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ADDIS ABABA INSTITUTE OF TECHNOLOGY

(AAiT)

SCHOOL OF GRADUATE STUDIES

ENERGY CENTER

DESIGN OF SOLAR PHOTOVOLTAIC SYSTEM TO POWER AIR CONDITIONING UNIT FOR A LIGHT CITY TRAIN

(CASE STUDY ON ADDIS ABABA LIGHT RAIL)

BY RUKIA HASSEN

A thesis submitted to the School of Graduate Studies of Addis Ababa Institute of Technology in partial fulfillment of the Masters of Science in Energy Technology

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Date: October 2020

CERTIFICATION

I, the undersigned, certify that I read and hear by recommending for the acceptance by Addis Ababa University Institute of Technology, Energy Center a thesis entitled "Design of Solar Photovoltaic System to Power Air Conditioning Unit for a Light City Rail." This certificate was used as partial fulfillment of the requirement for the design of Masters of Science in Energy Technology.

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Design of Solar Photovoltaic System to Power Air Conditioning Unit for a Light City Train

By: RUKIA HASSEN

Approved by Board of Examiners

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ABSTRACT

Energy is the basic utility required to drive trains. Trains use either fossil fuel or electricity to energize the system. The Addis Ababa city light rail has two routes namely: the North-south Line (MENILIK II Square to KALITI Route) and the East-west Line. The train gets electricity from the grid. Electrical energy coming from the grid enters the control unit from where to be supplied to different units. One of the energy-intensive units is the air-conditioning system.

This research work focused on designing a rooftop solar photovoltaic system to provide the energy required for the air conditioning units of the 17.1 kilometers from Ayat to Torhailoch Route. The data collected from the Ethiopian Methodology Agency, NASA, and PVGIS showed the sun can be provided at minimum solar insolation of 4.8 kWh/m²/day to the route line. The air conditioning system of the train is a DLD25 type air conditioning unit. The cooling capacity is 6 kW and power of 2.25 kW for each AC, the air supply volume is 1300m^3/h, and the total electrical power is 9 kW for 4 air conditioner.

The train travels at an average speed of 70 km/h without significantly changing its direction from East to West and vice versa. In a coach, 36 photovoltaic modules (having a 66.35 m^2 aperture area) can be installed in an effective rooftop area of 71.6 m^2. The battery size is 150Ah, 12V controller size of 80 A, 220V, and 30 KW of inverter size. The PVSYST and MATLAB software simulation results projected within different months electrical energy varying between 11.48 kW and 14.45 kW can be generated.

The train in general requires 260 kW of electricity. Of this 9 kW or 3.5 % amount of energy is consumed by the air conditioner. Hence, by supplementing the locomotive with solar PV modules 1034775 Birr can be substitute per annum. As compared to other researches, this thesis work is to simplify the mounting of the solar PV modules by considered the solar insolation variation within the route to know the performance of the system. Hence it is recommended to Addis Ababa Light Rail Train to apply this solar-powered air conditioning system.

Keywords: Solar energy, photovoltaic (PV), light train, PVSYST, MATLAB, air conditioning.

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NOMENCLATURE

W	*Watt*
h	*Hour*
m	*Meter*
V	*Voltage*
I	*Current*
KW	*Kilowatt*
KWh	*Kilowatt-hour*
P	*Power*
L	*Length*
A	*Area*
^{o}C	*Degree centigrade*
N	*number of the day in a year*
h	*object height,*
α	*Angle between Sun and horizon.*
η_{pv}	*solar cell efficiency*
ηe	*the maximum power point tracer coefficient*

ABBREVIATION

SL	*Standard Longitude*
LL	*Local longitude*
PPV	*Photovoltaic power*
NOCT	*Nominal operating cell temperature*
PV	*Photovoltaic*
MPPT	*Maximum power point tracking*
DC	*Direct current*
AC	*Alternating current*
STC	*Standard test condition*
PSH	*peak sun hours*
NP	*Number of panel required for a train*
A_E	*Effective area needed on the top roof of the train car*
A_p	*area of single panel*
Wp	*Requirement power for air conditioner*

GREEK SYMBOLS

η	*Efficiency*
δ	*Declination angle*
θ	*Incident angle of solar radiation*

β	*Tilt angle of Solar panel*
ϕ	*latitude*
θz	*zenith angle*
ω	*Hour angle*
ϕ	*latitude*
A	*The height of the area in km over the cruel ocean level*
τ_b	*The atmospheric transmittance for beam radiation*
τ_d	*The atmospheric transmittance for diffuse radiation*
I_d	*diffuse radiation*
I_b	*beam radiation*

SUBSCRIPTS

MPP	*maximum PowerPoint*
oc	*open-circuit*
sc	*short-circuit*
d	*diffuse*
b	*beam*
E	*Effective*
P	*panel*

CHAPTER ONE
INTRODUCTION

1.1. Background

Some countries have successfully commissioned and operated trains fitted with a solar photovoltaic system on its rooftop. To do rooftop solar photovoltaic system energy is an important term. Energy is to doing work and essential to mankind as he makes use of it in his daily life. It is an indispensable factor for continuous development and economic growth [1]. The energy demand is increasing rapidly in the developing countries due to automation, industrialization, and urbanization, the growing population and technological developments have shown that the present sources of energy in use are not adequate [2].

The world population has increased at an explosive rate in the 20th century [3] and continues to increase. Energy is the demand in the world and obtains energy from many sources. Most energy sources are not environmentally friendly, expensive, and difficult to transport; like fossil fuel. [4] Most energy sources are friendly with the environment like wind energy, solar energy, bio-gas, etc. Ethiopia has a big capacity for solar energy because it is located near the equator with an average daily solar radiation of 5.57 kWh/m2/day. And the minimum radiation recommended for this design is 4.57kWh/m^2 /day.[5]

Solar Photo Voltaic (PV) systems run on direct current electricity provided by solar energy. This energy is used for many applications, a Solar-powered integrated system for train auxiliary equipment is one of these applications. Company of solar arrays normally states that a properly installed system will give power to the solar refrigerator for over 20 years with no fuel costs and little maintenance.[6]

When contrasted to diesel fuel power production, in particular, PV is a cost-effective choice, especially in the developing world where electricity and diesel prices are often high [7]. PV system has high investment cost and needs planning to supply the load [8]. So the design compared the user’s power needs with the appropriate sun based system components.

The photovoltaic system has many functions especially in current days ; [9]

- For Concentrator photovoltaics
- Home power solar system for different household
- For telecommunication infrastructures function
- For Rural electrification function
- Urgent call boxes for interstates and college campuses
- Road Lighting and Network Associated supply of Electricity

Solar Photovoltaic systems run on direct current electricity provided by solar energy.it has main components to convert solar energy into electrical energy which are PV module, charge controller, battery bank, inverter, etc.….

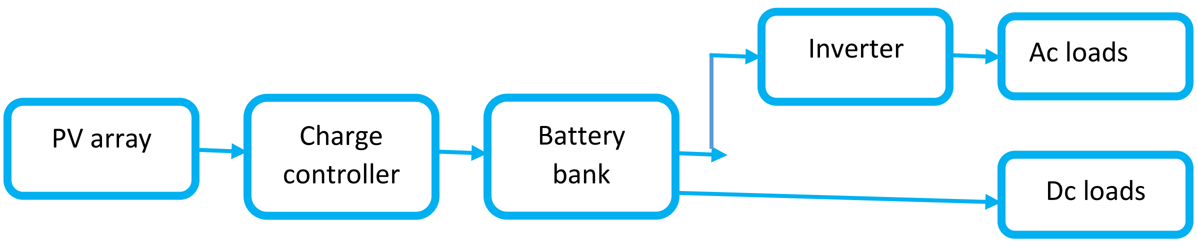


Figure 1.1 Rooftop PV System model [9]

Photovoltaic (PV) is power-producing frameworks or by using semiconductor material PV systems change sun energy into electricity. From different advantages of PV systems clean, reliable, and compatible power without using other sources are some and also PV can apply to many applications [10].

There are two different solar PV connections one is called an off-grid system, which means they are the solar source of power to a different application without connecting to the grid specifically for this thesis to feed air conditioner by rooftop solar system or other loads. Rooftop solar systems are designed with batteries as a backup or without batteries but in this research, the design considers battery bank for some specific hour. [11]

There are many off-grid solar systems applications rooftop solar system for a train system is one of many. It is often designed to run without battery backup thus to use anytime, the system uses solar power during daylight hours and stored power in a battery bank for use anytime. In another way, in the stand-alone domestic supply system, regular power is produced in the daytime and at night power is put away in a battery bank so the load that used in this thesis has a similar design [9].

When the power produced by the photovoltaic system greater than train air-conditioning loads, excess power is stored in the battery bank, turning the train electric need backward. In exchange, the load can receive the required power from the utility when power from the PV framework is deficient to control the loads. Thus by power exchange, the Addis Ababa rail month to month electric utility charge reflects as it were the net sum of energy gotten from the electric [12].

When we compare a stand-alone PV system with grid power it has less cost. Other PV systems are called grid-connected systems. This works when the amount of energy generated by the grid is low but for now, Ethiopia does not have an approved feed-in tariff so the only choice for the Addis Ababa light rail is an off-grid option.

Therefore in this research solar system is applicable to supply air conditioner so that when the solar system is not enough to supply the system the power supplied from the grid, thus utility bill will reduce also there will be a continuous power supply for the train air conditioner and there will not be any power interruption throughout the day.

1.2. Objectives of the study

The overall objective of this thesis is to design a solar power system to provide the electric demand required to run the air conditioning load for Addis Ababa light train.

Specific Objective

- Collect data of location from a different source and compare it
- Determining, Predicting, and evaluating the power required to derive the air-conditioning unit
- Developing a computer simulation for the system of solar sources using MATLAB and PVSYS software.
- Determine energy requirements and other design data and economic analysis
- Study photovoltaic for train system's and validation of the result

1.3. Statement of the problems

Ethiopia is founded in the equatorial region where solar energy is abundantly available throughout the year. Hence, there is a possibility to use solar energy for the railway train. Air conditioning units consume a lot of energy that is 9 kW. Daily, the grid-supplied 260 kW electrical energy to the different sections of the train passing through the control unit. Of this 3.6 % is to drive the air-conditioning system.

1034775 Birr is to be spent to run the AC annually. The purpose of this research work is to look for an option to substitute the energy required to drive the AC system using a solar photovoltaic system. This research aims to reduce the energy consumption of the Addis Ababa light rail train from the grid. The problem has been formulated to reduce the energy used for comfort function by using a solar photovoltaic system compromising the comfort quality for the passengers.

1.4. The Scopes of the research

Collecting data from the national meteorological office, energy bureau, and Railway Corporation. Assessing the sun oriented radiation utilizing an angstrom relationship show for a chosen station along the railroad of Addis Ababa. Calculating and estimating the solar radiation for the railway route of Addis Ababa light rail on a 9^{O} slope surface in turn to show the country's solar energy potential. Performing pre-design calculation for solar energy implementation on the rooftop of the rail car through the route of the railways. Develop a complete model of the train using mat lab software, analyzing the variation of power generation with a change of route direction, optimizing for better performance, Put recommendation towards the air-conditioning of solar technology on railway energy source and further studies.

1.5. Delimitation of the Research

The delimitation of this research as academic research, the design does not include the installation of a solar PV system on the Addis Ababa light train because it needs further regulation, perdition, and permission, and government approval.

CHAPTER TWO
LITERATURE REVIEW

2.1. Introduction

Ethiopia builds the primary light rail and fast travel in eastern and sub-Saharan Africa called Addis Ababa Light Rail is a light rail transportation system. The train running from the city center to industrial areas in the south of the city it has A 17-kilometer .the train start service on 9 November 2015 for the second line (west-east). The train has a total length of 31.6 kilometers, with 39 stations. Trains are moved at speed of 70 km/h. [15]

This rail was done by China Railway Group Limited. The double-track electrified light rail vehicle extends of Ethiopian Railroads Enterprise started development in December 2011 by the stores from the Export-Import Bank of China. On 1 February 2015 Trial operations were begun, with several months of testing following that. Ethiopian Railway Corporation is the national railway operator of the Federal Democratic Republic of Ethiopia, under the regulation of the Ministry of Transport. It is operated by the Shenzhen Metro Group. [15]

The Addis Ababa LRT covers the East-West and North-South transport direction. The East-West route passes through the city center from the eastern peripheries of the city to the west. The initial phase of this route is 17.1km in length and is expected to extend up to 37.7km in the long term plan. The North-South route is heavily used; it is utilized to access Africa's largest open market at MERKATO. The initial phase of this route is 16.97 km in length and is expected to extend up to 36km in the long term plan. The study covers all systems of the east-west line from Ayat to TORHYLOCH.[15]

There are several workshops scattered around Addis Ababa equipped with the potential for light maintenance of the train. The maintenance of gross and heavy works has provided them with potential in the city of quality workshops. Construction of a modern workshop for the maintenance is ongoing. Workshops were conducted by major maintenance in KALITI. Workshops were conducted by light maintenance deployed in all of the places in the line. In the main workshops, there are lathes workshop, foundry works, and welding workshop as well as other assistance and workshops with all these different types of machines to meet the need of main works. The following is a Profile of the main sections of the Directorate and its functions. [15]

Technical affairs and projects department**:** Prepare the technical studies of all offers for Locomotives, wagons, and equipment. Prepare technical specifications for all the needs of railways and the preparation of the budget for tugs and make control stocks and preparation of statistical data and periodic reports. Engineers and technicians in these department's efforts in research and study, testing, and analysis for the improvement and development of systems engineering and work procedures by conducting the necessary adjustments and develop specifications [15].

Mechanical workshop: Full supervision on the property of small and light cars and mobile cranes, lifters and technical assistance in overhauling machines small diesel and gasoline engines [15]**.** Commercial production: This section runs the business of the maintenance workshops, manufacturing, and electricity to provide business services to workers and the public institutions, including the work of wood and iron furniture and the needs of special workshop equipment and spare parts and Castings [15].

Besides as this research's main goal is to run an air conditioner with a solar photovoltaic system so knowing air conditioner operation is very important to decide how many hours per day the air conditioner works. The air conditioning unit has different operation modes: auto cooling, auto heating, ventilation, and stop. Available states of operations include pre-cooling, full cooling, half-cooling, pre-heating, full heating, half-heating, ventilation, cooling, power failure, and degraded power supply. For full cooling, two air compressors of the unit will be in operation. For half cooling, only one air compressor is operating. For automatic operation, the air conditioning unit will automatically adjust the temperature inside the passenger saloon following external temperature. The fresh air valve will turn off for pre-cooling (heating) so that the temperature inside the car can quickly reach the set point.[16]

2.2. Air Conditioner working Principle

The concurrent preparation and control of temperature, stickiness, filtration of air, and conveyance of air current in compliance with the necessity of space requiring are called air conditioner system.

Air Conditioner Principle many air conditioners use split-air conditioners, which are consist of the indoor unit and outdoor unit. The indoor unit is an evaporator outdoor unit are a condenser [17]

The working principle is Cooling in traditional AC systems is accomplished using the vapor-compression cycle, which uses the forced circulation and phase change of a refrigerant between gas and liquid to transfer heat. The vapor-compression cycle can occur within a unitary, or packaged piece of equipment that is connected to terminal cooling equipment such as a variable refrigerant flow terminal or fan coil unit on its evaporator side and heat rejection equipment on its condenser side. In an air-conditioning system heat is rejected from inside to outside under using of electricity for operating a compressor and fans. The transport medium evaporates at temperatures below room temperature at the inside unit. [18]

A device on the air conditioner that pressurized the gas by decreasing volume is called a compressor. This compressor is a specific type of gas compressor called an air compressor. Then the heat stored in the compressor is automatically removed outside by condensing the refrigerant back into a liquid. [19]

An expansion is a component in air conditioning systems that controls the amount of refrigerant released into the evaporator and is intended to regulate the superheat of the vapor leaving the evaporator. An expansion valve does not regulate temperature, the temperature of the evaporator will vary with the evaporation pressure. Fans on both sides support the heat transfer. a condenser is a device or unit used to condense a gaseous substance into a liquid state through cooling. In so doing, the latent heat is released by the substance and transferred to the surrounding environment. Figure 2.1 shows the operation of air conditioning.

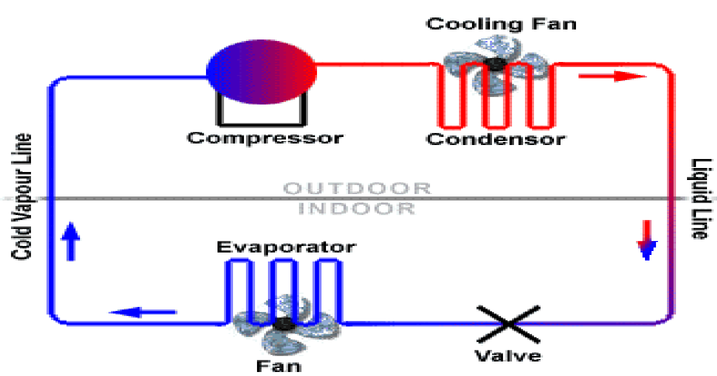


Figure 2.1 Air conditioning working flow [29]

2.3. Solar Energy

Sun-oriented energy is a free, inconsumable, and clean source of energy which is the center of numerous later investigations in the energy field, numerous of which are around overcoming the wasteful aspects of sun-powered control frameworks.[20] The sun energy delivered in one hour is equal to the annual energy demand of the earth.

Sun is like a black body radiator. That has a surface temperature of 5800 K which leads to a 1367 W/m2 energy density over the atmosphere [21]. While designing PV systems, the initial factor should be studied and taken into consideration. The importance of knowing the sun's property lies in the fact that this knowledge can help to understand the effects of the atmosphere on the radiation and guides us to select the best materials for solar cells [22].

2.4. Review of Semiconductor Device Physics of Solar Cells

Solar cell like the crystalline silicon-based is a solid-state semiconductor p-n junction device that converts sunlight into direct-current electricity through the principle of photovoltaic effect. Were principally deployed to provide electrical power for orbital satellites. [23]

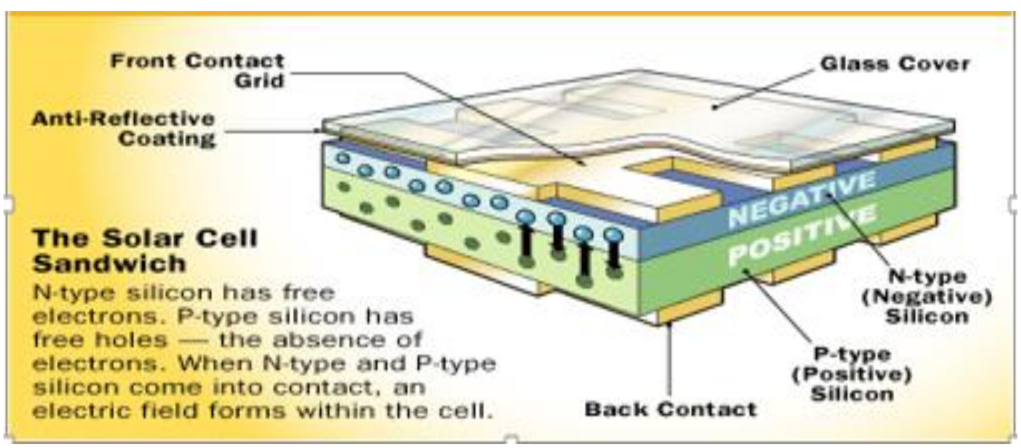


Figure 2.2 Solar cell structure [23]

2.4.1. Photovoltaic module

A PV module is an assembly of photovoltaic cells mounted in a framework for installation. Photo-voltaic cells use sunlight as a source of energy and generate direct current electricity. A collection of PV modules is called a PV Panel, and a system of Panels is an Array. Arrays of a photovoltaic system supply electricity to electrical equipment.

The most common application of solar energy collection is rooftop electricity generation systems number of modules can be connected. So the advantage of a PV system is added to an existing system when required because the modular structure is comfortable to add.[10]

There are several advanced PV innovations for making PV modules. From those Cadmium telluride (CdTe), Copper indium diselenide (CIS), undefined silicon (a-Si), and thin-film silicon (thin film-Si) are listed. [24] Amorphous silicon is the first commercial technology but it has small efficiency while the other three technologies are slowly reached the market and have big acceptance in the market because of their efficiency. [13].

Thus this review helps to select the proper advanced module for the design based on efficiency, tolerance (below or above-rated capacity that is positive tolerance), lifetime, and cell temperature so for this study monocrystalline module is selected .

2.4.2. Module performance

The power output of a photovoltaic module is a product of its operating current and output voltage. There is a performance curve that shows simple characteristics of a PV module called an I-V Curve which shows the current and voltage output characteristics of the module cell.

At 1000 watts per meter square of sun irradiation I-V curves are given at 25^{o} C (77 degrees F) cell temperature [25]. Most of the time 1000 watts per square meter is 'Peak Sun.' There are three important terms in the I-V curve [9].

1. Maximum Power Point (MPP) - is a point where the power is at its maximum. In MPP the Vmp, Imp on the I-V curve is visible. The power at the MPP is the product of the MPP voltage (Vmpp) and MPP current (Impp). the maximum power point is a point at the operating point at which maximum output power achieved this point clearly shown below in figure 2.3.

2. The Open circuit Voltage (V_{oc}) - is the difference of electrical potential between two terminals of a solar cell when disconnected from any circuit. There is no load connected. No electric current flows between the terminals. Alternatively, the open-circuit voltage may be thought of as the voltage that must be applied to a solar cell or a battery to stop the current. Thus the open-circuit voltage (VOC) shown in figure 2.3

$$V \text{ (at } I=0) = V_{OC}$$

3. The Short Circuit Current (Isc) - is an electrical phenomenon that allows a current to travel along an unintended path with no electrical impedance. This results in an excessive current flowing through the circuit

$$I \text{ (at } V=0) = I_{SC}$$

I_{SC} appears at maximum current value. For an ideal cell, this maximum current value is the total current that occurs in the module cell by photon excitation.

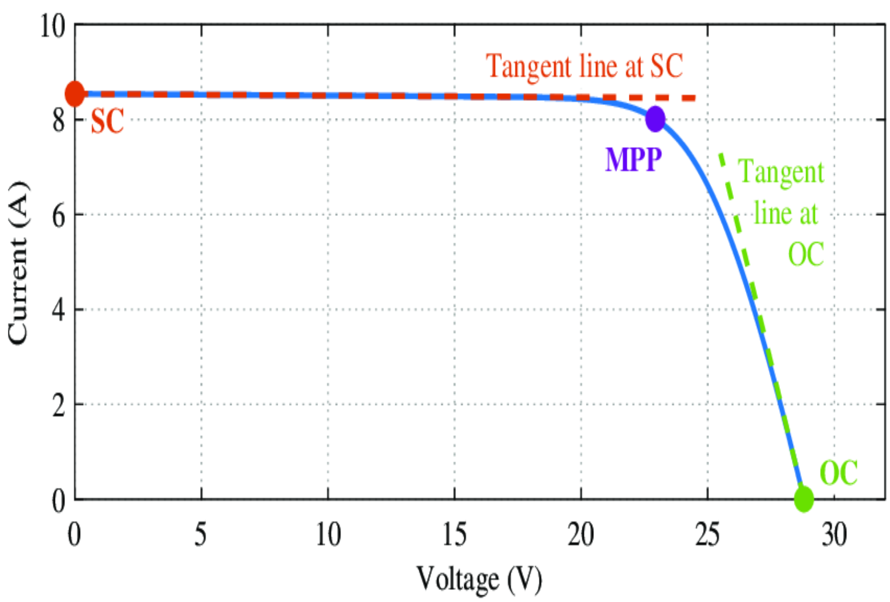


Figure 2.3 Sample Current Voltage graph of a Photovoltaic cell [8]

2.4.3. The constituent that influencing photovoltaic cell performance

1. Load Resistance- the load will decide at what voltage the PV will work. When the module work at a slightly high voltage than the battery, the battery starts charging. To get high efficiency from the module the load resistance must match with the current versus voltage graph at which the PV panel can operate near the maximum PowerPoint. Thus our load is compatible to work at high voltage because as we know air conditioner internal resistance meets with the module.

2. Intensity of Sunlight- a photovoltaic array output power is in direct relationship with the intensity of solar radiation to which it is exposed. To get a better module output power greater intensity of sunlight is needed and Ethiopia is compatible because Ethiopia is found on the equator.

3. Cell Temperature- The cell temperature is an important parameter for the Photovoltaic module's performance .when the cell temperature increases the efficiency of the module decreases. And at the same time, the operating voltage decreases with an increase in cell temperature. Therefor to manage this temperature convective air flow is chosen [9]

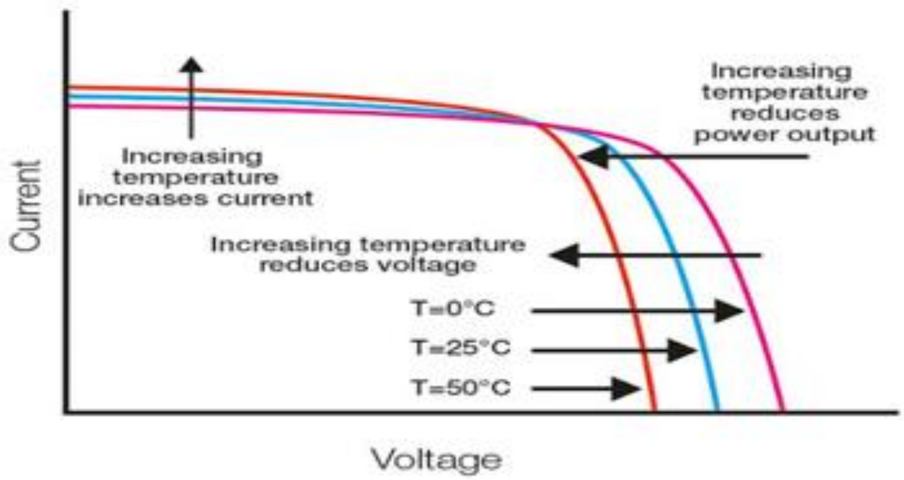


Figure 2.4 Effects of Temperature on module cell [9]

4. Shading- the photovoltaic modules also affect by cell shading. Shading results in loss of power on PV modules. One completely shaded cell can reduce the module's output by as much as 80%. So study the shading effect is important for this study because the train does not station its movable so studying the shading effect is important.

2.4.4. The photovoltaic cell

An important component in the photovoltaic module is the cell. When the sun irradiation crosses the module surface electric potential is produced in cell material. The photovoltaic cell is prepared from a wafer which is a semiconductor material like silicon and germanium but most of the time silicon is used because it is abundantly available [10].

For a photovoltaic cell, Silicon is used because of its semiconductor properties. To modify its electric properties boron and phosphorus are doped to create an imbalance in molecular charge [10].

2.4.5. Photovoltaic string

One module can deliver small power to supply the necessities of load in our case to supply air-conditioning load so the module connected based on series or parallel configuration called an array. The PV module produced direct current power so to supply for an alternating current most array uses an inverter that connects into the existing to power the load. In the photovoltaic module to get the target voltage the modules in a PV array connected in a series arrangement; to produce the targeted current the module is connected in a parallel arrangement. Thus photovoltaic systems output power measured by watts, kilowatts, or even megawatts [10].

2.4.6. Electrical characteristics of PV modules

Standard Test Conditions (STC) is a manufacturer standard that all PV modules are tested and differentiate from each other. There are three important factors while designing a solar system in STC this parameter are considered in this research. those parameters discussed as follow [10]

1. Irradiance (sunlight intensity), is the radiant power received by a surface per unit area. The SI unit of irradiance is the watt per square meter (1,000 Watts/m^2).

2. Air Mass, defines the direct optical path length through the Earth's atmosphere, expressed as a ratio relative to the path length vertically upwards. 1.5 is the standard Air mass the standard is 1.5.

3. Cell temperature, is the actual temperature of the solar cell, it is a different temperature from ambient which will differ from ambient air temperature. At STC cell temperature is 25 ^oC.

4. Efficiency (η), is the electrical power output Pout divided by electrical power input, Pin, into the PV cell. P_{out} is sun intensity-based because it operates at its maximum so maximum power can take P_{MAX} to get maximum efficiency.

$$\eta = \frac{p_{out}}{p_{in}} \Rightarrow \eta max = \frac{p_{max}}{p_{in}} \qquad 2.1$$

The p_{in} is a multiplication of the irradiance of the incident light, its SI unit is W/m^2 or suns (1000 W/m^2), which is at solar cell secure area (m^2). The efficiency can affect by different parameters like ambient conditions such as temperature so a simple test is not the only parameter for module performance. The maximum efficiency (η_{max}) gets after all the current versus voltage parameters [10].Therefor for this research monocrystalline module is selected .

Table 2.1 PV Module Characteristics for Standard Technologies [10]

PV	η_r (%)	0 (°)	β_p (% /°)
Mono-cry	16.5	45	0.4
Mono-si	13.0	45	0.4
Poly-si	11.0	45	0.4
Si	5.0	50	0.11
Cd Te	7.0	46	0.24
CIS	7.5	47	0.46

2.4.7. Advantages and drawback of using photovoltaic systems

A. Advantages

Reliability- solar power systems are preferred for loads that operate all the time to prevent power failures in case of continuous power supply with low maintenance is a must. So the reliability of a photovoltaic system is one of the advantages.

Cost- photovoltaic systems are less cost during operation compared to fuel or grid power cost because it needs only some inspection within some interval and some critical maintenance.

Universal Applications- from all renewable energy technology Solar photovoltaic system is preferred due to its versatility and due to its power generating capability under virtually all conditions, that is even in cloudy light conditions. `

Peak Shaving- peak shaving is a power cover during peak load demand so during hot sunny days air conditioner system needs peak demand thus the photovoltaic system is the best choice during peak demand.

Dual-use - Solar panels have two importance that is it produces electricity at the same time it can cover the top structure and can use as a cover for a structure .in this research solar panel will be installed in the roof of coach so it uses as strength of a Train structure.

Environmentally safe- Solar power systems are safer energy sources because it doesn't have any emissions and noise. And solar power systems are the most suitable technology for both urban and rular applications.

B. Drawback

Cost - as compared to other technology solar Photovoltaic systems have a high investment cost. Each solar assembly must be evaluated from an economic view and compared to available alternatives

Variability of Available Solar Radiation - solar system works by sun energy so if there is no sunshine the power output of the module will lost.

Energy Storage - the photovoltaic system needs energy storage to store energy at the time of no sunshine that uses to supply the load. So the cost and size of the system increased.

2.5. Batteries types and specifications

An electric battery is electrochemical cells that transform chemical energy into electricity, when the sun energy lost during night time and power is needed to supply load the battery is important. Since a module output is seasonal and different though out the day. The energy storage device is important to provide relatively constant power. even the energy comes from the module isolated in case of maintenance or during no sunshine [26].

Based on their specific design and performance characteristics the battery has many types. They are used for different applications from those applications solar system is one. All batteries have different characteristics and based on the characteristic design they have their strength and weakness. In the photovoltaic system most common battery type used is lead-acid batteries because it is widely available in different capacity and size with minimum cost .also they have the best performance when compared to other .the another type of battery most used now a day is nickel-cadmium but due to their cost most photovoltaic system didn't use it .while choosing a battery for a solar system there is no perfect battery so it's a task to choose better battery type based on the load .electrical storage are classified into two groups that are primary and secondary batteries. [26]

- **Primary Batteries-** is a battery that is designed to be used once and discarded, and not recharged with electricity and reused like a secondary cell (rechargeable battery). In general, the electrochemical reaction occurring in the cell is not reversible, rendering the cell un rechargeable. As a primary cell is used, chemical reactions in the battery use up the chemicals that generate the power; when they are gone, the battery stops producing electricity. Primary batteries are not used in PV systems because they cannot be recharged.
- **Secondary Batteries-** A secondary battery the reaction can be reversed by running a current into the cell with a battery charger to recharge it, regenerating the chemical reactants. Primary cells are made in a range of standard sizes to power small household appliances such as flashlights and portable radios. Lead-acid batteries are commonly used batteries in PV systems.

2.6. Charge Controllers

In most photovoltaic systems to protect the batteries from overcharge, charge controllers are used. Overcharging produces heat that heats the electrolyte inside the battery and causes failure of the battery. when the battery is discharged all it will cause permanent battery failure and it also cause damage to the load .there for charge controller is a basic equipment of the photovoltaic system [27].

The charge controller has many functions to protect battery charging and discharging. When the battery is fully charged and reaches its state of charge the controller controls the battery charge state and switches off module current. When the battery is empty and reaches its depth of discharge if the controller includes the low voltage disconnect capability and disconnects all load and charges the battery [27].

The state of charge is measured by the controller measuring device by checking the battery voltage. It also improves battery performance by checking battery temperature. To increase the life and performance of battery voltage of the controller must be matched with the nominal system voltage and they have to be capable of handling the maximum current produced by the PV module [27].

2.6.1. Classification of controllers

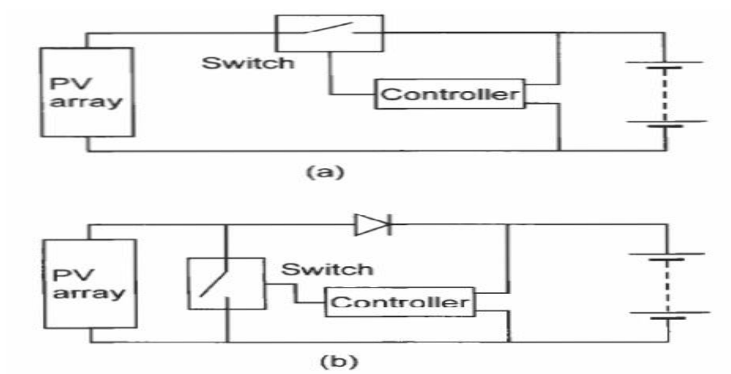
The charge controller has different types some are listed below [12].

Shunt controller – it works by shunts the charging current away from the battery. These types of controllers dissipate excess current by using a heat sink. Shunt controllers are used for smaller current system that is up to 30 amperes.

Series controller – it works by interrupting charging current by open-circuit. This controller current is handled by the switching controller to switch the direct current.

Single-stage controllers – is used to isolating the module when the storage reaches the maximum voltage level.

Multistage controllers – this controller is efficient than others on its charging level. thus it allows different charging currents as the battery nears full state-of-charge.to increase internal resistance the battery must be at full state of discharge.



6 Figure 2.4 (a) Series Controller (b) Shunt Controller *[27]*

2.7. Inverters

Inverters have known as Power conditioning units .they used to convert alternating current to direct current so it is important for a rooftop solar system. Based on operating direct current voltage the system inverter will choose [28].

To select the inverter all ac load requirements should be considered for tolerance, which are power, variation in voltage, frequency, and waveform. On the module output, dc voltage, surge capacity, and acceptable voltage variation have to be considered. To choose the best inverter for solar modules seeing many parameters is important [28].

To secure the performance and reliability of a PV system choosing a compatible inverter is important. Rooftop solar system inverters operate at 12, 24, 48 or 120 volts dc input and create 120 or 240 volts ac at 50 Hertz. There is a different category of inverter-based on the waveform, that is Square wave, Modified sine wave, and Sinewave and it is an important parameter. DC voltage is an important parameter to select the inverter input voltage [28].

2.8. Previous studies

Seeing many papers on the relation between air conditioners and photovoltaic electricity is important to design a solar-powered air conditioner. This paper is beneficial when it came to Ethiopia contexts, as seen below, the researchers are explained below.

Samah Izzeldeen Mohammed tried to design air conditioning supplied by a rooftop photovoltaic system, designed and select an air-conditioning unit for a Sudan train coach using solar energy as the only source of energy to decrease the cost and power consumption of train that generated energy from diesel generator[29].

M. Shravanth Vasisht, C. Vishal, J. Srinivasan, and Sheela K. Ramasesha predicted a study to assess the feasibility of installing solar photovoltaic (PV) modules on atop of train coaches. As they described most long-distance trains having coaches do not have self-generating systems, thus making power cars mandatory to supply the required power for lighting loads. Their work had shown that the area available on coach rooftops is more than sufficient to generate the required power, during sunlight hours, for the electrical loads of a non-A/C coach even during winter. Generally in their calculations, they got a result by taking the cost of diesel to be $0.88/liter, and as they stated, the installation cost of solar modules would be recovered within 2–3 year and Implementation of this scheme would also amount to an annual reduction of 239 tons of CO2 emissions. [6]

Indian Railways Get Promising Results from Solar Powered. Coach Indian Railways (IR) consumed over 17.5 billion kWh of electricity during 2013–14. this corresponds to about 4000 MW — which is almost 1.8% of India‘s power generation capacity. IR is the country‘s single largest high-speed diesel (HSD) guzzler. In 2012-13, two-thirds of IR‘s fuel bill was consumed by HSD, the remaining being spent on electricity. Indian Railways plans 1 GW solar power capacity. The Integral Coach Factory of IR had announced a project in association with the Indian Institute of Technology Madras to design coaches that will draw power from the sun for interior lighting and cooling.[30]

As a pilot project, one non-air-conditioned coach of the REWARI - SITAPUR passenger train was been fitted with solar panels on the rooftop. The panels have been generating 17 kWh of electricity every day, which has been used for lighting load. The cost of fitting these PV panels on a coach is estimated to be $6,095. Given that the coach is powered by a diesel-based electric generator, the subsidy-free-payback can be as low as 4 to 5 years [42]. According to reports, a train using solar power can reduce diesel consumption by up to 90,000 liters per year and also bring down carbon dioxide emission by over 200 tones. [30]

First solar-powered train in Europe In June 2011, the first solar-powered high-speed international train left Amsterdam bound for Paris. The train plugs into a solar energy source fitted along the line.[44] The roof of the 2.5-mile tunnel crossing from Antwerp, in northern Belgium, is fitted with 16,000 solar panels that produce about 3,300 megawatts per hour of electricity, or the average annual consumption of nearly 1,000 families. They will not only power the high-speed rail but also support inter-city trains while providing enough electricity to charge the train station. [31]

Also, another researcher predicts the monthly average totals of global radiation on a horizontal surface in Ethiopia had been modeled and analyzed using the Simple Model of Atmospheric Radiative Transfer of Sunshine (SMARTS) and for Vapor Pressure Radiation Model (VP-RAD). According to the Ethiopian energy authority, Ethiopia receives 5.5 to 6.5kWh /m^2/day of solar insolation almost more than an average of 345 days. [32]

Solar energy availability is fairly constant (less than 10% of average) throughout the year in the lowland areas of the country but varies substantially in the highlands more than 25% of average. [33] Therefore the country has huge potential to exploit more energy from the sun. [33] Another researcher estimates the solar radiation maps for Ethiopia by prepared measured solar radiation data from 6 sites and a sunshine hour from 136 sites using Angstrom’s correlation for the inland region and schuepp’s for the coastal region in which frequently low and high radiation and sunshine hour occur. From the prepared map they found that 500Wh/m2 /day shows the country receives a sizable and significant potential of solar radiation. [34]

J. Nelson studies Stand-alone PV (Photovoltaic System) systems can operate continuously and they used for different applications. The document shows and suggests a design for a rooftop solar system PV system characteristics with different components are described. This gives a base for the design. [11] In their research, the solar PV design technique takes into account to calculate the load. The sizing of a PV system is simple. In their research sizing of a complete solar system was presented. [11] As Marco Trentini said since 2005 a large quantity of PV systems has been installed in Italy. Almost all the systems are still operative and have demonstrated the capability to operate with much-reduced maintenance requirements offering a valuable service at reduced costs. Also different paper describes the applications which include level crossing protection units, signals, tunnel, and building lighting, telecom, and cathodic protection. [35]

VILI Solar Train Europe's first train powered entirely by its solar panels, the VILI was recently launched in Hungary to carry passengers from KIRALYRET and KISMAROS, a scenic route not far from Budapest. This solar train is particularly impressive because it carries a cabin full of passengers a task not required of many lightweight solar vehicles. [31] The train's maximum speed of around 15 miles per hour means it's not ideal for efficient travel, but it's perfect for sightseeing. [31]

220MPH Solar-Powered Bullet Train on Arizona Horizon Travelers going from Tucson to Phoenix may soon be blazing across the desert in speeding solar bullet trains propelled by the sun‘s rays. Hot on the heels of President Obama‘s plan for High-Speed Rail in the US comes the news that Arizona-based Solar Bullet LLC is proposing a new 220mph bullet train that will be entirely powered by the sun and will make the trip in 30 minutes flat.[36]

Therefore in this researchers, the Addis Ababa light rail for solar applications to run an air conditioning unit of a train .solar system is applied as an integrated source of energy while power interruption happened. Design of a solar photovoltaic system to power the air conditioning units of light city trains is considered Analysis of fixed solar panel related to its efficiency, shading, moving route, and solar irradiation. Besides, when it’s hottest and the sun is shining the brightest could make lots of power. This allows running the AC full blast to keep the train nice and cool all day without any power interruption. Even with the air conditioner on high the solar panel system still makes enough power to add into the batteries.

CHAPTER THREE

METHODOLOGY

3.1. Introduction

This section contains the methods and the design of the solar system to run the air conditioner. The best suitable equipment is selected and designed by studying appropriate properties.

The approaches used in this thesis are based on different reference[4][13][14]. And are as follows. Generally, the following diagram shows the detailed layout that follows while doing the research

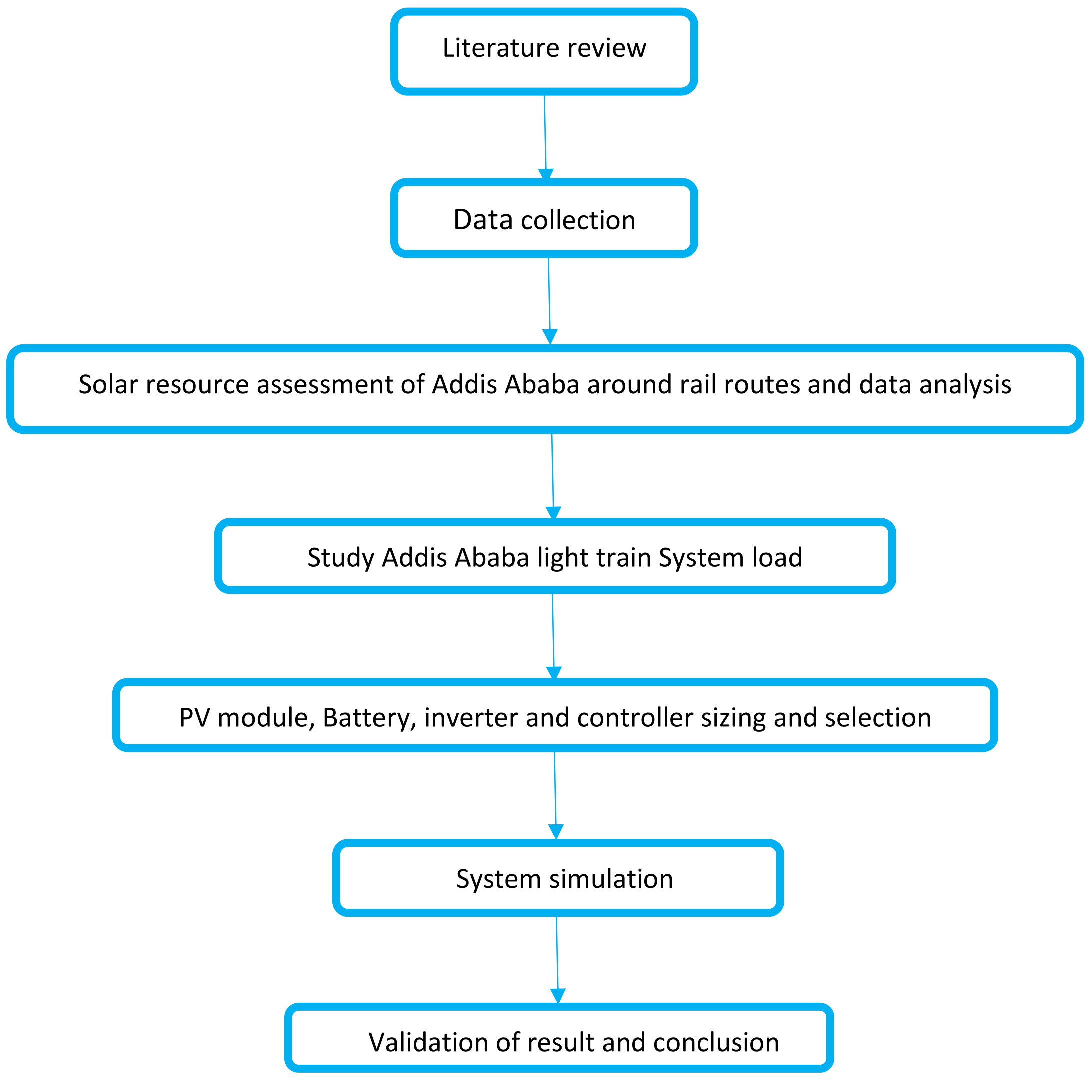


Figure 3.1 Methodology Flow Chart

The design specification and the data gathered from the metrology are also explained. Besides Air conditioning load, PV system sizing, Solar Radiation Data Collection, and Analysis, PV Sizing by PVsyst Software, Size of the PV modules, Solar charge controller sizing, Inverter sizing, Batteries sizing., Cables sizing, Layout design of PV module on the train coach are done.

From collected data Addis Ababa Light Rail is a light rail transportation system in Addis Ababa, train has two routes, these routes are east-west and south-north .the south-north line cover from Menelik II square to Kality and the east-west line covers from torhyloch to ayat in this research the only consideration is the east-west line.

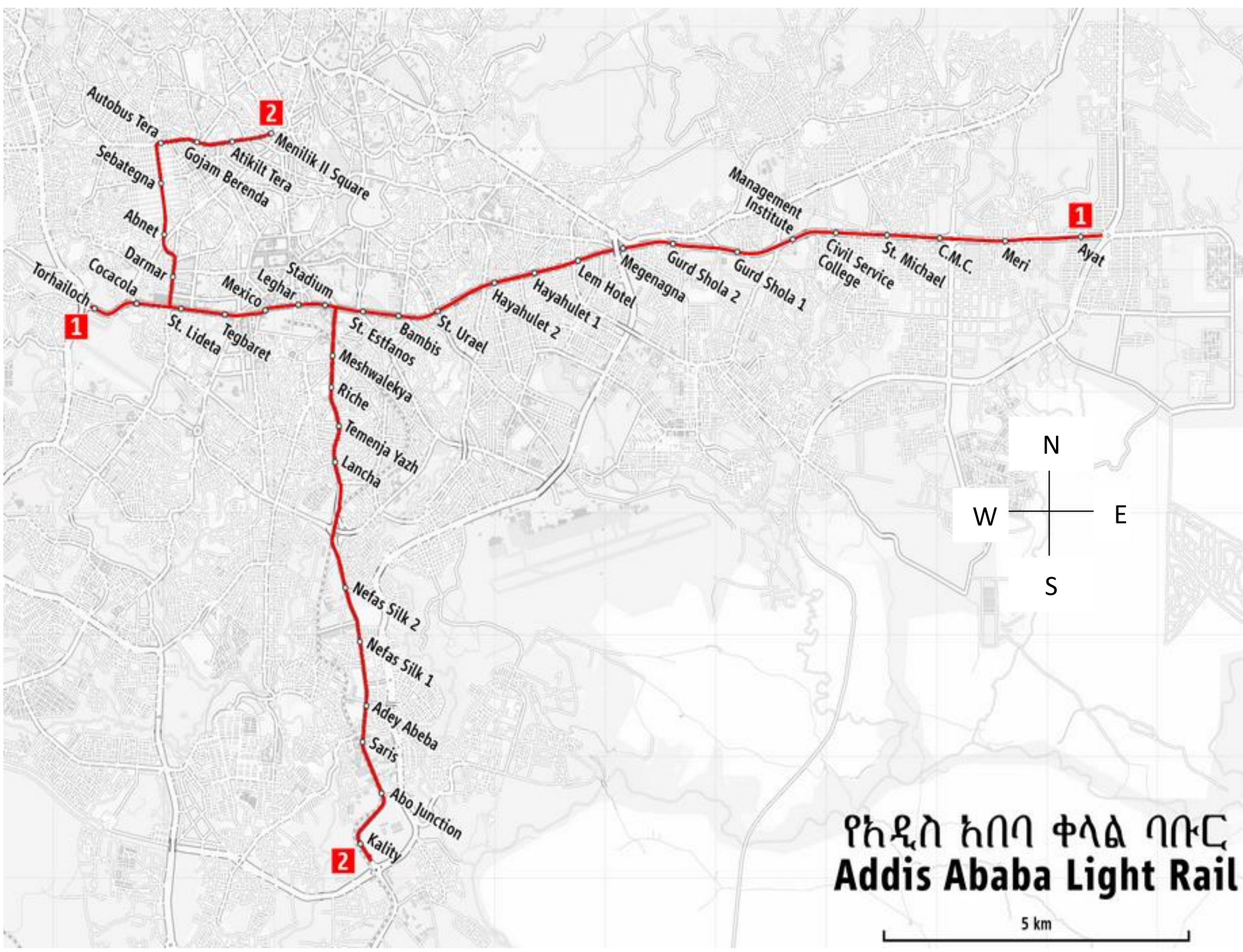


Figure 3.1 Addis Ababa light train lines [15]

Table 3.1 Summary of Addis Ababa light city train for Design Consideration [16]

Locale	Addis Ababa, Ethiopia
Transit type	Light rail
Number of lines	1
Number of stations	22
	Operation
Began operation	20 September 2015; 5 years ago
Operator(s)	Ethiopian Railway Corporation, Shenzhen Metro Group
Number of vehicles	20
	Technical
System length	17.1 km
Track gauge	1,435 mm standard gauge
Electrification	750V DC Overhead catenary
Pv module power	330w
Cooling load for air conditioner for each air conditioner	6kW
Total Air conditioner power consumption	9kW
Top speed	70 km/h
The minimum radius of the horizontal curve	50m

Mainlines between sections	50m
Yard line	30m
The minimum radius of the vertical curve	1000m
Maximum gradient	55%
Type of rails for main lines and depot	50kg/m
Maximum super elevation	120mm
Overload capacity (AW3)(standing: 8 persons/m2)	317 people

Train structure

Table 3.2 Detail structure of a train [16]

Purpose of locomotive	Passenger
Length(m)	28.4
Width(mm)	2.65
Operating temperature	20-30 ^{0}C
Max. configuration of a car in a train	4
Rooftop area of each locomotive(m^2)/car	75.26
The effective area of a locomotive (m^2)/car	71.669
Total effective area(m^2)	210

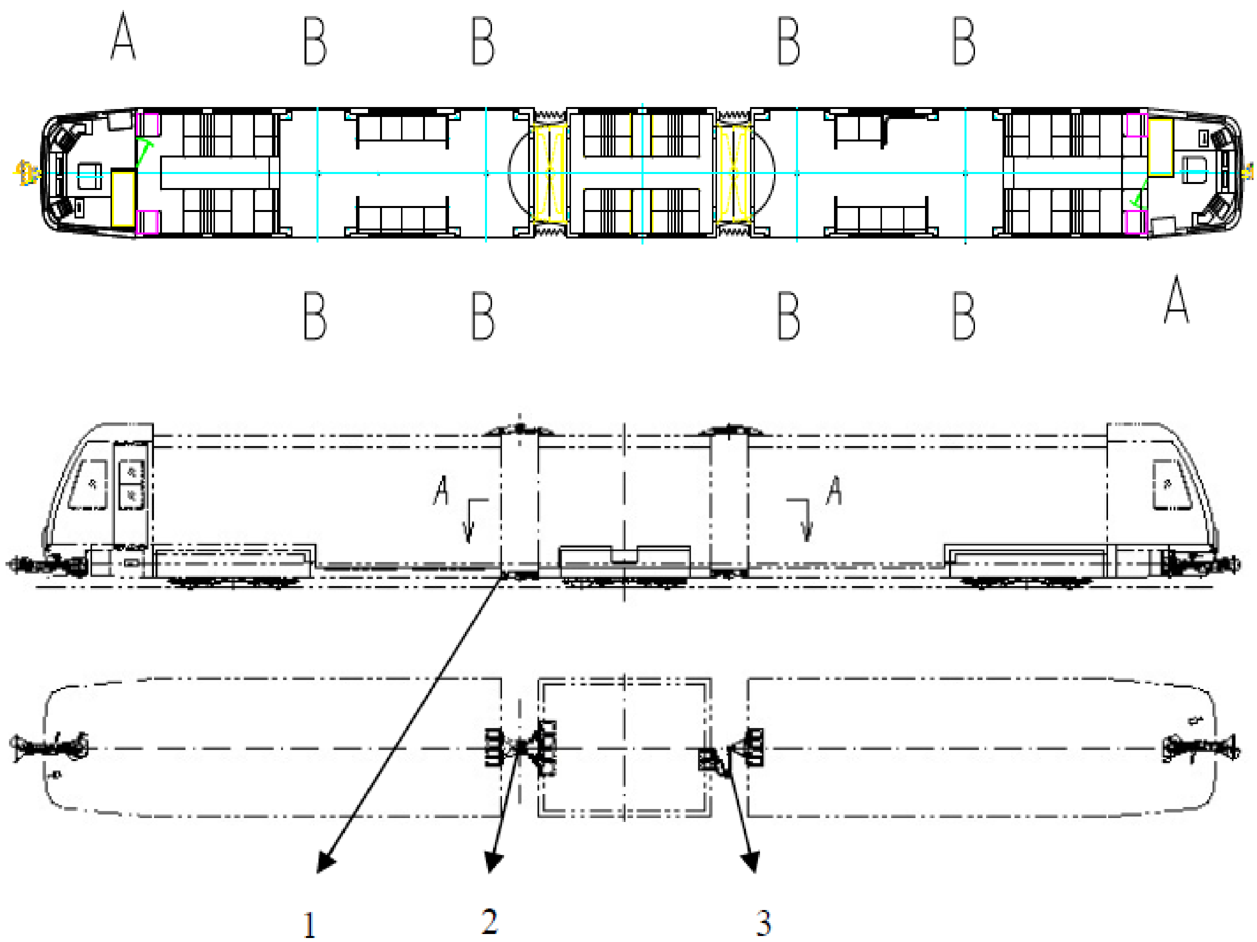


Figure 3.2 Schematic of view of a coach with the design [16]

3.2. Air conditioning load

While designing a solar-powered air conditioner for a light city train gathering information about the air-conditioning of a train is important to know load compressor power consumption and how many hours the air conditioner works. Trains for Addis Ababa are provided with air conditioning and ventilation systems to provide fresh and cooled air for both passengers and train operators.

The air conditioning unit has a built-in heating unit, which makes the car inside comfortable in winter. Parameters of the air conditioning system are designed in compliance with TB/T1804-2009 "Air condition unit for railway passenger car" standard. DLD25A type air conditioning unit has been supplied and used for Addis Ababa, Ethiopia project. The air conditioning system performs air treatment in a saloon, to achieve dehumidification and refrigerating function, and to create a comfortable environment for passengers. The air conditioning unit casing is made of stainless steel plate, has the advantages of high strength, low weight, corrosion resistance.[37]

3.2.1. Basic of air conditioning system in a train

From the collected data, each train set is installed with two sets of air conditioning units. All air conditioning units are identical and interchangeable. An exhaust unit is installed for each train set considering air exchange for driver's cab and passenger saloon. The ventilation unit is installed in the driver's cab to satisfy the required amenity for the driver's cab.[37]

For cooling and heating, fresh air volume by each unit is greater than $1300m^3/h$ considering permissible dust resistance on the strainer. Under nominal working conditions, the noise level of the air conditioning unit should comply with standard TB/T1804.[37]

The Air compressor incorporates a hermetic vertical turbo compressor. Air compressor is protected against overload, ground, and open phase, under-voltage, and over-voltage. An Air compressor is provided with a protective device against high and low voltages. Fans of air conditioning units comply with relevant standards. [37]

Fan motors of the air conditioning unit comply with relevant standards. The ventilation fan is provided with low noise centrifugal fan and protected against overload, short circuit, under-voltage, and open phase. It can operate in a humid environment. The condenser fan is low noise waterproof axial fan and protected against overload, short circuit, under-voltage, and open phase. It can operate in a humid environment. [37]

Throttling device: Throttling capillary tube or expansion valve should be applied. Environment-friendly refrigerant R407C is applied. Both evaporator and condenser are structured with copper tubes and aluminum fins. Frames of evaporator and condenser are made of corrosive resistant materials that have sufficient rigidity and strength. Drainage pipe has sufficient inclination necessary to discharge condensate or rainwater. [37]

The casing of the air conditioning unit is made of stainless steel without any coating. The air conditioning unit is controlled by a microcomputer. The temperature inside the passenger saloon is controlled by the respective temperature controller. Besides, it has functions for self-diagnosis and failure recording. The air conditioning unit has different operation modes: auto cooling, auto heating, ventilation and stop. Available states of operations include pre-cooling, full cooling, half-cooling, pre-heating, full heating, half-heating, ventilation, cooling, power failure, and degraded power supply. For full cooling, two air compressors of the unit will be in operation.[37]

For half cooling, only one air compressor is operating. For automatic operation, the air conditioning unit will automatically adjust the temperature inside the passenger saloon following external temperature. The fresh air valve will turn off for pre-cooling (heating) so that the temperature inside the car can quickly reach the set point. When the train is in normal operation, the train operator will execute centralized control over all air conditioning units throughout the train. The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system as follows. So from the collected data total air conditioning load for the train is 9 kW. [37]

3.3. PV system design selection

This chapter presents the photovoltaic panel design to produce electricity to supply the air-conditioning unit and then chooses the suitable one for this application based on a correct procedure that can use while designing the PV system.

3.3.1. Solar Radiation Data Collection and Analysis

Solar Resource Assessment of Selected Site

In this section, solar radiation data of Addis Ababa is obtained from Ethiopia the National Meteorological Services Agency, and PVGIS by inserting the required parameter as shown in the below figure.

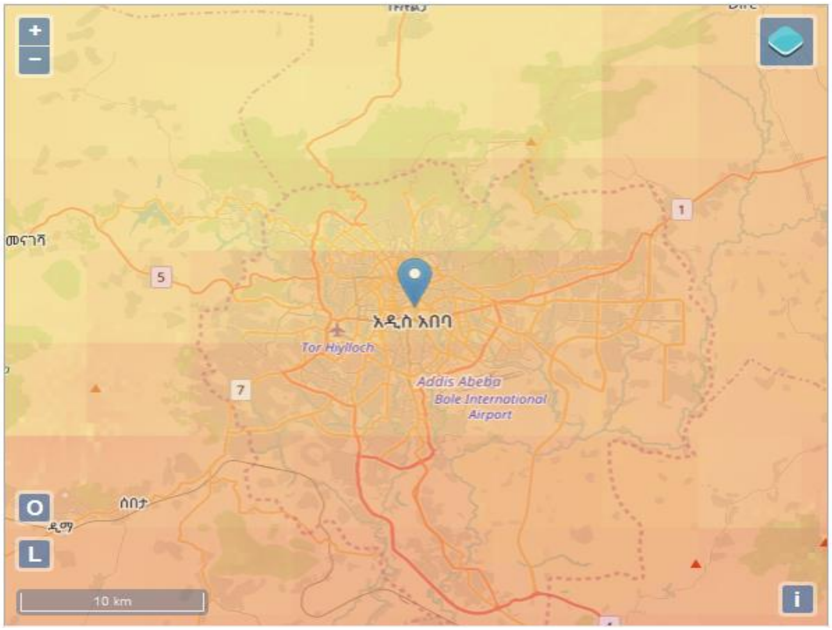


Figure 3.3 Addis Ababa PVGIS Solar radiation data [38]

PVGIS estimates of solar electricity generation [38]

Location: 8.9806° N, 38.7578° E, Elevation: 2,355 meters (7,726 ft).

Solar radiation database used: PVGIS-CMSAF

Estimated losses due to temperature and low irradiance: 12.9 % (using local ambient temperature)

The estimated loss due to angular reflectance effects: 2.2%

Other losses (cables, inverter, etc.): 13.0%

Combined PV system losses: 25.2%

Table 3.3 PVGIS estimates of solar electricity generation

Month	H_d	H_s
January	6.17	219
February	6.713	212
March	6.946	225
April	6.455	189
May	6.362	189
Jun	5.557	181
July	5.523	193
August	5.262	204
September	5.378	209
October	6.028	213
November	5.874	214
December	5.804	217
Yearly average	6.17	205.4

H_d : daily global irradiation that inter to the panel of the given system (kW/m^2/day)

H_S: a sum of global irradiation that inter to the panel of the given system (kW/m^2/day)

Collected site data from NASA

Latitude 9.18 / Longitude 38 .85 was chosen and Geometry Information is Elevation: **2,355** meters taken from them; NASA GEOS-4 model elevation; Northern boundary **10**; Western boundary **41**; Eastern boundary **42**; Southern boundary **9**

Table 3.4 Monthly Solar radiation data from NASA [39]

Monthly Averaged Clear Sky Insolation Incident (kWh/m^2/day)												
Month	1	2	3	4	5	6	7	8	9	10	11	12
17years average	6.17	6.94	6.71	6.94	6.45	6.36	4.77	5.55	5.55	5.56	6.02	5.87

Solar PV sizing: Sizing of the photovoltaic system is done in the worst operating condition. For the solar PV system design, solar data is available but check by numerical analysis in this method uses the minimum monthly solar irradiation. [22] The declination angle can be calculated

$$\delta = 23.45 sin[\frac{360}{365}(284 + N)] \quad 3.1$$

Since July month is minimum solar irradiation as shown in table 3.6 assume July 17 that is a number of days equals 212 is selected for PV sizing, and this value uses to calculate declination angle and gives a value 18.17^o by using equation 3.1.

By assuming 1:15 PM the Hour angle ω is calculated by using solar time.

$$\omega = (ST - 12) \times 15^0 \quad 3.2$$

Using equation 3.2 the hour angle gives 18.75^o this value needs to calculate the zenith angle.

For the surface, zenith (θ z) can be calculated using equation 3.3.and gives a value of 20.6^0 by latitude ϕ of approximately 9^o.

$$Cos\,\theta z = cos\,\varphi \times cos\,\delta \times cos\,\omega + sin\,\delta \times sin\,\varphi \quad 3.3$$

For this specific design the value of (ϕ − β) is needed for the calculation of the angle of incidence of surfaces sloped due to north or due to south where β is the slope of the panel, this slope β have the same angular relationship to beam radiation. For this design slope β for all year β = ϕ because the training structure is not normal it has 9^o inclination so for this research the slope angle is equal to the latitude of the site besides choosing a slope greater than latitude is not good for the train due to stability of train structure.

For summer $\beta = \phi - (10^0 - 15^0)$ *and for winter* $\beta = \phi + (10^0 - 15^0)$. 3.4

$$Cos\,\theta = cos\,\delta \times cos\,\omega \times cos\,(\phi - \beta) + sin\,\delta \times sin\,(\phi - \beta) \quad 3.5$$

Therefore the angle of incidence is 18.15^o

Where: δ is the declination (°) calculated from equation 3.1 and ϕ is the latitude (°), θz is zenith angle (°), θ is the angle of incidence (°), ω is Hour angle (°),β is slop and ϕ is latitude

Solar Radiation- The solar radiation inters to the surface is two types that are beam radiation and diffuse radiation. Beam radiation I_b is solar radiation entering the surface. It is also referred to as direct radiation

And Diffuse radiation I_d is the solar radiation scattered by different air molecules. Diffuse radiation has no unique direction. The total radiation (I) is adding the two radiation that is beam and diffuse radiation and is called global radiation.

Calculation of total Radiation on a Surface - When the amount of diffuse radiation reaching the earth's surface is less than or equal to 25% of global radiation, the sky is termed as clear sky. There is a method for determining the transmittance of beam radiation on a sunny day.

Thus to calculate the value the height of the area in km over the cruel ocean level, a number in the year N, and the zenith angle (θ z). The transmittance of diffuse radiation through a sunny day, the beam, and diffuse radiation is calculated as follows.

The beam radiation on an earth surface is:

$$Ib = In\, \tau b \cos \theta z \qquad 3.6$$

Where: $In = Isc[1.0 + 0.033 \cos(360\, N/360)]$

$$\tau b = ao + a1\ e(-k/\cos \theta z)$$

$$ao = ao \times ro\,,\ a1 = a1 \times r1,\quad k = k \times rk$$

Where

$$a0 = 0.4237 - 0.00821(6 - A)^2$$

$$a1 = 0.5055 + 0.00595\,(6.5 - A)^2$$

$$k = 0.2711 + 0.01858\,(2.5 - A)^2$$

r_0 = 0.95; r_1 = 0.91, r_k = 1.02, A= altitude in (2.355 km) = 2,355 m

A is the height of the area in km over cruel ocean level τ_b The atmospheric transmittance for beam radiation, τ_d The atmospheric transmittance for diffuse radiation, I_d diffuse radiation, I_b beam radiation

The diffuse radiation is:

$$Id = I\, n\, \tau\, d\, \cos\theta z \quad 3.7$$

Therefore, totally clear sky radiation on a surface is calculated as follow

$$IT = I\, b + Id \quad 3.8$$

Thus, total clear sky radiation on a horizontal surface is 991.17 W/m^2

Peak Sun Hours

For the solar PV system design, the minimum monthly solar irradiation is used in determining the peak sunshine hours. This approach is usually required for the design of solar PV systems (designing for worst conditions).

The performance of the solar PV system depends largely on the peak sun hours of the location of the application. The peak sun hour(s) of an area is determined to form the available solar irradiance of the location. The peak sun hours and total irradiation are related by Equation 3.9

$$\mathrm{PSH} = \frac{\mathrm{I}}{\mathrm{PSI}} \quad 3.9$$

Where: I –is irradiation (4576 Wh $/m^2$ /day) and PSI peak sun irradiation (991.71 W/m^2)

Therefore from equation 3.9, the peak sun hour is 4.84 h/day (This PSH is in July)

After compare, collected data of PVGIS, Ethiopian methodology agency, and NASA, take minimum solar radiation. The number of peak sun hours can be obtained by equation 3.9 using minimum monthly solar irradiation data in July 4.576 kWh/m^2 /day from Table 3.5.

Table 3.5 Average summarized solar data

Months	No. of Day	$\delta(d)$	G
1	31	-17.8	6.17
2	59	-8.67	6.713
3	90	3.62	6.946
4	120	14.6	6.455
5	151	21.9	6.362
6	181	23.2	5.557
7	212	18.2	4.576
8	243	8.1	5.262
9	258	0.096	5.523
10	304	-15.1	6.028
11	334	-22	5.874
12	365	-23.1	5.804

3.3.2. PV design by PVsyst Software

From irradiance of location and describe loss factor of energy on the sun-powered array and by utilizing this irradiance can calculate peak sun hours. The inputs of the PVSYST computer program for this work are latitude, Elevation, Time zone, and longitude of a location, power requirement types of PV board, etc.

$$P\,pv = Pd \times D \times PSH \qquad 3.10$$

Where P_{pv} is Power produced from PV panel per year (kWh), P_d is the power required per day (9kW), PSH is peak sun hour (4.84$\pm$0.25) and D is a day of the year (365) .therefore from equation 3.10 energy produce from PV panel per year is 16747.3 kWh. Power output per year is almost equal to that shown on the PVsyst diagram over the whole years. Therefore the diagram over the whole years is correct.

Vertical object shadow length: This simple calculation gives a vertical object shadow length for a specified day and geographic coordinate. The calculation uses the Sun position algorithm to calculate sun altitude. Thus it uses this formula to calculate shadow length:

$$L = h/tan(\alpha), \tag{3. 11}$$

Where h - object height, α - the angle between Sun and horizon.

3.3.3. Design the PV modules

The required power of the solar panel depends on the amount of energy needed to operate air conditioning on train systems.

Specifications of the PV Model: The PV model of the solar panel selected for this work depends on the power requirement is SUNTECH STC 330, 72 cell. The selected module Area and power are 1960 × 992 × 40mm and 330 W respectively. The PV model for this system is SUNTECH features total efficiency of 16.9% which delivers the maximum power output at peak hours. Ideal for off-grid and remote power systems. With a 25 year warranty, the module has high efficiency and long-lasting operating time even in a variety of rigorous conditions. Unique textured cell surface and bypass diode design are critical for the module to fully utilize and absorb sunlight and offer maximum usable power per square meter of a solar array. [Appendix A]

The area of the solar panel would be calculated as flow: Power requirement to operate 9 kW air conditioning unit, the minimum solar radiation of site is 4.578 kWh/m^2. The efficiency of the maximum power point of the module is 16.9 % and the efficiency of the maximum power point of electronics is 80% -90% Depending on the available area, select a standard PV panel of 1.944m^2 it can produce 330 W.

$$Wp \times PSH = Ap \times Gp \times \eta pv \times \eta e \tag{3. 12}$$

$$A p = \frac{Wp * PSH}{Gp\ x\ \eta\ pv\ x\ \eta e} \tag{3. 13}$$

From the 3.13 the area is 66.35 m^2. Area available on the roof of one car 2.65m x 28.4m= 75.26 m^2but this area is the total area. It will reduce for walkway, fixing access, etc. Then consider an effective available area 71.669$m^2$the energy produced from a set of a train and the number of panels required is calculated by using the following formula

$$N_P = AE \ / Ap \tag{3.14}$$

Thus the number of panels required for a train is 36

Where NP = Number of panel required for a train A_E = effective area needed on the top roof of the train car; A_p = area of single panel; η_{pv} = solar cell efficiency, Gp = solar radiation (kW/m^2/day), Requirement power for air conditioner = Wp, PSH is the peak sun hours of the location where the system would be installed ηe = the maximum power point tracer coefficient assumes that is 0.85 [13].

The calculated result of total Watt-hours per day is needed from the PV modules: Multiply the total appliances Watt by hours per day to know the total energy per day. The required energy is 9 kW, Operation hours during a day is from 7 am to 10 pm, System current is 430.90 Ah, No of module required = 430.90 Ah / (Imp x (monthly mean global solar radiation on a horizontal surface in Addis Ababa).

$No\ of\ module\ required\ =\ 430.90\ Ah\ /\ (8.91\ x\ 7.54)\ =\ 5.84\ \approx 6.$
$No\ of\ modules\ in\ serious\ =\ 220/Vmp\ =\ 220\ /\ 37.5\ =\ 5.95 \approx 6$

Total no of modules = 6 x 6 = 36 modules, this configuration is for electrical connection

3.3.4. Solar charge controller selection

A solar panel charge controller is the heart of a solar-powered system, responsible for converting solar energy into electricity to charge the battery or the inverter in the system. It’s important to pick a solar regulator that provides reliable solar battery charging, diversion regulation, and load control. Therefor for this design the controller size is:

$$C.C\ =\ NP\,p\ \times\ Imp \times 1.3 \tag{3.15}$$

Where NP_p = No of modules in parallel, I_{mp} = module current, C.C is a charge controller

3.3.5. Inverter selection

A solar inverter is the only device that supplies power to the air-conditioning load because for now, Ethiopia has no approved feed-in tariff so it's an off-grid system. The load power rate has to be at least of the inverter power rate. Manufacturers state that inverters release higher power for a short time, which is double of load power and it is higher than rated power. As manufacturers stated the Inverter peak power is in watts. But this power is feed to resistive loads with a unity power factor only.

For compressors and motors the power factor is low, thus look for the surge current of the inverter is very important. The inverter current is an important factor that must be considered. The starting power is typically 3 to 8 times higher than the operating power for air conditioners (to handle surge current during starting) and with it the current. Therefore starting current must be considered when selecting an inverter.

3.3.6. Batteries selection

There are certain specifications when evaluating solar battery options, such as how long the solar battery will last or how much power it can provide. Depth of discharge (DOD): Most solar batteries need to retain some charge at all times due to their chemical composition. If we use 100 percent of a battery's charge, its useful life will be significantly shortened so the best DOD is important.

The majority of new energy storage technologies, such as the use of some form of lithium-ion chemical composition. Lithium-ion batteries are lighter and more compact than lead-acid batteries. They also have a higher DOD and longer lifespan when compared to lead-acid batteries. However, lithium-ion batteries are more expensive than lead-acid counterparts. Therefore for this design the batteries with storage (150Ah, 24V), Cycle life to 80% depth of discharge (DOD). Charge efficiency from 20% discharged is selected. [12]

$$BC = \frac{P}{Vs} \qquad 3.16$$

Where V_s is system voltage, P is equipment power, BC is battery capacity (Ah)

3.3.7. Cables selection

Voltage drop in photovoltaic systems (220 V) $\leq 5\% = 11V$

$$V\ drop = IR = I(\rho L)\ /\ a \qquad 3.17$$

Where I: system current, ρ: resistivity of copper wire = 40×10-8 Ω. L: length m^2, A: cross-sectional area

3.3.8. Layout design of a PV module on the train coach

The front view of the roof of the coach is as shown in the Figure below. The roof of the coach can cover , mono-crystalline PV modules of rating 330 W and tilt angle of 9^O. The modules can be mounted along the axis of symmetry 18 module on the right side 18 on the left side with 6 x 6 electrical configuration . and the roof of the coach can flute because can Install panels a few inches above the roof so convective airflow can cool the panels, a flat surface is required to be created along with the profile of the roof to facilitate stiff and easy mounting of the modules. Batteries ,inverter charge contoller are placed in the trailer coach bottem free place.

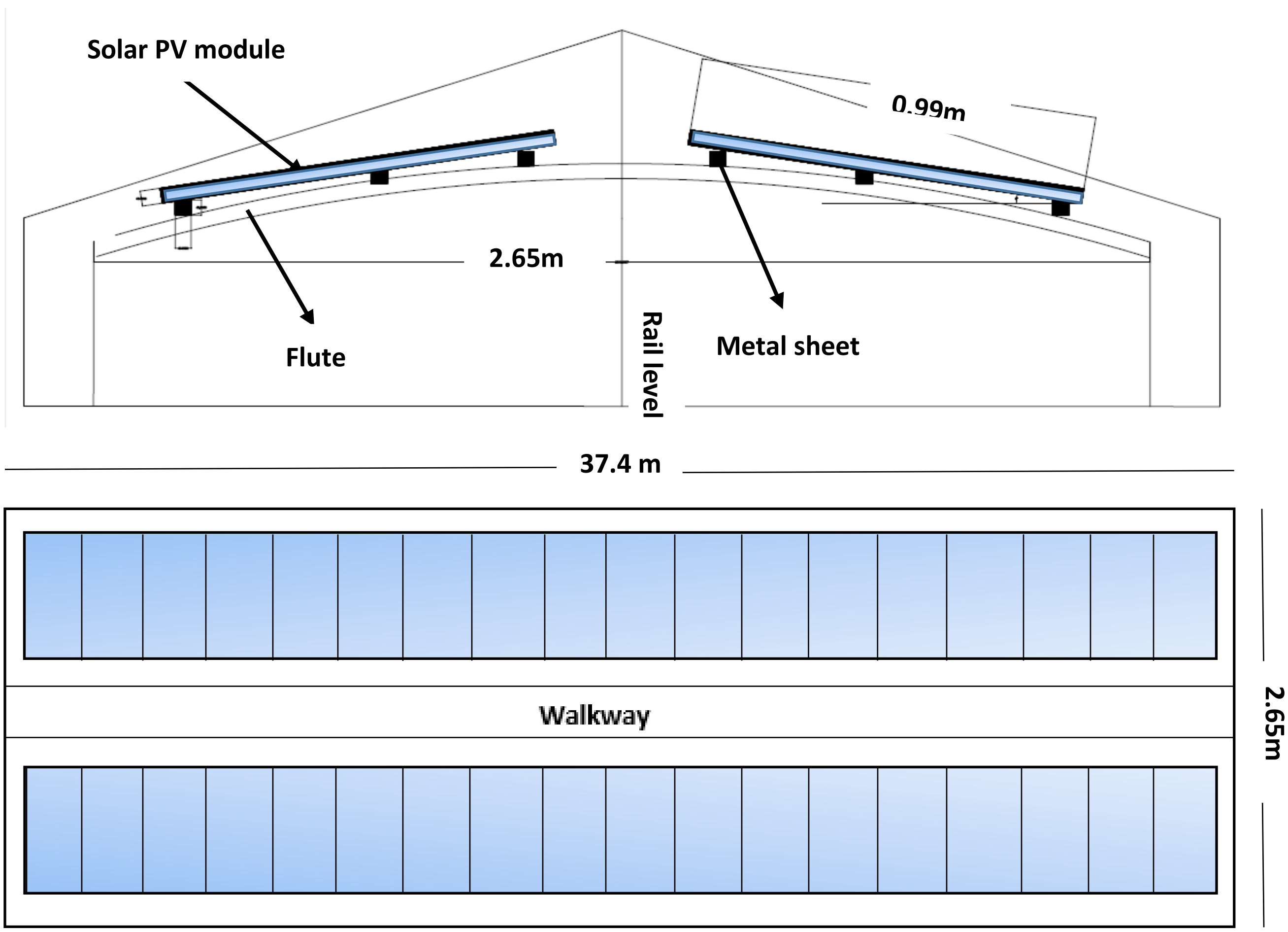


Figure 3.4 Front And Top Layout of solar PV module of the roof of the coach

3.3.9. Economic analysis`

Table 3.6 the initial cost for air conditioning unit powered by PV system [40]

Description	Quantity	Unit price	Total cost
PV modules , mono-crystalline	36	9000 birr	324000birr
Structure cost	-	-	40000 birr
Batteries	40	12000 birr	480000 birr
Cables	10 m	330 birr	3300 birr
Inverters and Charge controller	1	95600 birr	95600 birr
Others	-	-	18000 birr
Total			960900 birr

As shown in table 3.6 the total cost for the coach is 960900 birr and the running cost **is** 0 birr and batteries will be replaced every five years is 480000 birr.

$$NPW = Bt - Ct \quad 3.18$$

$$Bt = PVAB = A\left(\frac{(1+i)^n - 1}{i(1+i)^n}\right) \quad 3.19$$

$$Ct = PVFC = F(1+i)^{-n} \quad 3.20$$

Where: A: Annual benefit, F: Future cost I: Interest rate (0.4), N: Number of the year, NPW is the Net present worth of project and PBP is Payback period Bt is a total benefit, Ct is the total cost, PVAB is the present value of the annual benefit, AS is annual saving and PVFC is the present value of future cost. Payback analysis is another extension of economic analysis. Payback is the period it takes for the cash flows to recover the initial investment.

$$PBP = Ct/\ \text{AS} \quad 3.21$$

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Solar PV sizing using PVsyst software results

The design needs zenith angle, incident angle, declination angle, peak sunny hour, and irradiation as part of input parameters .using the equations discussed in the previous chapter 3, the calculated values of these input parameters are determined and written in bold (Table 4.1). Since July 17 has the minimum solar irradiation of around 4.57kWh/m^2/day (Table 3.6), it has been chosen for sizing the PV system.

Table 4.1 summery of PVsyst software input calculated parameters

Parameters	Value
Declination angle, δ	18.17^o
Hour angle	18.75^o
Zenith angle	**20.1^o**
Incident angle	18.15^o
Beam radiation	**910.76 W/m^2**
Diffuse radiation	80.41 W/m^2
Total radiation	991.17 W/m^2
Peak sun hour	4.84 h/day

Based on the above inputs, the results are shown in Figure 4.3. The monthly average power and energy outputs though out the year are clearly shown in figure 4.3 starting from January to march the energy was raging between 53 and 55 kWh /m^2 /days this has slowly dropped to 48 kWh/days. In July and august the value was a minimum of 36 kWh/m^2/days .starting from September its start significantly to grow back to its maximum value of 55kWh/m^2/days .discussed in detail as irradiance of location increase, the power required for a solar-powered train is about. 11.4 kW can be gotten this power at minimum irradiance.

Power output from PV panels per year is calculated from equation 3.10. Energy from PV panel per year (kWh) is 16747.3 kWh. Energy output per year is almost equal to that shown on the PVSYST diagram over the whole years. Therefore, the diagram over the whole years is correct.

As appeared in the below figure 4.3 as irradiance of location increment, the power required for a solar-powered train is about. 11.4 kW can be gotten this power at minimum irradiance. But these powers reduce by different losses like temperature increase, dust, etc. thus our load is 9kW so the power produced from the panel is enough to supply this load.

Vertical object shadow length: From collected data, the longest building around the east-west route is the NIB insurance headquarters building, its length is 131 m thus with latitude and longitude coordinates (9.005401, 38.763611) as calculated from equation 3.11 the shadow length is 20.17m. But the building is 20m far from the train line. Therefore the shadowing effect of the building is negligible for this case study. But as we see from the below result there is some sun irradiation variation based on the training structure. Thus, below figure 4.2 the shed loss for different parts of the PV module is shown.

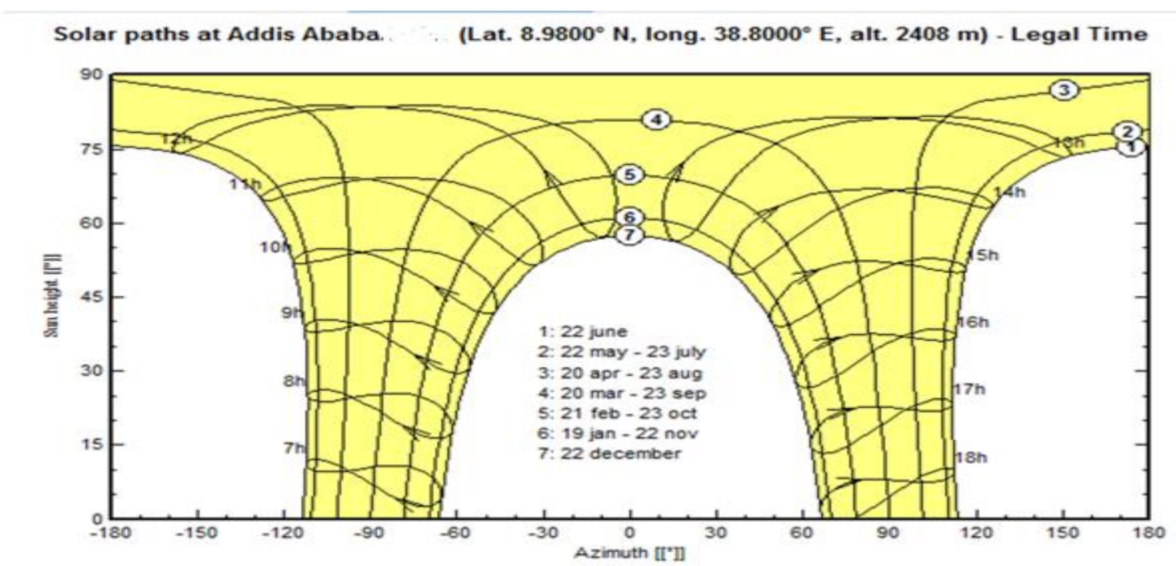


Figure 4.1 solar paths at Addis Ababa

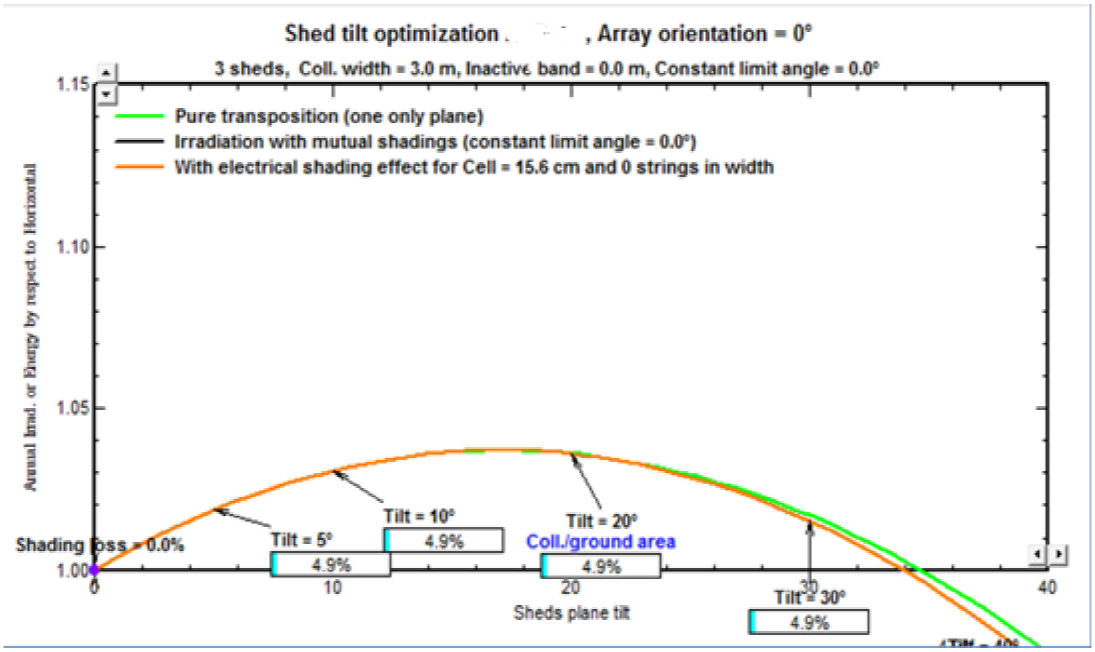
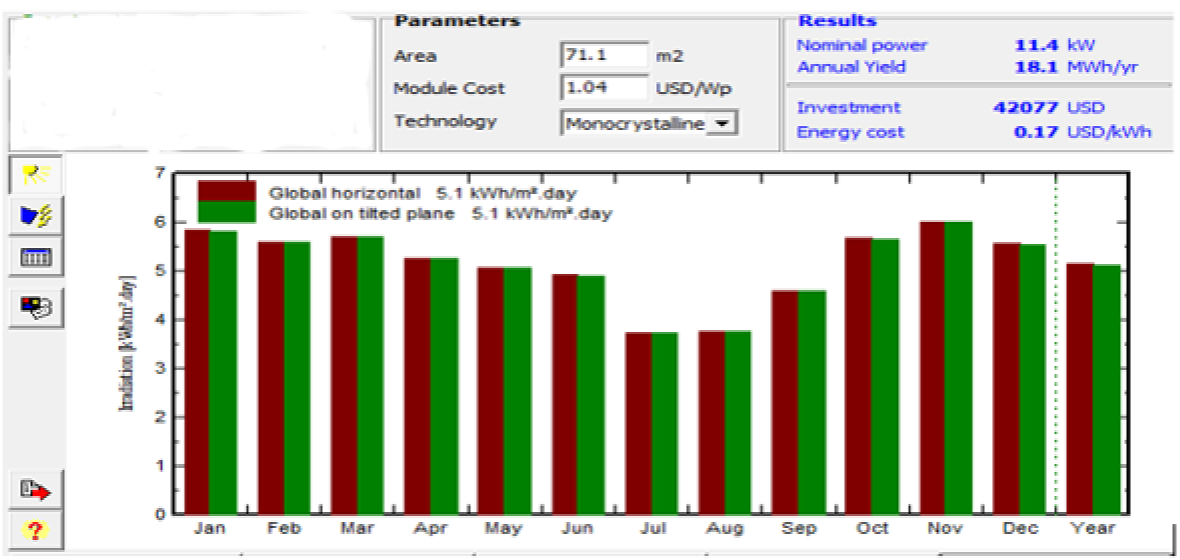


Figure 4.2 PVsyst curve diagrams for different situation

As shown below figure 4.3 from the horizontal plane that will be mounted on the roof of the rail coach by using the monocrystalline module type we can generate nominal power of 11.4kW. This means we can get 18.1 MWh/m^2/yr. annually from average 5.1kWh/m^2 .day global irradiation and we get 18064kWh/year system output energy.



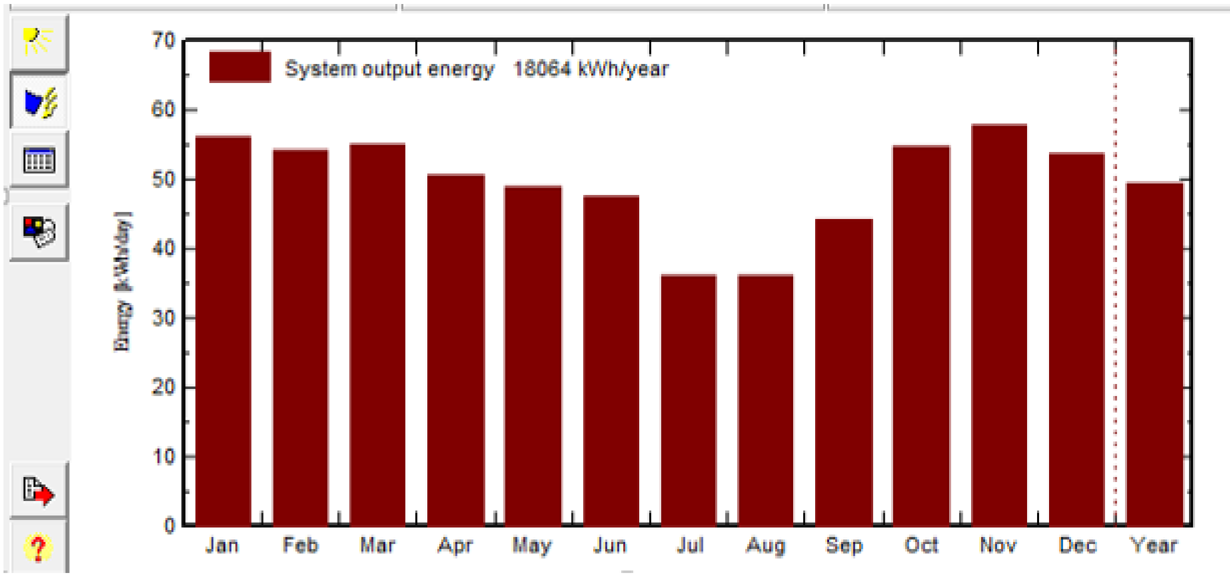


Figure 4.3 PVSYST simulation result of output power

4.2. PV modules selection and economic analysis results

The area of the solar panel would be calculated as flow: from equation 3.13 area of the panel is calculated. Depending on the calculated area, select a standard PV panel of 1.944m^2 it can produce 330 W. The selected PV panel can produce the above-required power. Therefore the design is safe. Area available on the roof of one car 2.65 m x 28.4 m = 75.26 m^2but this area is the total area. It will reduce for walkway, fixing access, etc. Then consider an effective available area 71.669 $m^2$the number of panels required is calculated by using equation 3.14.

$$Np = 66.35\ m^2/1.944\ m^2 = 36$$

Solar charge controller sizing result: from equation 3.15 solar charge controller needed is

$$\text{C.C} = 6 \times 8.91 \times 1.3 = 67.314\ \text{A} \approx 80\ \text{A}, 220\text{V}$$

Inverter sizing result: based on manufacturer data stated the peak power in watts Total required power is 9 kW; to handle surge current during starting inverter must be 3 times required power. And the type of inverter is switching power that has 95% efficiency of converting ac to dc. MUSTPOWER inverter is selected with 30kW.

$$\text{Inverter sizing} = 9\ \text{kW x } 3 = 28\ \text{kW Inverter sizing} \approx 30\ \text{kW}$$

Battery sizing result: For this research, the battery selected is the batteries with storage (150Ah, 24V), Cycle life to 80% depth of discharge (DOD). Charge efficiency from 20% discharged is selected. [31] Therefore from equation 3.16 battery capacity is from equation 3.16

$$\text{Battery Capacity (Ah)} = 409.09 \text{ Ah}$$

$$\text{Energy required from batteries} = 409.09 \text{ Ah} / \text{DOD} = 409.09 \text{ Ah} / 0.8 = 511.625 \text{ Ah};$$

$$\text{No of batteries in parallel} = 511.625 / 150 = 3.49 \approx 4$$

$$\text{No of batteries in series} = 220/24 = 9.16 \approx 10;$$

$$Total\ no\ of\ batteries = 10\ x\ 4 = 40$$

The air conditioner works from 12 – 4 o'clock LT suppose we are going to install 150A, 24v battery so each battery can cover 0.2 hours of energy and total backup hours of batteries are 8 hours with charging times of 3.5 hours because charging current should be 1/10 of batteries Ah and charging time of a battery is battery Ah divided by charging current.

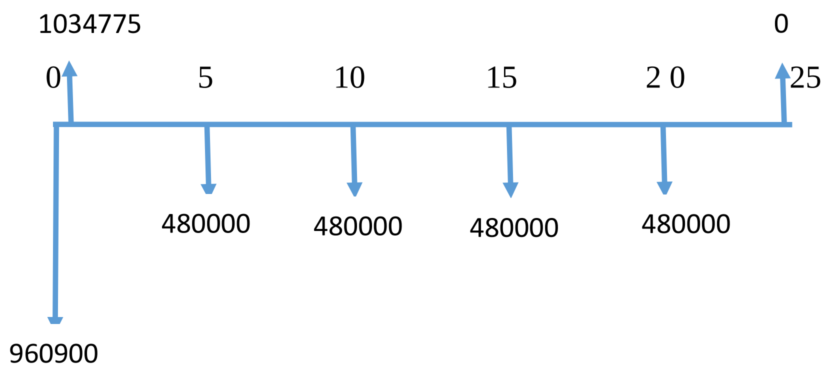
Cables sizing result: depend on equation 3.17 the cable size for this research is $54.545mm^2$

Table 4.2 summarized result of module design

Description	Result	Weight
PV modules , mono-crystalline	36	22.4kg
Batteries	40 (150A)	48.5kg
Cables	54.545 mm^2	-
Inverters	30kW	280kg
Charge controller	80A,220V	-

Therefore the train has a capacity of handling up to 53741.62 kg (59.24 tones) extra load but the total weight added on the train is approximately 3026.4kg so the design is perfect for the stability of train structure with a tolerance of 1+3% t. All equipment are from MUSTPOWER.

Economic analysis result: base on most power company data specification and universal supplier data listed in table 3.6 the economic analysis is done below.



Based on equation 3.18 - 3.20 Present value of future cost is

Present value of future cost = 480000 $(1+0.4)^{-5}$ + 480000 $(1+0.4)^{-10}$ + 480000 $(1+0.4)^{-15}$ + 480000 $(1+0.4)^{-20}$ = 89248.52 + 16594.37 + 3085.46 + 573.69 = 109502.06 birr

Total cost = (960900 birr + 109502.06 birr) **= 1070402.06 birr**

From the above economic analysis and equation 3.21, the payback period for this project is

$$= 1070402.06 \text{ birr}/1034775 \text{ Birr} = 1.03 \text{ years}$$

By comparing the 1.03-year payback systems above we found the air conditioning unit powered by the PV system is the best option economically. Finally, a short economic analysis is done for payback period considered options, and a solar air conditioning unit was found to be suitable to be utilized for the job because it is the cheapest and less than 8 years payback period option.

Thus this system is both technically and economically feasible. As a result, we can achieve the desired pleasant and comfortable interior thermal environment for the passengers at all expected external ambient environmental conditions, during the day time.

4.3. Simulation result of MAT LAB

To see the performance and characteristics of the module the short circuit point is a must, this condition happens when the current in the module is at maximum and when the voltage over the module is zero; the other characteristic performance is open circuit point, this condition happens when the voltage in the module is at maximum and when the current over the module is zero; the last characteristic performance is the maximum power point, this condition happens when the product of current and voltage in the module is at maximum and the power is at a maximum value at the points (Imp, Vmp).

There are three points (Isc, 0), (Voc,0), and (Imp, Vmp) are stated in the datasheet of the module at standard test condition (STC). But the accurate value of these points for the selected conditions is the main goal of this design. When the short circuit happens, the PV module acts as a current source and when the open circuit point happens, the PV module acts as a voltage.

Below figure 4.4 shows the simulation results of current versus voltage graph for different temperature values with constant solar irradiance 800W/m^2. In this condition, the current at zero voltage is almost constant which is 2.56 A. Similarly the voltage at zero current and maximum power output of the module both are decreases with an increase in temperature. Thus the graph shows the non-linear nature of the PV module.

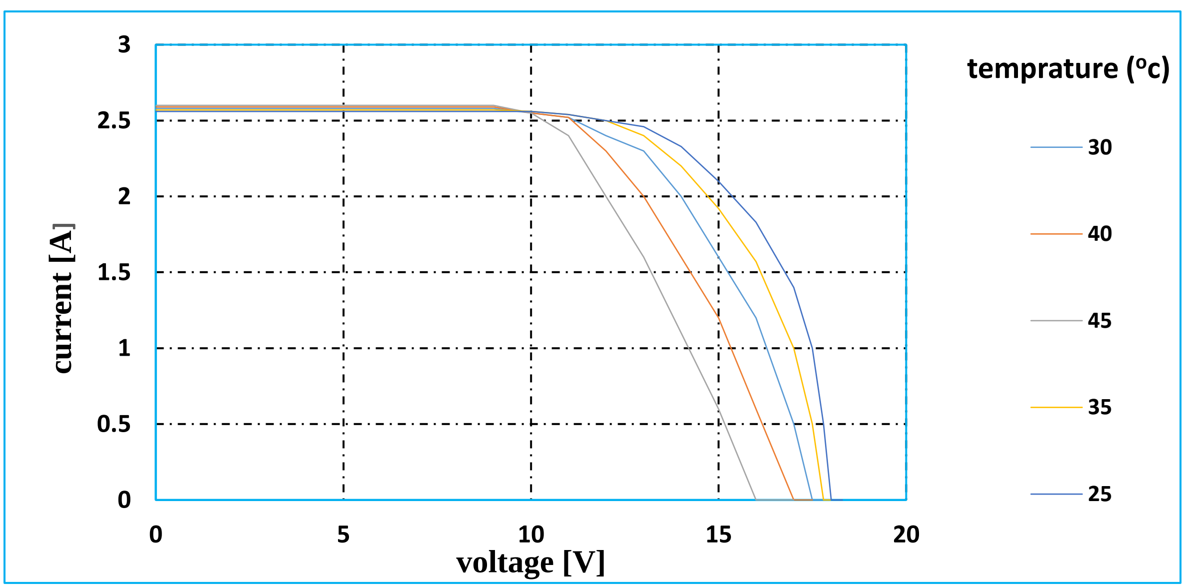


Figure 4.4 I-V graph with varying temperatures and 800 W/m^{2}solar irradiation.

Fig 4.5 and 4.6 show the simulation results of the current versus voltage graph, this graph is at different solar irradiance the current also increases. Similarly with an increase in solar irradiance the output power (Pm) also increases.

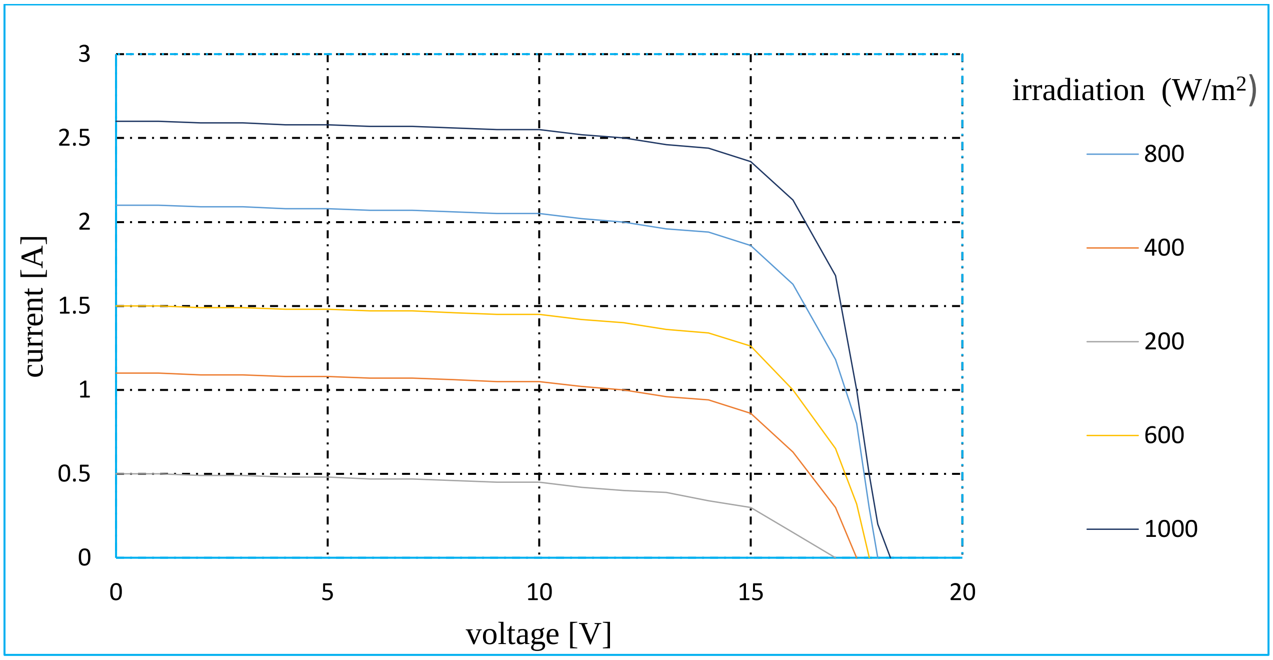


Figure 4.5 I-V graph of solar PV module at different solar irradiation

In fact, due to environmental change, solar irradiation fluctuates. When the solar irradiation increases, the solar input to the solar module also increases thus the power produced by the module increase for the same voltage value.

With an increase in solar irradiation, the voltage at zero current values increases. Because, sun incidents reach the solar cell, higher excitation of energy created electron mobility, thus higher the electron mobility therefore the power output is more.

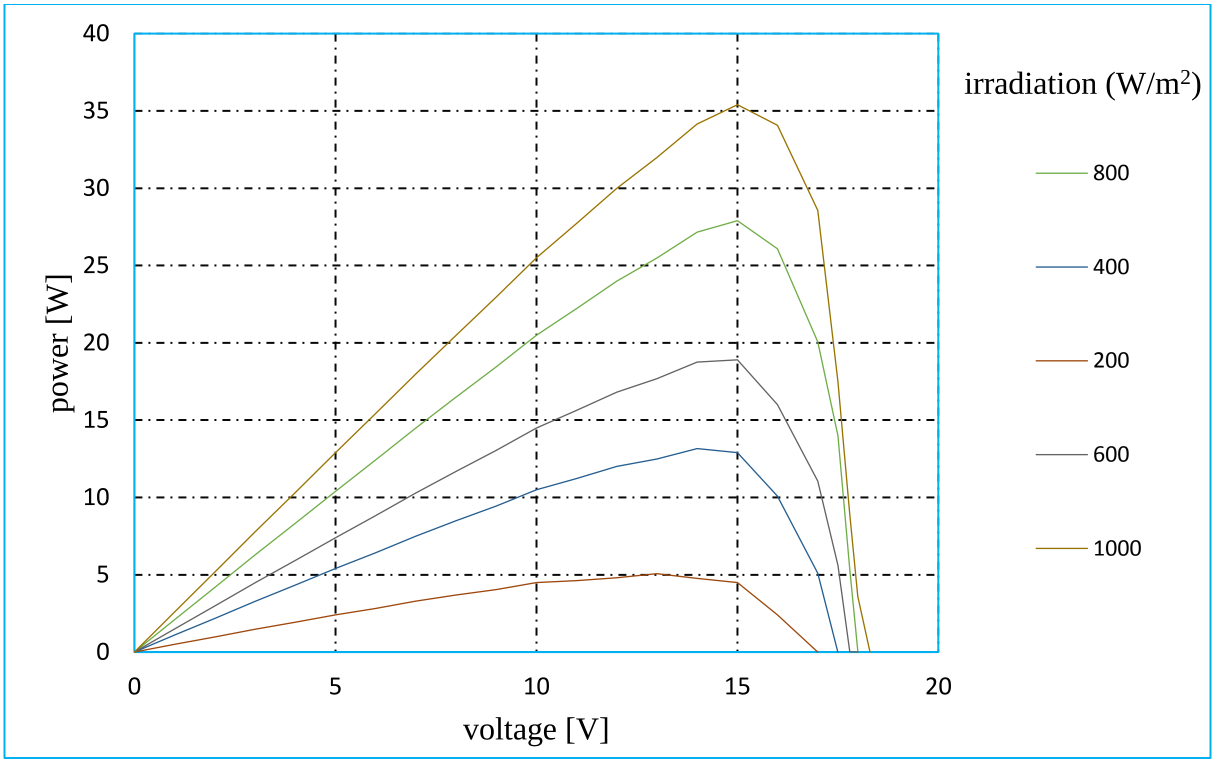


Figure 4.6 P-V graph of the solar PV module at different solar irradiation

To validate this model described above, a figure constructed after analyzing the solar data of the site, it was concluded that the data are consistent Therefore, the simulation data presented is used for validation purposes. Figures above have been constructed where the predicted outputs of the solar data are depicted under irradiation and temperature of the photovoltaic panel. It is quite apparent from these figures that my numerical model fairly predicted the power output. Besides, since this model assumes a fixed axis, the model could not take into account the tracking.

4.3.1. Data analysis for the maximum and minimum radiation Dates

The raw data obtained from the different data are very bulky, therefore, a program is developed which is capable of sorting out this raw data for which considers the mathematical sequence by which the data is presented. This program gives global radiation and power of the specific dates in 24 hours format graphically as presented in the Figures below. The day Chooses from maximum and minimum radiation day of the month of the year, the graphical data presented here shows power and radiation intensity throughout the day. Figure 4.7 shows the minimum and maximum hourly radiation and hourly power variation of 24 hours in a day for July and March in the average representative days of the months, which is the 17th of July and March. This month is selected because the minimum and maximum variation differences in solar radiation are shown clearly in these months.

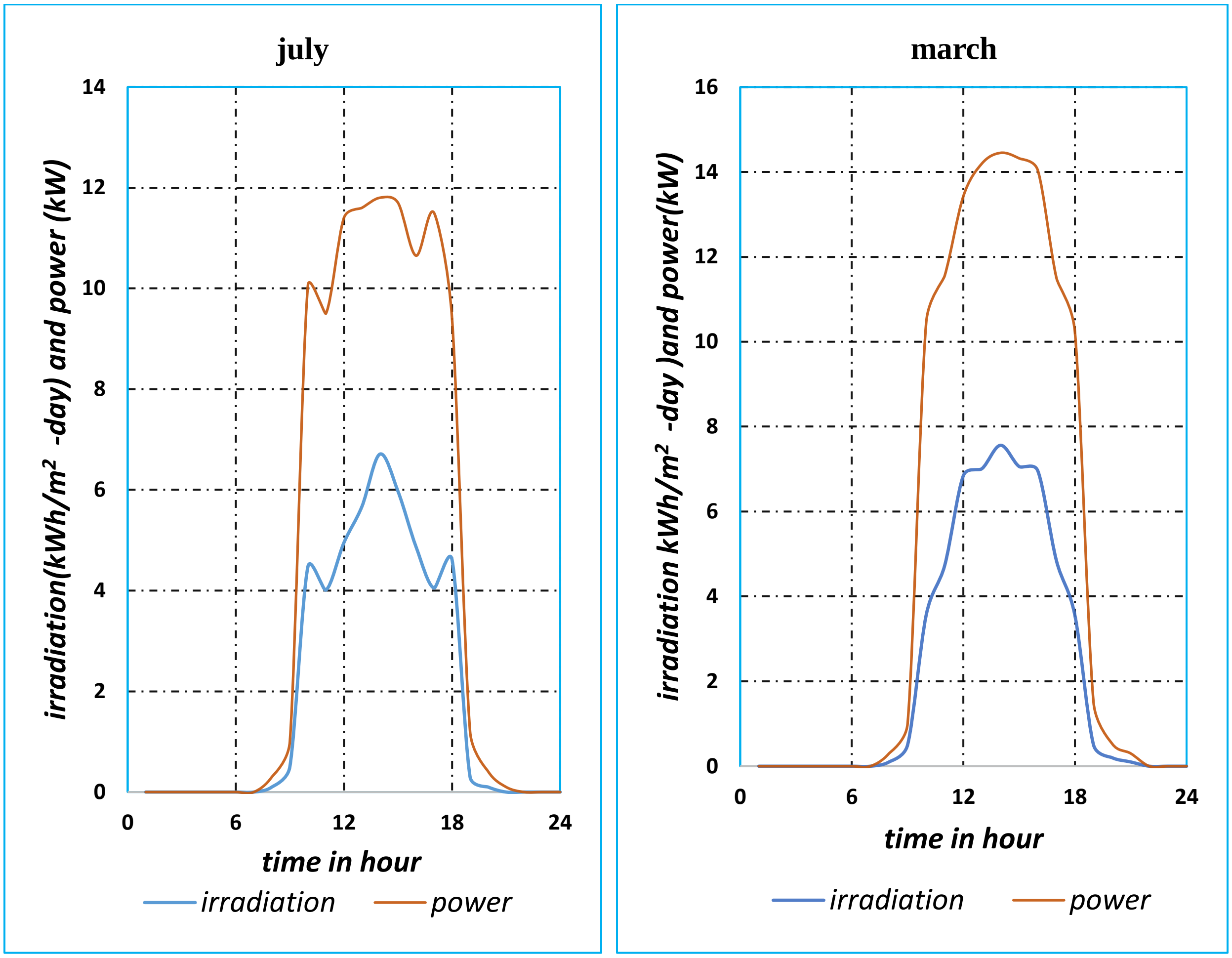


Figure 4.7 Global Radiation and power Data for July 17th and March 17th

Figure 4.8 and 4.9 show the minimum and maximum one trip radiation and power variation of 30 minutes in one trip for July and March in the average representative days of the months, which is 17th of July and March. This month is selected because the minimum and maximum variation differences in solar radiation are shown clearly in these months. Global Radiation and power Data are for one trip at sunny and partial sun hour based on the train path that is 17.1km (Torhailoch - Ayat) and this data consider both building shadow and 3-minute underground path around Megenagna and urael.

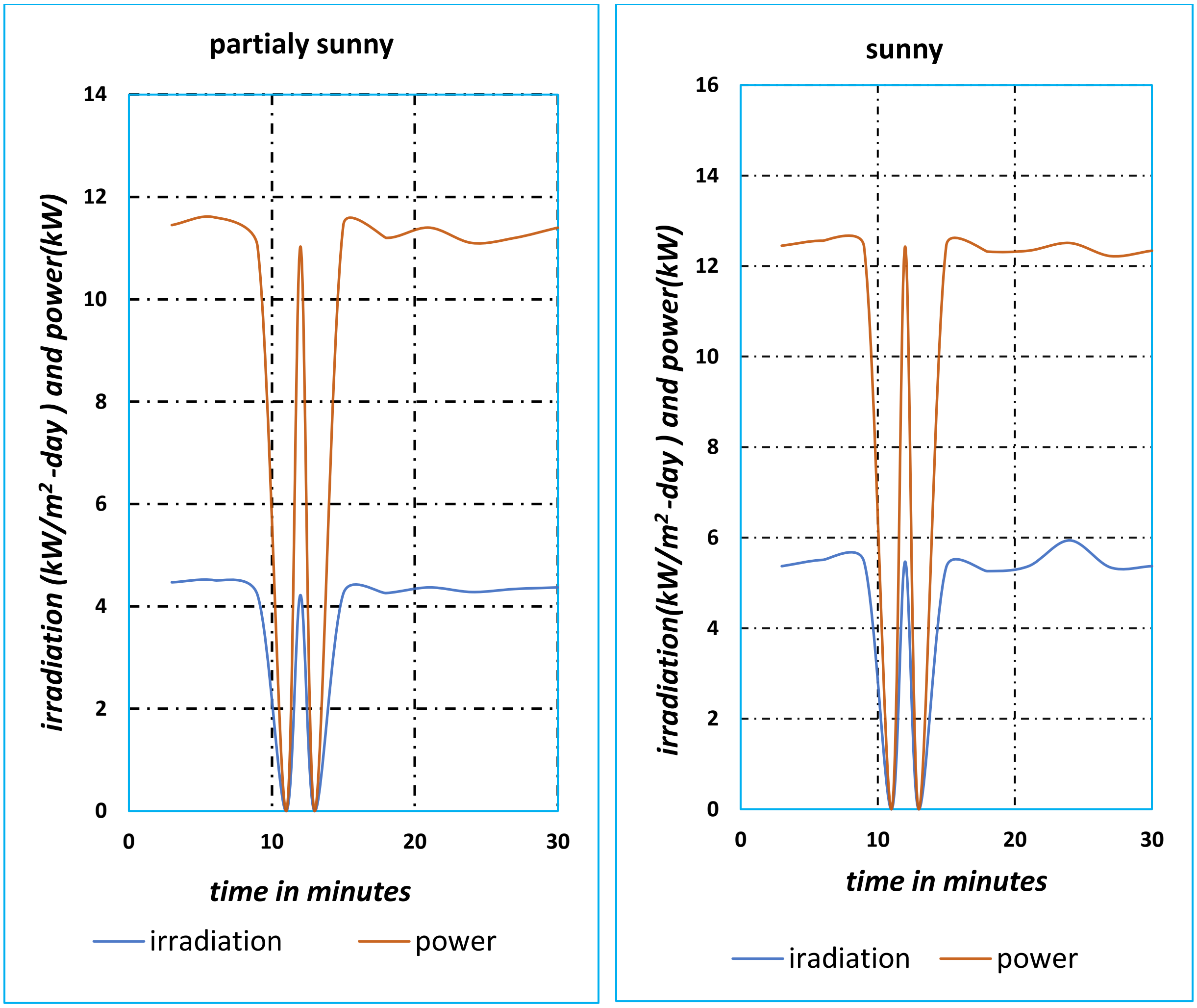
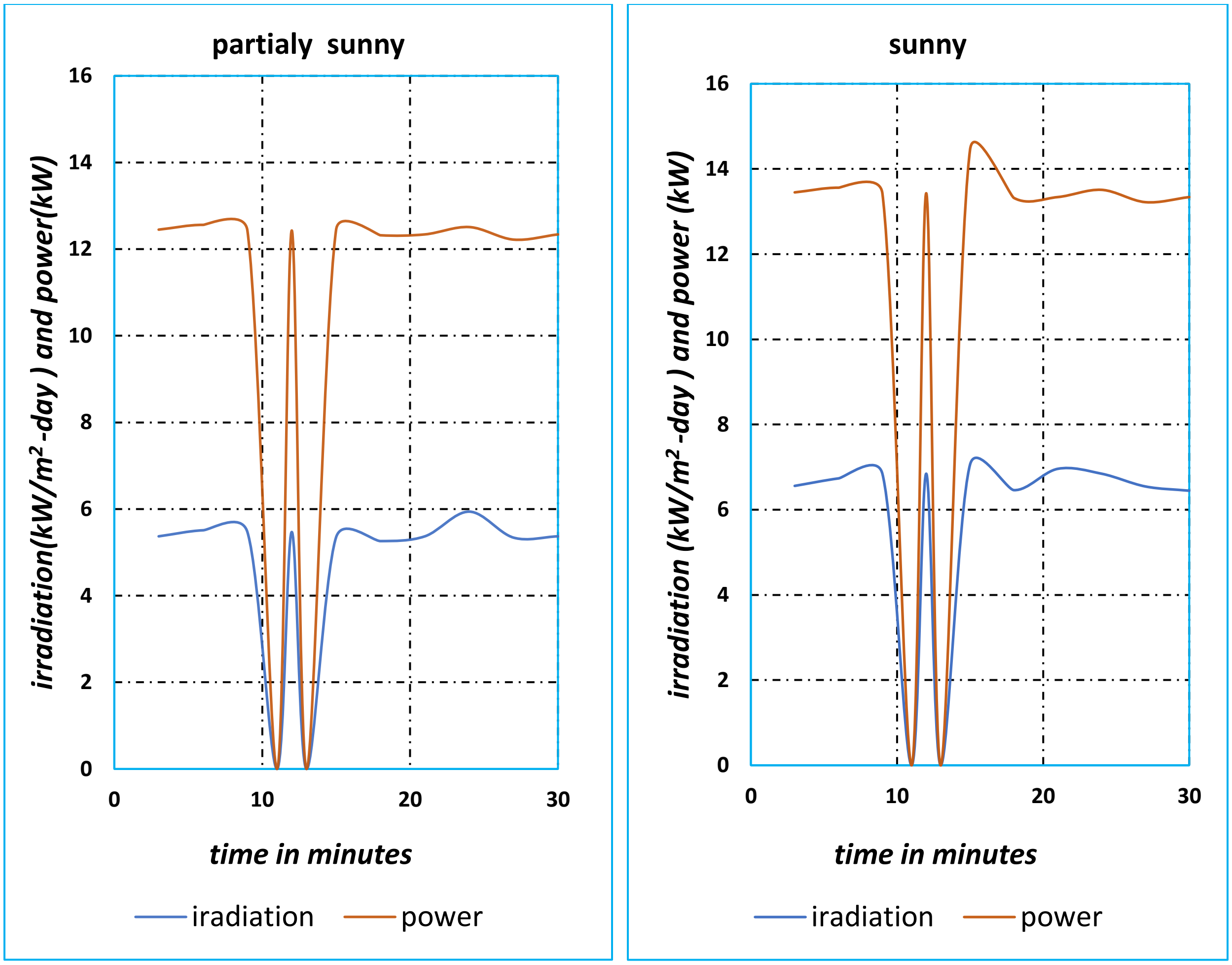


Figure 4.8 Global Radiation and power Data for July 17th for one trip at sunny and partial sun hour



[20] *Figure 4.9 Global Radiation and power Data march 17th for one trip at sunny and partial sun hour*

Based on the above analysis the least amount of energy generated from a panel is 11.8 kW in July which can be a substitute for 90 % and the highest 14.45 kW in March and can be a substitute for air-conditioning and other auxiliary loads of the total power consumed by the coach.

Here as observed from the figure the number of a car set in the train is increased the amount of power generated also increases in turn in increases the substitution amount. From the technical proposal information, the maximum train set for Addis Ababa city light rail is 3.which means the power generation will be the minimum 3 times the power produced by the designed panel.

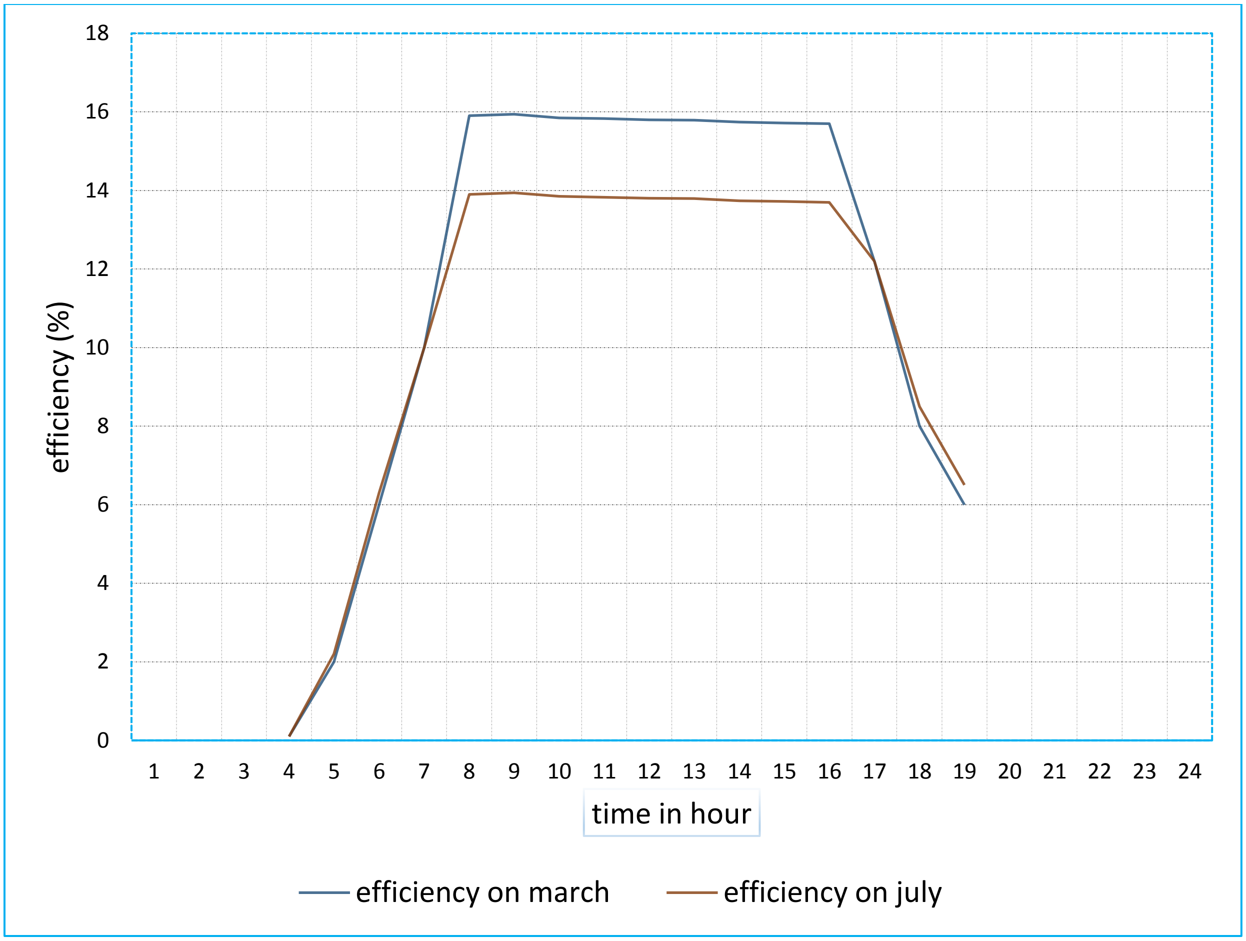


Figure 4.10 the PV Array Hourly Efficiency Variation

The above Figures shows the performance simulation of the selected solar cells, to show the hourly variation of power efficiency of the PV panel using the real weather data. The output power resulted from this simulation is the main input parameter to the air conditioning unit The overall efficiency of the system can also be identified. Thus it helps the efficient dispatching system to use efficiently the produced energy

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This thesis concludes that the system design considers PV systems to achieve space cooling because the system of the train consider the number of people, space area of the train, internal and external temperature, solar shading, efficiency, and the route that train goes. So by considering all the parameters all design was done with a total load of 9 kW and to supply this load, the system needs a total of 36 photovoltaic modules each 330W also several characteristics are considered to know either on the PV system. Electrical equivalent, IV characteristic curve, and factors affect the output of the PV cell was done to know characteristics in a photovoltaic system using PVSYST and MATLAB.

Addis Ababa has minimum solar irradiation of an average of 4.8 kWh/m²/day. This research was conducted on different data collection (from Ethiopian methodology agency, NASA, PVGIS, and calculation. A coach will fitted with solar photovoltaic modules that were designed at speeds up to 70 km/h. Based on the results. It is estimated that 71.6 m^2 solar rail coaches can generate at least 11.48 kW and at most 14.45 kW of electricity in a day which leads to big annual saving of grid energy.

The results from the analysis showed that for a peak cooling load of 6 kW, an off-grid and air-conditioner having a capacity of 9 kW, a solar PV array of surface area 66.35 m2 and a battery size of 150Ah, 24V, controller size of 80 A, 220V and 30 kW of inverter size will be required to meet the cooling demand for the train. The air supply volume is 1300m^3/h. One train coach in general requires 260 kW of electricity. Of this 260 kW or 3.6 % amount of energy is consumed by the air conditioner. Hence, by supplementing the locomotive with solar PV modules 1034775 Birr can be saved per annum.

Therefore for the air conditioning, cooling capacity 6 kW first as it will give a rough idea on how to design and construct the system with enough electrical energy supplied to it. Considering these several factors, paper tried to improve the stability and efficiency of the system for greener solutions to the world's energy needs. As a result, can achieve the desired pleasant and comfortable interior thermal environment for the passengers at all expected external ambient environmental conditions.

Thus this would help to reduce grid consumption not only for air-conditioning but for most axillary equipment. In general, it is possible to conclude that the energy generation from the top roof of the train can cover a significant amount of required energy for the air conditioner. In turn, it helps to reduce the cost of investing in-grid and increase the growth of the country's usage of renewable energy efficiency.

5.2. Recommendations

The solar-powered air conditioning system option is recommended to be applied in Addis Ababa light train railways as a pilot solar system to encourage future full utilization in all trains. The design of solar energy for train air conditioning power supply by installing the solar panel at the top roof of the train shows that there is a possibility to generate a high amount of electrical energy,

Therefore it is recommended to the Ethiopian power suppliers and railroad industry, a series of measures that shall be adopted to achieve energy security, sustainable development & minimize environmental damages. Modeling PV solar systems in their best performance in real weather conditions will give the required output results. Actual system implementation shall be tested in the study area for selected sites. Since this research was done under many constraints subsequently it requires further and deep study.

5.3. Future work

Based on the above research the least amount of energy generated from a single car is 11.48 KW/day which can substitute the required load and the highest 14.48 KW/day and can be substitute more than the required load of the total power consumed by the car. Here as observed the number of a car set in the train is increased the amount of power generated also increases in turn in increases the substitution amount.

From the technical proposal information, the maximum train set for Addis Ababa light rail train is 3 them the power generation will be the minimum 3 times the power generated from one car coach so as a future work researcher can focus on powering the whole train with solar systems especially locomotive generator of the system. Also, there are 39 stations through the train driving routes thus the solar system can also be installed on each station and can use that power for a different purpose, therefore there are many research areas in Addis Ababa city light train especially on a solar power system.

Therefore, for future works, the rooftop of a rail coach is enough to supply a lot of loads if a good solar design is done. And to get perfect sun direction, the design two-axis tracking mechanism is best compared to a manual tracking mechanism. Besides modeling this system using other energy sources is the other option to model the solar air conditioning system in train areas. The other recommendation is using a different type of solar equipment like A MPPT solar charge controller which is the charge controller embedded with an MPPT algorithm to maximize the amount of current going into the battery from the PV module and the aerodynamic effect of the moving air at the top surface

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APPENDIX A - SOLAR MODULE SPECIFICATION

Electrical Characteristics

STC	STP330-24/ Vfw	STP325-24/ Vfw	STP320-24/ Vfw
Maximum Power at STC (Pmax)	330W	325 W	320 W
Optimum Operating Voltage (Vmp)	37.5V	37.3V	37.1 V
Optimum Operating Current (Imp)	8.81A	8.72A	8.63A
Open Circuit Voltage (Voc)	46.2V	45.9 V	45.6 V
Short Circuit Current (Isc)	9.38A	9.26 A	9.14A
Module Efficiency	16.9%	16.7%	16.5%
Operating Module Temperature	-40 °C to +85 °C		
Maximum System Voltage	1500 V DC (IEC)		
Maximum Series Fuse Rating	20 A		
Power Tolerance	0/+5 W		

STC: Irradiance 1000 W/m², module temperature 25 °C, AM=1.5;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

NOCT	STP330-24/ Vfw	STP325-24/ Vfw	STP320-24/ Vfw
Maximum Power at NOCT (Pmax)	244W	240W	235W
Optimum Operating Voltage (Vmp)	34.4V	34.2V	33.9V
Optimum Operating Current (Imp)	7.22A	6.99 A	6.94 A
Open Circuit Voltage (Voc)	42.5V	42.2V	41.9 V
Short Circuit Current (Isc)	7.63A	7.49A	7.40 A

NOCT: Irradiance 800 W/m², ambient temperature 20 °C, AM=1.5, wind speed 1 m/s;
Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

Temperature Characteristics

Nominal Operating Cell Temperature (**NOCT**)	45±2°C
Temperature Coefficient of Pmax	-0.41 %/°C
Temperature Coefficient of Voc	-0.33 %/°C
Temperature Coefficient of Isc	0.067 %/°C

No. of Cells	72 (6 × 12)
Dimensions	1960 × 992 × 40mm (77.2 × 39.1 × 1.6 inches)
Weight	25.9 kgs (57.1 lbs.)
Front Glass	4.0 mm (0.16 inches) tempered glass
Frame	Anodized aluminium alloy
Junction Box	IP68 rated (3 bypass diodes)
Output Cables	TUV (2Pfg1169:2007)
	4.0 mm² (0.006 inches²), symmetrical lengths (-) 1100mm (43.3 inches) and (+) 1100 mm (43.3 inches)
Connectors	Genuine MC4

Packing Configuration

Container	20' GP	40' GP	40' HC
Pieces per pallet	25	25	25
Pallets per container	5	12	24
Pieces per container	125	300	600

APPENDIX B - Direct collected and calculated data

1. **Global Radiation and power Data for September 17th and March 17th**

time in hour	Irradiation(kW/m² /day)	power (KW)	Irradiation(KW/m²/ day)	power(KW)
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0.1	0.3	0.1	0.3
9	0.5	1	0.5	1
10	4.47	10.05	3.56	10.45
11	4.01	9.5	4.736	11.56

12	4.95	11.45	6.846	13.43
13	5.67	11.56	7.01	14.2
14	6.71	11.8	7.56	14.45
15	5.97	11.7	7.06	14.32
16	4.87	10.65	6.96	14.04
17	4.05	11.5	4.846	11.51
18	4.61	9.4	3.546	10.22
19	0.3	1.2	0.5	1.5
20	0.1	0.41	0.2	0.53
21	0	0.1	0.1	0.3
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0

2. **Global Radiation and power Data for September 17th for one trip at sunny and partial sun hour**

station	time (m)	irradiation(kW/M^2/day)	power (kw)	irradiation(kW/M^2/day)	power (kW)
1	3	4.47	11.45	5.37	12.45
2	6	4.51	11.6	5.51	12.56
3	9	4.22	11.03	5.47	12.43
4	12	0	0	0	0
5	15	4.25	11.45	5.35	12.45
6	18	4.26	11.2	5.26	12.32
7	21	4.37	11.4	5.37	12.34
8	24	4.28	11.1	5.94	12.51
9	27	4.34	11.2	5.34	12.22
10	30	4.37	11.4	5.37	12.34

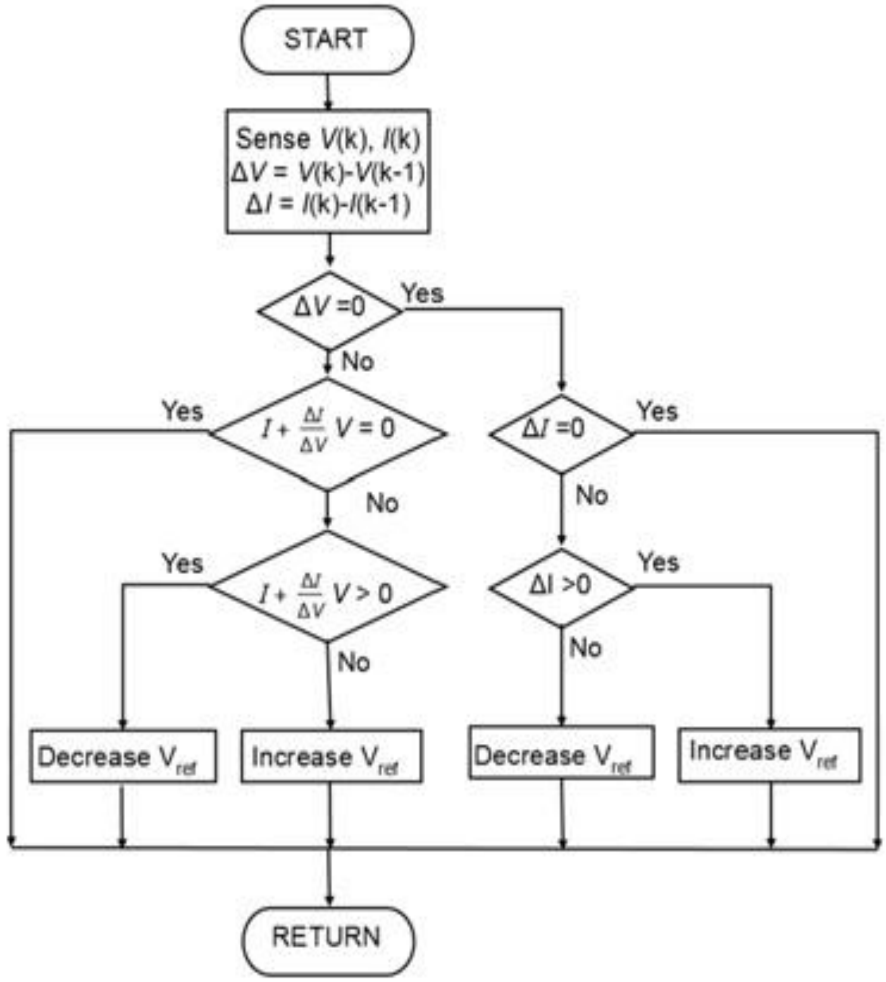
3. **Global Radiation and power Data march 17th for one trip at sunny and partial sun hour**

station	Time(m)	Irradiation ($kW/M^2/day$)	power(kW)	Irradiation ($kW/M^2/day$)	Power (kW)
1	3	5.37	12.45	6.56	13.45
2	6	5.51	12.56	6.736	13.56
3	9	5.47	12.43	6.846	13.43
4	12	0	0	0	0
5	15	5.35	12.45	7.06	14.45
6	18	5.26	12.32	6.46	13.32
7	21	5.37	12.34	6.96	13.34
8	24	5.94	12.51	6.846	13.51
9	27	5.34	12.22	6.546	13.22
10	30	5.37	12.34	6.446	13.34

voltage [V]	$800 w/m^2$	$400 w/m^2$	$200 w/m^2$	$600 w/m^2$	$1000 w/m^2$
0	2.1	1.1	0.5	1.5	2.6
1	2.1	1.1	0.5	1.5	2.6
2	2.09	1.09	0.49	1.49	2.59
3	2.09	1.09	0.49	1.49	2.59
4	2.08	1.08	0.48	1.48	2.58
5	2.08	1.08	0.48	1.48	2.58
6	2.07	1.07	0.47	1.47	2.57
7	2.07	1.07	0.47	1.47	2.57
8	2.06	1.06	0.46	1.46	2.56
9	2.05	1.05	0.45	1.45	2.55
10	2.05	1.05	0.45	1.45	2.55
11	2.02	1.02	0.42	1.42	2.52
12	2	1	0.4	1.4	2.5

13	1.96	0.96	0.39	1.36	2.46
14	1.94	0.94	0.34	1.34	2.44
15	1.86	0.86	0.3	1.26	2.36
16	1.63	0.63	0.15	1	2.13
17	1.18	0.3	0	0.65	1.68
17.5	0.8	0		0.321	1
17.8	0.3			0.001	0.5
18	0				0.2
18.3					0
18.5					

4. Algorithm of the MatLab program used to model a PV panel and layout of solar panel on a train


START
Sense V(k), I(k)
ΔV = V(k)-V(k-1)
ΔI = I(k)-I(k-1)
ΔV =0
Yes
No
Yes
I + ΔI/ΔV V = 0
No
ΔI =0
Yes
No
Yes
I + ΔI/ΔV V > 0
No
ΔI >0
Yes
No
Decrease V_ref
Increase V_ref
Decrease V_ref
Increase V_ref
RETURN

```
function y = MPPT(u,i,u0,i0,D)
m=0;
du=u-u0; di=i-i0;
if du==0
    if di==0,m=D;
    else
        if di>0, m=D-0.01;
        else
            m=D+0.01;
        end
    end
elseif di/du==-(i/u)
else
   if di/du>-(i/u),m=D-0.01;
   else
    m=D+0.01;
   end
 end
  y=m;
end
```