IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 6 Issue 8, August 2019
ISSN (Online) 2348 – 7968
www.ijiset.com

Optimal Sizing of Mini-grid System for Rural Electrification

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Abstract

Solar photovoltaic (PV) systems have shown their potential in rural electrification projects. A solar based mini-grid is a solar PV plant with a localized distribution network to a unit village. The proposed village Gwe Cho is very far from the national grid and the total household is 130. It is including in the dry zone and abundant of solar energy is obtained. This case study is to find out the optimal design of mini-grid for rural electrification. Battery and generator as a backup system is considered. The result is carried out by applying HOMER software. This paper is to provide as a guideline for balancing cost optimization process.

Keywords: *Battery, Generator, HOMER , Mini-Grid, PV Plant*

1. Introduction

The benefits of electrification is well known and demand of electricity is also increase day by day. Most the rural area are very far from the national grid and they faces many difficult and lack in their living standard. Therefore energy play the important role. Electrical energy can drive from various resources such as hydro, wind, geothermal and solar, etc. Energy can divided into two main categories. They are non-conventional and conventional energy. Non-conventional energy can reuse and can be covered one thing of life.

Among them, solar energy is widely used in all over the world. Solar photovoltaic is obtained directly from the sun and produced electricity. Energy produce electric from the sun when it is strike to the solar module. The more direct sunlight and the more energy can obtained. The utilization of solar energy can be broadly classified into two main type. They are off-grid and on-grid system.

A mini-grid (off-grid) is referred to the low voltage network within neighborhood supplied by solar PV. On-grid system is high voltage network as cluster network and supply to the industrial and commercial load[10]. In many countries the reliability of the gird is poor and high costs. But the load demand is increased and electricity supply is insufficient. Therefore, suitable technology is applied in nowadays. In Myanmar, 35% of household has access to electricity since 2016 and 70% of the population are lived in the rural area[1]. Government of Myanmar want to achieve 100% electrification by 2030. Therefore 60% of renewable source from Myanmar can cover all of the half of the new access. In the current study, the mini-grid system is focused which has distribution power source and supply electricity to the household. A mini-grid can be used as a backup power source for agriculture sector.

In section I introduction is described and literature review and theoretical framework are discussed. In section III methodology and system design are mentioned. Result outcome is present in section IV and conclusion discussed in detail from section V.

2. Literature Review and Theoretical Framework

2.1 Literature Review

In 2017, Chih-Ta, Yriga Belay Muna, Hsueh-Yunan Lin, Cheng-Chien Kuo and Rainy Hisung find the solution for the title of “Optimal design and performance analysis of solar power microsystem for mini-grid application”. The author considered the electrification strategies based on cost, efficiency performance, equipment utilization factor, excess electricity produced, etc[2].

In 2017, ADB point out the title of “Developing renewable energy mini-grids in Myanmar”. This guidebook documents the main experiences and lessons learned from the 12 pilot projects as well as training materials from the capacity building activities[3].

In 2013, Stephen Abaase determine the title of "Examining solar PV mini-grid system as a complement to grid extension for rural electrification with reference to YAMA community, Northern GHANA'. The author point out this system to compare the cost of electrification by using conventional grid system[4].

In 2013, Solomon Teklemichael Bahta, considered the title of "Design and analyzing of an off-grid Hybrid renewable energy system for rural electrification in Ethiopia". The author simulated and optimized for rural community by using HOMER software[5].

In 2011, Raymond Kimera focused on the title of "Consideration for a sustainable Hybrid electric power mini-gird". The author point out the renewable energy resources are identified, an estimation of the projected village short-term electricity demand is simulated by HOMER software[6].

2.2 Theoretical Framework

There are two main approaches to conduct rural electrification areas in a competitive and effective way; mini-grids and stand-alone system. Both types of systems operate independently of the national electricity gird and are thus known as off-gird systems.

Standalone system usually require battery banks to store energy and they must be carefully designed to meet expected loads during cloudy periods[6].

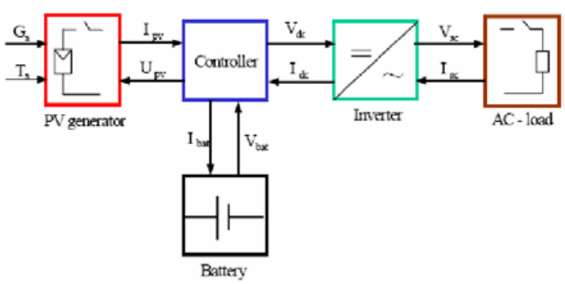


Fig.1 Block diagram for the standalone PV system[7]

Since Myanmar is quit e rich in solar radiation, the mini-grid system is provided sufficient electricity for both domestic and public lighting in rural area.

Solar mini-grid is divided into two partition for supplying load side. Centralized DC bus and distributed AC bus system configuration are shown in figure 2. The centralized DC-architecture is preferable in a situation of high solar fractions (e.g. PV/battery-systems) and evening loads. Centralized mini-grids can provide capacity for both domestic utilization and also support the growth of local businesses in rural communities.

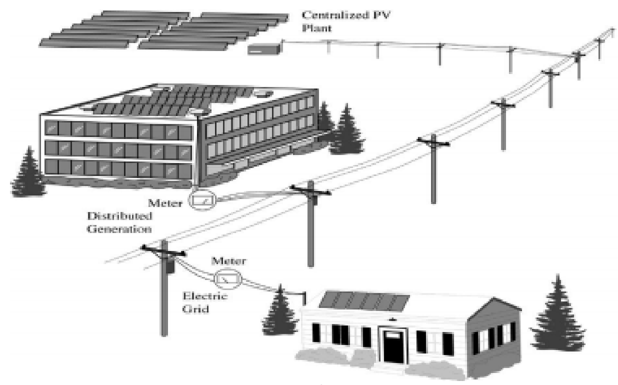


Fig.2 Schematic diagram of a PV mini-grid system[6]

The distributed AC-based system on the other hand proved to be the more efficient solution in system with smaller solar fraction and high energy use during the day.

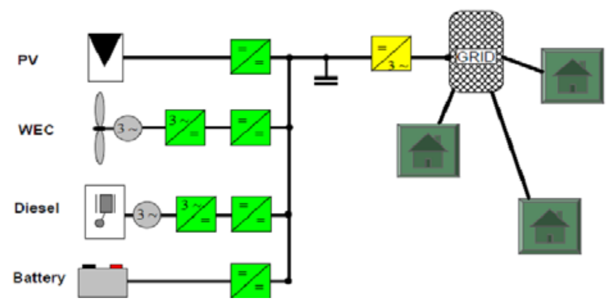


Fig.3 Schematic diagram of a PV mini-grid structure[6]

According to figure 2, four diference sources sare applied for generating electircity. PV is conneted to the DC converter and link to the DC busbar. After that power transfer to the inverter and to the load side. Nevertheless, thoer source are also used for using as a backup system.

This paper is foused on the remote PV mini-grid and it is distinguished from the PV cluster(PV neighbourhood). Generator characterisics of remoter PV mini-grid are following[8].

- Isolated grid only
- PV plus others (mainly diesel)
- Weak grid
- Many be required (normally battery storage)
- Grid stability and power quality
- Short-term power dispatch strategies
- Long-term energy management

3. Methodology and System Design

3.1 Methodology

Firstly selected location and collection the solar radiation data. Consider the resource from the desired location. Average energy demand is collected and selected the system component. Finally simulated by HOMER software.

3.2 Desired Location and Monthly Radiation

Myanmar has an average solar irradiance of 4.5–5.1 kilowatt-hours per square meter per day (kWh/m²/day), making solar a suitable technology for mini-grids in many locations. Nevertheless, strong variations exist in the different areas of the country. Solar irradiance at a particular site can be obtained from on-site measurements, or derived from satellite data and nearby weather stations. The Dry Zone (consisting of Magway, Mandalay, and Sagaing regions) is highly suitable with an average radiation of more than 5 kWh/m²/day and limited variation in radiation during the rainy season [3].

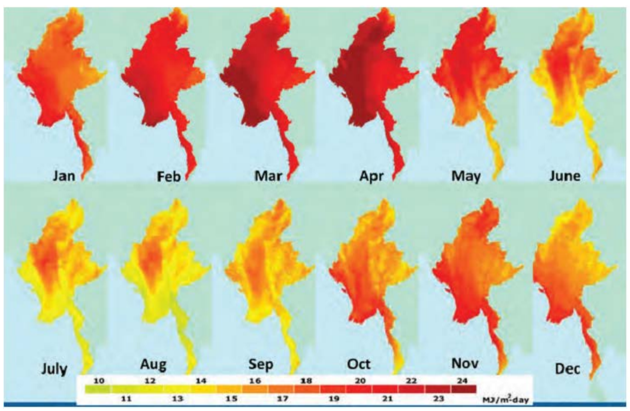


Fig.3 Monthy solar radiation in Myanmar[3]

Fig.4 Gaw Cho Village, Pinlebu Township[9]

The selected location is situated aroung in the latitude 22° 57′ and longuitude 95° 55′. Gaw Cho village which it is located in Pinlebu Township, Sagaing region.

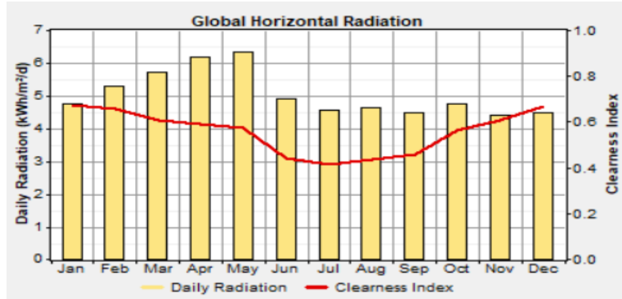


Fig.5 Monthly radiation data for Gaw Cho Village

3.3 Energy Demand for Proposed Village

The total household of the proposed side is 130 numbers. The consumers need electricity to apply their electrical equipment. Their economical are based on agriculture and livestock.

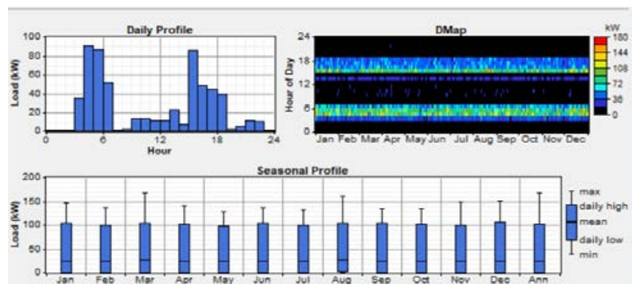
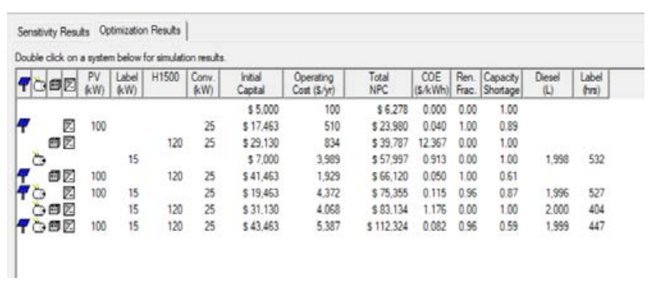


Fig.6 Monthly Energy demand data for Gaw Cho Village

A total load profile is then generated to represent the estimated annual short-term load profile. This is simulated in HOMER software to take on the shape as shown in figure 6. This presents Gaw Cho village daily demand at 182kWh, with a peak load of 180kW.

3.4 System Design


Sensitivity Results Optimization Results

Double click on a system below for simulation results.

				PV (kW)	Label (kW)	H1500	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
								$ 5,000	100	$ 6,278	0.000	0.00	1.00		
				100			25	$ 17,463	510	$ 23,980	0.040	1.00	0.89		
						120	25	$ 29,130	834	$ 39,787	12.367	0.00	1.00		
					15			$ 7,000	3,989	$ 57,997	0.913	0.00	1.00	1,998	532
				100		120	25	$ 41,463	1,929	$ 66,120	0.050	1.00	0.61		
				100	15		25	$ 19,463	4,372	$ 75,355	0.115	0.96	0.87	1,996	527
					15	120	25	$ 31,130	4,068	$ 83,134	1.176	0.00	1.00	2,000	404
				100	15	120	25	$ 43,463	5,387	$ 112,324	0.082	0.96	0.59	1,999	447

Fig.7 HOMER results analysis

According to the case study from system simulation, case study four is selected because it suitable not only for the load demand but also COE ($/kWh) is save. Diesel used for this system is 1999 Liter per year.

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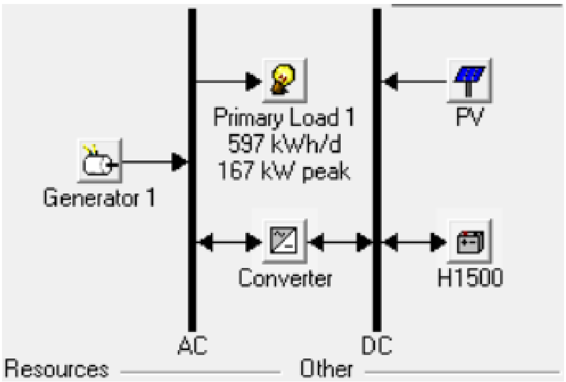

Fig.8 System design

In this configuration, the system utilizes all available generator options, with a diesel generator added in the mix to provide backup supply, to PV and energy storage.

4. Simulation Result

4.1 PV Output Simulation

The following result show their rated capacity, mean output, capacity factor and total production. The total production per year is 1447.92 kWh.

Quantity	Value	Units
Rated capacity	100	kW
Mean output	16.5	kW
Mean output	397	kWh/d
Capacity factor	16.5	%
Total production	144,792	kWh/yr

Fig. 9 Monthly PV output.

Quantity	Value	Units
Minimum output	0.0	kW
Maximum output	85.6	kW
PV penetration	66.4	%
Hours of operation	4,368	hr/yr
Levelized cost	0.00946	$/kWh

Fig. 10 Monthly PV output.

Above the figure 10 is mentioned the PV penetration is 66.4% and the hours of operation is 4.368 hr/yr. The levelized cost is 0.00946 $/kWh.

Figure 11 show the PV output of the every month. The maximum rate of the output is around 85.6 kW. The mid of July is very in power generation because of the solar radiation is very less when compare to the March. According to this PV generation data, system must used back up diesel generator and battery storage.

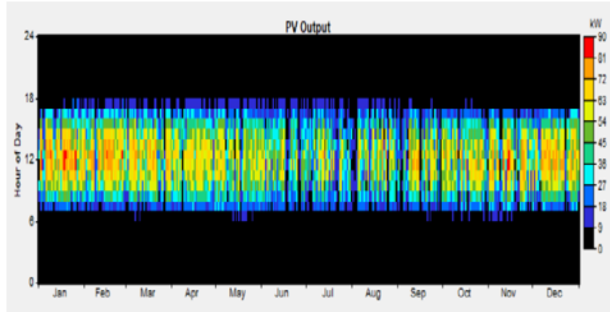

Fig. 11 Monthly PV output.

4.2 Electric Production Simulation

Average electrical production for every month is shown in the following figure.

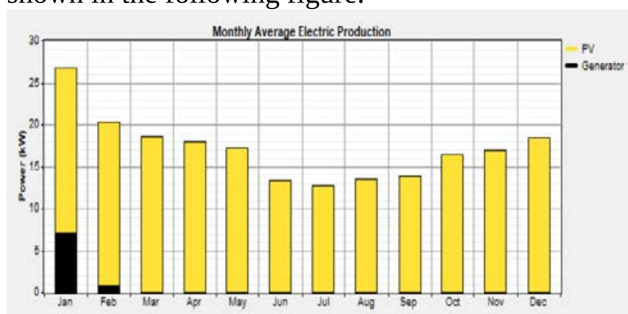

Fig. 12 Monthly average electrical production.

According to this result, the PV is not enough to produce the energy during January. Therefore, system is required to use generator back up system most to fulfill this requirement.

Production	kWh/yr	%
PV array	144,792	96
Generator 1	5,852	4
Total	150,645	100

Fig. 12 Production of PV output and generator.

Quantity	kWh/yr	%
Excess electricity	22,249	14.8
Unmet electric load	111,135	51.0
Capacity shortage	129,317	59.3

Fig. 13 Quantity of excess electricity.

Consumption	kWh/yr	%
AC primary load	106,770	100
Total	106,770	100

Fig. 14 Total AC primary load consumption.

ISSN (Online) 2348 – 7968
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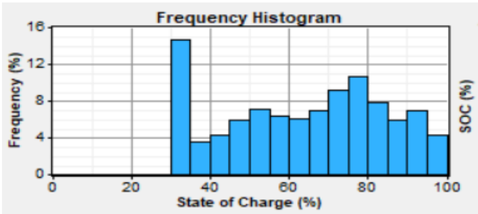
4.2 Battery State of Charge Simulation

Battery state of charge is described by the following figure.



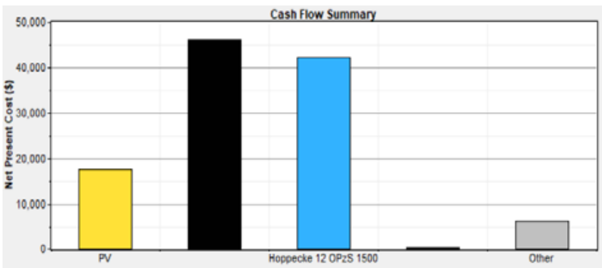


Fig. 16 Net present cost.

Total NPC is $112,324 and operating cost is $5,387/year. The generator NPC is higher when compare to the PV operating cost.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	12,333	2,079	4,261	0	-1,165	17,508
Generator 1	2,000	376	28,571	15,336	-119	46,164
Hoppecke 12 OPzS 150	24,000	11,216	7,670	0	-707	42,179
Converter	130	31	38	0	-6	194
Other	5,000	0	1,278	0	0	6,278
System	43,463	13,703	41,819	15,336	-1,997	112,324

Fig. 17 Total cost of the component.

4. Conclusions

The mini-grid system is proposed to the rural village developed for their lifestyle. According to this study, Gaw Cho village is applied total energy demand 597 kWh/day. The electrical production from generator and PV are around 150, 645kWh/year. The battery energy output is 67723kWh/year. Therefore this system design is sufficient to apply energy demand for 130 household. The HOMER simulations give the feasibility component structure of the mini-grid, which hence proved as an optimal design.

Acknowledgments

The author would like to express deeply gratitude to her parents and her husband for encouragement help throughout the period of study. The author is grateful to thank her colleagues who work at Rural Development Department and specially support for the required load data collected, help throughout the paper.

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