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Development of Solar PV Systems for Mini-Grid Applications in Tanzania

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ABSTRACT

Access to electricity offers great benefits to development through the provision of reliable and efficient energy sources in the country. Majority of the population living in the remote and rural areas of developing countries mostly sub-Saharan Africa are not supplied with electricity. Although the governments through their electricity companies put their effort to extends the grid distribution networks to remote and rural areas still the coverage were not sufficiently enough due to growing demands for safe and reliable electricity. However, solar as a source of energy remains the least utilized energy source in many countries including Tanzania. Solar Photovoltaic (PV) systems mini-grids have shown their potential in rural electrification projects in many countries mostly sub-Saharan Africa. A solar PV system mini-grid is a PV plant with a localized distribution network to a unit village, or a cluster of villages, providing alternating current (AC). Basically, it consists of solar PV modules of a certain capacity, charger controller, inverters for converting the DC power to AC power, housing for the battery bank and plant control systems. In areas where there is no grid connection or where diesel generation is the main power source, PV plants are able to generate electricity efficiently and relatively cheaply. This paper aims at giving out the overview of solar PV mini-grid applications in Tanzania basically, in terms of technical design and economic analysis of the selected mini-grid system at Juma Island village located in Sengerema District in Mwanza Region. The Juma Island settlements has the electricity demands estimated about 25 kWh per day. At the prevailing tariff conditions in the country, this project can be considered as financially viable with feed-in tariff scheme or other incentives such as grants/capital subsidies when applied. However, the other non-financial benefits like the greenhouse gas emissions savings can, in the long run, help mitigate the adverse effects of the climate change problem plaguing the entire earth.

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INTRODUCTION

Renewable energy is at the Centre of the transition to a less carbon intensive and more sustainable energy system. Since Tanzania is endowed with diverse renewable energy sources such as hydropower, solar, biomass, geothermal as well as wind energy, almost close to the

Congo DRC (Josue & Mushi, 2022). The industry for supplying electricity in Tanzania is currently dominated by the Tanzania Electric Supply Company Limited (TANESCO), which is a vertically integrated state-owned company (Nyanda et al., 2022). TANESCO owns and carries out generation, transmission and distribution of electricity up to the final end users, and sells electricity in bulk to Zanzibar Electric Company (ZECO) through submarine cables to Zanzibar and Pemba Islands. On the generation side there are other incubators which include Independent Power Producers (IPPs), Small Power Producers (SPPs) and Emergency Power Producers (EPPs). (IMF, 2016).

Rural electrification requires considerable resources (Justo & Mushi, 2020; Fungo et al., 2021, Minja & Mushi, 2022). Decentralized power production projects based on renewable energies could enable the exploitation of this market for it to become a key driver of economic growth and prosperity. Tanzania currently has 109 mini-grids located in 21 regions with installed capacity of 157.7 MW includes solar PV systems, hydropower, biomass, and hybrid systems with fossil fuel. The entitled mini-grids they serve around 184,000 customers. Sixteen (16) of the power plants were connected to the national grid while the remaining operates as isolated mini-grid. For the grid tied min-grids, a portion of the power generated is distributed directly to customers connected on the distribution network while other portion of the generated power is sold to the national utility company, the TANESCO.

Recently the number and installed capacity of mini-grids in Tanzania has nearly doubled since 2008, when the government introduced the small power producers (SPP) framework. More than fifty-eight mini-grids were commissioned between 2008 and 2019 and more than 67MW of new capacity was installed, see Figure 1 (Ordano et al., 2017).

Recently in Tanzania there are 58 solar PV systems mini-grids with installed capacity of 10,732.51 kW operated as isolated mini-grids in different areas and owned by SPPs in several regions. These are approved by Energy and Water Utilities Regulatory Authority (EWURA). The operators of the mini-grids in Tanzania are given a license of operation in a period of ten (10) years. Once the license expires, the entitled operator must renew it in order to continue with the business.

Apparently, the tariff for the solar mini-grid projects with the installed capacity of less than 100 kW the operators are free to set their own electricity tariff to connected customers according to their investment and operation cost incurred, but EWURA still has a mandate to register the business. Moreover, for those whose installed capacities are greater than or equal to 100kW up to 1MW, the tariff is fixed developed and approved by Energy and Water Utilities Regulatory Authority (EWURA) through the document known as Standardized Power Purchase Agreement (SPPA) for those solar projects that connected to national grid and isolated mini-grids their tariff is stated differently (Table 1). Furthermore, all SPPs developed a Solar PV and wind power plant with installed capacity above 1 MW up to 10 MW their tariff is determined through Competitive bidding process (URT, 2016).

Thus, the paper gives out the overview of development of solar PV mini-grid applications in Tanzania. The technical design and economic analysis of the selected mini-grid system at Juma Island village located at Sengerema District in Mwanza Region is taken as a case study in this study. Issues like electicity demand, prevailing tariff conditions as well as financial viability with feed-in tariff scheme or other incentives such as grants/capital subsidies when applied are also taken into consideration.

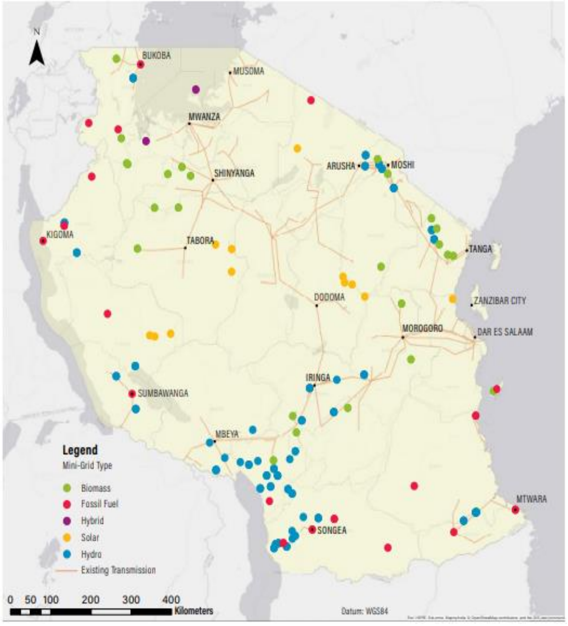

Figure 1: Map showing location of existing mini-grids in tanzania (source. mini-grid deployment in Sub-Saharan Africa lessons from Tanzania)

Table 1: Main grid and isolated mini-grid connected tariff for solar and wind SPPs up to 1 MW (EWURA)

Description	Approved tariff (US$/kWh)
Standardized small power purchase tariff for Solar and Wind projects of up to 1MW connected to the main Grid	0.165
Standardized small power purchase tariff for Solar and Wind projects of up to 1MW connected to the Isolated mini-grid	0.181

CURRENT STATE OF THE ART

Availability of solar radiation is the main factor for considering a solar PV system. Solar radiation data can be expressed as solar irradiation or solar insolation. Solar irradiation is the amount of solar radiation that is actually striking on a specific surface such as a solar PV module measured in Watt per square meter (W/m^2) (DGS, 2013). Solar insolation is the amount of solar radiation striking a surface at a specified period of time measured in kilowatt-hours per square meter per day ($kWh/m^2/day$). The surface that is perpendicular to the direction of the sun receives a maximum solar irradiance, compared to other surfaces facing the sun at other angles. Often, the month with lowest solar insolation is considered as a reference month for the design (Alakori, 2014).

Solar PV systems for mini-grid application have been installed in both small-scale and large-scale projects, such as hospitals or whole communities. For that purpose, hybrid solution includes Solar PV array and Storage battery are combined and fed into a local mini-grid, which can provide energy to a whole community. The mini-grids will be considered in this paper, since prior relevant efforts have been employed to address mini-grids operators and their users. When the dispersion within the community is modest, mini-grids are employed. These require a mix of diverse components, including solar PV array, charge controller, DC/AC invertor, and batteries for energy storage. Barriers that constrain the deployment of mini-grid Solar PV systems for rural electrification have been described in numerous studies (Feron, 2016).

The power supply options are autonomous PV systems, hybrid systems (e.g., diesel with wind, diesel with PV), or diesel generators. Therefore, it is crucial to make financial analyses for different power options, not only by considering capital cost of the system, but also the lifecycle cost (e.g. operation, maintenance and spare parts cost). Availability of fuel and transportation cost should also be considered. Autonomous PV systems with no diesel back-up are economically viable and recommended when energy requirements are determined by the energy storage batteries for the night use and there is a good constant sunshine. This frequently covers the energy consumption of the whole community entitled. When the energy requirements exceed the energy storage batteries for the night use and areas with defuse irradiance, hybrid systems are likely to be the economical option (Minja & Mushi, 2022).

In remote off-grid areas, the economic power solution is a hybrid diesel-PV system that deploys the available resource effectively at the appropriate time. This option shows significant improvement in saving fuel compared with only diesel generator (USAID, 2020). This power option is mainly adequate for medium and large health facilities where the daily load consumption is high. Nevertheless, the feasibility of integrated hybrid systems (e.g., PV with diesel generators) has to be investigated case by case. It should be considered that hybrid systems require skilled staff for systems operation and maintenance.

METHODOLOGY

To achieve the intended goal of this study, the various approaches and methods were employed during conducting this research. The aim of this research is to provide an overview on how to develop a solar PV mini-grid system for the purpose of supplying electricity to remote areas by considering its benefits from technological and economic point of view. Moreover, to capture all important parameters so as to address the study objectives. The following methods were employed in this research.

Energy demand assessment

It is an excel tool called energy demand survey which used to assess the energy requirement for the specified village for each household by capturing data of all appliances which use electricity energy owned by each household in the village. The data which helps to estimate total energy demands in the village and associated loads profile for project sizing (Marcel et al., 2021; Saulo & Omondi, 2015).

Solar resources assessment

The solar resources assessment tool known as RET Screen Expert software which used to identify the availability of the solar energy in the specified village and the amount of solar energy available. The global, direct and diffuse solar irradiance data were retrieved from RET Screen Expert software linked with National Aeronautics and Space Administration (NASA) satellite retrieved weather data from associated measuring stations. The data from RETScreen Expert software were analyzed by using model developed from MATLAB/Simulink software that provide optimum solar irradiance in the inclined plane for solar PV panel to be tilted to capture the maximum available solar energy to specified village with reference to Global Solar Atlas web (Khamisani, 2018; Marcel et al., 2021).

Solar PV system sizing

For sizing of the solar PV system, the mainly focus points on capacity of Solar PV module, Energy Storage Battery and Charger Controller. The model reveled from MATLAB/Simulink software to analyze the solar radiation data from variations weather conditions and power out from the panel. The solar PV system and the distribution network the result is solar PV systems for mini-grid application (Mbinkar, 2021).

Economic analysis

The economic analysis of an energy production system provides two types of information: the updated costs of the system and the annual costs it generates (Ghafoor & Munir, 2015). In this paper calculations, the choice of the economic lifetime is linked to the fact that, the estimated lifetime of the PV modules is about 20 years. The main concern of the population of the village is to have an electricity system that provides them with a minimum level of comfort at the lowest possible cost.

LITERATURE REVIEW

The literature review provides the theoretical background information to the intended mini-grid study by introducing the basic concepts in that research field. The science of the research field remains constant but the technology keeps changing. This section will discuss matter pertaining the contribution of the renewable energy sources in development of solar mini-grid systems in different countries around the world, how the electric power generated from solar PV modules and energy storage components for the different purpose of eradicating the energy shortage challenges in the world. The major benefits acquired and challenges faced during operation of solar mini-grid systems.

RESULTS AND FINDINGS

This section discusses the results and findings from the data analysed by empleted methods to attain the intended objective. The following are results and findings obtained during data analysis:

Assessment of the demands

Juma Island is a village located in Lake Victoria about 26 km from Sengerema District head quarter in Mwanza Region (Figure 2). The village is isolated from the main grid network. A study to examine the actual energy requirement for each household and systematically seek to reduce power consumption (watts) and the maximum coincident load is required.

Figure 2: Location of Juma Island village in Sengerema district.

The benchmark is in fact the rate of consumption or power per hour (Wh). In comparison with the capacity of the batteries in ampere-hours (Ah), the rate of consumption is converted into the same unit. This reduces the risk of oversizing the installation. The energy demand of the locality has a direct correlation with some parameters such as the size of the photovoltaic modules required to charge the batteries, the capacity of the storage batteries required to meet the needs of the consumers without having to use a generator at night or on dark days and the conductor used in the distribution system. Improper dimensioning of the system makes it more difficult to cover the capital investment and recurring costs of the system and therefore to ensure system sustainability as seen in Table 2.

The Juma Island village is the Island found in Lake Victoria in Sengerema district at Mwanza region and has 180 households estimated as potential customers. The total energy consumed by all appliances in the Juma Island settlements demand is estimated at about 25 kWh per day (Table 2 and Figure 3).

Table 2: Domestically load data for Juma Island village in Sengerema district

Appliance	Qty	Volt (V)	Power rate(W)	Hour /day	Power (kW)	Energy kWh/day	Users
Lamps(in)	4	220	13	5	0.052	9.36	180
Lamps(out)	4	220	18	12	0.072	12.96	180
Radio	1	220	15	6	0.015	0.30	20
Television	1	220	50	7	0.05	0.5	10
Refrigerator	1	220	200	8	0.20	1.0	5
Fan	2	220	75	5	0.15	0.75	5
Total load					**0.539**	**24.87**	

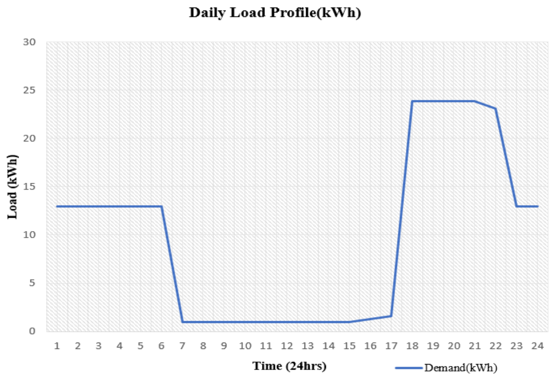

Figure 3: Load profile for Juma Island village in Sengerema district.

Solar Resource Assessment

Availability of solar radiation is the main factor for considering a solar PV system. Solar radiation data can be expressed as solar irradiation or solar insolation. Solar irradiation is the amount of solar radiation that is actually striking on a specific surface such as a solar PV module measured in Watt per square meter (W/m^2). Solar insolation is the amount of solar radiation striking a surface at a specified period of time measured in kilowatt-hours per square meter per day (kWh/m^2/day). The surface that is perpendicular to the direction of the sun receives a maximum solar irradiance, compared to other surfaces facing the sun at other angles (Figure 4). Often, the month with lowest solar insolation is considered as a reference month for the design.

The location of the project is quite important since this paper is concentrated on solar PV mini-grid power system. The consideration was made to maximise PV energy production. The Juma Island village in Sengerema district at Mwanza region is chosen as the main area which is in located at coordinates of 2°50' south and 32° 90' east. Due to its tropical climate, Sengerema provides abundant sources of solar energy. Table 2 is the daily solar irradiance available and the clearness index for Sengerema. The global solar irradiance data were retrieved from RETScreen Expert software linked with NASA.

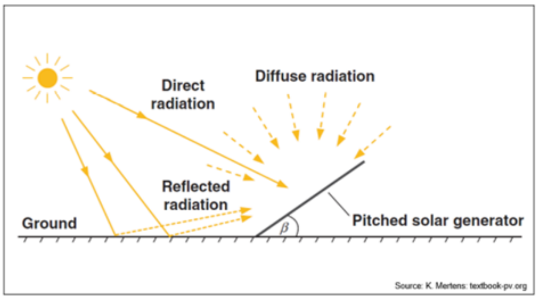

Figure 4: Solar irradiation types.

The irradiance was calculated to be approximately 6.59kWh/m^2/day for this location and the worst month is March with average irradiance of about 5.69 kWh/m^2/day (Figure 5 and Figure 6). The angle of tilt for the PV modules is determined by the latitude (2.50˚ + 15°), which gives 17.50˚ approximately to 18° for standard. The global solar irradiation at inclined plane with the angle of inclination (tilt angle β) which is 18° calculated from the following formulas:

$$Ht(\beta,\alpha)=Hb(\beta,\alpha)+H_d(\beta,\alpha)+H_r(\beta,\alpha) \qquad (1)$$

where H_b, H_d, and H_r are deam, diffuse and reflected radiation measured at inclined plane (W/m²) and H_t is the total solar irradiance at inclined plane (W/m²).

Then,

Beam Solar Radiation

$$H_b(\beta,\alpha) = Hb.0 * \cos(\theta) \quad (2)$$

where by:

$H_b,0$ is the beam (direct) solar radiation measured at horizontal plane (W/m²), and θ is solar zenith angle which is the angle between the inclination and the verticle.

Diffuse Solar Radiation

$$H_d(\beta,\alpha) = Hd,0 * ½(1 + \cos(\beta)) \quad (3)$$

whereby:

Hd,0 is the diffuse solar radiation measured at horizontal plane (W/m²0) and β is the inclination (tilt) angle.

Reflected Solar Radiation

$$H_r(\beta,\alpha) = H_t,0 * \alpha_2 * ½(1 + \cos(\beta)) \quad (4)$$

whereby:

α_2 is a ground reflectivity (*albedo*) and $H_t,0$ is the global solar radiation at horizotal plane (*W/m²*), H_t stands for irradiation on horizontal plane (kWh/m^2 /day), and $H_t(\beta)$: Irradiation on inclined plane at angle 18°

Table 3: Daily solar irradiation measured in (kWh/m²/day)

Month	Ht	Ht (18°)	Air Temp (°C)
Jan	5.51	6.59	22.6
Feb	5.49	6.56	22.7
Mar	5.69	6.80	23.1
Apr	5.52	6.60	23.0
May	5.31	6.35	22.7
Jun	5.56	6.64	22.1
Jul	5.49	6.56	21.7
Aug	5.66	6.76	22.3
Sep	5.65	6.75	22.8
Oct	5.68	6.79	23.4
Nov	5.37	6.42	22.8
Dec	5.19	6.20	22.5
Average	**5.51**	**6.59**	**22.6**

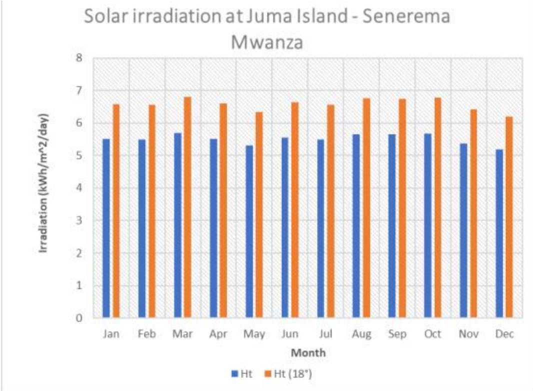

Figure 5: Solar irradiation in global horizontal and inclined for Juma Island in Sengerema

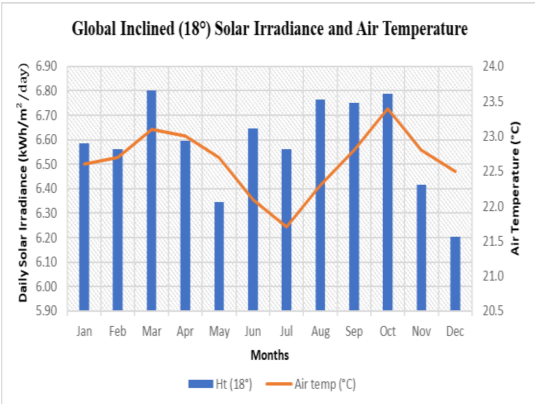

Figure 6: Global inclined solar irradiance and air temperature

Solar PV System Sizing

After determining the amount of load required by the community, it is necessary to adequately size the other components of the PV system, notably the number of PV modules to be operating in parallel and in series, the size of the storage battery bank and the distribution network (mini-grid) for the expected loads. This step is critical to the success of the project because it has a significant impact on the project cost. Unnecessarily oversizing a PV system increases the cost that the community must cover, and can lead to wastage of resources. Under-sizing it will lead to consumer frustration and dissatisfaction with service quality, a dissatisfaction that can easily lead to the loss of consumers and consequent inability of the remain consumers to cover the investment and operation costs.

The main components of the PV system, presented in Figure 7, include the PV array, the charge controller, Battery Storage bank, the DC-AC inverter and the Distribution network (mini-grid). The switchgear consists of circuit breakers, fuses and switches (circuit protection devices) that function to protect, control and isolate the other components from possible damage. These components need to be properly sized for the system to work reliably and efficiently.

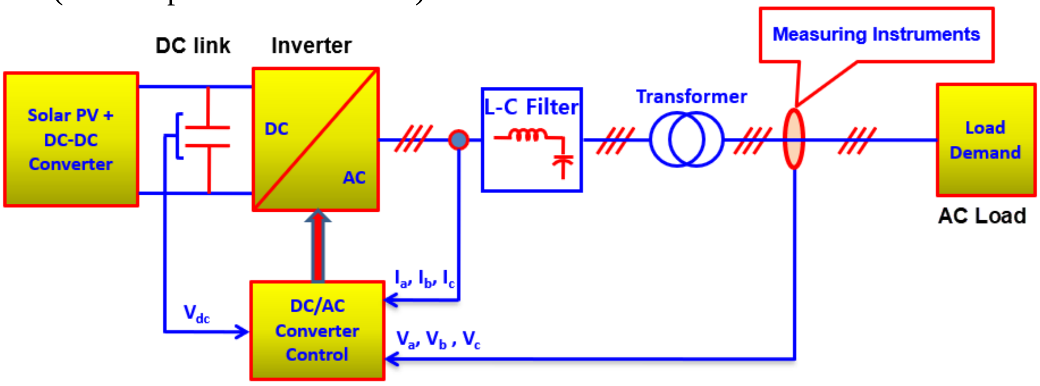

Figure 7: Solar PV System Mini-Grid

Solar PV Panel Sizing

Once the total load to be energized using the PV system is calculated we must find out what area of solar panels would be required to generate that much amount of power. It is an inherent property of any panel to have internal losses. This factor should be kept in mind. As in the energy calculation we have already found the total watt-hours, for finding the wattage of panels that would be required we need to divide the total watt-hours with peak sun hours.

Table 4: Module Electrical parameters at Standard Test Conditions (STC)

Module Type	Symbols	SI Unit	Test value
Power output	Pmax	Wp	540.0
Module efficiency	ηmax	%	20.94
Voltage at Pmax	Vmpp	V	40.70
Current at Pmax	Impp	A	13.27
Open-circuit voltage	Voc	V	49.42
Short circuit current	Isc	A	13.85

The evaluation of how the change of light intensity affects the output power of the module was done by using MATLAB software (Figure 8 and Figure 9).

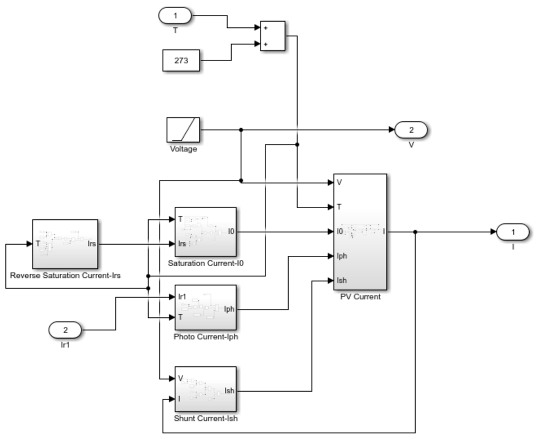

Figure 8: Modelling of Solar PV module

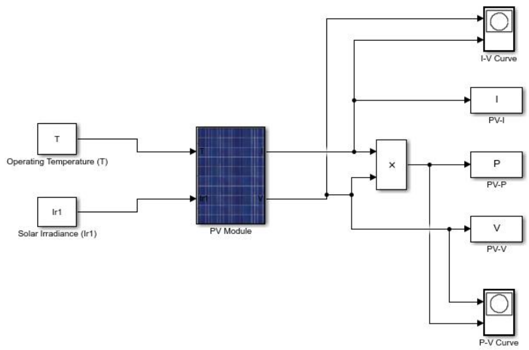

Figure 9: Solar PV Module Current, Voltage and Power output

The results of the simulations are presented by Figures 10 – 13. These are current-voltage (Figure 10) for variable solar irradiance;

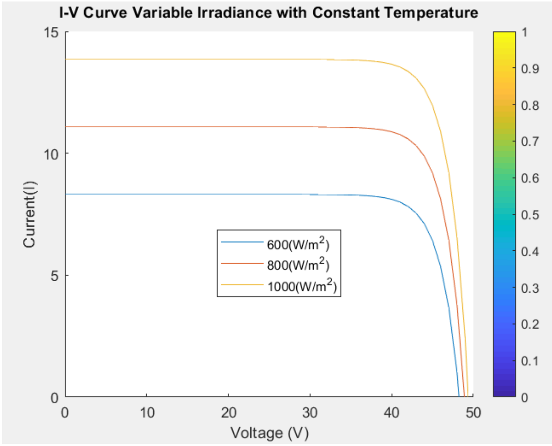

Figure 10: I-V curve for variable solar irradiance

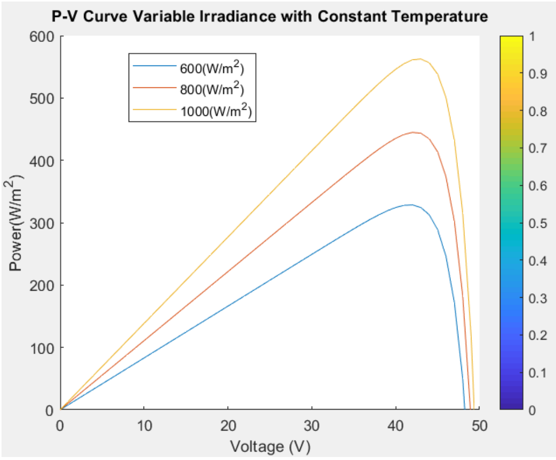

Figure 11: P-V curve for variable solar irradiance

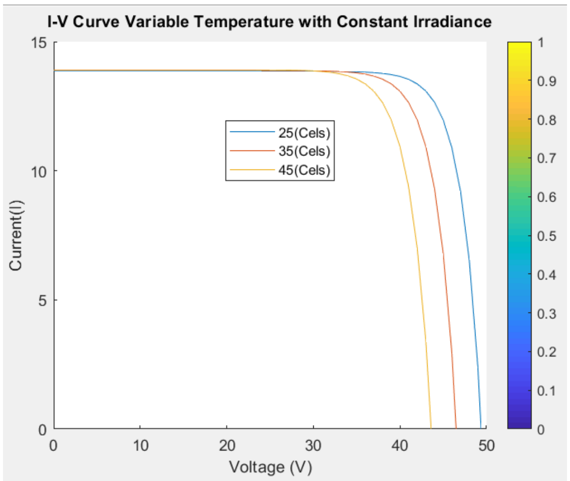

Figure 12: I-V curve for variable module temperature

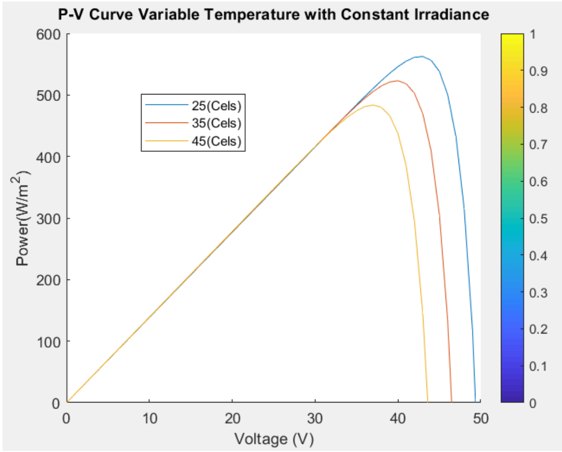

Figure 13: P-V curve for variable module temperature

It is essential to consider the nominal voltage of the system against the nominal voltage of the panels. The panels have to be connected in series /parallel combinations to give the nominal system voltage. The system voltage under normal condition works at 220 V as previously decided, and the panels are 40.70V each, groups of seven panels in series must be connected in parallel.

Any renewable energy source of electricity must be oversized to ensure that the battery can be recharged from maximum depth of discharge in an acceptable period while still meeting the daily load requirements. The worst month is determined by considering the month during which the ratio of PV array output to load energy consumption is the smallest.

From Table 3, the average daily solar irradiance is 6.59 kWh/m^2/day for the site under consideration and the worst month is December with an average irradiance of 6.20 kWh/m2 /day. When designing a PV system that will meet a specified amount of energy, the PV array must produce at least that amount of energy required to supply the peak load, while allowing for charging of the battery as well as derating of the PV modules. The maximum irradiation depends on the tilt angle and orientation of the PV array. The tilt angle for maximum irradiation coincides with the latitude of the geographical location.

In this case the latitude is 2.50 and the modules should be orientated to face the equator. The PV array is derated due to certain factors such as manufacturer's tolerance, dirt or dust cover and temperature effects. The operating temperature depends on many factors related to the module manufacturing process, the semiconductor used, the location of the module and the assembly of the module at that location. Module output power decreases with temperature above the ambient temperature of 25˚C and increases with temperatures below 25˚C. system.

$$N_{PVm} = \frac{DL}{\eta_{max} \times G_{d-avg}} \quad (5)$$

$$N_{PVm} = \frac{PV_{peak}}{P_{max\,gen}} \quad (6)$$

To be more precise, besides the performance of the solar panels, a little margin for temperature effects can be considered (l, typically 5%). Combining these formulas and considering the efficiencies of the different sub-systems with the derating factors we obtain an overall efficiency of 0.76 for the PV array system.

The PV system sizing is done by estimating PV module size and capacity of the battery required for the system. The total load of the day is 25 kWh/day, and electrical losses is 20% then (25 + 25 (0.76×0.2)) = 28.8 kWh/day. Thus, grand total load is 28.8kWh/day.

The panels have to be connected in series/parallel arrangement to give the nominal system voltage maximization. For this case with a system voltage of 220 V and PV module rated voltage of 40V;

Number of PV Module Connected in Series

$$N_{ss} = \frac{V_{sys}}{V_{md}} = \frac{220V}{40V} = 5.5 \quad (7)$$

Then, Number of PV module connected in series is six (6) for each string.

Number of PV Module Connected in Parallel

Since the average daily solar irradiance is 6.59 kWh/m2 /day

1 kWp = 6.59kWh/day

y kWp = 28.8kWh/day

y × 6.59kWh/day = 1 kWp × 28.8kWh/day

$$PV - Array = \frac{DW_p}{V_{sys}} = \frac{1kWp \times 28.8kWh}{6.59kWh/day} \quad (8)$$

Therefore, PV Array size is approximated to 4.4 kWp or 4400 Wp.

$$I_{sys} = \frac{DW_p}{V_{sys}} = \frac{4400W_p}{220V} = 20A \quad (9)$$

$$N_{ss} = \frac{I_{sys}}{I_{md}} = \frac{20V}{13.27A} = 1.507 \quad (10)$$

Thus, Number of PV module connected in Parallel is Two (2) strings. Therefore, The Solar PV array configuration with six (6) modules connected in series with two (2) strings connected in parallel. The total number of PV modules calculated is 12 solar PV modules with the specifications as Table 4.

Battery Storage Sizing

PV battery system assesses various strategies from a financial perspective. The valuable existence of the battery is limited to 5,000 cycles or in the planned living time of 20 years. The maintenance of photovoltaic and rechargeable annual activities and expenditure systems is set at 1.5% per the speculative cost. Assume that the cost system for the battery and PV is comparable to their size. Following is a formula that will enable to calculate what size of battery they should have.

$$Ah = \frac{E_{ah}}{V_{sys}} = \frac{25 \times 0.05 + 25}{220} = 0.119kAh \quad (11)$$

whereby: The average efficiency of the inverter is 95%, Maximum Depth of Discharge, DoD_{max} = 100% (Specified by the battery manufacturer. Number of Days of autonomy, Taut = 3 (is the maximum number of days that the batteries can supply the daily demand assuming that there is no input from the PV array)

$$B_{ah} = \frac{DD_L \times T_{out}}{DOD_{max}} = \frac{0.119 \times 3}{0.7} = 0.51kAh \quad (12)$$

$$I_{disc} = \frac{AC\ Power / \eta}{V_{sys}} = \frac{6.264kW / 0.95}{220V} = 29.97A$$

$$DR = \frac{DL}{I_D} = \frac{0.51kAh}{29.97A} = 17.92h \quad (13)$$

The number of batteries required is calculated as follows:

$$N_B = \frac{CB}{C_b} = \frac{0.52 / 0.97kAh}{50Ah} = 12 \quad (14)$$

Therefore, the solar PV System min-grid required 12 batteries with capacity of 50 Ah.

DC/AC Inverter Sizing

The DC-AC inverter is responsible for converting the DC voltage from the PV array or storage batteries to AC at the appropriate voltage level for consumption by the loads. To size the inverter, the possibility that all the loads may be turned on at the same time and run continuously is considered. This however, means that most of the time that the inverter is running, it is operating at a smaller load than its rated load. Running the system at a lower load reduces the efficiency and consequently some energy is wasted.

Inverter size = total load power oversize f × actor.

Where:

Oversize factor = 1.15

Total load power = 4.176 kW

Inverter size = 4.176 × 1.15 = 6.264 kW

Therefore, an inverter size of 7.0kW is chosen. The chosen inverter supplies loads connected to the mini-grid. The battery storage is charged with power from the PV array after passing through the switchgear that contains the charge controllers and system protection devices. The switchgear provides the logic for the power supplied to come directly from the PV array, when the batteries are fully charged during the day.

Charge Controller

The charge controller, sometimes referred to as a photovoltaic controller or charger, is only necessary for the system which involves a battery. The main capacity of the charge controller is to counteract the battery spoofing. The basic function of charge controller is to monitor charging and discharging of the battery. It prevents the battery from being completely charged or discharged. This is important because over charging can lead to destruction of the battery and under charging decreases the battery life. Another important reason to use a charge controller is to prevent a reverse current flowing from battery to the system. There are two types of controllers that are widely available in the market; 1) Pulse width Modulation (PWM), 2) Maximum Power Point Tracking (MPPT). Pulse width modulation: A pulse width modulation charge controller is set match the input power of the battery irrespective of the power generated by the panels. There is an inherent loss in power observed in this type of charger.

Economic Analysis of the Solar PV System

The economic analysis of an energy production system provides two types of information: the updated costs of the system and the annual costs it generates. In our calculations, the choice of the economic lifetime is linked to the fact that the estimated lifetime of the PV modules is about 20 years. These cost estimates shown in Table 5 do not include the mini-grid components such as poles, transmission line cables, etc. PV module prices have declined dramatically and, under some circumstances, PV is now cost-competitive with incumbent technologies.

Battery prices usually constitute 40% of the total system cost. The main concern of the population of the village is to have an electricity system that provides them with a minimum level of comfort at the lowest possible cost. A heavy investment is neither justified, nor major costs. The design process begins by enumerating the important input data that demonstrate the technical specifications.

Table 5: PV system cost estimation

Component	**Quantity**	**Unit price ($)**	**Total price ($)**
PV module	12	135	1620
Inverter	2	3520	7040
Battery	12	365	4380
Charger Controller	4	520	2080
String Combiner	4	392	1568
Circuit Breaker	12	34	408
Total			17096
Wiring and Cables		10%	1709.6
Grand Total			18,805.6

DISCUSSION AND COMPARISON

The following are discussion and comparison of the results/finding with the literature reviewed during the data analysis which revealed a clear actual situation specific to Juma Island village. The results show that the site has technically and economically viable in terms of energy demands in the Island, solar energy resources is available in sufficient amount with average of 6.59 kWh/m²/day. The good weather condition is much attractive to the installation of the solar PV power generation project with average temperature about 22.6 °C with comparison to the Standard Test Condition (STC). This indicates that the PV module will perform better with the air temperature at 25°C. If the temperature will be below the STC the PV module will perform excellent in power generation.

The economic analysis point of view of energy production system provides two types of information: the updated costs of the system and the annual costs it generates. In this paper calculations, the choice of the economic lifetime is linked to the fact that the estimated lifetime of the PV modules is about 20 years. These cost estimates shown in Table 5 do not include the mini-grid components such as poles, and transmission line cables. The PV module prices have declined dramatically and, under some circumstances, PV is now cost-competitive with incumbent technologies. Battery prices usually constitute 40% of the total system cost. The main concern of the population of the Juma Island village is to have an electricity system that provides them with a minimum level of comfort at the lowest possible cost. The both direct and indirect economic benefits were realized against importance of modern energy in economic growth.

CONCLUSION

There is a cost associated with electrifying houses in rural areas that increases with distance between the grid and the houses. Such instances where the cost of electrification becomes enormously highly one can always use a min-grids PV system. Both type of systems grid tied and mini-grid PV systems have their own advantages and disadvantages. Depending solely on the need one can decide what they would want to go for. It is trending that one can observe is that the grid-tied system is mostly found in urban and suburban setting where electrification of the area has already been achieved. The mini-grid system is more suited to areas where the electrification is yet to be accomplished and/or the consumer chooses not to supply back the energy generated at his/her end. This paper provides the methodology of designing Solar PV mini-grid system using MATLAB/SIMULINK software.

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