Autonomous PV Stand-Alone System for Rural Electrification in Myanmar

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Abstract: *Incremental consumption of electrical energy, reduction of fossil fuel resources and environmental pollution problems caused by them are the main reasons which tend to develop the use of renewable energy. In the not-too-distant future, the use of renewable energy such as wind and solar will be very important and will play predominant role in economic indices of power system. A stand-alone system with renewable technologies is a promising solution for rural electrification. Myanmar has many renewable energy resources, and many regions that cannot be supplied with electricity from the main grid. Therefore, in this paper, a village in Myanmar, Tha Yet Pin Kan village which is located far away from the substation has been selected. And then, the load profiles of the household data from the village and the solar radiation have been determined. The economic feasibility of a stand-alone system composed of a photovoltaic source, battery energy storage system, and converter have been evaluated with HOMER tool.*

Key Words*: Battery, Homer, Renewable energy, Stand-alone system, Solar PV.*

1. INTRODUCTION:

At present, fossil fuel is the world's major energy sources. The non-renewable nature of fossil fuel and increasing energy demand have made it scarcer than before and therefore its price is sky-rocketing. On the other hand renewable energy such as wind and solar is omnipresent free and abundant in nature. Since the renewable energy technologies are improving, the electricity cost produced by renewable form is certainly going to decrease significantly in near future. Energy crisis, ever increasing oil prices, climate changes due to greenhouse gases and limitations imposed by Kyoto protocol in production of these gases have increased people's attention towards effective, efficient sustainable and almost pollution free renewable energy systems.

Even though renewable energy is novel, it is stochastic in nature. Its availability is sporadic and should be complemented by other power storage devices like batteries in most of cases [1]. Solar off grid PV system have components like modules, battery (if battery backup), controller and inverter (as most of appliances are running on AC). For the whole system design, it is necessary to estimate the load and then each component is selected as per ratings [2]. Stand-alone systems need to have generation and large storage capacity enough to handle the load. In a grid connected system, the size of storage device can be relatively smaller because deficient power can be obtained from the grid[1]. In Myanmar, according to the Ministry of Electricity and Energy, 39.4% of population gets electricity and 60.6% of population does not still get electricity. As the town, among 482 towns, 350 towns get electricity from the national grid and the rest of 132 towns get electricity in other ways. From the point of villages, there are 63737 villages in Myanmar. Among them 32228 villages can use electricity and the rest that do not have electricity are 31509 villages. Additionally, Myanmar has many renewable energy resources, such as hydropower, biomass, wind, solar and other types of clean energy. Therefore, the standalone system is suitable for application in developing country like Myanmar.

However, despite its apparent suitability, no study has been conducted so far to evaluate the economic feasibility of a stand-alone system, considering the specific local conditions and resource availability in Myanmar. In this works, for the purpose of evaluation, the Ta Yet Pin Kan village has been selected. It is situated in Nathar village administrative unit, Pauk Township, Pakokku district, Magway division, upper Myanmar. This village has not been connected to the electric grid until now. Most people in the village mainly depend on small petrol engines and batteries for lighting, phone changers and other electrical appliances and a few people use candle lamps. This village has hot and dry climate because it is situated in tropical zone. Therefore, this village can get sunlight in most of year.

Based on this evaluation setup, the daily and monthly load profiles for the household data from the village have been estimated, and the daily and monthly solar radiation profiles from the climate data have been obtained [3]. Then, the advantages of the standalone system are analyzed in terms of the cost through simulations using the Hybrid Optimization Model for Electric Renewable (HOMER) software [4]. Furthermore, the optimal size of each component is determined for the selected stand-alone system.

The remainder of this paper is organized as follows. Specific data on the load and solar radiation are presented in Section II. In Section III, the standalone PV system components are described. The mathematical model for evaluation is presented in Section IV. The simulation results are given in Section V. The concluding remarks are given in Section VI.

2. LOADAND SOLAR RADIATION PROFILES:

An energy load profile, or consumption profile, is essential to determine the size of PV system. The load profile of the household from the village was proposed considering the general hourly based load usage. Solar energy is the sun's ray that reaches the earth being converted to energy through different processes. Solar irradiance, measure of incoming solar radiation, is very important for solar energy system.

A. Load Profile

The Ta Yet Pin Kan village is located at 20.462 degree (North latitude) and 94.462 (East longitude) in the Magway region in Myanmar. The electricity loads are divided into two groups, residences and communal facilities. The residences group consists of 101 households in the low-, medium-, and high-income ranges. The electricity demand in the low-income range is limited to the requirements for lighting and phone, and the annual growth rate of electricity consumption is small. The households in the medium-income range additionally use electric fans, satellite and TV and their annual growth rate of electricity consumption is increasing rapidly. The households in the high-income range use refrigerators, rice cookers, kettle and water pump. The communal facilities include schools, library, clinic and monastery. The power consumption of each component in Table I is estimated by assuming the hourly usage pattern of the appliances for each load component.

From the consumption pattern of each load component, the daily and monthly load profiles for the village are calculated, and are shown in figure 1 and figure 2, respectively. The base and peak loads are 2 kW and 21 kW, respectively, which corresponds to a load factor of 0.132. Mid peaks of approximately11 kW occur in the morning, and high peaks of approximately7 kW occur in the evening. In contrast, a low demand of approximately 0.5kW is observed during the day and after the mid night. It is assumed that the determined load profiles do not change during the project life span of 25 years, that is, from 2018 to 2043.

Table I Load Consumption For Ta Yet Pin Kan village

Consumption		Numbers	Power consumption (kWh/day)
Residence	Low income	23	2.599
	Medium income	73	34.456
	High income	5	29.7
Communal facilities	School	1	0.256
	Monastery	1	0.474
Total power consumption per day			67.355

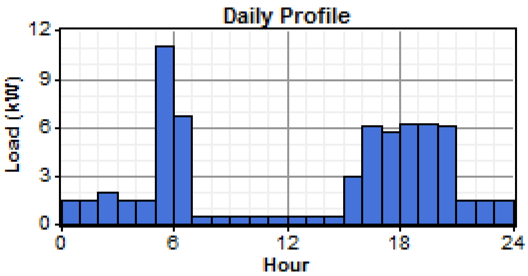

Figure 1.Daily Load Profile for the Proposed Area

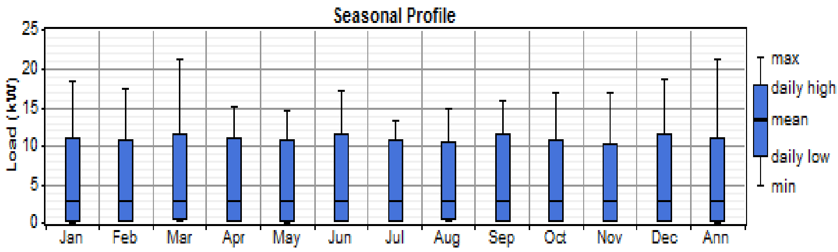

Figure.2 Load Profile for the Proposed Area

B. Solar Radiation Profile

The average solar radiation in Myanmar is more than 5 kWh/m^2/day during the dry season [5]. It varies from 2.3 to 3.2 kWh/m^2/day in the extreme north and south regions, while most parts of Myanmar, including the central area, receive a good amount of solar radiation ranging from 3.6 to 5.2 kWh/m^2/day [5]. Therefore, government and private sector organizations have been promoting and piloting solar PV systems for rural electrification [5].

The specific daily and monthly solar radiation profiles for the selected village are shown in figure 3 and figure 4, respectively. The daily profile in figure 3 shows the typical pattern for PV generation. The annual average radiation is 4.978 kWh/m^2/day. The highest and lowest solar radiation can occur in April and August, respectively. In April, the

PV array can satisfy the entire load during the day, and the load in the evening and night can be satisfied using the energy stored in the battery energy storage systems.

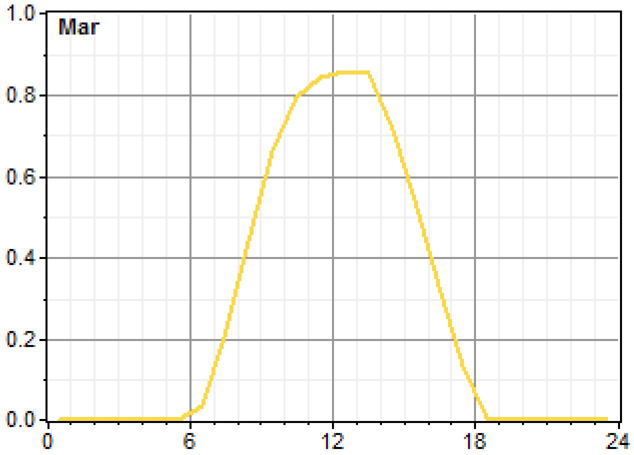

Figure 3.Daily Solar Radiation Profile for the Proposed Area

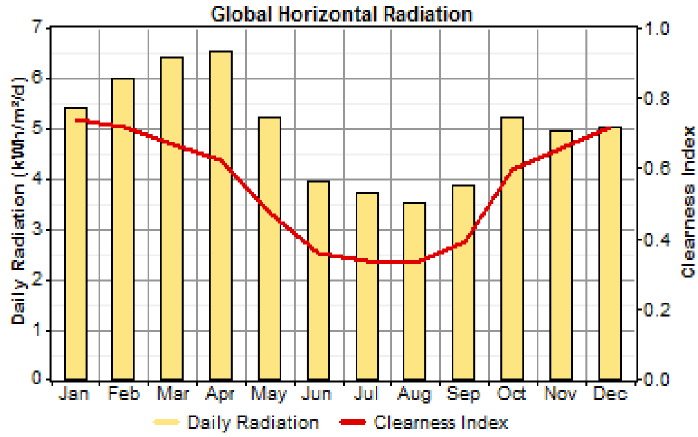

Figure4.Monthly Solar Radiation Profile for the Proposed Area

3. STAND-ALONE PVSYSTEM COMPONENTS:

The stand-alone system proposed in this research consists of solar PV arrays, battery energy storage and converters to obtain efficient and improve the system reliability of energy supply especially in rural areas. The power ratings or sizes of the systems are determined from the load profiles using the rule of thumb method in [7]. The configuration of the stand-alone system is shown in figure 5.

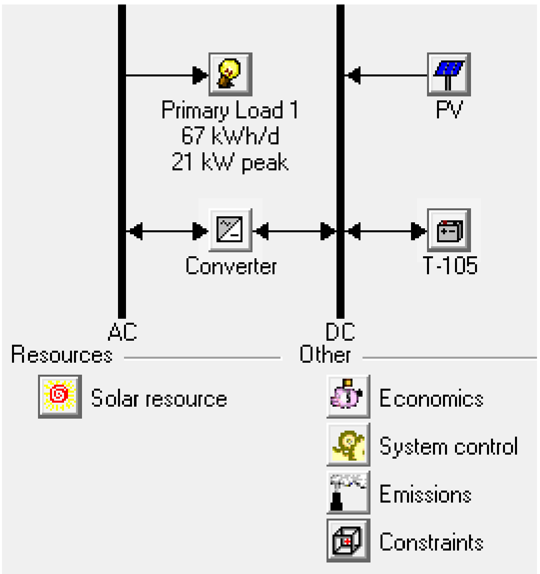

Figure 5.Structure of the Proposed Stand-Alone System

A. PV Array

The capital cost for the PV amounts to $36600 without considering other auxiliary components of the system. The module life time is estimated to be 25 years. The photovoltaic system has no tracking device. The technical and economical parameters of the PV system are listed in Table II.

Table I TECHNICAL AND ECONOMIC PARAMETERS OF THE PV SYSTEM

Parameter	Value	Unit
Capital Cost	400	$/Kw
Replacement Cost	0	$/Kw
Operation And Maintenance Cost	10	$/Yr
Lifetime	25	Years
Derating Factor	80	%

Tracking Factor	N/A	N/A
Ground Reflectance	20	%
Slope Degree	20.92	Degree
Temperature Effect	N/A	N/A

B. Battery Energy Storage System

The battery bank used in this paper contains TrojanT-105batteries with a string size of twelve. The battery energy storage system operates at a nominal voltage of 6V. The specific parameters of the battery system are listed in Table III.

TABLE III TECHNICAL AND ECONOMIC PARAMETERS OF THE BATTERY ENERGY STORAGE SYSTEM

Parameter	Value	Unit
Capital cost	200	\$/battery
Replacement cost	180	\$/battery
Operation and maintenance cost	5	\$/yr
Lifetime	10	years
Nominal capacity	225	Ah
Round trip efficiency	85	%
Minimum state-of-charge	30	%

C. Converter

The converter can operate as both an inverter and a rectifier, according to the direction of power flow. The specific parameters of the converter are listed in Table IV.

TABLE IV TECHNICAL AND ECONOMIC PARAMETERS OF THE CONVERTER

Parameter	Value	Units
Capital cost	340	\$/kW
Replacement cost	300	\$/kW
Operation and maintenance cost	10	\$/yr
Lifetime	20	years
Inverter efficiency	90	%
Rectifier efficiency	85	%

4. MATHEMATICAL MODEL FOR EVALUATION:

The performance of the stand-alone system can be analyzed based on the goals of cost minimization, system reliability improvement, and reduction of greenhouse gas emissions [4]. The net present cost is calculated by discounting the annual, quarterly, and monthly financial flows [8]. The net present cost of a system is the present value of all costs minus all values over its lifetime, and it includes capital costs, replacement costs, operation and maintenance costs, and fuel costs. The levelized cost of energy is calculated by dividing the total life-cycle cost by the total energy output during the project lifetime [9]. The mathematical equations are formulated for the simulations with HOMER tool, as follows [4], [8], [9].

$$C_{NPC} = \frac{C_{anntot}}{CRF(i,\ n)} \quad (1)$$

$$i = \frac{i_{non} - f}{1 + f} \quad (2)$$

$$LCOE = \frac{TlCC}{\sum_{n=1}^{N} \frac{Q(n)}{(1+r)^n}} \quad (3)$$

$$TLCC = \sum_{n=1}^{N} \frac{C(n)}{(1+r)^n} \quad (4)$$

$$S = C_{rep}\frac{L_{rem}}{L_{comp}} \quad (5)$$

$$f_{es} = \frac{E_{sc}}{E_{tot}} \quad (6)$$

$$CRF(i,\ n) = \frac{i(1+i)^{n}}{i(1+i)^{n} - 1} \quad (7)$$

The parameters in (1)−(7) are defined as follows.

C_{NPC} :net present cost ($)
C_{anntot} : total annualized cost ($/yr)
$CRF(i,\ n)$: capital recovery factor
i : annual real interest rate (%)
i_{non} : nominal interest rate (%)
f : annual inflation rate (%)
n : index for the year
N : project duration (yrs)
LCOE : levelized cost of energy ($/kWh)
TLCC : total life cycle cost ($)
$Q(n)$: energy output of power generation system in the specific year of *n* (kW)
$C(n)$: total cost in the specific year of *n* ($)
r : annual discount rate (%)
S : salvage value ($)
C_{rep} : replacement cost of the component ($)
L_{rem} : remaining life of the component (yrs)
L_{comp} : lifetime of the component (yrs)
f_{es} : capacity shortage fraction
E_{sc} : total capacity shortage (kWh/yr)
E_{tot} : total electric (kWh/yr)

5. SIMULATION RESULTS:

In order to investigate the optimization and economic analysis of the proposed stand-alone system, the HOMER software has been used. The technical and economical parameters of system component which are described in section 3 have been applied to perform the simulation with HOMER tool.

In the optimizing process, HOMER simulates every system configuration. Table V presents the HOMER simulation results with the interest rate of 3%.The table shows that the greatest optimal result is achieved when the system is composed of 23kW PV modules, 120 batteries, and a 10kW inverter and the least optimal result is obtained when PV is less used, and battery and converter are more used than the greatest result. The initial, operating, NPC, and electricity costs for this system is US$36,600,US$9,161,US$107,985 andUS$0.306/kWh respectively. The simulation result also shows that the second optimum system is for 23kW modules, 120 batteries, and a 20kW inverter. The size of inverter is bigger than the greatest result but its capacity shortage is less. The total initial and net present cost of this system are US$40,000 and US$114,021, the electricity cost and operating cost are US$ 0.322/kWh and US$4,251respectively. The most expensive system include 23kW PV module, 120 batteries and a 80kW inverter with initial, NPC, operating and electricity cost of US$ 60,400 US$ 5,053, US$ 148,387, and US$ 0.419/kWh respectively. The simulation result for the net present cost is shown in table VI and the simulation result of nominal cash flow and monthly average energy production are shown in Figure 6 and 7 respectively.

TABLE V SIMULATION RESULTOF PROPOSED STAND-ALONE SYSTEM

	PV (kW)	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
	23	120	10	$ 36,600	4,100	$ 107,985	0.306	1.00	0.20
	23	120	20	$ 40,000	4,251	$ 114,021	0.322	1.00	0.19
	23	120	30	$ 43,400	4,385	$ 119,748	0.338	1.00	0.19
	23	120	40	$ 46,800	4,518	$ 125,476	0.354	1.00	0.19
	23	120	50	$ 50,200	4,652	$ 131,204	0.370	1.00	0.19
	23	120	70	$ 57,000	4,919	$ 142,659	0.403	1.00	0.19
	23	120	80	$ 60,400	5,053	$ 148,387	0.419	1.00	0.19

TABLE VI Net Present Cost of System Components

component	Capitals($)	Replacement($)	O&M($)	Fuel($)	Salvage($)	Total($)
PV	9,200	0	4,005	0	0	213,205
Trojan T-105	24,000	58,750	10,448	0	-4,146	89,053
Converter	3,400	1,661	1,741	0	-1,075	5,728
system	36,600	60,441	16,194	0	-5220	107,985

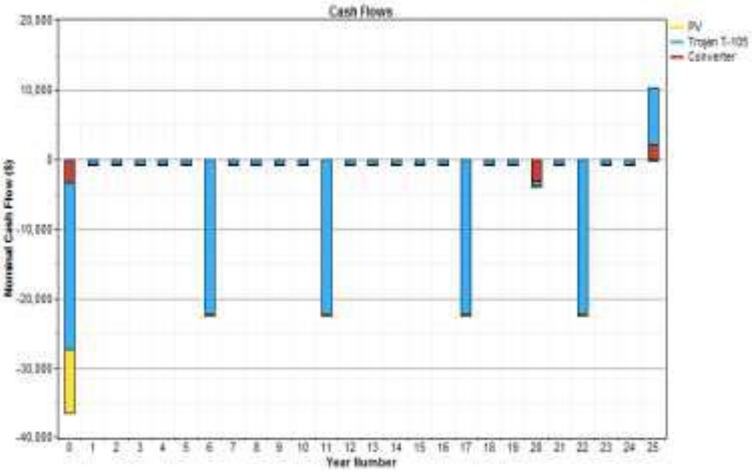

Figure.6Nominal Cash Flow of Proposed Stand-Alone System

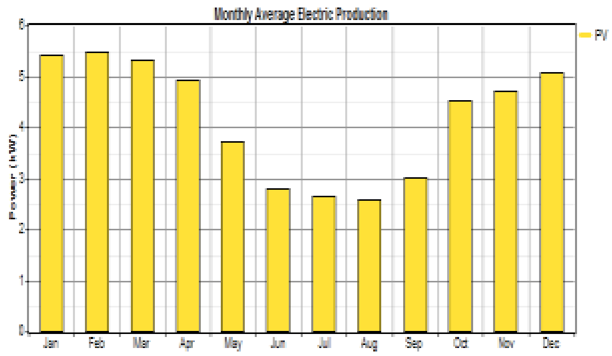

Figure.7 Monthly Average Energy Production

(1). Energy Production and Consumption: Table VII and VIII show the production and consumption of electricity. PV array produces 36,580kWh in a year and the energy consumption is 20,273kWh in a year.

TABLE VII ENERGY PRODUCTIONOF ELECTRICITY

Production	kWh/yr	%
PV array	36,580	100
Total	36,580	100

TABLE VIII
ENERGY CONSUMPTION OF ELECTRICITY

Consumption	kWh/yr	%
AC primary load	20,273	100
Total	20,273	100

(2). Cash Flow Summary: The cash flow summary in figure 8 shows that in the optimized proposed stand-alone system and most of the cost is required for the battery while the least cost is for the converter. The cost of PV is cheaper than the battery and is more expensive than that of the inverter.

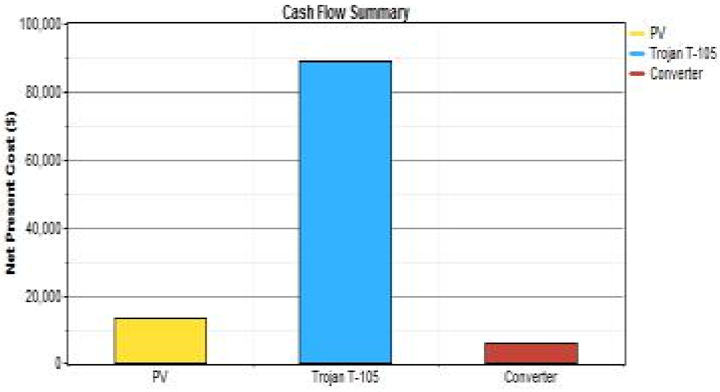

Figure 8.Cash Flow Summary of System Components

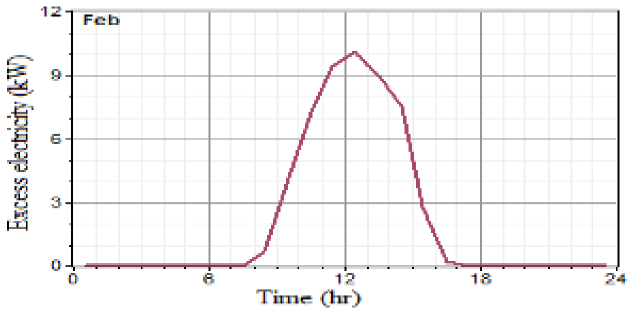

Figure.9 Production of Excess Electricity in Summer

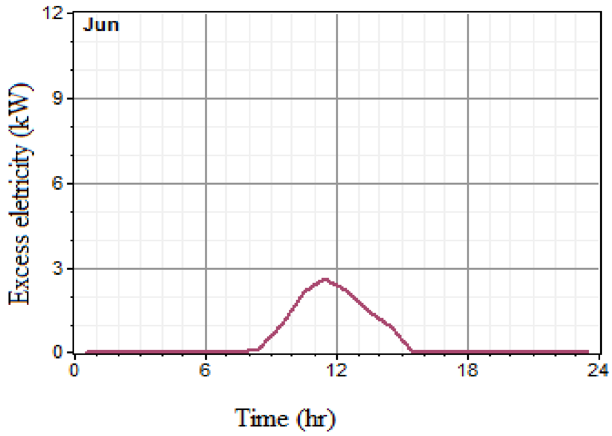

Figure.10 Production of Excess Electricity in Rainy Season

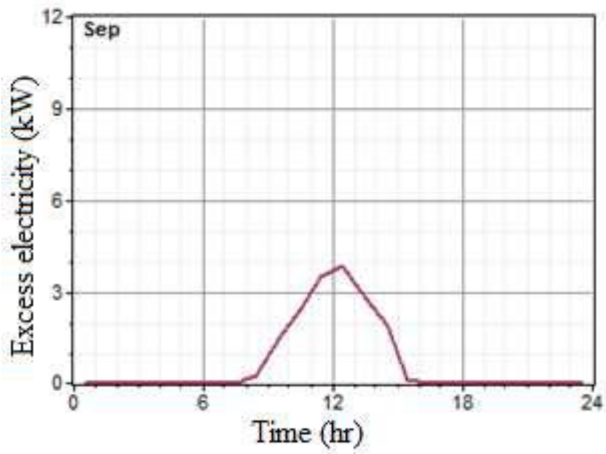

Figure. 11 Production of Excess Electricity in Winter

TABLE IX
ELECTRICAL RESULT OF PROPOSED SOLAR STAND-ALONE SYSTEM

Quantity	kWh/yr	%
Excess electricity	11,122	30.4
Unmet electric load	4,109	16.9
Capacity shortage	4,838	19.8
Quantity		Value
Renewable fraction		1.00

(3). Excess Electricity: The unused electricity are described in table IX. The proposed stand-alone system has produced an amount of 11,122 kWh/yr of excess electricity. This represents the excess energy due to fully charge battery or the loads that people do not use. Figure 9, 10 and 11 represent the excess electricity production seasonally and the amount of unmet load and capacity shortage are also shown in the table IX.

6. CONCLUSION:

Solar photovoltaic (PV) power system has a great potential in future as one of the renewable energy technologies for power generation. Myanmar is a country with a lot of renewable energy resources and non-electrified rural villages, which accord with the necessary conditions of the stand-alone system. According to the results obtained in this research, off grid standalone PV power plant can supply the whole village without other sources. According to the current cost of PV module, battery and the cost of energy ($/kWh) is still high, the initial cost is expected to decrease in the near future. Even though, using renewable energy sources is far more popular than the past while the cost of the components are decreasing. The proposed system is intended for not only to optimize the solar PV power system but also to decrease the air pollution which effects the environment.

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