeted to achieve 100% telecommunication coverage through (universal telecom access in the country by connecting all rural villages) so that the rural dwellers will get telephone communication access within a radius of about 5km. According to Ethio telecom report, about 80 % of the goal has been achieved so far. And in order to connect the rest 20 % of the villages and service centers, this would demand additional electric power of over 200 kWp (i.e. 8000 rural telephones x 30 WP) (Shanko, et al 2015).The off-grid locations ETC provides power to the rural base stations and wireless telephones with either solar PV or generators (Mandi 2010). Similarly in this paper the PV system that has been evaluated for its performance has a same application and characteristics for air craft communication antennas, radios, navigation equipment and radar stations.

2.5. Generating Solar Photovoltaic

The manufacturing process of silicon in a standard method includes the reduction of sand to metallurgical grade silicon, and purification to semiconductor grade silicon, then conversion to single crystal silicon wafers, finally processing to cells and encapsulation in to modules. In most cases semiconductor material used for solar cell production is silicon, and it has some advantages as it can be easily found in nature, does not pollute, does not harm the environment it can be handled and molded into any form by melt. First melt the sand with electric arc furnace to form crystalline silicon then add doping materials like boron or phosphorous to form crystalline ingot then slice it using diamond hack saw then screen /Contact/ the slice with Palladium, silver, nickel, or copper and finally coat with anti reflective material like titanium dioxide and silicon oxide.Fig.2.3. Shows the above description in picture form.

Silicon sand Crystalline silicon Monocrystalline ingot Silicon wafer Solar cell

Fig.2.3. Manufacturing process of a solar cell

The solar cells are constituted from two separate layers of semiconductors. The silicon solar cell layer with excess electrons is N-type and with excess hole is P-type. These two layers together form a PN junction by sandwiching together. When the sun irradiation hits the solar cell some of the photons of the irradiation absorbed by the solar cell. The absorbed photons will get energy greater than the energy gap between valence and conduction band of the semiconductor. As the electrons get energy from the absorbed irradiance photons, it becomes exited and jumps out and creates electron-hole pair. The electron near the p-n junction travelled to n-type side of the junction because of the electrostatic force. With these phenomena the Solar cells (the PN junction) generates electrical power by converting the absorbed solar radiation into direct current and the effect exhibit the photovoltaic effect. If there is a closed loop then the current flows through the circuit. The efficiency and performance evaluation of PV solar power system includes material fabrication, quality, installation, test and commissioning process. Fig.2.4. shows how DC electrical power generated from solar cell based on the above facts.

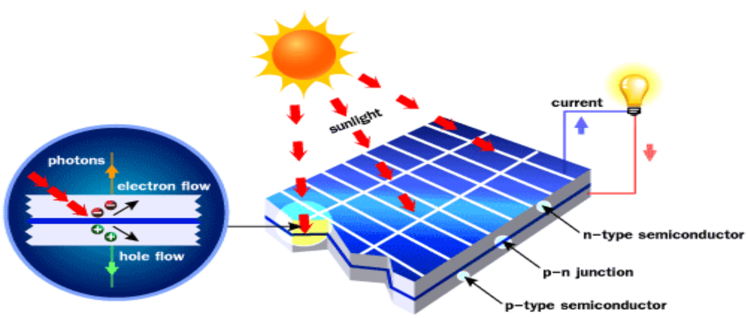


Fig.2.4. Solar cell generation of electricity (Rajput and Gwalior 2017)

2.6. Factors Affecting Photovoltaic (PV) Power Performance

Due to the low energy yield of PV systems, it is important to transmit the produced energy to the consumers with minimum losses as possible. Therefore, it is very necessary to reduce these PV systems losses by eliminating these factors that cause losses. Factors that cause losses in PV systems are environmental such as shade, dust, snow, temperature and the other losses are technical these are due to system components such as inverters, batteries and cables (Ekici and Kopru 2017). PV systems should be installed taking into account the major losses so that the energy must be consumed in local areas where it was produced with minimum losses as much as possible.

The later topics will show some losses occurred in a solar PV system. However, in order to capture the maximum amount of energy from the solar photovoltaic panel the following factors should also be taken in to account during and after the design of the system, total size of the solar PV array, the type of cell/module /array used, the orientation of the module/array, the angle from Horizontal, the solar irradiance , the wind and etc (Giday 2015)

2.6.1 Effete of PV Cells type

The main and the first factor of solar power generation is the efficiency of solar cell which is made of Crystalline Silicon cell abundantly. The performance and the efficiency of solar cell are not good yet, but the improvement chance of solar cell to produce better power is excellent. Secondly, there are many other affecting factors for the efficiency of PV system during sizing, installation and maintenance (Mehmood and Rashid 2019). The type of PV cell affects the performance of the PV system. Recently, there are many type of PV cells that have been manufactured and commercialized in market. Table.2.1 shows the summary of PV cell types. However, each type has its own strength and weakness. Nonetheless, customers still need to deal with their limitation rather than ignoring. For example, the polycrystalline modules experienced higher backside temperature compared to the mono crystalline modules while exposed to the same conditions. In addition, the performance and power yield capacity of mono crystalline module generation capacity around 5%-7% greater than that of polycrystalline under the same condition (Ahmed 2014). Fig.2.5. helps to identify the type, based on the color and arrangement of solar panels.

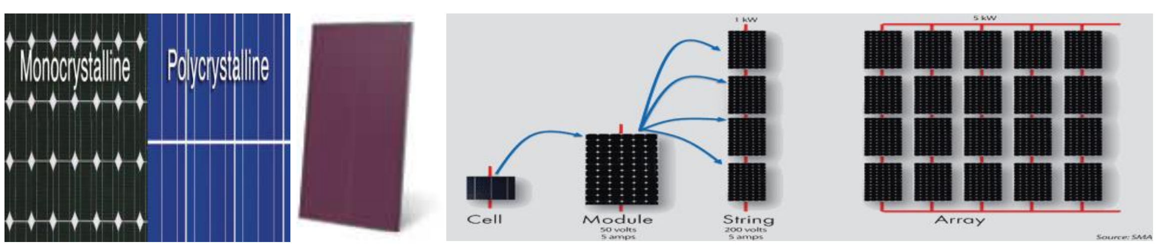


Fig.2.5. panel structure with mono, poly crystalline and thin film amorphous (E. A. Hailu 2020)

The Hybrid Silicon solar PV Module is a combination of mono crystalline silicon surrounded by thin layers of amorphous silicon it provides excellent sensitivity to lower light levels or indirect lights. The hybrid silicon solar PV modules has highest level of conversion efficiency of more than 17% (Syahirah et al. 2018).

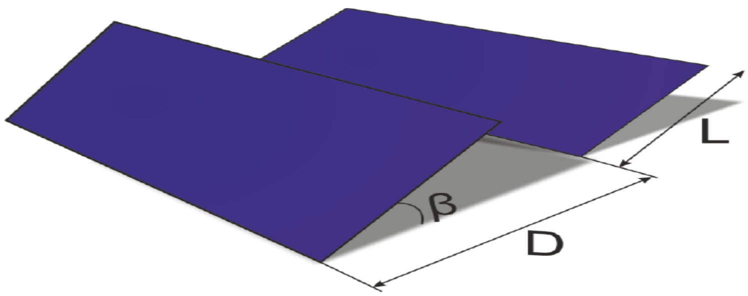
Table.2.1. PV cells performance Summary (Syahirah et al. 2018)

cell type	crystalline silicon		thin film		
	Mono crystalline	Polycrystalline	Cadmium Telluride	CIGS	Amorphous Silicon
efficiency	14-17.5%	13-15%	9-11%	10-12%	5-7%
hightemp. performance	Drop 10-15%	Drop 20%	Drop 0%	Drop 0%	Drop 0%
Optimal temp.	Perform well in cool weather, but poorly at extreme heat	Perform well in cool weather but poorly in extreme heat	Perform well in hot weather, even extreme heat	Perform well in hot weather, even extreme heat	Perform well in hot weather, even extreme heat
Cost	Most expensive crystalline silicon	Cheapest crystalline silicon	Cheaper than crystalline silicon, cost effective	Cheaper than crystalline silicon	Cheaper than crystalline silicon
additional details	Oldest solar cell technology and most widely used	Economical choice due to its cost to performance ratio	Cadmium is toxic, though very small amounts used	CIGS panels have posted impressive 20% efficiency	Requires a lot of roof space and can take longer to install than other cell

2.6.2. Effect of Shade and Dust

Shading is a problem for solar panels as it reduces the maximum power that can be generated. The most common cause of shade on a solar panels are; 1) Shade from neighboring trees and buildings in the vicinity, 2) typical cloudy weather and snow 3) shade from adjacent solar panels and 4) dust (Khamisani 2017). The dust particles on the modules disperse the sun rays falling on the PV panel surface, thereby reducing the amount of power produced and results a larger reduction in efficiency. The experimental result done shows that the PV module efficiency reduce from 7.2% to 5.6% during the dry period due to the absence of rain which is a cleaning agent of dust (Malvoni et al. 2017).The other author evaluated the PV module power output based on the dust accumulation effect and the outcome of the study shows that 50% of power output will be reduced if the PV modules are covered with dust. Moreover, the comparison of PV performance under clean and dusty conditions has been evaluated in several studies that the more accumulation of dust particles on PV panel increases the cell temperature that reduces the power generating performance of the cell. But, optimal angle of inclination and the presence of solar tracker have a big contribution to remove dust and to maximize the efficiency of PV output power.

Fig.2.6 shows the effect of row distance between modules or panels were represented as a spacing factor F, which is the ratio of minimal distance between neighboring rows D to the module length (width) L.



$$F = \frac{D}{L}$$

Fig.2.6. Distance between rows to avoid shade from adjacent solar panels (Fiedler 2015)

The spacing factor value above 2.5 doesn't matter how to put modules horizontal or vertical and usually the preference options is how lower installation costs for the customer. However, in case if the spacing during the installation is limited that the value of F should be reduced below roughly 2.4, it is preferable to put modules horizontally for its lower self-shading effect. According to (Fiedler 2015) the thin-film panels are less sensitivity to shading than crystalline types of cells, which allows to decrease the value of F from 2.5 to 2 with about the same losses.

2.6.3. Effect of temperature and irradiance

Like all other semiconductors photovoltaic cells are strongly influenced by temperature and it is temperature dependent. The higher the temperature can minimize voltage values while the low ambient and cell temperature lead to a higher $V_{oc.}$ The higher the voltage leads to the maximum power output and better efficiency. The curve from Fig.2.7 shows as temperature increases V_{OC} reduces.

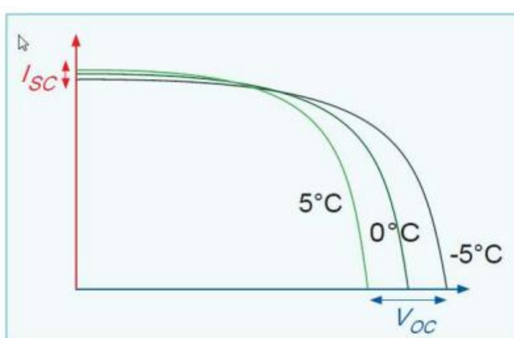


Fig.2.7. Showing as temperature reduce Voc increases (strathmore university 2018)

From Fig.2.8, the peak sun hour refers to the solar hour and the short circuit current or open circuit voltage decline with the reduction in the solar PV irradiance (World Bank 2018).

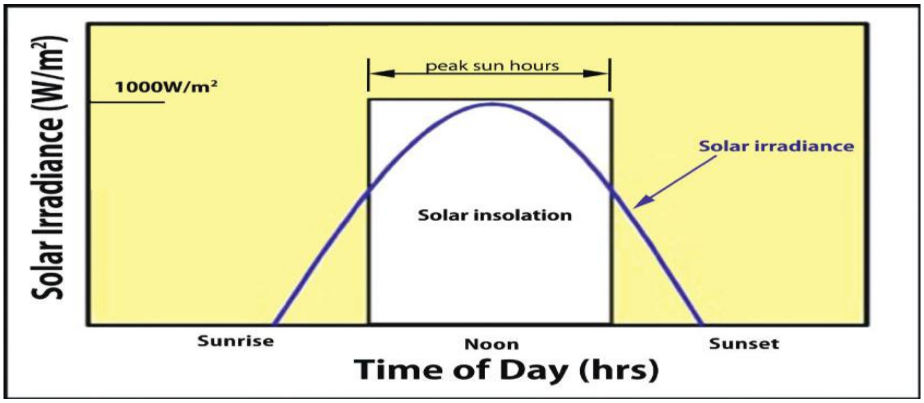


Fig.2.8. The peak sun hour and solar irradiance (World Bank 2018)

Literature survey shows that researchers practically found that the solar panel with the cooling system produces more power output than without cooling system. Based on the survey it can be concluded that the most effective coolant for the PV module is water rather than air (Chandrasiri and Lanka 2017). Fig.2.9 shows that as the strength of the irradiance increases current produced by the module increases. A fifty percent decrease in solar irradiation results a fifty percent decrease in I_{sc} but V_{oc} reduces only by a few volts (Hussin et al. 2018).

Besides the metrological conditions the solar irradiance path length through the atmosphere has a noticeable impact on the spectral irradiance distribution (Burgmans 2013). The longer the path (morning and evening) the bigger the impact of the atmosphere on the distribution of the spectral, and figured as the air mass (AM).The air mass is a measure for the length of the path that the irradiance takes through atmosphere to the earth’s surface. Thereby it is a measure of how much air the irradiance encounters before it reaches the solar module. When the sun is exactly overhead (at an angle of 90º) on the surface, then A.M is one, as the irradiance travels the angle and the beam length varies. The average value where taken as 1.5 at angle of 48.3^0.

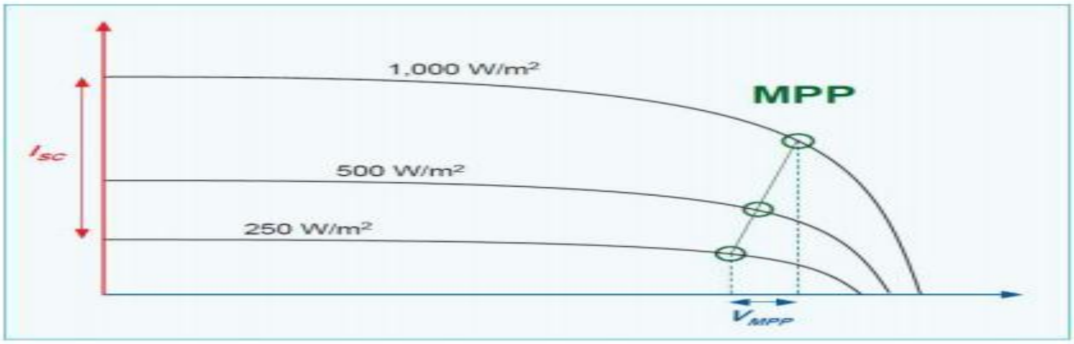


Fig.2.9. Current increases with the irradiance (strathmore university 2018)

Operating data of the PV panel are limited by the manufacturer, for instance the short circuit current (I_{sc}), the open circuit voltage (v_{oc}), the maximum power voltage (V_{mp}), the maximum power current (I_{mp}), the temperature coefficients at open circuit voltage and short circuit current and the nominal operating cell temperature (NOCT).The data's available at standard test condition (STC) where the cell temperature is $25C^0$ and the irradiance is $1000W/m^2$.This condition generates high power, nevertheless are rarely encountered in actual circumstance..

2.6.4. Effect of tilt angle and orientation

Possible to improve the output by installing PV modules on trackers to follow the sun from east to west during the day (for single-axis trackers), and from north to south during seasonal changes (dual-axis trackers).But this can be expensive, so it is not commonly practiced for most PV applications, rather mounted on a fixed position throughout the day. The highest efficiency of a PV module and peak power occurs when its surface is perpendicular to the sun's rays. As the rays deviate from perpendicular, more of the energy is reflected rather than absorbed by the modules. The orientation generally includes the direction of module facing and the tilt angle which is the angle between the base of the panel and the horizontal. Modules should be installed so that as much radiation as possible is collected. Ideally, the PV installations on the North of the equator perform optimally when oriented to the South and tilted at an angle 15 degrees higher than the site latitude (Bhatia, 2021). A costly tracking system not required, but fixed tilt angles of Latitude $\pm 15^o$ were recommended to increase energy production (Netsanet 2016).

2.6.5. Effect of module Degradation and Defects

From the physical structure solar panel of Fig.2.10 one can understand the components and safety measures.

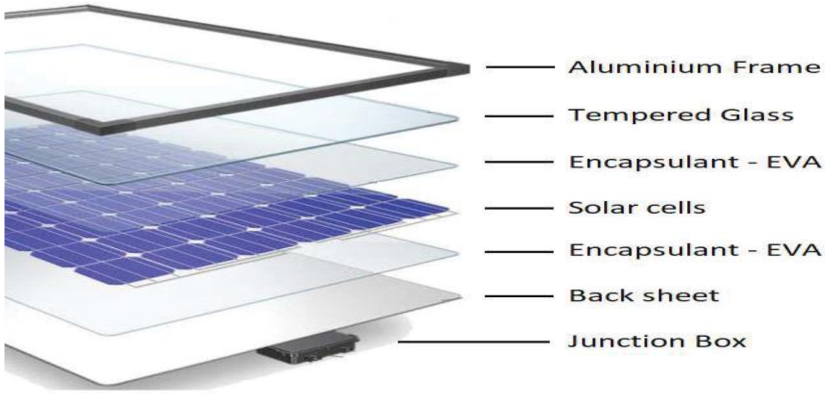


Fig.2.10. Practical structure of solar panel (E. A. Hailu 2020)

Degradation Rate (RD) is the gradual deterioration of component characteristics or of a system which affects its capacity to operate within the limits of acceptability criteria and mostly caused by the operating conditions. Degradation Rate can be calculated as: RD = initial PR− final PR initial PR is visual Degradation observed in field for all the modules under inspection using NREL visual inspection Checklist. Various modules Photographs were taken to observe the defects found in the modules (Ayompe 2011). Reports highlighted that modules in humid and hot climates show considerably higher degradation than those in moderate and desert climates. Delaminating and diode/j-box break causes are also more frequent in humid and hot climates than in other conditions. Internal circuitry discoloration and Encapsulates discoloration are the most common degradations type. From the analysis of module degradation found that modules discoloration and glass shattering are part of degradation in the field (see Fig.2.11 below). Beside such defects, dust accumulations found in most of the modules. Panel's discoloration is due to the presence of ultra-violet radiation due to high temperature. Glass shattering occurred due to poor handling of modules during transportation, installation and maintenance, but, dust accumulation is due to environmental factors, though performance upgrading means can be recovered by regular cleaning. As a performance analysis made on 1MW plant the annual degradation rate was found to be 0.98%/year (Umar et al. 2018).

(a) Broken glass Module (b) Decolorized Module (c) Module with dust

Fig.2.11. Solar panel degradation (Umar et al. 2018)

Under the real conditions measurements were carried out and it was found that degradation increases over time due to accumulation of dust on the surface of the dirty panel. After one month of exposure, a maximum degradation of 17.13% of the dirty module was noted than the clean module (Mohamed et al. 2018).

2.6.6. Effect of Battery temperature and Charge Controller

The charge controller (CC) switch off module/array current or to switch into a trickle charge mode should be allowed to vary according to the battery temperature. As the battery internal temperature reduces, the chemical reactions all precede slower. In order to fully charge the battery, the voltage must be more for a colder battery, so that the charging reaction can proceed to completion. The nominal final charge voltage at 25 C^o is about 14.5 V for a 12 V lead –acid battery. As the battery temperature drops, the voltage for charge must increase, and conversely as the battery heats up, the final charge voltage must be decreased. This phenomenon is handled by an option in many CC designs and called "temperature compensation" or TC (Tribhuvan 2015). In this thesis the discussion section describes some facts about the effect of temperature on the battery life in case of ECAA.

2.6.7. Effect of Array Mismatch

Mismatch losses are due to the variation of solar PV panels power output that are connected in series and parallel. The modules do not have same properties in their output from each other. Mismatching losses are a severe problem in solar PV modules and arrays because the execution is for the overall solar PV arrays and the effect distributed for the total array output, under worst conditions it is determined by the solar module with the lowest energy output (Ekici and Kopru 2017).

2.6.8. Effect of PV module connection and its parameters

The Electrical performance of Photovoltaic cells, modules and arrays are represented by their current-voltage (I-V) characteristic, at a given operating temperature and solar irradiance condition (Mehmood and Rashid 2019). PV modules produce current and voltage output that varies with solar irradiance and temperature. Key operating points are rated along the I-V curve by the manufacturer at specified test conditions labeled and affixed on the product (Hoang Anh 2021). Open-circuit voltage (V_{oc}) is the highest dc voltage on a given curves, and is the operating point with no load. V_{oc} corresponds to infinite resistance or open-circuit condition, with zero current and power output. Open-circuit voltage is independent of cell area. For crystalline silicon solar cells, the open-circuit voltage is on the order of 0.5 V to 0.6 V at 25°C. If PV modules have between 60 and 72 series connected cells then Voc ranges from about 34 V to 44 V. Currently typical PV modules have maximum rated power of 300W and more. The maximum power voltage (V_{mp}) is the corresponding operating voltage at P_{mp}, and is about 70% to 80% of the open-circuit voltage. The maximum power current (I_{mp}) is the operating current at P_{mp}, and mostly about 90% of the short-circuit current, I_{sc}. The operating point on the curve is determined by the electrical load according to Ohm's Law (Hoang Anh 2021).

The current produced by a cell is as a function of cell area, intensity of light, the PV material used and the surrounding temperature. The larger the surface area, the more light will enter to the cell and more current be produced. The typical value for I_{mp} of a mono crystalline cell is about 30 mA per square centimeter and for an Amorphous cell is about 9 mA/cm^2. The current and the voltage output from the PV modules depends on the connection pattern, for a high voltage output modules are connected in series where as for high current output modules are connected in parallel. Fig.2.12 shows the I-V curve pattern for series and parallel connection of PV modules.

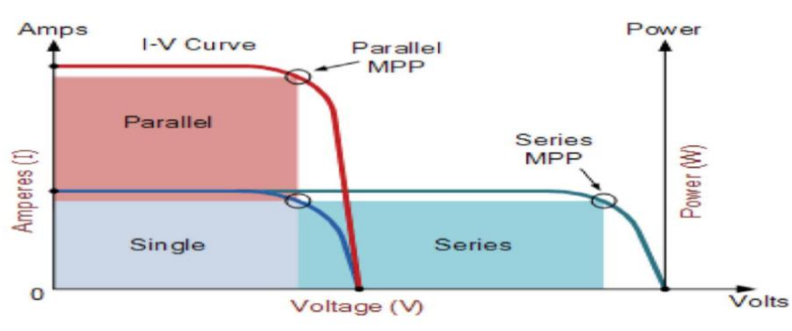


Fig.2.12. I-V curves represent the electrical Performance for PV modules (Bhatia, 2021)

2.6.9. Effect of system component selection

In a solar photovoltaic power supply system there are a number of components such as inverter, solar charge controller, and DC/AC cable and energy storage. Therefore PV panel is not the only factor affecting the performance of PV system. These components have different contribution to the solar output power. Therefore selection of the system component is mandatory in the preliminary design stage.Fig.2.13 shows the layout diagram of solar power component.

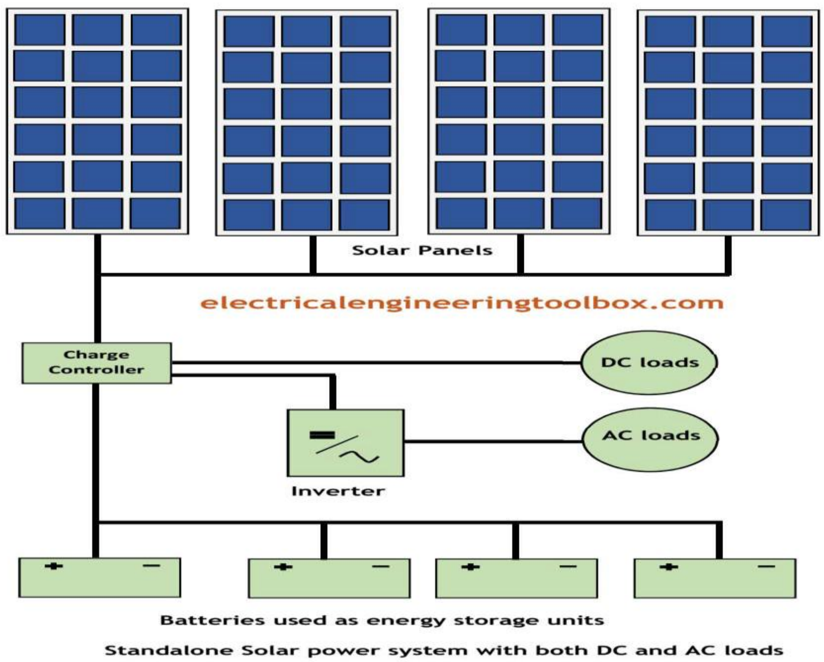


Fig.2.13. Stand Alone PV System (Electricalengineeringtoolbox.com)

Fig.2.14 shows that the inverter transformer contributes much of the inverter losses due to its core and copper windings losses therefore inverter without transformer or transformer less inverter is better.

Fig.2.14. 3-Phase 208/480V delta-wye 100KVA Transformer under test (Uri and Aribisala 2013)

Charge controllers and Inverters are power conditioners and selected from different angles such as size, weight, power, efficiency, and number of active reactive components, etc. The dc-dc converter topologies are a converter of boost type and it consists of three passive and one active component as shown in Fig.2.15 HERIC (Highly Efficient and Reliable Inverter Concept) inverter is one of solar PV inverter with transformer less topologies (Yuksel and Ozkop 2018).

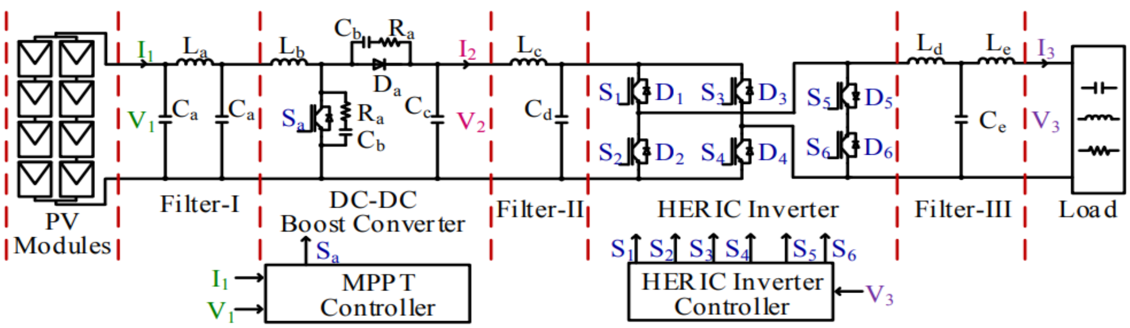


Fig.2.15.Schematic for standalone PV, MPPT with transformer less inverter (Yuksel et al.2018)

In PV system the other important component is battery charge controller which is much related to the lifetime of batteries. The consequences of an on and off charge controller in the PV system is defined as battery state-of-charge (SOC) and in any means the unused portion of the available PV array power needs to be regulated. The outcomes of studies shows that the battery SOC and solar PV energy is reduced by charge controller about 10-15% (Hussin et al. 2018).In some cases charge controllers are built in with inverter. The charge controller monitors charging and discharging condition of the battery. Controller prevents the battery from being over charged or highly discharged. The controller is important because over charging can lead to destruction of the battery and under charging or deep discharge reduces the life time of the battery. Another reason of using a charge controller it prevents reverse flow of current from battery to the system. There are two types of controllers in the market that are widely available these are 1) Pulse width Modulation (PWM) and 2) Maximum Power Point Tracking (MPPT).A pulse width modulation charge controller is set to match the input power to the battery irrespective of the power generated by the module. There is an inherent power loss were observed in this type of charger. The MPPT charge controllers enable to have better efficiencies and provides more power than PWM under similar condition, the main limitation of not operating with MPPT is its high price (Almere 2020). To select the size of charge controller one must know the voltage level and the maximum operating current of the system. For safety reasons it is a usual practice to oversize the controllers (Khamisani 2017). Similar topology can be adapted for charge controllers like transformer less inverters. DC/DC converters are charge controllers with better efficiency and less power loss, see Fig.2.15 again with detail reference of basic electronics. Fig.2.16 shows connection terminals and battery performance indicator LED lamps.

Fig.2.16 Solar battery charge controller (Solar and Development 2015)

Besides the above solar component selections, Solar batteries should be selected based on certain basic criteria's. The fluctuation of the solar output power forces customers to the usage of the storage system. Minimum size of storage bank is required to replace the PV integrated system without interruption. Storage technologies are available in the market, which is capable of smoothing out the unpredictable fluctuation in output energy. There are two conditions for characterizing the application of an energy storage device technology:

1) The amount of energy that can be stored in the device
2) The energy rate that can be transferred into or out of the storage device.

These factors depend mainly on the characteristic of the storage device itself. Now a days, there are many types of energy storage devices that have been commercialized including battery, super capacitor, flow battery and hydrogen storage (Manimekalai 2013). However always module voltage need to be higher than the battery voltage (Alayan, et al.2016).Battery stores chemical energy in DC voltage and mostly used during cloudy and night time and charged during the day time. The cell voltage for a battery is 2V which is the nominal voltage. The cell Voltage range is 1.85V to 2.40V, and a 12V battery has a number of 6 cells connected in series, where as 6V battery has 3 cells connected in series. Mainly the type of battery used in Solar PV systems is the Lead Acid type and it can be either flooded or maintenance free type. Capacity is a measure of the stored charge or energy that a battery can deliver under the required conditions. An ampere-hour (Ah) is the unit of battery energy capacity, and equals to the flow of one ampere for an hour. Capacity depends on several parameters like the battery temperature, discharge rate and cut-off voltage. To identify battery with capacity of 960Ah at 24h discharge rate [960Ah (C/24)], it means that 40A current can be discharged for 24hours and the cell voltage becomes 1.85V/cell. Based on the Lead-Acid Battery Chemistry, during discharge cycle current flow from the battery to the load, in this process the active materials are converted into lead sulfate (PbSO4) as shown by the following chemical reaction equation:

$$PbO_2 + 2H_2SO_4 + Pb \rightarrow 2PbSO_4 + H_2O \quad (2.1)$$

During battery charging the direction of chemical reaction is reversed as follows:

$$2PbSO_4 + 2H_2O \rightarrow PbO_2 + 2H_2SO_4 + Pb \quad (2.2)$$

When the battery is discharged the active materials PbO2 and Pb which are the positive and the negative plates respectively, combined with the sulfuric acid solution to form PbSO4 and H2O. The dilution of the electrolyte solution specific gravity for flooded type of battery (the mass ratio acid to water) can be measured with hydrometer (Tribhuvan 2015)**.**Sulfation is a normal process that occurs in lead acid batteries resulting from prolonged operations at partial state of battery charge. During sulfating lead sulfate crystals grow up on the positive plates, and reduce the chemically active area and thus capacity of the cell. However if a lead-acid battery is left at less than full state of charge for prolonged period (say days or weeks) the lead sulfate crystallizes on the plate and retards the conversion back to active material during recharge. During solar battery selection there are additional performance determining factors and characteristic curves, like

Ampere-Hour (Ah) or Capacity, State of Charge (SOC), depth of discharge (DOD), battery Autonomy and Self-discharge.

2.7. PV system performance upgrading mechanisms

The installed PV system performance upgrading mechanisms starts from identifying performance affecting factors and proceed to remove or reduce. One of the performances up grading mechanism is maintenance, such as PV inclination angle adjustment, dust and shade cleaning, cable louse tight, battery and inverter inspection with input output measurement and cleaning (Kobus, Klis, and Godlewski 2015).

2.7.1. Maintenance to solar batteries

Maintain electrolyte level optimal (use distilled water only to refill) for flood type. Maintain homogenous electrolyte (Avoid stratification).Maintain healthy electrode (Avoid sulfating). Very commonly check and maintain charge controller frequently, over discharge/undercharge damage or reduce battery life. Crystallized sulfating can covers the surface of electrode permanently if so you may need to replace it. Maintain equal cell voltage and use automatic charge controller

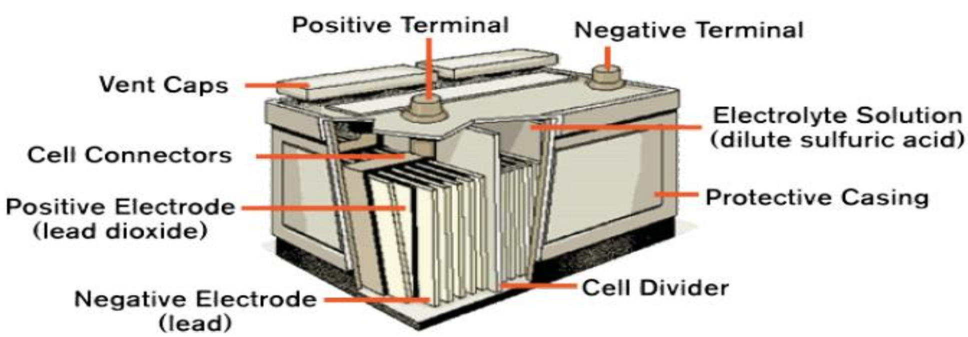


Fig.2.18. solar battery (Solar and Development 2015)

2.7.2. Implementation of PV module/cell cooling and cleaning techniques

The most simple, reliable and low cost method is to remove thermal energy (heat) from PV module using natural air circulation vent. The most known method for cooling PV modules is the Hybrid Photovoltaic/Thermal (PV/T) solar system. This method contains solar photovoltaic panels for the electric generation with a cooling system. The cooling agent of the cooling system is circulated around the heated PV modules in order to cool the solar cells. The thermal energy of heat can be absorbed by the water or air (cooling agent). Researchers found that, from the hybrid PV/T solar system with water cooling can be increased the solar cell power output by almost

50% (Sukarno et al. 2017). Designed hybrid PV/T solar system where water and air can be used as cooling agents and found that the water-based cooling system increases the solar cell efficiency than air-based cooling system, to decreases the PV module temperature, The water nozzle was mounted upper side of the PV module. The ambient temperature was sprayed to the PV water panel using PVC water pipe with little holes as figure2.19 shown. The PVC water tube was connected a flexible water hose with a water line. The cooling system automatically activates, when the PV solar module temperature is above 450C. The cooling system will automatically deactivate when the PV module temperature below 350C (Chandrasiri and Lanka 2017). The outcome of the researches shows that 50% of output power reduced if the PV panel is covered with dust for about six months (Syahirah et al. 2018).

Fig.2.19. PV arrays cooling and cleaning technique (Chandrasiri, et al 2017)

2.8. Simulation using PV syst software

The table below shows the main features of PV syst with its advantage and disadvantages.

Table.2.2.Main features of PV syst software tools for PV systems (Umar et al. 2018)

Software	Developer	Type of Analysis	Advantages	Disadvantages	Latest Version	Availably
PV syst	University of Geneva, Switzerland	Performance analysis; Financial estimation used for both grid-connected, stand-alone, pumping and DC-grid PV systems	Extensive meteorological and PV systems components databases; Has ability to identify the weaknesses of the system design through Loss Diagram; Results include several dozens of simulation	Program screen cannot be maximized to enable user to see all parameters if using a small monitor; Inability to handle shadow analysis; No single line diagram	PV syst version 6.70 released on 29th March, 2018 and 7.0 is currently a trial version	priced, 30-day trial version is available at http://www.pvsyst.com

2.8.1. Why PV syst software selected over the other

- There are several types of software that are used for evaluation of PV power supply like : Renewable Energy Technologies Screen (RET Screen), Hybrid Optimization Model for Electric renewable (HOMER), TRaNsient Systems Simulation (TRNSYS), INtegarted

Simulation Environment Language (INSEL),Photovoltaic F-Chart (PV F-Chart), National Renewable Energy Laboratory Solar Advisor Model (NREL SAM) and Environmental System Performance-renewable (ESP-r). Out of the these simulation software's, Homer, SAM and PV syst are found to be the most widely used and most effective tools because of their ability to carry out multiple analyses which makes it easier and faster to evaluate different system configurations more over pv syst selected for off grid.

- The investigated simulation software's were evaluated according to the following criteria's: their commercial and educational availability and cost, their working platform, their working capacities, their scope and output, their updatability. PV syst Version 6.7 were used in this project, the working platform is Windows 8, Windows 7, Vista, XP (older versions of Windows NT, 98, 95). 32-bits and 64-bits processors.MAC OSX and Linux with a virtual machine running window (Malvoni et al. 2017).

2.8.2. Sample results of PV syst software

In Germany a 100 kWp Si-poly photovoltaic system were simulated and Performance ratio (PR) of 80.0 % achieved, which is the annual average PR value. There is small variation in PR value on monthly basis, which can be observed from the graph or the monthly values can be tabulated in Table as well. For older installations the PR value were found to be lower due to the minimized energy yield with average mean of performance ratio as 0.65. But for new PV installations, a significant rise in PV system performance was achieved due to higher component efficiencies. The Switzerland PV system showed a higher PR (>0.80). It was observed that systems which are intensively monitored and equipped with better technology achieves higher PR values (SATSANGI 2013). In this paper the result section includes the performance ratio which is analyzed graphically and compared with standard values. Losses Occurred in The PV System due to low energy yield of the PV systems, it is essential to transmit the produced energy to the consumers with minimum losses as possible. Therefore, it is necessary to minimize these losses by eliminating the factors that cause losses occurred in PV systems. Factors that can cause losses in PV systems are environmental such as dust, shade, rain, snow, temperature and other losses due to system components such as cables, inverters and batteries. PV systems should be installed by taking losses into account and the produced energy should be consumed in local areas where it was produced as much as possible. Fig.2.20 shows some of the losses that occurred in a PV system (Ekici 2017).

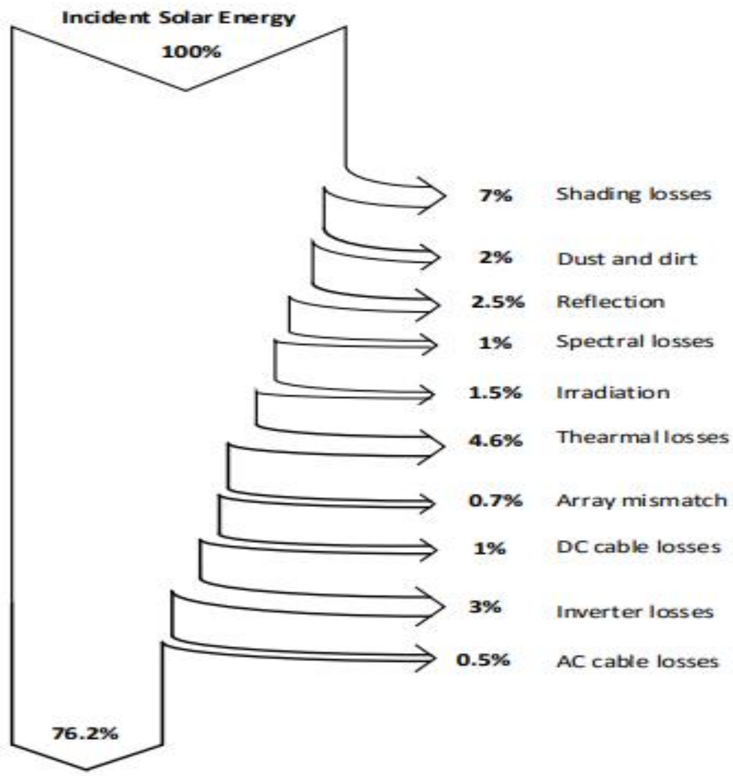


Fig.2.20.PVsystem losses and Energy injected in to the system (Ekici 2017)

2.9. Summary of Literature review

The performance evaluation methods were discussed in detail while considering different literatures. The basic review topic selection focused on similar situation with Arbaminch solar power .General and specific solar power performance affecting factors for standalone PV system components has been referred. So many published articles, journals, thesis and reports are available for a different country and location scenario. In the case of Ethiopia, it is possible to say that there is no best benchmark, published information on performance evaluation of the already installed stand alone or grid connected solar plant. The review method was aimed on the following main points:

1) The solar module type and performance affecting and upgrading factors.
2) The solar battery performance affecting factors, battery selection and care mechanisms.
3) The optimal and efficient solar power conditioning equipment selection advantage.

Both off Grid and Grid connected solar PV power plant of several power rating were cited, especially the technique (method) of evaluation based on performance parameters and ratios were considered. The PV syst software was used for the analysis purpose.

CHAPTER THREE
MATERIALS AND METHODS

3.1. Materials

The materials that are involved during the performance evaluation of the Arbaminch solar power system are: the solar PV modules, the solar batteries, the solar inverter, the solar charge controller, the connecting cables/wires, the loads, the generators and the digital multi meter. The materials were interconnected through the protective device to provide the desired output power to the load. There are connection boxes and input output terminals at each of the materials that were under test. Before and during performance test relevant name plate data’s considered and safety precaution were undertaken.

3.1.1. Measuring instrument

Test equipment for array, battery, inverter and charge controller performance measurement is divided into two categories: electrical, metrological measurements.

A) Pyranometer **B)multi meter** **C) clamp meter**

Fig.3.1. measuring equipments

Solar irradiance is the power per unit area received from the Sun in the form of electromagnetic radiation as measured in the wavelength range of the measuring instrument. The solar irradiance is measured in watt per square meter (W/m^2) in SI units. Irradiance and module temperature are required to evaluate the array performance data, regardless of the current and voltage measurement methods employed. Measurement kits designed for PV array measurements typically include irradiance and temperature sensors.

3.2. Method

The performance evaluation of the existing, installed solar PV power system of Ethiopian civil Aviation Authority site located at Arbaminch, by using PV syst software, some inputs data has to be provided such as hourly load profile, monthly solar radiation value for a PV system, the load power rating, the PV module type, the battery and the converter technical specification, etc. The solar radiation data of Arbaminch were taken from the PV syst software. Data for the performance affecting factors of the site were collected through actual visit and observation to each of the solar components at the site. In addition to the name plate data of the solar materials output and input measurement were considered as explained in subsequent section. Fig.3.2 show the steps for methodology from the technical data collection of each solar power components of Arbaminch site to the analysis stage.

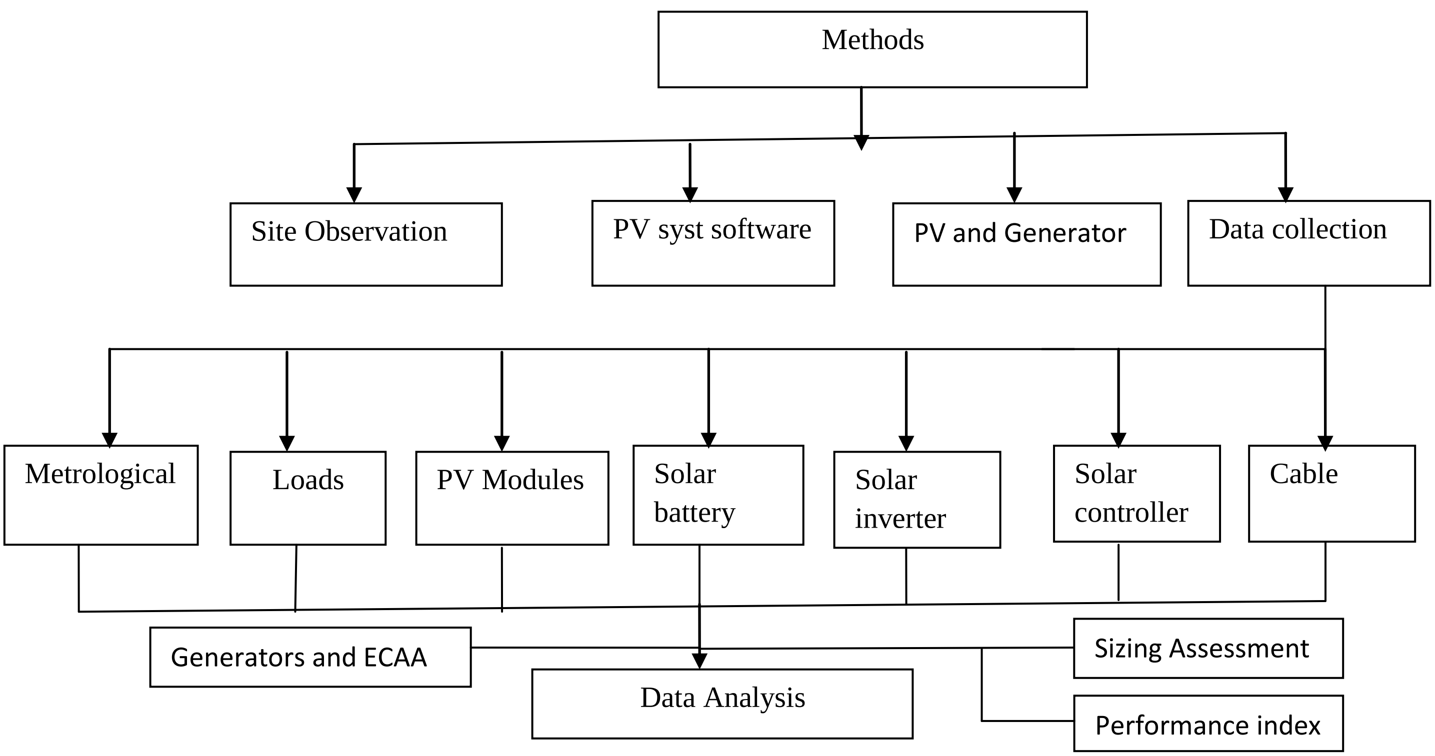


Fig.3.2. Steps for methodology

3.3. Site observation

Site selection has certain criteria's, such as shadow free, near to the power consuming load, good wind speed and dust free. To avoid shadowing the PV array is to be installed carefully at a proper location so that any part of the array or other obstructions free throughout the year. Care must be taken to reduce the cable losses by keeping loads and PV arrays as close as possible.

Ethiopia is a country located in the East of Africa lies between 3^o to 15^oN latitude and 33^o to 48^oE longitude. The Ethiopian civil Aviation authority installed PV array for electrical power supply at different regional air ports, this paper aimed at the Arbaminch radio and radar communication site and Arbaminch (6.0333° N, 37.5500° E) in the southern region of Ethiopia. There is a VSAT dish antenna to the left side of the PV arrays that transmit and receive voice message during the ground to air and air to ground radio communication, even there can be ground to ground or air to air communication possibly. The transmitter and receiver radios are at the back of the solar arrays inside the shade house. Battery room ventilation, maintenance or replacements of PV system components were necessary. The value of the panel tilt angle is below the standard, the nearby tree and dust shaded the array and reduces efficiency of panels, as a result the solar batteries were unable to be charged by the solar panels and the batteries become discharged frequently, farther more the battery room were out of ventilation that exposes battery for sulfation due to temperature rise. The exact location of the site is on top of mount shecha, between the town Arbaminch and Lake Chamo.

3.4. Photovoltaic systems software (PV syst)

PV syst is package software for the study, sizing and data analysis of complete PV systems. It works with grid-connected, stand-alone**,** pumping and DC-grid PV systems, and analyzes extensive PV systems component databases and meteorological data, including the general solar energy tools. This software is integrated to the needs of architects, engineers, researchers and for educational training. The software is a standard for PV system design and simulation worldwide. PV syst runs under any Windows operating system and Import irradiation data from PVGIS and NASA databases. PV syst has four main features which include Preliminary Design, Project Design, Databases, and Tools. It uses inputs like system components, plane orientation (with the tracking possibility of planes or shed support), PV arrays, inverters, battery bank etc. to perform the simulation. Results will be generated for several dozens of simulation variables that can be in monthly, daily or hourly values. A report can be printed for each simulation run. Based on real component prices a detailed economic evaluation can be performed, including investment and additional costs conditions. Off Grid PV system project is created in the project design menu by specifying the geographical location and the meteorological data of the particular location where the plant is planned or install, for this case Ethiopia, Arbaminch ECAA Radio communication site. In the second step, a data related to the plant design is specified.

That includes the orientation of the PV modules and available area of the installed PV plant and the power required to every loads, type of PV modules and type of inverter would be used form the PV syst database. Once all the required data is justified, successive variants were added and then simulation is carried out. In this thesis window7 were used. The database provide details of PV materials conditions that were shown in the result section.

3.5. Solar Power and Diesel Generator

The radio and radar communication equipments of ECAA are geographically highly fragmented areas and electrifying these places by using an extension of the national grid is not economically feasible. The decentralized approaches to electrify such remote locations by local supply can become competitive due to lower investments and maintenance costs compared to large-scale electrification by expanding interconnected grids. Different technological options are in practice, most commonly diesel generating sets and renewable energies. Diesel gen sets have problems with short durability, which is due to the fact that it works very inefficiently when running just at a short period of time. Moreover, frequent startup and shutdown procedures decrease its lifetime as well (Giday 2015).There is also a problem related to infrastructure, maintenance and covering running costs of the generator. Many rural schools and remote communication antennas and telecom base transmission stations (BTS) are far away from towns where the diesel fuel exists so that the regular supply with diesel fuel becomes a logistical and financial burden. The solution for the above problem is to use renewable energy such as solar photovoltaic and wind energy as an energy source for remote areas. However, among the main problems of standalone system of solar as well as wind energy is the fluctuation of the energy supply, resulting in intermittent delivery of power and causing risk if a continuous supply is mandatory. In a simple way this can be avoided by the use of standalone hybrid systems. A hybrid power system can be stated as a combination of different but complementary energy source system based on renewable energy or mixed renewable energy supply. Besides the reliability issue Table.3.1. Shows, the effect of GHG emission reduction for the hybrid system, similarly the currency expanse reduces in case of Ethiopia and the efficiency of the system appreciated.

Table.3.1. Greenhouse gas emission Comparison for gen set and hybrid

Pollutant	Solar PV only system Emission Kg/y	PV/Gen/battery Hybrid system Emission Kg/yr	Diesel Generator only system Emission Kg/y
Carbon dioxide	Null	584	36,450
Carbon monoxide	Null	1.44	90
Unburned hydrocarbons	Null	0.16	9.97
Particulate matter	Null	0.109	6.78
Sulfur dioxide	Null	1.17	73.2
Nitrogen oxides	Null	12.9	803

The solar power and the generator can be optimized based on the load requirement and accordingly the size of gen set and battery bank. In order to get more efficiency of the gen set, it is economical to operate the gen set more than 85 % of its capacity. When the load is less than 85 % of the gen set rating then the excess power shall be used to charge the battery bank and this could contribute much to the efficiency of the system. Depending on the type of loads such as must not off the whole day or not, the system operation can involve either load sharing or battery charging. When the load on the gen set falls below a chosen value, the system will switch to inverter operation. The PV-diesel hybrid system is projected to produce electricity at a cost of 0.12 USD/kWh. This cost is significantly lower than the 0.26 USD/kWh paid to the diesel operator, as well as lower than 0.13 USD/kWh paid to the utility grid (Alayan, Navarro, and Fiedler 2016).

3.6. Data collection and Analysis

The meteorological and technical data's were collected and analyzed from the site. The solar irradiance, the temperature, the wind speed were meteorological and the Solar PV array, the battery bank, the power conditioning system (Charge controller, Inverter), different types of loads, Cables and Protection (safety) devices are technical data.

3.6.1. Meteorological data of irrad., temp., and wind

The meteorological (metro) data are the solar resources that vary from place to place. Solar radiation is generally higher in regions near the equator**.** Factors that affect the amount of solar radiation on particular area Include latitude, prevalence of cloudy periods, humidity, atmospheric clarity, and seasonal variations. Long-term statistical weather data from meteorological stations is usually provided in the form of monthly averaged data for insolation on a horizontal surface, and includes daily variations of this insolation. The irradiance monthly data from Arbaminch were provided in tabular form for a quantitative analysis.

It enables to identify which month has the higher and the lower solar irradiance, temperature, wind and other similar meteorological parameters that affect the solar power performance.

Table.3.2 Arbaminch daily irrad. temp. and wind data (PV syst result)

Month	Global Irrad. kWh/m^2.day	Diffuse kWh/m^2.day	Temp (^{o}C)	Wind Velocity (m/s)
January	5.68	1.85	18.9	2.20
February	5.91	2.03	20.0	2.29
March	5.48	2.70	20.4	2.40
April	5.14	2.72	19.6	2.20
May	5.26	2.63	19.4	2.39
June	4.72	2.43	18.1	2.39
July	4.02	2.75	17.8	2.30
August	5.13	2.47	18.0	2.40
September	5.02	2.77	19.4	2.49
October	5.15	2.46	20.1	2.40
November	5.75	2.09	18.8	2.10
December	5.73	1.71	19.9	2.10
Average	**5.24**	**2.39**	**20.1**	**2.3**

3.6.2. The sun path diagram of the site

The horizon profile is only suited for shading objects that are located sufficiently far from your PV system, so that the shadings may be considered global on the array. The Horizon Profile is a curve that is defined by set of (Height, Azimuth) points. The Far Shadings operate in an ON/OFF mode: i.e. at a given time, the sun is there or not on the field. When the sun is behind the horizon the beam component becomes null. The effect on the diffuse component has to under consideration. For this the values (Height, Azimuth set of points) have to be recorded on-site using a compass and clinometers (measuring the height and angles), photographs, Sun Eye" device etc can also be used. The length of the sun hour from sun rise to sun set, from Fig.3.3 the irradiance is maximum at the azimuth angle of 0^0 at solar noon (12h).

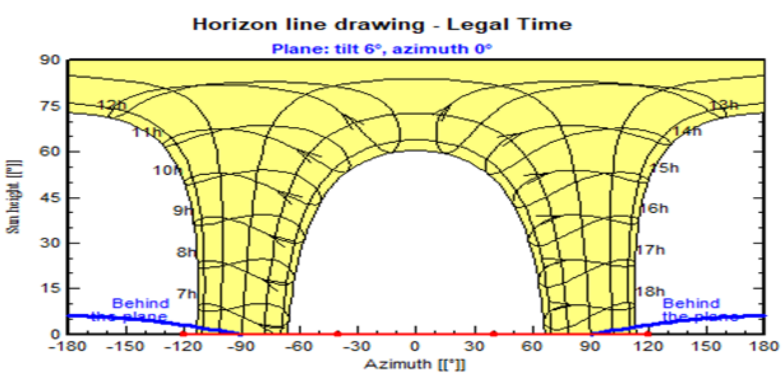


Fig.3.3 sun path diagram for Arbaminch

3.6.3. Load profile of Arbaminch Radio and Radar site

Load profile is an important step in the data collection and analysis of an off-grid system. It includes every device that uses electrical power as a source. The data contains the power rating and the working hours of each load per day. The PV panel size, quantity and connection, the battery capacity, voltage and quantity, the inverter and charge controller rating, the cable size and connecters are all determined based on the load profile analysis. In order to maximize the performance of the solar power system, the power losses across the load should be reduced.

Fig.3.4. Radar and Radio loads inside a rack at ECAA

From Fig.3.4 left side rack contains the radar, ADS-B, equipment with interfacing parts and the right side rack contains main with stand by transmitters and receiver radio, the switch, the modem and the mux. Table.3.3. Shows the radio loads of Arbaminch, but Radar loads were not connected to PV supply.

Table.3.3 Loads connected to solar PV power (Radios)

No	Qty	VHF Radios Load	power (watt)	time (hour)	Energy (wh)
1	1	Transmitter main & standby	400	24	9600
2	1	Reviser main & standby	50	24	1200
3	1	VSAT RFT SW	19	24	456
4	1	VSAT Modem	25	24	600
5	1	VSAT MMUX	10	24	240
6	2	Obstruction light	2x30	14	840
		Reserve(10% of radio total)	------	------	-----
		Total for radio	564 w		12936 wh

3.6.4. Solar modules of Arbaminch site

In order to capture the maximum amount of energy from the solar photovoltaic panel the following factors should be considered during and after the data collection of the PV module: total size of solar PV array and type of module /array used, orientation of the module/array and the angle from Horizontal, anything that shades the array and result module degrade with array mismatch, local minimum and maximum ambient temperature and etc. Table 3.4 refers to name plate data of the existing solar modules at Arbaminch ECAA site.

Table.3.4. Existing PV module Name plat data at STC

Parameter	Value
Peak power(P_{mpp})	68W
System voltage(V_{sys})	24V
Voltage at peak power(V_{mpp})	16.5V
Current at peak power(I_{mpp})	3.9A
Open circuit voltage(V_{oc})	21.3V
Short circuit current(I_{sc})	4.4A
Operating temperature	-40 to +85C
Number of modules	40

Fig.3.5 Shows the major parts of standalone PV solar power system single wire, wiring diagram of Arbaminch station. Similar concepts can be applicable for the rest of ECAA solar power sites.

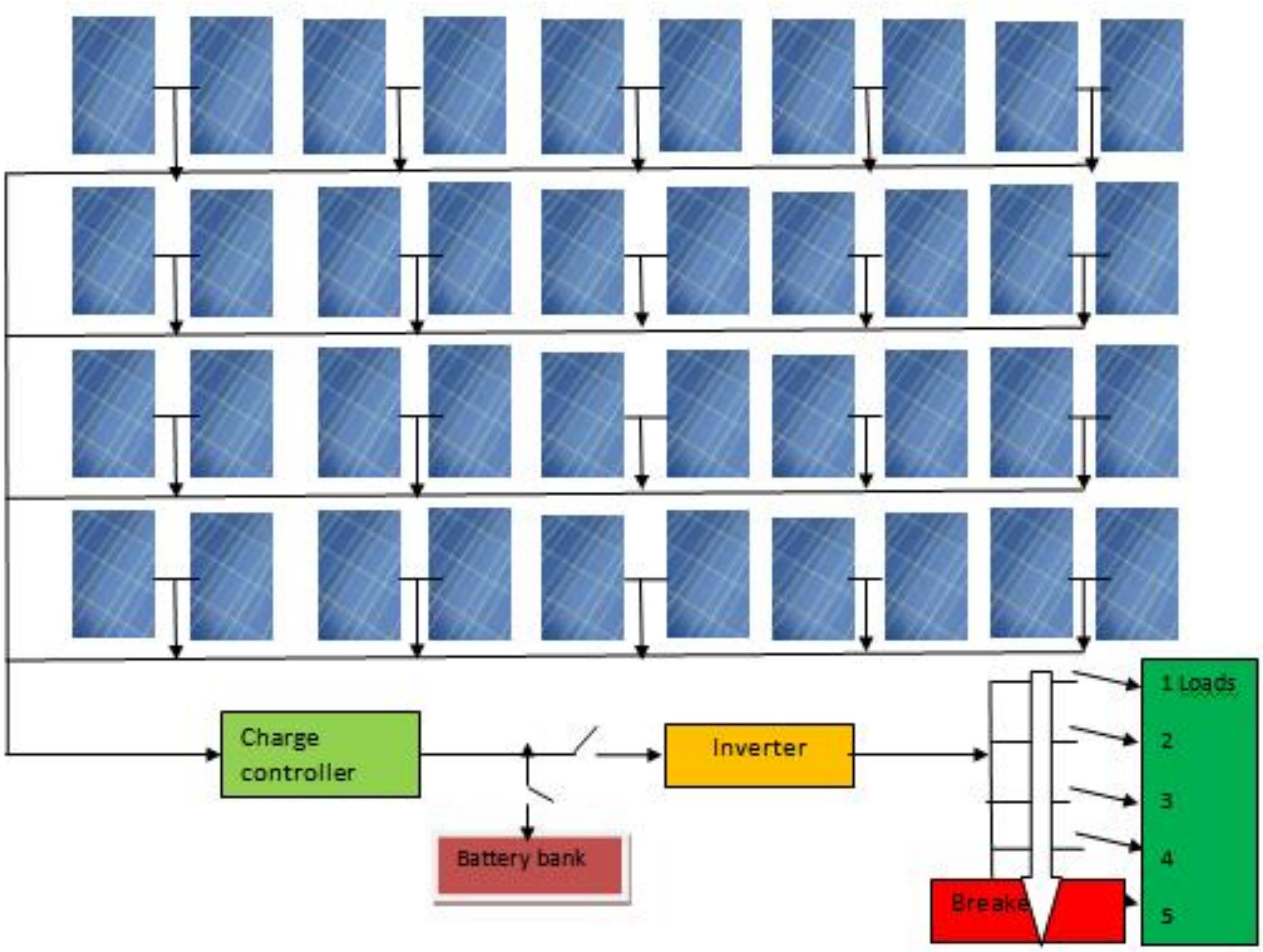


Fig.3.5. Solar power wiring diagram of Arbaminch site

From the above Figure, there are four rows (string) of panels each having ten modules and a total number of forty. Two consecutive modules are connected in series in order to provide the system voltage requirement that is 24V. In actual case the single module voltage (V_{mp}) were 16.5V and the sum of the two modules voltage were V_{mp}= 33V, and this voltage supplied to the charge controller. Then the charge controller acts like a buck DC to DC converter to reduce the voltage from 33V to the system voltage, 24V DC.

3.6.5. Solar Batteries of Arbaminch solar power sit

The authority installed the lead acid sealed batteries with Gel cell at different site. At Arbaminch site there are recently installed solar batteries at back side of the PV arrays, inside the battery room. The batteries are expected to be charged from the solar PV arrays. Table.3.5 below shows the name plate data of the existing solar batteries of Arbaminch radio radar station with basic technical details.

Table.3.5.The newly installed solar batteries technical data of Arbaminch

battery parameters	specification
Type of battery	OPZV
Quantity	12
System voltage	24V
Battery capacity	3266AH
Battery voltage	2V
Depth of discharge (DOD)	80%
Battery life cycle	1200 cycle
Discharge/charge rate or C – rate	1.85V @25^0C
Self discharge	<2% per month
Temperature range	-40 to +70^0C
Designed Floating Life	>20 years at 25℃
Weight of each battery	200kg

The Valve Regulated Lead Acid (VRLA) Battery is a type of rechargeable battery, they are also commonly known as sealed batteries or maintenance-free batteries. All of the energy storage devices show different characteristics, deployment status and applications. However, the state-of-charge (SOC) of the battery is important factors. The previous technology only limits the voltage in order to protect the battery from deep discharge without considering overcharge. This is why the excessively high or too low SOC can cause permanent battery damage. Some of the issues related to the battery such as the deep discharge reduce the battery life cycle. Moreover the lifetime of the battery depends on the operating conditions such as the depth of discharge cycles, the current, the electrolyte concentration, the cell voltage, the low state of charge duration and temperature. To protect batteries from overcharging or under charging situations, several types of charge controllers were introduced.

Fig.3.6. twelve newly installed OPZV valve regulated lead acid solar batteries at Arbaminch

From Fig.3.6, the battery types were OPzV battery constructed from single cell. The designation OPzV2-3266 stands for,“ OPzV” means stationary valve- regulated Sealed Gel battery,“3266”means the battery capacity is 3266 AH and number 2 represents the nominal voltage is 2V.

3.6.6. Solar inverter of Arbaminch site

The rating, the quality and the efficiency of solar inverter were analyzed in this paper that ECAA installed. Fig.3.7 shows photograph of the existing Arbaminch solar inverter.

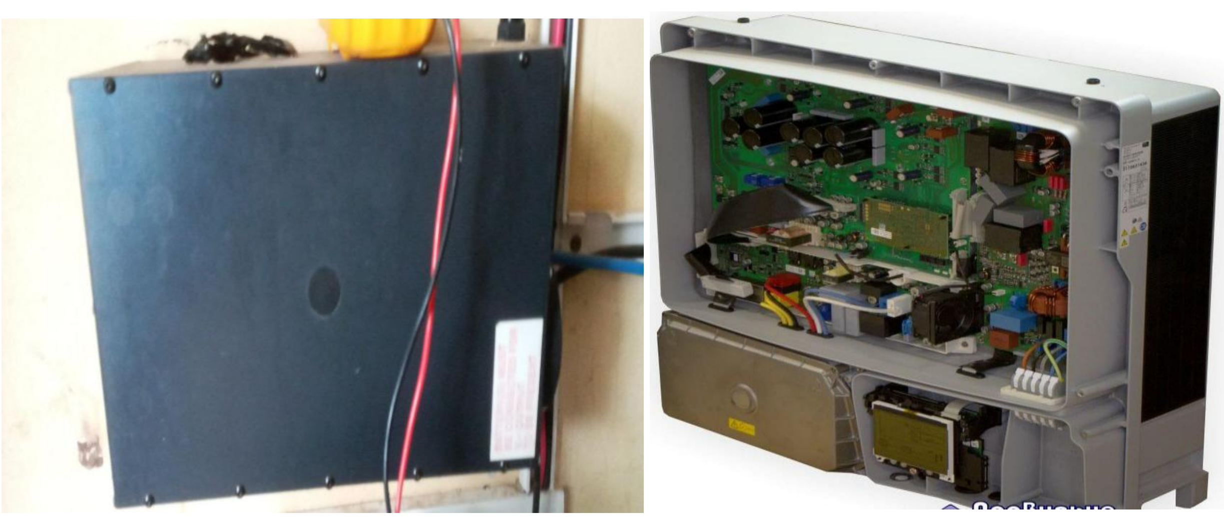


Fig.3.7. the external and internal part of Solar inverter of Arbaminch site

Table.3.6. technical solar inverter data of Arbanimch station

Inverter mode		Charger Mode	
Input voltage(DC)	24V	Input voltage(AC)	230V
Input current(DC)	112A	Input current(AC)	19A
Output voltage(AC)	220V	Frequency	50Hz
Output current(AC)	10A	Output voltage(DC)	24V
Frequency	50Hz	Output current(DC)	30A

It is necessary to convert the direct current into alternating current and adjust the voltage levels to match the load voltage demand. Conversion shall be achieved using an electronic Inverter and the associated control and protection devices.

There are of several types of inverters, the Arbaminch inverters are with built in charge controller as the name plate data shown in the above table.3.6.

3.6.7. Solar charge controller

The charge controller is the central equipment of a DC coupled PV stand-alone system. Its main feature was stated as: overcharge protection by automated disconnection, reverse current protection, controlled continuous recharging and deep discharge protection.Fig.3.8 shows actual photograph of ECAA solar power site charge controller.

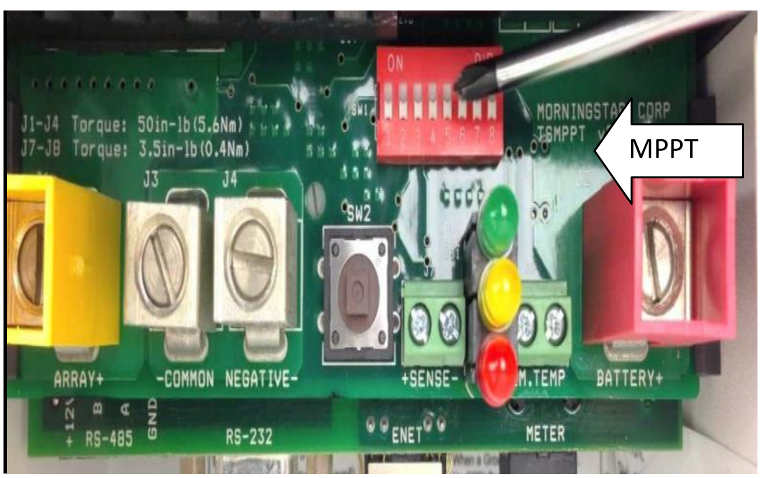


Fig.3.8. Solar charge controller with MPPT technology

Table.3.7 shows the name plat data of Arbaminch solar charge controller, the controller were connected with the system while supplying to the load and were not allowed to open or disconnect it for measurement purpose.

Table.3.7. Arbaminch Solar Charge controller technical data

Model	Steca power Tarom 2140
Input voltage(DC)	12/24V
Module Current (I_{max})	140A
Load current (I_{max})	70A
Reconnection voltage	>50%
Deep discharge protection	>30%
End of charge voltage	27.4V
Boost/Equalization voltage	29V
Over and under voltage shutdown	30V and 21V
Ambient temperature	-10^{0}C up to + 60^{0}C

The Pulse Width Modulation (PWM) is one of the design types. By electronically controlling the high speed switching or regulation elements, the PWM controller breaks the array current into pulses at some constant mode of frequency, and varies the width and time of the pulses to regulate the amount of charge flowing into the battery.

Maximum power Point tracking (MPPT) controllers are special type of these controllers which employ pulse-width modulation (PMW) techniques to switch from one dc voltage level to another dc voltage level at a different level, similar to that of switching dc power supply. The MPPT employs a feedback loop sensing algorithm to sense the output power and change the output voltage accordingly until the output power is maximized. The sizing and selection of charge controllers and system controls in PV systems involves several factors consideration, depending on the complexity and control options required.

3.6.8. Cables and wires installed at Arbaminch site

Mostly neglected PV solar system component design parameter that affects performance is DC/AC Cable Thickness sizing. At the planning and design stage of the photovoltaic system the size and length of cable needs deep insight consideration. The cable resistance per meter matters considerably. The home appliances are working with 220V and this is considerably higher than the usual solar PV system DC output voltages of 12V, 24V and 48V. This low voltage of the PV system causes high current. The presence of high resistance shows losses in the wiring system, for instance let a cable has resistance of 0.012 Ohms/meter having a cross section area of 1.5 mm^2 and length of 20 meters wire will offer a resistance 20 x 0.012 = 0.24 ohms. According to Ohm's law V = IxR, then the voltage drop as a current of 10A pass though it is 2.4V.So at charge controller end 2.4V will be less than from solar panel voltage. The allowable voltage drop for 220V is 2.5 % and for a 24V system that may not be acceptable. Array connecter cables should be heavy duty, so that the gauge of the wire should be selected as to keep resistive losses less than 1%. For reliability, splicing of wires from the load to the array output cable should be with crimp-on connectors with resin filled heat shrink tubing or equivalent, to ensure long lasting but not at Arbaminch. Wiring attached to support structures with wire ties of nylon type. PVC conduit was used for the outside array installation but output wiring to loads, to power conditioners and to batteries were out of the standards. The mounting frames and array were grounded using substantial copper wire. The DC cables are colored type wires like red for positive, black for negative and green for ground. DC power requires larger wire sizes than for AC power due to the high current. The array wiring were sized and selected to withstand the elevated temperatures. Wiring and sizing were detailed in NEC 690 under the standards and safety section of this thesis. Table.3.8 shows the size and the rating of electrical cables and used at Arbaminch site.

Table.3.8. Cable /wire Sizes at Arbaminch solar power station

	DC cables/wire						AC cables/wire	
	Between modules	Between panels	From panels to box	Array to controller	controller to battery	controller to inverter	inverter to AC board	AC board to loads
American wire Gage	14AWG	12AWG	10 AWG	4 AWG	4 AWG	4 AWG	-----	-----
Equivalent	2.1mm^2	3.3mm^2	5.3mm^2	21.1mm^2	21.1mm^2	21.1mm^2	4mm^2	2.5mm^2
I (max)	15A	20A	30A	95A	95A	95A	25A	16A

For Arbaminch radio station a 10 Ampere current is expected to flow and one can calculate the acceptable voltage drop level across the cable. If we have 20 meter long cable having 6 squire mm cross sectional area and resistance .003 Ohm per meter. Total resistance for 20 meter length would be 0.06 Ohms. So for 10 Ampere the total voltage drop is 10×0.06 or 0.6V.The PV arrays should be near to the loads to avoid cable power loss of I^2R.Similarly the Arbaminch ECAA solar arrays are very near to the appliance/loads approximately7 to 10 meters.

3.6.9. Generators for electrical power supply at Arbaminch site

Several KVA rated generators were found at different ECAA radio, navigation and radar communication stations at least two generators at a majority site. Fig. 3.9 shows photo graph picture of the two 15 KVA rated generators, 5,000 litter external fuel tanker and window type air conditioner that are found at Arbaminch radio and radar site. There is unserviceable and discarded old generator at Arbaminch beacon site, located to the left side of the air port next to the banana farming.

Fig.3.9. Two diesel generators at Arbaminch radio/radar station

However there are two generators at Arbaminch sit, currently only one Generator is working and the other has mechanical problem, even the third generator currently under process to be transported to the site. The nearby town “shecha” expanded towards the site and ECAA purchased transformer, electric pole and wire with labor fee from Ethiopian electric utility (EEU) and connected at the nearby utility grid. Question may rise that since the commercial power available, what is the reason for installing a number of generators and solar power, the case is the utility power were unstable (fluctuate) and out frequently.

As shown on the above figure, the air conditioner were installed on top of the generator exhaust, when the generator run the air conditioner start to suck the dirty suit and the heat from the generator exhaust and release in to the radio room, and this will shorten the life of the air conditioner and unable to cool the room properly. Even the radio and radar components may fail due to the rise in temperature. More over the air conditioner may run the whole day since it senses the room temperature to be on and off. The comparison analysis test interims of technical, economical and service quality can be of poor performance..The cases for the failure of generators estimated to be lack of maintenance, miss use, quality of generators and the likes. One can imagine easily the total number of generators, assuming that there are more than 18 local and international domestic air ports. This thesis focuses primarily on solar power supply but not on generator supply and ECAA communication equipments are not only VHF radios and radars but there are also Navigational Aid (NAV AID) equipments that were supplied electrical power from generators. The PV power supply terminology that was discussed in this thesis can be extended to supply the NAV AID equipments of the Authority.

3.7. System performance parameters /indices

The solar PV systems performance can be different according to their different locations and configurations. The performance of PV systems can readily compare by evaluating their performance indices like array yield, final yield, reference yield, performance ratio, capture losses and system efficiencies etc. These indices provide primary information about the performance of the PV system that the system is working properly or not. After calculating the indices, the performance of PV systems can be compare under various operating conditions.

The characteristics of the solar PV resources at any site are critical to system design. The performance of the solar PV power output influenced by various parameters. Besides the cell temperature and solar radiation

$$P_{pv}(T_a, G_{tot}) = \mu_{pv}(T_a, G_{tot}) S_{pv}\, G_{tot} \qquad (3.1)$$

T_a=the ambient temperature

G_{tot} =the total solar radiation

n_{pv} = Efficiency of PV panel

S_{pv} = Surface of PV panel

The solar panel efficiency can be prescribed from the cell temperature T_C

$$\mu_{pv}(T_c, G_{tot}) = \mu_{manuf}\,(1 - \beta_{pv}(T_c - T_r)) \qquad (3.2)$$

n_{manuf}= the manufacturer nominal efficiency□□

$ß_{PV}$= the temperature coefficient

T_r = Reference temperature

In addition, the cell temperature is calculated

$$T_c = T_a + (T_{NOCT} - T_{a,NOCT})\frac{G_{tot}}{G_{NOCT}} \qquad (3.3)$$

Where $T_{a\ NOCT}$ is the ambient temperature and T_{NOCT} is the nominal operating cell temperature and G_{NOCT} is solar radiation under the Nominal Operating Cell Temperature (NOCT) Condition. The Solar isolation is the measure of cumulative irradiance received at a specific area over a period of time. It is a measure of energy rather than power, and expressed in kilowatt-hours ($kWh/m^2/day$).

3.7.1. Several types of yield

Array yield (Y_A) is the energy output from a PV array (EA, DC) over the installed array's rated output power (P_o).Y_A, represents the number of hours per day that the array would need to operate at its rated power output to contribute the same daily array energy to the system as monitored**.** Reference Yield is represented with a notation, Yr and it is the total amount of energy produced in the system when the system is said to be running at nominal efficiencies. This nominal efficiency of the system is predefined by the array manufacturers at STC and can be seen on the name plate details. It is mathematically represented as the ratio of total horizontal irradiance, H_t to the global irradiance G_o at STC, in $kWh/m^2/day$. Final yield (Y_F) is the daily, monthly or annually net energy output (E_{AC}) of the entire PV plant, which supplied by the array per kW of installed PV array (P_o) at standard test conditions (STC) of 1000 W/m^2 solar irradiance and 25°C cell temperature. This is a characteristic parameter which allows comparing similar PV systems in a particular geographical location.

3.7.2. Performance ratio (PR)

It is the ratio of the final yield and the array yield. The PR is dimensionless quantity that represents the total losses in the system when converting from rated DC power to AC power output. PR values are useful for determining if the system is operating as expected and for identifying the occurrence of problems due to inverter operation (faults/failures, maximum power tracking), trip of the circuit-breaker, solder-bond failures in module junction boxes, inoperative trackers, diode failures, snow, shading , soiling, degradation of PV system, or other failures. The higher PR value suggests that the plant working for better rated power whereas the lower indicates production losses due to design or technical problem. Normally PR value varies within the range of 0.6 to 0.9 due to the variable weather conditions. In cool climates, where the temperature is low, it can exceed even 0.9.

3.7.3. Capacity utilization factor (CUF)

It is the ratio of the real amount of generated energy by the PV plant for 24 h per day for a year, to the maximum possible output energy from it for a year under the rated power. Capacity utilization factor usually expressed in percentage.

$$\mathrm{CUF}(\%) = \frac{\mathrm{YF}}{24\mathrm{X}365} = \frac{\mathrm{EAC}}{\mathrm{Po\,X}24\mathrm{X}365}\mathrm{X}100 \qquad (3.4)$$

CUF is a site dependent parameter. It varies according to the solar radiation received and the number of clear sunny days experienced by the PV plant's site. It affected significantly according to the type of module used. Besides the various technical losses SPV power plant generates less energy compare to rated energy due to variable climatic conditions and losses in Balance of System (BOS) Components.

3.7.4. Array capture losses (L_C)

Based on the measured data different losses can be calculated. L_C occur due to array operation and can represent as $L_C = Y_R - Y_A$. There are two types of capture losses, Thermal capture loss (L_{CT}) and Miscellaneous capture loss (L_{CM}). Thermal capture loss occurs when PV module operates beyond 25 °C. Thermal capture loss is the difference between reference yield and temperature corrected referenced yield, $Y_{CT} = Y_R - Y_R$ corr. Y_R corr. is temperature corrected reference yield which is given on the data sheet. Miscellaneous capture loss (L_{CM}), these losses occur due to wiring and cables losses, losses due to diodes, shading, mismatched losses between modules and strings, soiling and maximum power point tracking losses, $L_{CM} = L_C - L_{CT}$

3.7.5. System losses (L_S)

System losses contains all the losses of energy, that occur during the conversion of the array generated DC energy into the usable AC energy. These losses caused by inverter, conduction and other passive circuit element losses, $L_S = Y_A - Y_F$.

3.7.6. Efficiencies

Array efficiency (η_A) defined by the ratio of output energy to input energy. Actually, it represents the energy conversion efficiency of the PV array (Malvoni et al. 2017).

$$\eta\mathrm{A}(\%) = \frac{\mathrm{EA}}{\mathrm{Aa} * \mathrm{HT}}\mathrm{X}100 \qquad (3.5)$$

EA, Total generated DC energy per day (kWh). A_a , Overall array area (m^2). HT, In-plane irradiance per day (kWh/m^2). Inverter efficiency (η inv) can be formulated as the ratio of AC power generated by the inverter (PAC) to the DC power (PDC) generated by the PV array system. The instantaneous inverter efficiency given by.

$$\eta inv(\%) = \frac{PAC}{PDC} X100 \quad (3.6)$$

System efficiency (ηsys) , defined as the ratio of output total AC energy to the total input energy

$$\eta sys(\%) = \frac{EAC}{Aa * Ht} X100 \quad (3.7)$$

Finally the system efficiency represented as the array efficiency divided by inverter efficiency

$$\eta sys \% = \eta A / \eta inv \quad (3.8)$$

The following coefficient of table3.9 are used for the formula stated above, specially the performance ratio (PR) = 0.5 is the determinant value, for a normal PV plant it should be above 0.8, therefore the value 0.5 shows there is a loss at Arbaminch PV site.

Table.3.9 Normalized performance coefficient (PV syst result for Arbaminch)

	Yr kWh/m².day	Lu	Yu kWh/kWp/d	Lc	Ya kWh/kWp/d	Ls	Yf kWh/kWp/d	PR
Period	5.08	0.001	6.03	2.144	2.93	0.408	2.53	0.498

3.7.7. Fill Factor

Fill factor is one of the determining factor for performance, solar PV panel with value of fill factor 0.7 and greater were consider to be efficient. In this thesis the maximum values are stated based on the data collected from Arbaminch site.

$$P_{max} = I_{mp} V_{mp} \quad (3.9)$$

$$P_{Ideal} = I_{SC} V_{OC} \quad (3.10)$$

$$F.F = \frac{Pmax}{Pideal} = \frac{ImpVmp}{IscVoc} \quad (3.11)$$

Short-circuit current (I_{sc}) is the highest current on an I-V curve. I_{sc} refers to a zero resistance condition, at zero voltage and power output. Short-circuit current is directly corresponds to solar irradiance, and rated values are used to size circuit conductors and over current devices of the PV materials. Because PV panels are inherently current-limited, for testing PV modules can be short-circuited using an appropriately rated shorting device. Individual solar cells can produce a value of I_{sc}, with ratings of 8 A and higher depending upon the panel area. The maximum power point (P_{mp}) of a solar PV device is the operating point and the product of current and voltage is at a maximum value. The maximum power point is at “knee” of the I-V curve, and represents the highest operating efficiency point for a PV device under a given conditions of cell temperature and solar irradiance.

3.8. The existing solar power system design assessment

For a Solar PV system, there are proper procedure to maintain the performance the reliability and the efficiency of the whole system. Improper component sizing at design stage were one of the reason for performance loss, therefore PV module, solar battery, inverter, charge controller and cable sizing are important factors. Additionally there are several parameters to design an efficient system, like site location, tilt and azimuth angle, Irradiation level and Load calculation. After load energy demand calculation PV panel and battery sizing were the next step then the cable and power conditioning element rating.

3.8.1. The existing solar array and load compatibility check

For series connection of PV panels that the current is similar and minimum and it is high for parallel connection since the total current is the sum of the individual panels current. Regarding the voltage in parallel connection it is the voltage of one of the parallel panel or string and the value is minimum, whereas for series connection it is additive and high. The PV module power (P_{pv}) calculated as:

$$P_{pv} = \frac{E_L}{\eta_{BoS}\ K_{loss}\ I} X\ PSI \qquad (3.12)$$

Where EL is the average daily load energy consumption kWh/day, I is the average solar radiation incident over the site in $kWh/m^2/day$, PSI is the peak solar intensity at the earth's surface (1000 W/m^2), ηBoS is efficiency of balance of the system and $Kloss$ is a factor determined by the different losses such as: module temperature losses, circuit losses, dust, etc. The efficiency of balance of the system is given by $\eta_{Inverterlosses}$ and $\eta_{Wirelosses}$ which is 90% and 92% respectively. Hence η_{BoS}=$\eta_{Inverte\ losses}$×$\eta_{Wiring\ losses}$=0.90×0.92=0.828

The derating factor is thus $KLoss$=$ftemp$×$fman$×$fdirt$==0.937×0.97×0.95=0.863

$$P_{pv} = \frac{E_L}{\eta_{BoS}\ K_{loss}\ I} X\ PSI = \frac{12.936kWh \times 1000w/m^2}{0.828 \times\ 0.863 \times 5.24kWh/m^2} = 3454.84W$$

Number of modules $= \frac{3454.84W}{68W} = 50.8 = 51$, then 52 modules with power rating of 68W each were required to supply the daily energy demand of the Arbanimch radios, but the number of modules at Arbaminch were only 40, this implies that the existing solar modules are unable not only to charge the installed batteries but also to supply the radio loads.

3.8.2. The existing solar battery and load compatibility check

The second important component of the stand alone PV system during design and sizing is solar battery. The battery type recommended for using in solar PV system is deep cycle battery. These batteries are specifically designed to be discharged to low energy level and rapidly recharged and discharged day after day for years. The battery should be large enough to store sufficient energy to operate the loads at night and cloudy days. To find out the size of battery, follow the following procedure.

1. Calculate total Watt-hours per day used by appliances.
2. η_{BoS} Is efficiency of balance of the system and it's taken as 0.85
3. DoD is Depth of Discharge and it's taken as 0.6
4. The nominal battery voltage.
5. Days of autonomy (the number of days needed the system to operate when there is no power produced by the PV panel) then to get the required Ampere-hour capacity of deep-cycle battery.

$$\text{Battery Capacity (Ah)} = \frac{\text{Total Watt-hours per day used by appliances}}{(\eta_{BoS} \text{ x DoD x nominal battery voltage})} \text{ x autonomy} \quad (3.13)$$

$\text{Battery (Ah)} = \frac{12936Wh\times 2days}{0.85\times 0.6\times 24V} = 2114\text{Ah}$ (this is the total battery capacity)

Each battery has 2V, then the number of batteries $= \frac{24V}{2V} = 12$

Capacity (Ah) of each battery$= \frac{2114}{12} = 177\text{Ah} = 180\text{Ah}$, where as the Ah capacity of Arbaminch battery is 3266Ah and extremely excess energy were stored unusefully and eventually dead and discarded since it can't be charged sufficiently by the PV array.

3.8.3 The existing solar power conditioning equipments and load compatibility check

The third step in component sizing can be Inverter/ charge controller sizing**.** The rating of the inverter should never be below the total watt of appliances. Inverters must have the same nominal voltage as that of the battery. The size of the inverter should be 25-30% bigger than that of the total Watts of appliances. If in case of appliance is motor or compressor then inverter size should be at least 3 times the wattage of those appliances and should be added to the inverter capacity in order to handle surge current during starting. Considering of Lightning protection, bypass and blocking diodes needs to be included where appropriate. The fourth issue, array wiring must be sized and selected to withstand the elevated temperatures.

Wiring and sizing is detailed in NEC 690 (Washington State University 2009). In the case of Arbaminch 564W is the radio loads power demand which is supplied from the existing solar PV, assuming 1.25 to be a multiplying factor, then the inverter power will be Pinv=1.25x 564W=705W, but the Arbaminch inverter size, power rating is 3kW which is big enough, though it has no technical side effect, it is not cost effective. The logic is similar to the charge controller as well.

CHAPTER FOUR

RESULT AND DISCUSSION

Mainly there are two types of results that are obtained from the site, the measurement and the PV syst result. The results that are obtained from the actual observation of the site and the digital multi meter measurement were described from performance evaluation point of view. The PV syst software sensitized result output were recorder, compared and discussed.

4.1. Measurement and observation results and discussion

The discussions were generated from the site observation and instrument measurement values and results. Every solar power related components checked in reference of their performance effect on the output power or energy.

4.1.1. The radar and radio components power and energy demand

Almost all the loads that are listed in table 4.1 are expected to function daily and 24 hours/day.

Table.4.1.Power and energy rating of each loads

No	Quantity	Load description	Power rating(w)	Time(hr) /day	Energy (wh)
		Radar(ADS-B) system			
1	1	Dual 1090MHZ Rx(2)	250	24	6000
2	1	GPS Rx(2)	40	24	960
3	1	GDP(2)	240	24	5760
4	1	Transponder	140	24	3360
5	1	Monitor	50	24	1200
6	1	Work station	475	24	11400
7	1	Sit monitor	620	24	14880
8	1	Radio link	14	24	336
9	1	Lane switch	1440	24	34560
10	1	Air conditioner	4000	7	28000
		Reserve(10% Radar total)	-------	------	------
		Total for Radar	7269		106,456
		VHF Radios			
11	1	Transmitter main & standby	400	24	9600
12	1	Reviser main & standby	50	24	1200
13	1	VSAT RFT SW	19	24	456
14	1	VSAT Modem	25	24	600
15	1	VSAT MMUX	10	24	240
16	2	Obstruction light	2x30	14	840
		Reserve(10% of radio total)	------	------	-----
		Total for radio	564		12936
		Grand Total(radar and radio)	7,833		119,392

N.B The Air conditioner works from 9:00AM to 5:00PM for7 hrs/day

Most of the loads are not working at the same time, but simultaneously, therefore it is possible to reduce the total calculated power by multiplying with diversity factor of 0.75(assuming that only 75% of the loads are working at a time), for example radio voice or signal reception and transmission done respectively but not at the same time. One of the advantage of up-to-date technology is the components are of low power rating and in the future the power rating (energy demand) of each loads hopefully will reduce.

P_{Total} =7,833W=7.83KW $\quad\quad$ P_{max}= 7,833WX0.75=5874.75W=5.87KW

From the above load table 4.1 Loads with a red color are the radar (ADS-B) equipments with their respective power and energy rating and installed recently. The solar power supplies only to the blue color loads (VHF radio), therefore the loads connected to the solar power is the sum of the blue color loads (564W). Both the radar and the radio loads are used for air craft communication purpose. The radar and radio equipments work with dedicated frequency band width ranted form Ethio telecom. The south and the west part of the country air craft movement were controlled though the signal generated from the radar and radios that transmitted and received by the nearby antenna linked with the Addis Ababa station.

4.1.2. Arbaminch radio and radar site, Solar Arrays factors for power loss

From Fig.4.1 one can easily observe the performance losing factors for the PV solar arrays of the installed system.

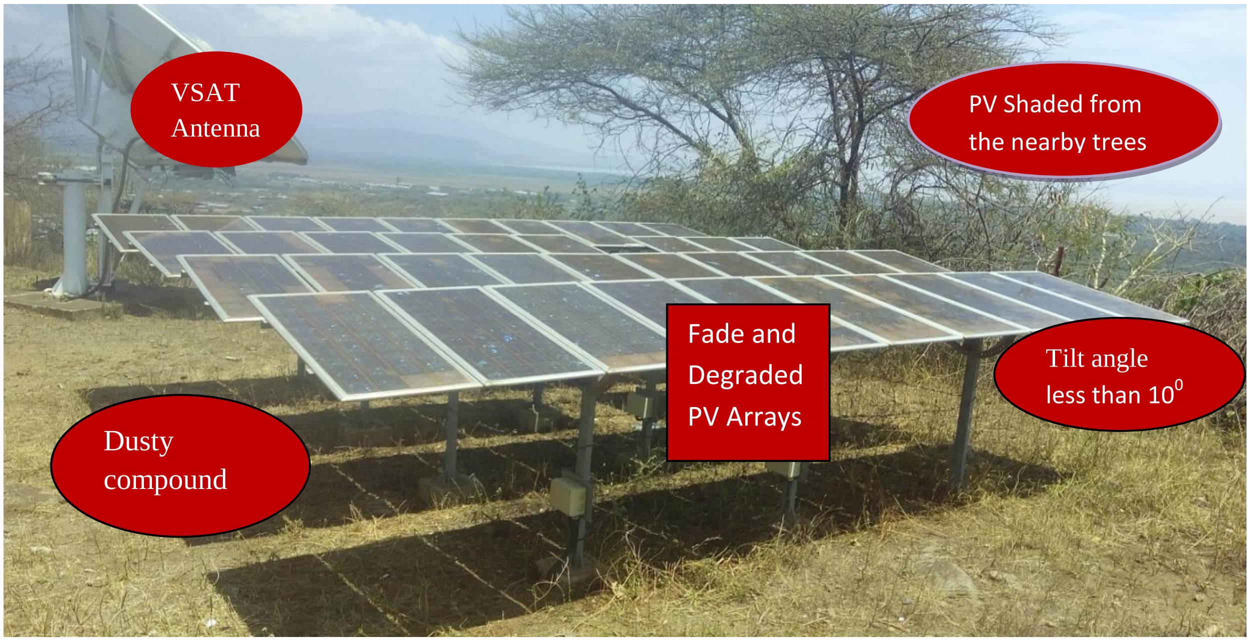


Fig.4.1. Picture of Arbaminch solar panels and its loss factors

The main electrical source of the proposed system is photovoltaic panel which converts solar irradiations directly into Electricity. From the solar power output and efficiency loss the major contribution comes from the solar module or panel, therefore a special attention should be given to any factors that affects the solar array performance. Since the solar radiation varies daily, hourly and seasonally the electricity produced by the PV array vary accordingly. The selected site has very good solar irradiation throughout the year it is possible to harness maximum irradiance during the sun hours. From the physical observation Arbaminch solar array consists of four rows of panels each having ten modules and a total number of forty modules. The types of the PV modules are polycrystalline silicon and the orientation of the arrays is towards the south. Table 4.2 enables to understand the degradation of the PV arrays, while comparing the measured and the name plate values.

Table.4.2. PV module voltage measurement table from Arbaminch site at solar noon

Voltage(V_{mp}) measured at five random point	Actual measured Value	Name plate values
Voltage at peak power(V_{mp}) maximum	13V	16.5V
Voltage at peak power(V_{mp})minimum	8V	16.5V
Voltage at peak power (V_{mp})average	10.5V	16.5V
Open circuit voltage(V_{oc})measured at a random single point	15V	21.3V

It is possible to understand that the PV modules are fading enough and can never generate the desired power output. The module tilt angle is very low and there is accumulation of dust and bird fouls during winter and snow during summer that reduces the performance of the module, under the real conditions measurements were carried out and it was found that degradation increases over time due to accumulation of dust on the surface of the panel. There is a shade from the nearby tree and array mismatch loss due to the module fade, dust and bird drops. Furthermore, this can also contribute considerable amount of array power losses.

Basically there are two types of angles that the PV modules depend on it, the azimuth and the tilt angles. The PV array azimuth angle represents the angle between true north and the direction of the array faces and in the case of Arbaminch it is 0^0. A tilt angle at less than 10^0 is typically not recommended because it requires regular cleaning (to avoid losses due to dust accumulation). The self cleaning ability and power output of solar panels is better at a tilt angle of 15° to 20^0. The tilt angle of Arbaminch solar arrays is less than 10^0 which is 6^0 (equal to the latitude of Arbaminch).Some literatures suggest that the value of the tilt angle is equal to the latitude of the installation site, but this is out of reality for the countries near to equator. From the above picture of Fig.4.1 the solar arrays were expected to charge the solar batteries of Fig.3.6, but in reality the solar arrays are Fade, Degraded, covered with dust and shaded by the trees unable to charge the storage battery that is the reason why ECAA replace solar batteries almost every three year while discarding rechargeable batteries before the warranty and service time. Similar phenomenon was happened at other regional air port communication site as well. The array distance from the ground is of standard high and it is sufficient for air circulation and free from ground heat influence. But the air (wind speed) were hindered and reduced by the nearby tree and guard house.

4.1.3. Fill Factor and PV modules Voltage measurement calculation

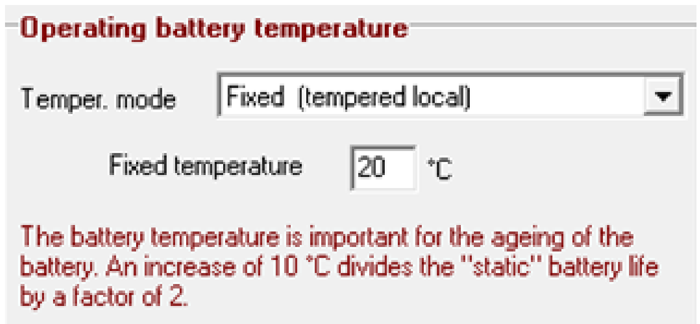
$$\mathbf{F.F} = \frac{\mathbf{I\,m\;X\;Vm}}{\mathbf{Isc\;\mathit{X}\;Voc}} = \frac{\mathbf{3.9A\;x\;10.5V}}{\mathbf{4.4A\;x\;15V}} = \frac{\mathbf{40.95}}{\mathbf{66}} = \mathbf{0.62}$$

As per the literature review, the value of the F.F more than 0 .7 shows that the plant performance is good but 0.62 were less than 0.7, therefore the Arbaminch radio/radar site solar power performance were weak. There is module mismatch losses, that is why the voltage (V_{mp}) reduced from 16.5V to 10.5V (reduced by36.36%) and the V_{oc} reduced from 21.3V to 15V (29.58%). Furthermore, the voltage reduction at the maximum power (V_{mp}) were 36.36% where as the reduction in V_{oc} were 29.58% there is a 6.78% difference and this shows that there is array mismatch loss. During V_{mp} measurement since the panels (modules) are not disconnected there is mismatch loss that contributes for 6.78% voltage difference. The source for mismatch can be the fade (degrade panel), the shade from the tree or the accumulation of the dust (bird foul) on the module in different concentration.

4.1.4. Arbaminch battery room and Temperature

Higher operating temperatures accelerate corrosion of the positive plate grids causing greater gassing and electrolyte loss from the battery. Lower operating temperature generally increases the battery life; however the battery capacity is significantly reduced at very lower temperatures, particularly for the lead-acid batteries. The Arbaminch station battery room is made of blocket, the doors and the windows are closed and there is no ventilation system. The room is very hot and exposed to frequent battery sulfation (discharge).The higher the temperature leads to frequent battery self discharge, especially during battery under operation the discharging cycle were very frequent. Similarly for much cooled areas batteries can take more time during charging (the acid inside the battery became dormant).In any case the battery room temperature needs to be moderate and regulated as much as possible. In most cases battery room temperature fixed nearly at 20^0C, table.4.3 shows that a 10^0C increase, divides (reduces) the battery life by a factor of 2.

Table.4.3. As operating temperature increases battery life reduces



4.1.5. Battery SOC and DOD

The state of charge (SOC) is the amount of energy in a battery and expressed as a percentage of the total energy stored in a fully charged battery. A battery that has been discharged 60% is having a 40% state of charge. The depth of discharge (DOD) represents the percentage of battery capacity that has been withdrawn from a battery compared to its fully charged capacity. By definition depth of discharge and state of charge of a single battery total is 100 %.

Fig.4.2. Shows the battery cell voltage verses SOC, normally the cell voltage needs to be above 1.85V and below 2.4V, if below 1.85V it is highly discharged and above 2.4V over charged and both cases the battery life affected significantly. To protect such conditions charge controllers are used. The SOC can be between 10% to 100%, the charging and discharging current and time determines the battery capacity (Ah).

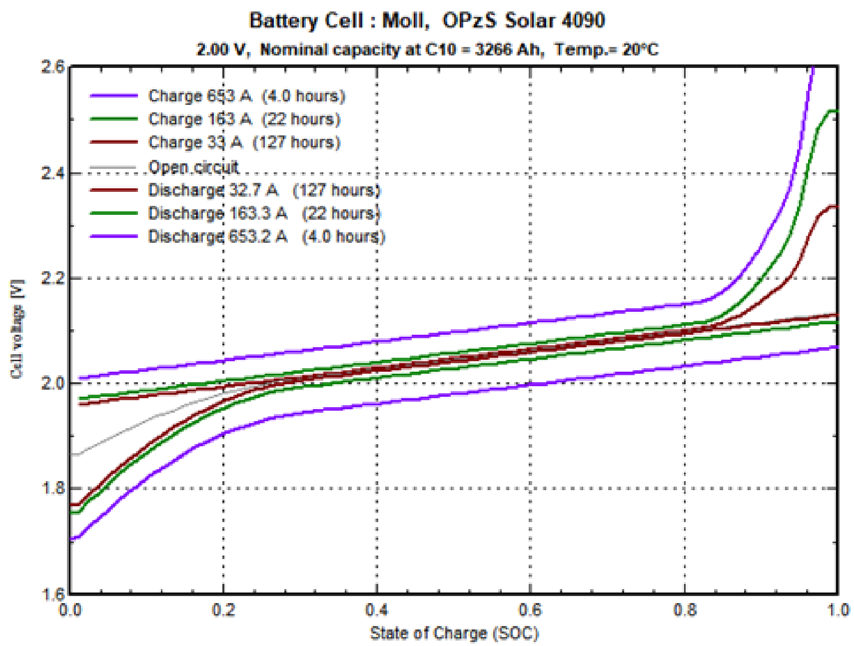


Fig.4.2.Solar battery cell voltage and stat of charge discharge

Allowable depth of discharge is the maximum percentage of fully rated capacity that could be withdrawn from a battery. Allowable DOD depends upon the design of cut-off voltage and discharge rate. In solar PV systems of standalone the low voltage load disconnect set point of the battery charge controller dictates the allowable DOD limit at a given discharge rate. Battery Autonomy in a stand-alone PV system refers to the time that a fully charged battery can supply the required level of energy to the system loads when there is no solar PV energy supply from the modules. For common and less critical PV systems the autonomy period ranges from two to five days. Fig.4.3Shows the three batteries discharging rate, battery with the red curve has bigger capacity (4153Ah) and slower discharging rate with longer life time, but it needs better capacity of solar modules and battery charge controller.

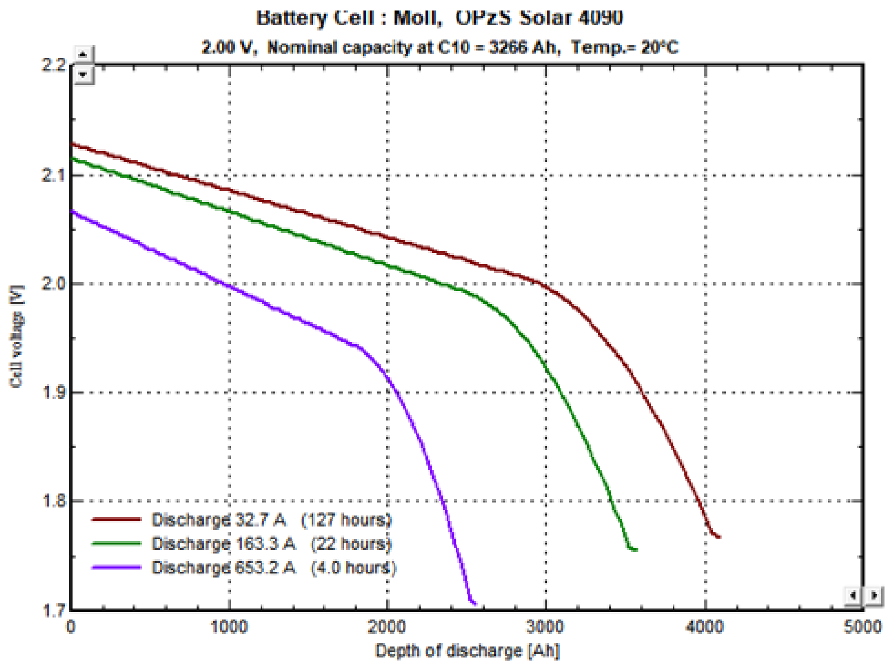


Fig.4.3. Solar battery cell voltage and Depth of discharge

4.1.6 .Battery storage and self discharge

Batteries are indispensable to any off-grid system. Unfortunately, batteries are also often the most problematic and costly part of a system. Solar renewable energy systems deploy deep cycle batteries to provide the energy storage for the system. Like car battery, deep cycle batteries that are used in renewable energy applications are meant to be discharged and recharged (cycled) repeatedly. To maintain healthy batteries and prolong battery life, most manufacturers suggest limiting the depth of discharge and stat of charge. In the literature review it is well stated that if the solar batteries are not charged sufficiently from the PV modules though the charge controller, it becomes discharged frequently and no more use full.

In open circuit mode (i.e., without any charge or discharge cycle) a battery undergoes discharging from its state of charge basically due to its internal resistance and produce losses within the battery itself. Different battery types of have different self discharge rates. Higher temperatures generally contribute to higher discharge rates especially for lead- type of batteries. In this regard ECAA solar batteries are stored on a battery shelf for several years before use and this situation leads to battery self discharge. The Arbaminch solar site battery rooms were closed and the batteries are exposed for self discharge due to high temperature.

The performance degradation starts at any point unless professional and belongingness involvement included. As per the literature review and common experience batteries can be self discharged if it is stored after fabrication. Almost all battery manufacturers recommend installing batteries frequently after purchasing and not to store it, if storing is mandatory during transportation it should be for a few months at a moderate temperature with enough space and ventilation. Don't store a battery on top of the other battery (keep vertical gap) and there should be also some horizontal gap between batteries. Some literatures suggest charging batteries in an interval of months with a proper charger. ECAA purchases several types of batteries with an expensive rate of foreign currency and store it unsafely, out of the recommended practice.

4.1.7. Gode radio and radar (ADS-B) station batteries

Fig.4.4 shows figure of solar batteries installed at Gode radio station, these batteries were purchased in 2013 and installed late 2020, stored for more than seven years at ECAA store unsafely, hopefully these batteries will be discarded and replaced in the near future regardless of the life time and the warranty period, because already expired while it was in ECAA store. The Gode PV solar system voltage is 48V, the number of batteries is 24, and the batteries are OPZV type with 2V, 200kg and more than 3000Ah each.

Fig.4.4.Twenty four newly installed OPZV solar batteries at Gode site

4.1.8. Batteries at ECAA stock for stand by purpose

Currently batteries are stored in such a manner for stand by purpose as shown below. Nobody knows for the storage life of these batteries, for how long has been here and for how long will it be. The reason behind why ECAA stock batteries is the life time of the installed batteries were unknown and unpredictable , from experience solar batteries failed suddenly and the foreign purchase process takes two three months , therefore to avoid such delay and interruption ECAA stock solar batteries in store and expired while it was there.. The solution is simple, before stocking batteries perform regular performance test and maintenance to the installed batteries based on performance check list and maintenance procedure, refer to manufacturer warranty and battery life time documents accordingly, try to sort out and justify the failure. If replacement is necessary replace it on time and charge batteries while it is in store during the delivery time.

Fig.4.5. Battery stock in side ECAA Store for stand by

Whenever higher variations in operating temperatures exist, batteries should be located in an insulated enclosure to minimize the battery temperature swings. Battery terminals are also undergoing corrosion due to the electrolyte gassing from inside of the battery. It is a good idea to have air gap between them to cool and equalize temperature. ECAA solar batteries at Arbaminch site are located in a closed hot room which is exposed to battery electrolyte gassing that shorten battery lifetime. ECAA discard the new rechargeable batteries and purchase other new solar batteries with expensive price of foreign currency and this is a common practice. Moreover nobody cares and investigates the reason for the frequent battery failure and no question about the warranty and the battery life time issues. Early detection and corrections of problems can help to prevent permanent damage to battery system that results economic loss. This paper will be helpful by resolving such problems though implementation of performance upgrading factors.

4.1.9. Battery Disposal and technical problems

These batteries are very special solar batteries recently replaced by batteries of Fig.3.6. There is no information about the service life time, but hopefully it could be shortly discharged and discarded before the service time. The first and simple reason can be these batteries were discarded because it was not properly or totally charged.. Frequent battery disposal were an economical loss.Fig.4.6 shows batteries disposed, sample photo taken from Arbaminch radio /radar site and ECAA dead item store..

Fig.4.6. Discarded solar Batteries at Arbaminch site and at ECAA dead item store

Batteries are hazardous item as they contain toxic elements such as lead, acids and plastics that can harm human beings and the environment. Under no circumstances batteries are disposed off in the landfills or near to the water springs and resources. There is degraded and totally dead battery disposal procedures listed on IEC 61429 (give the battery with electrolyte to manufacturing companies to recycle it or to the scrap dealers). Rechargeable batteries of any kind should not be placed in your trash can (dumpster). It is illegal in most states to do so because rechargeable batteries contain heavy metals that can be hazardous to the environment (ISO 14026 2014).

4.1.10. Summarized ideas on ECAA solar Batteries

Sulfation is the formation or deposit of lead sulfate on the surface and in the pores of the active material of the batteries' lead plates. If the sulfation becomes excessive and forms large crystals on the plates the battery will not operate efficiently and may not work at all. ECAA installed each battery having 2V, 3266AH, 200kg and a total number of 12 batteries connected in series at Arbaminch station. Batteries are purchased with a planed annual budget of foreign purchase system then transported and installed at a price of more than one million birr for Arbaminch site only. Similar scenario was followed to other site of the Authority as well. The types of batteries are valve regulated lead acid battery technology, the batteries warranty period not 5 years but 10 years. To improve battery life void the following, Continuous overcharging, Deep discharge, Stock discharged and Freeze discharged batteries.

4.2. Solar inverter and charge controller

The inverter is a device that converts DC output voltage into AC. Inverter is implemented in PV system to supply an AC loads. However, inverter sizing strategies are usually does not taken into account seriously during the design stapes. The inverter is sized with the nominal power output about 30% lower than that of the PV array nominal power output. Initially, selection Inverter with efficiency estimated around 95-97% at the partial load but it will minimize gradually at full load. In addition to the above facts, the undersized inverter can cause energy losses when reached at the operating temperature due to heat. Moreover, the quality of equipment shall also gives an impact of 8-20% of total energy losses for a single-phase inverter (Syahirah et al. 2018). The MPPT inverters are better than PWM inverters. Fig.4.7 shows actual multi meter reading, with a losses compensated by the charge controller.

Fig.4.7. Inverter input and charge controller output voltage measurement

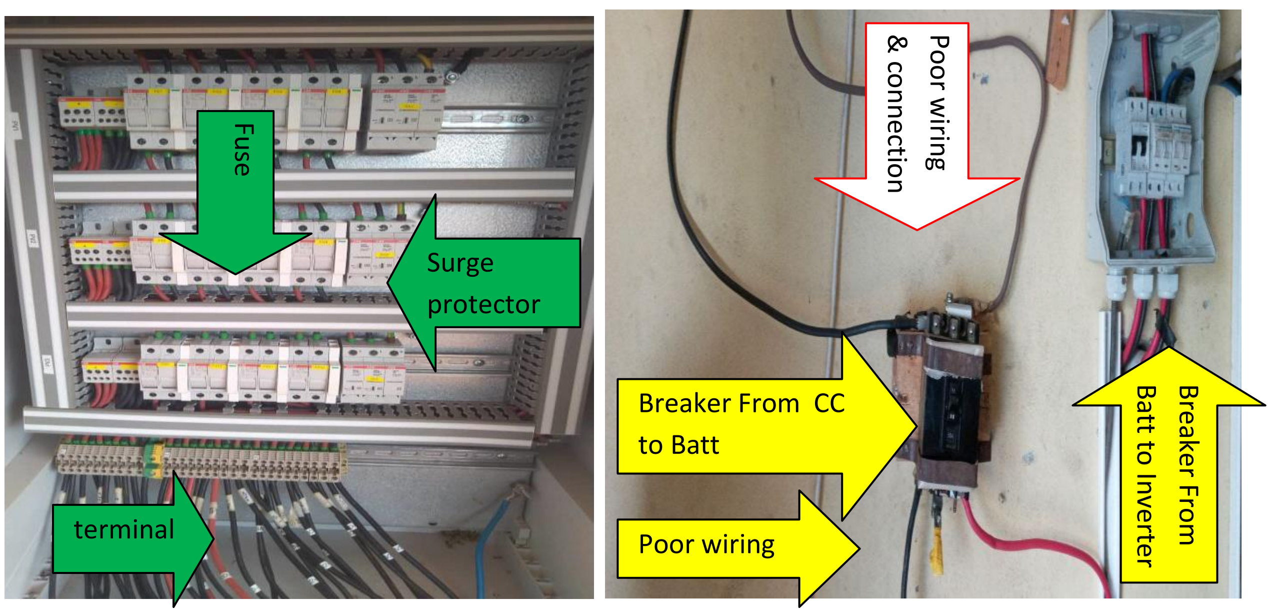
The inverter output of AC voltage were measured with a digital multi meter at the circuit breaker terminal and found 227.8V AC, similarly the output voltage of the charge controller which is the input to the inverter were measured with the same digital multi meter and a DC voltage of 26.06V were achieved as shown in the above figure. During the fabrication of inverters optimization procedure should be followed, that inverters needs to be free of power consuming components that encounter power loses of I^2R (I^2X_L), normally electronics components like SCR, BJ, IGBT and MOSFET are used and the better inverters are transform less to avoid iron core and copper loss, fan and heat sink mechanism included to reduce heat loss. Now a day's inverters had digital controllers for easy trouble shooting farther more there are single or three phase inverters. ECAA installed pure sin wave single phase, 24V, 30A DC input and 230V, 19A, 50Hz, AC output, and a 3kW power rating inverter at Arbaminch radio and Radar communication site.

4.2.1. The charging process and charger performance

In the constant current constant voltage (CCCV) method, it overcomes the disadvantages of the long charging period, overcharging and over temperature. This method is divided into three stages, the first stage is the bulk stage, a constant current (CC) is applied until the charging voltage reaches a predetermined value. In addition, the charging process goes into the second stage (absorption stage). In this stage, a constant voltage (CV) is applied for a while. The charging current will be automatically reduced along with the increase of the state of charge (SOC). At this time the third and last stage is started and continues until the charging process is completed. The battery-charging controllers are discussed showing their functions, design considerations, types, control algorithms, and structure. It was clear that, the MPPT based battery charging controllers are the most efficient controller and the multi stage-charging algorithm is the most safe and efficient for battery charging.

4.3. Performance loss due to connection

There is power loss that leads to performance degrading, during my visit to Arbaminch radar and radio station, the connection cable and the protecting devices burned, louse connected and it was out of safety. Fig.4.8 helps to compare the two sites protective device installation.



A) Gode B) Arbaminch

Fig.4.8. Picture of protective devices connection at Gode and Arbaminch

Comparing Gode and Arbaminch solar site protection device connection, the Gode protection device connection board is physical evidence how it is possible to change the Arbaminch poor and dangerous connection, really it is out of the standard. From practical experience the solar cable power loss can down the whole PV system supply, therefore proper cable rating and connection is a big deal in the case of solar power supply. The protective devices, the fuses and the circuit breakers are expected to disconnect the power line that goes to the load during short circuit and overload or any abnormal conditions in order to protect the very expensive radio and radar components from burn out. ECAA invest millions of birr every year for spar part replacement purchase due to power fluctuation burn.

4.4. The PV syst software Results and discussion

The PV syst software needs 'Basic Data' like: the name and the latitude of the site, the daily consumption of the load, the autonomy of the system, etc.

4.4.1. The solar irradiance result of the site

Solar power site with maximum irradiance and minimum temperature are preferable. From the result Arbaminch has average yearly Global irradiance of 5.24 KWh/m^2 and the defused irradiance of 2.39 KWh/m^2 and from the data the minimum is on July which is 4.02 kWh/m^2 and the maximum were on February 5.91 kWh/m^2, this can be taken the best compared to the standard value at STC, which is $1000W/m^2$ ($1kw/m^2$ x 4hour/day=4 kWh/m^2), as shown in the methodology chapter of this thesis, but in reality solar irradiance were not linear rather stochastic as shown in Fig.4.9

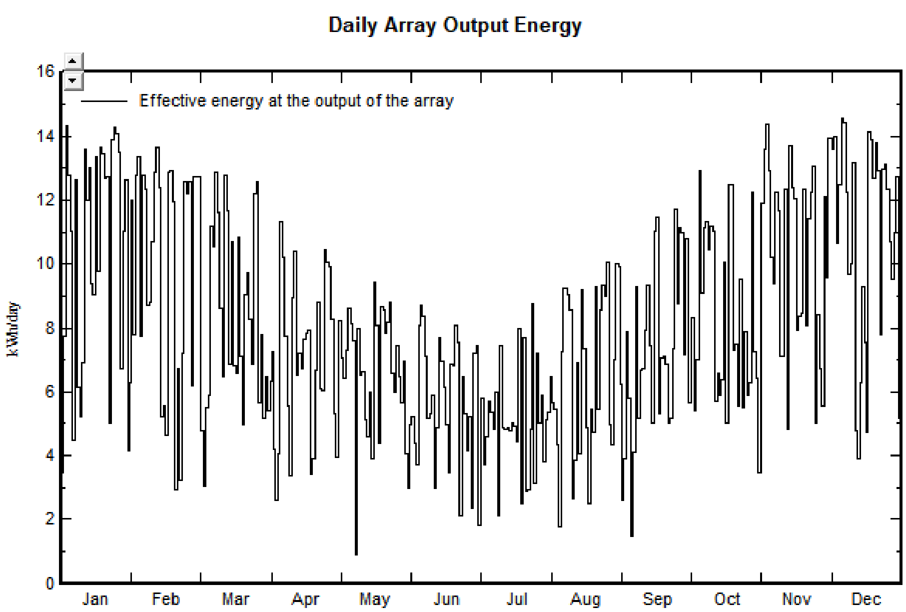


Fig.4.9. Solar irradiance of Arbaminch

Based on the collected data, Fig.4.10 Shows the I-V curve of the site. As the value of the irradiance increases the module current significantly increases and since power is the product of current and voltage, the MPP value also increases, thus at irradiance 1000 W/m^2 the corresponding maximum current and power is 3.9A and 63.2W respectively, but the voltage has no significant change and estimated as16.5V though out the experiment. It is also possible to indicate that as the size of the solar module increases the irradiance, the current and the power increases but the voltage do not affected as such. Therefore irradiance reducing factors like shad, dust, bird foul, improper tilt angle and fed modules are PV performance affecting factors.

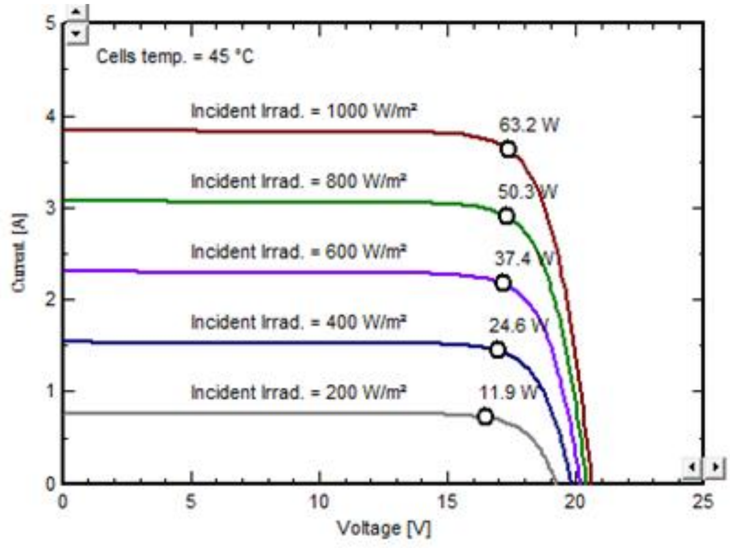
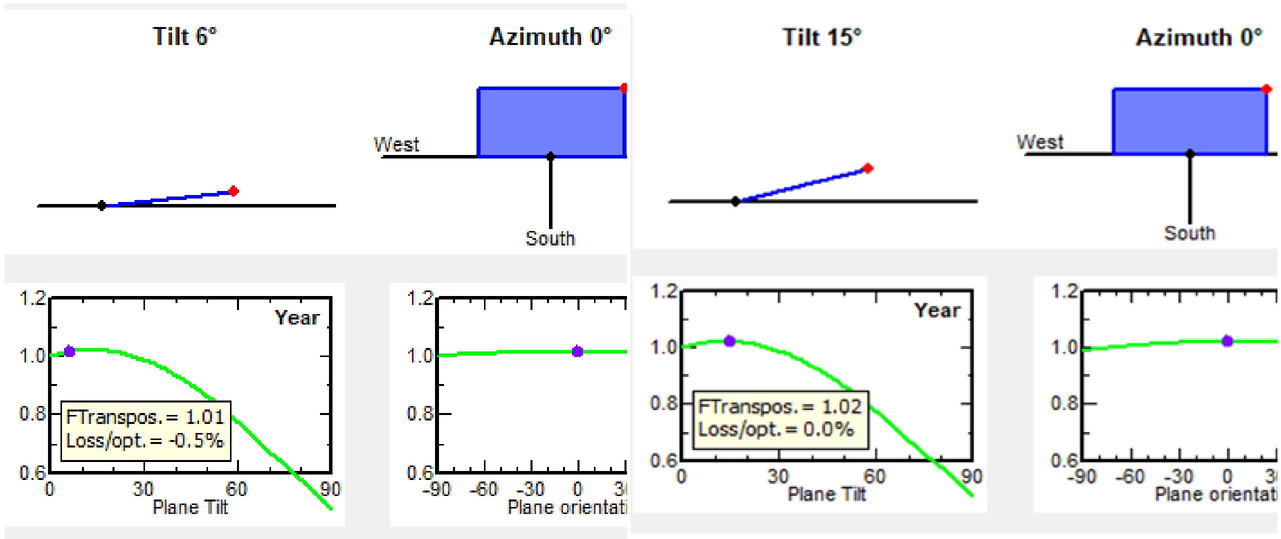


Fig.4.10. Solar irradiance and MPP on the I-V curve

4.4.2. Tilt angle and irradiation yield

The Sunshine reaches the surface of the earth through radiations. Solar irradiance is simply the power of the solar radiation received per unit area. In other words Irradiance is the instantaneous power measured in watts or kilowatts per square meter (W/m^2or kW/m^2). Irradiance is mostly affected by the angle of the sun, and at any time of the day irradiance is highest when the solar panels are perpendicular to the incident sun rays. Fig.4.11 (a) and (b) shows the influence of array tilt angle value on the irradiance and loss, which are a determinant factor for solar array output performance.



(a) (b)

Fig. 4.11.Yearly irradiation yield value for Arbaminch at tilt angle: (a) at 6^o and (b) at 15^o

The yearly irradiation yield was 1.01with a loss value of 0.5% at a tilt angle value of 6^0. But as the tilt angle value were increased to around 15^0 the yearly irradiation improved and the loss becomes zero and yield improved from 1.01 to 1.02, it full fills the optimization criteria. Therefore, the maximum power yield of Arbaminch radio and radar station were at an angle of 15^0 but not at 6^0, this shows that even though 6^0 were the value of the latitude of the area, as per some literatures the latitude cannot be taken as the solar array tilt angle. It is advised to have panel frames of adjustable type as the sun hours keep changing with in winters and summers. Hence for any specific area for a fixed panel a tilt angle is calculated to get the maximum radiance throughout the year. Also, it is advised to adjust the panels facing to the south for North hemisphere to get the optimal irradiance.

4.4.3. Cell temperature and efficiency

In the literature review and methodology chapter of this thesis the effect of temperature were well described with the help of evidences and formulas.Fig.4.12. Shows that the solar irradiance and the efficiency of the module is high at a lower temperature, therefore solar module temperature needs to be minimum for better performance. Below10 ^{0}C the loss became less than 0.4% and the efficiency increased above 13%.

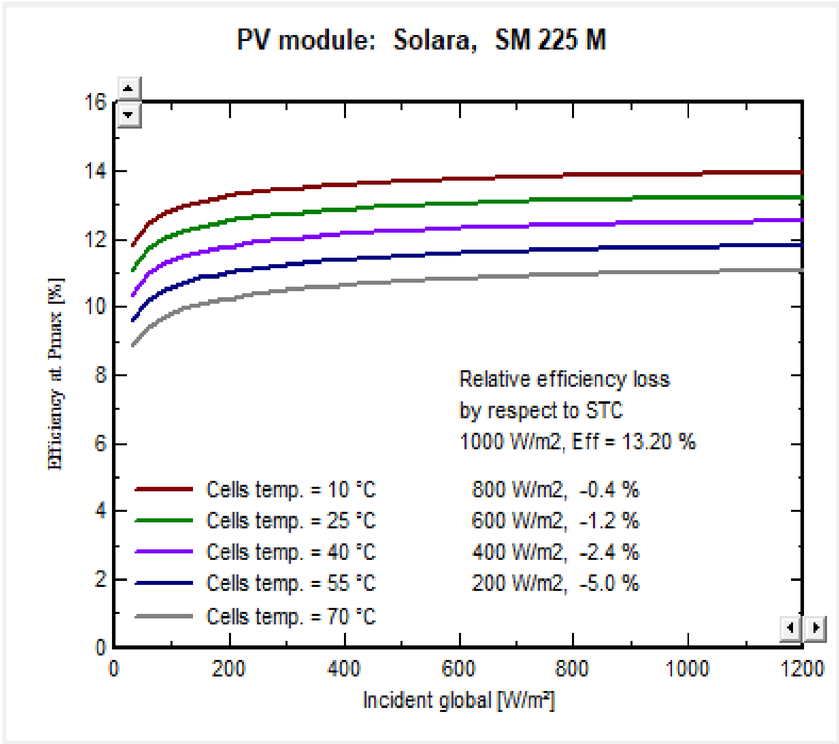


Fig.4.12. effect of temperature on PV modules performance

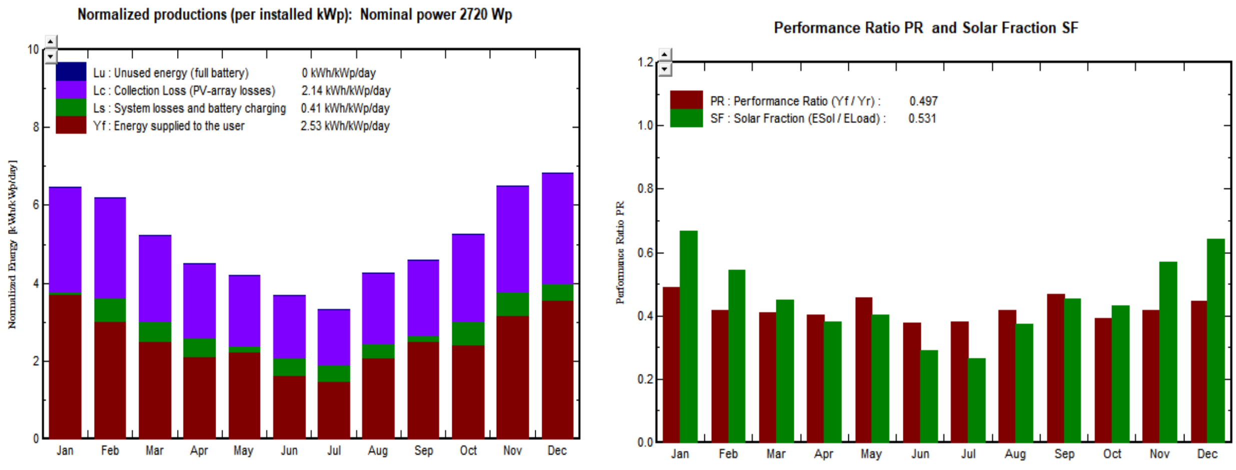
4.5. Solar components technical data, loss and performance ratio from PV syst

From the installed solar power plant of Arbaminch, two modules were connected in series to provide 33V for the 24V output charge controller, twenty solar modules are connected in parallel to generate a total current output of 20x3.9A=78A and the total array output power were 40x68W=2720W=2.72KW.The PV syst software takes input data from the component name plate and calculate the total power (2.72kW) and energy (4722kWh/year) output as shown in Table 4.4 and this is similar to the calculated values.

Table.4.4.Basic solar components without loss

Main system parameters	System type	**Stand alone**		
PV Field Orientation	tilt	6°	azimuth	0°
PV modules	Model	SM 225 M	Pnom	68 Wp
PV Array	Nb. of modules	40	Pnom total	**2720 Wp**
Battery	Model	OPzS Solar 4090	Technology	Lead-acid, vented, tubula
Battery Pack	Nb. of units	12	Voltage / Capacity	**24 V / 3266 Ah**
User's needs	Daily household consumers	Constant over the year	Global	4722 kWh/year

In reality there is no ideal case, but rather there always be losses and Fig.4.13 Shows the energy supplies and losses with the performance ratio value.



a) List of losses and energy supplied **b) Performance ratio**

Fig.4.13. Solar plant performance determining factors

Solar plant with performance ratio value less than 0.7 were considered to be weak but if the value were near to 0.9 then it is the best plant with minimum losses. Arbaminch solar power plant performance ratio value were achieved 0.497=0.5 and this value is below the standard and there is a minimum difference of 0.2 (0.7-0.5=0.2) from the standard value and this implies that there is a loss in performance by 20% at least.

4.5.1. The PV solar power degrade factors

Fig.4.14 shows the degradation factors for the solar PV system like: temperature, conductor resistance, module quality, array mismatch, soil cover and aging.

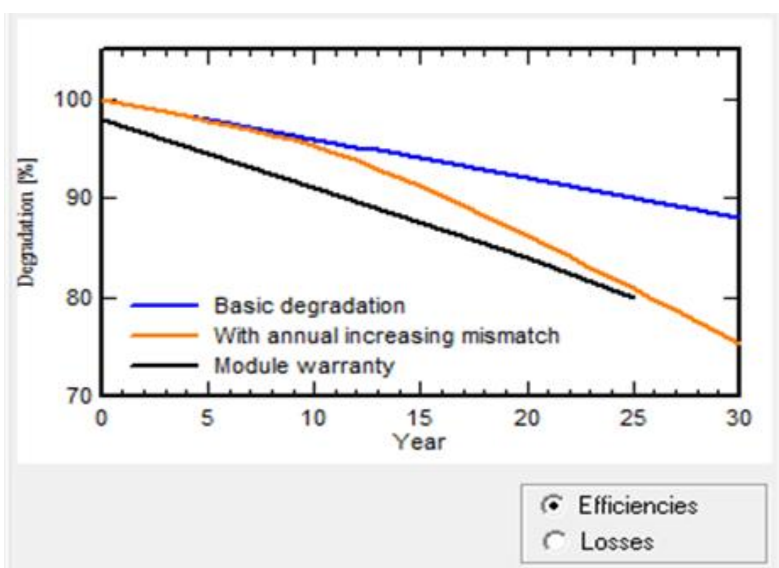


Fig.4.14 factors for solar PV loss

The above table shows that as the service year (age) of the module increases the losses increases and efficiency reduces.

4.5.2. List of losses diagram and I-V curve

The major factor that challenges the implementation of solar power supply are loss and performance issue. Based on Fig.15 the solar module conversion efficiency is 13.20% at STC, this is for poly crystalline module but if it was mono crystalline a better value can be achieved and also a module quality loss reduced. Soil and temperature loss can be reduced through regular array cleaning. Battery and charger loss can be reduced through better material selection. Ohmic loss can be reduced by selecting proper wire size and firm connection, furthermore the distance between the load and the PV plant should be minimum. Array mismatch loss can be reduced by confirming the similarity of module output voltage. Proper PV plant sizing with the help of PV software and formulas also minimize losses.

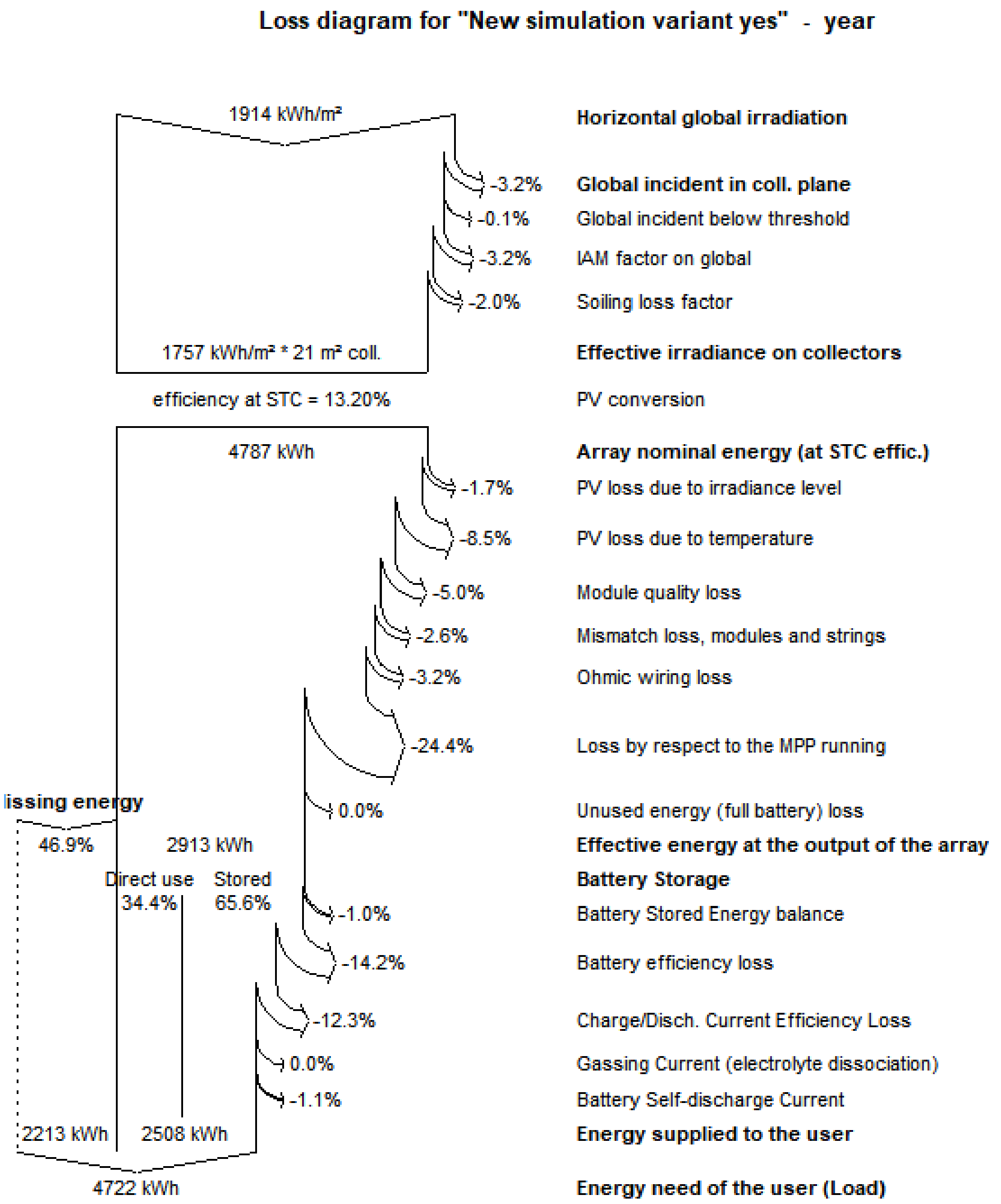


Fig.4.15 The PV loss diagram

Fig.4.16 Shows that at STC the total power were not 2.72kW but 2.13kW, labeled with the red I-V curve, then finally due to the 18.8% losses that are listed in the box, the total power output were reduced to 1.73kW.The following losses can be avoided by choosing the better quality of module, avoid array mismatching, minimize the diffused beam factors, reduce the module temperature, use proper wire thickness and connection.

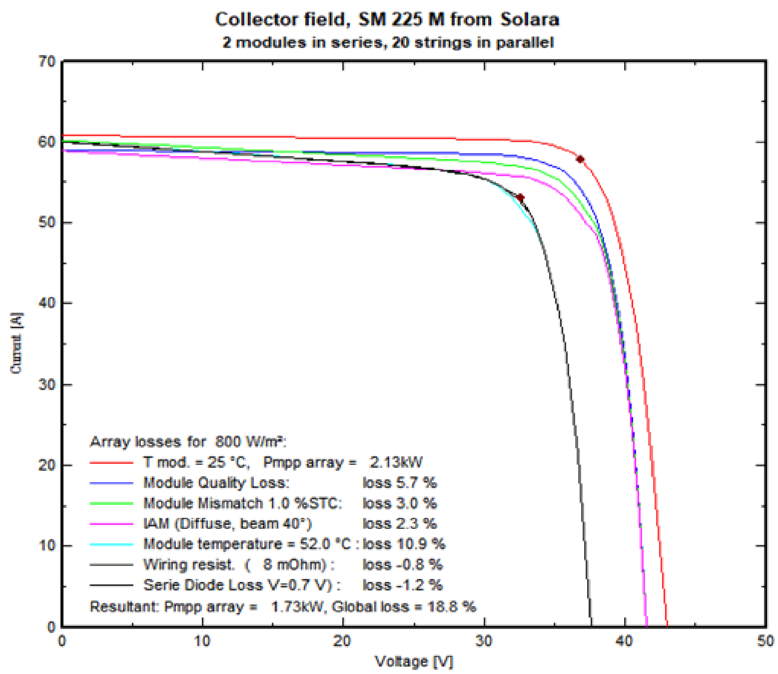


Fig.4.16.List of losses on the I-V curve in the case of Arbaminch

4.6. An intelligent System-Manager and PV performance

There are several points to be discussed regarding the solar PV power supply, the major points that must be included in any discussion about the solar PV components are its: advantage, disadvantage, performance affecting and performance improving factors. Under the major titles there are subtitled criteria's to be discussed like, Solar PV array installation site selection, solar material quality and standard specification for maximum power utilization, solar power (energy) demand and sizing, evaluation and maintenance, availability of trained and skilled personnel, installation, test ,commissioning and warranty issue are all part of the discussion. From the literature review and the formulated laboratory test as the cell temperature increases the cell (the array) voltage decreases, therefore there should be free space for air circulation that reduce cell temperature. Water cooling system is better than air cooling but since air is free of charge, air is preferred for regular cooling and array cleaning.

Arbaminch solar array compound is dusty specially during summer (where there is no rain), as the accumulation of dust on the PV modules increases the strength of the solar irradiance decreases similarly the temperature of the module increases and the overall effect will reduce the solar power output(affect the PV performance). The higher the value of array tilt angle is preferable for self cleaning but the strength and the period of solar irradiance per day should be considered. ECAA start to replace inverters without transformers and charge controllers without variable resistors (use MOSFET, IGBT, SCR) and reduce the 15-20% internal power loss to 3%. More over the maximum power point tracker (MPPT) and the pulse width modulator (PWM) where introduced as system optimization.

The System-Manager is an intelligent System-Manager in which a microprocessor has been employed for all regulating, controlling and indicating functions. The main power switching components consist of low loss MOSFET type-transistors that have a long operating life and guarantee high performance due to their excellent conductivity, thus leading to a low degree of internal heat generation in the System-Manager. The overcharge protection is accomplished by a pulse-width modulation parallel (shunting) type controller which is equipped with a MOSFET switch element and with a reverse diode in order to prevent current flowing back from the battery to the module at night. While following the standard IV curve, the charging process is also adjusted according to the temperature. Voltage drops of the battery cabling and connections and due to the internal resistance of the battery itself are compensated automatically in the sophisticated patented software inside the System-Manager, without using extra sensor cables.

Reverse battery and panel protection and current operating status. The first line informs briefly on the most important basic parameters and the second line displays fine parameters or system information. This display is changing their information every three seconds. The Electronic protection functions as: Overcharge protection, Deep discharge protection, Reverse polarity protection of module, load and battery, Reverse polarity protection by internal fuse, Electronic fuse, Short circuit protection of load and module, Overvoltage protection at module output, Open circuit protection without battery, Reverse current protection at night ,Over temperature and overload protection, Load disconnection on battery overvoltage.

4.7. Optimal power supply design option

This is more than recommendation but optimal design option were presented, that anybody can apply the technology, the block diagrams can be changed to detail design specification as per the interest and the request of the client.

4.7.1. Controlled without DC supply option

Fig.4.17 Shows sample connection for PV hybrid with diesel generator, and explained as follows

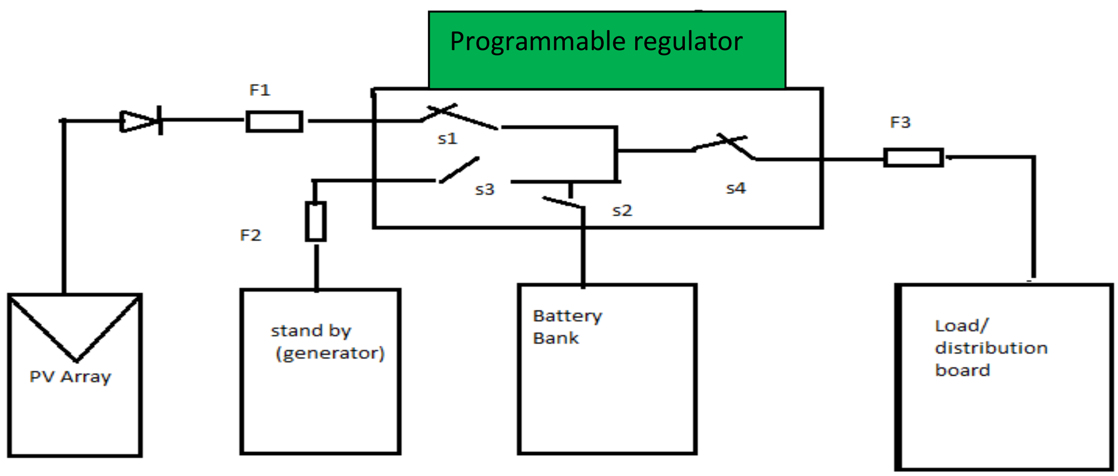


Fig.4.17. optimal hybrid power supply

- S_2 is open when the battery bank is fully charged or fully discharged but during the fully discharged period it checks the current flow from S_1 then S_3 if so S_2 will be closed and allow current flow until the bank fully charged.
- Under normal condition S_1 is always in a closed position and it works alternatively with S_3 but in the case of less voltage from the PV array during the night and cloudy weather then S_1 will be open and S_3 closed at the same time.
- In most cases loads needs AC supply therefore the generator output is supplied directly to the load but the solar or the battery output is supplied to the load though the charge controller and the inverter.
- Always the primary supply is the solar PV, the 2nd is the battery bank then the 3rd standby can be any kind of electrical source (generator in the case of ECAA).
- The first specialty of the above wiring from the existing is that the stand by generator or any stand by source charge the battery bank when it is on (running) besides the solar charging system.

- Secondly since the solar power is the primary supply there will not be major environmental and technical problem like that of discarded ECAA generators at different station. Even there is an encouragement support in financial and technical aspects from the international civil aviation organization (ICAO) and other institutions (stated in the literature review section).

- The third advantage is the unstable leased commercial power material, installation and maintenance cost will be off. Even no monthly bill.

- The fourth advantage is the power outage and fluctuation will be reduced, air lines and air operators has a complain on ECAA communication equipment service interruption(failure).The power outage interrupts the communication, but power fluctuation burns the most expensive communication equipments, that is why the annual foreign purchase budget for spar part is beyond the expectation.

4.7.2. Controlled with Dc supply option

From the Fig.4.18, the PV array is the primary source and it supplies the designed voltage to the charge controller (C.C) then the charger supplies the regulated voltage to the battery bank and to the inverter (INV). The output of the inverter feed to the automatic transfer switch (ATS),that switches the load to inverter or to the generator (Gen set) alternatively. The Generator similarly supplies to the regulator (Reg) that converts the alternating current (AC) output of the generator to DC in order to charge the battery bank. The programmable logic control (PLC) performs the priority and the voltage level comparison test and allow the selected source to the load. The following Fig.4.18 shows the procedure how the source selection priority performed.

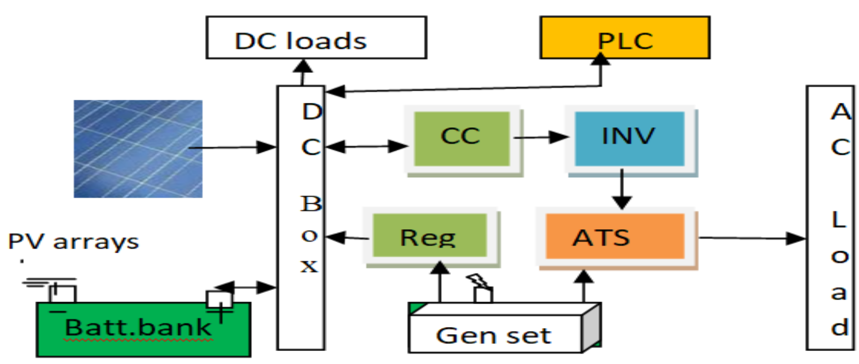


Fig.4.18. Block diagram for the optimal Solar Diesel Hybrid design

4.8. Discussion on performance based Standards and Safety

A challenge in many countries has been the lack of quality regulation, leading to an influx of cheap, substandard, and counterfeit products in the local market. Purchasers of solar panels should seek for quality assurance, now a day's well-developed global standards and testing procedures for panels are appearing, especially notably from the International Electro technical Commission (IEC) and similar organizations.

4.8.1. Standards Related to solar PV system

The main globally recognized standard for crystalline silicon modules is IEC 61730 safety, IEC 61215 or IEC 61646 and similar standards, is awarded largely based on tests done to the samples of modules produced. Since modules cannot be tested throughout their 25-year lifetime, regular stresses testing for performance were required. One of the main test is the verification of the peak nominal power that a PV module deliver at a standard testing conditions (STC), which include 1000 W/m^2 of isolation when it is perpendicular to the panels at 25°C of PV cell temperature. The National Electrical Code (NEC), NFPA 70 governs to the requirements for most non-utility Electrical installations in the U.S.A. As the standards adopted into the building codes by states or local jurisdictions then the NEC becomes base for inspections and approvals of electrical installations system. Article 690 of the NEC includes special Installation requirements for solar PV systems, however many other articles are also apply. Additionally, Article 705 includes requirements for the interconnecting of PV systems and other equipment for distribution, generation system of other sources, like the utility grid. In Ethiopia Solar energy and power equipment is currently imported from various places in different qualities. Unregulated importation of PV equipment and accessories from suppliers which are uncertified has been a challenge to solar companies that provide services and products at standard level as they hardly compete with cheaper but inferior quality products. The Quality and Standard Authority of Ethiopia (QSAE) have standards and codes to solar equipment and installation of the systems. However, on the other hand, capacity building of PV technicians' both in quantity and quality is high quest.

4.8.2. Lightening Protection and earthing

The current and the high voltage are extremely dangerous and could be fatal to the human. The human body acts as a conductor of electricity and when certain amount of electricity flowing through the human body exceeding 9-12 mA range, fatal consequences can be observed. The amount of current through the body depends upon the resistance of the body and the applied voltage. The body resistance of a healthy and cheerful fellow can be above 3 kilo Ohms under normal condition. In this case the single battery or module voltage may not be fatal when touched. But if the body is moist and the mental condition is worse, the resistance can drop significantly and even the low voltage as that of 12V battery can be fatal when touched. The effect of current flow in the body also depends upon the current path. Including the module frames, array mounting structures, any metal housing of regulators or load centers, and all loads should be grounded. Lightning protection (arrester) are to attract lightning strikes away from the installation structures though a down conductor to earth and a grounding system that adequately and safely dissipates the sudden current into the earth.

4.8.3. Array Mounting

All support structures should be anodized aluminum, galvanized or stainless steel and need to be designed to withstand the maximum possible wind loading for the particular location. Lock washers or equivalent should be used on all bolts to remove risk of the coming loose during the subsequent 20 years. The structures should be located as close as possible to the load to minimize wire lengths, and where necessary fencing may be utilized to protect from animals, theft, vandal etc.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The performance evaluation helps to avoid or minimize the effect of performance affecting factors and increases the efficiency and interest of utilization. There are different solar power software's that are available in the market used to analyze and size the PV system easily. In this thesis PV syst software were used for technical performance analysis of ECAA, Arbaminch VHF radio and ADS-B (radar) solar power supply and it is applicable for all other solar power sites. The performance affecting and upgrading factors were identified and discussed in detail. The solar PV power technology updated from time to time, the price of the solar materials reduced, even in Ethiopia solar materials are imported tax free. In this thesis solar module efficiency degrading factors were discussed and yet a special attention was required to improve the weak efficiency of the solar module. The power conditioning element technology grown from transformer to transform less, from variable resistor to electronics switching and this is a great jump towards maximum efficiency and negligible loss. Solar batteries are one of the most expensive components of the solar materials next to panels, battery life time affecting factors, like poor battery room ventilation and extra time storage that leads to self discharge, lack of proper charging concept and maintenance, file miss handling were sort-out and solution suggested. From battery sizing calculation the required battery for the 564W load were 2V/180Ah but not 2V/3266Ah. Moreover, the incompatibility of load power (energy), array and battery, increases the loss. Cable loss and circuit breaker connection can be adjusted as per the standards. The involvement of trained and skilled man power is mandatory to resize and replace the solar materials as per the standards. The radar (ADS-B) loads can be supplied from the solar PV power after the resizing and adjusting the solar component. The selection and sizing of solar components like, Panels, batteries and power condoning systems involves several factors, depending on the complexity, the cost and control options required. During data collection and observation, most of the loads have dc voltage supply option and this can be a good opportunity to supply the dc output of the controller directly to the dc loads out of the inverter. Hybrid option was available. The technical and environmental efficiency loss (performance degrade) can be caused by module mismatch losses, soiling and other shading losses, Temperature losses, sizing and selection loss, component aging and miss handling loss.

The PR and FF values obtained from Arbaminch solar site shows that the performance of the plant was degraded. The Degradation Rate (RD) is the gradual deterioration of component characteristics or of a system which affects its capacity to operate within the limits of acceptability criteria and mostly caused by the operating conditions. Degradation Rate can be calculated as: RD = initial PR− final PR, initial PR is the standard value where as the final value is the current PV syst software value, therefore the degraded value of Arbaminch solar power were calculated as, 0.7-0.5 =0.2=20%, this shows that there is a minimum of 20% losses.

5.2. Recommendation

- Remove the nearby tree that shade the array or shift the Array position, grow short height grass to reduce compound dust and temperature. The guard house and the nearby bush fence hinder the free air circulation and better to replace it.
- Adjust the array tilt angle not less than 10^0, replaced the burned DC-cables and breaker, Relocate the position of either the generators or the air conditioner.
- Implement optimization like MPPT controller, transformer less inverter, and the suggested hybrid sources with optimal system. Ventilate the battery room and clean the solar array and power conditioners regularly. Measure input output power of solar component as per the technical manual. Provide training for technicians. Manuals and check list should be on site.
- Air port compound is free for solar farm with large area, solar power is CO_2 free as per ICAO recommendation, funded, cost effective, not obstructing air craft movement, loads can be energy saving like LED, it avoid EEU leased line and generator expense, therefore it can be considered as future bright project.
- It is very advantages and cost effective if ECAA implement the findings of this thesis as soon as possible before the new solar batteries died and there is a chance for optimal redesign with the help of PV syst while including the Radar loads. Install batteries frequently after purchasing and not to store it, to protect self discharge and damage.

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