International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 3 Issue 5, August 2019 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

# Feasibility Study on Battery Energy Storage System for Mini-Grid

**Nang Saw Yuzana Kyaing, June Tharaphe Lwin, Chris Tie Lin**

Department of Electrical Power Engineering, Ministry of Education,
Technological University Loikaw, Loikaw, Myanmar

***How to cite this paper***: Nang Saw Yuzana Kyaing | June Tharaphe Lwin | Chris Tie Lin "Feasibility Study on Battery Energy Storage System for Mini-grid " Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-3 | Issue-5, August 2019, pp.2086-2089, **https://doi.org/10.31142/ijtsrd27863**

IJTSRD27863



**ABSTRACT**

Mini-grids defined as a set of electricity generators and battery energy storage system is connected between the load side and the source side. A key feature of mini-grids is that they can operate autonomously with no connection to a centralized grid. Gaw Cho village, Sagaing Division, Myanmar is selected because of the higher potential of solar energy. This paper presents the unbalance condition between the load side and the source side because the solar energy is changing under weather condition. Diesel generator is used as a backup system for this proposed area but the operation of the fuel cost increased for long term period. Here, battery energy storage system is used as a secondary supplier to balance between them. This paper focus on to used HOMER software for pointing out the result outcome not be oversizing the system requirement. Using real time data, storage characteristics and HOMER simulations, optimal sizing for both approaches were established. A well design min-grid offered available tool for the rural electrification system.

***KEYWORDS:*** *battery energy storage, diesel generator, HOMER, mini-grid*

## INTRODUCTION

Photovoltaic and other renewable energy technologies can significantly contribute to economic and social development. For developing countries, providing and maintaining energy access is an important driver for off-grid renewable energy systems[1]. Currently live without access to electricity an estimated 615 million of them in Asia[2].

Until recently, mini-grids have been a stepping stone towards grid expansion. Mini-grids are particularly relevant for island states, both developed and developing. As renewables increasingly become cost effective resources for off-grid systems.

The government faces the challenge of providing reliable electricity to most of its population. In addition, a village should also have sufficient demand for electricity and consist of a concentrated group of at least 150–200 households to make a mini-grid viable. Larger villages are preferable as these will be able to provide stronger revenue streams that will help sustain the mini-grid operation in the long run[3]. Mini-grids can operate autonomously, they cannot rely on the central gr id to control line voltage and frequency and balance power supply with power consumption.

Mini-grids often contain significant amounts of intermittent generation (e.g. PV or wind) whose power output can't be controlled (dispatched) in the same fashion as conventional generators. Many mini-grid generators interface to the mini-grid with power electronic inverters whose control characteristics are different from the rotating synchronous machines used in conventional large generators[4]. Energy storage can play in PV-hybrid mini-gr ids to match the fundamental requirement of stabilization in the sub-minute period: the balance between generated power and power consumption at any time[5].

In mini-grid system where both long-term energy storage and short-term power supply are required. Short term power balancing requires fast response (milliseconds), good, symmetrical (charge/discharge) power handling capability, good cycling life, and low cost per rated kWh of capacity, but generally requires only modest energy storage. Longer term energy management requires high energy storage capacity, good net efficiency, and low cost per kWh of capacity.

In section one, the general background theory is introduce and the main concept of the system is point out. Material and Methodology is describe in section three. Outcome simulation result based on HOMER software is present in section four and conclusion is summarized in section five.

### A. Main Concept of the System

Deployment of photovoltaic (PV) are service for the developing region mentioned in the following subsystem. They are:

- PV for rural community needs
- PV for mini-grids and hybrid systems
- Integration of PV in the urban environment
- Large-scale PV systems

Mini-grids combining both renewable and conventional diesel generation systems could provide a more competitive technical solution[6].

In planning rural electrification development, an important consideration is the decision between the overall technology options of[7]:

- Grid-based electrification;
- Mini-grids; and
- Stand-alone solutions such as Solar Home Systems.

Mini-grids combining both renewable and conventional diesel generation systems could provide a more competitive technical solution[6]. When a grid based development is considered to supply a particular area, a further consideration is whether to use standards appropriate for urban or rural areas. For rural networks, such stringent conditions do not need to be adhered to, enabling simpler network designs at lower cost. Rural networks have significantly lower load densities than in urban areas (usually measured in kW per unit area or kW per km of line)[8]. A mini-grid is used low AC voltage 230 t0 400V.

**TABLE.I MINI-GRID AND OFF-GRID PARAMETER[9]**

| Solar PV System | Parameter |
|---|---|
| Grid Connected | 50 GW/0.5 min large systems>50kW |
| Mini-grid<5o MW/ own consumption | Diesel-PV hybrid<10000 village systems |
| Stand-alone systems/ individual electrification | SHS<1kW<br>5-10 mln System |

This paper is focus on the Mini-grid system for Gaw Cho village, Sagaing Division, Myanmar. This publication aims to present the state of the art situation of PV / diesel hybrid systems for rural electrification and to highlight remaining the design, technical and implementation results.

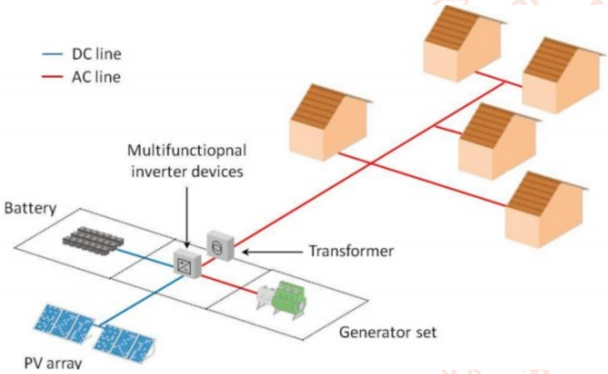


**Fig.1 Schematic view of mini-grid system [3]**

Battery Energy Storage (BESS) is the most effective storage technology for rural electrification applications. Its provide the permanent source of electricity that is independent from variable power generation. It size to keep supplying power for 4 to 10 days. It is essential for effective and reliable bringing between different sources.

Lead based, iron based, Nickel based or sodium deep cycle can be used depending on the sysem requirement. All batteries used in off-grid mini-grid system must be specially designed for deep cycling application.

**TABLE.II BATTERY TECHNOLOGICAL AND CHARRCTERISTICS [10]**

| Battery Technologies | Characteristics |
|---|---|
| Lead based (Pb) | Proven in application, low production cost |
| Nickel based (Ni) | Proven off-shore and harsh environments, long life |
| Lithium based (Li) | High energy density, small and light |
| Sodium based (Na) | High energy density, light |

Four technical limitation of battery energy storage are the following[11]:

- Rated voltage and ampere-hour capacity of each storage cell as the rated discharge rate,
- Permitted maximum DOD,
- Self-discharge rate,
- Cycle life of the storage cell and the anticipated life (in years) of the battery bank.

Typically, BESS will be operated at high state of charge between 80 to 100% of rated capacity during seasons other than the monsoons. A voltage regulator system normally limits the maximum battery voltage during the recharge period. Charge controller should be sized accordingly to keep the battery and load always safe and getting charged.

### B. Material and Methodology

Firstly, the data assessment from the selected location and their radiation data is required. Daily load profile of the electrification is collated and the required sizing of the mini-grid component is considered. The energy output is taken from the simulation results and examine the energy need during the shortage the supply sources.

The Dry Zone (consisting of Magway, Mandalay, and Sagaing regions) is highly suitable with an average radiation of more than 5 kWh/m$^2$/day and limited variation in radiation during the rainy season.

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. The total household is 130 numbers. It is 10 km far from the national grid. It is still consist in the unelectrified village.

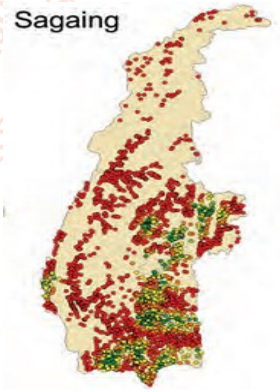


**Fig.2 Unelectricfied village from Sagaing Region [3]**

The red color from the Fig 2 is described the highest kilometer far from the national grid.

The annual average radiation for the proposed village is shown in the following figure.

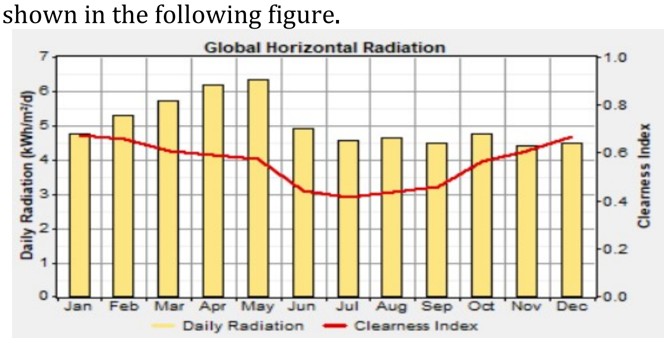


**Fig.3 Annual average radiation for the proposed village**

The annual average of the solar radiation is 5.05 kWh/m2/d. The highest radiation is in May and the lowest radiation is in January.

The system configuration used by HOMER for the design simulations. Daily load profile is shown in Fig. 4. The maximum energy consumption during the whole day is around 4a.m to 7 a.m. Nevertheless, the night time energy consumption is more.

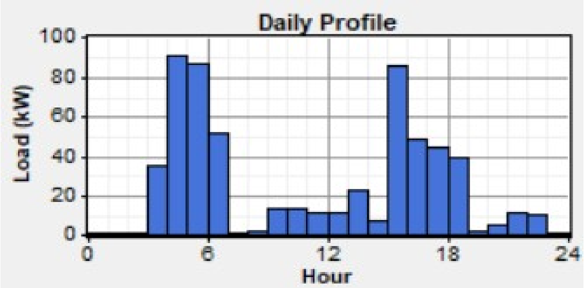


**Fig.4 Daily load profile**

The annual average energy demand is 597 kWh/day.

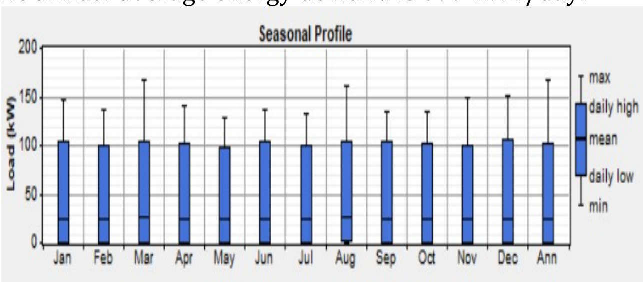


**Fig.5 Seasonal load profile**

The peak load of the baseline and scaled are 168 and 167 kW. The average and load factor are the same for baseline and scaled.

| | Baseline | Scaled |
|---|---|---|
| Average (kWh/d) | 597 | 597 |
| Average (kW) | 24.9 | 24.9 |
| Peak (kW) | 168 | 167 |
| Load factor | 0.149 | 0.149 |

**Fig.6 Baseline and scaled**

The state of charge (SOC) of the BESS is the parameter related to the number of charges stored in the battery (a SOC of 100% means that the BESS is fully charged, whereas it is considered to be empty at 0%). In [12], the online estimation of SOC named "coulomb counting" is proposed. This method is based on the measurement of current and takes into account the columbic efficiency (ampere-hour efficiency):

$$\text{SOC}(t) = \text{SOC}(t-1) + \eta_{ch}\frac{I_{ch}(t).Dt}{C_n(t)} - \frac{I_{Dis}(t).Dt}{\eta Dis.C_n(t)} \quad (1)$$

Where ηCh and ηDis are, respectively, the charge and discharge columbic efficiencies of the BESS. ICh(t) and IDis(t) are the current level at the charge and discharge, respectively. Cn(t) is the nominal capacity of the BESS. It is to notice that the nominal capacity of the BESS is decreasing all along the lifetime of the BESS.

Battery manufacturers often provide the maximum number of cycles that a battery can perform for different Depth of Discharge (DODs), as depicted in Equation (2).

DOD (t)= 1- SOC(t) (2)

### C. Simulation Results

In the design of a mini-grid system, the choice and sizing of the components, and the most adequate control and management strategy must be obtained. In this study, HOMER software is used to size and simulate the different supply configurations and performance elements of the hybrid mini-grid system design.

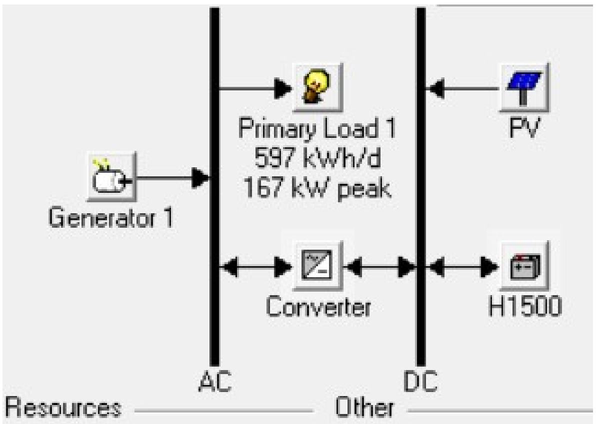


**Fig.7 Parallel architecture design**

This configuration allows all energy sources to supply the loads separately depending on the demand, as well as meeting an increased level of demand by combining the various energy sources. The bi-directional inverter charges the battery when excess energy is available from the other generators, as well as acting as a DC-AC (Direct Current to Alternating Current) converter (inverter) under normal operation. 15kW generator is selected for this proposed system.

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 |

**Fig.8 Simulation case I**

| PV (kW) | Label (kW) | H1500 | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Capacity Shortage | Diesel (L) | Label (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 |

**Fig.9 Simulation case II**

| PV (kW) | Label (kW) | H1500 | Conv. (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Capacity Shortage | Diesel (L) | Label (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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.10 Simulation case III**

According to this case study I, II and III, PV/diesel/battery storage is selected for this proposed system.

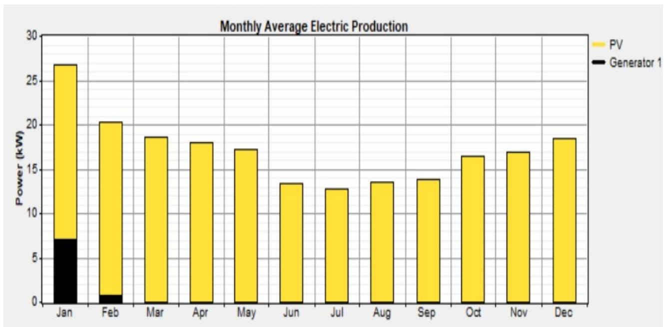


**Fig.11 Monthly average electrical production**

Fig.11 shown the PV and generator output energy output for the annual. The combination of the output from this two sources are 150,645 kWh/yr and total AC primary load consumption is 106,770 kWh/yr.

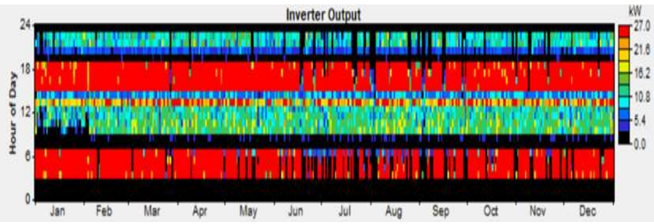


**Fig.12 Inverter output**

According to the simulation results, energy output from this inverter is 102,243 kWh/yr.

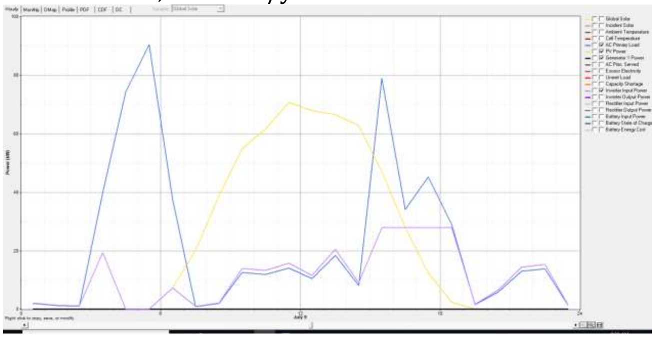

**Fig.13 PV/diesel and inverter compare with load profile**

According to this results, only PV/diesel cannot sufficiently supply to the load side during day time and night time. 3 hour in the early morning and 4 hour in the evening time. Due to this problem, the backup energy source is required to fulfill this requirement.

| Quantity | Value |
|---|---|
| String size | 120 |
| Strings in parallel | 1 |
| Batteries | 120 |
| Bus voltage (V) | 240 |

**Fig.14 Battery sizing**

| Quantity | Value | Units |
|---|---|---|
| Energy in | 72,870 | kWh/yr |
| Energy out | 62,804 | kWh/yr |
| Storage depletion | 122 | kWh/yr |
| Losses | 9,944 | kWh/yr |
| Annual throughput | 67,723 | kWh/yr |
| Expected life | 9.10 | yr |

**Fig.15 Energy output from battery**

120 Hoppecke 1 cycle charging battery type is selected. According to this result, total number of battery is 120 number and bus voltage is 240 V. The energy output is 62,804 kWh/yr. The expected lifetime is 9 yr.

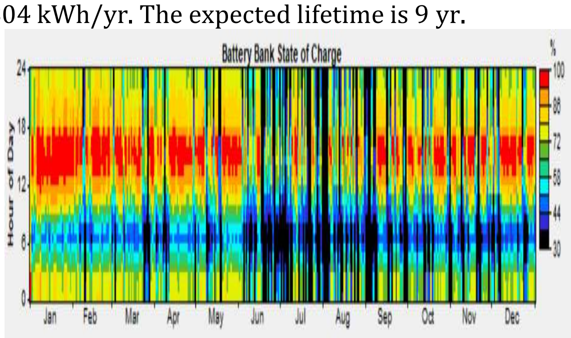


**Fig.16 Battery state of charge**

According to this results, battery energy storage can fulfill the energy demand requirement during the whole year.

## D. Conclusion

This paper has considered the village-level electrification in Gaw Cho village, Sagaing Division. Using HOMER software, different configuration options of the generation systems were simulated to establish the most appropriate design. 100kW PV is selected and it energy production is 144,792 kWh/yr. From the generator, energy production is 15kW. 25kW inverter and 25KW controller is selected for this proposed system. Battery energy storage is charged 90% to 40 % during the whole day. With energy storage, the electricity supply system will be more efficient in matching the resources to the demand, thus improved reliability, resulting in a lower energy cost.

## AKNOWLEDGEMENT

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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