Identifying and Analyzing the Technical challenges of grid tide inverters for PV system: A case study of Ethiopia and Zambia

ABSTRACT

Aims: to identify and analyses the technical challenges of for grid tide inverter for PV system.
Study design: combined quantitative and qualitative approaches, mixed methods were used.
Study Area: The study was based in the southern region (Lusaka Zambia) and eastern region (Addis Ababa Ethiopia) of Sub-Saharan Africa.
Methodology: In Ethiopia 8 site were selected (mini off-grid sight) and in Zambia two site were selected (on-grid sight). Primary data used to get empirical investigation. The study used physical observation and interviews in order to identify the problems in the existing site related to grid tide solar inverter.
Results: 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 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 Zambia there are few national grids connected plant. 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.
Conclusion: From on- grid and off-grid inverter performance challenges, the main ones are climate or environmental effect and also over load.
***Keywords**: inverter beeping, Sub-Saharan, Environment, Renewable Energy Technologies, and GTI (Grid Tide Inverter) MPPT modules (maximum power point tracking)*

1. INTRODUCTION

The electricity demand in the world's developing countries is increasing rapidly, and it is a great challenge to meet this demand [1]. 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 [2]. The work done related to PV grid connected systems published so far [3] 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.

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 [4]- [5]. Several researches have been conducted on the grid-connected photovoltaic systems in the use of photovoltaic energy effectively [6] [7]

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. Solar farm operators should be cognizant of 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 [8]. Doing so will ensure their inverters will continue to deliver power efficiently over an increased lifespan [9] . Especially for developing countries like Ethiopia and Zambia it need to be protected from harsh temperatures for which we can able to have sun shine almost the whole year.

Solar system normally was exposed to outdoor environment, may frequently work at high and low temperature, high humidity, windy, sandy, rainy and salty environments. Inverter must adapt different operation environments, especially the harsh environments. Electricity generated by PV systems need to be converted to an alternating current (AC) in order to satisfy the specification of the utility or the load. For this, the working environmental condition of the inverter is very important.

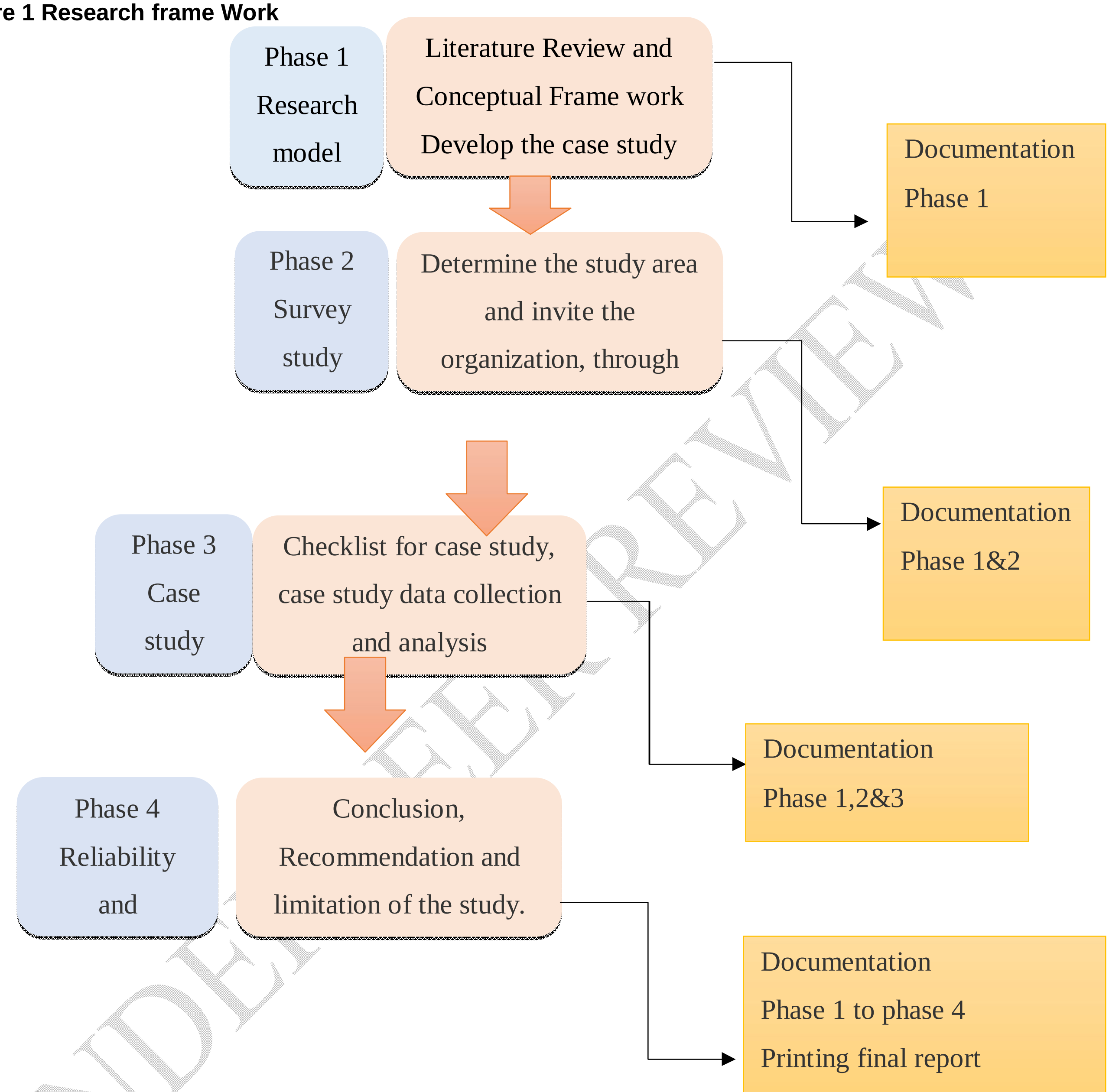
2. METHODOLOGY

2.1 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. 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 we shall have a detailed view on the study area on section 3.2, from the horn of Africa Ethiopia and southern of Africa Zambia. 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 1 Research frame Work



2.2 Study Area

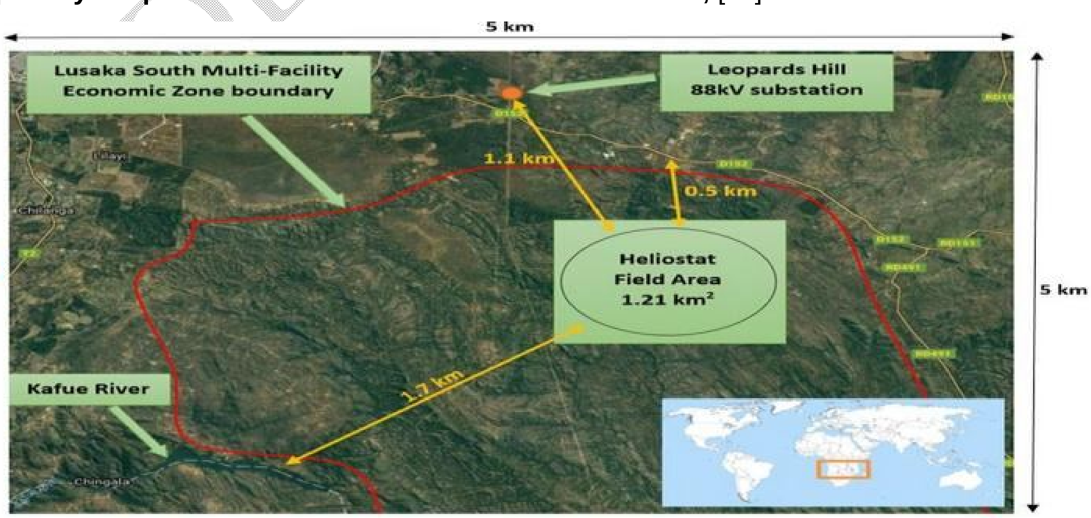
2.2.1 Geographical Location of Zambia

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. [14]

Figure 2. Geographical location of Zambia [15]

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) [16] .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*. [17].

Figure 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, [18]



2.2.2 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. [19]

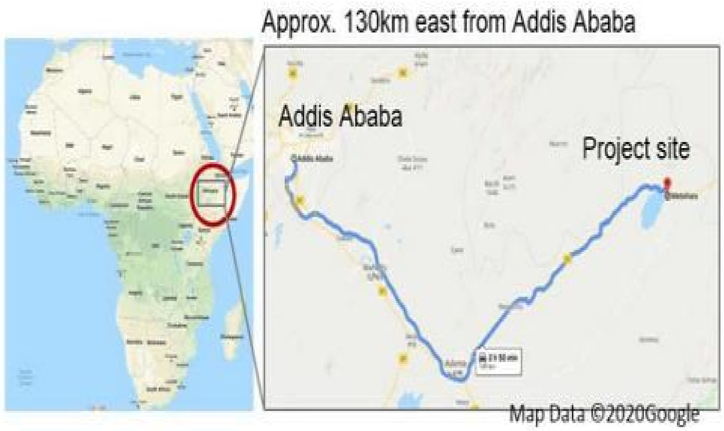
Because Ethiopia is located in the tropical latitudes, its areas of lower elevation experience climatic conditions typical of tropical savanna or desert. However, relief plays a significant role in moderating temperature, so higher elevations experience weather typical of temperate zones. Thus, average 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). [20]

Figure 4. Geographical location Ethiopia [21]

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. [22]

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).

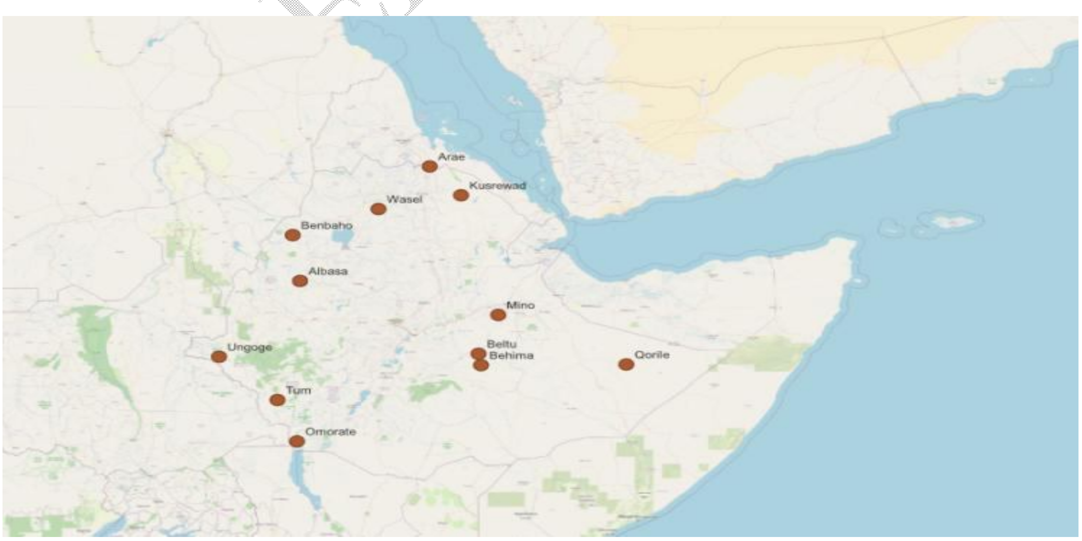
Figure 5. Satellite view of Metehara PV solar power plant. [23]



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: [24]

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. [25]

Figure 6. Mini grid sites in Ethiopia:



2.3 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.

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 esey 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.

2.4 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, Ethiopia 8 mini off-gride site and Zambia 2 on-grid solar plant are included.

Table 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 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 analysed for the selected site

D. The basic inverter challenges are investigated from the collected data and the problem is analysed 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

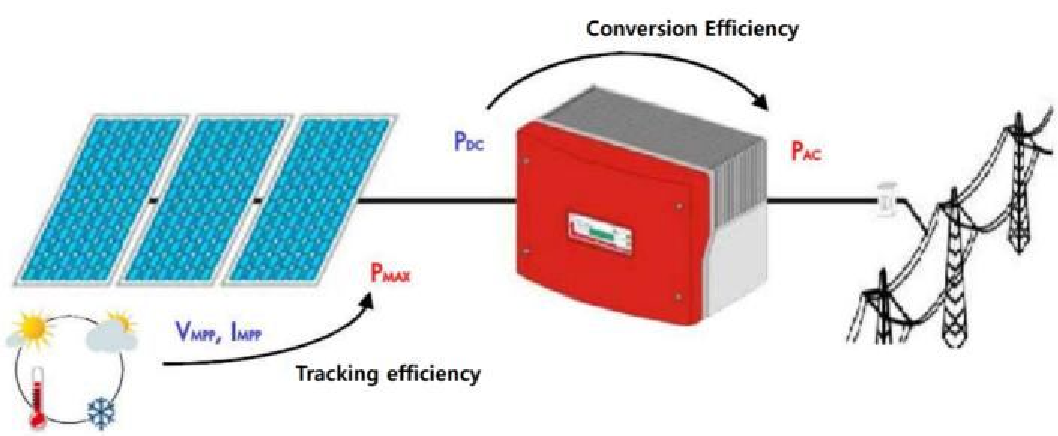
The efficiency of the inverter directly affects the performance of Solar power plant.

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 7. Demonstrate the efficiency of the inverter



2.5 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.

2.6 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 a 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.

3. RESULTS AND DISCUSSION

3.1 The common types of inverters used in grid connected PV system in Ethiopia on the selected site 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 we don't have 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 8. 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).

	Name min grid site	**Types of inverters**	**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

Table 2. List of mini grids sites in Ethiopia which is shown on the above map

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 9. 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 2.

3.1.1 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.

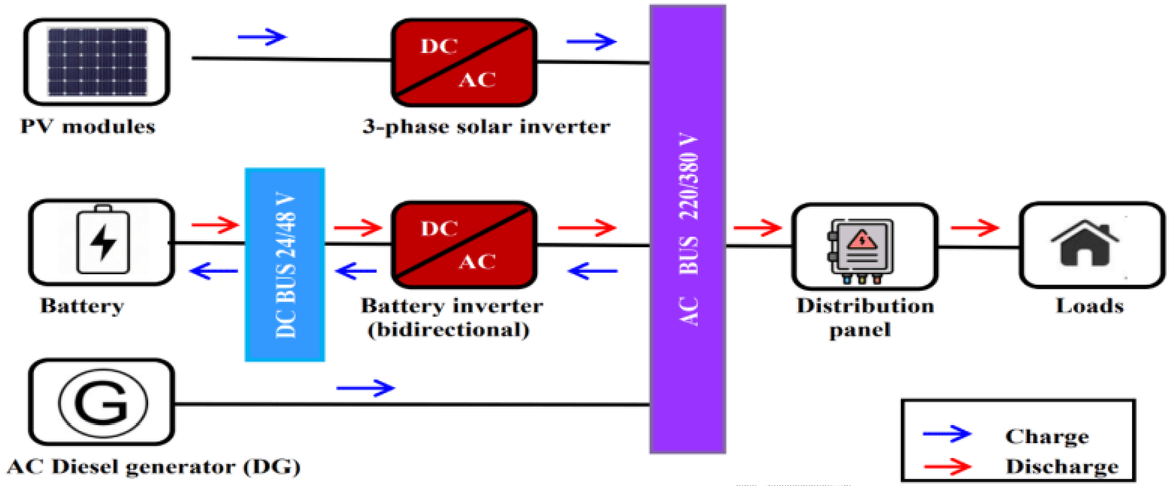
The MG in Omorate has a total installed capacity/rated power of 375 kWp. The PV array consists of 1210 series-connected monocrystalline PV modules from Jinko (Model: JKM310M-60). Each PV module has a rated power of 310 Wp and a rated efficiency of 18.94 %. The modules are assembled into 9 strings in two parallel rows. 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 10. Area of Omorate ,dasanech district southern Ethiopia

Figure 11. 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 12 solar plant schematic diagram for omorate mini off-grid site

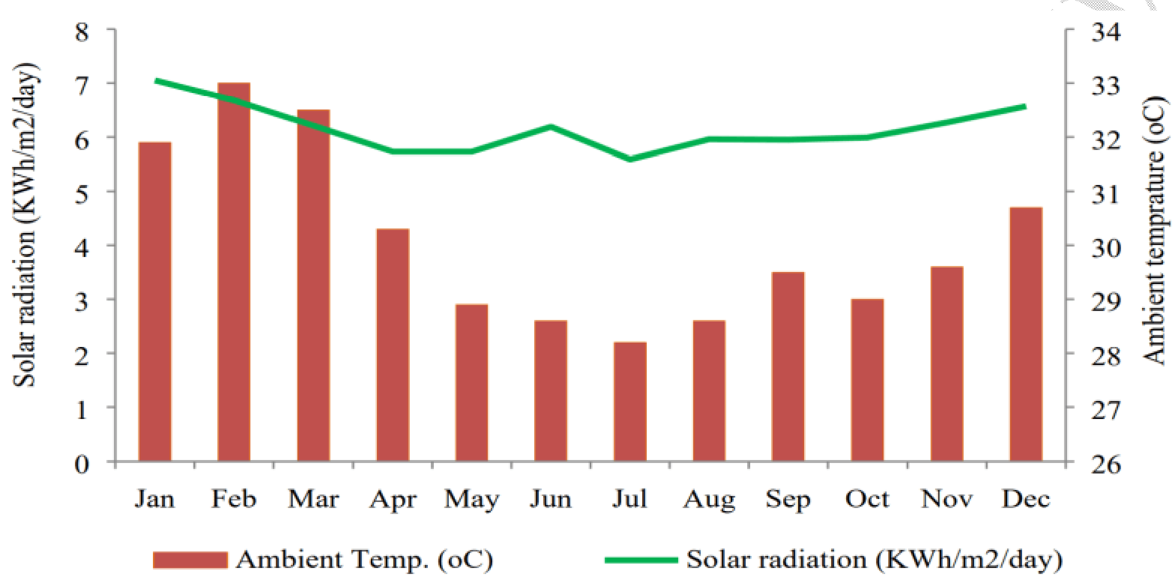


All the modules in each string are fixed on ground-mounted racks and positioned in a direction facing towards south at a tilt angle of 15°. The MG system is alternating current (AC)-coupled and is equipped with five Lithium Iron Phosphate (LiFePO4) battery packs with a total rated storage capacity of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

3.2.2 The environmental condition of the area: 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. 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 13 shows that the distribution of solar irradiation at the MG site has little seasonal variation.

Figure 13. solar radiation and Ambient temperature of Omorate, Dasanech district, Southern Ethiopia



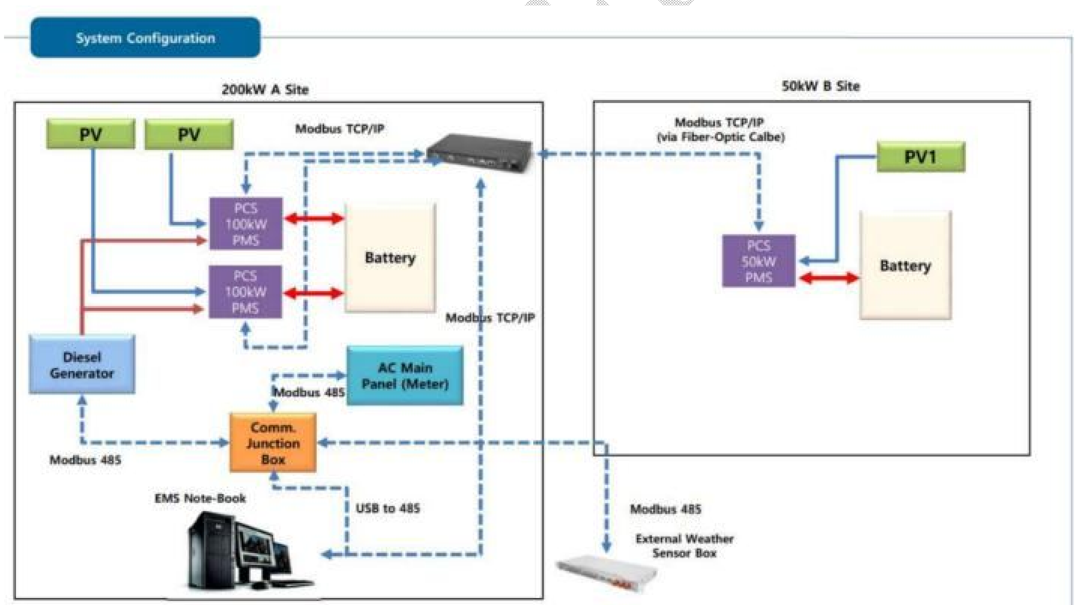
3.2.3 Kofute Model Mini-Grid Site

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 14. 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 15. The schematic diagram of koftu solar power site.

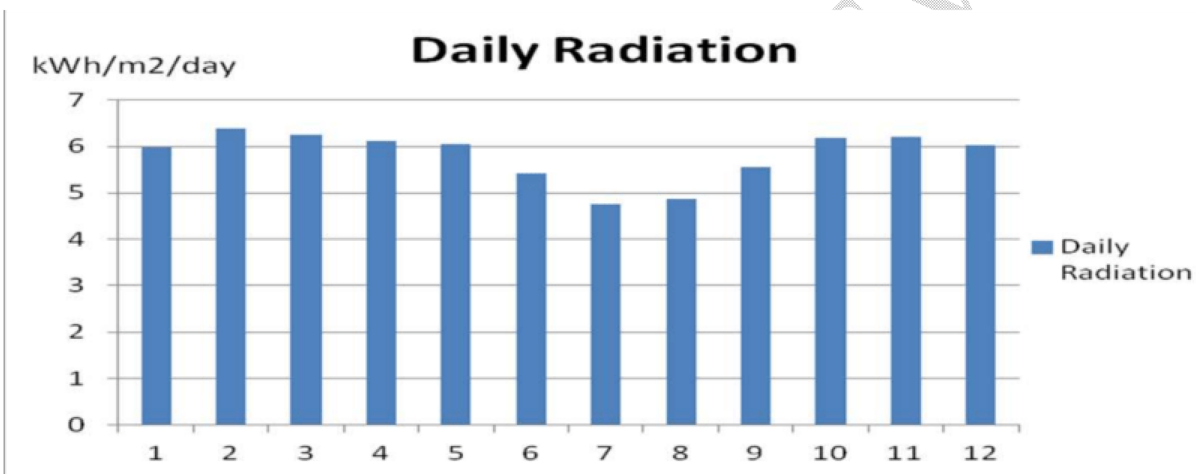


Us we can see from the schematic there are two sites in koftu site “A ’The AC/DC conversion unit PCS (power conversion unit) is 100kw each. Both they are bi lateral and connected to the battery. On the other side site “B” is operating inverter 50kw bi lateral PCS directly connected to the battery and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

3.2.4 The environmental condition of the area: Koftu South West from the Capital City of Addis Ababa.

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

Figure 16. Daily radiation curve KWh/m^2 of Koftu



3.3 The common types of inverters used in grid connected PV system in Zambia on the selected site and the climate condition of the area.

In Zambia there are few national grids connected plant among the few on this study will try to investigate two independent grid connected solar plant in multi facility zone, the 54 megawatts Bangweulu solar power plant by Neon Investment of France and the 34MW Ngonye solar photovoltaic (PV) plant by Enel Green power investments.

3.3.1 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 17. 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 18. Smart String Inverter SUN2000-42KTL circuit diagram and efficiency curve

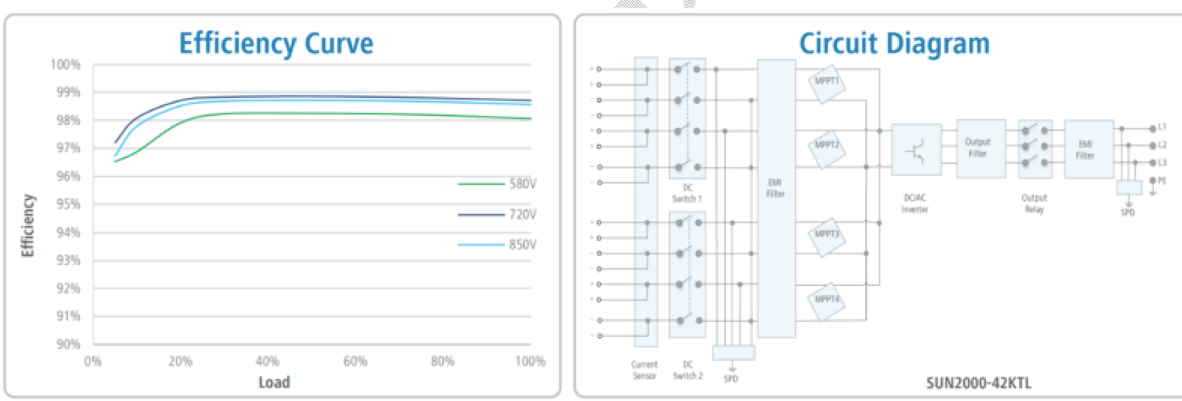


Figure 19. Huawei - 480-volt Inverter from Bangweulu Solar Power Station

3.3.2 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 20. 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 21. Efficiency curve FIMER – Model: R15015 TL central inverter

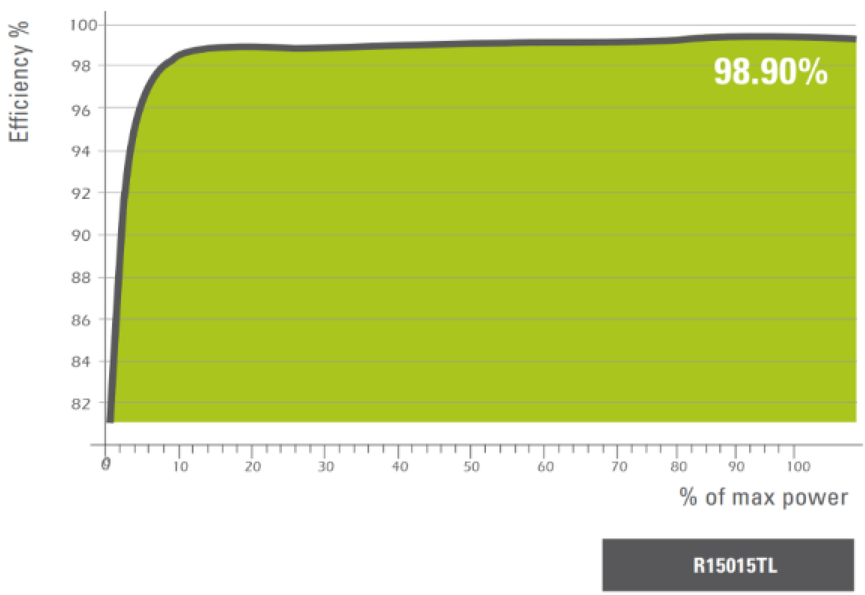
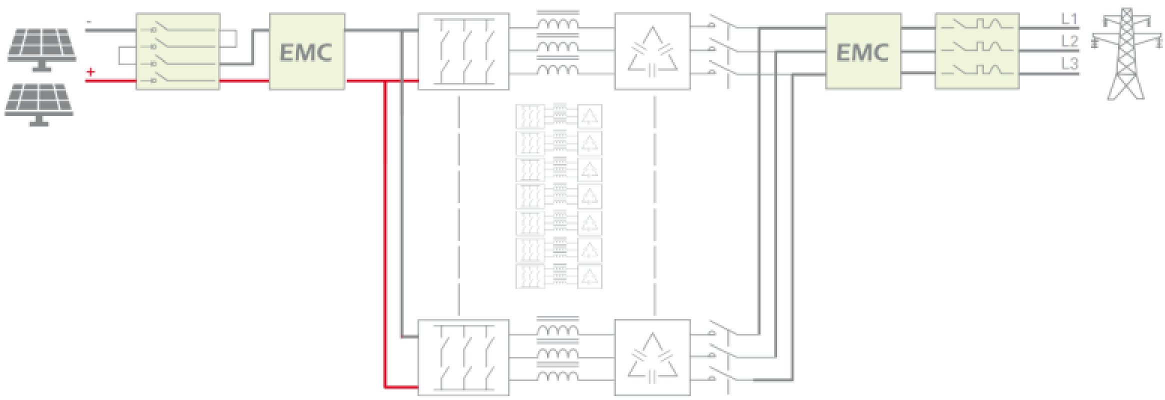


Figure 22. Circuit diagram FIMER – Model: R15015 TL central inverter



3.3.3 Environmental Condition of Ngonye solar power station (NSPS) and Bangweulu solar pant station (BSPS)

Both power plants they are found on the same area at multi facility zone Lusaka Zambia they are experiencing the same environmental condition even though they are managed by different company. with different types of inverters and different set up. From the interview which is conducted and the data which is collected

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; a rainy season from November to April.

The area receives annual rainfall in the region of 500 mm to 1000 mm with the mean annual rainfall being in the order of 800 mm. Moderate temperatures with mean monthly temperatures ranging between about 15^{0}c in the cold season to about 30^{0}c in the hot season are experienced in the area. 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.

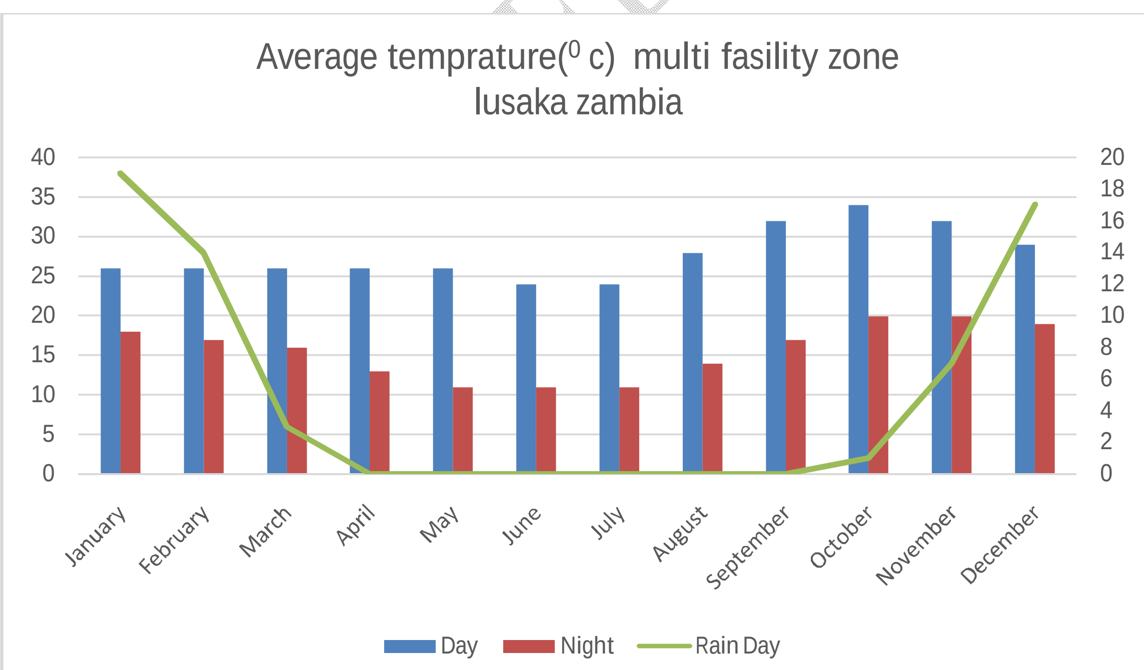
The table below displays max and min temperature and rain data for the whole year as an average taken from last 12+ years of historical data for Kafue. (Multi facility zone Lusaka Zambia)

Table 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 23. Average temperature day, night and number of rain days:



3.4 Technical Performances challenges of grid tide inverter

From the survey collected data in Ethiopia from the selected mini grid site and Zambia from the well-known solar farm at malty facility zone. The following are the main grid tide solar inverters technical performance challenges.

4.4.1 Weather Condition

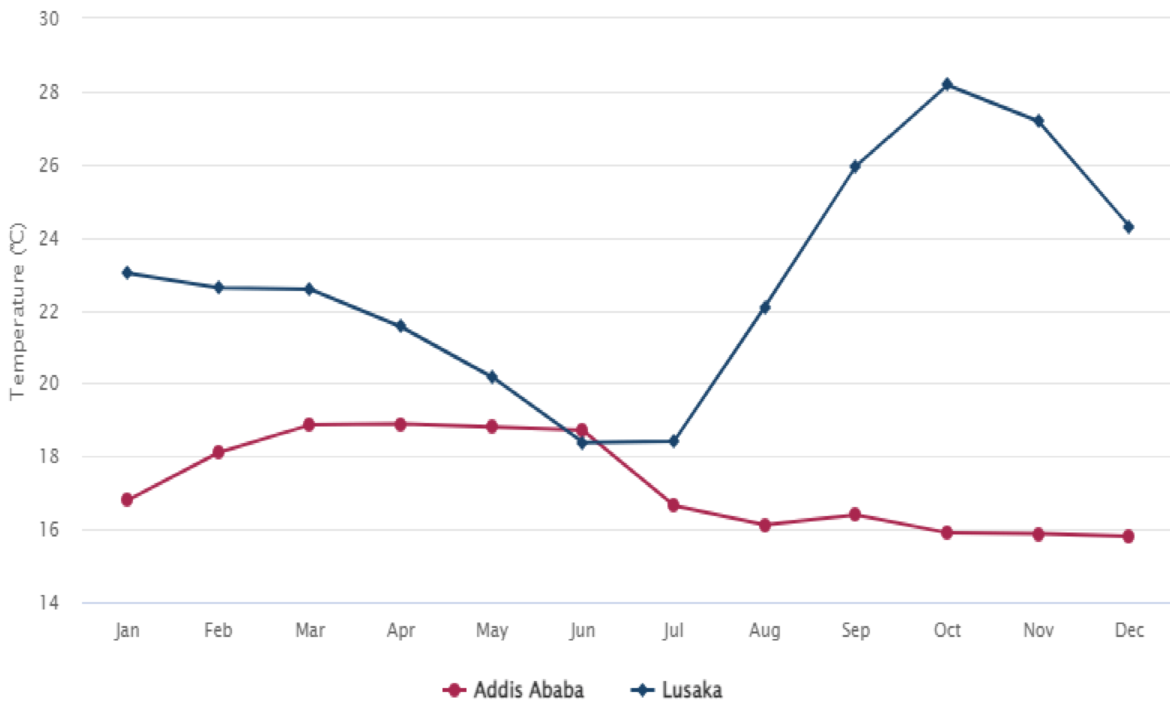
The weather change which we experience every day it affects the solar plant specially temperature is one of the basic issues which Couse inverter component fail. Operating temperature affect the inverter performance directly. From the interview I conducted in both region Ethiopia on the selected mini grid site and Zambia on Ngonye and Bangweulu, whether affect the solar plant in both sides.

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. [26].

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, when 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 24. compere the average annual temperature Addis Ababa the capital city of Ethiopia and Lusaka the capital city of Zambia. [27]



A. The Effect of Temperature Rises on the ambient Temperature of the Inverter

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 increasing the ambient temperature. As the ambient temperatures increases the rate of heat flow from the transistor to the ambient decreases. There is a derating factor of the allowed power dissipated in the device as the environmental temperature increases. This power derating curve is given in the data sheet of the power transistors.

3.4.2 Inverter operating mode and fault detection

The inverter will 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 they have an operational manual base on their model number.

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

- 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. Hard were 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

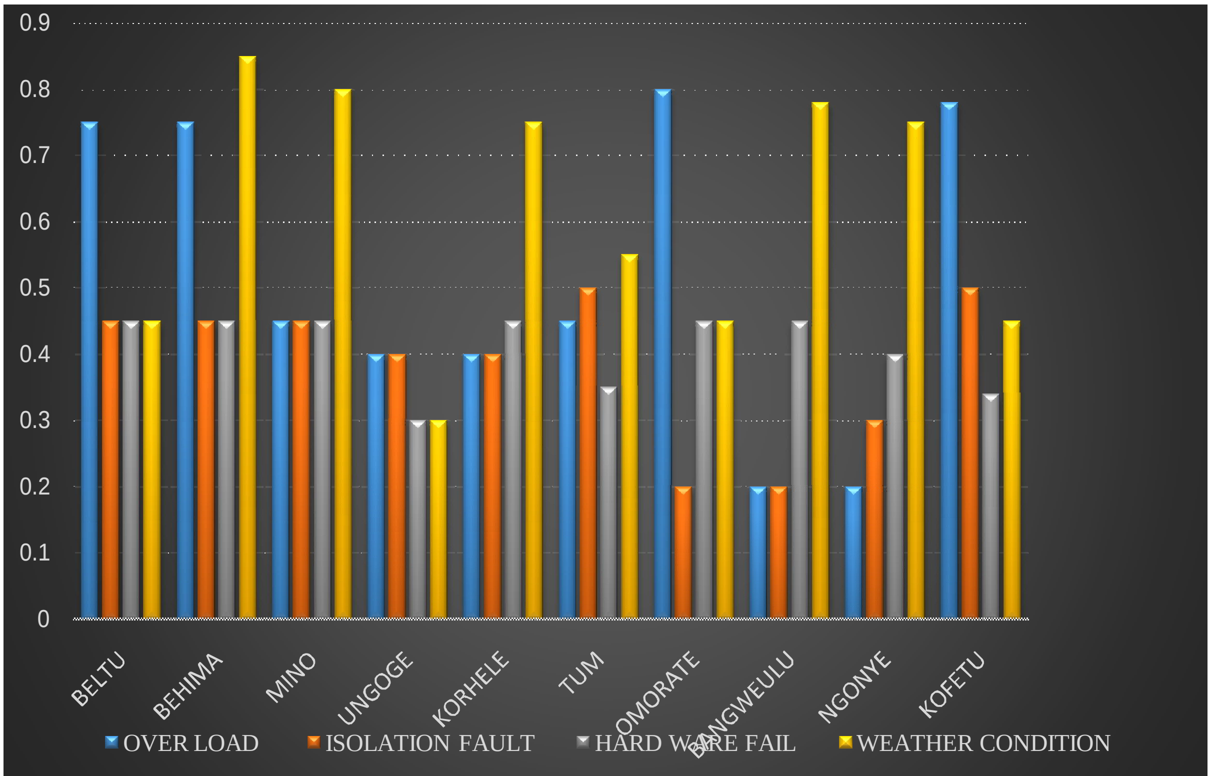
In photovoltaic systems with a transformer-less inverter, the DC is isolated from ground. Modules with defective module isolation, unshielded wires, defective power optimizers, or an inverter internal fault can cause DC current leakage to ground (PE – protective earth). Such a fault is also called an 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 25. Inverter Main Challenges analyzed from the collected data: over load, isolation fault, hard ware fail and weather condition are the main challenges collected.



3.5 Conclusion

From the data collected and analysed the researcher comes up the following conclusions. All the data is collected and the information are analysed 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 sim- structured interview from the plant operator and Engineers this are the conclusion which is made.

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 analysed 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.

Environmental condition affects almost all solar plant site which is under this study. If we compere the climate of east which is Addis Ababa Ethiopia and southern of Africa Zambia Lusaka. 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 are affected by heavy rain condition. Most of the time the inverter is installed under the panel so when there is an excessive rain water cumulates under the panel and affect the inverter performance it can even burn the whole inverter that is what happened in one of plant in Ethiopia.

CONSENT

I, Redate Shawell Endalamaw, do declare that ‘written informed consent was obtained from approved parties for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editorial office of this journal."

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