CASE STUDY DESIGN OF A STAND-ALONE PHOTOVOLTAIC POWER SYSTEM IN GAZA-STRIP AND GENARALIZING APROGRAM SIMULATION

Eng. Husam Awad[1]

[1](*Palestine Broadcasting Television)*
Gaza University /Technical Engineering
Gaza, Palestine
husam20111@gmail.com

 Mr. Naem Harb[2]

[2](*Palestine Broadcasting Television*)
TV Producer &Director
Gaza, Palestine
Husamawwad2015@hotmail.com

Dr. Ghada abu Al goboz[3]
[3]Palestine University)
(Instructor and Trainer of projects)
 Gaza, Palestine
g.m.s.a@hotmail.com

Eng.Shareif Shurrab[4]
[4]*Gaza, Palestine*
Mechanical Engineering Department
(Palestine Broadcasting Television)
shareifshurrab@gmail.com

Abstract— **This paper considered the design of a stand-alone PV system that would be adequate to power a single residence and estimate the appropriate size of the solar panel. This system converts solar energy directly into electricity using photovoltaic principle in PV panel arrays. The electricity produced can be used to power most ac and dc electrical appliances. Inverter is used to convert the dc generated by the PV panels to ac for most domestic and industrial use. For continuous availability of power during days of autonomy (low insolation or cloudy days), battery storage system and charge controller (for battery charge and discharge control) are required. inverter, charge controller, battery, components interconnection wires. The sizing processes considered the quality of solar irradiation of the geographical location, effect of temperature de-rating, efficiency of components, system voltage selection, days of autonomy and load demand (in watt-hour). A residence in Gaza town was chosen as a case study. The minimum electrical load of 7.875kWh per day, household, Finally excel program simulation was designed to satisfy calculation equations process and generalize the program.**

 Keywords— Electrical load demand, Photovoltaic system, Stand-alone, Solar irradiation, System sizing

I.   INTRODUCTION

Harnessing solar energy to power electrical appliances starts by converting the energy from the sun to electricity. A photovoltaic (PV) cell converts sunlight into electricity. These cells are quite small and are connected together to form larger units called modules which can be connected to form even a larger unit called array. These arrays are connected in parallels and series formations to meet the required electricity demand. PV arrays produce electricity only when illuminated and is therefore necessary to employ a large energy storage system, most commonly a series of rechargeable batteries. Also to prevent harmful battery over-charge and over-discharge conditions and to drive AC loads and a charge controller and converters have to be implemented [2]. PV systems can be used to exploit the solar energy in almost all applications.

A stand-alone PV Systems are systems which use photovoltaic technology only and are not connected to a utility grid. The systems use the DC output of the PV modules to power DC loads, while a bank of battery is used to store energy for use when there is demand. The DC output of the batteries can be used immediately to run certain low DC Voltage loads such as lighting bulbs or refrigerators or it can be converted by an inverter to AC voltage to run AC-loads that constitutes most appliances. Off-grid PV system provides affordable electricity in area where conventional electricity grids are unreliable or non-existing [8]. Schematic of a typical stand-alone photovoltaic system is shown below in fig1:
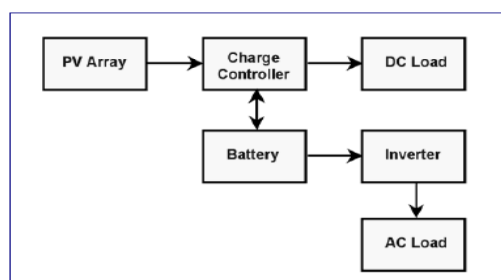

fig1: PHOTOVOLTAIC SYSTEMS –Standalone System

II.   METHODOLOGY

The first task was to determine the system load. This load estimate is one of the key factors in the design and costing of the stand-alone PV system. The electrical loads available at the resident were profiled with their respective power ratings and average operation hours during the day noted to obtain the

power demand in watt-hour per day. The result of the analysis obtained was used to determine the proposed stand-alone photovoltaic system components sizes.

A. Resident Electrical Demand

The household is a medium size resident not requiring very large quantity of electrical energy. Table 1 below shows the various electrical appliances and their load chat.:

Table 1-Electrical Load Demand for Residence**:**

Load Description	Qty	Load Power(w)	Hours use (Hrs)	Load Power (W- h)
Refrigerator	1	260	6	1560
Television	2	120	5	1200
Toaster	1	750	0.4	300
Fan	4	65	4	1040
DVD Home Theater	1	60	4	240
Sat Decoder	2	25	4	200
Laptop	2	140	6	1680
Light	8	36	4	1152
Electric Iron	1	1000	0.5	500
Clipper	1	15	0.18	2.7
Total Power		**2,471**		**7,874.7**

The residence under consideration consumes an approximate electrical load of 7.875kWh/day of electricity and daily watt power of 2.471kW.

B. System Voltage Selection

The operating voltage selection for a stand-alone system is dependent on the voltage requirement of the loads and the total current. However in a standalone PV system, the voltage is also dependent on the inverters that are available. When loads

C. Pv Array Sizing

The output power of PV array (PPv array) is determined by Equation. (1) [2]

$$P_{Pv\ array} = \frac{E_{ld}}{\eta_{B.O} \times K_{Loss} \times I_s} \times PSI \qquad (1)$$

Where
Eld = Average daily load energy in kWh/day,
Is = Average solar radiation in peak sun hour's incident for specified tilt angle in kWh/m2/day.
PSI = Peak solar intensity at the earth's surface (1kW/m2),
ηBO = Efficiency of balance of system
$\eta_{B.O}$ = $\eta inverterloss \times \eta wiringloss$ (2)
In this design, $\eta inverterloss$ and $\eta wiringloss$ are taken as 94% and 97% respectively
KLoss = Factor determined by the different losses such as module temperature losses, circuit losses, dust, etc [4].
K_{Loss} = $fman \times ftemp \times fdirt$ (3)
Where,
fman = manufacturer′s tolerance ftemp = Temperature de-rating factor

fdirt = De-rating due to dirt if in doubt, an acceptable de-rating would be 5% and is given by equation below, [4]
$ftemp = 1 − (\gamma(Tcell.eff − Tstc))$ (4)
Where,
γ = Power temperature co-efficient per °C
Tstc = Cell temperature at Standard Test Conditions, in
Tcell-eff = the average daily effective cell temperature in degrees Celsius (°C) [14]
$Tcell.eff = Ta.day + 25$ (5)
Where,
Ta.day = Daytime average ambient temperature in This average is about 28
Substituting this value into equation 5 above, we have 53
From equation 4 above,
$ftemp = 1 − (\gamma(Tcell.eff − Tstc))$
Using the selected manufacturers specification for the module, $Tcell.eff = 53$, $\gamma = 0.48\%/$ $Tstc = 25$
$ftemp = 1 − [0.48 (53 − 25)] = 0.8656$
fman = 97%
fdirt = 95%
Substituting these into equation (3) we have
$K_{Loss} = fman \times ftemp \times fdirt$
$= 0.97 \times 0.8656 \times 0.95$
$= 0.7976$
From equation 2,
$\eta inverterloss = 94\%$ and $\eta wiringloss = 97\%$
$\eta_{B.O} = \eta inverterloss \times \eta wiringloss$
$= 0.94 \times 0.97 = 0.912$
Substituting the above values into equation (1)

$$P_{Pv\ array} = \frac{E_{ld}}{\eta_{B.O} \times K_{Loss} \times I_s} \times PSI$$

$= (7.875 \times 1) / (0.912 \times 0.7976 \times 3.45)$
$= 3.14kW$
Number of Modules in Series
Determining the number of modules that would be in series Nms is designed to accommodate the system voltage required to power the entire load. This is achieved by dividing the designed system voltage Vsystem (usually determined by the battery bank or the inverter) with the nominal module voltage Vmodule at Standard Test Condition (STC) [2,14].

Nms = VSystem/Vmodule
Nms = VSystem/Vmodule = 48/24 = 2 modules

Numbers of Modules in Parallel

A. The number of modules in parallel Nmp is found using the equation below, and is determined by the dividing the designed array output PPv array by the selected module output power Ppower and the number of module in series Nms [2].
$Nmp = Ppv\ array\ /\ Nms \times Pmodule$ (7)
$Nmp = 3.14 \times 10^3 / 2 \times 180$
$= 8.7 \cong 9$ modules
The total number of modules is given by the product of the series and parallel modules, which is

Nmt = Nms × Nmp = 2 × 9 = 18 modules

D. Storage (Battery) System Sizing

In the design of the capacity of the battery bank, it is necessary to consider some very important factors that determine the availability of power at all times, proper operation of the batteries, they include, the days of autonomy-days where there is little or no solar irradiation or cloudy days, allowable depth of discharge, possible battery loss, nominal system voltage of selected battery and estimated load energy in W-h [14]. The storage capacity can be calculated using the equation below [3,9].end of a sentence is punctuated outside of the closing parenthesis (like this).

$$C_B = \frac{E_{ld} \times N_a}{DOD \times V_{system} \times \eta_{bat}} \qquad (8)$$

Where,

CB = Required minimum battery capacity

Na = Number of days of autonomy

DOD= Depth of discharge

Eld = Average daily load energy in kWh/day

Vsystem = System voltage

ηbat = Battery efficiency

The battery selected is Rolls Series 4000 Deep Cycle batteries, T12 250, having the following characteristics, a capacity of 200AH, and a voltage of 12Vdc.

In this design, the days of autonomy is taken as 5 days, maximum allowable depth of discharge (DOD) taken as 50% and efficiency (ηbat) of 85%. Computing the battery capacity using the above variables gives us as below,

CB = $7.875 \times 10^3 \times 5/0.5 \times 48 \times 0.85 = 1930$Ah

Calculating the number of battery units required can be done using the equation below

Nbreq = CB/ Csel $\qquad$ (9)

CB = 1930Ah

Csel = 200Ah

Nbreq = 1930/200

= 9.6 ≅ 12 batteries

The approximate number of batteries required would be 12 batteries.

To determine the number of batteries in series, we divide the nominal system voltage with the battery voltage

Nbs = Vsystem / Vbat $\qquad$ (10)

Applying the above expression gives us the series as

Nbs = 48/12

= 4 batteries

We also have to calculate the number of parallel by applying the formula below.

NPb = Nbreq /Nbs $\qquad$ (11)

NPb = 12/4 = 3

The battery arrangement would be 4 series and 3 parallel combinations of 12Vdc 200AH Rolls 4000 series.

III. INVERTER SIZING

When designing a system inverter size, the actual power drawn from the appliances that will run at the same time must be determined as a first step. Also, we must consider the possibility of having large motors with very high starting current by multiplying their power by a factor of 3. Also to allow the system to expand, we multiply the sum of the two previous values by 1.25 as a safety factor [3].

$$P_{invt} = (P_{rs} + P_{lsc}) \times 1.25 \qquad (12)$$

Where,

P$_{invt}$ = Inverter power rating

P$_{rs}$ = Power of appliances running simultaneously

P$_{lsc}$ = Power of large surge current

This design does not have large surge current machines and as such, P$_{lsc}$ is zero and

P$_{rs}$ = 2.471kW from table Table 1

P$_{invt}$ = (2471 + 0) × 1.25 = 3088.75W ≅ 3.50kW = 3.5kVA

From the above calculation, an inverter of 3.5kVA and 48VDC capacity was chosen. LS-3548 3500-W, 48-VDC, 220-Vac

A. Charge Controller Sizing

The charge controller regulates the flow of electricity from the solar modules to the battery bank. When the battery bank is low, the charge controller feeds all of the electricity from the array to the batteries. When the batteries reach a state of full charge, the charge controller stops or redirects the supply of electricity to prevent overcharging. Charge controllers are generally selected by their size or ability to control a given amount of current and by their operating voltage [4,10]. The rated maximum current of the charge controller is obtained by multiplying the short circuit current I$_{sc}$ of the modules connected in parallel by a safety factor f$_{safety}$ to allow for short periods of high irradiance produced by momentary cloud enhancement. The rated maximum current is given by this expression below [12,13].

$$I_{max} = N_{mp} \times I_{sc} \times F_{esafety} \qquad (13)$$

We consider a safety factor $F_{safety} = 1.25$

$$I_{max} = 9 \times 5.38 \times 1.25 = 60.525 Amps$$

Xantrex C60 Charge Controller was considered for this design. The number of charge controllers needed is given by the equation below

N€€= Imax / Iselected $\qquad$ (14)

Where,

Imax = 60.525Amps and Iselected = 60Amps Therefore,

N€€ = 60.525/ 60= 1.00875 ≅ 1

Hence, 1 charge controller was selected

Sizing of System Cables

After sizing and selecting the major components, the interconnections wires are next. Selection of appropriate wire size and type enhances the reliability and performance of the photovoltaic system. The size of the wire must be capable of carrying the current at the operating temperature without excessive losses

B. Cable Size: PV Module through Charge Controller to Battery

The maximum current produces by the PV panels is given by equation 13 [12],
Imax = Npb × Isc × Fsafety
The cross section that would be adequate for this current would be given by equation 15 [11]
Where,

$$S = L \times I / \gamma \times Vd \qquad (15)$$

Vd = 2% of maximum allowed voltage drop for the 2 series array PV

= 2/100× System Voltage at maximum power =
0.02 × 35.8 × 2 = 1.432V L
= distance from the PV array to the battery through the charge controller
= 2 × 15m = 30m

Imax = 9 × 5.38 × 1.25 = 60.525Amps
γ = 58m/Ω. mm2 = Conductivity of copper The cross section becomes

S = (30 × 60.525) /(2 58 × 1.432) = 21.86 mm

The optimum wire size for this current is #3copper wire (AWG) which is equivalent to
25mm2 copper.

C. Cable Sizing between Battery Bank and Inverter (Inverter Input Circuit Current)

The DC wire from the battery to the inverter must withstand the maximum current at the input of the inverter. The maximum current carrying capacity of the cable is the continuous inverter input current rating when the inverter is producing rated power at lowest input voltage and is given by equation 16 below [12].

$$I = Pinvt / VD€ \times \eta invt \qquad (16)$$

Where,

ηinvt = inverter efficiency = 94%
Pinvt = 3.5kw

VD€ = 48V, at lowest possible of -2Vdc,
$I = 3.5 \times 10^3 / 46 \times 0.94$
= 80.9Amps

A minimum wire of #2 copper wire (AWG) equivalent to 35mm2 is required to terminate the battery and inverter. This selection takes into consideration the possibility of having 2Vdc drop at the inverter input.

D. Cable Size between Inverter and Load

The ac-wire from the inverter to the electric panel of the residence must withstand the maximum current that the inverter can produce at full load. This current is given by the following formula for a rated ac-voltage (Vac) of 220V [12].

$$Imaxinv = Pinvt / Vac \times pf \qquad (17)$$

Where,
pf = power factor = 0.8

I max inv =3500 / 220 × 0.8
= 19.9Amps

An optimum wire size of #10 copper wires (AWG), equivalent to 6mm2 was considered for this design.

The complete system Excel Program Simulation was designed to get the PV modules, Batteries, inverters characteristics, Charge controller and Cable Sizing and attached file scanned is supported as clarified in Table 2.

Table 2: PV-Stand Alone System design by Scanned Excel Program Simulation:

Sizing of solar system for Atya House

Ser.	Equipment name	No.	Power (w)	Working hrs/day	Total Energy (w-hr/day)	Battery Working hrs on battery	48
1	computer	1	260	6	1560	3120	
2	Freezer	2	120	5	1200	2400	
3	lighting	1	750	0.4	300	600	
4	Fan	4	65	4	1040	2080	
5	Tv	1	60	4	240	480	
6		2	25	4	200	400	
7		2	140	6	1680	3360	
8		8	36	4	1152	2304	
9		1	1000	0.5	500	1000	
10		1	15	0.18	2.7	5	
11						0	
12						0	
13						0	
			2471		7,874.70	15,749.40	

Ser.	Equipment name	No.	Power (w)	Working hrs/day	Total Energy (w-hr)	
1						0
2						
					-	-

	batteries energy
	15,749.40

Needed Energy	7,874.70	w-hr/day
Needed Energy	7.87	kw-hr/day
no. of average sunshine	5.50	hrs/day
System Power size	1.43	kw

IS1	3203	EID	7.87		EFFECIECY(inv)	0.94
IS	3.45	EFFECIECY(B.O	0.9118		EFFECIECY(wiring)	0.97
Ta.day	28	Kloss	0.7976504		Fman	0.97
Tcell.eff	53	Is	3.45		Ftem	0.8656
		PSI	1.00		Fdirt	0.95
		Ppvarray	3.13835991		Gama	0.0048
					Tcell.eff	53
					Tstc	25

Number of moduls in series			Number of moduls in parallel	
Vsys	48		Pmodule	0.18
Vmod	24		Nmp	8.717666415
Nms	2			
			Total#of modules	17.43533283 → 18

Storage battrey sys. Sizing	
EFF.bat	0.85
DOD	0.5
Na	5
Cb	1930.073529
Csel	200
Nbreq	9.650367647 → 12
Vbat	12
Nbs	4
Npb	3

Inverter Sizing	
Prs	2.471
Pisc	0
Pinv	3.08875

IV. CONCLUSION/RECOMMENDATION

The proposed stand-alone PV system was designed based on estimated load demand in watt-hour rating of appliances. The result of the estimated daily demand is shown in Table-1. The result of which amounted to 7.875kWh/day. The detailed result of the design and component sizes are in Table 3 comprising of 18 ENP Sonne 180W, 24V PV modules which is capable of producing an array power of 3.14kW. The PV array design is composed of 9 parallel and 2 series so as to meet the desired current and voltages for the load system. The storage system consideration was designed to meet the load demand. Total of 12 numbers of 12Vdc 200AH Rolls 4000 series T12 250 with a bank capacity of 1930AH, having 4 series and 3 parallel battery combinations. The total current from the PV arrays is 60.525Amps and Xantrex C60 Charge Controller was selected for this design. The rating of the designed inverter for the conversion of dc to ac is 3.5kW, and Latronic Ls-3548 3500-W 48Vdc inverter was selected. The wire sizing considered the current carrying capacity of each of the components. Between the PV panel through Charge controller and the battery which carries a current of 60.525Amps, #3copper wire (AWG) which is equivalent to 25mm2 copper wire was selected. From the design calculation, the optimum wire of #1 copper wire (AWG) equivalent to 35mm2 is required to terminate the battery and inverter. While feeding the load distribution would require an optimum wire size of #10 copper wires (AWG), an equivalent of 6mm2 which is adequate to carry the 19.02Amps the inverter is capable of delivering at full load. The complete system Excel Program Simulation was designed to get the PV modules, Batteries, inverters characteristics, Charge controller and Cable Sizing and attached file scanned is supported.

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