Journal of Energy Technologies and Policy
ISSN 2224-3232 (Paper) ISSN 2225-0573 (Online)
Vol.4, No.12, 2014

Maximizing Solar Output Power: Load Shedding Design Approach

Morakinyo Adefunminiyi A.

Department of Electrical and Information Engineering,
School of Engineering, Covenant University

Ota, Ogun State, Nigeria.

Tel: +2348031158868 E-mail: morakinyo.adefunminiyi@gmail.com

Abstract

Renewable energy is currently at the centre of meeting the world energy needs. A notable number of offices and home-users have employed the renewable energy technologies, which are usually used for power backup purposes. High cost of generation is the major factor militating against solar power system affordability. Therefore, an effective way of maximizing the limited generated solar power is paramount. This research presents a viable method of minimizing the overall cost of implementing a solar power system by adequate management of the load to be powered.

This paper presents a load shedding design approach in maximizing the solar output power usage in meeting the ever dynamic power need in a typical office setting. The estimated cost of implementing the full load design was compared side by side with a proposed load shedding design approach. In addition, the shed loads were carefully considered to ensure the office day to day activities were not hindered.

The load shedding design was found to reduce the total effective load of the office complex. It also reduced the total cost of implementing the solar power design to meet a required load by 90.87%.

Keywords: Solar Power, Maximize, Load Shedding, Renewable Energy, Full Load

1. Introduction

Generation of solar power is a holistic approach in meeting load demands in most part of Africa, which is a result of an erratic power supply in most nations of the continent. (Agbetuyi et al. 2013) Powering the whole load of an industry or an office setting is expensive as most industrial equipment are electrical loads. In maximizing the installed solar power capacity, there is need to shed a reasonable amount of load intelligently to reach an equilibrium point between the load to be powered and the installed solar power capacity.

Also, the cost of installing a solar power design to meet such huge load is high. Considering the individual cost of each component needed to meet the full load design need, results in a value which is rather not feasible for most growing industries in Africa. Striking a balance between the purse of the above highlighted industries, their total load capacity and the installed capacity of a solar power system is of great necessity.

This paper is thus organized: Firstly, the key components of an ideal solar power system design are highlighted. Secondly, the various reviewed methods of maximizing a typical solar output power are considered. Thirdly, the research methodology employed is discussed with a quick introduction of the surveyed area. In addition, the load survey result is presented and adequately considered. Fourthly, two different load design approaches are considered for the solar power system. Furthermore, the result from both designs are considered and carefully compared. Lastly, a conclusion is drawn based on the achievements of the research.

2. Key Components of a Solar Power Design

A typical solar power design is made up of the battery bank, solar panels (with xW rating for each of the panel), charge controller, inverter, combiner boxes, panel rack, battery rack, AC circuit breaker (if not included in the inverter inbuilt circuitry, changeover switch or/and an automatic changeover switch, distribution box , cables and accessories.

3. Reviewed Solar Power Maximization Techniques

Solar Power Maximization has been on the increase as the need to power devices using solar energy is also on the increase. A lot of research has gone into increasing the overall efficiency of the system. Some of methods are highlighted below;

3.1 Maximum Power Point Control (MPPC) Algorithm (Trevor Barcelo, Feb. 2014)

This method uses an algorithm to ensure the connected load to the PV panel is effectively varied as the incident light on the PV panel also varies. It takes the advantage that the maximum power voltage of a PV panel has less variation with variation in the incident light on the PV panel. This is illustrated below in figure 1 and 2.

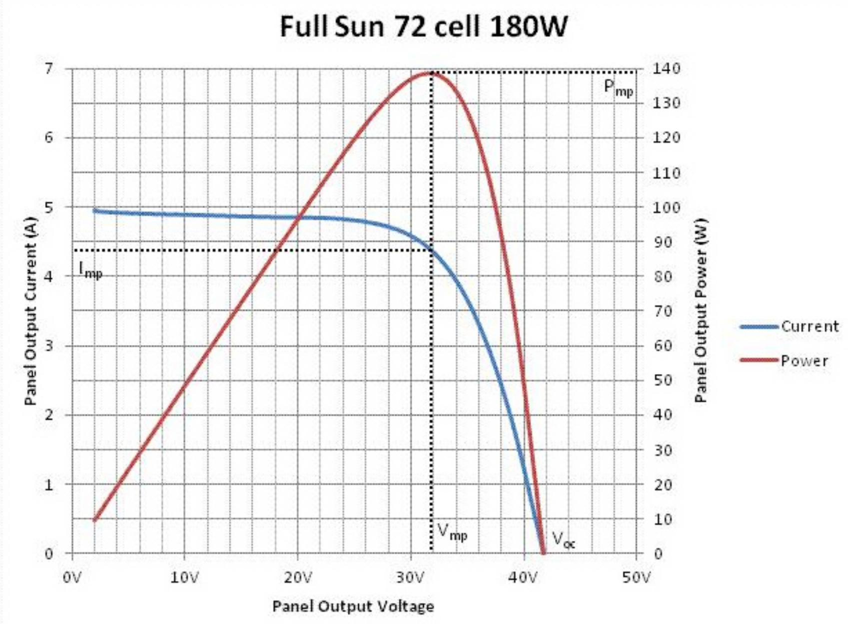

Figure 1: Graph of Panel Output Voltage against the Panel Output Power and Panel Output Current under a Full Sun Scenario (Source: Trevor Barcelo, Feb. 2014)

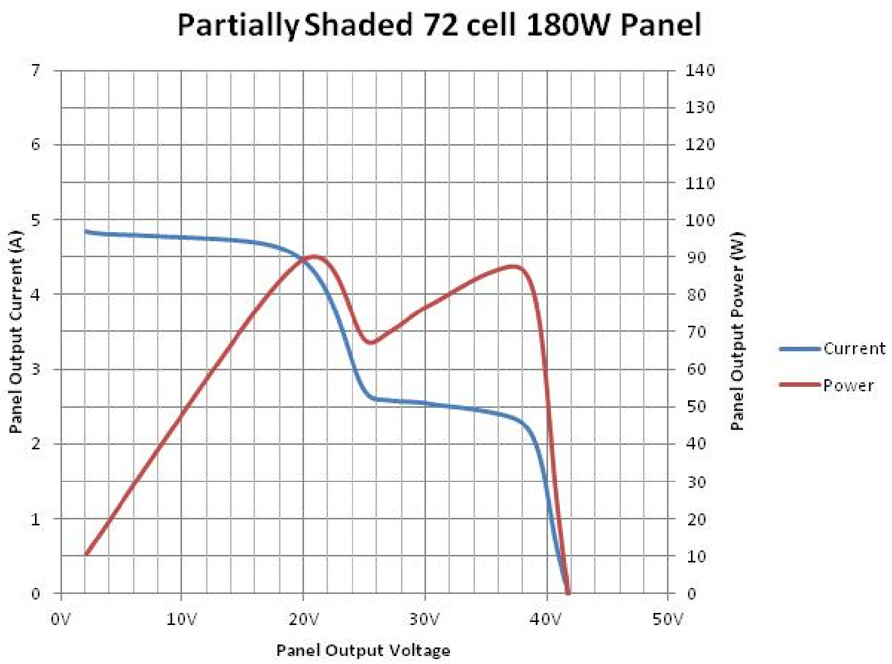

Figure 2: Graph of Panel Output Voltage against the Panel Output Power and Panel Output Current under a Partially Shaded Sun Scenario (Reduce incident light on the PV Panel) (Source: Trevor Barcelo, Feb. 2014)

The fixed panel output voltage is achieved by using a voltage divider which helps to measure panel output voltage and then compare it with a programmed reference voltage. If the panel output voltage is lesser than the referenced voltage, the connected load is (shed) reduced until the panel output voltage equals to the referenced voltage. The referenced voltage is established by connected a diode with the output voltage of a battery which is close enough to the expected output voltage of the PV panel. The above described system helps to maximize the output power of a solar power system.

3.2 Dual Axis Solar Tracking System (**Mahesh Kannan et al, 2013)**
Mahesh Kannan et al employed the usage of a dual axis solar tracking system. The solar panel changes it's polarity as the sun rise and set. The system block diagram is shown in figure 3 below.

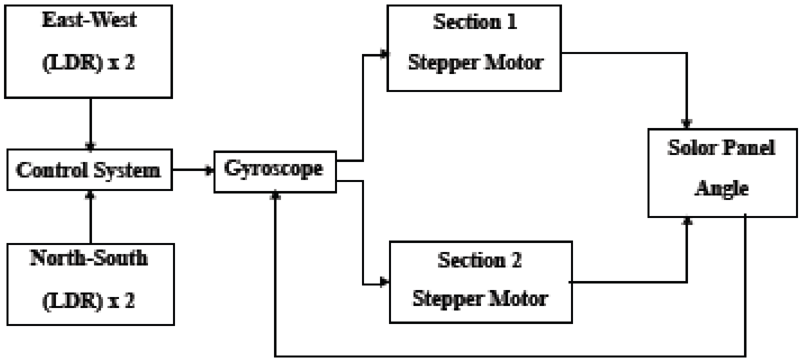

Figure 3: The Block Diagram of a Solar Tracker (Source: **Mahesh Kannan et al, 2013)**

The first axis rotates in the east-west direction while the second axis rotates in the north-south direction. The Light Dependent Resistors convert light intensity to its corresponding resistance value. Two stepper motors are also integrated in the system to effect the various rotation needed in steps. Also, a gyroscope was included to measure the angle of the plate as close loop.

The power generated after putting the system to test increases by 35% with the same PV panel size. This shows the effectiveness of the dual axis solar tracker system designed and constructed. The image of the dual axis solar tracker is shown in figure 4 below.

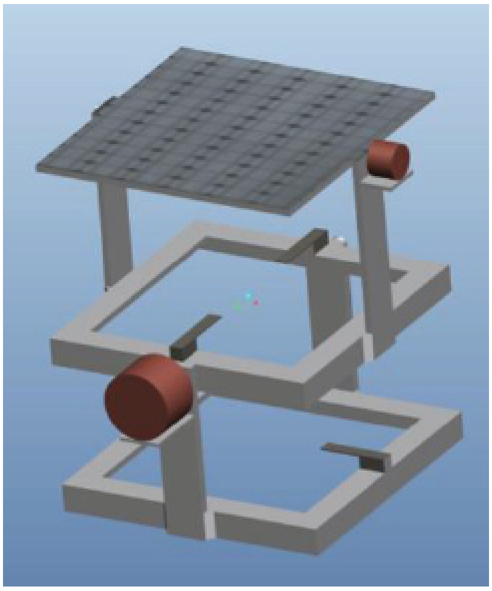

Figure 4: The Dual Axis Solar Tracker (Source: **Mahesh Kannan et al, 2013)**

4. Methodology

A load survey was conducted on the available load capacity of an office complex. The surveyed office complex is the headquarter of a youth empowerment agency that is located in the heart of Ibadan, Oyo State, Nigeria. The office complex comprises of 8buildings/blocks that are considerable isolated from each other. The surveyed load was carefully classified using a tally method and an average power rating was used for similar devices by different manufacturers with different rating.

The result was further processed to the design stage for a full load design and a load shedding design in meeting the power supply need of the office complex. With the erratic power supply nature of the office location, there was need to maximize the generated power from the solar power supply system.

5. The Load Survey Report

After a careful load survey of the case study, the office complex, a load survey report was integrated in a table as shown below.

Table 1: Load Survey Report (Source: Author's Survey)

S/N	Classified Office Electrical/Electronic Devices/ Fittings	Quantity	Wattage(W)	Total(W)
1	Air Condition	15	1125	16875
2	Refrigerator	17	500	8500
3	LaserJet printer	12	600	7200
4	Desktop computer (plasma screen)	23	180	4140
5	Ceiling fan	50	50	2500
6	Energy saving lamp	73	25	1825
7	Desktop computer (cathode ray tube)	5	351	1755
8	Mobile public address system	2	800	1600
9	Stereo	3	455	1365
10	Photocopier	1	1000	1000
11	Standing fan/ wall fan	12	70	840
12	LaserJet printer (smaller size)	2	345	690
13	Television 42"	2	300	600
14	Laptop	12	40	480
15	Standing fan(OX)	2	200	400
16	Television 19"	4	75	300
17	Projector	1	250	250
18	Nebulizer	1	90	90
19	Electric bell	1	50	50
20	DeskJet printer	4	10	40
21	VHS	1	28	28
			TOTAL LOAD IN WATTS	**50528**

6. Full Load Deign Approach

For the full load design approach, the whole 50,528W load is considered.

6.1 Battery Sizing Information

6.1.1 Parameters

DC system voltage: 24 volts
Hours of autonomy: 8 hours
Depth of discharge: 80%
Voltage of a single battery: 12 volts
Amperage of battery: 200AH

6.1.2 Calculation

Watt of 1Battery= 12 x 200 =2400W
Depth of Discharge in one battery = 0.8 / 2400= 1520
Amount of battery needed for total load = 50528/1520 = 33.2 ≈ 34 batteries for one hour
Therefore, for 8hours, 34 x 8= 272 batteries are needed.

Total number of 12V/ 200AH batteries needed = 272batteries

6.2 Inverter Sizing Information

6.2.1 Parameters

Total load= 50528 W

Considering power factor of 0.1, we approximate total load = 55.6kVA.
Since we need an inverter higher than 55.6kVA, we are going to cascade 6 x10kVA inverters = 60kVA

The total number of 10kVA inverter needed is 6

6.3. PV Panel Sizing Calculation

6.3.1 Parameters

Load =50528 W

Panel Power= 120watts

Average sun hours = 5hours

Percentage Efficiency = 70%

6.3.2 Calculations

Total watt in 1 panel = 120 x 5hours = 600watts

%Efficiency in 1 panel = 0.7 x 600 = 420watts

For a 50528W load, amount of panel needed for the design = 50528/420 = 120.3 ≈ 121PV panels(120W, 24V)

Therefore, for 8hours a total of 8 x 121= 968panels are needed

An array of 968 solar panels (120W, 24V) are needed for 8hours

6.4 Charge Controller Sizing Information

6.4.1 Parameters

Current in 1 panel = 6.8Amps

Short Circuit current= 7.75Amps

Total panel = 968

24Volts configuration

6.2 Calculation

Total maximum current passing through all panels = 7.75 x 968 = 7502A

But due to light reflection and cloud effect, the controller amperage is increased by 25% that is, 0.25 x 7502 = 1876A

Adding 25% = 9378A,

Therefore, a 9000A charge controller is needed.

Table 2: Full Load Estimated Cost (Source: Author's Survey Analysis)

s/n	Equipment	Specification	Quantity	Estimated Cost/one (₦)	Total Cost (₦)
1.	Batteries	Deep cycle battery	272	45, 000	12,240,000
2.	Solar PV panel	120W, 24V	968	17, 000	16,456,000
3.	Charge controller	50A, 24V	180	20, 000	3,600,000
4.	Inverter	10kVA, 220V	6	310, 000	1,860,000
5	Combiner boxes	--	97	1,500	145,500
6.	Panel rack	--	1	950, 000	950,000
7.	Battery rack	--	1	550, 000	550,000
8.	AC breaker	270A	1	95, 000	95,000
9.	Change over switch	350A		75, 000	75,000
10.	Distribution box	--	1	90, 000	90,000
11.	Cables and accessories	--	--	150, 000	150,000
				TOTAL COST(₦)	**36,211,500**

7. Load Shedding Design Approach

This centres on coming up with effective load calculation. That is, considering all electrical appliances that are more important in an office setting. These include printers, desktop computers, ceiling fan, and nebulizer, laptops, standing fan, projector and energy saving lamps.

The considered note include:

- One printer per building/block making a total of 8printers three in one DeskJet printers(photocopier/ scanner/ printer)
- Cathode ray tube computers are neglected
- Appliances such as air condition, refrigerator, desktop computers with cathode ray tube monitors, Mobile public address system, televisions etc are shed for the sake of reducing total cost implication of the project.
- Offices with two ceiling fans will make use of one to avoid redundancy
- All lamps are energy saving lamps
- All security lamps are off in the day, while all office lamps might be on and all security lamps are on at night while all office lamps are switched off at night
- All standing fans are on the average of 70W rating.

All the above stated conditions can as well be integrated in a load shedding/ reduction algorithm as stated in Trevor Barcelo, Maximum Power Point Control (MPPC) Algorithm. This results in a shrinked load report as shown in table 3 below.

Table 3 Effective Load After Shedding (Source: Author's Survey)

S/N	Office Electronic Devices/ Fittings	Quantity	Wattage(W)	Total(W)
1	Desktop computer (plasma screen)	23	180	4140
2	Ceiling fan	50	50	2500
3	Energy saving lamp	50	25	1250
4	Standing fan/ wall fan	12	70	840
5	Laptop	12	40	480
			TOTAL LOAD	**9210**

7.1 Battery Sizing Information

7.1.1 Parameters

DC system voltage: 24 volts
Hours of autonomy: 8 hours
Depth of discharge: 80%
Voltage of a single battery: 12 volts
Amperage of battery: 200AH

7.1.2 Calculation:

Watt of 1Battery= 12 x 200 =2400W
Depth of Discharge in one battery = 0.8 x 2400= 1920
Amount of battery needed for total load = 9210/1920 = 4.7 ≈ 5 batteries for one hour
Therefore, for 8hours, 5 x 8= 40batteries are needed.

7.2 Inverter Sizing Information

7.2.1 Parameters

Total load= 9210 W
Since we need an inverter higher than 9.5KVA, we are going to go for a standard size of 10KVA inverter.

7.3 Panel Sizing Calculation

7.3.1 Parameters

Load = 9210W
Panel Power= 120watts
Average sun hours = 5hours
Percentage Efficiency = 70%

7.3.2 Calculations

Total watt in 1 panel = 120 x 5hours = 600watts
%Efficiency in 1 panel = 0.7 x 600 = 420watts
For a 9210W load, amount of panel needed for the design = 9210/420 = 21.9≈22 solar panels (120W, 24V)
Therefore, for 8hours we need a total of 8 x 22= 176 PV panels

7.4 Charge Controller Sizing Information

7.4.1 Parameters

Current in 1 panel = 6.8Amps
Short Circuit current= 7.75Amps

Total panel = 176
24Volts configuration
7.4.2 Calculation
Total current passing through all panels = 7.75 x 176 = 1364A
But due to light reflection and cloud effect, the controller amperage is increased by 25% that is, 0.25 x 1364 = 341A
Adding 25% gives 1705A, 1705A charge controller is needed.

Table 4: Load Shedding Estimated Cost (Source: Author's Survey Analysis)

s/n	Equipment	Specification	Quantity	Estimated Cost/one (₦)	Total Cost(₦)
1.	Batteries	Deep cycle battery	40	45, 000	1,800,000
2.	Solar PV panel 120W	120W, 24V	22	17, 000	374,000
3.	Charge controller	50A, 24V	34	20, 000	680,000
4.	Inverter	10kVA, 220V	1	310, 000	310,000
5	Combiner boxes	--	3	1,500	4,500
6.	Panel rack	--	1	95,200	95,200
7.	Battery rack	--	1	81, 000	81, 000
8.	AC breaker	45A	1	16,000	16,000
9.	Change over switch	50A	1	11,000	11,000
10.	Distribution box	--	1	5, 000	5, 000
11.	Cables and accessories	--	--	15,000	15,000
				TOTAL COST (₦)	**3,305,700**

Table 4 above shows an estimated cost of implementing the load shedding design approach.

8. Result Comparison

First and foremost, the full load design approach gives quite a high load summary of **50528VA.** This value is approximately 5.5 times larger than the load shedding design approach. The load shedding design approach further helps in generating a sufficient amount of power for a definite load without adversely affecting the office complex activities.

Also, the load shedding design approach helps to drastically reduce the cost to be incurred if the full load design approach was to be used.

The cost reduction percentage is given as:

= ((36,211,500-3,305,700)/ 36,211,500) x 100
=90.87%

From the above calculation it can be inferred that the load shedding design approach further helps in maximizing the generated solar power.

9. Conclusion

Conclusively, the key components of an ideal solar power system design were highlighted. Also, the Maximum Power Point Control (MPPC) Algorithm method (Trevor Barcelo, Feb. 2014) and the usage of a Dual Axis Solar Tracking System method (Mahesh Kannan et al, 2013) were considered. In addition, the research method used was considered. Lastly, two different design approaches were broadly considered with their respective estimated cost implications. The result shows the broad variation in the cost implication (about 91%) and the total load needed to be powered. The load shedding design approach is a viable method in maximizing the generated solar output power.

This research can be further improved by developing a robust algorithm to cater for the load shedding approach design. Such algorithm should be robust enough to cater for different load preferences of the end-users. A Programmable Logic Control (PLC) is a viable choice for the above recommendations.

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