Optimal Sizing of Photovoltaic Based Rural Electrification System under the Influence of Various Seasonal Conditions

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Abstract: *The characteristics of power produced from photovoltaic (PV) is based on the weather condition. It is very unreliable in itself without sufficient capacity storage devices like batteries or back-up system like conventional engine generators. Sufficient battery bank capacity is required to provide power to the load in extended cloudy days. But, the weather conditions are changed in every season of a year. On the other hence, load consumption of rural people are also changed in each season depend on their requirements. Changing the system sizing for each season is not easy and the optimal sizing of system component represents the important part of PV power system for each season. This paper summarizes a case study of Kokekokwa village which is situated at 20.53 latitude and 95.01longitudes, Yenangyaung Township, Magway Region in Myanmar. In Myanmar, we have three seasons in a year. The load consumption of the village and the temperature and irradiation of this region for three seasons are taking into account to calculate PV power system. In this paper, a new idea of optimal sizing calculation of PV power system for every variations of seasonal weather conditions and load consumptions.*

Key Words: *photovoltaic, rural electrification, optimal sizing, weather conditions, load variations.*

1. INTRODUCTION:

Nowadays, due to the decrease of conventional energy sources and growing problem of environmental pollution, renewable energy sources are playing a big role in producing electricity. Among them, solar and wind are popular renewable energy sources, that have concerned with more and more attention. Solar energy has become a promising, popular and alternative source because of its advantages such as abundance, pollution free, renewability and maintenance free. Today's electricity supply in Myanmar is generated by fuel generators and hydroelectric power plants[1].

In the remote areas, which are isolated from utility grid, standalone operation of PV system is the best option. But due to diurnal cycle of the earth and weather condition, solar energy is not constant to fulfill the power demand of the varying local load. So, the use of dedicated energy storage system needs to be taken into account to make this intermittent PV power more dispatchable and stable.

The number of PV installations increases day by day. Since the initial cost of the PV system is high, the users need to be ensured that the PV system installed will be reliable and energetically efficient. Moreover, photovoltaic panels generate energy intermittently, due to the frequent changes in the solar radiation. Therefore, the main objectives of this system are to develop the optimum size of the system's components, namely the surface of the photovoltaic panels and the battery bank capacity and to establish an optimum algorithm for the installation's energy management.

The problem statement of this research is that the energy generation depends on the climatic parameters (namely the solar radiation), the site and panel characteristics. In general, photovoltaic energy is abundant during the warm season, characterized by an important sun light, and it is low during the cold season, characterized by rapid changes in the solar radiation

Kokekokwa village is situated in Kokekokwa Group, Yenangyaung Township, Magway Division of Myanmar. It is between 95.02 degrees (East Longitude) and 20.53 degrees (North Latitude). Therefore, it can get plentiful sunshine. It is a small village that has about three hundred fifty households and two public buildings. Lighting and water pumping are so important that people want to achieve sufficient electricity for their village. The climate data for PV energy has been found through NASA's website and the average solar insolation for this area is observed as 5.178 kWh/m2/ day.

2. PHOTOVOLTAIC BASED RURAL ELECTRIFICATION:

Photovoltaic (PV) systems are composed of interconnected components designed to accomplish specific goals, ranging from powering a small device to feeding electricity into the main distribution grid. More specifically, PV devices convert sunlight into DC electricity. Such energy is transferred to the load or to the utility grid by means of a subsystem [5].

There are two main classifications:
(a) Stand-alone systems;
(b) Grid connected systems.

The main distinguishing factor between these two categories is that in stand-alone systems the solar energy output is matched with the load demand. When a PV system is interconnected with the main grid, it may deliver excess energy to the grid or use the grid as a backup system, in case of insufficient photovoltaic generation. Stand-alone systems are mostly used in the cases of rural electrification [6].

Solar mini-grids are an ideal alternative to grid electricity in remote villages that do not have grid connectivity. And because mini-grids are independent entities, they can also be controlled and managed without presenting threats to the conventional grid [7]. Such distributed energy systems also provide more reliable electricity, as any outages or interruptions to electricity supply can be quickly identified and corrected. Additionally, having the site of power generation closer to the load also reduces transmission and distribution losses.

3. GEOMETRY OF PROPOSED AREA:

The case study is considered for supplying electricity to Kokekokwa village; it is located in Yenangyaung Township, Magway Region, Myanmar. The people who live in this area do not access grid electricity; they are located away from the national grid. The standalone PV system can help supplying electricity to this area and improve their livelihood. Figure 1 shows the map indicating the Kokekokwa village.

Figure 1. Location of Kokekokwa Village (Google map)

Table 1. Temperature and Sunshine Hour of Kokekokwa Village for the Year 2017

Month	Maximum (˚C)	Minimum (˚C)	Mean (˚C)	Sunshine hour
Jan	35.8	8.6	22.2	5.09
Feb	38.8	10	24.4	5.70
Mar	41.2	11	26.1	6.13
Apr	45.5	16.7	31.1	6.38
May	41.7	18.8	30.25	5.84
June	37.7	18.8	28.25	5.05
July	35.5	19	27.25	4.91
Aug	35.2	19	27.1	4.71
Sep	36	19.5	27.75	4.68
Oct	36	16.5	26.25	4.57
Nov	35.7	10.2	22.95	4.45
Dec	33	11.5	22.25	4.63

Kokekokwa village is situated between North Latitude 20˚ 31′ and East Longitude 96˚ 09′. The elevation above sea level is 0.395 km and situated Magway region within tropical zone. The local standard time of meridian is 97˚ 30′ E. The available average temperature is 26.32 ˚C. The maximum, minimum, mean temperatures and sunshine hour of Kokekokwa village for the year 2017 are maintained in Table 1. The data are obtained from "NASA surface Meteorology and Solar Energy".

4. LOAD DEMAND FOR PROPOSED SYSTEM:

The demand side load profile has to size the load and to calculate the daily energy consumption in kWh. The electrical loads include lighting, medium size refrigerator, pump, computer and other ordinary household electrical appliances, e.g. TV sets, electric fan, phone charger, Rice cooker, etc. For this village, five models are sized and designed for the provision of electricity to different target groups. By collecting questionnaire survey to these target groups, total power consumption for Kokekokwa village can be determined. The application of the village is AC residence only.

The village has public buildings such as School, Clinic and Monastery. Not only residential loads but also street light is taken into account in calculation. There are two numbers of pumping motors and each motor consumes 1119 W. Its maximum working hour is limited to two hours. Total power consumption of the Kokekokwa village is listed in Table 2.

Table 2. Total power consumption of the Kokekokwa village

No.	Load Description	Power Consumption(W)	Quantity	Total Power Consumption(W)
1	Florescent Lamp (2', 4')	(20W, 40W)	(500, 216)	18640
2	LED lamp, Flood Lamp, Street Lighting	(13W, 200W, 13W)	(39, 2, 36)	1375
3	TV and DVD (19"(CRT), 21", 24", DVD)	(180W, 120W, 100W, 10W)	(150, 65, 37, 252)	41020
4	Phone Charger	(3.7 W)	(534)	1975.8
5	Fan, Air cooler, Ceiling fan, Freezer	(50W, 100W, 47W, 300 W)	(211,37,2,103)	45244
6	Rice Cooker, Iron, Kettle	(500W, 1500W, 500W)	(101,36,1)	105000
7	Pump	(1119 W)	(2)	2238
Total Power Consumption				215492.8

Although total connected load of Kokekokwa Village is 215.5 kW, due to the behaviour of electric power consumers from this village, the maximum demand of load consumption is 83 kW in summer. Daily load energy consumption for summer (February, March, April, and May), monsoon (June, July, August, September) and winter (October, November, December, January) are shown in Figure 2.

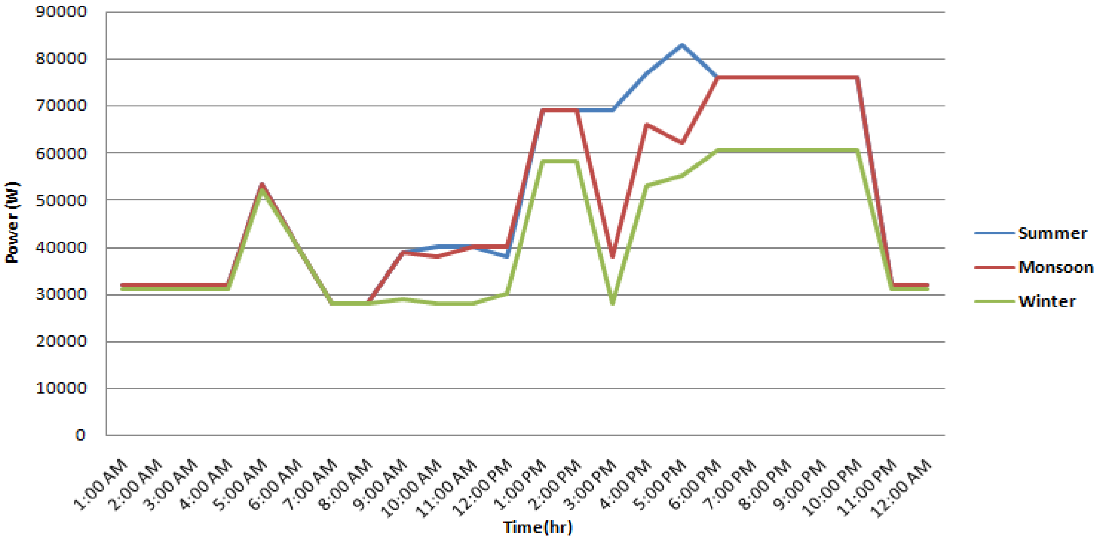

Figure 2. Daily Load Profile of Kokekokwa Village for Three Seasons

5. CALCULATION OF SOLAR RADIATION FOR THE PROPOSED AREA:

In design calculation of the solar radiation, design location is considered for Kokekokwa village, Yenangyaung Township, Magway Region, Myanmar. The weather is assumed clear sky day and the seasonal variation is negligible. In addition, the environmental parameters are taken from the department of Metrology.

For the target region, the parameters are calculated as; for site elevation parameters a_0 = 0.1577 m and a_1=7125m, constant k = 0.36, angle of radiation incident θ_i = 48.97˚, the azimuth angle θ_z = 44.02˚, slope angle of azimuth angle β=28.82˚ and ground reflectivity ρ_g is 20%.

Table 5. Calculation of solar radiation for target area for 21st April 9 am

Parameter	Symbol	Equations	Values
Effective solar radiation	$I_{o,eff}$	$I_{o,eff} = I_o\left(1+0.033\cos\frac{360n}{365}\right)$	1351.96 W/m^2
Beam radiation	I_b	$I_b = I_{o,eff}\left[a_o + a_1\exp\left(\frac{-k}{\cos\theta_z}\right)\right]$	797.337 W/m^2
Diffuse radiation	I_d	$I_d = [0.271I_{o,eff} + 0.294I_b]\cos\theta_z$	94.89 W/m^2
Hemisphere radiation	I_h	$I_h = I_b\cos\theta_z + I_d$	668.25 W/m^2
Total solar radiation	I_t	$I_t = I_b\cos\theta_i + I_d\left(\frac{1+\cos\beta}{2}\right) + I_h\rho_g\left(\frac{1-\cos\beta}{2}\right)$	620.705 W/m^2

For 21st April 9 am, beam radiation (I_b), direct radiation (I_d), total radiations on the horizontal surface (I_h), and total solar radiations on the tilted surface (I_t) can be calculated as above procedures. These procedures are also used for calculating the other months and times. The calculating results for 21st January to December are shown in Figure 3.

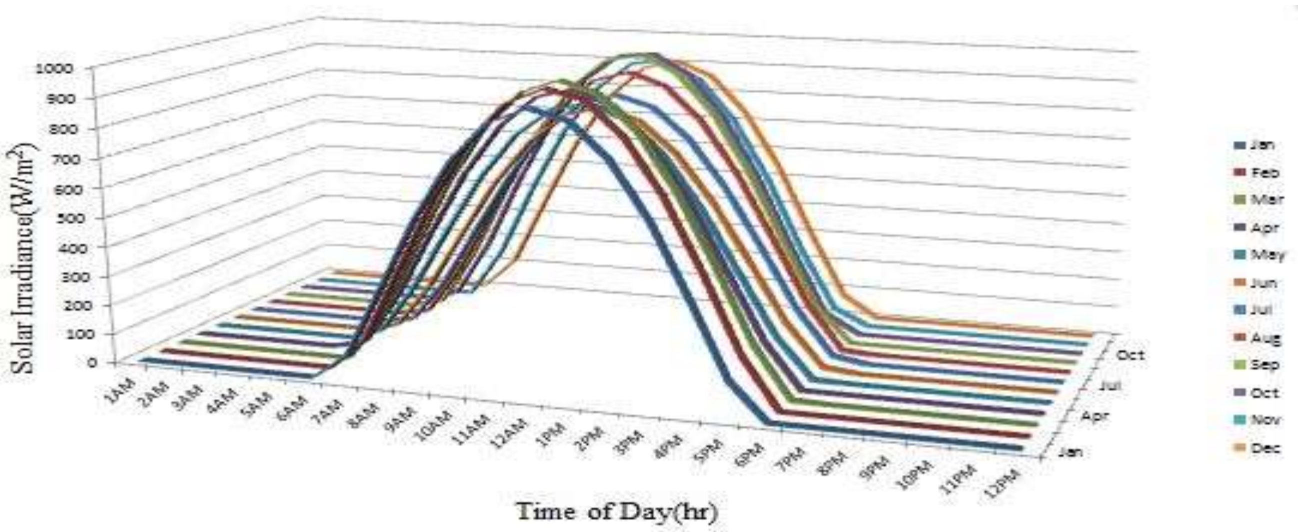

Figure 3. Calculated Result of total Solar Radiation (I_t) for 21st January to December

6. DETERMINING THE SIZING OF PV ARRAY :

In designing PV array, daily energy consumption for three seasons is assumed. The daily energy consumption in summer is higher than the other two seasons. The daily energy consumption for rainy season is lowest, in which fan load is less and pump load is not as used as other seasons. PV array sizing is based on the energy demand (Wh) of the proposed system. The energy demand data are referred from Figure 2. Assuming that energy losses factor is 1.2 and overall efficiency of PV array (η) is 0.8, we can calculate energy required per day by the equation; Energy required per day = 1.2xE/ η. The energy required per day is calculated as shown in Table 6.

Table 6. Energy required per day for each seasons

Seasons	Summer	Monsoon	Winter
Energy demand per day (E)	1243.875 kWh	1182.675kWh	1017.385kWh
Actual Energy required per day	1865.813 kWh	1774.01kWh	1526.078 kWh

7. PV ARRAY SIZING :

The average value of sunshine hours is obtained from summer (February, March, April, and May), Monsoon (June, July, August and September) and Winter (October, November, December and January). The following data are referred from Table 1.

Table 7. Irradiance, Peak sun hour and Ambient temperature of target area for each seasons

Parameters	Symbol	Values for each season			Unit
		Summer	Monsoon	Winter	
Irradiance	G	800	607.5	655	W/m2
Peak sun hour	PSH	6.01	4.84	4.69	hrs/day
Ambient temperature	TA (ºC)	27.1	25.27	22.15	˚C

From these values, we can calculate PV system parameters for each season with the following equations;

Cell temperature of module TC $= TA\,(^\circ C) + \left[\frac{NOCT\text{-}20}{800}\right] \times G$ (1)

Heat Losses from Temperature Degradation = (TC – 25) × Temperature Coefficient (%) (2)
Heat Losses Efficiency Factor (%) = 100% – Heat Losses from Temperature Degradation (%) (3)
PV's Efficiency = 100% × [Tolerance / Dust / Mismatches efficiency factor (%)]
× (PV module) Heat losses efficiency factor (%) (4)
PV's output (W) = PV's Power Rating × PV's Efficiency (%) × Battery Efficiency (%)
× Wire Efficiency (%) × Inverter Efficiency (%) (5)
Energy output per = PV's Power Rating × PV's Efficiency (%) module per day ×Battery Efficiency
× Wire Efficiency (%) × Inverter Efficiency (%) × PSH (6)

$$\text{Total number of modules required} = \frac{\text{Total energy needed}}{\text{Energy produced by 1 panel per day}} \quad (7)$$

$$\text{Number of series connected modules} = \frac{\text{Nominal system voltage}}{\text{Module rated voltage}} \quad (8)$$

$$\text{Number of parallel connected modules} = \frac{\text{Total number of modules}}{\text{Number of series connected modules}} \quad (9)$$

Array rated current = Number of parallel connected modules × Rated current of module (10)
Array short circuit current = Number of parallel connected modules× Short circuit current of module (11)
Array rated voltage = Number of series connected modules × Rated voltage of module (12)

Array open circuit voltage = Number of series connected modules× Open circuit voltage of module (13)
Output power of PV array = Total number of modules required × Output power of PV module (14)

Based on the parameters from table 2 and table 3 and by using equation (1) to (14), we can calculate design parameters of PV power system for Summer (February, March, Apirl and May), Monsoon (June, July, August and September) and Winter (October, November, December and January). Design parameters of PV power system for each season are described in table 4. In this case, SunPowerSolar Panel is chosen.

Table 4 Design parameter of PV power system for each season

Parameters	Symbol	Values for each season			Unit
		Summer	Monsoon	Winter	
Number of parallel modules	Npm	133	157	139	Nos.
Number of series modules	Nsm	8	8	8	Nos.
Total number of modules	Nt	1064	1256	1112	Nos.
Array rated current	Ir	756.77	893.33	790.91	A
Array short circuit current	Isc	809.97	956.13	846.51	A
Array rated voltage	Vr	583.2	583.2	583.2	V
Array open circuit voltage	Voc	682.4	682.4	682.4	V
Module area	A	2298	2713	2402	m2

Table 4 shows short-circuit current, open-circuit voltage, array rated current, array rated voltage, and number of required modules for summer, monsoon and winter. From this table, if we choose the summer option, the required panels are 1064numbers and the winter is 1112 numbers and for monsoon 1256 number of solar panels will be required. If summer or winter option is chosen, it may not supply enough power in monsoon. So, the design of PV array for monsoon is chosen for proposed area.

8. CHOOSING INVERTER BATTERY BANK SIZE:

Since the generated power of the array is greater than 6kW, the usable inverter should be three phases. According to the results in Table.2, total capacity of power consumption is 215.493kW. For the purpose of safety, the inverter size should be more than 25 to 30 percents of load consumption power. Thereafter, the inverter, 269.366kW, is accommodated with solar generation system. So, the suitable inverter for the system will have to be 300 kW and three phases.

Batteries used in all solar systems are sized in Ampere hours under standard test condition (Temperature 2˚C). Battery manufactures usually specify the maximum allowable depth of discharge for their batteries. The depth of discharge is for measuring how much the total battery capacity has been consumed. For most batteries the maximum allowable depth of discharge is 0.8. Table 4.12 illustrates the design data sheet for system battery size required for the proposed system or 80 percent. Daily energy consumption is 1676.268 kW and system voltage is set as 600V. So required battery capacity is calculated as 6985 Ah with 2 autonomy days. Deep cycle high efficiency 2V 1500Ah battery is selected and from these data, we can calculate number of batteries in series is 300, number of batteries in parallel is 5 and total batteries requirement is 1500 numbers. Table 5 shows required parameters of battery bank.

Table 5. Parameters for Battery Bank of PV System

No	Parameters	Values
1	System battery capacity	1500 Ah, 2 V
2	Number of parallel batteries	5 Nos
3	Number of series batteries	300 Nos
4	Total number of batteries	1500 Nos
5	Required battery capacity	6985 Ah
6	Total battery Ah capacity	7500 Ah
7	Charging time to full battery	6 hrs.
8	Allowable depth of discharge	0.8

9. CONCLUSION:

In this research, a standalone photovoltaic (PV) system is taken, in which a storage device is used as a backup source. Daily energy consumption for Summer (February, March, Apirl and May), Monsoon (June, July, August and September) and Winter (October, November, December and January) are taking into account and solar radiation for these three season are also decided. Detailed calculation of PV system for Summer, Monsoon and Winter are calculated and Monsoon option is decided as most suitable. This is one kind of idea for consideration of system reliability for target village. Although system size is larger than load demands of Summer and Winter, it will cover for the future increment of load demands. The energy storage system is used to make the intermittent PV power more dispatchable and stable. In this system, the storage device is mainly taken as lead-acid battery, as it is more convenient to use in high power application such as solar and wind systems because of its low cost and availability in large size. A buck-boost DC-DC converter is used to maintain continuous power flow between DC bus and BSS with a constant DC-link voltage. A constant DC-link voltage is maintained by charging or discharging the lead-acid battery depending on the load change or solar irradiance change. Three phase voltage source inverter (VSI) is used to maintain the stable voltage and current at local load. When the load power demand is more than the PV generation, the battery should provide the extra power and when PV generation is more than the load power demand, the battery should store the extra power. This proves the power balance condition of the system.

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