Load Estimating and Calculating the Components of Solar System

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ABSTRACT

This paper is focused to develop solar system in rural area because the electricity is the backbone of the country's economy and only 40% is electrified in Myanmar. In design load estimating and calculation the components for the solar system and moreover environmental impact and climate change is also a fact to consider in it. Myanmar has high solar potential, photovoltaic (PV) system must be installed for most of the rural areas where there is no national grid line. To develop off-grid PV system which support for people to lift up their lives in rural areas. Mono-crystalline or single crystalline silicon photovoltaic cells and lead acid batteries are going to use in the system. The load estimation, PV sizing, inverter selection and battery sizing are calculated mainly. Based on the results, the design consideration can be absolutely applicable for the one village.

KEYWORDS: *solar radiation, load estimation, solar system, charge controller, batteries capacities*

1. INTRODUCTION

The solar constant for the Earth is the irradiance received by the Earth from the sun at the top of the atmosphere, i.e., at AM 0, and is equal to 1367Wh/m². After passing through the atmosphere with a path length of AM 1, the irradiance is reduced to approximately 1000Wh/m², and has a modified spectral content due to atmospheric absorption.

The irradiance for AM 1.5 is accepted as the standard calibration spectrum for photovoltaic cells. Irradiation is the measure of energy density of sunlight and is measured in kWh/m². Since energy is power integrated over time, irradiation is the integral of irradiance. Normally, the time frame for integration is one day, which means during daylight hours.

The average solar radiation in Myanmar is more than 5 kWh/m²/day during the dry season. It varies from 2.3 to 3.2 kWh/m²/day in the extreme north and south regions, while the majority regions in Myanmar including the central area have good solar radiation ranging from 3.6 to 5.2 kWh/m²/day in figure (2). Therefore, government and private sector organizations have been promoting and piloting solar PV systems for rural electrification[3].

The specific monthly solar radiation profile for the selected village model is shown in Figure (1). The radiation is over 2000 Wh/m². From this figure, the radiation is highest in April (6.422 kWh/m²/day) and is lowest in August (4.532 kWh/m²/day).

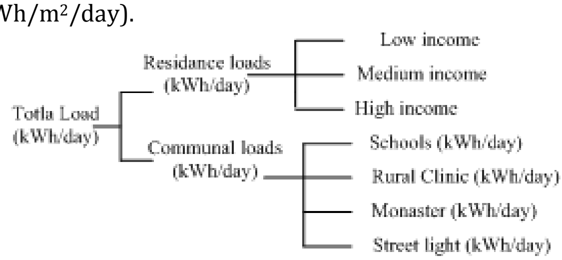

Figure1. Model of Load Design for a Village

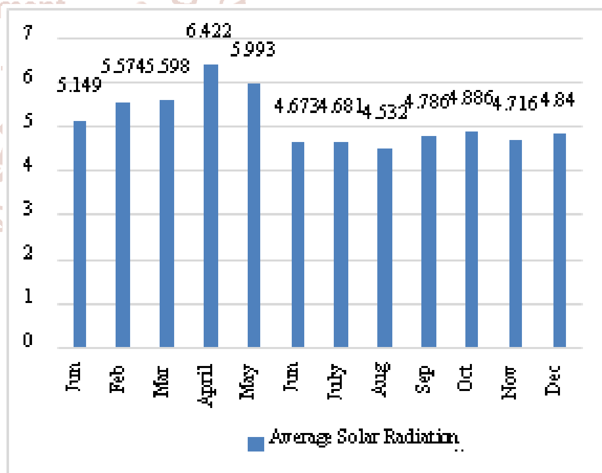

Figure2. Monthly Solar Radiations of the Selected Village

2. Mathematical Review

The necessary equations are considered for designing covered of solar system which is applied for a village. 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°, and a simple sinusoidal relationship that assumes a 365 day per year and which puts the spring equinox on day n = 81 provides a very good approximation.

$$\delta = 23.45° \sin\left[\frac{360}{365}(n-81)\right] \quad \text{Equation (1)}$$

where,
δ = the angle between the plane of the equator and a line drawn from the center of the sun and center of the earth (varies between extremes of ± 23.45^0)
β_N = altitude angle of the sun at noon
L = latitude angle of the selected location

$$\beta_N = 90° - L + \delta \quad \text{Equation (2)}$$

The tilt angle that would make the sun's rays perpendicular to the module at noon would therefore be:
Tilt angle of array, $\theta = 90° - \beta_N$

Total load demand (Wh /day)
= Power in Watt × Hours in use Equation (3)

Total load demand (Ah/day)

$$= \frac{\text{Total load (kWh/day)}}{\text{System Voltage} \times \text{Inverter efficiency}} \quad \text{Equation (4)}$$

Equivalent sun hours is equal to total sum hours/365 days. System battery size can be calculated by using the following Equations. The required daily average energy demand has already been calculated.

the required daily average energy demand, E_{rd}

$$E_{rd} = \frac{E_d}{\eta_{bat}\eta_{inv}\eta_c} \quad \textbf{Equation (5)}$$

where,
η_{bat} = the efficiency of the battery
η_{inv} = the efficiency of the inverter
η_c = the efficiency of the cables

The estimate energy storage, E_{est}
= E_{rd} × the number of autonomy days Equation (6)

The safe energy storage,

$$E_{safe} = \frac{\text{the estimate energy storage, } E_{sd}}{\text{maximum depth of discharge, } D_{dish}} \quad \text{Equation (7)}$$

The total capacity of battery bank in ampere-hours, C_{tb}

$$C_{tb} = \frac{\text{the safe energy storage, } E_{safe}}{\text{the rated dc voltage of one battery, } V_b} \quad \text{Equation(8)}$$

The total number of batteries,

$$N_t = \frac{\text{total capacityof batterybank Ahs}}{\text{the capacityof slectedone battery}} \quad \text{Equation (9)}$$

The number of batteries in series,

$$N_{sb} = V_{dc}/V_b \quad \text{Equation (10)}$$

The number of parallel batteries,

$$N_{pb} = N_{tb}/N_{sb} \quad \text{Equation (11)}$$

The total number of batteries,

$$N_{tb} = N_{sb} \times N_{pb} \quad \text{Equation (12)}$$

2.1. Determining the Sizing of PV Array

System array size is essential for the calculation of standalone solar electricity generation system. The more there is system capacity, the more the module capacity is selected.

The average peak power,

$$P_{ave,peak} = \frac{E_{rd}}{T_{sh} \times \text{Derating factor}} \text{ kWh/day} \quad \text{Equation (13)}$$

where,
T_{sh} = the peak sun hours (hrs./day)

The total dc current of the system,

$$I_{dc} = \frac{P_{peak}}{V_{dc}} \text{ A} \quad \text{Equation (14)}$$

The total number of modules,

$$N_{total} = \frac{\text{Average Peak Power}}{\text{Power of one module}} \quad \text{Equation (15)}$$

The number of modules in series,

$$N_s = \frac{V_{dc}}{V_{rm}} \quad \text{Equation (16)}$$

The number of parallel modules strings,

$$N_p = \frac{I_{dc}}{I_{rm}} \quad \text{Equation (17)}$$

Where,
V_{dc} = the dc voltage of the system
V_{rm} = the rated voltage of each module
I_{rm} = the rated current of each module

The total number of modules,

$$N_{total} = N_s \times N_p \quad \text{Equation (18)}$$

The output power of PV array
= N_{total} × Power of one module Equation (19)

And then, Array rated current
= $N_p \times I_{mpp}$ Equation (20)

Array short-circuit current
= $N_p \times I_{sc}$ Equation (21)

Array rated voltage
= $N_s \times V_{mpp}$ Equation (22)

Array opened-circuit voltage
= $N_s \times V_{oc}$ Equation (23)

Where,
I_{sc} = the short circuit current
I_{mp} = the current at maximum power point
V_{mp} = the voltage at maximum power point
V_{oc} = the opened circuit voltage

Minimum Controller Input Current,
$I_{sc,min} = N_p \times I_{sc} \times$ safety factor Equation (24)

This is the input current that comes from the solar array. The number of parallel strings in the array increases the current. To be on the safe side, it is advised to multiply the result by a safety factor of 1.25.

2.2. Determination of Cables Size

The wiring must not reduce the performance of any of the components of the system. The cables in a mini grid connected system must be sized correctly to reduce the voltage drops in the cable and to make sure that the safe current handling capacity of the cable is not exceeded. The voltage drop in a cable is given as,

$$\Delta V = 2\,(L \times I \times \rho) / A \quad \text{Equation (25)}$$

where,

ρ = the resistivity of copper wire which is normally taken to be $1.724 \times 10^{-8}\ \Omega m$

L = the length of cables in meters

I = the current through the cables in amperes

A = the cross-sectional area in mm^2

The multiplication by 2 accounts for total circuit wire length.

ΔV = Maximum cable voltage drop (5%) × system voltage Equation (26)

In the design of the system, a maximum cable voltage drops of 5% was used that is why the maximum allowable drop in PV mini grid connected systems.

2.3. Considering System Voltage

Total load demand (W/day) is divided by the system voltage. It is smaller less than 100A.

Thus, Let system voltage be 12V, 18kW/day ÷ 12V
= 1500A > 100A

Let system voltage be 24V, 18kW/day ÷ 24V
= 750A > 100A

Let system voltage be 48V, 18kW/day ÷ 48V
= 375A > 100A

Let system voltage be 96V, 18kW/day ÷ 96V
= 187A > 100A

Let system voltage be 192V, 18kW/day ÷ 192V
= 94A < 100A

Therefore, system voltage 192V is chosen.

2.4. Calculating Inverter Size

Inverter size is important

= Maximum Peak Hour Demand ∗ 1.25

= 55 kW ∗ 1.25 = 68750 W

Therefore, 70 kVA three phase inverter is chosen.

Total load demand (Wh /day)

= Power in Watt × Hours in use

= 428 kWh

Total load demand (Ah/day)

$$= \frac{\text{Total load (kWh/day)}}{\text{System Voltage} \times \text{Inverter efficiency}}$$

= 2623 Ah/day

Assuming; The efficiency of the inverter is 85%.

2.5. Considering System Losses

The total loads plus the system losses (10%)
= Total Estimated Load (Ah/day) + 10%
= 2623 + 10%
= 2885 Ah/day

2.6. Calculating the Solar Irradiation in Daily Equivalent Sun Hours

Total sun hours = $2000 kWhm^{-2}/1000 Wm^{-2}$
Total hours = 2000 hrs
Therefore, Equivalent sun hours = 2000hrs/365days
= 5.5 hrs/day

3. Consideration for Results

The demand side has to size the load and calculate the daily energy consumption in kWh. The configuration for managing the total load consumption for the entire site is shown in table. which describes the total daily load demand for residence, communal facilities, and commercial facilities.

The proposed area is a village as a sample selection, which is located in central Myanmar at 19.00^0 Latitude and 95.00^0 Longitude nearly. Most of the people in this village mainly depend on small patrol engine, batteries and some of people are using candle lamp for lighting, phone charger and other electricity appliances.

Load profile is mainly divided into three portions that are residence, communal facilities and commercial facilities. In residence, there are many kinds of household level such as a high-income level, medium income level and low-income level respectively. Electricity demand in low income level is limited to lighting and TV, and the annual growth rate of electricity consumption is small. In such Medium household level, the annual growth rate of electricity consumption is rapidly increasing. It is considered the facts as shown in table 4.

It is calculated in the whole in which system battery size; no of parallel batteries, battery capacity and data for PV array, Total Daily Demand Estimation for Proposed Village and Maximum Peak Hour Demand for Proposed Village. Maximum peak hour demand is 55kW/h, no of batteries are (12V 200Ah) (608) nos as shown in table (7).

Table2. Total Daily Demand Estimation for Proposed Village

No.	Types of Loads		Daily Demands (Wh)	Remark
1.	Households	Low-income	177000	200 households
		Medium-income	167800	100 households
		High-income	61875	25 households
2.	School 1		1179	
3.	School 2		683	
4.	Clinic		2863	
5.	Monastery 1		3286	
6.	Monastery 2		2876	
7.	Street Lights		10800	
Total Daily Demand			428362 Wh/day	18 kW/day

Table3. Maximum Peak Hour Demand for Proposed Village

No.	Types of Loads		Peak Hour Demand (W/h)	Remark
1.	Households	Low-income	20000	200 households
		Medium-income	30000	100 households
		High-income	7500	25 households
2.	School 1		175	
3.	School 2		130	
4.	Clinic		1060	
5.	Monastery 1		1200	
6.	Monastery 2		1120	
7.	Street Lights		900	
Maximum Peak Hour Demand (W/h)			55000 W/h	7-10 pm

Table4. Daily Load Estimation for Medium Income Households

Type of Load	Time of usage /day(h)	Capacity of load (W)	Daily usage (Wh)
LCD/LED	4	75	300
Portable Player	2	25	50
LED bulb	22	3	66
Florescent Lamp	9	8	72
Street Light	11	10	110
Mobile Charger	6	10	60
Power Bank	2	100	200
Torch Light	1	10	10
DVD Player	4	20	80
Set-Top Box	4	20	80
Sound Box	2	100	200
Refrigerator	9	50	450
Total daily usage (Wh)			1678

Table5. Design Data for System Battery Size

System battery capacity	200Ah, 12V
Number of parallel batteries	38
Number of series batteries	16
Total number of batteries	608 Nos
Required battery Ah capacity	122687.5 Ah
Allowable depth of discharge	80%
Max. efficiency	95%

Table6. Design Data for PV Array

Model	24V 250W PV Panel
Number of parallel modules	55
Number of series modules	8
Total number of modules	440 Nos
Array rated current	436.7 A
Array short-circuit current	478.5 A
Array rated voltage	252 V
Array opened-circuit voltage	302.4 V

Table7. Summarized Design Data of Proposed System

Site name	Central Myanmar
Site location	19.00 Latitude and 95.00° Longitude
Equivalent sun hour (ESH)	5.5 hrs
Total daily demand	18 kW
Maximum peak hour demand	55000 W/h
System voltage	192 V
Solar panel (24V 250W)	440 nos
Number of modules in series	8 nos
Number of parallel modules strings	55 nos
Battery (12V 200Ah)	608 nos
Number of batteries in series	16 nos
Number of batteries in parallel	38 nos
Charge Controller (MPPT)	600 A
Inverter (Pure Sine Wave)	70 kVA, 3 phases

4. Conclusions

This paper hope that to support the designed solar system for rural area development in which load demand and design focus components were expressed in detail. There are medium income households, monastery, clinic, school and street lights. Moreover the inverter type, PV array, Solar Irradiation in Daily Equivalent Sun Hours, system losses, system voltage and cable size is mainly considered. It will be useful for a village at central Myanmar inwhere 200 households are living in these areas.

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