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Investigation of how operational and climatic factor affect PV-grid tied inverter: A case study of Ethiopia and Zambia

BY

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A Research Submitted to The University of Zambia in partial fulfilment of the requirements of Master of Engineering in Electrical Power Engineering

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Identifying and Analyzing the Technical challenges of grid tide inverters for PV system:

[A CASE STUDY OF Zambia and Ethiopia]

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THE UNIVERSITY OF ZAMBIA

LUSAKA

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DECLARATION

I, Redate Shawell, do hereby declare that this piece of work is my own, and that all the work of other persons has been duly acknowledged, and that this work has not been previously presented at this university and indeed other universities for similar purposes.

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Signature
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CERTIFICATE OF APPROVAL

This dissertation by Redate Shawell is approved as fulfilling part of the requirement for the award of the degree of Master of Engineering in Electrical Power Engineering the University of Zambia.

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Date…………………

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ABSTRACT

Zambia and Ethiopia are two countries from southern and eastern of Africa due to their geographical location and other factor the environment condition is different. The research aims to Investigation how operational and climatic factor affect PV-grid tied inverter In Zambia the study focused on the two main solar plants which is under ZESCO national grid at malty facility zone (MFZ), the first one is the 54 megawatts Bangweulu solar power plant, second one is 34MW Ngonye solar photovoltaic (PV) plant. In Ethiopia eight min off-grid site under Ethiopian Electric Utility (EEU) is included. Beltu, Behima, Mino, Ungoge, Korhele,Tum, Omorate and Kofetu. A survey is conducted how operational and climatic factor affect PV-grid tied inverter (GTI) in the above-mentioned area. Using Microsoft excel the environmental \climate condition, Solar radiation, Air temperature and Rain falls of the two country Zambia and Ethiopia is investigated and analysed for each selected site. A questionnaire and a Simi-structure interview are conducted. The basic inverter challenges are investigated from the collected data and the problem is analyzed based on the specific inverter data sheet. The data sheets of the inverter for each site under this study are attached.

Environmental condition affects almost all solar plant sites which are under this study. The temperature of Lusaka is higher than Addis Ababa by 5.63°C and even in the plant under this study; temperature rise is one of the challenges on the inverter performance, sensitive electronic component bent due to excessive temperature. On the other side in Ethiopia Addis Ababa excessive rain affect the inverter. Addis Ababa has about 1.32 times more rainfall than Lusaka, (Addis Ababa's 79.54mm vs Lusaka's average of 60.34mm). For that reason, most of the inverter in Ethiopia on the mini off-grid site is affected by heavy rain condition. Finally, the real-time performance of the inverter of the off-grid PV mini-grid system installed in a small remote town in Ethiopia is analyzed using measured meteorological data. From on- grid and off-grid inverter performance challenges, which the researcher collected from different plant the main ones are climate or environmental effect and also over load. Overload is one of the frequent challenges in koftu, behama and amorita this can be due to high population growth and unexpected power demand from the community.

Keywords: *Solar Photovoltaic; Grid Tide Inverter; Ethiopian Electric Utility;* Malty Facility Zone.

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ACRONYMS

PWM	Pulse Width Modulated
MPPT	Modules Maximum Power Point Tracking
EMI	Electromagnetic Interference
GTI	Grid Tide Inverter
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
PV	Photovoltaic
IEA	International Energy Agency
IRENA	The International Renewable Energy Agency
ESRI	Environmental System Research Institute
NMSA	National Meteorological Services Agency
UG	Utility Grid
MG	Mini Grid
MMEMS	MG Monitoring and Energy Management System
UEAP	Universal Electric Access Project
DC	Direct current
AC	Alternating current
VSI	Voltage source inverter
ACEC	African clean energy corridor
EAPP	East African power pool
SAPP	Southern African power pool
GIS	Geographic information system
MCA	Multi Criteria analyses
MWh/m^2	Megawatt hour per meter square
PPA	Power purchase agreement
GOE	Government of Ethiopia
ACWA	Australian Community workers Associations
MW	Mega watt

US cent	United states cent
KWh	Kilo watt hours
KV	Kilo volt

CHAPTER 1: INTRODUCTION

1.1 Background

Solar resources are fuel to solar power plants and local geography and climate determine their operation. Free fuel makes solar technology very attractive; however effective investment and technical decisions require detailed and validated solar and meteorological data. Such data are also needed for the cost-effective operation of solar power plant and for management of solar power in the transmission and distribution grids. [1][3] Solar panels generate direct current electricity, which can't be used by the grid or any other appliances. An inverter ensures the power you generate is compatible with the grid by switching it to alternating current. Inverters today do a lot more, though. They're the bit of equipment that monitors and reports power generation and usage. [2]

Figure 0.1 Simplified layout of a common grid connected (on-grid) solar power system [3]

The electricity demand in the world's developing countries is increasing rapidly, and it is a great challenge to meet this demand [4]. To balance the energy demand and generation, renewable energy resources such as Photovoltaic (PV), Wind, and Biomass could be a good solution. Among these, solar energy is considered to be one of the most useful sources because it is free, abundant, pollution free and less maintenance fee. Since the generated voltage from PV is DC, inverters are required to convert DC voltage from PV to AC before connecting it to grid or electronics equipment. The output voltage and frequency of inverter should be same as that of grid frequency and voltage [5]. The output of grid connected inverter can be controlled as a voltage or current source and pulse width modulated (PWM) voltage source inverters (VSI) are most widely used in PV systems.

The work done related to PV grid connected systems published so far [4]- [5] reveals how an inverter should be designed and output should be synchronized with the grid or any standalone solar pant. The inverter is what converts generated energy into deliverable power. The inverter may have different challenges due to faulty installation, harsh temperatures/ environmental factors and others. It will undoubtedly suffer in performance, passing the cost of that lost efficiency on to the end customer. Because every application is unique, there is no one-size-fits-all solution to inverter challenges. Solar farm operators should have an awareness' of this fact when selecting a solution, and know what questions to ask the manufacturer in relation to basic inverters challenges airflow/cooling, environmental protection, operations and maintenance concerns. Doing so will ensure their inverters will continue to deliver power efficiently over an increased lifespan.

In fact, the renewable energy sources such as photovoltaic offers greater supply security to consumers while respecting the environment and could be a good solution to balance the energy demand and generation [6]- [7]. Several researches have been conducted on the grid-connected photovoltaic systems in the use of photovoltaic energy effectively [8] [9] [10] [11]

1.2 Problem Statement

The continuous increase of electricity demand needs to be supplied with alternative power plant. Solar energy is the best solution to fill in the gap; it is a free energy source available in everywhere. The inverter is what converts generated energy into deliverable power.

One of the biggest problems that solar energy technology poses is that energy is only generated while the sun is shining. Another concern is that the performance of the inverters will not be efficient to the standard when the sun is not shining, Solar farm operators should know this fact when selecting a solution, and know what questions to ask the manufacturer in relation to inverter installation, and take in to considerations, some of inverter's challenges like inverter beeping, the MPPT modules, operating climate, Airflow/cooling, environmental protection, operations and maintenance concerns, and EMI (electromagnetic interference) shielding [12].

This research investigates how operational and climatic factors affect the performance of PV grid-tied inverters: in doing so the operation of different selected solar plant: in relation to climatic factor and other factor is investigated. in Zambia and Ethiopia. This will ensure their inverters will continue to deliver power efficiently over an increased lifespan. Especially for developing countries like Ethiopia and Zambia, which they can able to have sun shine almost the whole year the research can be an input for the upcoming solar project. [13]

1.3 Overall Objective

The main objective of this project is to investigate how operational and climatic factors affect the performance of PV grid-tied inverters:

Specific Objective

The research will be conducted in Zambia and Ethiopia on the selected existing grid connected and mini grids PV systems. The specific objective for this research includes:

i. To identify different type of grid tide inverters commonly used in Zambia and Ethiopia.

ii. Determine the factors that affect the performances of the identified PV grid-tied inverters.

iii. Analyse the effect of the factor on the performances of PV grid-tied inverters.

1.4 Research Question

i. What is the main/common types of inverters used in grid connected PV system in Ethiopia and Zambia?

ii. How to determine the factor that affects the performances of the identified PV grid-tied inverters?

iii. What are the effects of the factor on the performances of PV grid-tied inverters?

1.5 Significance of the Study

An inverter is the brain of photovoltaic system.

The production loss of solar PV systems is often attributable to the poor performance of inverters; this can lead to significant production loss. The inverters are responsible for converting and feeding the power to the grid or to any electronic equipment. Therefore, optimal performance of inverters is very essential for successful operation of the solar PV system. Hence, this research Investigated on how operational and climatic factor affect PV-grid tied inverter

1.6 Limitation and Delimitations of the Study

1.6.1Limitation of the study

This study Investigated on how operational and climatic factor affect PV-grid tied inverter and analyses the technical challenges of inverters for grid connected and standalone PV system in Zambia and Ethiopia. The study was limited only to detailed investigations on the challenges of grid tied inverters excluding the off-grid inverters due wide variant and usage of standalone inverter in both countries; Zambia and Ethiopia. Therefore, the research identified and analyzed the grid tied inverter challenge in Zambia and Ethiopia.

1.6.2 Delimitations of the study

This research is basically focused on identifying and analyzing the technical challenges of grid tied inverters for solar plants in Zambia and Ethiopia. In Zambia the study focused on the two plants which are connected to national grid (Zesco Grid). The first one is the 54 megawatts Bangweulu solar power plant by Neon Investment of France, second one is 34MW Ngonye solar photovoltaic (PV) plant. In Ethiopia, currently there is no fully functional national grid connected solar power plants but, Methera 1000MW solar power plant project was one of the focus of researcher. However, due to different factors the project could not be completed. The study thus, investigated and analyzed the challenges of grid tied inverter in mini grids solar power plant under Ethiopian Electric Utility (EEU).

1.7 Ethical Considerations

Ethical clearance to conduct this study was obtained from the University of Zambia Research Ethics Committee (See Appendix C). All the participants in this study were clearly informed of the objectives of this research, given adequate time to consider their participation and consent was signed in agreement to participate. Further, the participants were assured of confidentiality of all the information given and no names were recorded.

We conduct our investigation through the rubric of the affirmative and prohibitive principles for every company, to every individual and a group of people involved in this research paper. All the information and the data will not be abused and corrupted, in study it will be just for educational purpose. Grid connected photovoltaic system technology development has and continue to have different impacts in different social contexts, and by considering the different impacts/challenges grid tide inverter explicitly across global contexts due to different challenges like faulty installation, inverter beeping, the MPPT modules, Environmental condition and others related issues based on the geographical Environmental differences between Zambia and Ethiopia contexts, this paper contributes to identifying and understanding how, in what ways, and in what particular conditions and circumstances grid connected photovoltaic electricity technologies may correspond with or work to promote (electric power) energy justice.

1.8 Chapter Summary

Among all renewable energy sources, solar energy is considered to be one of the most useful sources and effective. The main objective of this project is to investigate how operational and climatic factors affect the performance of PV grid-tied inverters: the specific objectives and the research questions are included under section 1.1and section 1.4 respectively. The next chapter will be a review of literature; related research paper, magazine, journals and other published papers are included .

CHAPTER 2: LITERATURE REVIEW

2.1 Solar Energy Potential

Africa is endowed with a rich bounty of natural resources. The sun is one of them. Generally referred to as the "sunny continent", Africa is the sunniest place on earth. Despite its fortunate conditions, the penetration of solar power in Africa's energy mix is still very slow and its massive solar photovoltaic potential remains untapped. [14] Africa has been historically relying on hydropower, which is, unfortunately, decreasing as the climate changes are causing a water crisis in the continent. [15] Africa is the only region in the world where a measure indicating "excellent conditions" for solar power is exceeded. It's interesting to know that Africa is now beginning to take advantage of its abundant renewable energy resources to provide utility-scale electricity to the approximately 600 million people who lack access to reliable electricity. [16]

According to the International Energy Agency (IEA), Africa has 60% of the world's best solar resources, but only 1% of solar generation capacity. To achieve its energy and climate goals, Africa needs $190 billion of investment a year. [17]

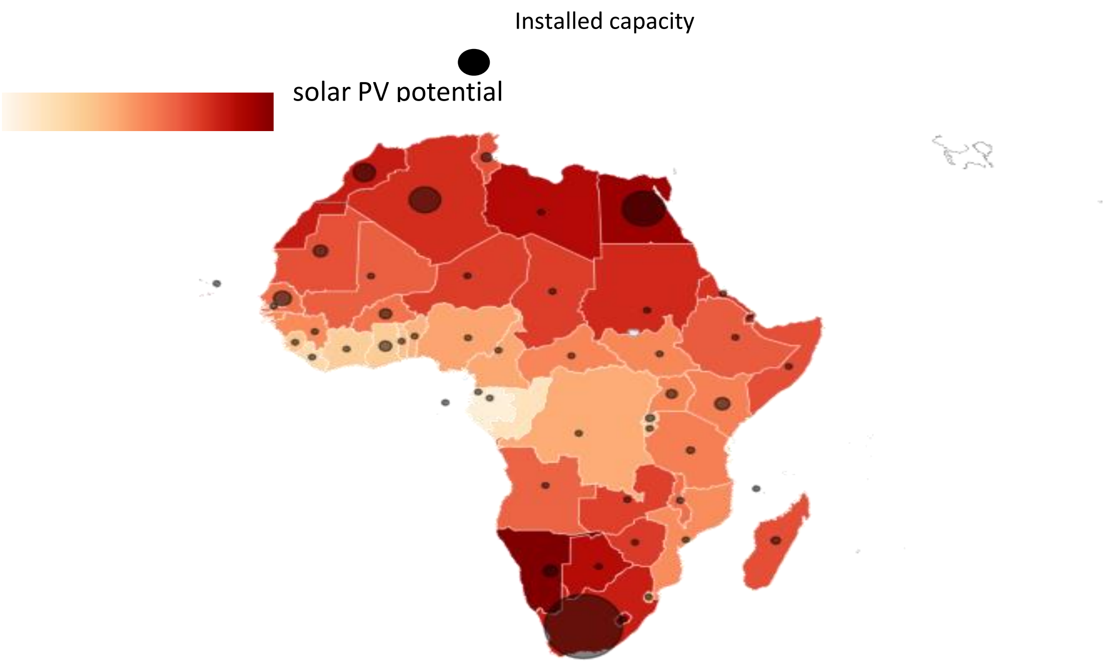


Figure 2. 1 Solar photovoltaic potential and installed capacity (2018) by country Installed capacity 2018 (MW) Source: [18]

East and Southern African countries possess vast potential for renewable energy development. In the crucial years ahead, coordinated regional plans will play a vital role in scaling up the use of renewables for power generation, strengthening regional power supplies, meeting national climate commitments and ensuring energy security. [19] The International Renewable Energy Agency (IRENA) supports countries across East and Southern Africa in their endeavor to establish a regional transmission corridor for sustainable electricity, based specifically on renewable sources and technologies. IRENA's Africa Clean Energy Corridor (ACEC) framework envisages a broad, North–South power transmission chain that encompasses 21 continental countries in the East African Power Pool (EAPP) and Southern African Power Pool (SAPP). [15] [16] [18]

2.2 Solar Power Potential in Ethiopia

Ethiopia is a country of great geographical diversity. Located within the tropics, its physical conditions and variations in altitude have resulted in a great range of terrain, climate, soil, flora and fauna.

According to GIS-based MCA (Multi criteria analyses), the eastern part of the country is relatively suitable for large scale solar panel installations. It has 1.9 MWh/m2 /year of solar radiation on average with ideal 30 land cover for large-scale solar farms. Moreover, it is the least densely populated region which also is a very important criterion. [17]

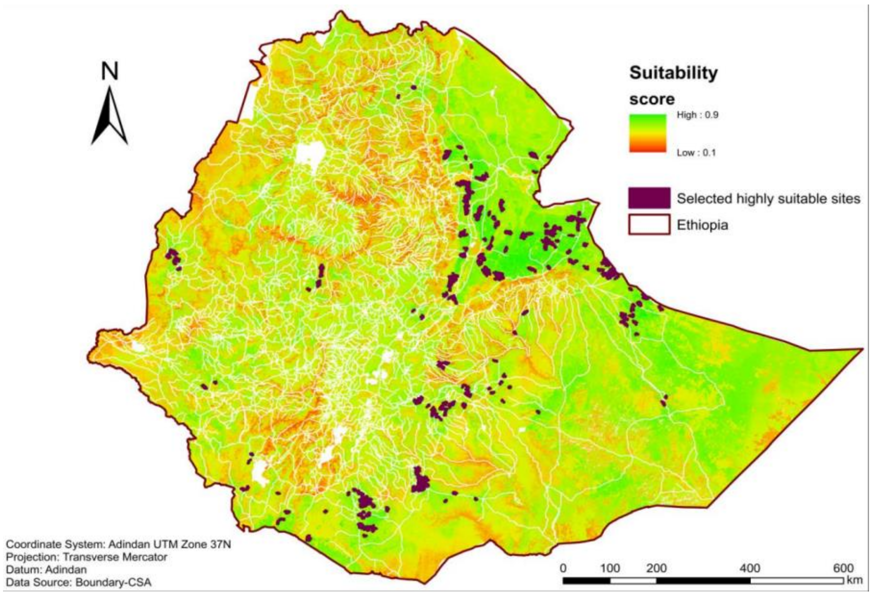


Figure 2. 2 Selected highly suitable sites for large-scale Photovoltaic installations in Ethiopia [17]

2.2.1 Solar Power Project in Ethiopia

There are many ongoing projects related to solar power, The Metahara solar independent power producer (IPP) project is one of them. It expected to generate 100 MW. A Power Purchase Agreement (PPA) and approval of the Implementation Agreement (IA) between Enel Power, an Italian firm, and the government of Ethiopia (GOE) has been reached. [18] Enel will develop and operate the project.

On the other hand, A Saudi firm, ACWA Power, has won a tender to develop two solar power projects, valued together at $300 million, in Afar and Somali regional states with a capacity of 250MW each. [19] ACWA Power offered 2.5260 US cents/kWh for power generated at these two sites, Gad and Dicheto. There are also six other IPP solar power projects in the pipeline, but these are currently suspended due to financing related matters. [20]

In March 2022, Green People's Energy Ethiopia has conducted a series of trainings for planners and technical implementers of solar mini-grids. With more than 200 prospective mini off-grid sites in the pipeline, Ethiopia is gearing up for a massive roll-out of off-grid electrification – and for this, the capacities of public- and private sector actors are to be strengthened. [21]

The Ethiopian Electric Utility (EEU) currently have 25 sites under construction among the 25 solar power mini off-grid site, 8 minis off- grid site are currently fully operating and also 201 mini off-grid sit is to be implemented up to 2027.

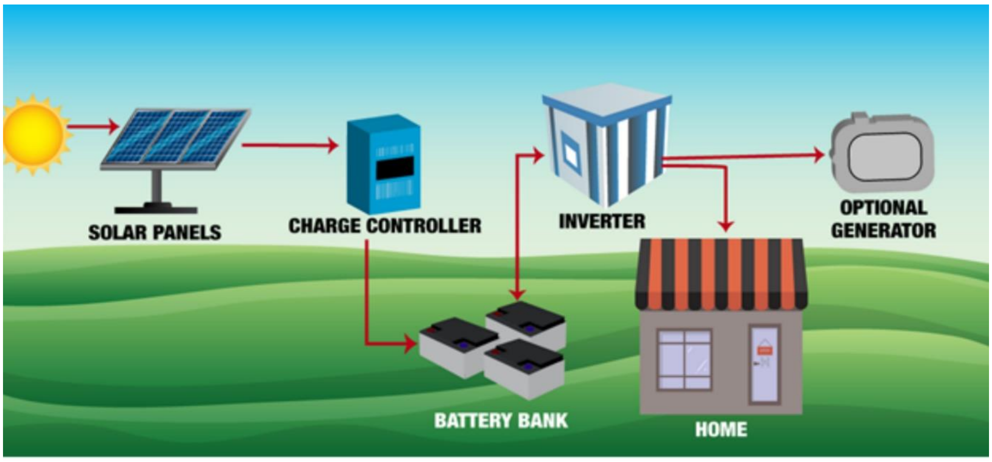


Figure 2.3 Solar off grid power generation schematic

Ethiopian Electric Utility EEU - Mandated for 66/45 kV sub-transmission and substation operation - Distribution network construction and operation - Energy retail - Implementation of National Electrification Program. [22]

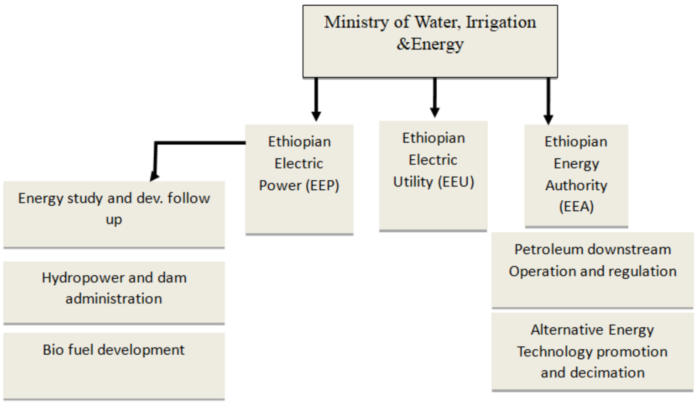


Figure 2.4 Ethiopian Power Sector institutional and regulatory Framework

2.2 Zambian Solar Power Potential

According to the previous studies and data undertaken by Meteorological Department of Zambia, the country has a significant potential of solar energy for both power production and thermal from solar energy technologies. The country is situated at the latitude of 8 to 18 degrees south of the equator and longitude 22 to 34 degrees east of prime meridian with an average sunshine of about 6-8hours per day and high monthly average solar radiation incident rate of 5.5kWh/m2 /day throughout the year. [23] [24]

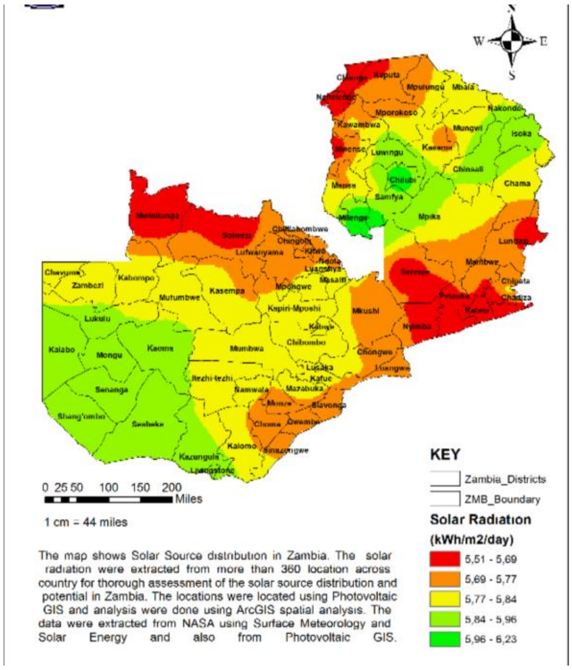


Figure 2.5 Solar Source Distribution and Potential in Districts of Zambia [24]

2.2.1 Solar power project in Zambia

The Zambian government aims to deploy 500 MW of solar PV by 2023, in order to ease chronic power shortages. The sub-Saharan country currently relies on 2.8 GW of installed power, with about 85% coming from hydropower. Its access to electricity is about 40%. [25]

Solar PV mini grids make only a small contribution to rural electrification in Zambia, compared to hydro and diesel mini-grids. Currently , 5 solar PV mini grids (4 private and 1 public run by a cooperative) were operational and 2 public solar PV mini grids were under construction in Zambia (ranging from 10 KW to 300 KW) Most mini grids are concentrated as they are densely populated with an average off grid site of 110 connections. ENGIE, a private developer, inaugurated its first Power Corner (mini grid) in 2019 providing electricity access to 378 households. [25]

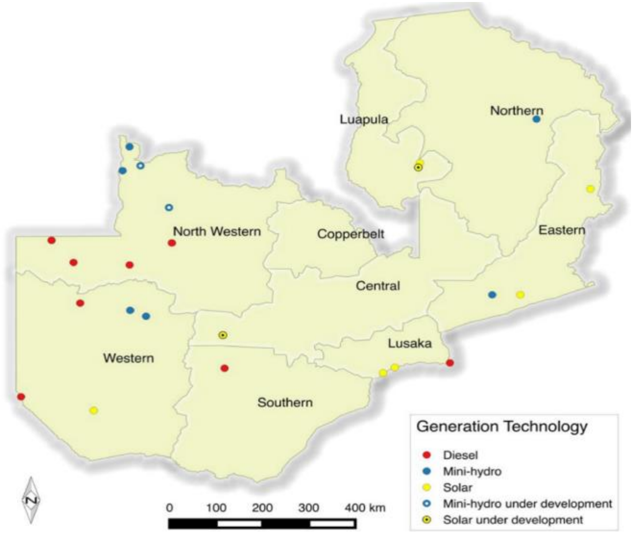


Figure 2.6 Existing and planned mini grids in Zambia [26]

Table 2. 1 Solar PV mini-grid site in Zambia

Owner (# mini-grids)	**Site**	**System Capacity (kWp)**	**Beneficiaries'**
Kafita co-operative society-1	Mpanta	60	450 HHs, 1 school, 1 health center, a market, churches and fish refrigeration depots
Muhanya Solar -1	Sinda	30	60 HHs and 5 businesses; Provides SHS to peripheral customers
Standard MicroGrid -3	Multiple	10,10,24 respectively	N/A
REA-1	Kafue National Park	200	Targeting 570 HHs, public institutions and businesses
REA-1	Kasoma Lunga Island	300	Targeting 1,600 HHs, public institutions and businesses

Zambia had 96 MW of installed solar power at the end of 2021, with around 95 MW deployed in 2019 alone. The Zambian government aims to deploy 500 MW of solar PV by 2023, in order to ease chronic power shortages. [27]

The Bangweulu solar PV plant, with installed capacity of 47.5 MW alternating current (AC) (approximately 55-megawatt peak [MWp]), is located in the Lusaka South Multi-Facility Economic Zone, 20 km south of Lusaka, Zambia.

It generates around 100 GWh per year, sold to ZESCO on 25-year power purchase agreement (PPA). The Bangweulu Power Company Limited is a special purpose vehicle (SPV), established according to the shareholder agreement on November4, 2016, and co-owned by

Neoen, First Solar, and the IDC of Zambia with 55 percent, 25 percent, and 20 percent shareholding, respectively. [28] [29] [30]

The Ngonye solar PV plant with the capacity of 28.2 MW AC (approximately 34 MWp) is also located in the Lusaka South Multi-Facility Economic Zone, next to the Bangweulu project. It will generate around 61 GWh per year, sold to ZESCO under a 25-year PPA. The Ngonye project is led by the EGP. Its parent company—Enel S.p.A. (Enel) —was Italy's largest power company and Europe's second largest utility with an installed capacity of 90 GW. The EGP and the IDC signed their shareholder agreement on November 11, 2016. On April 3, 2017, the Ngonye Power Company Limited (the project company), signed a PPA with ZESCO and a Government Support Agreement (GSA) with the GRZ. The project company is co-owned by the EGP (80 percent) and the IDC (20 percent). [29]- [31]

2.3 Solar Inverter

An inverter is one of the most important pieces of equipment in a solar energy system. We can say "the heart of the whole solar system". It's a device that converts direct current (DC) electricity, which is what a solar panel generates, to alternating current (AC) electricity, which the electrical grid uses. [32]

The term inverter was probably introduced by David Prince in 1925 and published an article "The inverter". There are all important elements in this article required for a modern inverter. This article is one of the earliest such publication in which the term "Inverter" is used in open literature. [33]

Most of the commercial, industrial, and residential loads require Alternating Current (AC) sources. One of the main problems with AC sources is that they cannot be stored in batteries where storage is important for backup power.

Inverters are classified into many different categories based on the applied input source, connection wise, output voltage wise etc. In this paper, we will see the type of inverter based on modes of operations. Standalone inverter and grid connected inverter. Grid connected inverter basically have four types: central inverter, micro inverter, string inverter and bimodal inverter. [34]

2.3.1 Modes of Operation of an inverter

Inverters have different modes of operation. The most known modes of operation are stand-alone inverter and grid tide inverters, the following table illustrate different types of inverter classifications according to different scenarios.

Table 2.2 different types of inverter classifications according to different scenarios

Types of inverters					
According to the Output Characteristic	According to the Source of Inverter	According to the Type of Load	According to different PWM Technique	According to Number of Output Level	According to Modes of operation
Square wave inverter.	current source inverter	Single Phase Inverter a) Half Bridge Inverter b) Full Bridge Inverter	Simple Pulse Width Modulation (SPWM)	Regular Two-Level Inverter	stand-alone inverter
sine wave inverter	voltage source inverter	Three Phase Inverter a) 180-degree mode b) 120-degree mode	Multiple Pulse Width Modulation (MPWM)	Multi-Level Inverter	grid connected inverter a) string inverter b) micro inverter c) hybrids inverter d)central inverter
modified sine wave inverter.			Sinusoidal Pulse Width Modulation (SPWM)		
			Modified sinusoidal Pulse Width Modulation		

			(MSPWM)		

A. Stand-Alone inverter

Stand-alone inverters are directly connected to the loads without being interrupted by other sources. Stand-alone inverters or ‘Off-Grid mode inverters”, the inverters provide power to the load on its own where there is no effect of the grid or other sources. [35]

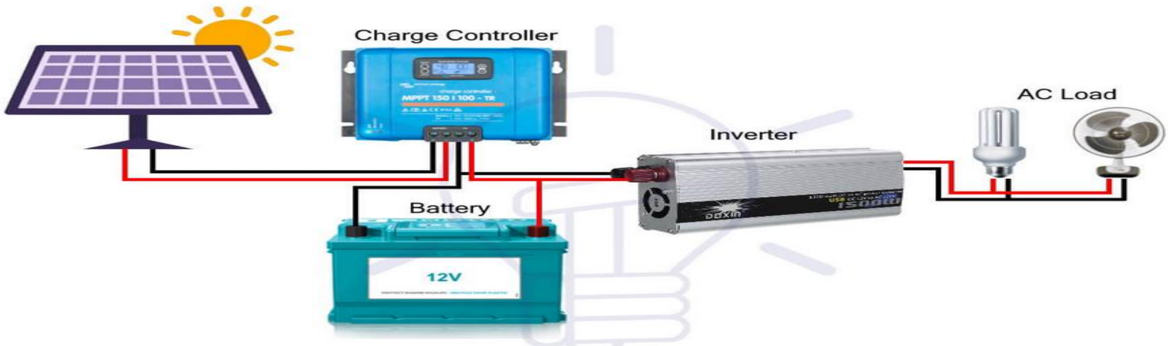


Figure 2.7 Stand-alone inverter [35]

These inverters are known as Off-grid mode inverters because these inverters are free from the utility grid. These inverters cannot be connected to the utility grid because they don’t have the ability of **synchronization,** where synchronization is the process of matching phase and nominal frequency (50/60 Hz) of both AC sources. [36]

B. Grid Connected inverter

Grid connected or Grid-Tie inverter (GTI) has two main functions. One function of Grid-connected inverter is to supply AC power to AC loads from storage devices (DC sources) while the other function of grid-connected inverter is to feed extra power into the grid. These inverters are also known as on-grid, utility-interactive, grid inter-tie or grid back-feeding inverters. [37]

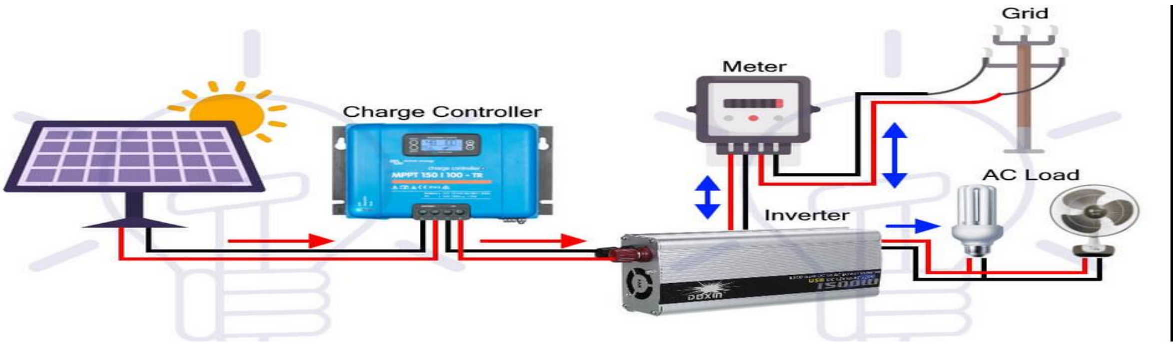


Figure 2.8 Grid connected inverter [37]

Based on the configuration topology, grid-connected inverters are further divided into 4 main categories which are briefly discussed here. [38]

i. Central inverter

Before connecting DC sources from renewable energy sources and storage devices to the utility grid, strings of DC sources are fed into one main central inverter which converts the power from DC into AC and feeds it into the utility grid. Power ratings of central inverters range from few KW to 100MW. [38]- [14]

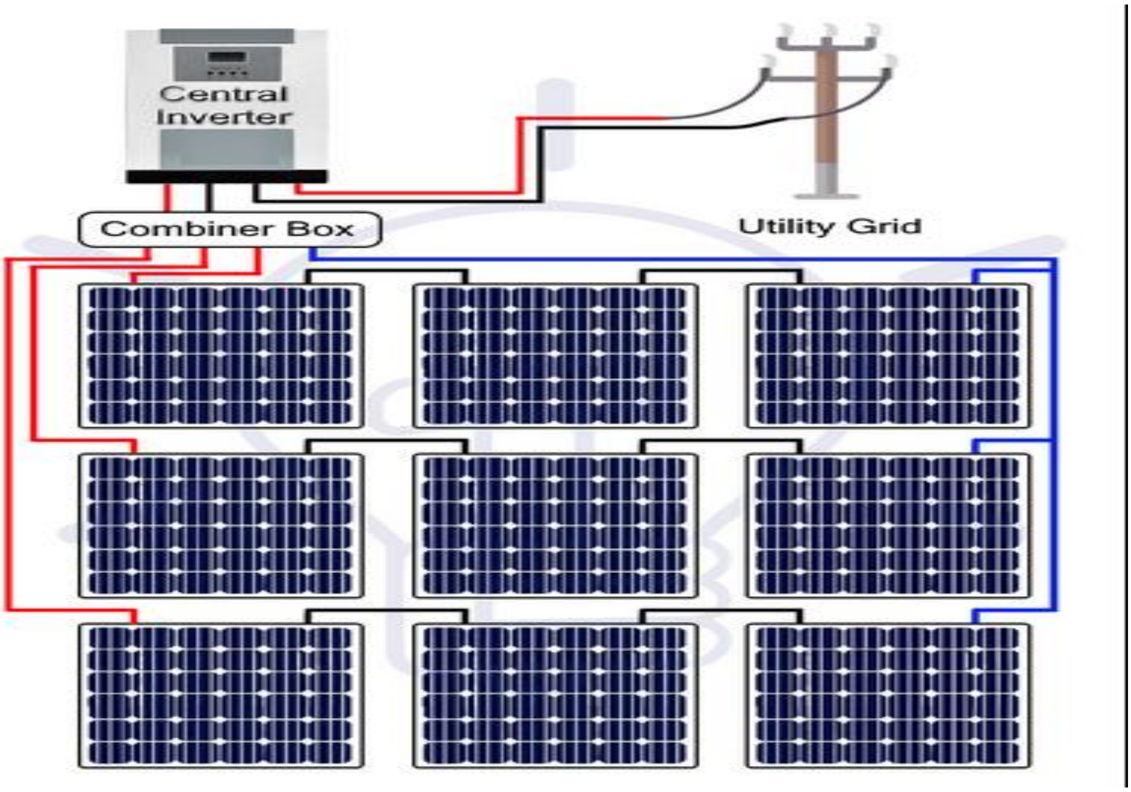


Figure 2.9 Central Inverter

ii. String inverter

Another way of connecting DC sources to the grid is to connect each string of DC sources (as shown in figure 3.10) to each inverter and then to the grid. In other words, each string of DC sources is connected to each inverter and outputs of all inverters are combined together and fed to grid. The power rating of these inverters ranges from few hundred watts to few kilo watts. [38]

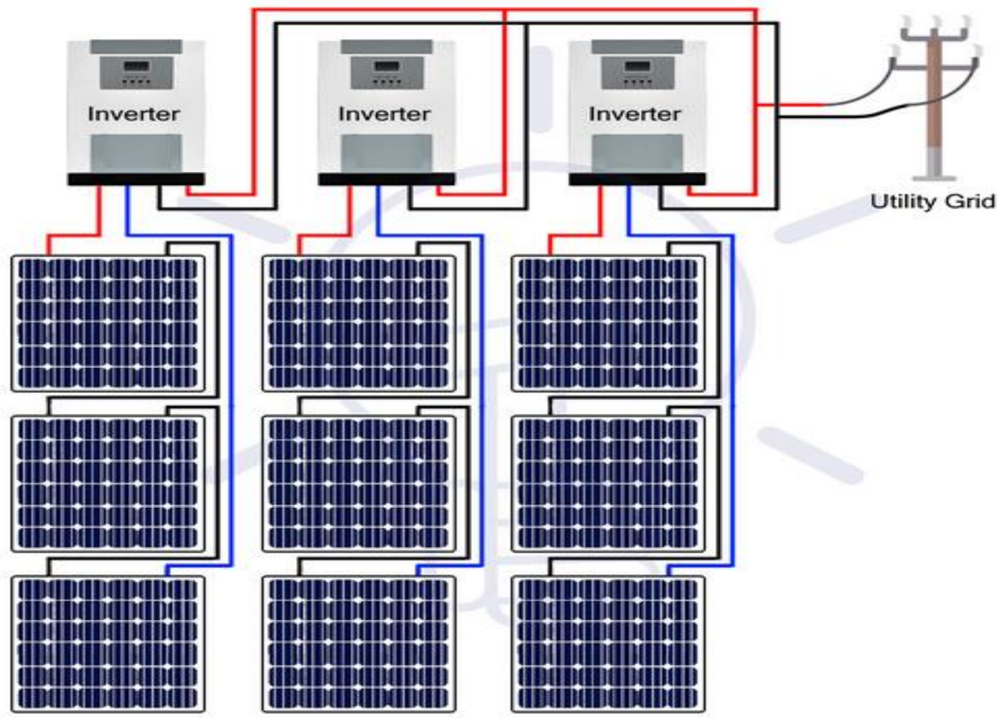


Figure 2.10 String Inverter [38]

iii. Microinverters

These inverters are also known as module inverters because each DC module is connected to each micro inverter. The output of all inverters is combined and fed into the utility grid. Typically, module inverters are rated from 50 watt to 500 watts. [38]

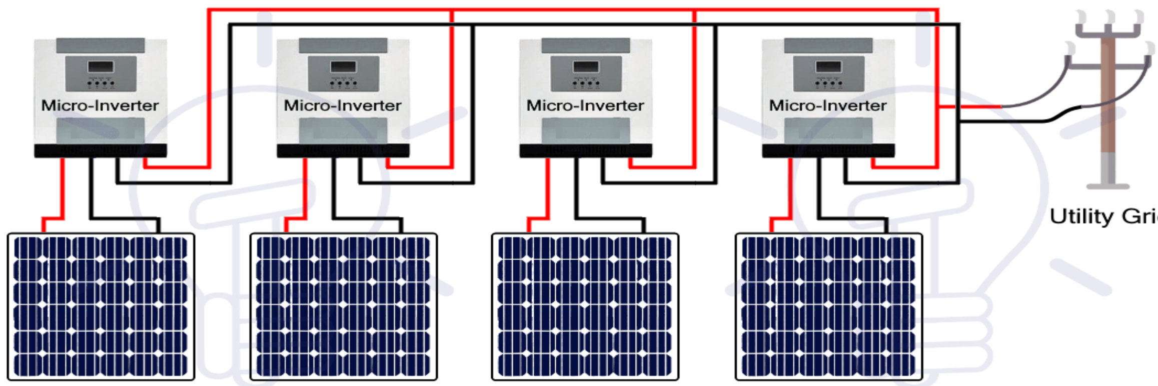


Figure 2.11 Microinverter [38]

iv. Bimodal Inverters

Bimodal inverters work both as grid-connected and as a stand-alone inverter. These inverters can inject extra energy from renewable sources and storage devices into grid and take back power from grid when the energy produced from renewable energy sources are not enough. [38]. In other words, these inverters can perform as stand-alone and grid-tie inverter depending on the requirement of load. Bimodal inverters are multifunctional, including the functionality of stand-alone and grid-tie inverters.

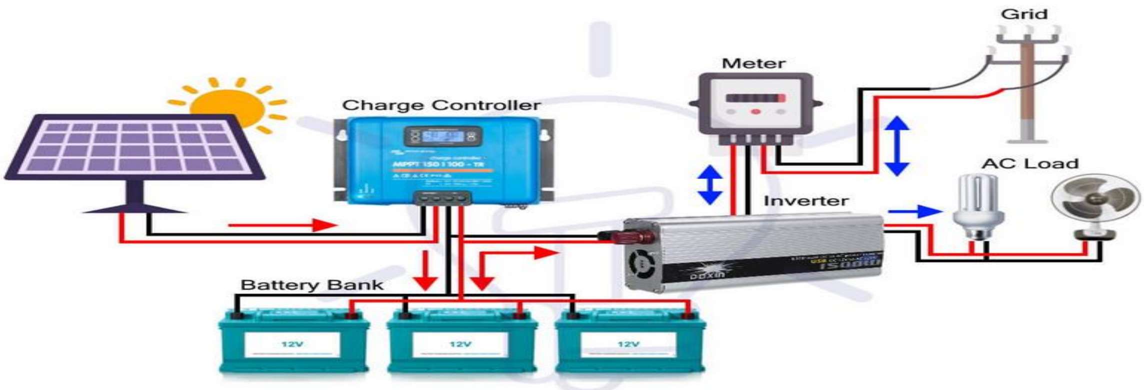


Figure 2.12 Bimodal Inverter

Table 2.3 the general types of grid tide inverter, their capacity, advantage and disadvantage

Types of Grid Tide solar inverter		
	Advantage	Disadvantage
1.string inverter Their sizes can range from 1kW to 100kW.	- Cheaper than the other type of inverter - kept in the closer proximity of fuse box and electricity meter	- if one panel is obstructed with shading, the remaining panels will be sabotaged too, and the efficiency will go down to a significant

	- The oldest type of solar inverters, they are also the most reliable. - It can be located centrally This allows easier access to monitor, repair, or replace the inverter.	amount - less scope to expand the solar panels for the future - string inverters only offer total-system monitoring as opposed to panel-level monitoring. (it can be an issues when diagnosing issues with solar production,)
2.micro inverter Their sizes usually range from 250W to 1kW, which accommodates 1-4 PV modules.	- Minimally impacted by shading on individual panels. If shade covers one panel, only that panel will produce less power output - Easy to expand with your solar system in the future. - allow for panel-level monitoring of the solar system,	- are the most expensive of the solar inverter options. - Because micro inverters are installed on the back of each solar panel, it is more difficult to repair or replace.
3.hybrid inverter This is the combination of standalone inverter and grid connected inverter	-It helps in storing of excess solar energy. -During evening time this stored solar energy can be used. This process is known as self-use or load shifting. -Hybrid inverters always come with power backup system.	-High cost of battery often comes as issue. -Installation cost is high -More space required to install entire system
4.central inverter Their sizes can range from 100kW to a few megawatts.	-more credibility than the others inverters - low cost - reliable (Usually central	- Potential for a single point of failure (if one panel is shaded or fails due to some other reason say 10%, it will

	inverters are housed in protective environments)	affect the performance of the entire system by 50%.) - Higher risk factor (Handling of this DC power from the panels to the central inverter of high rating could be life threatening to both the installers and owners.) - Higher Replacement Cost

2.3.2 The most common challenges with Grid tide solar inverter

The most common cause of failure or malfunctioning for inverters are as follows often combinations of the following are some of solar inverter challenges. Basically, all the major problems common with all Inverters or common error displays will fall under one or more of the headings listed below.

a. Faulty Installation of an inverter

Incorrect installation of an inverter has been a very common problem. This can range from physically misconnecting them to incorrect programming of the inverters.

Correct installation can then be checked at the handover of the solar park or during the start-up phase of the project by carrying out a number of tests, such as: Yield test, Regulation of the reactive power Remote activation and deactivation. [39]

b. Over Heating

Inverters, like all semiconductor-based equipment, are sensitive to overheating and, in general, operate best at cooler temperatures, while suffering power losses and damage at higher internal temperatures. Poor heat dissipation is usually caused by dust, fan trouble and air duct blockage, which leads equipment trouble to stop production.[43]

What is not as well understood is that heat also affects solar inverters. The reasons are not the same – although the solar inverter has semiconductor parts in it which loose efficiency as they heat up. [40]

c. Isolation fault

The Isolation Fault means that the inverter has detected an isolation fault: this could be an internal fault with the inverter or a fault with the solar system cables or wiring. In the event of an isolation issue, the

Solar inverter will stop working completely or continue to work at the minimum "required" isolation level. In the meantime, the solar inverter has problems and is not performing at its maximum capacity. In both cases, production is lost. [40]-[43]

d. The MPPT Models

Modern inverters operate on the basis of the MPPT technique. MPPT stands for Maximum Power Point Tracking, and this module has been developed in order to maximize the performance of inverters. [39]

Solar panels generate different voltages - it is important to get the maximum efficiency irrespective of the different voltage levels. MPPT algorithms extract the maximum power from the solar panels. The MPPT tracker adjusts itself constantly to keep the solar panels at their Maximum Power Point. [41]

e. Inverter over loads

When an inverter is overloaded with the minimum capacity, the panels work at their maximum and no production is lost. Meanwhile, if there is overload, the inverter will heat up and its operation will stop. This will not only reduce its useful life, but it will also alter solar production. Therefore, it is recommended to overload the inverter to a maximum of 30%. [42]

The solar panel installation it should be done taking into account the capacity and shade. Obviously, each inverter has a defined capacity, so it can be 100% loaded or under loaded to a greater or lesser extent.

Please, take note that some Inverters are also overrated that is, they are rated above their real capacity. [43]

f. Inverter not charging

The problem of inverter charger not charging batteries may have several causes. The batteries may have too much load, not enough power, or too high a charge current. Check the battery connections for corrosion and tighten them to ensure proper charging. If you cannot solve this problem, you may have a loose connection. [44]

g. Battery related inverter problem

Battery is the major component of Inverter that needs to be carefully selected from reliable shop as their replacement is very costly and success of repair cannot be guaranteed. When battery fails, one or more of the following can be responsible: [45]

Battery Under Charged/Over-Charged, Battery Charges/Discharges fast, Battery Low Volt, Swollen/Hot Battery, and etc.

2.6 Environmental Condition and Climate

Various environmental factors affect the performance of PV systems such as: Solar irradiance, temperature, dust and shades. Each of these factors have direct or indirect impact on the on the inverter. [46]

Inverter is a device that changes the direct power (DC) from the PV array to alternating power (AC) used in the electrical grid or AC loads at home [21,22,23].. The inverter affects the overall performance of the photovoltaic (PV) systems [22, 24]. In other words, if the power conversion efficiency (a measure of the losses experienced during the conversion from DC to AC) of the inverter in a grid-connected PV system is too small, the power generated by the PV array cannot be output to the AC utility system effectively.

These losses are due to multiple factors, some of which are: the presence of a transformer and the associated magnetic and copper losses, inverter self-consumption, and losses in the power electronics. It is thus necessary to increase the conversion efficiency to be as possible [46].

It is important to note that the inverter efficiency declines with a small rate after peaking with incident energy levels around 400–700 W/m2 due to the temperature increase inside the inverter when it handles loads with more power [47].

Actual field conditions usually result in overall DC-to-AC conversion efficiencies of about 88–92%, with 90% reduction factor as an average value [48]. So following the example of 100-watt module, it will operate at about 90 W (100 × 0.9 = 90 W). Gonzalez et al. [49]

Some studies show proposed transformer achieved higher efficiencies that can reach 97% and that reduced the losses to about 3% only. Thus, it can be concluded that the quantity of losses due to inverters depend on the type of inverter used as well as the presence or un-presence of transformers. [47]

2.4 Environmental condition in Ethiopia

Ethiopia is a country on the Horn of Africa. The country lies completely within the tropical latitudes and is relatively compact, with similar north-south and east-west dimensions. The solar radiation, Air temperature, rain fall and wind of the country is included on this paper.

a. Solar Radiation

The monthly and annual global solar radiations of Ethiopia were calculated from 30 m resolution ASTER Global DEM using Environmental System Research Institute (ESRI) ArcGIS solar radiation analysis tools. [50] According to the GIS model, large portion of Ethiopia receives solar radiation exceeding 1.8 MWh/m2 /year. In total, 195 sites located in different regions at 0.5 percent of the total area of Ethiopia, were selected with aggregate electricity generation potential of 65 GW per year purely from solar radiation. [50]

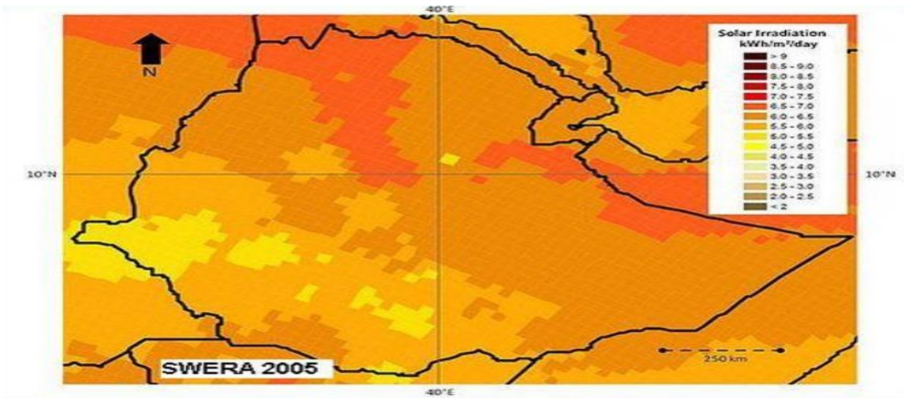


Figure 2.13 solar radiation in Ethiopia in (KWh/m^2/day)[50]

b. Air Temperatures

The wide variation in elevation (the height of land above sea level) in Ethiopia produces three types of climates, illustrated in Figure 2.13: [51]

- The hot *Kolla* climate occurs in regions below 1500 m and has an average annual temperature of about 30–33°C with an average annual rainfall of 300–1000 mm.
- The temperate *Woina dega* climate occurs in regions between 1500 and 2500 m and has an average annual temperature of 16–29°C with an average annual rainfall of 400–2400 mm.
- The cool *Dega* climate occurs in regions above 2500 m and has an average annual temperature of 10–16°C with an average annual rainfall of 1000–1600 mm.

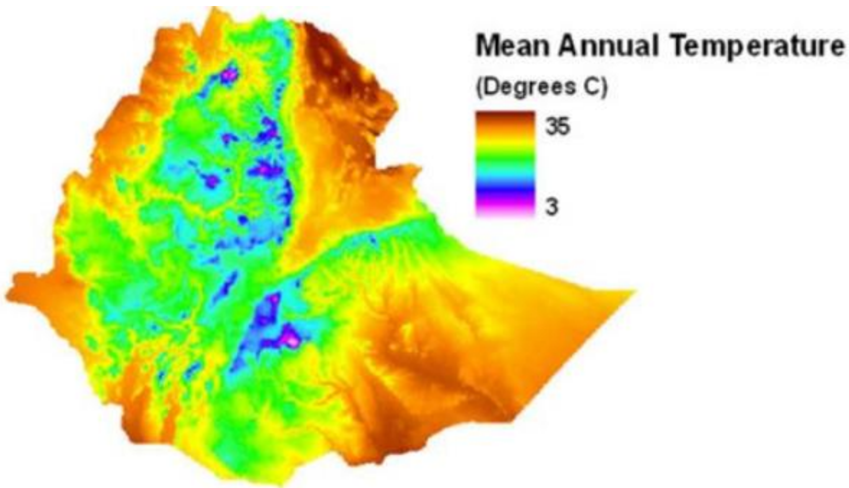


Figure 2.14 Mean annual temperature [51]

c. Rain falls

Rainfall in Ethiopia is the result of multi-weather systems that include Subtropical Jet(STJ), Inter tropical Convergence Zone(ITCZ), Red Sea Convergence Zone (RSCZ), Tropical Easterly Jet(TEJ), and Somali Jet [52] This makes the rain fall system of the country fore complex

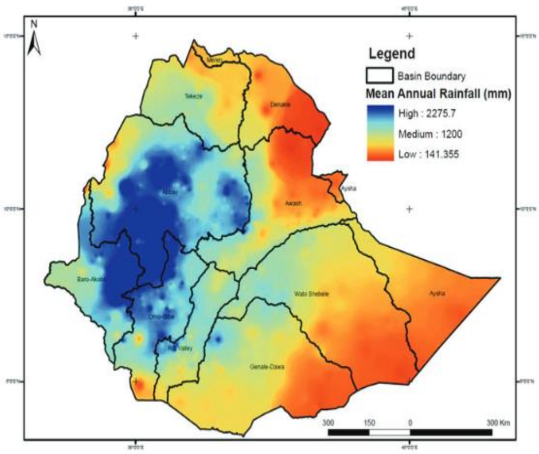


Figure 2.15 mean annual Rainfall (mm) [52]

d. Wind

Ethiopia has good wind resources with velocities ranging from 7 to 9 m/s [53] Its wind energy potential is estimated to be 10,000 MW [54] (see fig. 2.15). The Ethiopian National Meteorological Services Agency (NMSA) began work on wind data collection in 1971 using some 39 recording stations located in selected locations. Ever since the establishment of these stations, wind velocity is measured and data made available to consumers. However, the number of stations established, quality of data (in terms of comprehensiveness) and the distribution of the stations leaves much to be desired.

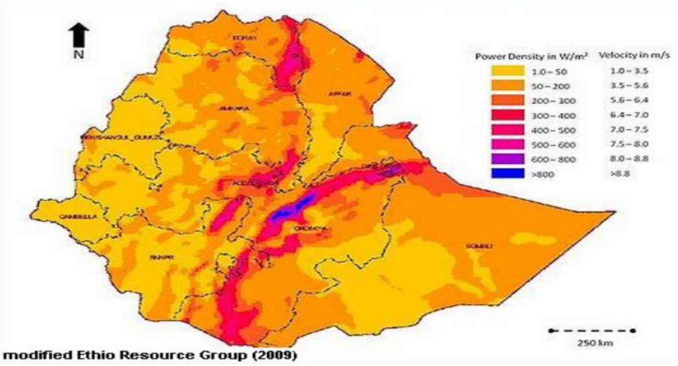


Figure 2.16 annual mean wind power density in W/M^2 and velvety in m/s [54]

2.5 Environmental condition in Zambia

Zambia is a landlocked country in Africa. It is situated on a high plateau in south-central Africa and takes its name from the Zambezi River, which drains all but a small northern part of the country [9]. The solar radiation, Air temperature, rain fall and wind of the country is included on this paper.

a. Solar Radiation

The country has an average 2,000-3,000 hours of sunshine per year. Average irradiation is 5.5 $kWh/m^2/day$, with northern areas recording the highest global solar irradiation, of 2,300 $kWh/m^2/year$ [55]

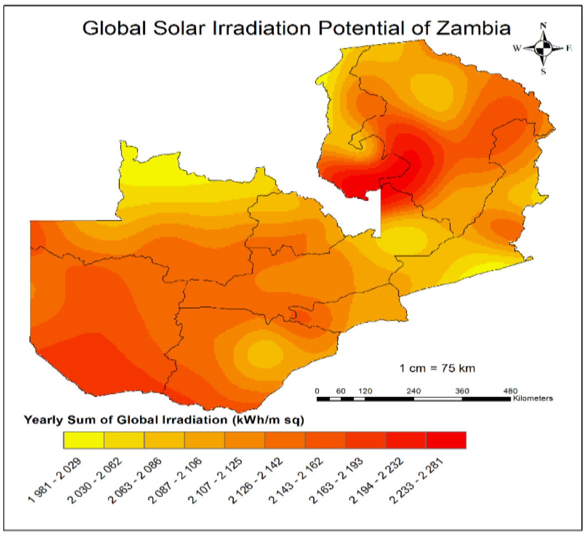


Figure 2. 17 Annual Total Global Solar Radiation Intensity source: [55]

b. Air Temperatures

Knowledge of air temperature is important, as it determines the operating environment and performance efficiency of solar power systems. Air temperature is used as one of inputs in energy simulation models. [56] In case of PV power plants, air temperature determines energy conversion efficiency in the PV modules, and it also influences one of the main components (inverters, transformers, etc.) [56].

Increasing air temperature has negative influence on performance of PV systems. The temperature data in time series are derived from CFSR (climate forecasting Reanalysis) and CFSv2 01Apr2011 - Present meteorological models by Solar GIS (geographic information system) post-processing, and they represent regional climate patterns rather than local microclimate. This means that extreme values may be partially smoothed and they not always well represent the local microclimate. [57] The temperature maps are developed only using the CFSR model data for Zambia in Figs.2.2.1 are shown below.

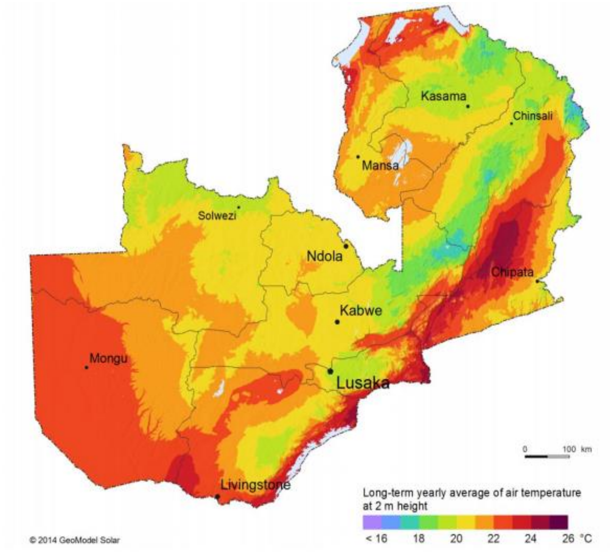


Figure 2.18 Long term yearly average of air temperature at 2 meters. Source: CFSR

c. Rain falls

Mean annual rainfall ranges from 500 to 1400 mm annually, depending on the location within Zambia. The map below (Fig.2.18) illustrates mean annual rainfall in Zambia from the period 2000–16, showing annual rainfall as low as 500 mm in the south and as high as 1400 mm in the north and northwest of the country. [58]

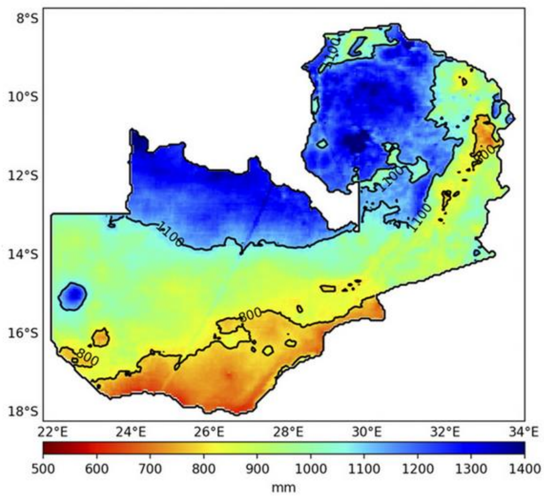


Figure 2.19 average annual rainfall map of Zambia, 2000-16, source: CHIRPS [59]

It displays three zones over the 2000-16 period constructed by tracing natural breaks in the climatological data. These rainfall zones range from dry (zone 1:800 mm annually) to intermediate (zone 2: 800-1000 mm annually) to wet (zone 3: .1000 mm annually).

d. Wind

The windier part of the year lasts for 4.2 months, from July 13 to November 21, with average wind speeds of more than 9.6 miles per hour. The windiest day of the year is October 4, with an average hourly wind speed of 12.7 miles per hour. The calmer time of year lasts for 7.8 months, from November 21 to July 13. The calmest day of the year is February 6, with an average hourly wind speed of 6.6 miles per hour. [60]

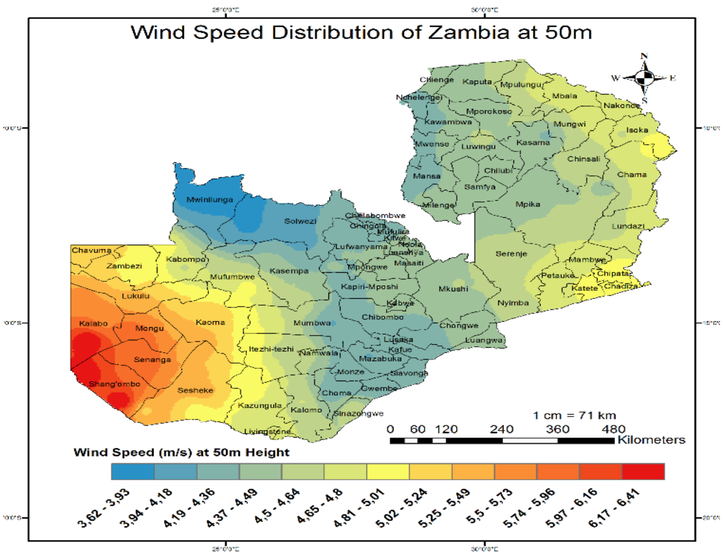


Figure 2.20 Annual Wind Speed at 50m [61]

2.6 Solar PV Plant Implementation Sites

PV installations are mainly ground mounted. By contrast, integrated photovoltaic (BIPV) and roof top installations have a big role in PV projects these projects through a reduction in their energy bills. [62] Photovoltaic power output depends on many factors, such as sun position, the intensity of solar irradiance, temperature, and load demand. Accordingly, the dynamic response of PV systems must be evaluated thoroughly for utility grid (UG) performance, since interconnecting a PV system with a UG may lead to instability. [62] The uncertainty of the PV performance models is still too high. The focus point of much of the existing current research on this subject has largely been on evaluating module performance rather than system performance.

The effect of dust accumulation on the performance of PV systems has been investigated in many studies. [59] The results indicated that dust accumulating rate predominantly depends on the weather conditions of the site. For example, due to presence of dirt or dust this thus causes considerable number of losses in the generated power. Since the solar irradiance is scattered on the surface of the solar panel [63] [64]. A typical annual dust reduction factor is 93% or 0.93 so if we take a 100-watt Module as an example, it will typically operate at about 93 W (100 × 0.93 = 93 W) due to dirt accumulation [65]

Summery

This chapter has put together all the information collected from the two countries Zambia and Ethiopia based on to the target of the research question. Solar potential in both country is untapped resource of energy based on that the government of the countries and the energy sector should work together to use the solar energy source in the country. On the other hand on this chapter the researcher review the different types of solar inverter and their application table 2.2 and 2.3 shows the summary of different types of an inverter.

The environmental condition of country temperature, rain fall, wind, and solar radiation is presented on section 2.10 And 2.11 Finally, the basic inverter challenges in relation to working environment and other scenario is included.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents a detail discussion about the type of research design approaches which have been employed in this study in acquiring the necessary information to fulfill the objective of the study. Moreover, topics related to method of data collection, materials, data analysis and interpretation tools are included.

3.1.1 Research design and Approach

The goal of this project is Identifying and Analysing the Technical challenges of inverters for grid connected PV system due to different condition. The methodology combines quantitative and qualitative approaches, Mixed methods are used. This allows for the phenomenon that is being researched to be better understood.

A detailed literature review is conducted which has direct or indirect relation on technical challenges of inverters for grid connected PV system due to different conditions. different research has been done and is on-going. In each review, the contribution made, research not done and limitations has been documented. Some of the missing achievements are being investigated in this research.

On this study different site are selected, a detailed view on the study area on section 3.2, from the horn of Africa Ethiopia and southern of Africa Zambia is included. In Ethiopia 8 site are selected (mini off-grid sight) and in Zambia two site are selected (on-grid sight). The researcher collects and analyses numerical data via a quantitative technique, such as a survey and qualitatively the researcher make an observation, formulate research questions, and conduct interviews. The following are the main research approach.

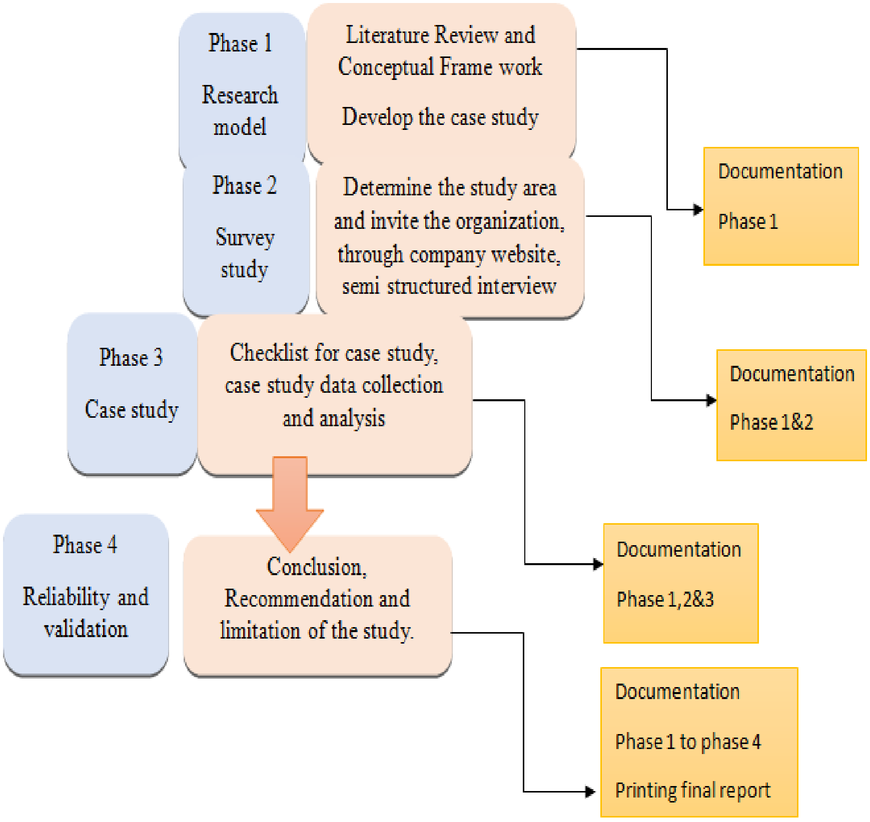


Figure 3. 1 Research frame Work

3.2 Study Area

3.2.1 Geographical Location of Zambia

Zambia is a landlocked country in Africa. It is situated on a high plateau in south-central Africa and takes its name from the Zambezi River, which drains all but a small northern part of the country. [66]

Figure 3. 2 Geographical location of Zambia [67]

Zambia 2020 population is estimated at 18,383,955 people at midyear according to UN data. Zambia population is equivalent to 0.24% of the total world population. Zambia ranks number 65 in the list of countries (and dependencies) by population. The population density in Zambia is 25 per Km^2 (64 people per mi^2) [68]

The study basically based in Lusaka south multi-facility economic zone. There are two grid connected independent solar plant, the 54 megawatts Bangweulu solar power plant by Neon Investment of France and the 34MW *Ngonye solar* photovoltaic (PV) *plant*. [69]

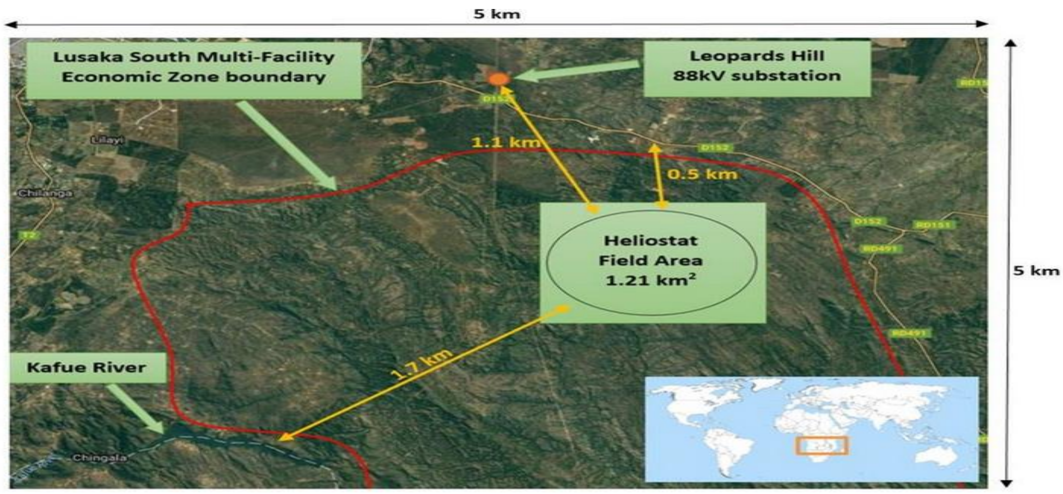


Figure 3.3 Satellite view of Lusaka South Multi-Facility Economic Zone showing the total field area occupied by the plant and estimated distances from the river, [69]

3.2.2 Geographical Location of Ethiopia

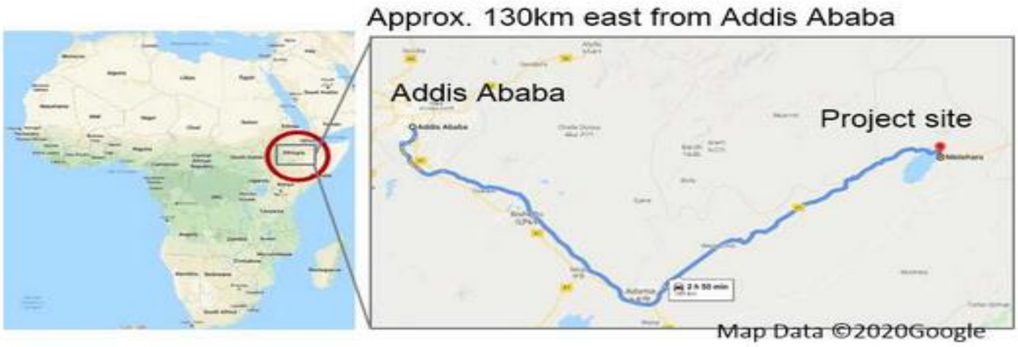
Ethiopia is a country on the Horn of Africa. The country lies completely within the tropical latitudes and is relatively compact, with similar north-south and east-west dimensions. The capital is Addis Ababa ("New Flower"), located almost at the centre of the country. Ethiopia is the largest and most populated country in the Horn of Africa. [70]

Because Ethiopia is located in the tropical latitudes, its areas of lower elevation experience climatic conditions typical of tropical savanna or desert. However, relief plays a significant role in moderating temperature, so higher elevations experience weather typical of temperate zones. Thus, average annual temperatures in the highlands are in the low 60s F (mid-10s C), while the lowlands average in the low 80s F (upper 20s C). [71]

Figure 3.4 Geographical location Ethiopia [71]

Ethiopia can be divided into four rainfall regimes. Rain falls year-round in the southern portions of the Western Highlands, where annual precipitation may reach 80 inches (2,000 mm). Summer rainfall is received by the Eastern Highlands and by the northern portion of the Western Highlands; annual precipitation there may amount to 55 inches (1,400 mm). The Eastern Lowlands get rain twice a year, in April–May and October–November, with two dry periods in between. Total annual precipitation varies from 20 to 40 inches (500 to 1,000 mm). The driest of all regions is the Denakil Plain, which receives less than 20 inches (500 mm) and sometimes none at all. [72]

In Ethiopia there are two government institutions which are working under supplying electricity. The first one is Ethiopian Electric power (EEP) and Ethiopian Electric Utility (EEU).



The Metahara Solar PV power plant, which were planned to supply electricity to the Ethiopian national grid under (Ethiopian Electric Power) EEP, is of the largest solar power facilities in Africa. The project location encompasses 250 hectares of undeveloped land adjacent to the main road between Addis Ababa and Djibouti. As shown: [73]

Figure 3.5 Satellite view of Metehara PV solar power plant. [74]

Due to multiple factors from regulation to tariff to currency made it impossible to implement the project. Because of that, the research will focus on: The Ethiopian Electric utility (EEU) mini grid project, which have 12 minis off grid solar power site. Out of this, 10 sites are energized before two years and fully functioning. As shown below on the map. [74]

Figure 3.6 Mini grid sites in Ethiopia:

3.3 Data collection procedure

a. Primary data

Primary and Secondary sources of data used for data analysis. Primary data used to get empirical investigation. Thus, this study used physical observation and interviews in order to identify the problems in the existing site related to grid tide solar inverter.

Primary Data: Data that has been generated by the researcher himself/herself, surveys, interviews, Photographs which shows different grid tide inverters site, the questionnaire specially designed for understanding and solving the research problem at hand. Primary data are the main input to the researcher final conclusion and recommendation for farther investigation.

The primary data are collected by the researcher going through each and every site or if not the head offices. And also by contacting a short interview virtual and also in person. This are the main input to investigate the real time problem of an inverter. A questionnaire is distributed the selected site in Zambia and Ethiopia.

b. Secondary data

Secondary data are basically second-hand pieces of information. These are not gathered from the source as the primary data. To put it in other words, the secondary data are those that are already collected. Secondary sources that are not first-hand, i.e., that cannot be traced back to its source by directly linked. This data allows the researcher to visualize the type of problem faced by past researchers, regulation boards and the ministry. The following are the main source of secondary data collection mechanizer the researcher used.

- Internet

The data got from the internet i.e., YouTube, Websites on different challenges of solar grid tide inverter by different organizations in the world, and written journals that cannot be obtained in physical form. But they are the easy to access and give a good start to the researcher based on the objective of the researcher.

- Journals and Conference papers

These are important papers from academics who have walked that path before. They may not be directly linked to the area under study, but will give direction through the findings that were done, recommendations made and suggestions for further research.

- Books and Magazines

Many books are written on solar energy, solar energy efficiency related to inverter performance, smart grids micro-grids, mini on-grids / off -grid solar plant. The gestures written in the documents give direction to the work at hand. All the resources used on this research is indicated on the reference section.

3.4 Data Analysis

This will be the case study, collection and analysing data. The data is processed using Microsoft Excel. each and every data collected from each site, through questioners which is attached on appendix A, the most frequent inverter challenges are shown in chapter 4 on figure 4.18. in Ethiopia 8 mini off-gride site and in Zambia 2 on-grid solar plant are included.

From the real time data collected among the 8 sights in Ethiopia on different mouth of the year, the energy output in KWH for 2021 is also shown on chapter 4 table 4.2. but in Zambia the real time data of the inverter performance is an able to get by the researcher due to the company policy.

Table 3. 1 Name of the selected site in Ethiopia and Zambia with the site location and the type of inverter.

	selected min off- grid site in Ethiopia	**Site location**		**Types of inverters**	**Completion/commission date**
		Latitude	**Longitude**		
1	Beltu	7.878	40.99	KELONG-grid tie	08.02.2021
2	Behima	7.48	41.058	KELONG-grid tie	04.03.2021
3	Mino	9.24412.048	41.526	NR-grid tie	09.08.2020
4	Ungoge	7.775	33.931	NR-grid tie	03.12.2020

5	Korhele	7.504	7.504	NR-grid tie	24.10.2020
6	Tum	6.255	35.522	GroWatt-grid tie	31.03.2020
7	Omorate	4.801	36.05	GroWatt-grid tie	23.02.2021
8	Kofetu	1.23456	9.87654	Homer	
	Name of on-grid site in Zambia				
1	Bangweulu solar power plant	15.5239	28.3906	Huawei - SUN 2000-42 KTL (string inverter)	11.03.2019
2	Ngonye solar photovoltaic	15.5239	28.3906	FIMER – Model: R15015 TL (central inverter)	29.04.2019

A. Based on the objective of the research to identify and investigate the main grid tied inverter challenges due to different scenario mainly environmental condition which is the operating environment of the inverter. a questionnaire and a Sime structure interview is conducted. Which is attached to Appendix: A and Appendix B. The participant is selected based on their profession experience on monitoring and operating the solar plant.

B. a detailed literature review is conducted on chapter two in both countries based on the ongoing solar project and also the upcoming grid tide solar plant and mini grid site. in Ethiopia the researcher focused on the mini grid sites as it is indicated on table 3.1. also, in Zambia the two main grid connected site at malty facility zone is included.

C. investigate, compere and identify the environmental \climate condition of the two country Zambia and Ethiopia. Solar radiation, Air temperature, Rain falls and Wind Using Microsoft excel for each selected site annual solar radiation, air temperature, rain falls and wind is investigated and analyzed for the selected site

D. the basic inverter challenges are investigated from the collected data and the problem is analyzed based on the specific inverter data sheet. The data sheet of the inverter for each site under this study is attached on Appendix D

E. finally, a conclusion is made on how an inverter technical performance (efficiency) affected due to the inverter challenges. based on
The efficiency of the inverter directly affects the performance of Solar power plant.

The overall efficiency of the inverter = Conversion efficiency Tracking efficiency*

Conversion Efficiency: Power conversion efficiency of the Constant in laboratory conditions
Tracking efficiency: The maximum power point tracking efficiency in a rapidly changing load condition

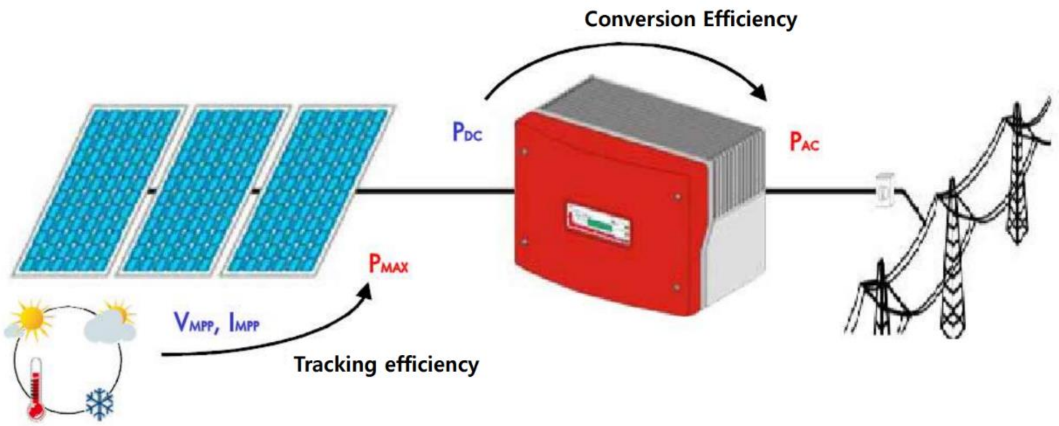


Figure 3.7 demonstrate the efficiency of the inverter

3.5 Validity and Reliability

Validation is a point where the researcher measure or test how the result is valid by correlating with the expected result. On the other hand, Reliability is a stage which allows you to assess the degree of consistency in your results based on your data analysis. Reliability provides an answer to the question of how similar your results are after that the researcher will conclude and recommend what is needed for future study.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Introduction

This chapter presents the findings of the study on Identifying and Analyzing the Technical challenges of inverters for grid connected PV system: A case study of Ethiopia and Zambia. In Zambia: The discussion basically based, at south multi-facility economic zone. There are two grid connected independent solar plant, the 54 megawatts Bangweulu solar power plant by Neon Investment of France and the 34MW *Ngonye solar* photovoltaic (PV) *plant*. On the other side in Ethiopia the study basically based at The Ethiopian Electric utility (EEU) mini grid project.

4.2 Types of Grid Tied Inverters Used in PV system in Ethiopia and the climate condition of the area.

In Ethiopia there are two government institutions which are working under supplying electricity. Ethiopian Electric power (EEP) and Ethiopian Electric Utility (EEU). Ethiopian Electric Power owns and operates the Ethiopian national power grid with all High voltage power transmission lines *above* 66 kV including all attached Electrical Substation and almost all power plants within the national power grid including the controversial Great Ethiopian renaissance dam (GERD) project which is Africa's largest hydroelectric project, with a capacity of 5,000 MW.

Currently Ethiopia has not fully function grid connected solar plant. The Metahara Solar PV power plant, which were planned to supply electricity to the Ethiopian national grid, is of the largest solar power facilities in Africa. The project location encompasses 250 hectares of undeveloped land adjacent to the main road between Addis Ababa and Djibouti. Due to multiple factors from regulation to tariff to currency made it impossible to implement the project. The memorandum of understanding was signed for a private developer to develop the plan and sell to the grid. The project was planned to have an Inverters which convert the DC current produced by PV modules to grid-exploitable AC current (three-phase 400V at utility frequency). They typically range from approximately 20 kVA (decentralized) up to 2,500 kVA (centralized inverters). Inverters are central components in the communication with the SCADA system, since they monitor the strings operation. PV inverters also have special functions like maximum power point tracking or anti-islanding protection. The preliminary design was including a total of 80 inverters.

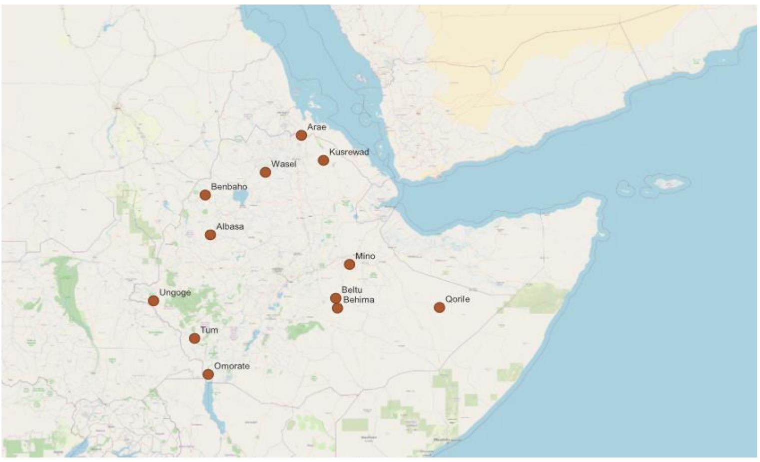


Figure 4.1 mini grid sites in Ethiopia which currently working:

On the other hand, The Ethiopian Electric utility (EEU) mini grid project, have 12 minis off grid solar power site. Out of this, 10 sites are energized before two years and fully functioning. For each site different contractor install the system so the type of inverter differs from site to site based on the contractor selection. The above map shows the site location for the mini grid solar power station in Ethiopia under Ethiopian Electric Utility (EEU).

Table 4. 1 list of Mini-grids Sites in Ethiopia which is shown on the above map

S/N #	**Name Mini-Grid Site**	**Types of Inverters**	**Inverter Capacity**	**Number of inverters**	**Total expected output power**
1	Beltu	KELONG-Grid Tie	60kW	14	750kW
2	Behima	KELONG-Grid Tie	60kW	4	204.6kW
3	Mino	NR-Grid Tie	33kW	7	225.1kW
4	Ungoge	NR-Grid Tie	33kW	6	175kW
5	Korhele	NR-Grid Tie	33kW	10	325kW
6	Tum	GroWatt-Grid Tie	50kW	11	550kW
7	Omorate	GroWatt-Grid Tie	50kW	8	375kW
8	Kofetu	Homer	100kW	2	200kW

Among the list of types of inverter NR-grid tie inverter are shown below from the site photo. It is also used in three sites Mino, Ungoge, and Korhele.

Figure 4.2 NR-grid tide inverter rating 33kw

All sites are far away from the grid, as a backup they have diesel generator. Which serve only critical load and to recharge the battery. Under EEU there are also 25 sites under construction and also 201 mini grids sit to be implemented up to 2027.

On this paper we are going to see two mini off grid site in detailed among the above table 4.1

4.2.1 Omorate Model Mini-Grid Site

Omorate is a town in southern Ethiopia near the Kenyan border. Located in the Debub Omo Zone of the Southern Nations, The MG was selected for the study owing to its location in a hot tropical climate, the availability of operational data and the fact that the MG is among the first PV power plants installed in Ethiopia. The town lies between 4° 80′ 16″N Latitude and 36°3′29″ E Longitude with an average elevation of 368 m.a.s.l. The mean annual temperature in Omorate is 28.2 °C.

The MG in Omorate has a total installed capacity/rated power of 375 kWp. The PV array consists of 1210 series-connected monocrystalline PV modules from Jinko (Model: JKM310M-60). Each PV module has a rated power of 310 Wp and a rated efficiency of 18.94 %. The modules are assembled into 9 strings in two parallel rows (Fig 2). Each string is connected to one inverter from Growatt *(Model: MAX 50KTL3 LV)* that has a maximum output power of 50 kWp. Each inverter has 6 maximum power point trackers (MPPT).

Figure 4. 3 area of Omorate ,dasanech district southern Ethiopia

Figure 4.4 A view of the PV MG infrastructure in Omorate, Dasanech district, Southern Ethiopia

The main system components of the MG include: PV modules, converters (solar direct current (DC) to alternating current (AC) inverters, and battery DC/AC inverters), battery energy storage system (BESS), MG monitoring and energy management system (MMEMS), a diesel generator (DG), a distribution panel (with three AC power feeders) and loads.

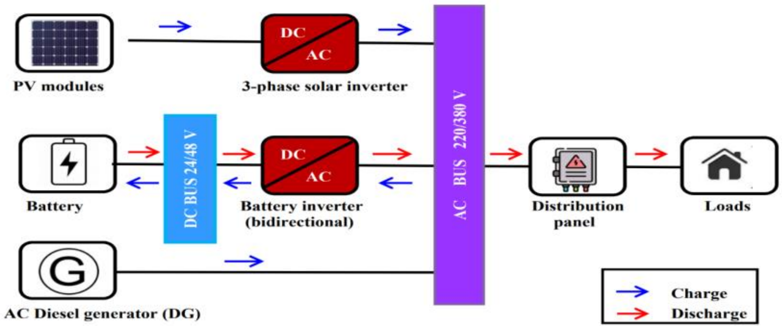


Figure 4.5 solar plant schematic diagram for omorate mini off-grid site

All the modules in each string are fixed on ground-mounted racks and positioned in a direction facing towards south at a tilt angle of 15°. The MG system is alternating current (AC)-coupled and is equipped with five Lithium Iron Phosphate (LiFePO4) battery packs with a total rated storage capacity of 600kWh.

4.2.2 Environmental Condition of Omorate, Dasanech District, Southern Ethiopia

According to the measured solar irradiation data, the total annual solar energy resource incident on the tilted PV array is 2247 kWh/m2 /year. The average daily solar irradiation is 6.1 kWh/m2 , however, it varies between 4.6 and 7.5 kWh/m2 /day. The monthly average daily solar irradiation and ambient temperature are shown in Fig. 4.6 The figure displays that the lowest average daily solar irradiation (5.59 kWh/m2 /day) is recorded in July. The peak irradiation (7.05 kWh/m2 /day) is recorded in January. The average daily ambient air temperature at the MG site is 30.1 °C, with a minimum of 28.2 °C in July and a maximum of 33.0 °C in February. In general, Fig 4.6 shows that the distribution of solar irradiation at the MG site has little seasonal variation.

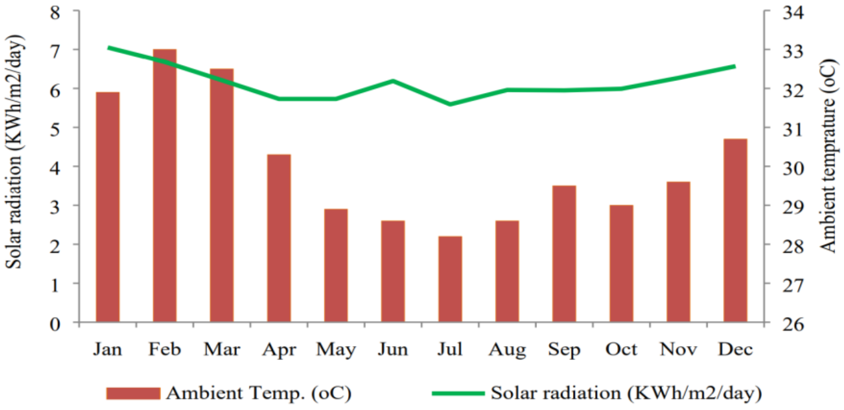


Figure 4. 6 solar radiation and Ambient temperature of Omorate, Dasanech district, Southern Ethiopia

4.2.3 Kofute Model Mini-Grid Site

The plant site Koftu, located 40km South West from the Capital City of Addis Ababa.The project is built as a model project by the support of South Korea from KIAT (Korea Institute for Advancement of Technology) given to EEU and was completed 2019. The Project implementation unit was – EEU, UEAP (Universal Electric Access Project)

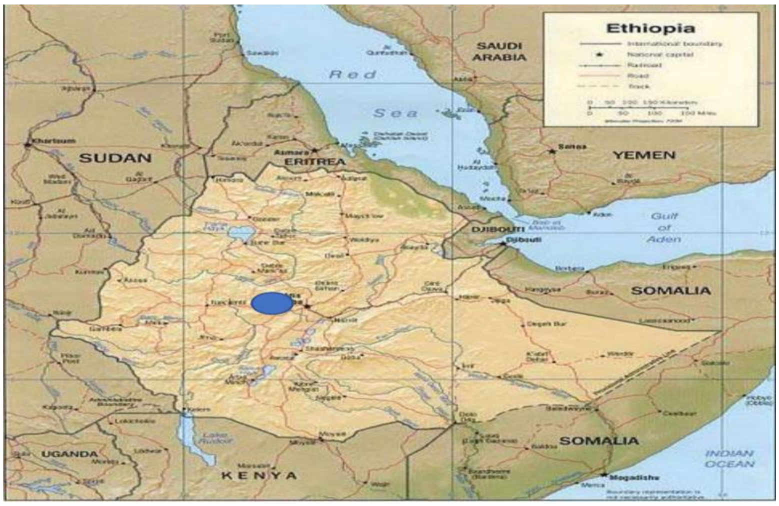


Figure 4.7 geographical location of koftu

The solar mini grid site can supply 327 house holed by satisfying the power demand 100kw of load power and 151 kw of work load with eco-friendly energy. The selected panel is 320w there for the total panel required for 250kw is 630 panel. The optimum design is made by homer. The following shows the schematic diagram of the system in koftu.

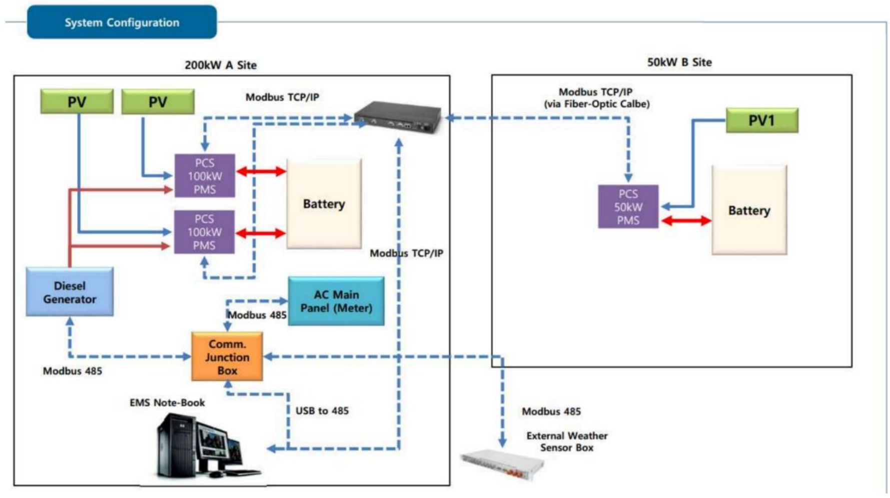


Figure 4.8 the schematic diagram of koftu solar power site.

Us we can see from the schematic there are two sites in koftu site “A ’The AC/DC conversion unit PCS (power conversion unit) is 100kw each. Both they are bi lateral and connected to the battery. On the other side site “B” is operating inverter 50kw bi lateral PCS directly connected to the battery and the solar panel. The backup diesel generator is rating 30kw.

4.2.4 Environmental Condition of Koftu South West of Addis Ababa.

The solar radiation of the site is 5.81kw/sqm/d, the panel inclination is 5^0 the solar

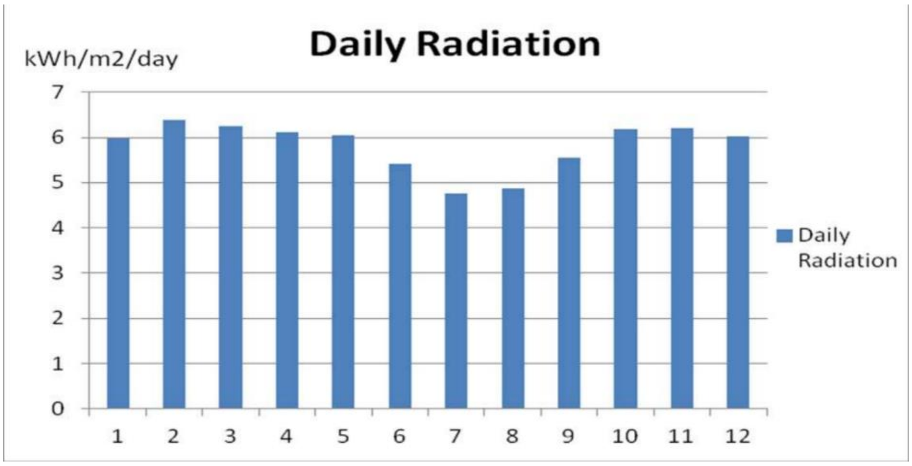


Figure 4.9 daily radiation curve KWh/m^2 of Koftu

Table 4.2 List of mini grid sites in Ethiopia; energy produced in KWH; 2021

NO	Name mini grid site	Month	Energy in KWH
1	Tum	March	199,152,00
		April	219,012.00
		May	238,570.00
		June	258,462.00
2	Uguge	March	110,119.00
		April	118,671.00
		May	127,945.00
		June	135,902.00
3	Behima	March	64,587.00
		April	70,557.00
		May	74,758.00
		June	80,211.00
4	Mimo	March	98,748.00
		April	106,885.00
		May	114,876.00
		June	122,666.00
5	Omorate	March	395,690.00
		April	435,768.00
		May	462,273.00
6	Beltu	March	381, 560.00
		April	422,800.00
		May	669,912.00
		June	519,376.00

4.3 Selected solar power plant in Zambia and Climate Conditions

4.3.1 Bangweulu Solar Power Station (BSPS)

Bangweulu Solar Power Station (BSPS), is a 54 MW (72,000 hp) solar power plant in Zambia. The solar farm that was commercially commissioned in March 2019 was developed and is owned by a consortium comprising, Neoen a French IPP, Industrial Development Corporation of Zambia (IDC Zambia).

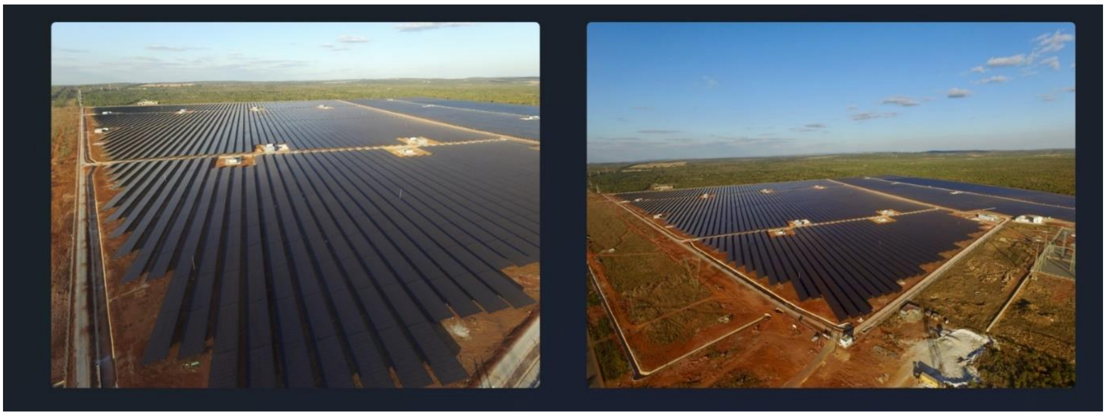


Figure 4. 10 the Bangweulu solar power plant at multi facility center

The Bangweulu solar power plant has been producing 54 MW solar power and feed to the national grid ZESCO, for three years since 2018 up to now. There are 12 blocks; each block is accompanied by 33kv step up transformer, circuit braker (sf6-gus insulated circuit breaker). There are a total of 1230 string inverter each produced 480 volt which is 42 KW power. The inverter has a capacity to receive DC power from 2000v to 1000v (Huawei - SUN 2000-42 KTL).

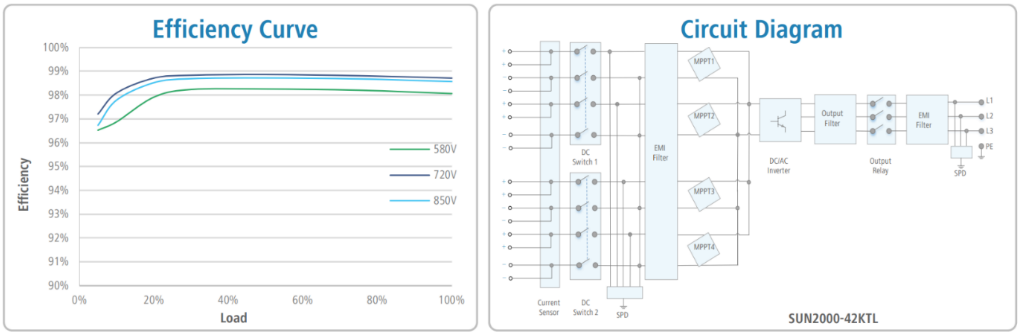


Figure 4.11 Smart String Inverter SUN2000-42KTL circuit diagram and efficiency curve [the full data shit will be attached on Appendix A]

Figure 4.12 Huawei - 480-volt Inverter from Bangweulu Solar Power Station

4.3.2 Ngonye Solar Power Station (NSPS)

Ngonye Solar Power Station (NSPS), is a 34 MW (46,000 hp) solar power plant in Zambia. The solar farm that was commercially commissioned in April 2019 was developed and is owned by a consortium comprising Enel Green Power of Italy, a multinational renewable energy corporation, and the Industrial Development Corporation of Zambia (IDC).

Ngonye solar plant, in the Lusaka South Multi Facility Economic Zone, is using tracking systems that feature solar photovoltaic (PV) panels to track the movement of the sun throughout the day, capturing sunlight and converting the energy into electricity. There are a total of 24 grid connected central PV inverter each produced

550 volt which is 1410 KW power. The inverter has a capacity to receive DC power from 1320v to 850v (FIMER – Model: R15015 TL).

Figure 4.13 Ngonye solar plants, in the Lusaka South Multi Facility Economic Zone

The tracking of the sun is achieved using a global positioning system (GPS) connected to an electronic tracker control board (ETCB). The integrated GPS device acquires both date and time. Each single-axis tracker automatically tracks the sun's East to West movement during the day. A single ETCB controls a maximum of ten structures with a PV energy capacity of about 97.5 kW. The primary benefit of the tracking system is that it improves plant efficiency by increasing energy output as it lengthens the plant’s peak generation period above similar-sized fixed axis plants.

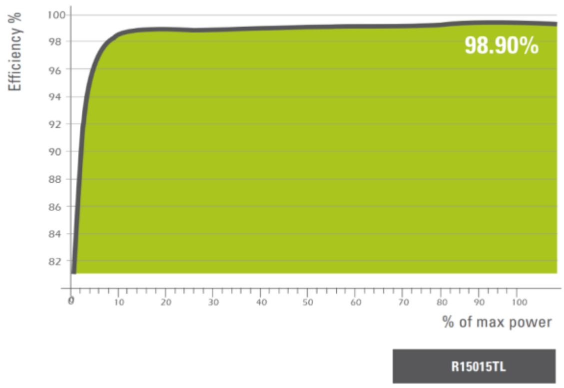


Figure 4.14 efficiency curve FIMER – Model: R15015 TL central inverter

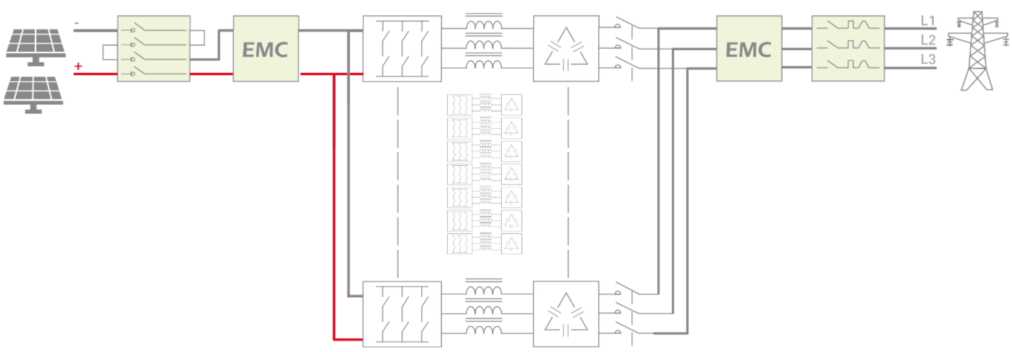


Figure 4.15 circuit diagram FIMER – Model: R15015 TL central inverter

4.3.3 Environmental Condition of Ngonye solar plant station (NSPS) and Bangweulu Solar Plant Station (BSPS)

The plants are located at Multi Facility Zone in Lusaka. Hence, both power plants are subjected to similar environmental condition. However, the power plants have different types of inverters and set up. According the interview which was conducted and collected data, it was observed that, the climate of the area is characterized by three distinct seasons;

- Cool dry season from mid-April to August;
- Hot and dry season from September to October;
- Rainy season from November to April.

The area receives annual rainfall between 500 mm and 1000 mm with the mean annual rainfall being in the order of 800 mm. Moderate temperatures with mean monthly temperatures ranging between about 15^0c in the cold season to 30^0c in the hot season. Prevailing easterly winds dominate the area during the dry season with fresh winds experienced in the months of July and August. Mean wind speed recorded in the area ranges from 4 km/hour to 9 km/hour. Extreme wind events in the area are associated with thunderstorms and transient, short-term “dust devils” and may reach 112 km/h. Sunlight hours per day range from 5 hours to 9 hours in August with an annual average of 7 hours per day.

The table below shows temperatures and rain days for the whole year as an average taken from last 12+ years of historical data for Kafue. (Multi facility zone Lusaka Zambia)

Table 4.3 Average Annual Temperature (^{o}C) of day, night and rain days

Month	Day	Night	Rain day
January	26	18	20
February	26	18	19
March	26	17	14
April	26	16	3
May	26	13	0
June	24	11	0
July	24	11	0

August	28	14	0
September	32	17	0
October	34	20	1
November	32	20	7
December	29	19	17

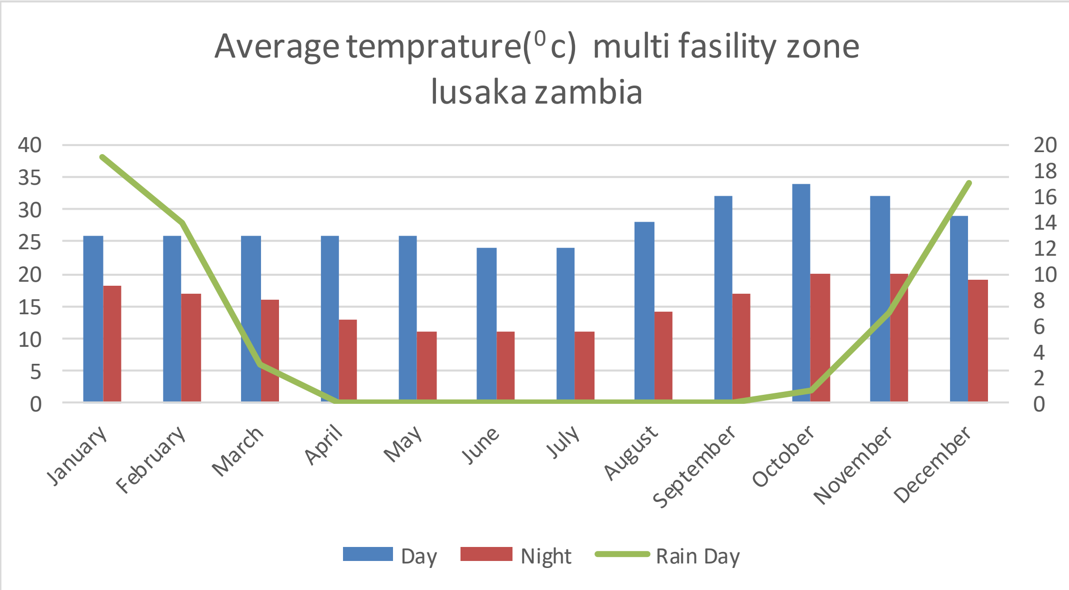


Figure 4.16 average temperature day, night and number of rain days:

4.4 Factor affecting the performance of grid-tide inverter

From the survey, on the selected solar plant site, the following are the main factor which affects the performance of PV grid-tide inverter.

4.4.1 Weather Condition

The weather change has an effect on the solar plant performance; it was observed that temperature is one of the basic issues. Operating temperature affect the inverter performance directly. From the interviews conducted in both Ethiopia on the selected mini grid site and Zambia on Ngonye and Bangweulu, whether affected the solar plant.

Addis Ababa is 2930.5 kilometers (1820.9 miles) away and 1.0 hours ahead of Lusaka, Zambia. Addis Ababa's climate is classified as temperate highland tropical climate with dry winters while Lusaka has a Humid subtropical, dry winter climate. [64].

Addis Ababa generally has cooler weather than Lusaka. The average mean temperature in Addis Ababa is 17.24°C (63.03°F) while Lusaka’s temperature is 22.87°C (73.17°F) and the difference is 5.63°C (42.13°F). Addis Ababa is warmest on average in April, when the day time temperature may reach 18.89°C (66.0°F), while Lusaka is hottest in October when the average high temperature is 28.17°C (82.71°F). Addis Ababa is coldest in December when the average low temperature is 7.56°C (45.61°F), while July is the coolest month in Lusaka, the night time temperature often falls below 10.51°C (50.92°F).

Finally, Addis Ababa has about 1.32 times more rainfall than Lusaka, (Addis Ababa's 79.54mm vs Lusaka's average of 60.34mm).

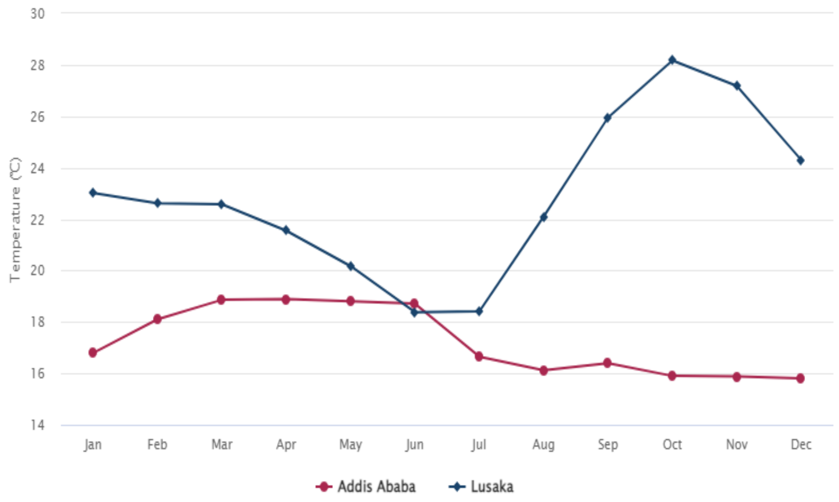


Figure 4.17 Comparison of the Average Annual Temperature: Addis Ababa, Ethiopia and Lusaka, Zambia. [65]

4.4.2 Ambient Temperature Rises

As the inverter works to convert DC power to AC power, it generates heat. This heat is added to the ambient temperature of the inverter enclosure, and the inverter dissipates the heat through fans and / or heat sinks. The heat needs to stay below a certain level at which the materials in the inverter will start to degrade. In order to keep the heat low, the inverter will stop generating power or reduce the amount of power it generates by "derating" as it passes programmed temperature milestones. Most inverters will derate at around 45 – 50 Degrees Celsius.

As the ambient temperature increases, the switching transistors are the elements which mostly suffer from the increase in the ambient temperature. As the ambient temperatures increases the rate of heat flow from the transistor to the ambient decreases.

4.4.3 Inverter Operating Mode and Fault Detection

The inverter can be set to, the appropriate model according to the standard of different country or region before it is leaving the factory. For example, the inverters shipped to

Australia are configured as Australian model in the factory. Note: The inverter is configured for Australia at the factory

Inverter intelligent control system will continuously monitor and adjust system status. When there is a fault detected, LED will show the fault message. All inverter have an operational manual based on their model number.

The following is modes of inverter operation. The information is taken from the inverter operating manual. Every inverter has their own application software. The operator can be able to see how the inverters are performing.

- Working modes

  At this mode, inverter work normally, and the shows the power delivered by the inverter to the grid. When the DC voltage is more than the rated Vdc from the data sheet, inverter converts the DC power generated by the PV modules into AC power and supplies them to the grid. When the DC voltage is lower than the minimum range Vdc, inverter will enter into "waiting" state and try to connect to the grid, at this status, inverter consume very small power to check the internal system status. Note: only when the PV modules supply enough power (voltage＞ minimum Vdc) then the inverter will start automatically.

- Off modes

  When the sunlight is weak or no light, inverter will stop working automatically. When it is off, inverter will not consume gird power or PV module. At the same time, the LED of inverter will be turned off.

- Fault modes

  Inverter intelligent control system will continuously monitor and adjust system status. When there is a fault detected, LED will show the fault message.

The following are some of the faults registered from the selected site in relation the inverter performance.

A. Hardware fail

The most common cause of failure or malfunctioning for inverters is an improper installation, often a combination of not following the user manual recommendation and selecting inappropriate cable type, gauges or in line fuses.

In Ethiopia among the Mimi grids which is in stole and currently operating. Belt of Southern Ethiopia which is one of the mini grid sites the inverter experienced a hard were failed on November 11 2022, and the engineers are investigating the cases. The inverter type is KELONG rating 60 Kw. According the information collected from the site the hard ware fail can be due to excessive water under the inverter due to heavy rain on the area.

B. Over load

The most common reason for a power overload is when the inverter is used to its hilt or instead reaches its peak power output. You may argue here that industrial power inverters can withstand as much as twice its peak power. However, there is always the possibility of your connecting too much equipment to the inverter.

Omorate (also known as Kelem) is a town in southern Ethiopia near the Kenyan border. Located in the Debub Omo Zone of the Southern Nations, Nationalities and Peoples' Region, this village has a latitude and longitude of 4°48′N 35°58′ECoordinates: 4°48′N 35°58′E with an elevation of 395 meters above sea level. It is the administrative center of Kuraz woreda.

In Omorate site have a mini grid solar powered station, the total capacity of the station is 550kw the inverter which is named Grow watt grid tide inverter rating 50Kw got an over loaded fault. Among other type of inverter fault over load is one of the frequent one.

C. PV isolation fault

In photovoltaic systems with a transformer-less inverter, the DC is isolated from ground. Modules with defective module isolation, unshielded wires, defective power optimizers, or an inverter internal fault can cause DC current leakage to ground (PE – protective earth). Such a fault is also called an isolation fault. [65] in Tum site most of the inverter fail due to PV isolation fault as the site engineer explained, they noticed that three inverters have got this problem due to water under the ground. For Kofetu site they experience some kind of fault the site technician are also investigating what makes the total inverter circuit to be burnt. The following photo shows tum site which is one of the 12 minis off grid solar power site.

D. Failure of Electronic component

Equipment, even electronics, has a higher likelihood of failure at the end of its life; electronics also have a significant failure rate at the beginning of service. One of the causes of failure of the equipment in solar plant is Over temperature which affects the solar panels as well as components in the inverter. Based on the data collected from the site, the component which experience significant failure are the IGBTs (insulated get bipolar transistor) have high rate of fail.

The following graph shows the overall inverter challenges analyzed from the data collected from different site mentioned above.

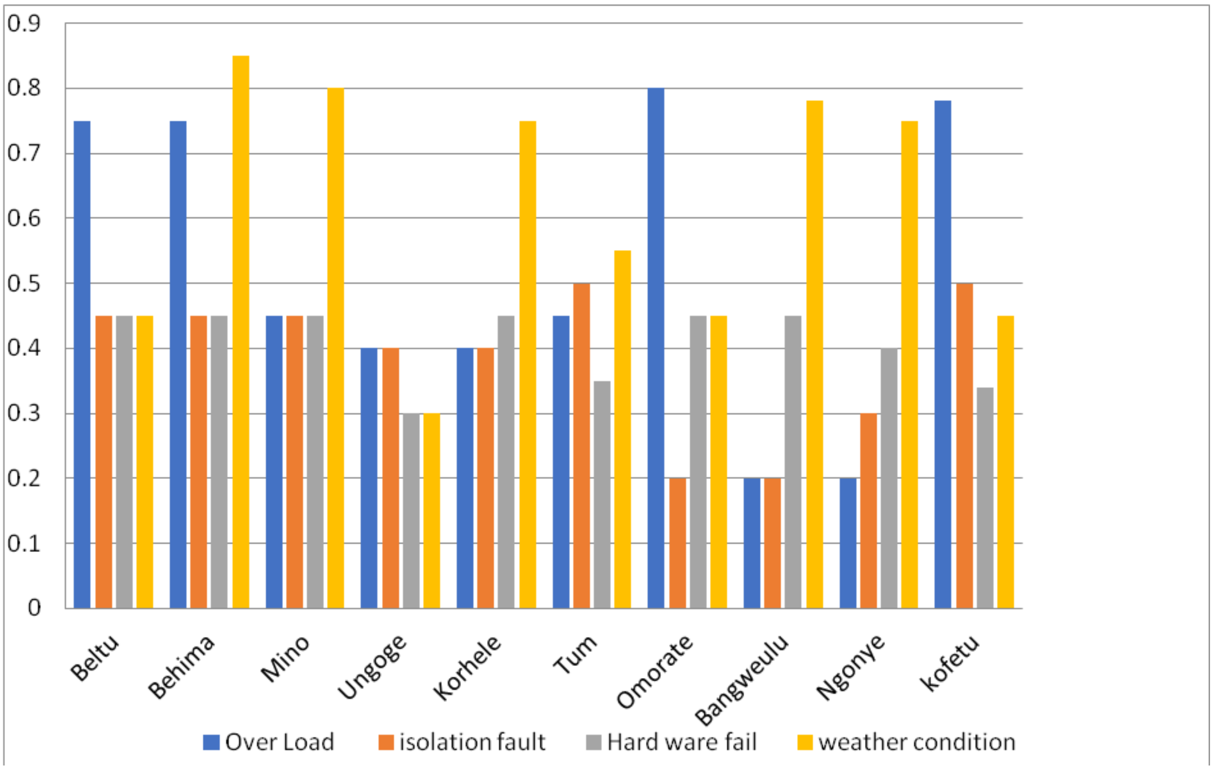


Figure 4.18 Inverter Main Challenges analyzed from the collected data: over load, isolation fault, hard ware fail and weather condition are the main challenges collected.

CHAPTER 5: CONCLUSION, RECOMMENDATION AND LIMITATION

5.1 Conclusion

From the data collected and analyzed the researcher comes up the following conclusions. All the data is collected and the information's are analyzed based on the real time situation of the plant. The researcher had a big challenge to retrieve the real time data from solar plant monitoring system. But Based on the questionnaire and semi- structured interview from the plant operator and Engineers this are the conclusion which is made. following specific objective.

- To identify different type of grid tide inverters commonly used in Zambia and Ethiopia.
- Determine the factor that affects the performances of the identified PV grid-tied inverters.
- Analyse the effect of the factor on the performances of PV grid-tied inverters.

5.1.1 Type of Grid Tied Inverters Used in Zambia and Ethiopia.

Among the type of inverter being used on the selected site NR-inverter are frequently used. The following table shows list of inverters used on different mini-grid and on grid site in Zambia and Ethiopia.

Table 5.1 different type of grid tide inverters used in Zambia and Ethiopia in a selected PV plant site are listed

selected min off- grid site in Ethiopia	**Site location**		**Types of inverters**	**Completion/commission date**
	Latitude	**Longitude**		
Beltu	7.878	40.99	KELONG-grid tie	08.02.2021
Behima	7.48	41.058	KELONG-grid tie	04.03.2021
Mino	9.24412.048	41.526	NR-grid tie	09.08.2020
Ungoge	7.775	33.931	NR-grid tie	03.12.2020
Korhele	7.504	7.504	NR-grid tie	24.10.2020
Tum	6.255	35.522	GroWatt-grid tie	31.03.2020
Omorate	4.801	36.05	GroWatt-grid tie	23.02.2021
Kofetu	1.23456	9.87654	Homer	
Name of on-grid site in Zambia				
Bangweulu solar power plant	15.5239	28.3906	Huawei - SUN 2000-42 KTL (string inverter)	11.03.2019
Ngonye solar photovoltaic	15.5239	28.3906	FIMER – Model: R15015 TL (central inverter)	29.04.2019

5.1.2 Factor Affecting Performances of PV Grid-Tied Inverters.

The real-time performance of the inverter of the off-grid PV mini-grid system installed in a small remote town in Ethiopia and on-grid PV system from Zambia at multi facility zone is analyzed using measured meteorological data.

From on- grid and off-grid inverter performance challenges, which the researcher collected from different plant the main ones are climate or environmental effect and also over load. Figure 4.18 shows overload is one of the frequent challenges in koftu, behama and amorita this can be due to high population growth and unexpected power demand from the community.

5.2.3 Analyse the effect of the factor on the performances of PV grid-tied inverters.

Environmental condition affects almost all solar plant site which is under this study. The studay compere the climate of east which is Addis Ababa Ethiopia and southern of Africa Zambia Lusaka. From figure 4.17 the temperature of Lusaka is higher than Addis Ababa by 5.63°C and even in the plant under this study, temperature rise is one of the challenges on the inverter performance, sensitive electronic component bent due to excessive temperature.

Additionally, Addis Ababa has about 1.32 times more rainfall than Lusaka, (Addis Ababa's 79.54mm vs. Lusaka's average of 60.34mm), thus in Ethiopia, Addis Ababa excessive rain affect the inverter as it can observe from the chart on fig 4.17 for that reason, most of the inverter in Ethiopia on the mini off-grid site are affected by heavy rain condition. Inverter installed under the panel, during excessive rain: water cumulates under the panel affects the inverter performance which can lead to destroying inverters as observed in one of plant in Ethiopia.

5.2 Recommendation

In general, when selecting the inverter should be based on the inverter working environment. From the study it can be understood that in Ethiopia the highest annual temperature is 17.24 °C which is less by 5.63°C from Zambia. Temperature is not the main challenges in Ethiopia, heavy rains are very common. Specially most of the mini grids are found in a very remote area the rain is more excessive than the central city Addis Ababa. Therefore, this research recommends the inverter should install around 3m above the ground including the panels in most cases the inverter is found under the panel. If the inverter is in door, it just needs good ventilation.

In Zambia as it can be observed from chapter- 4 figure 4.17 Lusaka temperature is higher than Addis Ababa also as it can be noted from the study, the temperatures increases causes derating of an inverter, which should be one of the main important things to consider on selecting the inverter. The derating temperature of the inverter is found in the data sheet. The data sheet of the inverter on the selected plant is attached on appendix C.

The other main challenge of the inverter is over load, especially on mini grids solar plant there should be a way of an extension of the capacity of the plant. As the population is growing the demand of the electricity is increasing.

This research can be an input for more investigation and brooder study because of the upcoming solar based project. The International Renewable Energy Agency (IRENA) supports countries across East and Southern Africa in their Endeavor to establish a regional transmission corridor for sustainable electricity, based specifically on renewable sources and technologies. IRENA's Africa Clean Energy Corridor (ACEC) framework envisages a broad, North–South power transmission chain that encompasses 21 continental countries in the East African Power Pool (EAPP) and Southern African Power Pool (SAPP).

5.3 Limitation of the study

The study output is based on a specific selected area. The areas are selected based on availability of the needed information and accessibility of data. The researcher able to get most of the needed data except one company. Due to unavailability of the data. Also, the study is limited to the two specific country Zambia and Ethiopia based on the general geographical location and environmental condition. All the mini grid site in Ethiopia which currently fully functioning is able to accessed, currently there is no fully functioning national grid tide solar plant in Ethiopia and in Zambia among the few national grids tide solar plant the main ones under ZESCO are able to acceded. All the inverter which are working on different solar plant are selected based on the contractor, with in the country or outside of the country.

APPENDICES

Appendix A: Data Collection Questions

Questioner

Date…………………………

Company name ………………………..

Position in the company …………….

Education background ……………………….

1. What kind of inverter are you using? And its capacity? ……………………
   ………………………………………………………………………………………………
   ……
2. What are the basic challenges of your solar plant in related to inverter performance in general, explain briefly? …………
   ……………………………….
3. From the following list of challenges of the inverter which one of the following affects the solar plant expected power output? Please indicate as shown below.

Challenges of the inverter	**frequently**	**Sometimes**	**Not at all**
a. Faulty installation of the inverter			
b. Overheating			
c. Isolation fault			
d. The MPPT models			
e. Climate condition			

Appendix B: Semi-Structured Interview Guide

Solar plant operators

Introduction

Thank you for participating in this interview. We are interviewing you to better understand how the inverter is working on delivering the expected solar power output. So, there are no right or wrong answers to any of our questions, we are interested in your own experiences.

Participation in this study is voluntary and your decision to participate, or not participate, will not affect the care you currently receive from the University of Zambia. The interview should take approximately one hour depending on how much information you would like to share. With your permission, I would like to audio record the interview because I don't want to miss any of your comments. All responses will be kept confidential. This means that your interview responses will only be shared with research team members and we will ensure that any information we include in our report does not identify you as the respondent. You may decline to answer any question or stop the interview at any time and for any reason. Are there any questions about what I have just explained?

Establishing Rapport

Before we begin, it would be nice if you could tell me a little bit about yourself. Tailor question here to specific person and/or situation. For example "how long have you been working in the company?"

1. Information about the solar plant ,faults in solar plant and its courses

    - When did the solar plant start functioning? Have you ever come across any faults? Pleases explain on this matter.

2. Inverter types and capacity

   Can you tell me about the type of inverter the company uses?

    - How much is the capacity in KV and how do you connect it with the solar panel? Is it a string or central connection or any other?

3. Inverters challenges
    - In general, what are the basic challenges of the inverters? Can you explain? How is the inverter interaction in different environments condition?

Appendix C: Data sheet of the inverters: ZAMBIA

Bangweulu solar power plant(BSPP) inverter data sheet.

Smart String Inverter (SUN2000-42KTL)

HUAWEI

Technical Specifications	SUN2000-42KTL
	Efficiency
Max. Efficiency	98.8%
European Efficiency	98.6%
	Input
Max. Input Voltage	1,100 V
Max. Current per MPPT	22 A
Max. Short Circuit Current per MPPT	30 A
Start Voltage	250 V
MPPT Operating Voltage Range	200 V ~ 1,000 V
Rated Input Voltage	720 V
Number of Inputs	8
Number of MPP Trackers	4
	Output
Rated AC Active Power	42,000 W
Max. AC Apparent Power	47,000 VA
Max. AC Active Power (cosϕ=1)	Default 47,000 W; 42,000 W optional in settings
Rated Output Voltage	480 V, 3W + PE
Rated AC Grid Frequency	50 Hz / 60 Hz
Rated Output Current	50.6 A
Max. Output Current	56.6 A
Adjustable Power Factor Range	0.8 LG ... 0.8 LD
Max. Total Harmonic Distortion	< 3%
	Protection
Input-side Disconnection Device	Yes
Anti-islanding Protection	Yes
AC Overcurrent Protection	Yes
DC Reverse-polarity Protection	Yes
PV-array String Fault Monitoring	Yes
DC Surge Arrester	Type II
AC Surge Arrester	Type II
DC Insulation Resistance Detection	Yes
Residual Current Monitoring Unit	Yes
	Communication
Display	LED Indicators, Bluetooth + APP
RS485	Yes
USB	Yes
Power Line Communication (PLC)	Yes
	General
Dimensions (W x H x D)	930 × 550 × 283 mm (36.6 x 21.7 x 11.1 inch)
Weight (with mounting plate)	62 kg (136.7 lb.)
Operating Temperature Range	-25°C ~ 60°C (-13°F ~ 140°F)
Cooling Method	Natural Convection
Max. Operating Altitude	4,000 m (13,123 ft.)
Relative Humidity	0 ~ 100%
DC Connector	Amphenol Helios H4
AC Connector	Waterproof PG Terminal + OT Connector
Protection Degree	IP65
Topology	Transformerless
	Standard Compliance *(more available upon request)*
Certificate	EN 62109-1/-2, IEC 62109-1/-2, IEC 62116, IEC 60068, IEC 61683
Grid Code	IEC 61727, AS/NZS 4777.2, G59/3, PEA, MEA, Resolution No.7

Ngonye solar power plant (NSPP)

FIMER– Model: R15015 TL central inverter data sheet

DC Input - PV Module	R12015 TL	R13515 TL	R15015 TL
Nr Modules	**8**	**9**	**10**
MPPT voltage range(V_{DC})		850 - 1.320 V	
Max no-load PV voltage (V_{OC})		**1.500 V**	
DC-voltage ripple (%)		>2%	
Maximum input current (A_{DC})		1.600 A	
DC control mode		Rapid and efficient MPPT control	
Number of MPPT		1	
Reverse polarity protection		•	
DC input connection		DC Switch under load	
Overvoltage protection		SPD device Class I+II	
Reverse Polarity Protection		•	

AC Output grid			
Nominal power (kVA)* (Note1)	1.128 kVA	1.269 kVA	1.410 kVA
Max current (A_{AC})	1.184 A	1.332 A	1.480 A
Max unbalance current		< 2%	
AC output Voltage (V_{AC})		$550V_{RMS}$ ±10%	
Nr Phase		3-phase (L1-L2-L3-PE)	
Frequency (Hz)		50/60 Hz	
Aux. power supply (V_{AC} - I_{AC})		230V ±10% - 16A (L-N)	
Auxiliary control supply		230V ±10% - 10A (L-N)	
Distortion factor (THD)		< 3%	
Galvanic insulation		No (transformerless)	
AC input connection		Magnetothermic AC grid switch	

General Data			
Maximum efficiency		98.90%	
European efficiency		98.62%	
Static MPPT efficiency		> 99.9 %	
Dynamic MPPT efficiency		> 99.8 %	
Night consumption (W)		< 60 W	
Maximum power dissipated in overload condition	34,0 kW - 29250 Kcal/h	38,0 kW - 32675 Kcal/h	42,0 kW - 36113 Kcal/h
Weight (kg)	1.400 kg	1.500 kg	1.600 kg
Protection degree		IP20	
Cooling		Air forced cooling fan speed controlled	
Dimensions (WxDxH mm)		1.996x825x2.235 mm	
Noise level (dBA)		< 70 dBA	
Operating temperature (°C) *(Note3)		-10° C +53° C	
Storage temperature (°C)		-20° C +60° C	
Humidity Not condensing		0 ÷ 95%	
Height above the sea (without derating) *(Note 2)		1.500 m	
Air Flow	4.000 m³/h	4.400 m³/h	4.800 m³/h
Protection class		II	
Colour		RAL 9006	

DATA SHEET OF GRID TID INVERTER ON THE SELECTED MIN GRID SITE ETHIOPIA

Tum and Omorate solar power site 60 KW Grow watt inverter data sheet

Datasheet	MAX 50KTL3 LV	MAX 60KTL3 LV	MAX 70KTL3 LV	MAX 80KTL3 LV
Input Data				
Max.DC power	65000W	78000W	91000W	104000W
Max.DC voltage	1100V	1100V	1100V	1100V
Start Voltage	250V	250V	250V	250V
MPP work voltage range	200V-1000V	200V-1000V	200V-1000V	200V-1000V
Nominal voltage	585V	585V	600V	685V
Max. input current per MPPT	25A	25A	25A	25A
Number of MPP trackers / strings per MPP tracker	6/2	6/2	6/2	6/2
Output (AC)				
Rated AC output power	50000W	60000W	70000W	80000W
Max. AC apparent power	55500VA	66600VA	77700VA	88800VA
Max. output current	80.5A	96.6A	112.7A	128.8A
AC nominal voltage	230V/400V;340-440V	230V/400V;340-440V	230V/400V;340-440V	230V/400V;340-440V
AC grid frequency	50Hz/60Hz,±5Hz	50Hz/60Hz,±5Hz	50Hz/60Hz,±5Hz	50Hz/60Hz,±5Hz
Power factor	0.8leading ...0.8lagging	0.8leading ...0.8lagging	0.8leading ...0.8lagging	0.8leading ...0.8lagging
THDi	<3%	<3%	<3%	<3%
AC grid connection type	3W+N+PE	3W+N+PE	3W+N+PE	3W+N+PE
Efficiency				
Max.efficiency	98.8%	98.8%	99%	98.8%
Euro - eta	98.3%	98.3%	98.4%	98.3%
MPPT efficiency	99.9%	99.9%	99.9%	99.9%
Protection Devices				
DC reverse polarity protection	yes	yes	yes	yes
DC Switch	yes	yes	yes	yes
DC Surge protection	Type II	Type II	Type II	Type II
Ground fault monitoring	yes	yes	yes	yes
Output short circuit protection	yes	yes	yes	yes
AC Surge protection	Type II	Type II	Type II	Type II
String fault monitoring	yes	yes	yes	yes
Anti-PID protection	opt	opt	opt	opt
General Data				
Dimensions (W / H / D) in mm	860/600/300	860/600/300	860/600/300	860/600/300
Weight	82kg	82kg	82kg	82kg
Operating temperature range	-25°C ... +60°C	-25°C ... +60°C	-25°C ... +60°C	-25°C ... +60°C
Noise emission (typical)	≤55dB(A)	≤55dB(A)	≤55dB(A)	≤55dB(A)
Self-Consumption	< 1W*	< 1W*	< 1W*	< 1W*
Topology	Transformerless	Transformerless	Transformerless	Transformerless
Cooling concept	Smart cooling	Smart cooling	Smart cooling	Smart cooling
Environmental Protection Rating	IP65	IP65	IP65	IP65
Altitude	4000m	4000m	4000m	4000m
Relative Humidity	0-100%	0-100%	0-100%	0-100%
Features				
Display	LED/WIFI+APP	LED/WIFI+APP	LED/WIFI+APP	LED/WIFI+APP
Interfaces:USB/R485/GPRS	yes / yes / opt	yes / yes / opt	yes / yes / opt	yes / yes / opt
Warranty:5 years / 10 years	yes / opt	yes / opt	yes / opt	yes / opt
CQC, CE, VDE 0126-1-1, UTE C 15-712, VDE-AR-N4105, EN50438, DRRG, CEI 0-16, BDEW, IEC 62116, IEC61727, IEC 60068, IEC 61683, AS 4777				

Appendix D

Specific conditions will apply to this approval; As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be informed.

Conditions of Approval

- No participant may be involved in any study procedure prior to the study approval or after the expiration date.
- All unanticipated or Serious Adverse Events (SAEs) must be reported to NASREC within 5 days.
- All protocol modifications must be approved by NASREC prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address.
- All protocol deviations must be reported to NASREC within 5 working days.
- All recruitment materials must be approved by NASREC prior to being used.
- Principal investigators are responsible for initiating Continuing Review proceedings. NASREC will only approve a study for a period of 12 months.
- It is the responsibility of the PI to renew his/her ethics approval through a renewal application to NASREC.
- Where the PI desires to extend the study after expiry of the study period, documents for study extension must be received by NASREC at least 30 days before the expiry date. This is for the purpose of facilitating the review process. Documents received within 30 days after expiry will be labelled "late submissions" and will incur a penalty fee of K500.00. No study shall be renewed whose documents are submitted for renewal 30 days after expiry of the certificate.
- Every 6 (six) months a progress report form supplied by The University of Zambia Natural and Applied Sciences Research Ethics Committee as an IRB must be filled in and submitted to us. There is a penalty of K500.00 for failure to submit the report.
- When closing a project, the PI is responsible for notifying, in writing or using the Research Ethics and Management Online (REMO),both NASREC
- and the National Health Research Authority (NHRA) when ethics certification is no longer required for a project.
- In order to close an approved study, a Closing Report must be submitted in writing or through the REMO system. A Closing Report should be filed when data collection has ended and the study team will no longer be using human participants or animals or secondary data or have any direct or indirect contact with the research participants or animals for the study.
- Filing a closing report (rather than just letting your approval lapse) is important as it assists NASREC in efficiently tracking and reporting on projects. Note that some funding agencies and sponsors require a notice of closure from the IRB which had approved the study and can only be generated after the Closing Report has been filed.

- A reprint of this letter shall be done at a fee.
- All protocol modifications must be approved by NASREC by way of an application for an amendment prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address or methodology and methods. Many modifications entail minimal risk adjustments to a protocol and/or consent form and can be made on an Expedited basis (via the IRB Chair). Some examples are: format changes, correcting spelling errors, adding key personnel, minor changes to questionnaires, recruiting and changes, and so forth. Other, more substantive changes, especially those that may alter the risk-benefit ratio, may require Full Board review. In all cases, except where noted above regarding subject safety, any changes to any protocol document or procedure must first be approved by NASREC before they can be implemented.

Should you have any questions regarding anything indicated in this letter, please do not hesitate to get in touch with us at the above indicated address.

On behalf of NASREC, we would like to wish you all the success as you carry out your study.

Yours faithfully,

Dr. E. M. Mwanaumo

CHAIRPERSON
THE UNIVERSITY OF ZAMBIA NATURAL AND APPLIED SCIENCES RESEARCH ETHICS COMMITTEE - IRB

cc: Director, Directorate of Research and Graduate Studies
Assistant Director (Research), Directorate of Research and Graduate Studies
Assistant Registrar (Research), Directorate of Research and Graduate Studies

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