Design Of Stand-Alone Solar Photovoltaic System For Residential Buildings

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Abstract: The provision of adequate and sustainable power supply to the country's citizens has been a mirage since the 80's when the nation neglected signals to improve its power generation capacity. The rapid population growth and increase in industrial activities necessitate the injection of solar photovoltaic technology into the nation's energy mix. This paper therefore is an attempt to design a stand-alone solar photovoltaic system for residential application. in this study, direct current (DC) appliances (lighting, fan, DVD player, radio) and alternative current (AC) appliances (television, refrigerator, and blender) were considered. The total load power of these appliances is 1981w. The array to load ratio determined as well as the daily watt-hour load shows that the use of hybrid system in this design is not recommended. To power these appliances, 64 modules with power rating 13052.8W under standard test condition (STC), 56 batteries in the battery bank with system battery capacity of 4900 Ah and one charge controller are required. Therefore, for sustainability, reliability and accessibility of power, the use of stand-alone solar photovoltaic technology is recommended.

Index terms: Photovoltaic systems, Off-grid, Residential, Appliances, Power

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1.0 introduction

Energy plays a pivotal role in our daily activities. The degree of development and civilization of a country is measured by the amount of utilization of energy by human beings. The increase in energy demand is linearly proportional to the increase in population, urbanization and industrialization. Due to the depletion of fossil fuel on worldwide bases, the increase in energy consumption outstrips the energy supply leading to what is called the "energy crisis". The desirability and usefulness of electrical energy to the world cannot be overemphasized. Electrical energy is useful in industries, commercial and residential establishments. The availability and sustainability of electrical power in any country enhances the economy of such nation. Nigeria faces serious energy crisis due to declining electricity generation from domestic power plants which are basically dilapidated, obsolete, and unreliable and in appalling state of disrepair, reflecting the poor maintenance culture in the country and gross inefficiency of the public utility provider [1]. This scenario to a very large extent epitomizes what is obtainable in other parts of Africa.

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Despite Nigeria's vast oil wealth, majority of Nigerians have no access to electricity and the supply to those provided is epileptic in nature [2]. According to the Nigerian energy policy report, it is estimated that the population connected to the grid system is short of power supply over 60% of the time [3]. This inadequate and unreliable power supply has forces many industries to reduce their productions in order to break even or they are forced to shut down completely. Some industries that managed to survive resorted to self electrification which consequently increases the prices of their products. On household or residential bases, the use of small generators for electrification purposes has become the order of the day. These small generating sets to a very large extent, cannot power some household appliances such as refrigerators, air conditioners, etc. and the amount of harmful gases they release to the atmosphere is a thing of concern. In spite of the expectation that the current reforms in the power sector will boost electricity generation and supply in the country, the injection of solar photovoltaic system in the nation's energy mix is imperative. The integration of solar photovoltaic in the energy mix is what is obtainable in some countries such as Germany, India, and China, Brazil etc which have relatively reliable and sustainable power. This development is in consonance with the global energy transition. This paper is therefore an attempt to design a stand-alone solar photovoltaic system for residential building application.

1.1 Description of the PV System

The off-grid photovoltaic system consists of the following components: PV array, batteries and charge controller as shown in figure 1.0 while figure 2.0 shows the off-grid roof integrated PV system. The PV array is a collection of electrically connected photovoltaic modules; battery is a device that converts the chemical energy contained in its active materials directly into electrical energy by means of an electrochemical oxidation-reduction (redox) reaction; charge controller is a device that controls the charging rate and/or state of charge for batteries.
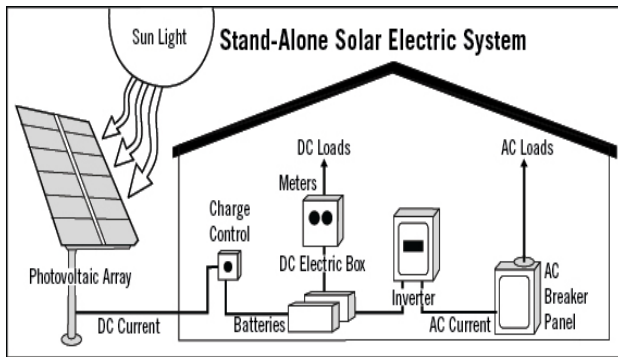
Figure 1.0 stand-alone solar photovoltaic system

Figure 2.0 Off-Grid Roof Integrated Solar Photovoltaic System

2.0 Methodology

To design the stand-alone solar photovoltaic system for residential applications, a modest residential building with the following electrical appliances: lighting bulbs, fans, DVD, radio, television, refrigerator and blender is considered. The residential building considered is situated in Mubi-South local government area of Adamawa State, Nigeria. The building is located on latitude $10^0 12'$N and longitude $13^0 10'$E. In this design, it is assumed that the batteries are located in the storage room in order to maintain moderate temperature, and the rated module current is provided at standard test conditions (STC) of $1000\,\text{W/m}^2$ irradiance and 25^0C temperature. The battery and module information used in this study were obtained from the work of [4]. In this design, a hybrid indicator curve shown in figure 3.0 was employed in order to determine whether additional energy source (hybrid system) is required to power the loads considered. This curve is a plot of daily load in watt-hours versus the array/load ratio. The design of the stand-alone solar PV was carried on the worksheets 1-6. The wiring diagram of the PV plant designed for the electrification of the study area is shown in figure 4.0.
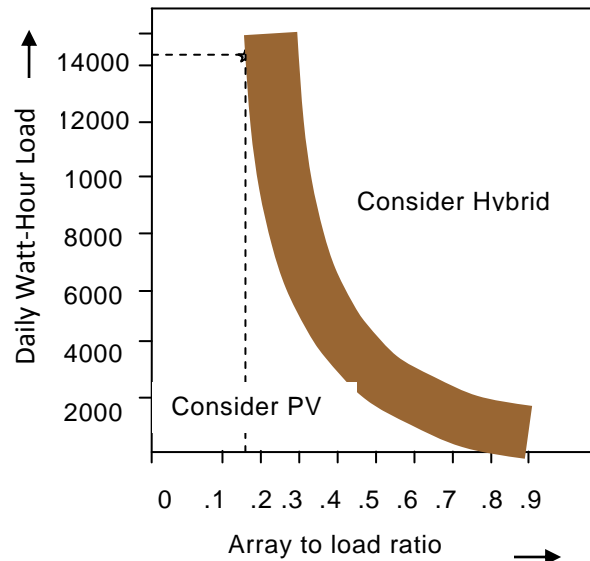

Figure 3.0 Hybrid Indicator Curve

3.0 Discussion

In this study, the DC load power is 877.6W; the AC load power is 1104W while the total load power is 1981W. This shows that the total power requirement of the residential building considered in this study is 1981W. The quantity of energy required to be stored in the batteries in order to meet the power requirement of 1981.6W is 558.2Ah/day as shown in worksheet 1. From worksheet 2, the usable battery capacity of the battery bank is 3430 Ah. This battery bank consists of 14 batteries in parallel and 4 batteries in series. This shows that a total of 56 batteries arranged as shown in Figure 2.0 and with the information given on worksheet 3, is capable of storing the charge required for the operation of the photovoltaic system. In this design, 64 modules with information provided worksheet 4 are required. The modules are arranged in figure 3.0. The power ratings of these modules under standard test conditions are 3052.8W. This implies that if these 64 modules are properly arranged, installed and maintained, they can generate the power required for the dc and the ac loads. The array to load determined on worksheet 6 is 0.17 and the daily watt-hour load is 13396.8Wh. The combination of these two values does not touch or is not below the hybrid indicator curve shown in Figure 2.0. This shows that hybrid design is not recommended in this stud [4].

4.0 Conclusion

The availability and sustainability of power supply requires the injection of solar photovoltaic systems into the country's energy mix. In this design, solar photovoltaic system with 56 batteries and 64 modules are required to meet the power demand of 1981W of the appliances of the residential building considered. Although the stand-alone solar photovoltaic has high initial cost, its durability, reliability, sustainability, ease of maintenance, environmental friendliness, make the system attractive for residential and other pertinent applications.

References

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worksheet 1: determination of power rating and corrected-amp-hour load

Load Description		QTY	Load Current (A)	Load Voltage (V)	DC Load Power (W)	AC Load Power (W)	Daily Duty Cycle (hrs/day)	Weekly Duty Cycle (days/wk)	Power Conversion Efficiency (Decimal)	Nominal System Voltage (V)	Ampere-hour Load (Ah/day)
Light		10 ×	0.75 ×	24 =	180	N/A ×	11 ×	7/7 ÷	1.0 ÷	24 =	82.5
Fan	dc	6 ×	4.15 ×	24 =	597.6	N/A ×	7 ×	7/7 ÷	1.0 ÷	24 =	174.3
DVD		2 ×	1.04 ×	24 =	25	N/A ×	6 ×	7/7 ÷	1.0 ÷	24 =	6.25
Radio		1 ×	3.12 ×	24 =	75	N/A ×	4 ×	7/7 ÷	1.0 ÷	24 =	12.5
TV		2 ×	1.60 ×	120	N/A	= 384 ×	6 ×	7/7 ÷	0.85 ÷	24 =	112.9
Refrigerator		1 ×	2.66 ×	120	N/A	= 320 ×	6 ×	7/7 ÷	0.85 ÷	24 =	94.1
Blender		1 ×	3.33 ×	120	N/A	= 400 ×	0.5 ×	7/7 ÷	0.85 ÷	24 =	9.8

Total Load Power (W)	DC	877.6	AC	1104	Total Ampere-hour load (Ah/day)	492.35

	Total DC Load Power (W)	Total AC Load Power (W)	Nominal System Voltage (V)	Peak Current Draw (A)	Total Ampere-hour Load (Ah/day)	Wire Efficiency Factor (Decimal)	Battery Efficiency Factor (Decimal)	Corrected Amp-hour Load (Ah/day)
	877.6	+ 1104	÷ 24	= 82.6	492.35	÷ 0.98	÷ 0.9	= 558.2

Worksheet 2: Determination of Design Current and Array Tilt

Corrected Load (Ah/day)		Peak sun (hrs/day)		Design Current (A)		Tilt Angle
558.2	÷	6.5	=	85.8		10.5

Worksheet 3: Determination of System Battery Size

Corrected Amp-hour Load (Ah/day)		Storage Days		Maximum Dept of Discharge (Decimal)		Derate for Temperature		Required Battery Capacity (Ah)		Capacity of Selected Battery (Ah)		Batteries in Parallel
558.2	×	6	÷	0.7	÷	1.0	=	4784.6	÷	350	=	14

	Nominal System Voltage (V)		Nominal Battery Voltage (V)		Batteries in Series		Batteries in Parallel		Total Batteries
	24	÷	6	=	4	×	14	=	56

Battery Information

Make	Interstate
Model	U2S – 100
Type	Flooded Lead Acid
Nominal Voltage (V)	6
Rated Capacity (Ah)	220

Batteries in Parallel		Capacity of Selected Battery (ah)		System Battery Capacity (Ah)		Maximum Depth of Discharge (Decimal)		Usable Battery Capacity (Ah)
14	×	350	=	4900	×	0.7	=	3430

Worksheet 4: Determination of System Array Size

Design Current (A)		Module Derate Factor (Decimal)		Rated Module Current (A)		Derated Design Current (A)		Modules in Parallel	
85.8	÷	0.9	=	95.3	÷	3.0	=	32	

		Nominal Battery Voltage		Batteries in Series			Voltage Required for Load (V)		Highest Temperature Module Voltage (V)		Modules in Series		Modules in Parallel		Total Modules
1.20	×	6	×	4		=	28.8	÷	14.4	=	2	×	32	=	64

PV Module Information								Modules in Parallel	Rated Module Current (A)		Rated Array Voltage (V)	
Make/Model	Siemens m75		Nominal Volt			12			×	3.0	=	96
Length	48	Width	13		Thickness	1.5						
Weight	5.4 kg				Bypass Diode	Y/N			Module Short Circuit Current (A)		Array Short Circuit Current (A)	
	At STC	Open Circuit		At Highest Expected Temperature					×	3.4	=	108.8
Voltage (v)	15.9	19.8		14.4				Modules in Series	Rated Module Voltage (V)		Array Rated Voltage (V)	
	At stc	Short Circuit							×	15.9	=	31.8
Current (a)												
	3.0	3.4							Open Circuit Module Voltage (V)		Array Open Circuit Voltage (V)	
									×	19.8	=	39.6

Worksheet 5: Controller Specification

1.25	Array Short Circuit Current (A)		Minimum Controller Current (A)		Rated Controller Current (A)		Controllers in Parallel
	×	20.4	=	26	÷	30	=	1

Controller				
Make/Model	Bobier electronics ndr.30		Adjustable set points	
Rated voltage	24v option		High voltage disconnect	
Rated current			High voltage re-connect	
Features			Low voltage disconnect	
Temperature compensation			Low voltage re-connect	
Reverse current protection			meters	
	+		Battery voltage	
			Array current	

Worksheet 6: Hybrid Design Determination

Corrected Amp-hour Load (Ah/day)	Nominal System Voltage (V)		Watt-hour Load (Wh/day)		Conversion Factor		Annual kilowatt-hour Load (kWh/year)
558.2	×	24	=	13396.8	×	0.365	=	4889.8

Derated Design Current (A)	Nominal System Voltage (V)		Design Array Power (W)		Watt-hour Load (Wh/day)		Array to Load Ratio (Decimal)
95.3	×	24	=	2287.2	÷	13396.8		0.17

64 Modules, 3052.8 Watts (60 parallel strings similarly Connected between A and B)

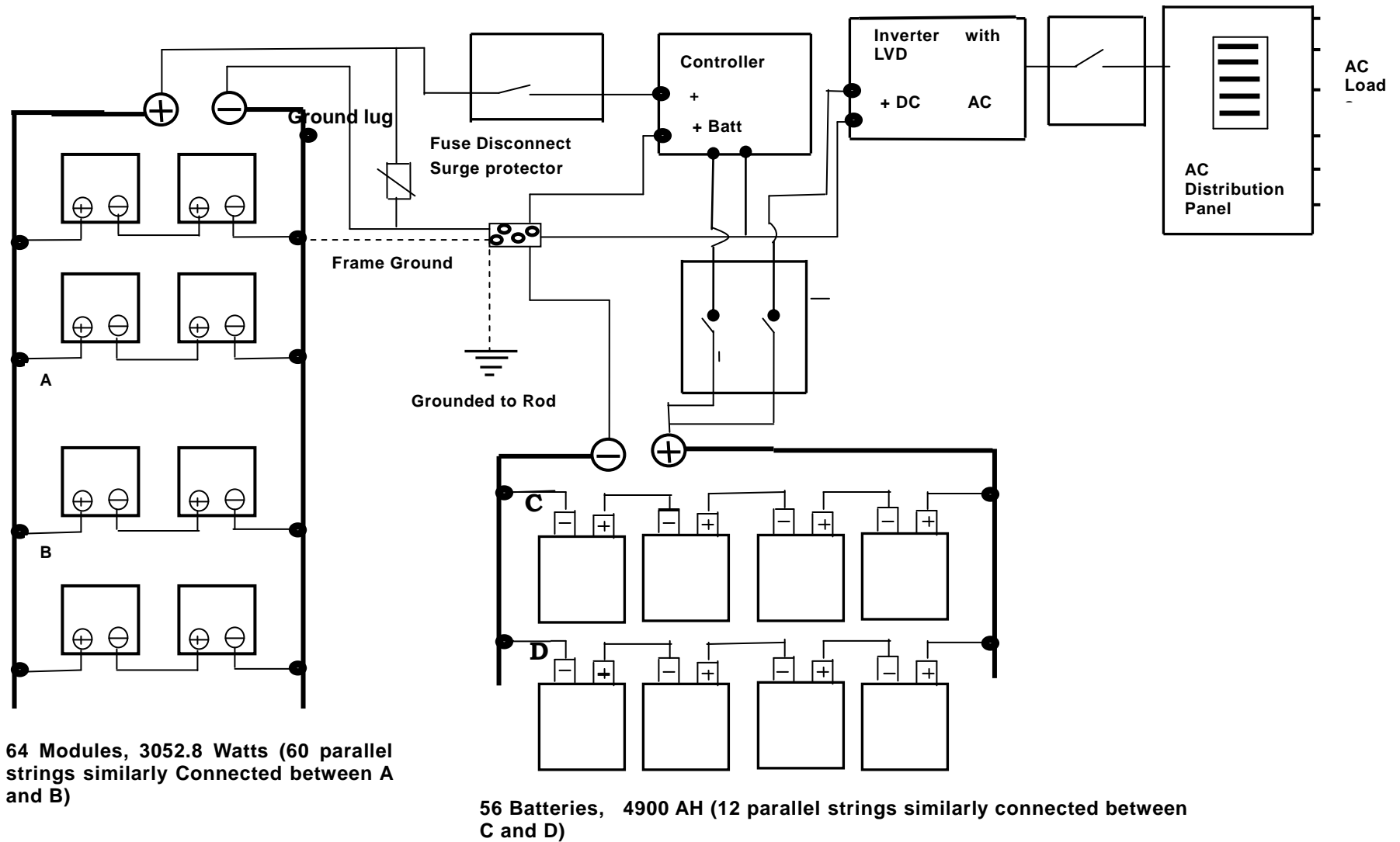56 Batteries, 4900 AH (12 parallel strings similarly connected between C and D)

Figure 3.0 Wiring Diagram of the Stand Alone PV System for Residential Building