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Analysis of Solar Diesel Hybrid off Grid System in Myanmar

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ABSTRACT

A hybrid system combining renewable technologies with diesel generators is a promising solution for village electrification. Shortage of electricity is the main obstacle for economic and social development. Myanmar has abundant renewable energy resource. There are many places that cannot supply electricity from the main grid. Tat Thit Kyun village is selected from these areas. The selected village where is situated Latitude 18°44′N and Longitude 95°11′E 5.6 mile away from Padaung Township is supplied by hybrid off grid system. 312 kWh demand is needed for 387 numbers of household. Data is obtained from Meteorological data of the village and NASA. The hybrid system is composed of photovoltaic source, diesel generator, battery energy storage system and converter. The hybrid system is analyzed for the life time 20 years by using HOMER software.

KEYWORDS: *hybrid system, renewable energy, off grid, NASA, HOMER software*

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INTRODUCTION

In Myanmar, about 35 % of country areas is covered by national grid (MOEE). The extension of utility grid is complicated and expensive due to geographical, economical and social barriers. So, the source of electricity in those remote islands and villages is diesel generator. This is both costly and hazardous for the environment due to the global warming. Renewable energy resources like hydro and solar energy are getting popularity for these reasons.

Solar energy is the energy that is available from the sun in abundance. Solar power plant is based on the conversion of sunlight into electricity by using photovoltaic (PV). Photovoltaic converts light into electric current using the photoelectric effect.

Solar power in Myanmar has the potential to generate 51,973.8 TWh/year, with an average of over 5 sun hours per day. The country aims to generate 8% of electricity through renewable energy sources—through wind and solar energy—by 2021 and 12% by 2025. The solar radiation of Tat Thit Kyun Village is 6.6 kWh/m^2/day.

Hybrid energy system is an excellent solution for electrification of remote rural areas where the grid extension is difficult and not economical. Such system incorporates a combination of one or several renewable energy sources such as photovoltaic, battery and wind energy. A hybrid system uses a combination of energy producing components that provide a constant flow of uninterrupted power.

The following solar energy technologies can be successfully propagated: solar cookers; solar water heating systems for industrial application; solar distillation units for battery charging; solar photovoltaic systems for water pumping, battery charging, and power supply to children's hospitals for operating vital equipment. Solar air driers can be used for agricultural and industrial products.

Off-grid photovoltaic (PV) systems are used for supplying electricity to rural areas. Since Myanmar is a land of plentiful sunshine, especially in central and southern regions of the country, the first form of energy- solar energy could hopefully become the final solution to its energy supply problem. The direct conversion of solar energy into electricity using photovoltaic system has been receiving intensive installation not only in developed countries but also in developing countries.

It is mainly intended to present solar energy potential and application in Myanmar. It is also wanted to get the benefits of using solar energy for people in remote areas which are not yet connected to the national grids because of the high price of fossil fuel. MEPE (Myanma Electric Power Enterprise) experimental measurements indicate that irradiation intensity of more than 5kWh/m^2/day was observed during the dry season.

The Republic of the Union of Myanmar is a developing country with 53.37 million people of a total population

(Population of Myanmar 2018 andhistorical); about 70 % of people live in rural areas (UNFPA Myanmar Country Profile). The national grid electricity of capacity in Myanmar is lower than demand because of the rapid increase of population. As a result, 50 % of population still lack of electricity. there is a problem to solve the lack of electricity especially in rural areas. Therefore, off-grid PV-diesel hybrid system is applied to get electricity for rural areas in the Republic of the Union of Myanmar.

A. CASE STUDY AREA

Mega Global Green Automation Company Ltd is tendered to build solar power plant in Tat Thit Kyun Village. Tat Thit Kyun Village is locality in the middle of Ayarwaddy river, there is one of island, Tha Yey Lane village track, Pa Daung township Bago Division in Myanmar. Travel mode is just river cross by boat. Major business is agribusiness and fishery. One Primary School and three Buddhist Monastery. It was long village and five main road in Village.

The village is 4.89 miles away with National Grid but cannot to connect with it by river cross. Hydro power, wind power cannot use in this village because the source of this power aren't sufficient to use. The cost of diesel generator is more expensive than solar power. The propose project can be distributed the electrification to 387 household, 101 street lamp throughout 6 main road, multimedia classroom in one primary school, three Buddhist monastery and many of small scale industry business in village. If extension of national grid, the situation is ready to connect.

Village Name	-Tat Thit Kyun
No: of households	- 387
Location	- Latitude 18°44′N,
Longitude	- 95°11′E,

5.6 mile away from Padaung Township

Figure 1.Location of Tat Thit Kyun

B. Solar Radiation

When the incident solar radiation falls on a body of water, some of the sunlight is reflected back to the sky and the rest is absorbed by the surface of the water, the energy penetrates to over a hundred meters in depth.

The total solar radiation incident on a horizontal surface often referred to as global radiation on the surface can be calculated as the sum of the beam and the diffuse solar radiation on a surface. In Tat Thit Kyun, the highest solar radiation can be received in April according to Table 1.

Table 1: Solar Radiation of TAT THIT KYUN Village

No	Months	Solar Radiation (kWh/m2/day)
1	January	5.26
2	February	5.9
3	March	6.44
4	April	6.6
5	May	5.31
6	June	3.78
7	July	3.82
8	August	3.73
9	September	4.36
10	October	4.59
11	November	4.64
12	December	4.88

C. Load Forecasting

Firstly, load forecasting is very important to build a solar power plant. After knowing amount of total load, the plant design can be drawn.

In this village, there are 5 types of households such as

1. Household type 1 (Low income)
2. Household type 2 (Middle income)
3. Household type 3 (High income)
4. Public Utility Electricity Supply
5. Productive Energy Users electricity demand (PEU)

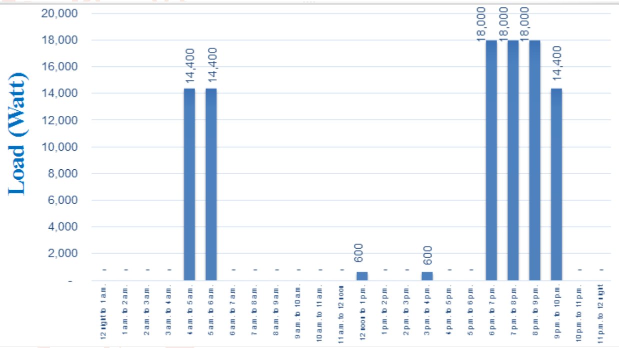

Figure2: Daily Load Cycle Bar Chat for household type1

Figure 2 is load estimation of Household type 1. In this type, 10W bulb, phone charger and radio can be used. Other electrical appliances cannot be used. At very early morning 4:00am, 5:00am and night 9:00pm, load is 14400W, 600W at afternoon 1:00pm and 4:00pm, 18000 W at night 6:00pm to 8:00pm.

In Figure 3, Household Type 2 is shown. 400W rice cooker can be applied. By showing this table, total Wh is increased than type 1. During 9:00am and 10:00am, the least load is 1890W and the most load is 50240W during 5:00pm to 6:00pm.

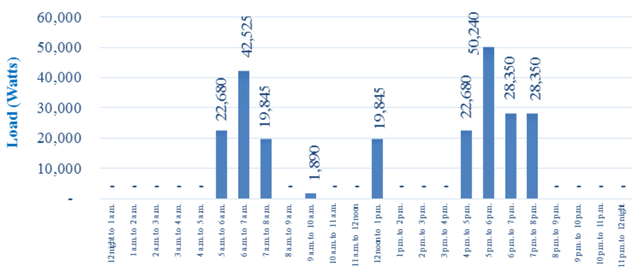

Figure3: Daily Load Cycle Bar Chat for household type2

Extra load such as 90W Refrigerator and 1000W oven can be replaced with modern life in traditional life.

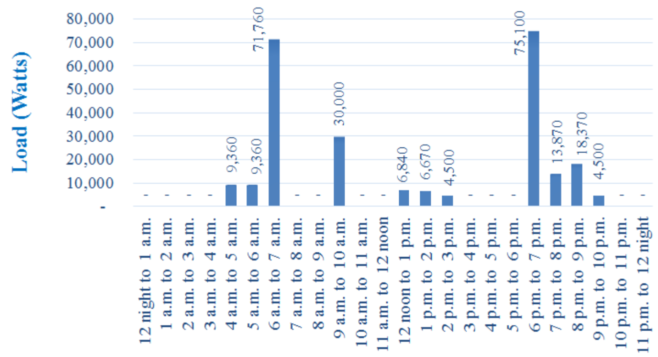

Figure 4: Daily Load Cycle Bar Chat for household type3

So, the total load is 112940Wh. In Figure 4, Type 3 the least and most loads are 4500W at 2:00pm and 9:00pm and 75100W at 6:00pm.

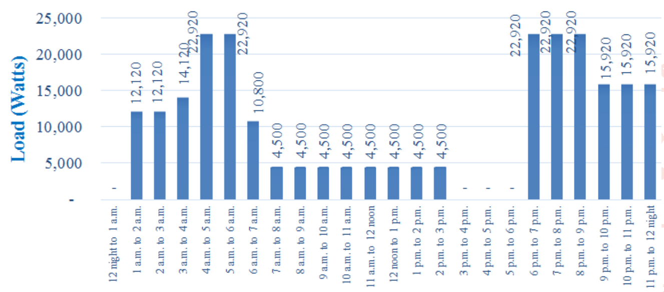

Figure 5: Daily Load Cycle Bar Chat for household type4

Type 4 is Public Utility Electricity Supply in Figure 5. In this type, there are many loads that are concerning with public such as street light, monastery light, school light and so on. Total load is 26420 Wh. Equal load 4500W is consumed from 7:00am to 3:00pm. Not only between 4:00am and 6:00am but also between 6:00pm and 9:00pm is 22920W.

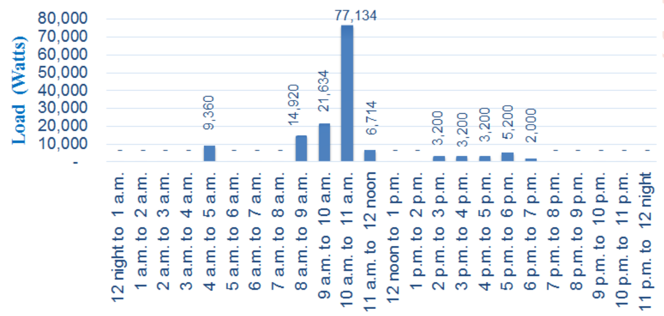

Figure 6: Daily Load Cycle Bar Chat for productive energy users electricity demand

Figure 6 is load estimation for productive energy users electricity demand. Water pump, cutter and welding machine are used in this type of consumers. 82334 Wh is total load for this type. 2000W is used at 6:00pm and 77134W at 10:00am. The sum of all type of load is 312 kWh from Figure 1 to 6.

Figure 7 is Daily Load Cycle Bar Chat for Tat Thit Kyun Village. According to the detail times, the minimum load is after 10:00pm. The maximum load is over 30kW during 8:00pm and 9:00pm.

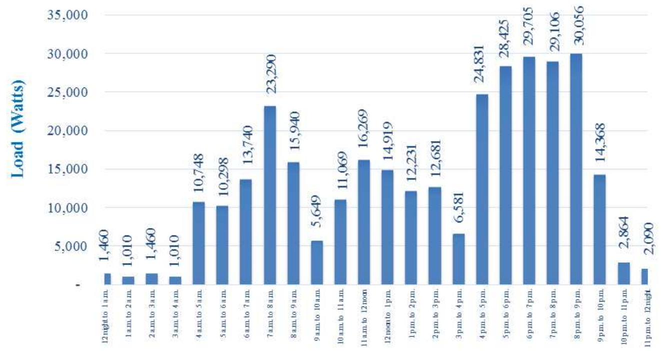

Figure 7: Daily Load Cycle Bar Chat for Tat Thit Kyun Village

D. Solar Panel

Since an individual cell produces only about 0.5 V, it is a rare application for which just a single cell is of any use. Instead, the basic building block for PV applications is a *module* consisting of a number of pre-wired cells in series, all encased in tough, weather-resistant packages. When photovoltaics are wired in series, they all carry the same current, and at any given current their voltage add. There are 72 cells in one PV panel to produce 36 V.

By substituting equation 1, 2 and 3, the voltage and current of 315 W solar panel can be calculated substituting

$R_p > \frac{100V_{oc}}{I_{SC}}$ and $R_s < \frac{0.01V_{oc}}{I_{SC}}$

$$I = I_{sc} - I_0\left(e^{38.9V_d} - 1\right) - \frac{V_d}{R_p} \qquad (1)$$

I_{SC} = short-circuit current,
I_0 = the reverse saturation current (A)

R_P = parallel resistance,
$V_{module} = n\,(V_d - I\,R_s)$ (2)
R_S = series resistance,
P = V module ×I (3)

By combing many cells, one module becomes. The electrical specification for 315 W solar panel is expressed in Table 2.

Modules can be wired in series to increase voltage, and in parallel to increase current.

TABLE2. CHARACTERISTICS OF GOLDI GREEN SOLAR MODULE

Manufacturer	Goldi Green
Rated Power (Pmax)	315W
Open Circuit Voltage(Voc)	46V
Short Circuit Current(Isc)	8.9A
Voltage at Maximum Power(Vmp)	37V
Current at Maximum Power (Imp)	8.52A
Maximum System Voltage	1000V

1. Solar Panel Position

The sun rises in the east and sets in the west and reaches its highest point sometime in the middle of the day. In many situations, it is quite useful to be able to predict exactly where in the sky the sun will be at any time, at any location on any day of the year. In the context of photovoltaics, we can, for example, use knowledge of solar angles to help pick the best tilt angle for our modules to expose them to the greatest insolation.

In Figure 2, the angle formed between the plane of the equator and a line drawn from the center of the sun to the center of the earth is called the solar declination, δ. It varies between the extremes of ± 23.45.

$$\delta = 23.45 \text{ x } \sin\left[\frac{360}{365}(n-81)\right] \qquad (4)$$

where, δ = solar declination
n = day number

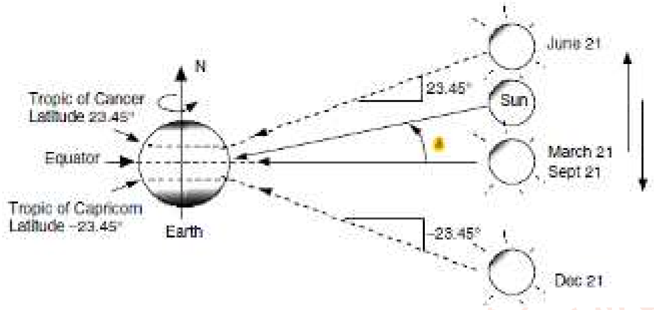

Figure 8 An alternative view with a fixed earth and a sun that moves up and down. The angle between the sun and the equator is called the solar declination *δ*.

For convenience we are using the twenty-first day of the month for the solstices and equinoxes even though the actual days vary slightly from year to year. To calculate solar declination, the day number from Table 8 is needed.

TABLE3. Day Numbers for the First Day of Each Month

January	$n = 1$	July	$n = 182$
February	$n = 32$	August	$n = 213$
March	$n = 60$	September	$n = 244$
April	$n = 91$	October	$n = 274$
May	$n = 121$	November	$n = 305$
June	$n = 152$	December	$n = 335$

The altitude angle is the angle between the sun and the local horizon directly beneath the sun. From Figure 9, we can write down the following relationship by inspection:

$$\beta_N = 90° - L + \delta \qquad (5)$$

β_N = altitude angle of the sun at solar noon
L = the latitude of the site

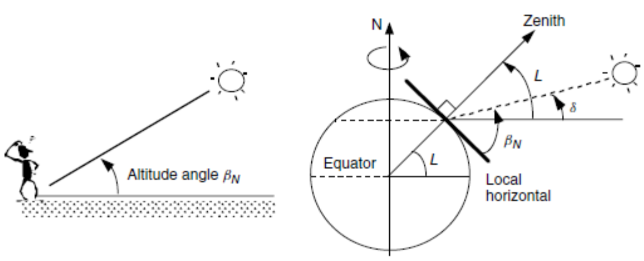

Figure 9 the altitude angle of the sun at solar noon.

2. Sizing of the PV Array

Designing stand-alone PV–battery systems is clearly much more demanding than sizing grid-connected systems. Month-by-month load estimates and solar resource evaluations, making trade-offs between ac and dc loads, choosing a system voltage, and determining battery storage with or without a back-up generator are things that simply don't apply to grid-connected systems. Having addressed those topics, the most important part of the system: the PV array.

Our simple sizing procedure will be based on the same "peak hours" approach used for grid-connected systems.

For the solar power plant, the step by step calculation is required by using the following equations.

Required array output per day

$$= \frac{\text{Total energy demand per day}}{\text{Inverter efficiency}} \qquad (6)$$

Energy output per module per day= PV module power at STC x peak sun hr (7)

Module energy output of operating temperature = derating factor x energy output per module (8)

No. of module required =

$$\frac{\text{Required array output/day}}{\text{Module energy output at operating temperature}} \qquad (9)$$

No. of string in parallel

$$= \frac{\text{Inverter maximum current}}{\text{Module current}} \qquad (10)$$

No. of module required per string =

$$\frac{\text{no: of total module}}{\text{no: of string}} \qquad (11)$$

3. Battery Sizing

Stand-alone systems obviously need some method to store energy gathered during good times to be able to use it during the bad.

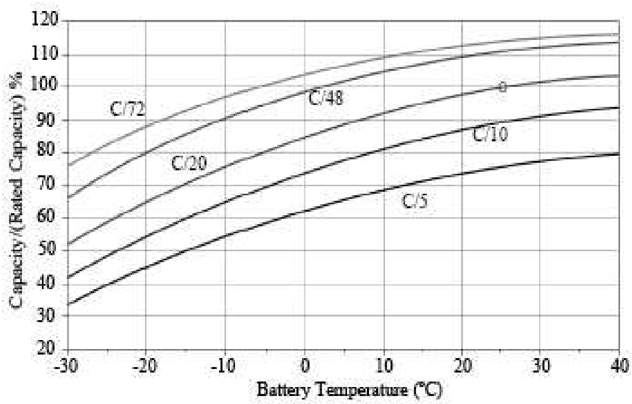

Figure10. Lead-acid Battery Capacity Depends on Discharge Rate and Temperature

Among the many possible battery technologies, it is the familiar lead-acid battery that continues to be the workhorse of PV systems.

Lead-acid batteries are by far the least expensive option, they have the highest efficiencies, and the more expensive ones, when used properly, can last nearly as long as their competitors.

The amp-hour capacity of a battery is not only rate-dependent, but also depends on temperature. Figure4 captures both of these phenomena by comparing capacity under varying temperature and discharge rates to a reference condition of $C/20$ and 25°C.

These curves are approximate for typical deep-cycle lead-acid batteries, so specific data available from the battery manufacturer should be used whenever possible.

Battery capacity C is given in amp-hours rather than watt-hours; charging and discharging are expressed in C/T rates, which are amps. For batteries wired in parallel, amp-hours add. For batteries in series, voltages add.

For battery sizing, the following equations are required.

$$\text{DC load} = \frac{\text{AC load}}{\text{Inverter efficiency}} \qquad (12)$$

$$\text{Usable storage (Ah)} = \text{Total load (Ah/day) x Day of storage(days)} \qquad (13)$$

$$\text{Total storage capacity} = \frac{\text{Usable storage capacity}}{\text{MDODx (T, DR)}} \qquad (14)$$

$$\text{No. of battery in series} = \frac{\text{System voltage}}{\text{Nominal battery voltage}} \qquad (15)$$

$$\text{No. of string of battery in parallel} = \frac{\text{Total storage capacity (Ah)}}{\text{Capacity of a single battery}} \qquad (16)$$

$$\text{Storage days } (99\%) \approx 24.0 - 4.73 \text{ (Peak sun hours)} + 0.3 \text{ (Peak sun hours)}^2 \qquad (17)$$

To account for a range of load criticality, two curves are given: one for loads that must be satisfied during 99% of the 8760 h in a year and one for less critical loads, for which a 95% system availability is satisfactory.

The OPzV series adopts an immobilized Gel and Tubular Positive Plate technology. It offers high reliability and stable performance. By using die-casted positive grid and patented active material formula, it exceeds the DIN standard values and offer 20+ years design life in float service. It is very suitable for cyclic use under extreme operating conditions. This series is recommended for telecom outdoor applications, renewable energy systems and other harsh environment applications.

TABLE 4.CHARACTERISTICS OF BATTERY

Name	Rating
Model	OPzV tubular gel battery
Nominal capacity	1500Ah
Nominal voltage	2V
Designed Floating Life	20 years

E. Homer Input Data

HOMER (Hybrid Optimization of Multiple Energy Resources) is an optimization software for hybrid energy simulation. It is developed by American National Renewable Energy Laboratory (NREL) which aims to help users access with wide range of renewable energy options, in terms of different technical and economic manner.

It can evaluate the design issue in the planning and decision making for many rural electrification projects. It can conduct in the program: simulation, optimization, and sensitivity analysis. It is used as a tool for techno-economic analysis.

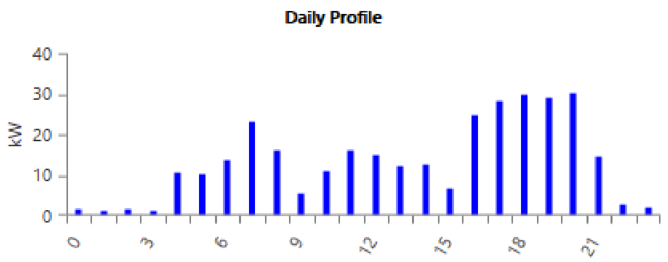

Figure 11: Daily Load Profile for Tat Thit Kyun

The inputs for Homer software are Daily Load Profile for Tat Thit Kyun village in Figure 11 and Monthly Solar Radiation Profile for Tat Thit Kyun village as Figure 12.

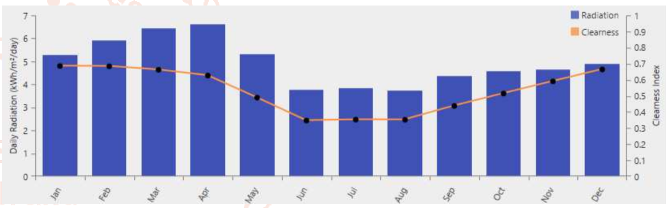

Figure 12: Monthly Solar Radiation of Tat Thit Kyun Village

TABLE5. HOMER INPUT DATA

Data	PV panel	Diesel generator	Converter	Battery(2V,1500Ah)
Size	100KW	89KW	120KW	192 batteries
Capital cost	$576/KW	$160/KW	$388/KW	$533/battery
Replacement cost	0	$112/kW	0	$533/battery
O&M cost	$10/yr	$0.01/yr	$10/yr	$10/yr
Lifetime	25yrs	15000hours	25yrs	10yrs

Table 5 is input data for Homer software. Though Tat Thit Kyun village is really consumed over 30 kW, 100kW solar is considered for the construction site. And Diesel for hybrid 80kW is added in site. 192 numbers of (2V, 1500 Ah) battery is used by calculating above equations from battery sizing. 120kW converter is applied for DC to AC. Capital cost for PV, Diesel, Converter and Battery may be changed as these are cost during 2018. Assume PV cannot added for replacement cost for 20 years life time. But operation and maintenance cost may be paid for all components.

Structure of the Solar Hybrid System is shown in Figure 13. On DC bus, there is PV and battery. As Kohl89 is Diesel generator, it goes to AC bus. Converter is between AC and DC bus. Electric load uses from AC bus.

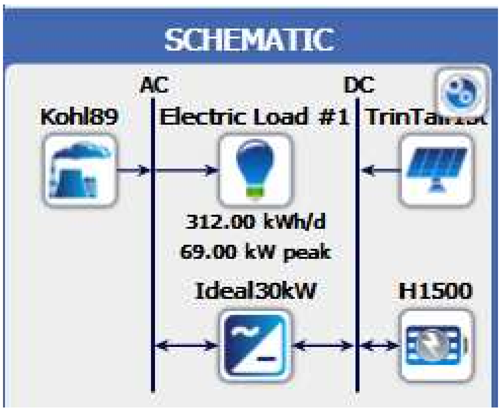

Figure 13: Structure of the Solar Hybrid System

Result

The national grid electricity of capacity in Myanmar is lower than demand because of the rapid increase of population. As a result, 50 % of population still lack of electricity. Therefore, the lack of electricity especially rural areas in Myanmar becomes one of recent main issues to be solved. Electricity is an essential role to be comfortable for people in rural area.

TABLE6. SIZING RESULT OF THE TAT THIT KYUN

Description	Values
Total Estimate load	312 kWh/day
PV module	315 W
Total number of modules	320 nos
Total number of PV module string	20 strings
Number of modules per string	16 nos
Total number of battery	192 nos
Ah per battery module	1500 Ah
Inverter capacity	120 kW
Diesel generator	80 kW

To solve these problems, solar power plant can be built in Tat Thit Kyun according to the design as Table 6.

Among them, Tat Thit Kyun village is lighted with solar and this village will consume 312 kWh per day. 16 numbers of 315W solar panel are connected in series in a string and 20 strings are needed for this plant. By connecting 192 numbers of batteries in series and 3 numbers of 40kW that is total 120 kW diesel generator, back up supply when night or rainy days is ready. Solar Power Plant Design which can get by surveying, estimating and calculation of above equations.

Figure 14: Seasonal Load Cycle Bar Chat for Tat Thit Kyun Village

Seasonal load cycle bar chat for Tat Thit Kyun Village is shown in Figure 14. Many loads is more used in April than other months. Moreover, maximum load can be increased nearly 50kW around a year.

Simulations are performed for four cases.

Case I : only diesel generator

Case II : diesel generator, battery and converter

Case III : PV, diesel generator and converter

Case IV : PV, diesel generator, battery and converter For all cases, Nominal Cash Flow and Comparison of Total Production and Consumption are expressed in following Table 7~14.

Table 7: Nominal Cash Flow for Case I

Component	Capital($)	Replacement($)	O & M ($)	Fuel ($)	Salvage ($)	Total ($)
Generator	$14202.00	$72546.71	$1132.45	$559828.18	-$958.23	$646751.12
Generator	$14202.00	$72546.71	$1132.45	$559828.18	-$958.23	$646751.12

Table 8: Comparison of Total Production and Consumption for Case I

Description	KWh/day	%
Total Production	564	100 %
Consumption	312	55.3 %
Excess Electricity	252	44.7 %

Table 7 and Table 8 are for Case I. In Generator only case, replacement is more than capital cost. Total cost for generator only case is $646751. Fuel cost may be increased by depending on World Bank. 312kWh consumption and excess electricity is 44.7%.

Table 9: Nominal Cash Flow for Case II

Component	Capital($)	Replacement($)	O & M ($)	Fuel ($)	Salvage ($)	Total ($)
Battery	$102336.00	$32625.47	$24820.83	$0.00	-$18386.54	$141395.76
Converter	$11666.50	$4949.79	$0.00	$0.00	-$931.60	$15684.69
Generator	$14202.00	$51332.63	$823.22	$412327.29	-$926.29	$477758.85
System	$128240.50	$88907.89	$25644.06	$412327.29	-$20244.44	$630839.30

Table 10: Comparison of Total Production and Consumption for Case II

Description	KWh/day	%
Electrical Production	418	100 %
Consumption	312	75.3 %
Excess Electricity	103	24.7 %

Table 9 and Table 10 are for Case II. In Diesel Generator, Battery and Converter case, replacement is less than capital cost. Total cost for this case, $630839. Savage value of Case II is -$20244. Fuel cost may be changed by depending on many factors. 312kWh consumption and excess electricity is 24.7%.

Table 11: Nominal Cash Flow for Case III

Component	Capital($)	Replacement($)	O & M ($)	Fuel ($)	Salvage ($)	Total ($)
Converter	$11666.50	$4949.79	$0.00	$0.00	-$931.60	$15684.69
Generator	$14202.00	$66163.23	$1026.70	$504441.16	-$1828.62	$584004.47
Solar	$57600.00	$0.00	$6463.76	$0.00	$0.00	$64063.76
System	$83468.50	$71113.02	$7490.46	$504441.16	-$2760.23	$663752.91

Table 11 and Table 12 are for Case III. In Solar, Generator and Converter case, replacement is less than capital cost. Total cost for this case, $663752. Salvage value of Case III -$2760. 312kWh consumption and excess electricity is 66.7%.

Table 12: Comparison of Total Production and Consumption for Case III

Description	KWh/day	%
Electrical Production	939	100 %
Consumption	312	33.3 %
Excess Electricity	626	66.7 %

Table 13 and Table 14 are for Case IV. In Solar, Generator, Battery and Converter Case, replacement is less than capital cost. Total cost for this case, $472264. Salvage value of Case IV is -$20799. 312kWh consumption and excess electricity is 50.9%.

Table 13: Nominal Cash Flow for Case IV

Component	Capital($)	Replacement($)	O & M ($)	Fuel ($)	Salvage ($)	Total ($)
Battery	$102336.00	$32625.47	$24820.83	$0.00	-$18386.54	$141395.76
Converter	$11666.50	$4949.79	$0.00	$0.00	-$931.60	$15684.69
Generator	$14202.00	$24165.04	$417.43	$213817.53	-$1481.27	$251120.73
Solar(PV)	$185804.50	$0.00	$6463.76	$0.00	$0.00	$64063.76
System	$185804.50	$61740.30	$31702.02	$213817.53	-$20799.41	$472264.94

Table 14: Comparison of Total Production and Consumption for Case IV

Description	KWh/day	%
Total Production	652	100 %
Consumption	312	49.1 %
Excess Electricity	332	50.9 %

Table 15: Comparison of Simulation Results

Description	Case I	Case II	Case III	Case IV
Total net present cost ($)	646751.10	634839.30	6637532.90	472264.90
Levelized cost of energy ($/kWh)	0.43	0.43	0.45	0.3
Capital cost ($)	14202.00	128204.50	83468.50	185804.5
Replacement cost ($)	72546.71	88907.89	71113.02	61740.3
O&M cost ($)	1132.45	25644.06	7490.46	31702.02
Fuel cost ($)	559828.18	412327.29	504441.16	213817.53
Renewable fraction (%)	0	0	0	29.6
Fuel consumption (L/yr)	86610	63791	78041	33079
CO_2 emission (kg/yr)	227325	167430	204834	86823

By comparing Case I, II, III and IV in Table 15, Case IV which is hybrid with solar and generator is the best. Total net present cost is the less $472264 among other cases. Moreover, Replacement cost and Fuel costs are less than other cases. The main generation is from Solar so not only fuel consumption which is 33079 L/yr but also CO2 emission 86823 kg/yr is very few.

Recommendations

For future work, other renewable energy sources should be added such as wind. Other hybrid system should be designed such as solar and hydro and solar and wind. The control system should be added to get more stable power. Optimization methods should be analyzed in this system. Moreover, generator detail design and wire sizing should be considered. Next, extra load and extra line length can be guessed for other years because the population of village can be increased. Or people can be extended many industrial due to good Government and Economic. Maintenance and operation should be thought as other factors. In Myanmar, it is required to think weather though peak sun hour is nearly 6 hour.

Conclusion

In Myanmar, renewable energy especially solar power is applied in many villages without connecting National Grid. This research work has been carried out in three parts. The first part is oriented in the collecting of the energy consumption and meteorological data of selected area. The second part is oriented in the consideration of the design procedure, and then the system is designed based on the data collected. In this design, all energy which is needed from village is sufficient by supplying solar power 100kW. But, battery and diesel generator are applied for back-up power during the night and no shining days. At present, demand is very less than supply about 50 percent. Finally, all data are analysis in Homer Software. The Case IV result is optimum solution for proposed area. It can fulfill the daily needs of electricity in rural area far from grid. It can improve the living standard of the rural community. It can decrease the fuel consumption. It can achieve the cost benefits and lesser greenhouse gas emission. Solar and Generator Hybrid is very suitable for rural area in Myanmar according to the many factors such as fuel consumption and CO2 emission.

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