OPTIMAL SIZING OF STANDALONE PHOTOVOLTAIC DIRECT CURRENT POWER SUPPLY: *(THE CASE ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY-ICT CENTER BUILDING)*

BY:

AYNALEM W/MICHAEL (ID. A/PE16395/10)

A THESIS SUBMITTED TO ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT OF POWER ENGINEERING POSTGRADUATE PROGRAM (MSC)

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTING

ETHIOPIA, ADAMA

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ADVISOR: TAFESSE A. ABERA (PhD)

ETHIOPIA, ADAMA

JUNE, 2020

APPROVAL SHEET

We, the undersigned, members of the Board of Examiners of the final open defense by Aynalem W/Michael have read and evaluated her thesis entitled “Optimal Sizing of Standalone Photovoltaic Direct Current Supply: (The Case Adama Science and Technology University-ICT Center Building)” and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Postgraduate Program (Msc).

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Post graduate Dean		

DECLARATION

I, Aynalem W/Michael, hereby declare that this research entitled "Optimal Sizing of Standalone Photovoltaic Direct Current Supply: (The Case Adama Science and Technology University-ICT Center Building)"is my own original work. I have carried out it independently with the guidance and suggestions of the research advisor. And it has not been presented to Adama Science and Technology University or to any other university for any form of qualification and that all sources of materials used for the study have been duly acknowledged.

Name: Aynalem W/Michael

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Date: ______________

Confirmation

I, Dr. Tafesse A. Abera, hereby confirm that the MSc thesis entitled "Optimal Sizing of Standalone Photovoltaic Direct Current Supply: (The Case Adama Science and Technology University-ICT Center Building)" is the research wrote by Aynalem W/Michael under my supervision. I also confirm that the research is submitted to Adama Science and Technology University for defense through my confirmation.

Name of Advisor: Tafesse A. Abera (PhD)

Sign: ______________

Date: ______________

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ABBREVIATIONS

AC – Alternate Current

Ah–Ampere-Hour

BLDC – Brushless DC Motor

BoS– Balance-of-System

DC – Direct Current

EMI– Electromagnetic Emissions

EEU– Ethiopian Electric Utility

Isc – Short Circuit Current

ICT–Information and Communication Technology

KW–Kilowatt

KWh – Kilowatt Hour

LCOE– Levelized Cost of Energy

LED– Light Emitting Diode

NPC – Net Present Cost

LVAC –Low Voltage AC

LVDC – Low Voltage DC

PMSM –Permanent Magnet Synchronous Motor

PV– Photovoltaic

SMPS –Switch Mode Power Supply

TVs–Television

UV–Ultraviolet

W– Watt

Wp – Peak Watt

ABSTRACT

Renewable energy, with the availability of its renewability and minimum pollution will grow to be an effective and practical choice to guarantee the future development of the world. Low voltage direct current distribution system has been widely used in data centers, aerospace, automotive and marine. Now a day's dc system gaining advantage over ac system in data centers due to increasing number of dc-based loads, advancement of power electronic convertors and wide spread use of renewable energy resources like solar and wind. Solar photovoltaic power generation system is one of the burning issues toward increasing the amount of power generation from renewable energy sources. This thesis work focuses to investigate the technical and economic analysis of optimal sizing of standalone photo voltaic direct current power supply. Different appliances in the building selected and assessment made on their energy consumption by considering voltage drop, power loss and efficiency by comparing AC and DC system. From the comparison DC system had minimum loss with a better efficiency. However, selection of standardized DC voltage level by referring Emerge Alliance standard that had been chosen 380V for the system. Finally, Homer software was used to size and simulate photovoltaic system required for the building. The result shows that PV system with optimal size of 120 KW and 12V, 400Ah battery on the technical and total net present cost $ 333,754, levelized cost of energy *result $ 0.224/KWh and operating cost $ 9,208/yr. in economical result. DC system design improves the power shortage and reduced fluctuation of power and conversion stage. Therefore, Dc system had been best alternative to supply sustainable, reliable and environmentally friendly source from PV.*

Key Terms: Renewable energy, Optimal size, Standalone, DC power supply, Photovoltaic.

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

Technology is best interconnecting channel in each part of world with the means of energy, transportation, communication or business which led to a highly increase to use renewable energy. Solar energy is the light that comes from the sun and the earth's most abundant energy source. Every day the sun radiates extra ordinary amounts of energy into space and due to the development of technology such as the solar cell, which is able to collect this energy and convert it into usable electricity [1].

Starting in the late 1880s, Thomas Edison and Nikola Tesla were involved in a battle known as the War of the Currents. Edison developed direct current (DC) that runs continually in a single direction. Direct current is not easily convertible to higher or lower voltages. High voltage dc transmission allows more power to be transmitted over a long distance with a less loss compared to an AC transmission. On the other hand, Tesla showed that alternating current (AC) can be stepped up easily using a transformer which reduces the transmission loss. Tesla's empirical results were the deciding factor, at least for the time being that an AC system was to be preferred [2].

The growing concern about environmental issues and the strong need of low-cost energy sources have a great importance in the use of renewable energy such as the PV solar energy. Currently, PV solar energy has become a perfect promising renewable energy source due to its many benefits namely; low cost maintenance, non-necessity of moving and no pollution. However, the low efficiency of a PV panel and high cost of PV system installation may be a discouraging factor as far as its use [3].

Today AC systems have been widely used for supplying power for residential, commercial and industrial appliances. But AC systems suffer a number of problems. The voltage conversion uses transformers which causes power losses even at no load conditions. The harmonic current, power factor and many other power quality problems exist in AC system.

Most parts of Ethiopia, locally available renewable energy resources can be used for small scale electricity generation. Energy obtained from sustainable sources like solar, fuel cell and wind (coupled with dc generators) produce dc as an output. The number of devices that operate on dc continues in both homes and offices. The fact that communication like internet has become main stream and has entered all aspects of life means, that there is an increased use of IT hardware around the globe. The growth in ICT sector is increasing the burden on the electricity grid which is already not able to meet the demand. One of the fastest growing service equipment sectors that require uninterrupted power supply for working safely without frequent power cuts. The service sector covers a wide variety of activities.

In the past, AC system gains advantage over DC, but in recent year's DC has seen a bit renaissance with the development in the power electronics and availability of renewable energy resources that produce DC. Now a day's, many electronic appliances such as computers, televisions and digital set top boxes operate internally at dc voltages and thus have built-in voltage conversion circuits. DC systems are free from inductance, skin effect, dielectric losses, and interference with communication system [4]. The absence of inductance in DC system makes voltage drop very low. Due to the absence of skin effect, small cross section conductor is required in DC system compared with AC. The current electronic device requires the conversion of AC to DC. Losses can be reduced if the number of successive voltage conversion is decreased by using DC voltage within electronic appliances.

1.2. Statement of the Problem

Renewable energy sources will provide, to solve various problems especially with respect to rendering quality service by a well-designed delivery system for its customers. The country has a huge potential of renewable energy resources like solar energy. In recent years the cost of solar energy per kWh has been reducing since the price of solar panels keep falling. Moreover, frequent power interruptions happen in developing countries like Ethiopia, due to the problems which arise from transmission and distribution networks and poor infrastructure of the currently existing system.

The devices that are currently used in the building are used dc internally and this requires ac to dc conversion between ac supply and the dc side of the devices. This energy has been converted back to ac using dc-ac converter to supply power for the currently existing ac loads and again ac is converted back to dc internally inside the devices. This causes multiple power conversions to take place and to increase power loss in the devices. The harmonic currents, power factor and many power quality problems exist in ac systems. Power failure and interruption is also a big issue in these systems. The size of equipment's is also higher due to the inclusion of transformers.

Therefore, Optimal Sizing of Standalone Photovoltaic Direct Current Supply would promise candidate that can create an innovative solution for the networks that can serve electric power with high quality and efficiency to meet the challenges of power stress to efficient and reliability besides the wide range of services that gets from EEU. To come up that allocated from EEU would be supported by solar PV system.

1.3. Significances of the Study

The researcher hopes that this study has contributes numerous benefits in terms of theoretical as well as practical perspectives. Therefore, the outputs of this study would assume to contribute to solve the existing shortage of power. The findings have been useful to transfer technology using renewable resources in this world in general and in developing countries in particular.

It will also serve as a source of information that brings to the switching intentions of the current renewable energy source and standalone energy source of PV who have potential to use it.

1.4. Objectives of the Study

1.4.1. General Objective

The general objective of this research is to develop mathematical calculation to size optimal Standalone Photovoltaic Direct Current Supply: in the case of Adama Science and Technology University– ICT Center Building.

1.4.2. Specific Objectives

The specific objectives of the study are to:

- ❖ analyze the advantage of DC over AC distribution in terms of power losses and efficiency.
- ❖ selection of standard voltage level for DC system.
- ❖ analyze the economic feasibility of dc system.

1.5. Delimitations of the Study

The study has been with in a boundary to standardized voltage level of an Optimal Sizing of Standalone Photovoltaic Direct Current Supply system for ICT building due to scarcity of DC appliance products in case of flexibility to use it. But this study specifically addresses Adama Science and Technology University – ICT Center Building, Oromia region, Ethiopia.

1.6. Organization of the Study

This thesis contains six chapters. The second chapter describes review of related literature and related studies to the topic area including the framework designed for the study. Chapter three presents the research methodology, which consists of data collection instruments and procedure and the data analysis techniques. Chapter four presents design specification and voltage standardization which include location and load estimation. Chapter five describes about the details of optimal sizing, analysis and interpretation. Finally, chapter six discusses the summaries, conclusions and recommendations forwarded based on the findings of the study.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Theoretical Review

The study focuses on the details of optimal sizing of standalone photovoltaic direct current power supply for ICT building appliances on the basis of theoretical and practical perspectives. This review emphasizes on renewable energy source concepts particularly solar energy, direct current system, distributed generation, voltage standardization, application and compatibility of appliance for dc distribution system for building and factors influencing DC electrical distribution system.

2.1.1. Basics of Renewable Energy

As the fears of climate change increase, the demands for devices that generate electricity that are environmentally friendly will steadily increase. Most of the electric power generated in the world comes from the burning of fossil fuels to generate a consistent supply of energy. Every year, the demand for electricity increases, pushing the current power plants and power distribution grids to their limits. To meet this growing need, more fossil fuel power plants are being constructed, thus increasing the pollutants dispensed into the environment. The need to develop clean energy producing systems that can perform as reliably as fossil fuel plants must be implemented throughout the world in order to decrease the effects man has on the planet. In order for a renewable energy source to be added to a power utility, the three conditions to be met are reliability, cost, and lifespan. Due to the high initial cost of building a renewable power source and a slower rate of return than fossil fuel plants, progress has been slow in the construction of renewable energy plants outside of wind power plants [5]. The design of this study focuses on using a renewable-energy-based stand-alone system to decrease the energy usage at times of low power consumption and promotes the use of an environmentally friendly energy resource. There are many forms of renewable energy resources that are currently available for integration into the power grid; the top four energy sources are sun, wind, water, and geothermal.

2.1.2. Areas of the World Using Renewable Energy

Geography plays an integral role in determining what forms of renewable energy will be the most useful. Hydroelectric energy is the primary source of electricity for the countries of

Canada and Brazil [6]. Denmark, Germany, and the United States are increasing the number of wind turbines and offshore wind farms to meet the increasing energy demands [5]. Other European nations are moving towards a renewable energy with increased photovoltaic and wind energy projects that will make up a large portion of their future infrastructure [5]. Australia, Japan, and third world African countries use solar energy in isolated regions and cities to harness the sun's energy [7].

The Midwest is not known for employing renewable energy due to the lower cost of producing power from coal plants. Also, the conditions of the land make implementing hydroelectric dams difficult, the lack of mountain ranges and water sources reduce the average speed of the wind, and the high percentage of clouds in the winter hampers the use of solar panels. The implementation of wind power and solar energy has come from individual home owners that accept the cost involved and the number of consumers will continue to increase with a reduction in equipment cost and utility rate hikes.

2.1.3. Basics of Solar PV

A photovoltaic system is made up of several photovoltaic solar cells. An individual small PV cell is capable of generating about 1 or 2 W of power approximately depends on the type of material used. For higher power output, PV cells can be connected together to form higher power modules. In the market the maximum power capacity of the module is 1 kW, even though higher capacity is possible to manufacture, it will become cumbersome to handle more than 1 kW module. Depending upon the power plant capacity or based on the power generation, group of modules can be connected together to form an array.

Solar PV systems are usually consisting of numerous solar arrays, although the modules are from the same manufactures or from the same materials, the module performance characteristics varies and on the whole the entire system performance is based on the efficiency or the performance of the individual components. Apart from the solar PV module the system components comprise a battery charge controller, an inverter. A Balance-of-System (BoS) includes components and equipment’s that convert DC supply from the solar PV module to AC grid supply. In general, BoS of the solar PV system includes all the components of the system except the Solar PV modules. In addition to inverters, this includes the cables/wires, switches, enclosures, fuses, ground fault detectors, surge protectors, etc. BoS applies to all types of solar applications (i.e. commercial, residential, agricultural, public facilities, and solar parks).

In many systems, the cost of BoS equipment can equal or exceed the cost of the PV modules. When examining the costs of PV modules, these costs do not include the cost of BoS equipment. In a typical battery based solar PV system the cost of the modules is 20–30 % of the total while the remaining 70 % is the balance of systems (BoS). Apart from the 50 % of the system BoS costs a lot more maintenance expense is also required for proper maintenance of the BoS. By controlling the balance-of-system components, increase efficiency, and modernize solar PV systems can be maintained. BoS components include the majority of the pieces, which make up roughly 10–50 % of solar purchasing and installation costs, and account for the majority of maintenance requirements. Thus, suitable integration of the BoS is vital for the proper functionality and the reliability of the solar PV system. However, it is often completely overlooked and poorly integrated. Costs are steadily decreasing with regard to solar panels and inverters.

As per the statistics, the Solar PV module world market is steadily growing at the rate of 30 % per year. The reasons behind this growth are that the reliable production of electricity without fuel consumption anywhere there is light and the flexibility of PV systems. Also, the solar PV systems using modular technology and the components of Solar PV can be configured for varying capacity, ranging from watts to megawatts. Earlier, large variety of solar PV applications found to be in industries but now it is being used for commercial as well as for domestic needs.

2.1.4. Applications of Solar Photovoltaic

Photovoltaic energy comes in three forms: stand-alone, grid-connected, and hybrid system. Stand-alone systems use a completely independent operation that stores energy in batteries for night time usage. Stand-alone systems rely on PV power. When using batteries charge regulators are included, which switch off the PV modules when batteries are fully charged, and switch off the load in case batteries become discharged below its limit? The batteries must have enough capacity to store the energy produced during the day to be used at night and during periods of poor weather.

The grid-connected form connects directly to the power grid, eliminating the need for batteries. Tying into the grid increases the number of individual users that utilize solar energy on a small scale, and provides the dependability of continuous power no matter the cloud conditions. A hybrid system combines the consistency of the grid with a battery backup, in case grid power is lost.

DC energy produced by photovoltaic panels has to be converted into AC energy due to the fact that the consumers are all AC. Such a DC/AC conversion causes harmonics and loss of energy in the convertors during conversation stages.

2.1.5. Estimate Solar PV System Sizing

PV system sizing involves determining how many solar PV panels and/or batteries need, choosing an appropriately-sized controller and/or inverter and experimenting with various combinations to create a final design that fits need and budget. A load includes anything that uses electricity from the power.

The battery type recommended for using in solar PV system is deep cycle battery. Deep cycle battery is specifically designed for to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years. The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days.

Wire Sizing

- ❖ Usually copper wire is used
- ❖ For Indoor, ordinary PVC insulation wire are used
- ❖ For outdoor, UV resistant insulation wire are used
- ❖ The wire from the array to battery should have an ampere capacity rating of at least 4 times the array operating current

For DC wire calculation we need

- ❖ System voltage
- ❖ Total current(A)
- ❖ Length of wire
- ❖ Tolerance voltage drop (2%, 3% & 5%)

Then, to determine the daily amount of sunlight in specific region. And finally will determine PV array size and battery bank size. The following flowchart will explain how to estimate the size of a PV array and battery bank. Figure. 2.1

Determine Load – to estimate all the different loads in the house on a typical day and sum them.

Determine Available Sunlight – to calculate the sunshine available for the panels on an average day during the worst month of the year. It is called the insolation value.

Determine PV Array Size – the size of the array is determined by the daily energy requirement divided by the sun-hours per day

Determine Battery Bank Size – the size of the battery which are connected in parallel and series.

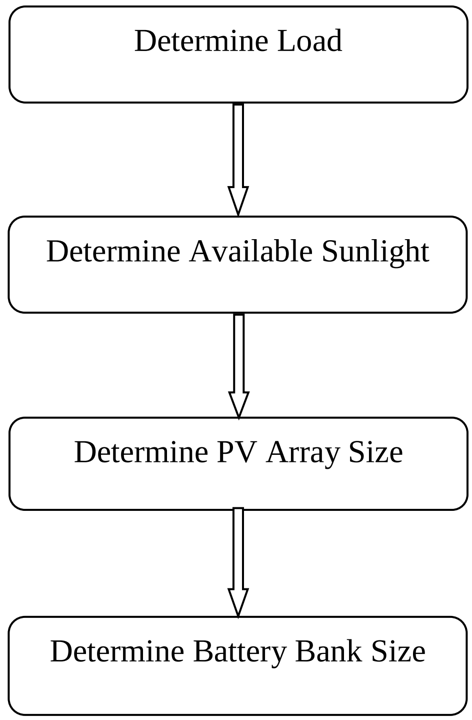


Figure 2.1. Flow Chart of Estimate Solar PV System Sizing [8]

2.1.6. Estimate Solar PV System Cost

When we will buy modules, verify that the modules meet electrical safety standards, and long-term warranties. Generally, in PV systems, lead acid batteries, an inverter or Converter which is needed to convert to AC or DC power. Besides PV modules and batteries, complete PV systems also use wire, switches, fuses and connectors. Generally, we use a factor of 20% to cover balance of system costs [9] (Figure 2.2.).

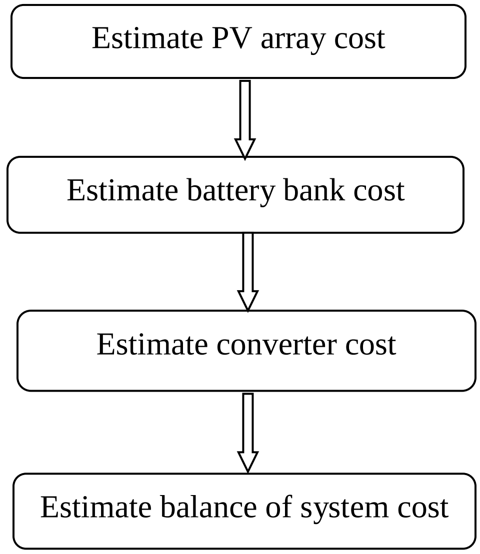


Figure 2. 2. Flow Chart of Estimate Solar PV System Cost [8]

2.1.7. DC Supply System

On the development of electricity, AC has been a better choice for power transmission and distribution. However, Thomas Edison one of the founders of electricity, supported the use of DC. No method at that time existed for boosting and controlling DC voltage at the load, so that transmission of DC power from generation to load resulted in a large amount of losses and voltage variations at different load locations. The problem was resolved by Westinghouse proposing AC distribution. Later on, Nikola Tesla developed the transformer which had the capability of boosting voltage in AC. This makes the transmission losses to be reduced and efficient transmission of power to takes place from one location to another resulting in a complete transformation of the power systems to AC [10].

Although many things have changed since the invention of electricity, AC is still the fundamental power type of our power infrastructure. However, due to the development of power converters and DC energy sources, interest in DC has returned.

The existing distribution system is based on alternating current (AC), but a number of the renewable energy sources, in particular solar cells, produce direct current (DC). This requires the application of power electronic devices to convert the DC energy from renewable sources to AC for transmission and distribution. Yet, this can induce considerable losses into the system, reducing the acceptance and impact of renewable energy. Furthermore, a significant portion of loads now within buildings are DC, demanding more power electronic devices to reconvert the AC to DC.

Since DC power is purely real, the inductive and capacitive elements of the distribution line can be ignored, condensing the complexity of calculations for system analysis. Moreover, these reactive components have been linked to an increase in the magnitude of current ensuring the depreciation of real power transmission and magnifying losses. DC distribution improves energy conservation by avoiding standby losses that are caused due to transformers [11]. The power electronics devices implemented in power converters have the capability to deactivate when not needed whereas the transformer conducive to AC systems must remain energized. DC system is also favorable over AC system as it does not require synchronization as it is mandatory for AC system.

The reason why DC systems are a viable option now a day is the development of power electronics industry, which allows conversion of DC voltage to the required level for transmission, distribution and consumption.

Most appliances are able to work internally with DC power; they contain an input transformer and a rectifier to obtain the proper DC operating voltage. Standby losses still happen even in open circuit due to the inclusion of transformers in AC systems.

Recently, a lot of research is going on in DC distribution system due to advantages such as higher efficiency and reliability, fewer conversion stages, and uninterrupted power delivery compared to conventional AC systems [12]. Furthermore, renewable resource systems, such as photovoltaic power generation, wind power generation, and electric vehicles are considered to be good alternatives in electric power systems. Due to these advantages, the applications of DC systems in residential areas becoming increasing.

Internally electronic devices (such as computers, florescent lights, variable speed drives, and many other household and business appliances and equipment) operate on direct current (DC). However, all of these DC devices require conversion of the building’s AC power into DC for use, and that conversion typically uses rectifiers. Moreover, most distributed renewable sources produce DC power but must be converted to AC to be consumed by household appliances. These AC-DC conversions result in substantial energy losses.

2.1.8. Distributed Generation

Distributed generation is the arrangement of multiple generation sources within the distribution system instead of at a centralized location. The established distribution system is founded on a centralized theme: a utility transmits power from generation facilities to substations and substations reduce the voltage for transmission to its customers. This transmitted power causes sizable losses and extensive costs from transmission lines and transformers. A distributed generation network can reduce energy transmission by applying energy sources in the more immediate neighborhood of the loads. Decreasing the transmission power not only conserves energy but enables a reduction in distribution line and power device rating. Additionally, distributed generation liberates the transmission lines to deliver more power to necessary loads without incorporating extra lines.

Environmental concerns and new energy policies are making the energy systems to shift towards decentralization and sustainability. By decentralizing the electricity generation, the production is moved closer to the consumer, therefore avoiding transmission and distribution losses, and increasing the efficiency of the electricity grid, as well as, higher power reliability.

2.1.9. Low Voltage Distribution System Topologies

There is a lack of regulation and standardization on direct current technology. Therefore, there are several different configurations and voltage levels that can be employed. Since DC distribution systems have been widely implemented in the telecommunication industry, the voltage level used for residential application seems to converge to the standards used in data centers (380-400Vdc) [13]. However, it is still far from being standardized and several topologies of LVDC distribution system are being studied.

DC distribution system can be made with different connection types. The most common types are uni-polar and bi-polar connections and are the most commonly known in DC system. The difference between these two connections is the number of voltage levels [14].

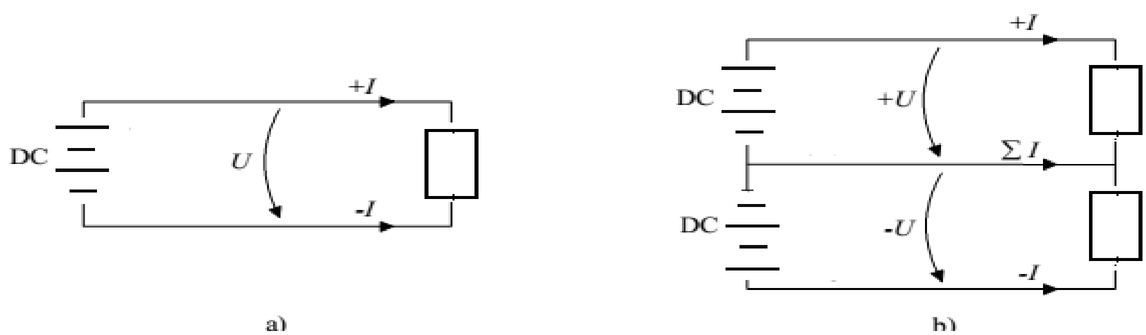
Uni-polar DC Distribution System

The distribution in this system is made by a 2-wire line, with positive and neutral line. The uni-polar system is in expensive but decreases the transmission capacity of the system.

Bi-polar Type DC Distribution Systems

The distribution in the system is made by a 3-wire line, with positive, negative and neutral line. It can be easily appreciated that this concept reduces the voltage level with respect to ground, which makes the distribution system safer for the users. Also, this concept allows the converter on the load side to choose from three different voltage levels; $+Vdc$, $-Vdc$ and $2Vdc$. Furthermore, the system increases the reliability of the power supply, because, in case of a fault in one of the lines, the energy can still be supplied using the other two lines.

In bipolar system, the loads can be connected either (i) between the current conductor and zero conductors, or (ii) directly between the ± conductors.



a) Uni-polar connection system and b) Bi-polar connection system

Figure 2.3. DC distribution connection types

2.1.10. Voltage Standardization

Selection of the voltage level is one of the most important tasks in defining a DC system setup. The lack of standardization is evident when observing the voltage levels used for DC systems. When analyzing DC systems, there are some voltage levels that come as natural choices, depending on the regulation imposed by the standards, the availability of commercial solutions, or to ensure compatibility with the AC grid.

Currently there are broadly available DC compatible devices that can be used with either AC or DC system that makes it suitable to bring DC systems to homes and buildings. Different voltage levels are sensitive to be used for different groups, while optimizing efficiency for each scenario, safety, and compatibility with other systems. The appropriate DC bus voltage level selection is the key step in the DC system design which has great impact on the performance and characteristic of the entire power system.

The distribution voltages adopted for different solutions basically depend on what features are the main design criteria. For instance, 12V distribution systems are used, in the automotive industry. Nevertheless, since modern cars becomes advanced in electronic technology, this leads to higher electricity consumption. Due to this reason the voltage level is boosted to 24-48 V to improve the efficiency and reduce the size of the conductors. This voltage level safely supply power to a number of low power electronic equipment in homes. Medium power consuming appliances can be supplied with 230-400 V. Beyond 400V there is no significant efficiency improvement and the protection system becomes a concern [15].

Power distributions in data centers can be accomplished with voltage levels of 380-400 V dc [16]. This voltage level is convenient because, it has been tested in different applications with uni-polar model. Power consumption of a regular home is much lower than the consumption of the data center; therefore, lower DC voltages could be used, without significantly increasing the distribution losses, while increasing safety in the system. For instance, power distribution up to several hundred watts, can be efficiently performed using 48 V DC, which would cover low power consuming equipment. The increase of the voltage level is unavoidable, if the distribution losses need to be minimized, and therefore a more effective protections system need to be developed.

Table 2.1. LVDC levels, standards, codes and application areas [15].

DC voltage level (V)	**Standards and codes**	**Applications**
1500	IEC60038	Traction systems
400	ETSI EN 300 132-3-1	Electric vehicles
380	Emerge alliance standard	Data centers
120	IEC61140 Limit of SELV	--------
75	EU LDV 2014/35/EU	--------
50	IEEE 802.3bt,802.3bu	Power over Ethernet
48	Not known	Telecom rural PV systems, trucks
24	Emerge alliance standard	Lighting systems
12	Not known	Automotive, lighting
5	Not known	Microprocessors, electronics

The Emerge Alliance, an industry consortium advocating the adoption of direct current power distribution standards for buildings announced the release of the Emerge Alliance standard for safe low voltage DC power in commercial buildings. [17].

Table 2.2. Summary of the basis for selecting a voltage level [18]

Suggested DC Voltage Level	**Basis for Selection**
Vdc ≥ 220	Adaptability with existing building's grid
Vdc ≤ 238 or 457(phase to phase)	Compatibility with single phase loads
463 < Vdc < 617	Compatibility with 3-phase loads
Maximum possible	Efficiency (use the same equipment)
Vdc ≤ 373	Insulation
Vdc ≤ 350-450	Component and device matching (rated levels)

2.1.11. Applications of DC Distribution System for Building

A wide expansion of distributed generation sources especially solar photovoltaic (PV) panels, battery energy storage systems, and advanced electronic loads, provides DC technologies a competitive advantage over its rival AC system for building applications.

Most of modern electronic appliances (TVs, LED lights, satellite receivers, DVD, computers, etc.) are all internally DC loads, and the energy consumed by these devices is increasing every day. In doing so significant loss reduction and simplicity can be achieved which shows DC distribution system a more natural interface between mostly DC devices, which allows a considerable power conversion stages reduction, hence achieving a significant loss reduction, as well as simplicity and potential cost reduction in the power converter units.

Since the frequency of DC system is zero, the voltage drops and reactive power which comes due to inductive component of the distribution line is negligible. DC system becomes apparently simpler and more efficient than AC system as it does not need any synchronization.

Furthermore, the absence of reactive power lowers the current needed to transfer the same amount of power [19]. Though some appliances might need a DC/DC converter to properly adjust the DC voltage needed for the appliance, harmonics and power factor issues are eliminated. Furthermore, with advances in power electronics technology, motor driver devices and brush less DC motors are being considered to replace actual motors in home appliances.

2.1.12. Compatibility of Appliances for DC System

Commercially, most appliances are readily available with an input voltage of 12 and 24V. Some appliances are available with an input voltage of 48V [20]. Low voltage DC appliances demand higher currents, making feeder losses considerable, and the overall appliance efficiency is practically low. In a near future, the market for DC appliances will be so high that appliances will be manufactured at higher voltage levels.

Resistive Loads: Current ac home appliances that are considered as resistive loads (heaters) include Stoves, Electric-Mitad, Ovens, dryers, toasters, kettle, coffee machine and tungsten halogen lamp. Since these loads can be effectively modeled as a resistance [21], they can be directly supplied with DC system without any modification.

Appliances equipped with Motors: As of today, many different types of motors are used in most home appliances. Mixers, vacuum cleaners, automatic gates, freezers, garage doors, dish washers, ventilation fans, cloth washers and cloth dryers, among other appliances, are examples of loads that incorporate the use of single-phase AC motors. Motors produced for home applications vary up to 1hp, and their efficiency is often very low, often less than 50% [22].

With advances in power electronics technology, the use of three-phase induction and synchronous motors with drivers in DC applications is becoming attractive, due to the fact that these motors exhibit greater efficiencies and higher power densities than the actual motors used for appliances. However, the usage of induction motors with drives provide many disadvantages, as compared to the Brushless DC motor (BLDC): Induction motors may never achieve synchronism, and at the same time, rotor losses will always be higher due to the fact that they depend of the slip. Another disadvantage of induction motor is that they are manufactured to be operated at a rated frequency; operating these motors at different frequencies means increased iron losses and the possibility of thermal breakdown of the motor [23].

Efficiencies of different AC and BLDC motors for various home appliances are collected and it is estimated that an overall 24% efficiency of the system is improved by replacing AC motors with BLDC motors [24].

Electronic Loads: Laptop computer, TVs, satellite receivers, phone chargers and security cameras are the major electronic loads which can be made efficient or even energy star just by replacing input AC/DC converter with the buck-boost converter. Old electronic loads use a low-frequency transformer to step down the voltage, which is then rectified using a diode bridge. This type works only with a certain voltage amplitude and frequency. But due to the introduction of switch mode power supply (SMPS), the load can be connected to a wide range of inputs. However, SMPS can be operated with DC without any design modifications as long as the DC voltage is in the same range as the appliance's voltage requirement [25].

2.1.13. Factors Influencing DC Electrical Distribution System

DC system for residential/ building application has brought high expectations regarding simplicity, cost reduction, reliability improvement, and energy savings.

The major factors which influence the choice of DC grid voltage are safety, connection type, and compatibility, with or without storage system, system efficiency and cost savings. Standards, codes and regulations are not well developed for DC system as it was done for AC. For a consumer, the lack of commercially available products that operate on DC is also a major challenge for this system [15].

When designing the DC electrical power system, it would not be easy to find products (power converters, protection devices, connectors, chargers, plugs, switches, circuit breakers etc.) that are compatible with the system's requirements, especially regarding the voltage level.

2.2. Empirical Review

A literature review was carried out, however in many cases in the above theoretical parts. Past studies provided an increased level of understanding of how solar energy is utilized around the world, and how this study fits with the application of low voltage DC system. Some reviews on the study variables as follows: -

In [26], study about Efficiency and Reliability Analysis of AC and 380V DC Data Centers. The paper presented a method to improve data centers efficiency and reliability with and without PV integration. The efficiency analysis shows that 380V DC distribution system is more efficient than the typical AC distribution system at all PV installation sizes ranging from 0MW to 50MW. The efficiency of the power distribution system can be increased if numbers of power conversion stages can be reduced and more efficient converters are used. Use of wide band gap (WBG) converters will further improve the overall system efficiency because of its high efficiency. Maintaining high availability at all times is very critical to data centers. The distribution system with higher number of series components is more likely to fail, resulting in increased down time. This study aims at comparing reliabilities of AC against 380V DC architecture. Reliability assessment was done for both AC and DC systems complying with Tier IV standard. The analysis was done for different level of redundancy (e.g. N, N+1, N+2) in the UPS system for both AC and DC systems.

Monte Carlo simulation method was used to perform the reliability calculations. The simulation results showed that the 380V DC distribution system has higher level of reliability than AC distribution system in data centers but only up to certain level of redundancy in the UPS system. The reliability level of AC system will approach to that of a DC system when a very high level of redundancy in the UPS system is considered, but this will increase the overall cost of a data center.

In [27], presented DC micro grid in residential buildings. The concept and comparison of AC versus DC system and DC micro grids architecture has been discussed. The distribution topologies discussed very helpful to understand the most efficient way of interconnection. The data of energy dissipated in DC appliances and the cable cost data representing are used to show the correlation of different parameters associated with the losses. A power system control strategy-based approach is used for the voltage standardization. This approach enables the development of energy efficient economy and flexible LVDC system and as well as medium voltage standardization. A comparative analysis of AC and DC residential building shows the superiority DC residential building, in respective energy saving. Simulation results also show that the power consumed in the DC residential building is less than the power consumed in the AC residential building. As the converter stages and conversion losses are much less in the DC residential building compared to the AC residential building.

In [28], discussed a simulation-based efficiency comparison of AC and DC power distribution networks in commercial buildings. The electrical building models are composed of realistic load and generation profiles, converter efficiency curves based on market data, and precise wiring models. The research discussed in this paper uses Modelica- based simulation to compare the efficiency of DC building power distribution with an equivalent alternating current (AC) distribution. The buildings are all modeled with solar generation, battery storage, and loads that are representative of the most efficient building technology. These simulations also validate previous studies that use simpler approaches and arithmetic efficiency models. This work shows that using DC distribution can be considerably more efficient: a medium sized office building using DC distribution has an expected baseline of 12% savings, but may also save up to 18%. In these results, the baseline simulation parameters are for a zero-net energy (ZNE) building that can island as a micro grid. This study also confirms that DC distribution is best suited for buildings with a large solar capacity, a large battery bank, and a high voltage distribution backbone. Although this work contributes in establishing a baseline for efficiency savings with DC, other metrics besides efficiency must be examined in order to reach a decisive verdict. For example, this study does not account for power quality. While power quality may translate to efficiency loss in the grid, there are other important ways in which a system can suffer from low power quality. Ultimately, a comprehensive techno-economic analysis is required to thoroughly measure the savings of DC distribution. Such an analysis would ideally encompass the differences in up-front cost, life-cycle cost, metering (i.e., efficiency), and power quality.

In [29], presented Techno-Economic Analysis of DC Power Distribution in Commercial Buildings. Techno-economic evaluation of DC distribution in highly efficient commercial buildings with DC loads. TEA results were generated for three commercial building types in two California cities with several PV and battery capacities, for current and future market conditions. This work was based on (1) a technical analysis of the building distribution systems and end-use topologies, (2) a detailed efficiency model that incorporates real converter efficiency curves and (3) Life Cycle Cost and Payback period analysis framework that utilizes Monte Carlo simulation and price data from commercially available products. The sensitivity analyses reveal that coincidence of load and PV generation increases efficiency savings and economic benefits. Perhaps one of the most important factors affecting energy and cost savings is the DC system configuration.

The current market for DC systems is at its nascent stage, therefore costs not considered in this analysis, such as installation costs and soft costs are expected to be higher for DC systems in the short run. However, as the market for DC distribution continues to edge towards maturity, such costs are expected to become comparable to those of AC systems while other potential benefits of DC could translate to additional cost savings for DC distribution. Indeed, resiliency, ease of communications and controls, and increased reliability from simpler appliances (without internal AC/DC conversions) may actually be more important motivation factors for adoption of DC power in buildings than just energy savings. Therefore, more research related to quantifying the benefits of the non-energy attributes of DC distribution is warranted.

Statements made from these sources come with the caveat that further work to prove these statements will have to be carried out.

2.3. Conceptual Framework

The following conceptual framework is developed based on PV source block diagram of the system related literature on the study variables.

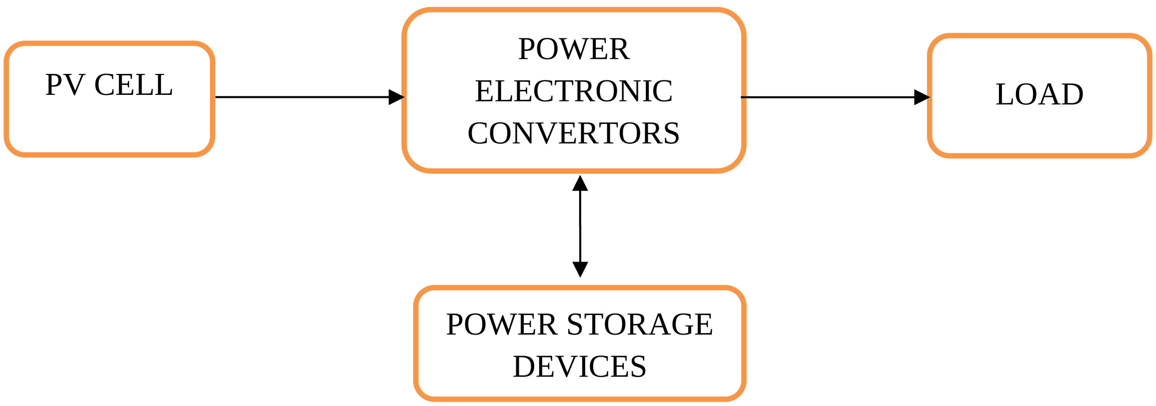


Figure 2.4. Block Diagram of Solar Powered Low Voltage DC System

Source: *Own Source (2019 G.C)*

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1. Description of the Research Context

The use of photovoltaic (PV) to produce electricity from sunlight would strongly benefit and improve the quality of life for those fewer developing countries such as Ethiopia. The decentralized approach based on power produced with locally available renewable energy resources is, for various reasons, gradually being recognized as a viable alternative source. This study to apply in Adama Science and Technology University – ICT Center Building which is in Adama City located 95 Km from Addis Ababa, Ethiopia. ICT sector has growing tremendously in the country and is continuing to grow as well as in universities.

3.2. Research Method

The study that have been used to reviewing literatures related to the currently existing AC system and the newly proposed low voltage DC system. The PV source to load and classifying loads in to appropriate groups according to energy consumption of appliances within a day at which the equipment is in normal operational mode conditions. The loss of power on wires and converters had also investigated. Appropriate voltage level has been selected considering technical compatibility to the appliances and efficiency.

DC system has been made on solar resources in terms of cost, compatibility and technological advancement. Optimal sizing of PV system sizing and battery energy storage system design is done mathematically based on the loads connected to the system.

3.3. Methods of data collection

Data had been collected quantitatively from records that include sunshine duration. Field survey done to identify the load to be selected and to have idea on the existing system and the total number of loads and watt rating used on Adama Science and Technology University – ICT Center building. Then finally Design of power generation has to supply the building based on data collected and load demand.

3.4. Methods of Data Analysis

The analysis had been done using simulation and mathematical model in Spread sheet (Excel) that would be used different devices and modules. Generally, to optimize the generated power and load (demand) using appropriate software called Homer. The study that would be used to designed for DC electrical equipment's and system sizing. Although DC system model design for the selected building loads and the behavior of the system has been simulated considering the daily load profiles. The investment cost of the new system and installation of PV system had estimate. Generally, the system has been studied in detail.

CHAPTER FOUR

4. DESIGN SPECIFICATION AND VOLTAGE STANDARDIZATION

Data center use grid electricity and diesel generators (during the absence of grid supply), but there are other possible alternative methods such as solar, that the researcher use for this research. Power distribution architecture for data centers, for example, techniques and standardization with associated apparatus to efficiently deliver uninterruptible power to Scalable and/or modular data processing equipment.

4.1. Location and Load Estimation

Adama is one of Oromia region of Ethiopia located 95Km from Addis Ababa, Adama science and technology which is in Adama city, to install PV have been used at latitude: 8.468^{0}N and longitude: 39.159^{0}E for ICT (Data Center) building to have uninterruptable power supply. Adama Science and Technology University daily average solar insolation is shown in table 4.3.

Table 4.3. Monthly average insolation (KWh/m^2/day) … Specific to Adama Since and Technology University.

At Lat=8.468^{0}N and Lon=39.159^{0}E	Jan	Feb	Mar	Apr	May	Jun
	6.08	6.57	6.52	6.31	6.36	5.77
	Jul	Aug	Sep	Oct	Nov	Dec
	5.23	5.36	5.84	6.31	6.27	6.08

Solar modules are usually mounted on roofs. If roof area is not available, PV modules can be pole-mounted, ground-mounted, and wall-mounted or installed as part of a shade structure. PV system is installed to avoid the cost of removing and reinstalling the PV system. Optimum orientation can be influenced by typical local weather patterns. Modules be installed at the same pitch as a sloping roof, whatever that slope is, primarily for If your location limits the physical size of your system, you may want to install a system that uses more-efficient PV modules.

For roof-mounted systems, typically compositions are easiest to work with and slate and tile roofs are the most difficult. Nevertheless, it is possible to install PV modules on all roof types. Keep in mind that access space around the modules can add up to 20 percent to the required area.

In case of load estimation, I have collected the data in ICT building which have a huge dependency on the electrical energy as most of their work is done on computers. However along with the large number of computer and networking hardware, there is other office equipment as well. From a load stand point we can subdivide an IT office electrical load in to the following categories:

General loads: - Categories of these are major ICT building appliances. Examples of such are Ventilators, Printers, Scanner, Copiers, Air conditioner, refrigerators and Socket Outlets to uses any appliances in the building as well.

Sensitive loads: - An electronic load which is commonly found in office buildings with digital computers, network switch and data communication centers appliances and these are nonlinear in nature. Other examples of these modern appliances are consumer electronics products, such as TV's, DVD players, mobile phones, game consoles etc., which are used in office buildings.

In [30], described the use of LVDC distribution system for sensitive electronic loads in office buildings using four different loads, which includes a fluorescent lamp, a compact fluorescent lamp, a computer and a coffee maker, using AC and DC system for evaluation and comparison purposes. Experimental results showed less losses when the load was supplied with the DC system compared to the conventional AC UPS (uninterrupted power supply) system.

There are numerous energy efficient products that are internally compatible with DC. These DC appliances utilize DC power internally. Among these products are the LED lights and many electronic loads such as DC refrigerators, 12V DC blenders and heaters.

Different sets of loads are considered from the collected data in ICT building such as lightings, socket outlets, ventilators, refrigerator, printers, scanners, copiers, projectors, TV set, air conditioners, Network switches and servers. Load demand estimation of the selected ICT building were 51.54KW of total load and the average power demand per day that can be obtained by itemizing all appliances and their hour's use each day which is 434.58KWh of energy demand.

4.2. Analysis for Voltage Standardization

The increasing power consumption due to the increasing population and growing industries including ICT center, is not matched by the increase in power generation. The main requirement for ICT building is standard voltage with uninterruptable power supply. The secondary requirement is moderate costs for the system.

4.2.1. Low Voltage AC System

For the AC supply, the existing single phase 220 -240 V_{rms} AC voltage level (line-to-ground) is considered. The DC load includes the isolation transformer, the rectifier and the DC/DC converter to operate from the AC source. The AC loads can be directly supplied from the AC supply. The schematic diagram of the LVAC system with both AC and DC loads is shown in Fig 4.3.

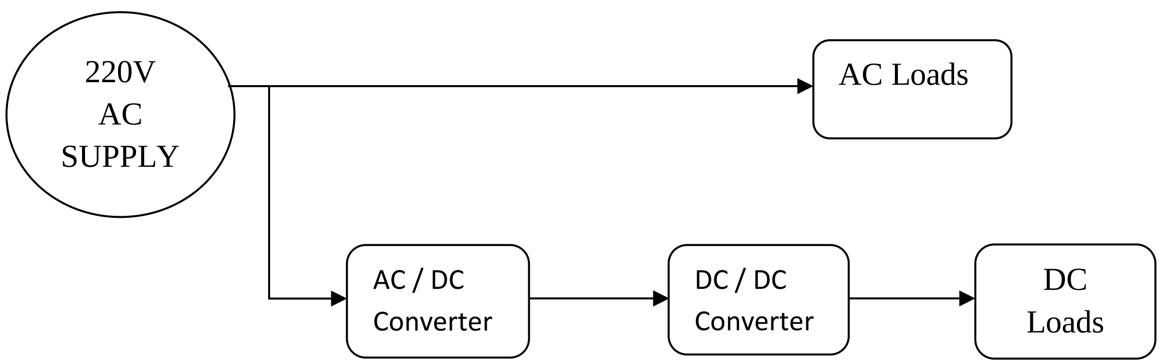


Figure 4.5. Schematic diagram of the LVAC distribution system.

4.2.1.1. Resistance and Inductance of Feeder

Electrical conductors or wires in buildings run mostly using PVC pipe with an inner diameter of 13 mm. The inductance of the conductors varies since the distance between the conductor's changes. The inductance of the feeder (in Henry) is given by

$$L=0.05+0.2ln\,(d/r) \qquad (1)$$

Where d is the distance between the phase and the neutral conductors (in meter), r is the radius of the wire (in meter). The ac resistance of the conductor varies with little amount from the dc resistance due to a phenomenon known as skin effect. A skin effect correction factor k, for a 50Hz frequency is estimated to be 1.02. [31]. The minimum dc resistance of the conductors in mΩ/m according to IEC 60228 is given in Table 4.4.

The ac resistance of solid copper conductor is determined by multiplying the dc resistance given in Table 4.4.by skin effect factor 1.02.

Table 4.4. DC resistance of wires [32]

Cross-sectional Area (mm^2)	Copper resistance (mΩ/m)
0.5	36
0.75	24.5
1	18.1
1.5	12.1
2.5	7.41
4	4.61
6	3.08
10	1.83
16	1.15

Then from table 4.4, resistance and inductance of the feeders for various cross-sectional areas is given in Table 4.5.

Table 4.5. Inductance and resistance variation with respect to cable size of conductors

Conductor Area (mm^2)	Distance (mm)	Radius (mm)	Resistance/m	Inductance (μH/m)	Reactance/m
1.5	10.24	0.69	0.0123	0.589	184.95
2.5	9.43	0.89	0.00756	0.522	163.91
4	8.48	1.13	0.00470	0.453	142.24
6	7.48	1.38	0.00314	0.388	121.83
10	5.86	1.78	0.00186	0.288	90.43

Most commonly used ICT office building equipment including high power consuming ones are selected for analysis. Their normal power consumption data is obtained from the collected data that consumed by electronic and electrical appliances. The input voltage of the ac system at the source is taken to be 220V-240V_{rms} for single phase and 380V for three phases. The length of the distribution feeders for the selected building appliances identified power rating, feeder length and operation-hours per day is given in Table 4.6.

Table 4.6. Power consumption, feeder length and on time duration of selected appliances

NO	Appliance Name	Rated Power (W)	Current at 220V Ac (A)	Wire Cross-Sectional Area (mm^2)	Wire Length (m)	Power on time in day (hrs.)
1	Lighting	25	0.1136	1.5	1000	12
2	Socket Outlets	50	0.227	2.5	3000	13
3	Ventilators	25	0.1136	2.5	200	4
		60	0.272	2.5	400	24
4	Refrigerator	200	0.909	2.5	250	24
5	Printers	100	0.455	2.5	280	4
6	Scanners	50	0.227	2.5	280	2
7	Copiers	1000	4.55	2.5	265	2
8	Projectors	100	0.455	2.5	280	7
9	TV Set	150	0.682	2.5	200	5
		500	2.273	2.5	100	24
10	Air Conditioner	250	1.136	4	500	9
		500	2.273	4	150	24
11	Network Switches	25	0.1136	2.5	250	24
		50	0.227	2.5	100	24
12	Server	500	2.273	4	130	24

The total resistance, inductance, reactance and impedance of the distribution wires is calculated and given according to cross sectional area calculated in table 6, Reactance X is calculated by using equation,

$$X = 2\pi fL \qquad (2)$$

Making the value of impedance by calculating the value of resistance (R) and reactance (X) by using equation,

$$Z = \sqrt{(R^2 + X^2)} \qquad (3)$$

The real power loss across the feeder (in Watt) is given by

$$P_{Loss} = I^{2*}R \qquad (4)$$

Table 4.7. Power loss across the feeder during normal conditions

No	Selected Appliances	Appliance Quantity	Current at 220V Ac (A)	Resistance (Ω)	Inductance (μH)	Reactance (Ω)	Impedance (Ω)	Feeder Power Loss (W) $P_{Loss}=I^{2*}R$
1	Lighting	152	0.114	12.3	589	0.185	12.31	0.159
2	Socket Outlets	498	0.23	22.65	1566	0.492	22.66	1.167
3	Ventilators	8	0.114	1.51	104.4	0.033	1.51	0.019
		14	0.272	3.02	208.8	0.066	3.02	0.223
4	Refrigerator	8	0.91	1.888	130.5	0.041	1.89	1.560
5	Printers	10	0.455	2.114	146.2	0.046	2.115	0.438
6	Scanners	10	0.227	2.114	146.2	0.046	2.115	0.109
7	Copiers	9	4.55	2.001	138.3	0.043	2.001	41.421
8	Projectors	10	0.455	2.114	146.2	0.046	2.114	0.438
9	TV Set	6	0.682	1.51	104.4	0.033	1.51	0.702
		1	2.273	0.755	52.2	0.016	0.755	3.901
10	Air Conditioner	24	1.136	2.35	226.5	0.071	2.35	3.033
		2	2.273	0.705	67.95	0.021	0.705	3.642
11	Network Switches	8	0.1136	1.888	130.5	0.041	1.888	0.024
		4	0.227	0.755	52.2	0.016	0.755	0.039
12	Server	4	2.273	0.611	58.89	0.019	0.611	3.157

Yearly energy consumption of the building is determined for normal case by summing the energy consumption of all the appliances selected for this study.

$$\text{I.e. Energy consumption (kWh/yr.)} = \frac{\text{on power} * \text{Turn on time perday} * 365}{1000} \qquad (5)$$

Power is distributed to consumers through ac distribution lines. Almost all electronic equipment like computers, TV, mobile phones and other appliances are powered by dc power sources, either by batteries or dc power supplies obtained from an AC source. AC has to be converted to direct current to supply these loads internally. During this AC to DC conversion within electronic equipment, there will be some power loss due to the voltage drop on the diodes.

The power loss in the diodes is given by:

$$P_{diode} = V_F * I_{rms} \quad (6)$$

Where V_F the forward voltage drops of diodes and I_{rms}, is the rms value of the current flows through the diode. Approximately the forward voltage drop of diodes can be taken as 0.7V [33].

Table 4.8. Voltage drop and energy loss across the feeder during normal conditions

Selected Appliances	Voltage Drop (%)	Rectifier Loss (W)	Rectifier Loss (KWh/Yr.)	Energy Loss in the Feeder (KWh/Yr.)	On Energy Consumption (KWh/Yr.)
Lighting	0.636			0.70	109.50
Socket Outlets	2.338	0.318	1.5080	5.54	237.25
Ventilators	0.078	0.159	0.2322	0.03	36.50
	0.373	0.381	3.3358	1.96	525.60
Refrigerator	0.781	1.273	11.1480	13.66	1752.00
Printers	0.437	0.637	0.9300	0.64	146.00
Scanners	0.218	0.318	0.2320	0.08	36.50
Copiers	4.138	6.370	4.6501	30.24	730.00
Projectors	0.437	0.637	1.6275	1.12	255.50
TV Set	0.468	0.955	1.7425	1.28	273.75
	0.780	3.182	27.8761	34.17	4380.00
Air Conditioner	1.213	1.590	5.2245	9.96	821.25
	0.728	3.182	27.8761	31.91	4380.00
Network Switches	0.097	0.159	1.3932	0.21	219.00
	0.078	0.318	2.7839	0.34	438.00
Server	0.631	3.182	27.8761	27.65	4380.00
TOTAL			**118.44**	**159.48**	**18720.85**

The total consumption energy requirement of the selected building is 18,720.85 KWh/Yr. and 159.48 KWh/Yr. is lost energy in the feeders. Additional losses in AC system, is rectifier loss which is 118.44 KWh/Yr.

4.2.2. Low Voltage DC System

Analyzing LVDC systems for commercial applications, there are some voltage levels that come as natural choices, depending on the regulation imposed by the standards, the availability of commercial solutions, or to ensure compatibility with the AC grid. Currently there are broadly available dc compatible devices that can be used with either ac or dc system that makes it suitable to bring LVDC distribution systems to homes and buildings.

The appropriate dc bus voltage level selection is the key step in the dc system design which has great impact on the performance and characteristic of the entire power system. Different voltages levels are sensitive to be used for different groups. The DC lines also have very low corona losses. The voltage stress in DC system is as follows;

$$Vdc = \sqrt{2} \times Vac \qquad (7)$$

where, V_{dc} is the DC system voltage and V_{ac} is the AC system voltage.

According to (6), the DC system has a less potential stress over AC system for same voltage. For example, if a system is designed for 230V AC, it can bear 326V DC without any rapture in insulation. This helps to reduce the gap between two conductors of the distributed line. For the low voltage DC several voltage levels such as 48V, 120V, 240V, 326Vand 380V can be considered. The AC load includes the DC/DC converter, inverter, filter, and isolation transformer to operate from the DC source. The DC load can be supplied directly from the DC source if the DC voltage level is compatible with the device voltage level. The schematic diagram of the LVDC system is shown in Fig 4.4.

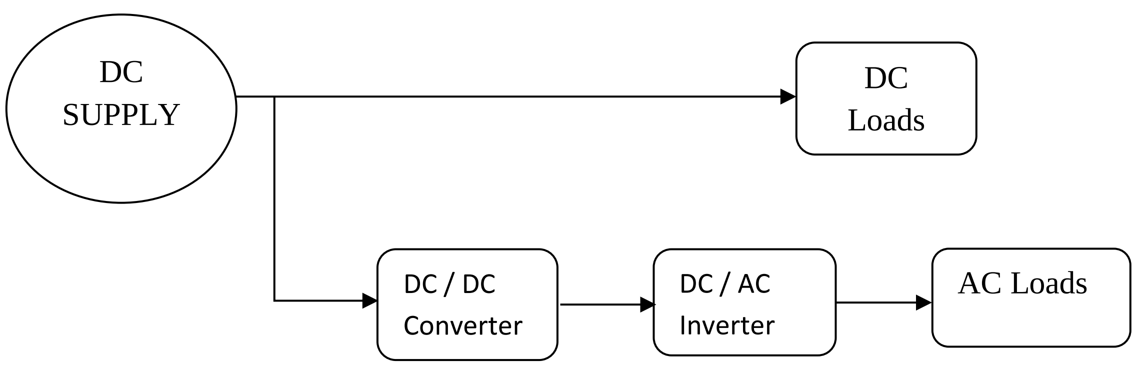


Figure 4.6. Schematic diagram of the LVDC distribution system.

In dc system the voltage and currents are in phase which implies that the power factor becomes 1. Therefore, there will be only real power loss in the feeder. And the frequency of the supply system is zero in dc system, the reactance of the feeder becomes zero i.e. $XL = 0$

Electronic devices have to convert AC to DC internally using rectifiers. This incurs loss due to the voltage drop across the switch. In this proposed design building appliances are supplied with dc directly. This avoids some of the conversion steps, meanwhile avoids rectifier losses.

For this thesis work 48V, 120V, 240V, 326V and 380V dc systems are analyzed for dc system. The energy consumption, feeder power loss and percentage of voltage drop are calculated for the selected voltage levels.

Table 4.9. Energy consumption and feeder power loss for 48V DC system

Appliance Name	**Rated Power (W)**	**Wire Cross-Sectional Area (mm^2)**	**Wire Resistance (Ω)**	**Current (A)**	**Voltage Drop (%)**	**Power Loss (W)**	**Energy Loss (KWh/Yr.)**	**Energy Consumption (KWh/Yr.)**
Lighting	25	1.5	12.3	0.52	13.35	3.34	14.61	109.5
Socket Outlets	50	2.5	22.65	1.04	49.15	24.58	116.62	237.25
Ventilators	25	2.5	1.51	0.52	1.64	0.41	0.60	36.5
	60	2.5	3.02	1.25	7.86	4.72	41.34	525.6
Refrigerator	200	2.5	1.8875	4.17	16.38	32.77	287.06	1752
Printers	100	2.5	2.114	2.08	9.18	9.18	13.40	146
Scanners	50	2.5	2.114	1.04	4.59	2.29	1.67	36.5
Copiers	1000	2.5	2.00075	20.83	86.84	868.38	633.92	730
Projectors	100	2.5	2.114	2.08	9.18	9.18	23.44	255.5
TV Set	150	2.5	1.51	3.13	9.83	14.75	26.91	273.75
	500	2.5	0.755	10.42	16.38	81.92	717.64	4380
Air Conditioner	250	4	2.35	5.21	25.50	63.75	209.41	821.25
	500	4	0.705	10.42	15.30	76.50	670.12	4380
Network Switches	25	2.5	1.8875	0.52	2.05	0.51	4.49	219
	50	2.5	0.755	1.04	1.64	0.82	7.18	438
Server	500	4	0.611	10.42	13.26	66.30	580.77	4380
TOTAL							**3349.17**	**18720.85**

Table 4.10. Energy consumption and feeder power loss for 120V DC system

Appliance Name	Rated Power (W)	Wire Cross-Sectional Area (mm^2)	Wire Resistance (Ω)	Current (A)	Voltage Drop (%)	Power Loss (W)	Energy Loss (KWh/Yr.)	Energy Consumption (KWh/Yr
Lighting	25	1.5	12.3	0.21	2.14	0.53	2.34	109.5
Socket Outlets	50	2.5	22.65	0.42	7.86	3.93	18.66	237.25
Ventilators	25	2.5	1.51	0.21	0.26	0.07	0.10	36.5
	60	2.5	3.02	0.50	1.26	0.76	6.61	525.6
Refrigerator	200	2.5	1.8875	1.67	2.62	5.24	45.93	1752
Printers	100	2.5	2.114	0.83	1.47	1.47	2.14	146
Scanners	50	2.5	2.114	0.42	0.73	0.37	0.27	36.5
Copiers	1000	2.5	2.0008	8.33	13.89	138.94	101.43	730
Projectors	100	2.5	2.114	0.83	1.47	1.47	3.75	255.5
TV Set	150	2.5	1.51	1.25	1.57	2.36	4.31	273.75
	500	2.5	0.755	4.17	2.62	13.11	114.82	4380
Air Conditioner	250	4	2.35	2.08	4.08	10.20	33.51	821.25
	500	4	0.705	4.17	2.45	12.24	107.22	4380
Network Switches	25	2.5	1.8875	0.21	0.33	0.08	0.72	219
	50	2.5	0.755	0.42	0.26	0.13	1.15	438
Server	500	4	0.611	4.17	2.12	10.61	92.92	4380
TOTAL							**535.87**	**18720.85**

Table 4.11. Energy consumption and feeder power loss for 240V DC system

Appliance Name	Rated Power (W)	Wire Cross-Sectional Area (mm^2)	Wire Resistance (Ω)	Current (A)	Voltage Drop (%)	Power Loss (W)	Energy Loss (KWh/Yr.)	Energy Consumption (KWh/Yr.)
Lighting	25	1.5	12.3	0.10	0.53	0.13	0.58	109.5
Socket Outlets	50	2.5	22.65	0.21	1.97	0.98	4.66	237.25
Ventilators	25	2.5	1.51	0.10	0.07	0.02	0.02	36.5
	60	2.5	3.02	0.25	0.31	0.19	1.65	525.6
Refrigerator	200	2.5	1.8875	0.83	0.66	1.31	11.48	1752
Printers	100	2.5	2.114	0.42	0.37	0.37	0.54	146
Scanners	50	2.5	2.114	0.21	0.18	0.09	0.07	36.5
Copiers	1000	2.5	2.00075	4.17	3.47	34.74	25.36	730
Projectors	100	2.5	2.114	0.42	0.37	0.37	0.94	255.5
TV Set	150	2.5	1.51	0.63	0.39	0.59	1.08	273.75
	500	2.5	0.755	2.08	0.66	3.28	28.71	4380
Air Conditioner	250	4	2.35	1.04	1.02	2.55	8.38	821.25
	500	4	0.705	2.08	0.61	3.06	26.80	4380
Network Switches	25	2.5	1.8875	0.10	0.08	0.02	0.18	219
	50	2.5	0.755	0.21	0.07	0.03	0.29	438
Server	500	4	0.611	2.08	0.53	2.65	23.23	4380
TOTAL							**133.97**	**18720.85**

Table 4.12. Energy consumption and feeder power loss for 380V DC system

Appliance Name	Rated Power (W)	Wire Cross-Sectional Area (mm^2)	Wire Resistance (Ω)	Current (A)	Voltage Drop (%)	Power Loss (W)	Energy Loss (KWh/Yr.)	Energy Consumption (KWh/Yr.)
Lighting	25	1.5	12.3	0.07	0.21	0.05	0.23	109.5
Socket Outlets	50	2.5	22.65	0.13	0.78	0.39	1.86	237.25
Ventilators	25	2.5	1.51	0.07	0.03	0.01	0.01	36.5
	60	2.5	3.02	0.16	0.13	0.08	0.66	525.6
Refrigerator	200	2.5	1.8875	0.53	0.26	0.52	4.58	1752
Printers	100	2.5	2.114	0.26	0.15	0.15	0.21	146
Scanners	50	2.5	2.114	0.13	0.07	0.04	0.03	36.5
Copiers	1000	2.5	2.00075	2.63	1.39	13.86	10.11	730
Projectors	100	2.5	2.114	0.26	0.15	0.15	0.37	255.5
TV Set	150	2.5	1.51	0.39	0.16	0.24	0.43	273.75
	500	2.5	0.755	1.32	0.26	1.31	11.45	4380
Air Conditioner	250	4	2.35	0.66	0.41	1.02	3.34	821.25
	500	4	0.705	1.32	0.24	1.22	10.69	4380
Network Switches	25	2.5	1.8875	0.07	0.03	0.01	0.07	219
	50	2.5	0.755	0.13	0.03	0.01	0.11	438
Server	500	4	0.611	1.32	0.21	1.06	9.27	4380
TOTAL							**53.44**	**18720.85**

Low voltage DC system for the building application carried out by different voltage level of DC systems. In Direct Current System on table 4.8, 4.9, 4.10 and 4.11 in the analysis, feeder energy losses and voltage drops have been decreased when we increase the standard voltage level. According to different study such as [34] suggested that 326Vdc, the maximum of the rectified sine-wave, could be the optimum voltage to supply electricity to modified loads directly. Further, the same study also showed that voltages below 120Vdc turned out to be impractical in terms of voltage drop and current ratings for a typical distribution feeder. The voltage drops shown graphically in Fig.4.5.

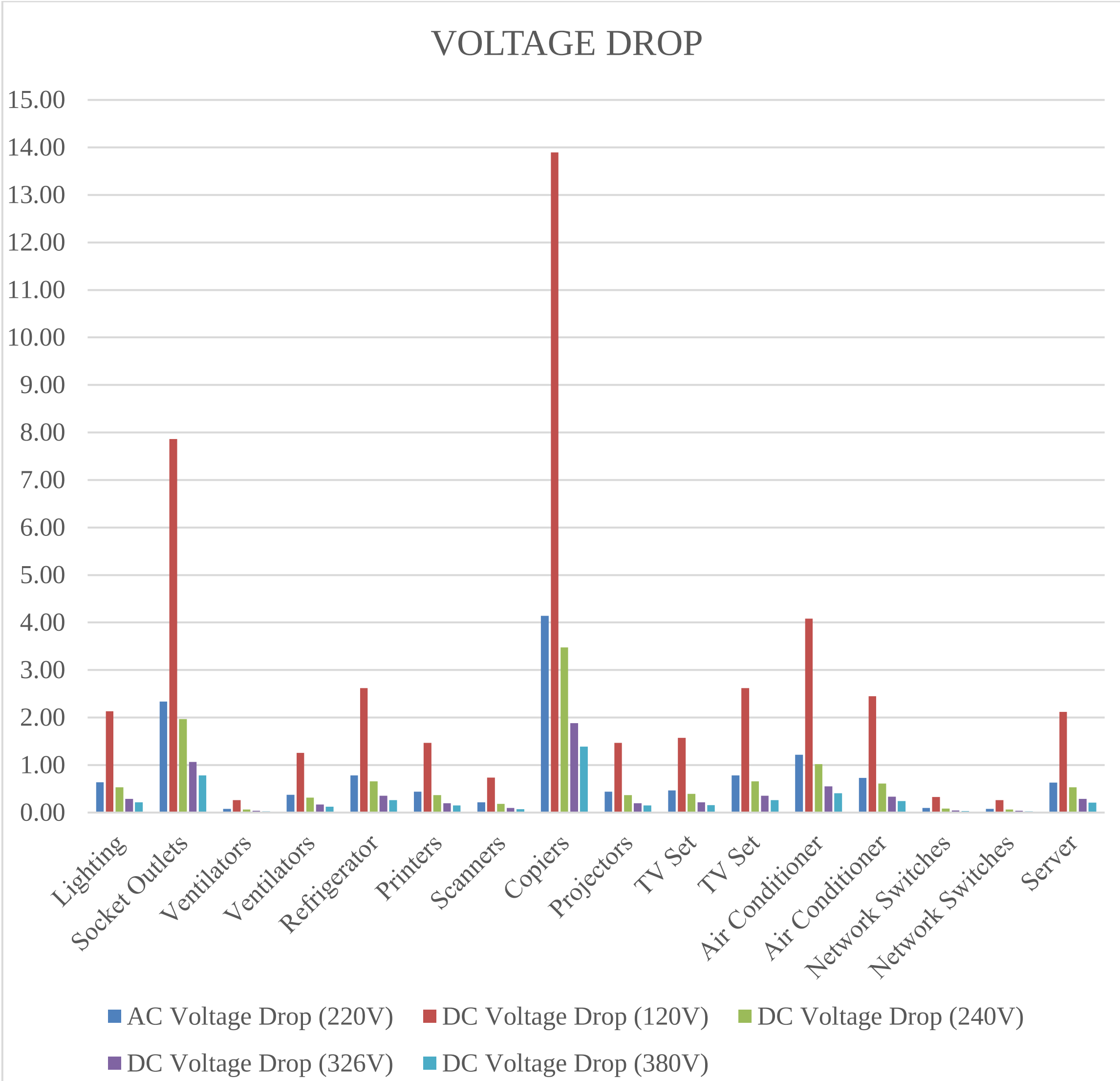


Figure 4.7. AC versus DC Voltage Drop

Based on the analysis of overall voltage level, graph of voltage drops in each appliance of Dc system (240V, 326V and 380V), that provides less voltage drop than 220V ac systems. It's not possible to have zero voltage drops, because some voltage loss is going to occur naturally from the resistance of the conductors. It takes voltage to push current through a conductor. Due to voltage drop caused by improperly sized circuit, the operating voltage at electrical equipment will be less than the output voltage of the power supply. This will result operating at voltages below its rating which in turn can cause them to overheat-resulting in shorter equipment operating life and increased cost, as well as inconvenience for the consumer. Under voltage for sensitive electronic equipment can cause possible equipment failure. However, the goal is to minimize the voltage drop by using appropriate voltage level.

The power required for LVDC loads vary with the activity when using the equipment. In a computer for example, the supplied 230 V AC is converted to mainly 5 and 12 V DC. It is therefore evident that a power supply unit (PSU) for a computer that is rated at 650 W does not utilize power of 650 W all the time. The PSU of the computer only draws the power required when the computer is working, and the computer does therefore not require 650 W constantly. The 650 W is therefore not necessarily the power that the computer utilizes, but it is the maximum power the charger can deliver [35].

The discussion of AC versus DC in the ICT Building appliance starts with losses and efficiency. To calculate the efficiency of both AC and DC systems by using the equation: -

$$\eta = (P_{load} /(P_{load}+P_{loss})) *100 \qquad (8)$$

Since it draws a notable amount of power, a comparatively small increase in efficiency can lead to a reduction in operating costs. In the selected equipment, losses are occurring due to the AC-DC conversion (rectifier losses) in the power converters and it produces high heat losses during operation, with power supplied from the existing AC system. There for Dc system had only real losses which leads to the idea that try to reduce these losses by applying DC power directly to the end use equipment.

Table 4.13. Energy efficiency for the selected Appliance.

Supply Type	**Energy Efficiency**
220 V AC	99.18
48 V DC	87.04
120 V DC	97.35
240 V DC	99.31
380 V DC	99.72

LVDC in buildings have been done based on appliances, converters and their power losses in both systems. The researcher chooses DC system to minimize losses and voltage drops that incurred in AC system. In reference [36], the energy efficiency analysis of DC products was analyzed operating with AC for AC and DC voltage supply. Comparison was made for DC and AC products using DC lamps, air conditioners, refrigerator/freezers and it was observed that the DC products were more energy efficient than the AC products. The absence of reactive power and skin effect are other reasons for improved efficiency in a DC system compared to an AC system.

It has two categories of power losses which are conductor losses and converter losses. Conductor losses described in the above low voltage AC and DC system. For converter losses, there are three main power electronics which is rectifier, Inverter and DC-DC converter.

The majority of commercial loads comprise of electronic loads that require DC, to supply DC loads using a conventional AC distribution system, a power electronic converter is required to first convert AC to DC. Power conversion from AC to DC results in additional power losses, usually about 4–15% of the input power; assuming the converters are 85–96% efficient. Therefore, the total system losses become relatively high as the number of power converters increase.

In this thesis work DC is selected for low voltage dc system to supply power for the selected building, with more energy efficiency as compared to the AC system and other low voltage dc systems. Lawrence Berkley national laboratory (LBNL) started investigating the DC distribution efficiency in data centers in 2004. The results obtained in their study stated that DC distribution consumed 28% less power compared to a typical AC distribution in data centers [37].

This voltage level is also compatible with most building appliances with little or no modification made on the internal circuitry of the appliances. DC power generated by solar PV can be directly stored in a battery. Energy storage can also be used to power DC devices, which reduces energy conversion losses.

4.2.3. Specifications

To realize the analysis of PV, tilt angle $=23^0$ facing towards south having better average daily insulations, battery round- trip efficiency = $(0.6<x<0.8)$ and Yingli Solar YL300P-35b (300W) Solar Panel is selected with the specification given in Table 4.14, which is available in Ethiopian market to get 300 watts.

Table 4.14. Electrical characteristics of Yingli Solar YL300P-35b (300W) Solar Panel

DC Electrical Characteristics

STC power Rating	300W
I_{mp}	8.17A
V_{mp}	36.7V
I_{sc}	8.77A
V_{oc}	46.3V
NOCT	460C
Series Fuse Rating	15A

Table 4.15. Mechanical characteristics of Yingli Solar YL300P-35b (300W) Solar Panel

Mechanical characteristics

Type	Polycrystalline Silicon
Output Cable Wire Gauge	12 AWG
Size(L*W*H) (mm)	1970*990*50
Weight	26.8 Kg.
80% power output warranty period	25yrs
90% power output warranty period	10yrs
Workmanship Warranty Period	10yrs

4.2.4. Selection of Voltage Standardization

The renewable energy sources and energy storage can be integrated to have the better utilization and standard of the DC system compared to AC system. To select the standards for DC grid voltage, analysis done on PV array on AC sizing and DC is sizing to select relatively better performance. The design done based on the collected data which are 51.54 KW, Length of the cable 10m and acceptable loss of 5% voltage drop.

Table 4.16. The PV Array on AC Sizing.

DC Voltage	Feeder Size (A)	Feeder Cable Size (mm^2)	Number of PV Modules	Number of Batteries
48 V	1074	630	306x2=612	70x4=280
120 V	430	150	123x4=492	28x10=280
240 V	215	50	62x7=434	14x20=280
380 V	136	35	39x11=429	9x32=288

Table 4.17. The PV Array on DC Sizing

DC Voltage	Feeder Size (A)	Feeder Cable Size (mm^2)	Number of PV Modules	Number of Batteries
48 V	1074	630	354x2=708	70x4=280
120 V	430	150	142x4=568	28x10=280
240 V	215	50	71x7=497	14x20=280
380 V	136	35	45x11=495	9x32=288

Renewable generation coupled with energy storage and native DC loads are the key elements enable DC distribution in buildings. The researcher selects 380V, as an optimal voltage level for the DC system by considering the feeder size, feeder cable number of PV modules and number of batteries described on the above table 4.17.

CHAPTER FIVE

5. OPTIMAL SIZING

Component of ICT is responsible to provide electrical energy to the building appliance for its operation. The primary energy source used is the grid supply. In addition to grid supply, ICT building uses backup energy sources during emergency situations like diesel generators. Renewable energy sources (Solar) that being used as a source in the electrical grid distribution of ICT building.

A convergence of factors is driving recent interest in using direct current (DC) from solar electric systems in its DC form to power electricity loads in buildings, rather than totally converting it to alternating current (AC).

5.1. PV Array Sizing

Solar Energy is an environmentally friendly renewable energy resource that does not emit carbon to the atmosphere that causes global warming. Research conducted by US Energy Firm Green Technology Africa Incorporated, shows that solar is a viable renewable energy for Ethiopia [38]. 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:

Calculate total Watt-hours per day for each appliance used - Add the Watt-hours needed for all appliances together to get the total Watt-hours per day which must be delivered to the appliances.

Calculate total Watt-hours per day needed from the PV modules - Multiply the total appliances Watt-hours per day times 1.2 (the energy lost in the system) to get the total Watt-hours per day which must be provided by the panels.

Different size of PV modules will produce different amount of power. To find out the sizing of PV module, the total peak watt produced must be known. The peak watt (Wp) produced depends on size of the PV module and climate of site location. We have to consider “panel generation factor” which is different in every site location. For our country, the panel generation factor is average sun shine duration per day. To determine the sizing of PV modules, the calculation is as follows:

Calculate the total Watt-peak rating needed for PV modules: Divide the total Watt-hours per day needed from the PV modules (from the 2nd item) by average sun shine duration per day to get the total Watt-peak rating needed for the PV panels needed to operate the appliances.

Calculate the number of PV panels for the system: Divide total Watt-peak rating by the rated output Watt-peak of the PV modules available. Increase any fractional part of result to the next highest full number and that will be the number of PV modules required.

Result of the calculation is the minimum number of PV panels. If more PV modules are installed, the system will perform better and battery life will be improved. If fewer PV modules are used, the system may not work at all during cloudy periods and battery life will be shortened. In general, the modules in a PV array are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more current as desired and the formulas as follows: -

$$I_{total} = \frac{\text{Peak power}}{\text{System dc voltage}} \quad (9)$$

Number of series modules $$N_s = \frac{\text{System dc voltage}}{\text{Module rated voltage}} \quad (10)$$

Number of series modules $$N_p = \frac{\text{Whole module current}}{\text{Rated current of one module}} \quad (11)$$

Total number of modules $$N_t = N_s * N_p \quad (12)$$

Based on resource capacity, solar energy is highly preferable for the country. On this thesis, PV system design has been done for 380V dc system, Emerge Alliance standard of data center. To size the PV array, the collected data that used to show Adama Science and Technology University daily average solar radiation (KWh/m^2/day) of the months and clearness index profile in figure 5.6.

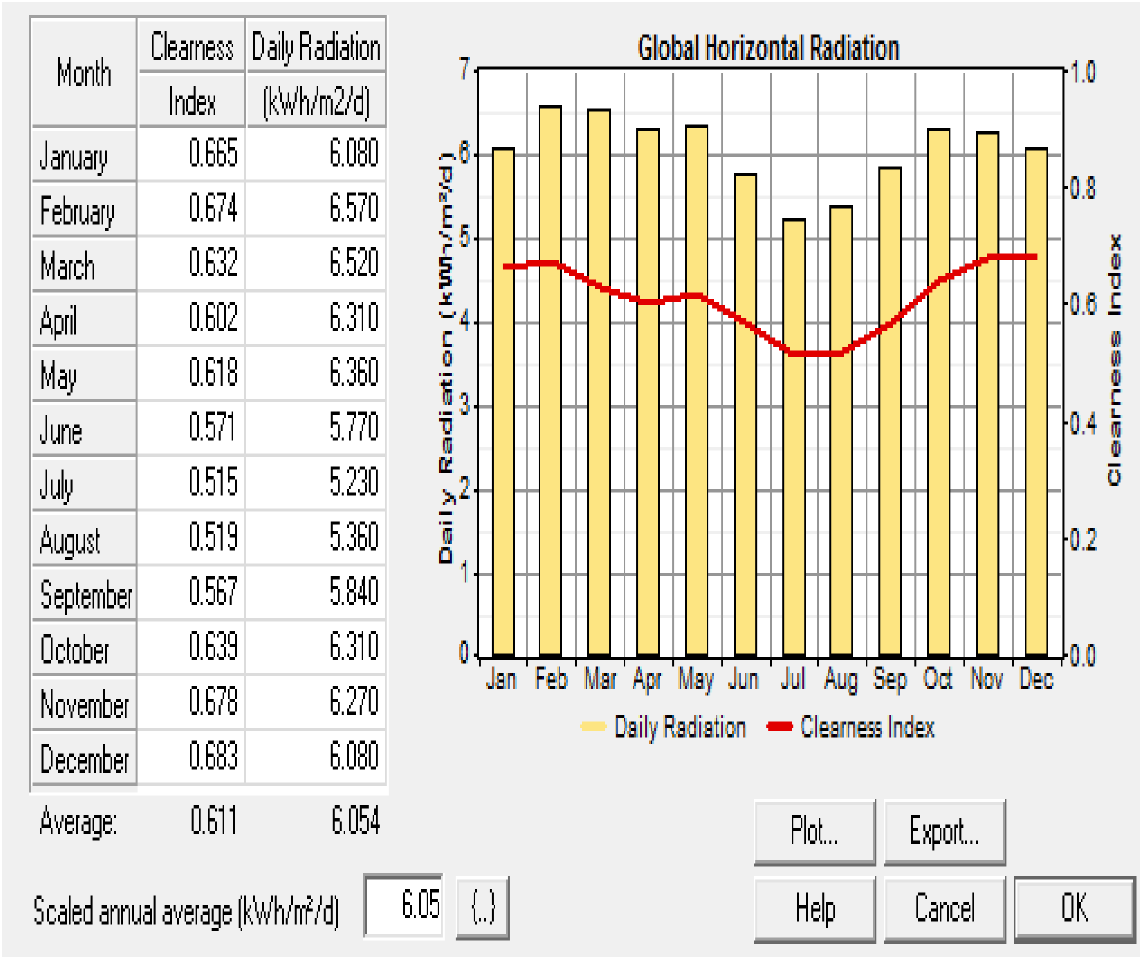


Figure 5.8. Homer output graphic for solar daily radiation and clearness index profile for ASTU.

Photovoltaic (PV) power system convert sunlight directly in to electricity. Use the lowest mean daily insolation value amongst all the months over the year that is July for the design of standalone solar system, so that when the sun is least available due to weather conditions, the solar system can work [39]. The PV system is designed to fulfill the building load demand and expected to produce a constant voltage for the selected building. To size PV in selected IT building collected loads of 434,580-watt hrs. With these collected loads to determine the size as follows: -

5.1.1. PV Array of AC Sizing

The following technical considerations for the sizing of photovoltaic array, charge controller, battery bank inverter and cable for the connection of these components are very important for designing an optimal solar PV system for stand-alone application.

Step-1 Multiply AC watt hours per day by 1.2 to correct for inverter losses, wiring losses and other losses.

434,580*1.2= 521,496-watt hrs. /day

Step-2 Divide step-1-watt hours by inverter dc input voltage

$$I_{total} = \frac{521{,}496}{380V}\text{-watt hrs. /day} = 1{,}372.36A$$

Step-3 Multiply total amp hours per day by 1.2 to compensate for loss from battery charge/discharge.

1,372.36*1.2 = 1,646.83A

Step-4 Divide amp hours in step-3 by minimum sun hours per day in Adama 5.23

$$\frac{1{,}646.83}{5.23} = 314.88$$

Step-5 To determine total number of solar modules in parallel required- divide step 4 by optimum or peak amps of solar modules from module specifications.

$$N_p = \frac{314.88}{8.17} = 38.54 \approx 39$$

Step-6 Number of modules in series divides nominal system voltage by individual array voltage.

$$N_s = \frac{V_{req.}}{V_{mp.}} = \frac{380V}{36.7V} = 10.35 \approx 11$$

Step-7 To determine total number of solar modules required, multiply step-5 by step-6

39*11 = 429 Modules

5.1.2. PV Array of DC Sizing

Load demand estimation of a typical Dc building (Ed) = 434,580 Wh/day

Watt-hour from PV System (Combined efficiencies = 0.6)

Energy of PV (E_{pv}) =E_{demand} /0.6 = 434,580Wh/d/0.6 = 724,300

By considering summer season lowest average daily insolation taking minimum Generation (G_{min}) =5230Wh/m^2d

Step-1 PV array Sizing **(P_{pv})** = (E_{pv}/$G_{min.}$) x 1000W/m^2 = (724,300/5230) x 1000W/m^2

= 138,490 W

Step-2 Load Current (I_{pv}) = P_{pv} / V = 138,490W/380V = 364.45A

The researcher chooses Yingli solar YL300P – 35b (300 W) Panel, I_{mp} = 8.17A, V_{mp} = 36.7v and 300W Polycrystalline Silicon PV module.

Step-3 Number of PV module in Parallel (N_p) = 364.45/8.17 = 44.61 ≈ 45

Step-4 Number of PV module in Series (N_s) = 380/36.7 = 10.35 ≈ 11

Step-5 Total number of PV (N_t) = N_s x N_p = 45 x 11 = 495

5.2. Battery Sizing

Stores energy for supplying to electrical appliances when there is a demand. Battery bank was involved in the system to make the energy available at night or at days of autonomy, (sometimes called no-sun-days or dark days), when the sun is not providing enough radiation. The different types of rechargeable batteries are available in market but the most commonly used type is lead-acid because they are readily available, cost-effective, longevity and more suitable for stand-alone solar electric power systems [40]. These batteries, usually lead-acid, are designed to gradually discharge and recharge 80% of their capacity hundreds of times.

To have safe energy storage for the required battery of IT building, calculate based on the formula with two options as follows: -

Option 1. Battery Capacity = $\frac{EC*N*\text{Battery multiplier}}{DOD*V*\eta_{inv}}$ (13)

EC = Energy consumption Wh/day

N = Autonomy days

DOD = depth of discharge

V = System Voltage

η_{inv}= inverter efficiency.

Step- 1 Multiply Daily ampere hour by number of days of autonomy or maximum number of consecutive cloudy weather days expected in an area = 2

1,372.36 * 2 = 2,744.72Ah

Step-2 Divide ampere hours' storage needed by the depth of discharge for the battery that provides a safety factor so that to avoid over draining of battery bank is 0.8

$$\frac{2,744.72}{0.8} = 3,430.90$$

Step-3 To have enough capacity to overcome cold weather effects are total battery capacity need multiply by average winter time ambient temperature battery bank experience = 1.02

$$3,430.90 * 1.02 = 3,499.52$$

Step-4 Choose ampere hour rating, for the battery from Specification to calculate number of parallel batteries, (deep cycle; 400Ah, 12V). Divide the total battery capacity by Ampere hour rating.

$$3,499.52/400 = 8.75 \approx 9$$

Step-5 Number of batteries wired in series equals divides the nominal system voltage by the battery voltage.

$$380/12 = 31.67 \approx 32$$

Step-6 The total number of batteries required

$$9*32 = 288 \text{ batteries}$$

Option 2. Energy Consumption (E_c) 434,580 Wh/day

Days of autonomy (N) = 2

State of charge = 0.65

Step-1 Energy Consumption of Battery (E_b) = E_c x N/0.65 = (434,580 x 2) /0.65

$$= 1,337,169.23 \text{ Wh/d}$$

Step-2 Battery Ampere hour capacity $C_{bat} = E_b/V_{nominal}$ = 1,337,169/380 = 3,518.87 ≈ 3519

Select the battery which is any kind, 12V nominal and 400Ah rating

Step-3 Battery required for parallel ($B_{req.}$) = C_{bat} /Ah_{rating} of battery = 3519/400 = 8.79 ≈ 9

Step-4 Battery required for Series (B_s) = Bv_{rating} /$V_{nominal}$ = 380/12 = 31.6 ≈32

Step-5 The total number of batteries required

$$9*32 = 288 \text{ batteries}$$

5.3. Charge Controller Sizing

The solar charge controller is typically rated against Amperage and Voltage capacities. Select the solar charge controller to match the voltage of PV array and batteries and then identify which type of solar charge controller is right for the application. Make sure that solar charge controller has enough capacity to handle the current from PV array.

For the series charge controller type, the sizing of controller depends on the total PV input current which is delivered to the controller and also depends on PV panel configuration (series or parallel configuration).

According to standard practice, the sizing of solar charge controller is to take the short circuit current (Isc) of the PV array multiply it by factor of safety (1.25), and number of parallel wired batteries (Np).

Total current of charge controller = 1.25 x Isc x Np (14)

Number of charge controller = I controller/Amperes of individual controller from specification. (15)

where: - 1.25 is the factor of safety recommended by solar energy international.

I_{sc} is short circuit current of PV module.

N_p is the number of modules connected in parallel.

The charge controller regulates the (energy levels) voltage and current coming from the PV panels going to battery and prevents battery overcharging and prolongs the battery life. These problems can be overcome by balancing the charging of batteries by utilizing a solar charge controller of accurate size between the batteries and solar array [41]. To select charge controller current using the equation: -

$$I\ Controller = 1.25 * 8.77A * 45 = 493.313A$$

$$\text{Number of charge controller} = 493.313/60 = 8.22 \approx 9$$

5.4. Cable Sizing

The size of cables is very important for stand-alone solar system as they are used to connect the different components of the PV system with each other and to the electrical load. In general, their size depends on the maximum current carrying capacity and should be sufficient in order to minimize the voltage drops and resistive losses. Moreover, they need to be UV and water resistant, and suitable for outdoor applications [42]. The low voltage systems usually encounter the issue of high voltage drop owing to inappropriate cable selection. Therefore, they must be sized correctly to give minimum voltage drops, typically less than 2% [43]. The undersize cables will not only produce energy losses but can also be highly hazardous by producing excessive heat and even fire. While, the oversize cables are simply the wastage of money. The size of the cable includes the length and cross-sectional area of the cable. The length of the cable is obtained by physically measuring the distance on site between the components of solar system.

Selecting the correct size and type of wire will enhance the performance and reliability of a photovoltaic system. The cross-sectional area (A) of the cable is calculated mathematically as [41]. Cables must cause less than 3% voltage loss between PV modules and charge regulator calculated as: -

Length of cable = 10m

Resistivity of copper = $1.72*10^{-8}\Omega$

Conductivity of copper = $58*10^{6}$s/m

The maximum controller module gives 125% of the short circuit module current. That is

I_{max} =1.25*8.17A = 91.913A,

So cross sectional area of cable, $(mm^2) = \frac{2 \text{ x Lx I}}{58\text{x}10^6 \text{ s/m x } V_{drop}}$ (16)

$$= \frac{2\text{x}10\text{x}91.913\text{A}}{58\text{x}0.03\text{x}380} = 2.78mm^2$$

Then from cable standard use $4mm^2$ Cable

The maximum controller to load current is found by dividing the total load power by system voltage, which is 51540w/ 380V = 135.63A ≈ 136A

Length of cable = 10m

So, if 5% of voltage losses between load and charge controller, calculate cross sectional area of cable, $(mm^2) = \frac{2\text{x Lx I}}{58 \text{ x } V_{drop}} = \frac{2\text{x }10\text{x }136}{58\text{x }0.05\text{x }380} = 2.47 \text{ mm}^2$

Then from cable standard use 2.5mm^{2}Cable

For voltage losses between battery and charge controller in 2% of losses, cross sectional area of cable, $= \frac{2x\ Lx\ I}{58\ x\ V_{drop}} = \frac{2x\ 10x\ 136}{58x\ 0.02x\ 380} = 6.17\ mm^2$

Therefore, from cable standard use 10mm^{2}Cable

5.5. DC- DC Converter Design

Converters contribute the most to overall building network electricity loss, and the DC building network is designed to reduce the number of conversions. In general, the efficiency of converter products increases with power capacity and operating voltage.

DC-DC converters are used to regulate and control output DC voltage in modern electronics. To obtain a desired DC voltage range for the load, a power electronic converter which converts a source voltage to another voltage level is needed. In the boost converter, the output voltage is greater than the input voltage, while in the buck converter, the output voltage is lower than the input voltage.

The researcher uses buck converter for some equipment's that are used less than the output voltage of PV array. A buck converter which, steps down voltage input to output supply. The buck converter converts to lower value 48v, and supply it to the load. The equivalent circuit of buck converter is shown in the Figure 5.7.

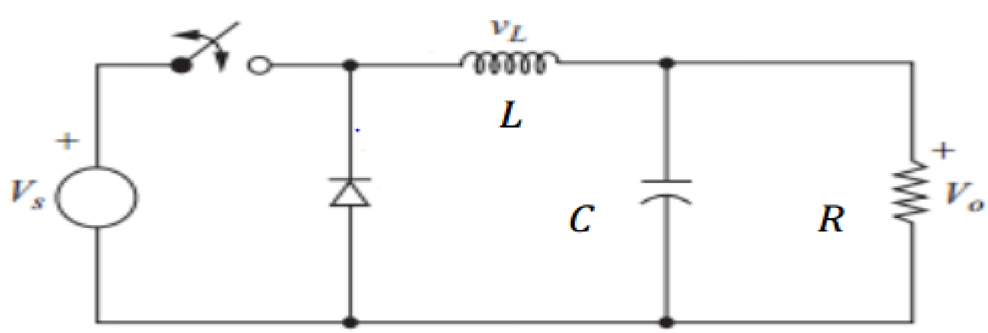


Figure 5.9. Buck DC-DC Converter [44].

It can be seen that from the load profile, the peak and the minimum load is 28.3Kw and 2.9Kw respectively and the corresponding load resistances for the buck converter becomes,

$$R= V_o/ P \qquad (17)$$

R_{min} = $(48)^2$/28,300 =$\underline{0.0814\ \Omega}$

R_{max} = $(48)^2$/2,900 = $\underline{0.7945\ \Omega}$

$$V_o = DV_s \text{ [41]} \qquad (18)$$

The duty ratio of the buck converter becomes D = V_o/ Vs = 48/380 = 0.13

For continuous output of voltage and current, the capacitance C and inductance L is given by [44]

$$L \geq R\,(1\text{-}D)/\ 2f_s \qquad (19)$$

$$C \geq 1\text{-}\ D\ /\ 16Lf_s^2 \qquad (20)$$

where fs are the switching frequency and inductor size must be selected for continuous current operation. Let the switching frequency arbitrarily be 40 KHZ, which is well above the audio range and is low enough to keep switching losses small. Calculate the inductance by using equation 10: -

$$L \geq 0.7945\ (1\text{-}0.13)/\ 2(40 \text{ X } 10^3) = 0.00864018 \text{ mH} = 8.6402\mu\text{H}$$

Let the inductor be 25 percent larger than the minimum to ensure that inductor current is continuous.

$$L= 1.25\text{X } L_{min}= 1.25 \text{ X } 8.6402\mu\text{H} = 10.8\mu\text{H}$$

Average inductor current and change in current are determined from equation.

I_L= Vo/R= 48V/0.7945= 60.42A

Δi_L= ((Vs-Vo)/L) DT = ((380-48v)/10.8X10^{-6}) X 0.13 X (1/40,000) = 99.91A

I_{max}= I_L+Δi_L/2= 60.42A+99.91/2 =110.375A

I_{min}= I_L - Δi_L/2= 60.42A - 99.91/2 =10.465A

The inductor must be rated for rms current, which is computed as

$I_{L,\ rms}=\sqrt{}\ (I_L^2+ ((\Delta i_L/2)/\sqrt{3})^2) = \sqrt{}\ ((60.42)^2+ ((99.91/2)/\sqrt{3})^2)= 66.95A \approx 67A$

The Capacitor is selected using the above equation 11.

$C \geq 1\text{-}\ 0.13\ /\ (16\text{X } (10.8\text{X } 10^{-6}) \text{ X } (40 \text{ X } 10^3)^2) = 0.87/\ 276{,}480 = 3.1467 \text{ X } 10^{-6}\text{F} = 3.15\ \mu\text{F}$

Peak capacitor current is $\Delta i_L/2$= 49.96 A, and rms capacitor current for the triangular wave form is 49.96/√3= 28.842A. The maximum voltage across the switch and diode is Vs, or 380V. The inductor voltage when the switch is closed is Vs-Vo= 380-48= 332V. The inductor voltage when the switch is open is V_o= 48 V. Therefore, the inductor must withstand 332 V. The capacitor must be rated for the 48-V output.

5.6. Cost Estimation

The researcher used to relate the currently existing ac system, and the newly proposed low voltage DC system of cost estimation. The cost estimation of designed system and PV overall cost of the system in economic point of view has been made in terms of replacement cost; all required equipment has used to invest the DC system. All cost inputs are reflective of the current market.

$$\text{Replacement cost} = \frac{A_1}{(1+i)^n} \qquad (21)$$

where, A_1 initial cost of battery, charge controller and converter.

i- Discount rate of 4%

n- Life time 10 years.

Table 5.18. Cost Data of Components

Item	Cost ($)
PV Panel	76/ Piece =37,620
Battery Bank	175/Unit
Charge Controller	155.16/ Unit
Converter	1250/Unit
Installation	10% of PV Cost
O & M / Year	2% of PV Cost

$$\text{Replacement cost of battery} = \frac{A}{(1+0.04)^{10}} = \frac{50,400}{(1+0.04)^{10}} = \underline{\$34,048.43}$$

$$\text{Replacement cost of charge controller} = \frac{A}{(1+0.04)^{10}} = \frac{1,396.44}{(1+0.04)^{10}} = \underline{\$943.385}$$

$$\text{Replacement cost of converter} = \frac{A}{(1+0.04)^{10}} = \frac{1,650}{(1+0.04)^{10}} = \underline{\$1,115}$$

Total replacement cost = $34,048+$943.384+$1,115 = $36,106.4

Maintenance cost of all the installation parts = $3,762

Operation and Maintenance cost= $ 752.4

5.7. ICT Building Energy Design Simulation Using HOMER

Numerical optimization methods described here have been used to develop computational algorithms and are used in commercially available optimization software called Homer. The process of computationally solving the optimization problem is termed as mathematical programing and includes both linear and nonlinear programming. The simulation runs based on HOMER that allow to simplifies the task of evaluating design of energy for more flexibility purposes in Energy. The results from the optimization by the software were used to calculate the selected data. The life cycle costs and estimated energy supply were calculated for different system component combinations.

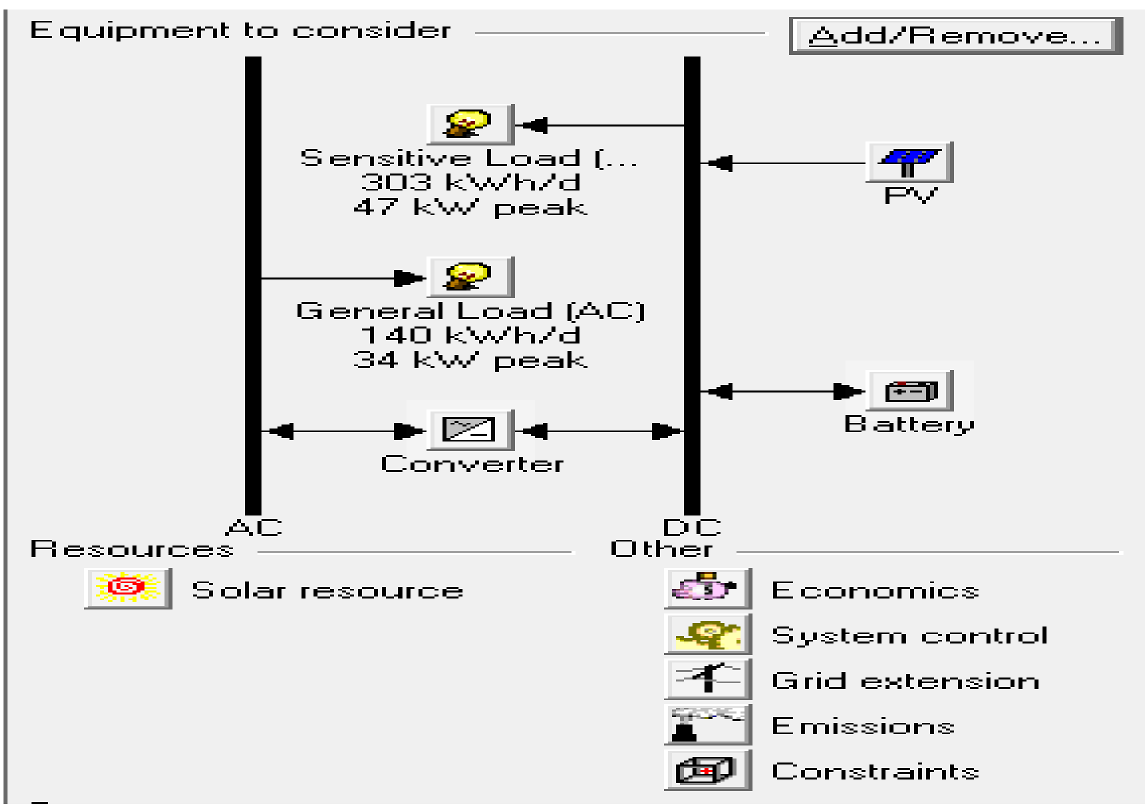


Figure 5.10. Homer implementation of the stand-alone PV system.

To simplify the analysis, the load considered here is the Sensitive load which connected to DC system and General load which connected to AC system, with a power consumption of 28.3KW and 23.24KW respectively and the result of the simulation shown in Figure 5.8, with peak load 47 KW and 34 KW respectively. This is, in fact, representative of most of the loads present in an office. On the basis of these assumptions, the comparison of new system with the existing system analyzed based on technical as well as economical.

5.7.1. Optimization Results

The basis numerical methods to solve nonlinear problem is the iterative solution method that initializes from an initial guess and iteratively refines it in an effort to reach the minimum or maximum of a multi- variable objective function. The optimization search space for the stand-alone system mixes and matches the components to find what combination satisfies the load requirements at the lowest net present cost. In this optimization process, various sizes of power converters, and batteries were included in the search space of the program. Several runs were made to determining the optimum sizes of equipment to get the best results.

The optimization result for the given solar radiation in Data center or ICT building using Homer, that simulates one optimal configuration from the given search space. This configuration (Figure 5.9.) shows a stand-alone PV system that supplies the electrical energy to the load with the lowest net present cost and with optimal size of PV (120 KW).

Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

			PV (kW)	Battery	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Batt. Lf. (yr)
			120	288	10	CC	$ 243,304	9,208	$ 333,754	0.224	1.00	0.08	10.0

Figure 5.11. Optimization result of homer.

5.7.2. Cost Result

Battery cost result - the cost results of the battery which shows, 50,400$ capital cost and 20,457 replacement cost on Figure 5.10 of the cost curve.

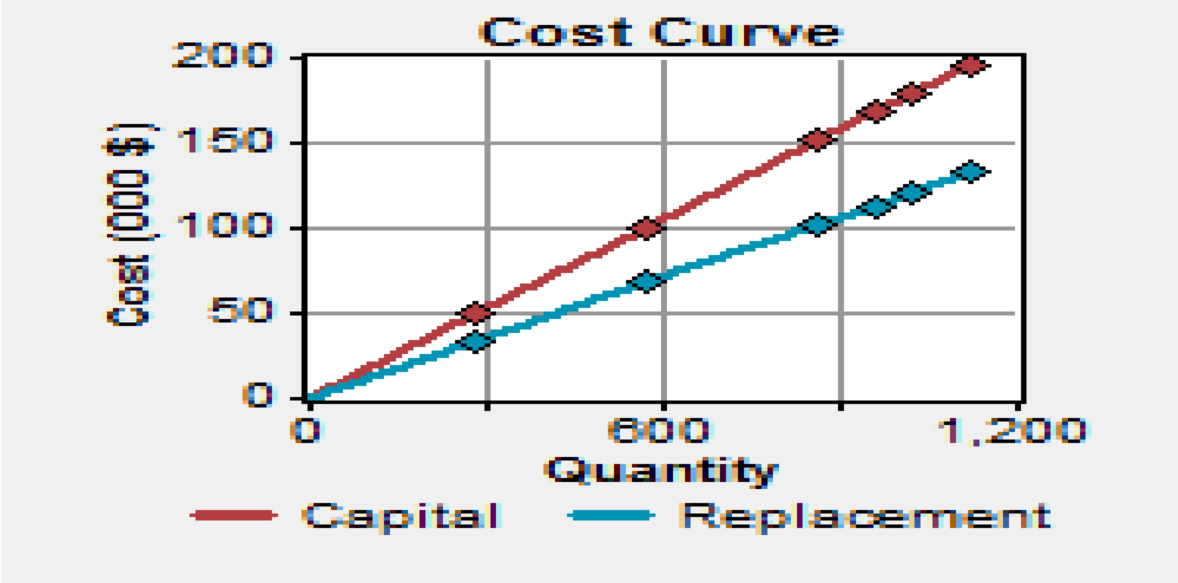


Figure 5.12. Cost Curve of Battery.

Converter cost result - The cost results of the converter which shows, 485$ capital cost, no replacement cost and 95$ operation and maintenance cost on Figure 5.11 cost curve of converter.

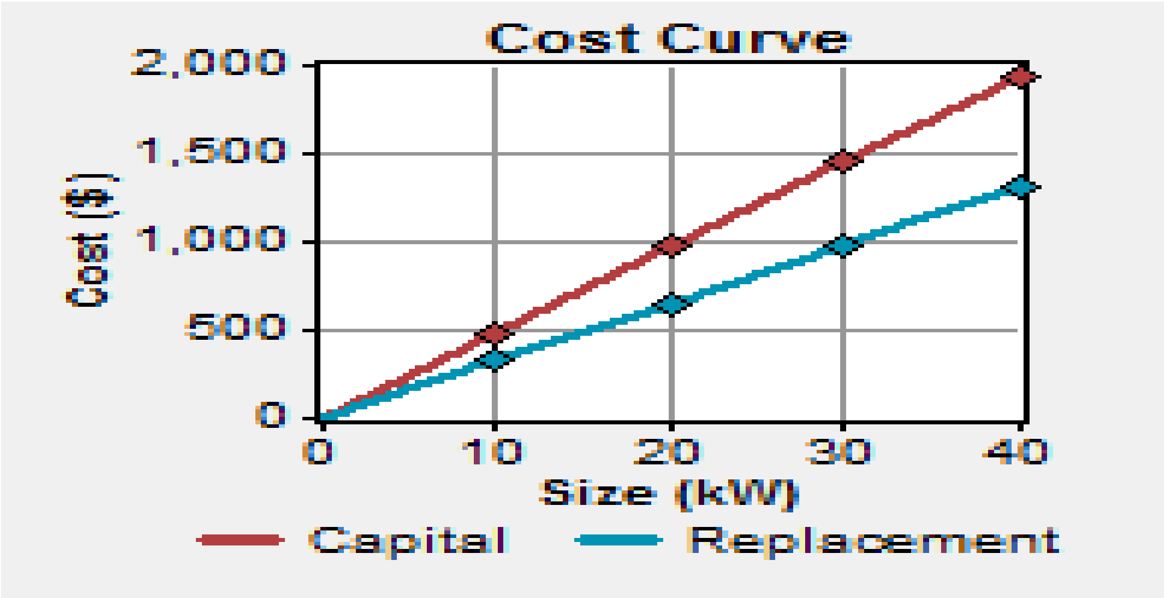


Figure 5.13. Cost curve of converter

PV cost result - The cost results of the photovoltaic which shows, 87,590$ capital cost on Figure 5.12 cost curve of PV that operate within 25 years of life time.

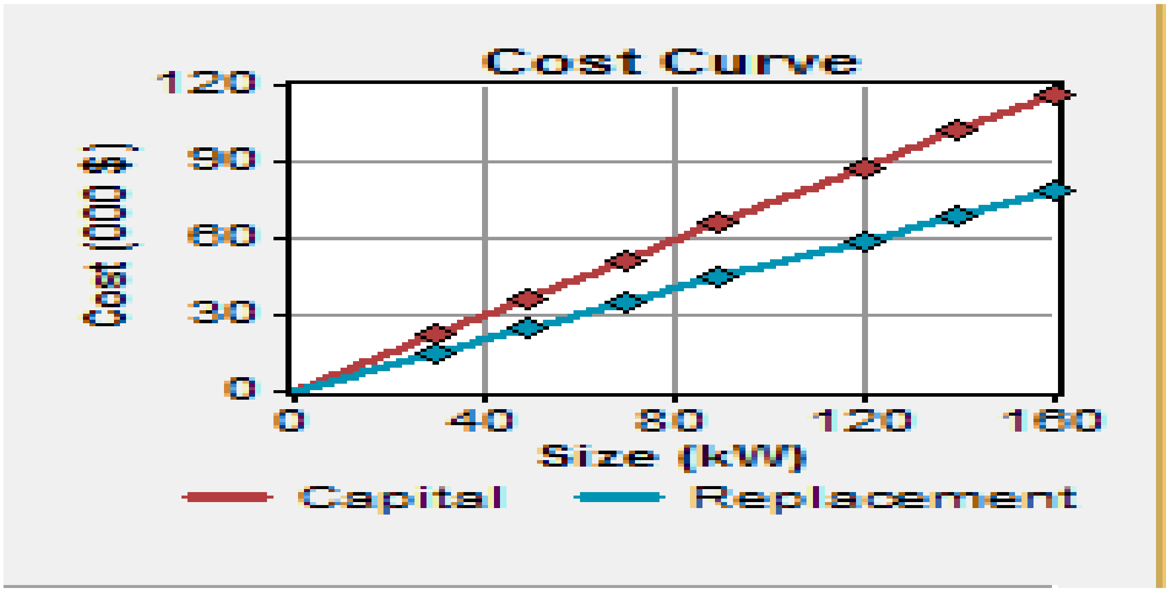
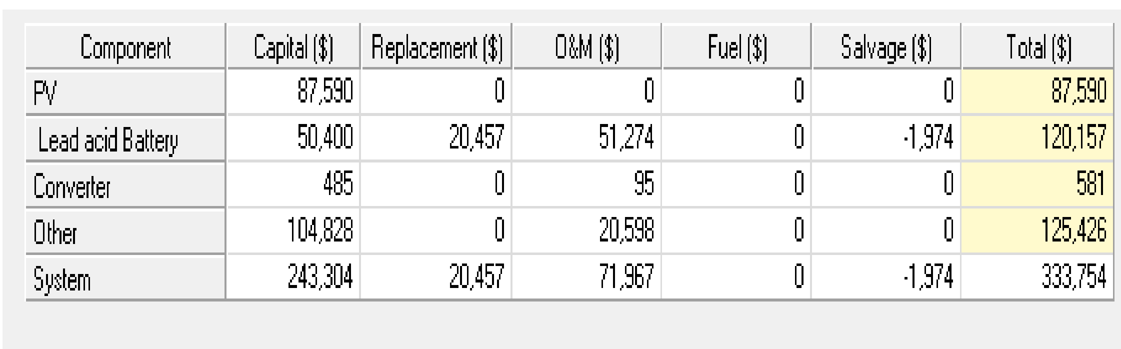


Figure 5.14. Cost curve of PV

The cost results of the main equipment's are shown in Figure 5.10 up to 5.12. The cost results of the system summarized in Figure 5.13. The initial capital cost is 243,304 $ where the replacement cost is 20,457 $ and the maintenance cost is 71,967 $. The total net present value of the system is 333,754 $.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	87,590	0	0	0	0	87,590
Lead acid Battery	50,400	20,457	51,274	0	-1,974	120,157
Converter	485	0	95	0	0	581
Other	104,828	0	20,598	0	0	125,426
System	243,304	20,457	71,967	0	-1,974	333,754

Figure 5.15. Stand-alone PV system cost summary.

5.8. Economic Analysis

The general concept of optimum design is to design a standalone PV system that can meet the load demand at a defined level of security, and at minimum capital and operational costs. Thus, economic aspect is of concern in designing a standalone PV system and the economic parameters are shown in Figure 5.14 and Figure 5.15 below.

Cash flow of standalone PV- cash flows of standalone PV for 25 years show by cost type which are capital, replacement, salvage and operating cost of the system.

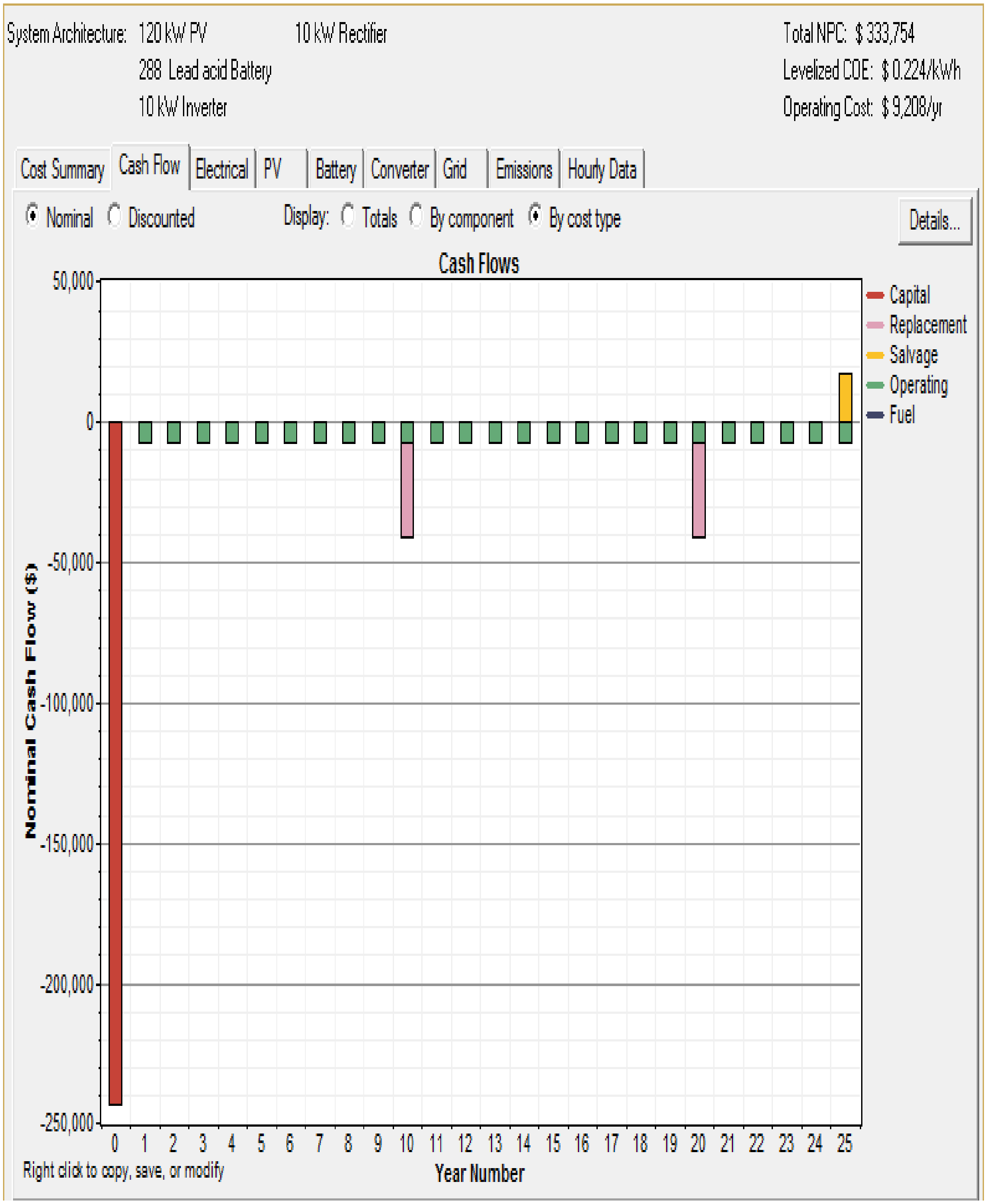


Figure 5.16. Cash flow of standalone PV.

Economical comparison of standalone system with grid extension – show that grid extension increasing of net present cost within 25 years and standalone system with a constant net present cost for 25 years of life time.

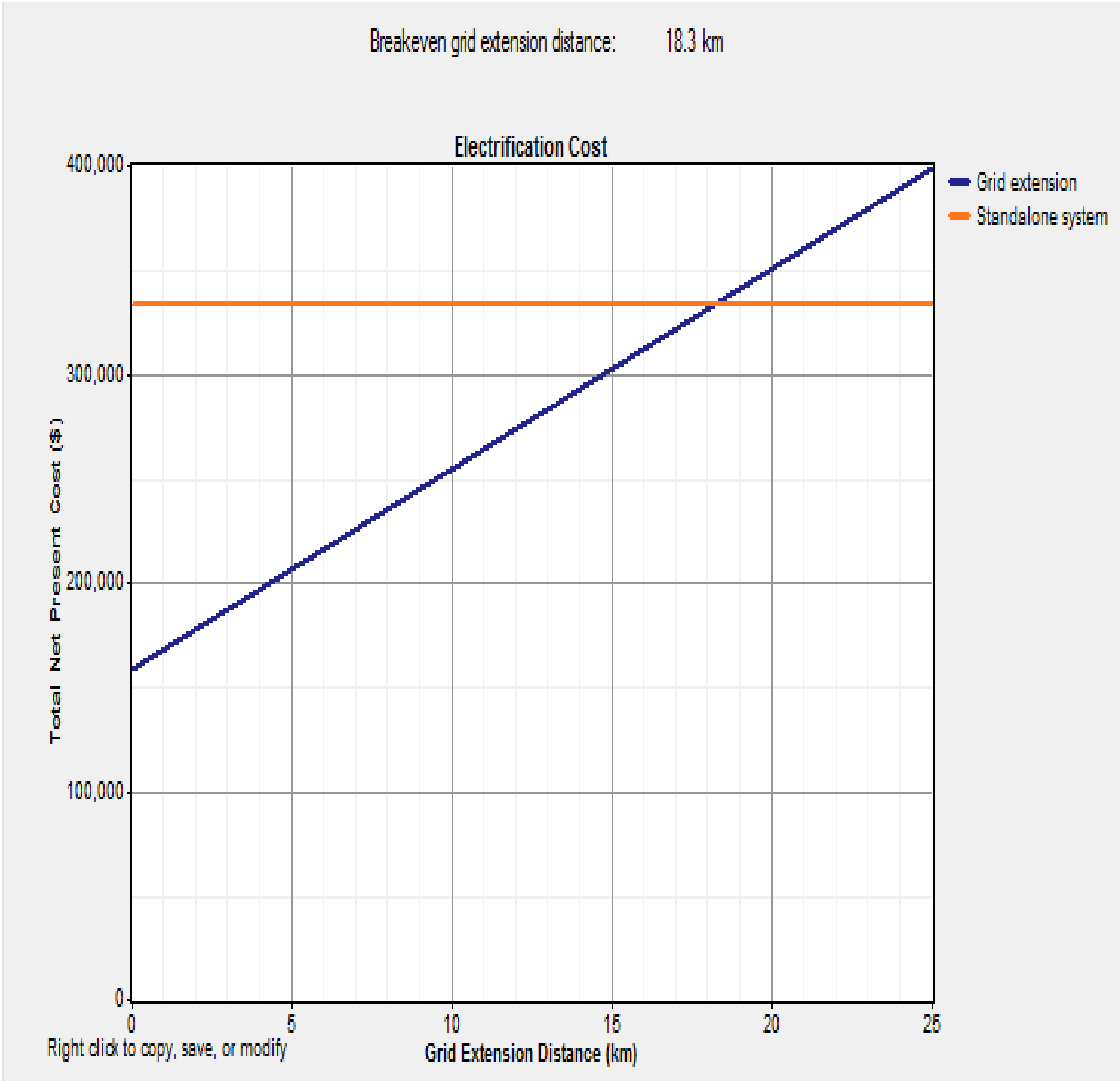


Figure 5.17. Economical comparison of standalone system with grid extension.

Levelized Cost of Electricity (LCOE) is one of the economic parameters usually employed in the assessment of the economic feasibility of the energy system. When evaluating the costs of the dc system, a scenario has been imagined in which dc components for the applications are available on the market. Therefore, Total NPC $ 333,754, LCOE result $ 0.224/KWh, operating cost $ 9,208/yr. and additional costs of designing and producing customized components have been neglected. This assumption is made for the system components as well as for the loads.

5.9. Simulation Result

The Technical simulation result of an optimum standalone PV design in figure 5.16 that can supplied the system with rated capacity of PV 120KW, minimum output of 0 KW, maximum output 115 KW and with PV penetration of 132% and capacity factor of 20.4%.

Quantity	Value	Units
Rated capacity	120	kW
Mean output	24	kW
Mean output	587	kWh/d
Capacity factor	20.4	%
Total production	214,113	kWh/yr

Quantity	Value	Units
Minimum output	0	kW
Maximum output	115	kW
PV penetration	132	%
Hours of operation	4,445	hr/yr
Levelized cost	0.0416	$/kWh

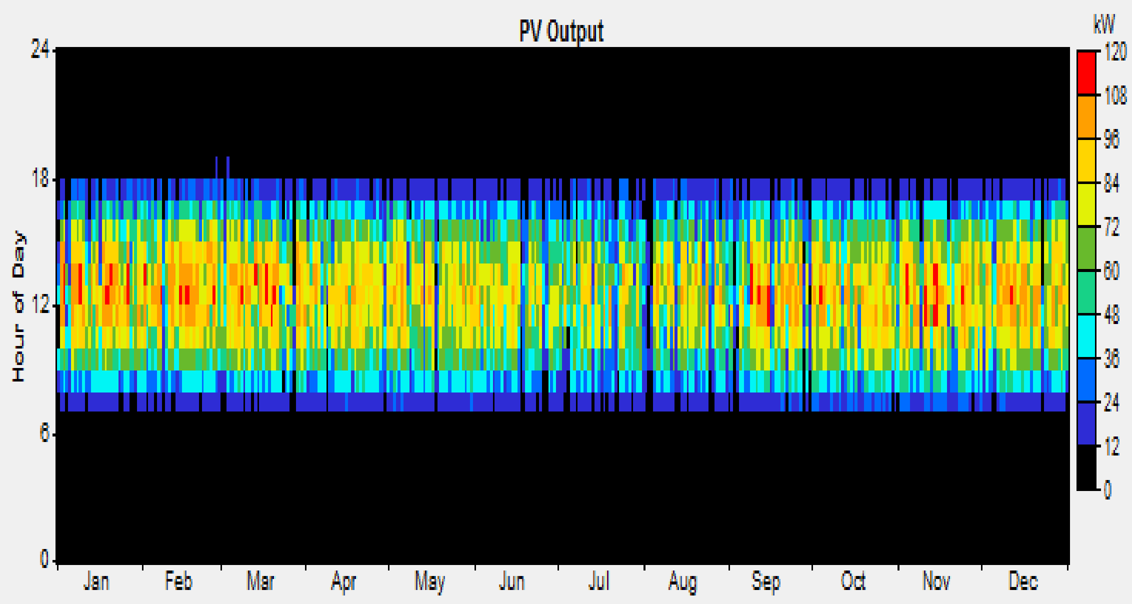


Figure 5.18. PV simulation Result.

Battery Bank and Converter Simulation Result - battery bank of 12V, 400Ah with state of charge shown minimum up to maximum yearly state of charge between 60-100% graphically with monthly distribution on figure 5.17. And AC load hours of operation 8,625 hrs/yr. with energy in 46,948 Kwh/yr out, the losses 4,694 KWh/yr. that the capacity of 10 KW in figure 5.18.

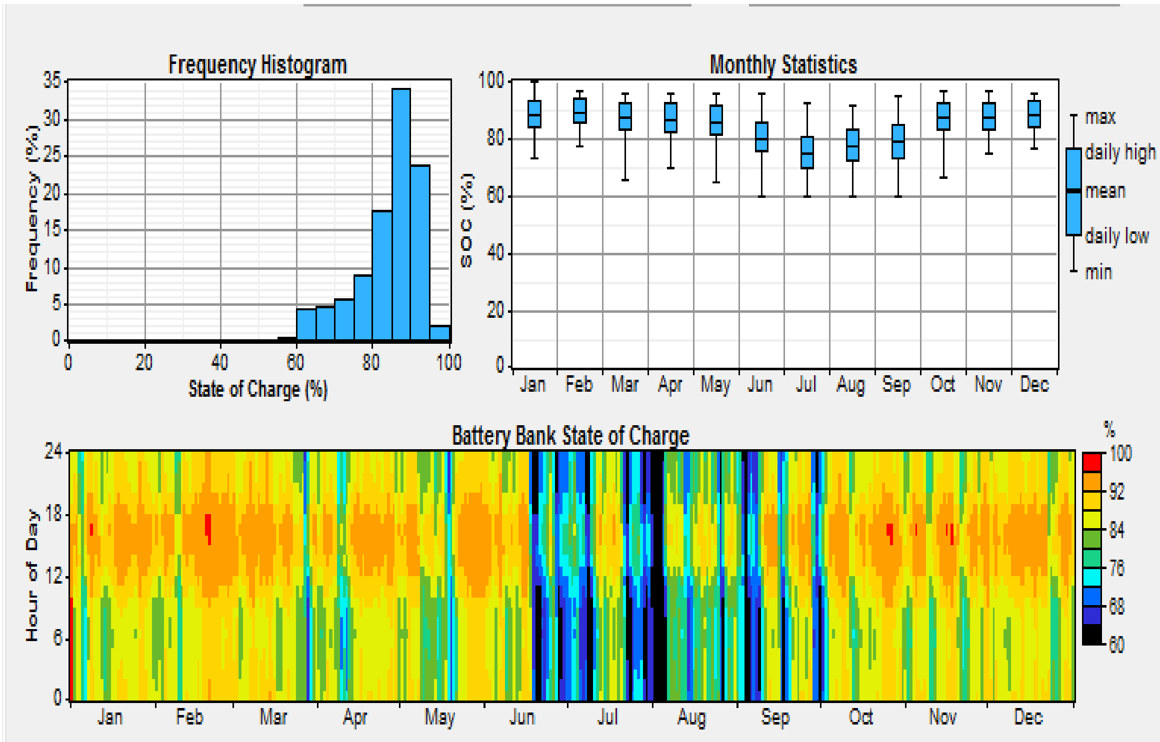


Figure 5.19. Battery Bank Simulation Result.

Quantity	Inverter	Rectifier	Units
Capacity	10.0	10.0	kW
Mean output	4.8	0.0	kW
Minimum output	0.0	0.0	kW
Maximum output	10.0	0.0	kW
Capacity factor	48.2	0.0	%

Quantity	Inverter	Rectifier	Units
Hours of operation	8,625	0	hrs/yr
Energy in	46,948	0	kWh/yr
Energy out	42,254	0	kWh/yr
Losses	4,694	0	kWh/yr

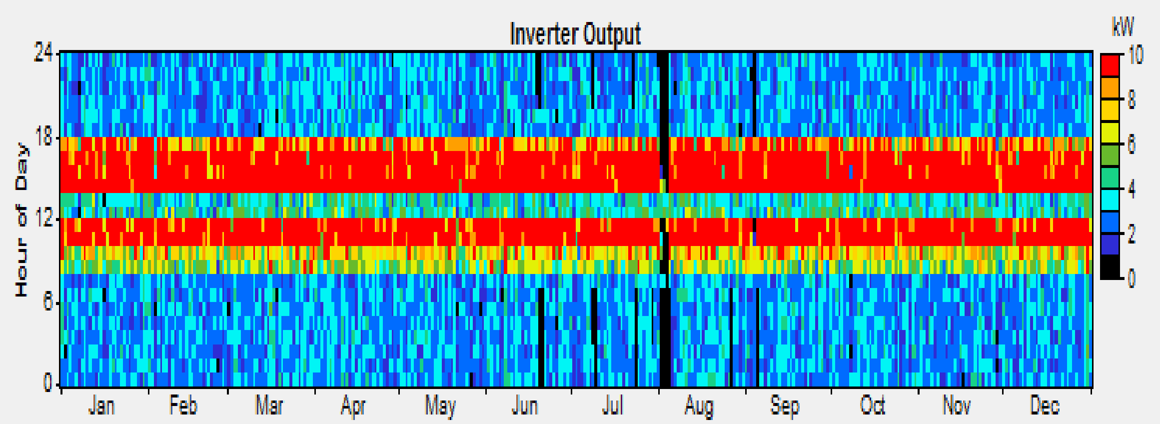


Figure 5.20. Converter Simulation Result.

Electric production– the total simulation result production of PV array 214,113 KWh/yr, consumption with AC primary load 42,254 KWh/yr and DC primary load 109,759 KWh/yr which is 28% and 72% respectively. All the total production details show, on simulation of figures 5.19.

Production	kWh/yr	%
PV array	214,113	100
Total	214,113	100

Consumption	kWh/yr	%
AC primary load	42,254	28
DC primary load	109,759	72
Total	152,013	100

Quantity	kWh/yr	%
Excess electricity	42,128	19.7
Unmet electric load	9,682	6.0
Capacity shortage	13,111	8.1

Quantity	Value
Renewable fraction	1.00

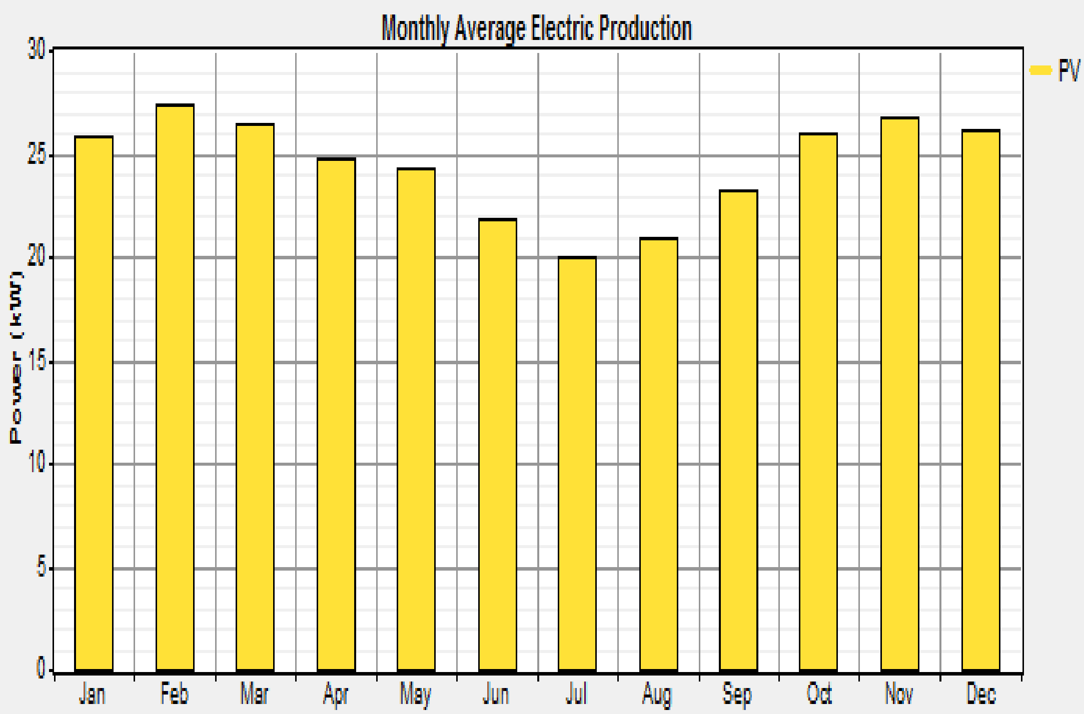


Figure 5.21. Electric production simulation result.

CHAPTER SIX

6. CONCLUSIONS, RECOMMENDATION, SUGGESTION FOR FUTURE WORK AND LIMITATIONS

6.1. Conclusions

The main focus of this research was the important consideration of sustainable power in the design of optimal size of PV and demonstrates the viability of DC as an alternative system within buildings. A Dc system for the supply of ICT building has been proposed and explored that the goal of more efficiently serving modern loads and easier integration of renewable energy sources and energy storage systems.

Comparing AC and DC based system is promoting the power distributed in DC, like, the absence of harmonics and frequency stabilization issues minimize voltage drop, have no reactive power or skin effect which result in reduced copper losses. If there is no reactive power in a DC system, the apparent and active powers are equal.

Implementation of a DC system instead of AC system results in fewer power conversions of the system which improved the overall efficiency of a system by reducing the number of power conversion stages in the power distribution path. The probability of electric power supply failure for IT equipment is reduced with fewer number of power converters in the power distribution path. DC systems have many integral advantages over AC systems that enable simpler integration of renewable energy sources and energy storage systems.

DC system for the supply of ICT building has been proposed and different voltage levels (48, 120, 240, 326 and 380V) have been considered. The analysis Voltage drops and power losses have been calculated for an existing ac system and compared with the results obtained for the same system, with the same cables, operated using a dc voltage. It can be concluded that a dc supply can lead to big advantages if a proper voltage level is chosen. From both the technical and the economical point of view, the most suitable dc voltage level seems to be 380 V. It has been shown that this voltage is readily applicable to existing systems, which make it possible to use the existing cables.

A few industry standards have already been established and some are still under development. Many companies have started providing products used in 380 V_{dc} systems. With growing market applications and new industry standards under development of 380 V_{dc} is using among telecom and data centers. The modeled DC building power supply with infrastructure and plug voltage levels at 380 V and distributes 48 V, respectively. To reduce wire losses, 380 V supply are assumed for connecting PV generation, battery storage, and high-power loads. For electronics and other plug loads, 48 V distributions are assumed through localized 380-48 V DC-DC converters.

A data center's sensitive load comprises of IT equipment such as servers, switches and storage devices that are typically DC-based loads. The battery backups used in the uninterruptible power supply systems, which are required during critical situations, are also based on DC. Power interruption is the main problem of ac transmission and distribution system. This problem can be greatly reduced and the power quality can be improved, using power produced from locally available renewable sources, solar power with DC distribution system.

Finally, the design of a stand-alone PV system for supplying the electrical load of an ICT building in Adama Science and Technology University was presented. An optimization model includes sizing, simulation an economic estimation of the system. The simulation interprets that stand-alone PV system sizing depends on load data, solar radiation, and investment cost of the system components. The results show that a 120 KW PV array capacity and 288 (12V, 400 Ah, 4.8 Kwh) batteries are needed to supply the electrical load of the building.

6.2. Recommendation

The price of PV panels has fallen rapidly in the past few years. This in turn reduces the unit price cost of the PV system. Therefore, the proposed DC system with PV integration can be best alternative especially for ICT building of university, Clinic as well as commercial building to increase sustainability.

Most data center uses burning of diesel fuel as a stand by source which is the main cause of pollution in developing countries. Nowadays carbon dioxide emission becomes a global concern. So that solar powered LVDC system becomes a viable solution of the above-mentioned problems, to transfer sensitive loads in data centers to use solar systems for alternate energy provision. It is cheaper, more reliable and environmentally friendly.

An optimal sizing of a stand-alone PV system has been presented to have sustainable power in ICT building. To overcome the loss and cost of cables, data center building must be near or confined in the area of ICT building. And also minimize challenge of power stress in Ethiopian Electric Utility.

6.3. Suggestion for Future Work

DC system is not widely used as a source. This research work mainly focuses on the optimal size of PV on low voltage dc distribution system for ICT building. A lot of research is already being done in this field. Further research should be done in low voltage dc distribution system that would lead realization of the low voltage dc distribution system be standardized distribution system. The following research areas may put the foundation for such that realization;

- ❖ Analysis on Fault detection and protection of dc system to improve the power quality and reliability
- ❖ Developing appliances, dc plugs, switches, sockets and circuit breakers that are compatible with dc distribution system.
- ❖ Research on improving efficiency by developing highly efficient convertors.

6.4. Limitations

The low voltage dc system design works well for the proposed application. The scope of the research is limited to Data center optimal PV applications. Further research needs to be done to expand the dc system in commercial and industrial areas to improve scarcity of Dc appliance.

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APPENDIXES

Table Summary of Electric Loads at ASTU ICT Building							
No.	**Type of Load**	**Quantity (pcs)**	**Rating (W)**	**Total P (kW)**	**Hrs. /day**	**Energy/day (KWh)**	**Op. hrs**
1	Lighting	16	16x 25	0.4	1	0.4	19-20
	Lighting	8	8 x 25	0.2	1	0.2	18-19
	Lighting	64	64 x 25	1.6	3	4.8	18-21
	Lighting	4	4 x 25	0.1	3	0.3	18-21
	Lighting	10	10 x 25	0.25	3	0.75	18-21
	Lighting	24	24 x 25	0.6	2	1.2	19-21
	Lighting	18	18 x 25	0.45	1	0.45	19-20
	Lighting	8	8 x 25	0.2	12	2.4	18-6
		152		**3.8**		**10.5**	
2	Socket outlets	8	8 x 50	0.4	1	0.4	10-11
	Socket outlets	16	16 x 50	0.8	6	4.8	10-16
	Socket outlets	4	4 x 50	0.2	2	0.4	9-12 & 14-17
	Socket outlets	400	400 x 50	20	11	220	8-12 & 14-21
	Socket outlets	6	6 x 50	0.3	4	1.2	8-12
	Socket-outlets	40	40 x 50	2	8	16	8-12 & 14-18
		498		**23.7**		**242.8**	
3	Ventilators	8	8 x 25	0.2	4	0.8	12-16
	Ventilators	4	4 x 60	0.24	12	2.88	0-23
	Ventilators	10	10 x 60	0.6	8	4.8	10-12 &15-17
		22		**1.04**		**8.48**	
4	Refrigerator	8	8 x 200	1.6	18	28.8	0-23
		8		**1.6**		**28.8**	
5	Printer	8	8 x 100	0.8	2	1.6	10-12
	Printer	2	2 x 100	0.2	2	0.8	14-16
		10		**1**		**2.4**	
6	Scanner	8	8 x 50	0.4	1	0.4	12-13
	Scanner	2	2 x 50	0.1	1	0.1	9-10
		10		**0.5**		**0.5**	
7	Copier (Xerox)	8	8 x 1000	8	1	8	14-15
	Copier (Xerox)	1	1 x 1000	1	1	1	16-17
		9		**9**		**9**	

8	LCD projector	2	2 x 100	0.2	5	1	9-12 & 14-17
	Projector	8	8 x 100	0.8	6	4.8	8-11 & 14-17
		10		**1**		**5.8**	
9	TV set	2	2 x 150	0.3	2	0.6	14-17
	TV set (room)	4	4 x 150	0.6	4	2.4	10-12 & 15-17
	TV set Corridor	1	1 x 500	0.5	24	12	0-23
		7		**1.4**		**15**	
10	Air-conditioner	4	4 x 250	1	5	5	9-12 & 14-17
	Air-conditioner	16	16 x 250	4	6	24	10-12 & 14-18
	Air-conditioner	2	2 x 500	1	24	24	0-23
	Air-conditioner	4	4 x 250	0.1	7	0.7	10-17
		26		**6.1**		**53.7**	
11	Network Switches	8	8 x 25	0.2	24	4.8	0-23
	Network Switches	4	4 x 50	0.2	24	4.8	0-23
		12		**0.4**		**9.6**	
12	Servers	4	4 x 500	2	24	48	0-23
				2		**48**	
	TOTAL LOAD	**4**		**51.54**		**434.58**	

Yingli Solar YL300P-35b (300W) Solar Panel

Manufacturers Data Sheet

DC Electrical Characteristics	
STC Power Rating	300W
PTC Power Rating	270.7W [1]
STC Power per unit of area	14.3W/ft^2 (153.8W/m^2)
Peak Efficiency	15.38%
Power Tolerances	0%/+2%
Number of Cells	72
Nominal Voltage	not applicable
Imp	8.17A
Vmp	36.7V
Isc	8.77A
Voc	46.3V
NOCT	46°C
Temp. Coefficient of Isc	0.06%/K
Temp. Coefficient of Power	-0.45%/K
Temp. Coefficient of Voltage	-0.153V/K
Series Fuse Rating	15A

Mechanical Characteristics

Type	Polycrystalline Silicon
Output Terminal Type	Amphenol H4
Output Cable Wire Gauge	12 AWG
Output Cable Wire Type	PV Wire
Output Cable Wire Length	47.2in (1,200mm)
Frame Color	Clear
Backsheet Color	data not available
Length	77.6in (1,970mm)
Width	39in (990mm)
Depth	2in (50mm)
Weight	59.1lb (26.8kg)
Installation Method	Rack-Mounted

Warranty and Certifications

80% Power Output Warranty Period	25yrs
90% Power Output Warranty Period	10yrs
Workmanship Warranty Period	10yrs
UL 1703 Fire Classification	data not available
Compliances	UL 1703
CSI Listed	Yes