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System Design of Photovoltaic-Solar Home Lighting for Household in Gaza strip

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Abstract. Solar electricity is a steadily growing energy technology today and solar cells have found markets in variety of applications ranging from consumer electronics, and small scale distributed power systems to centralized megawatt scale power plants. Direct utilization of solar radiation to produce electricity is close to an ideal way to utilize the nature's renewable energy flow. According to the Political situation on Gaza Strip and the mandatory siege since 2006 by the Israeli occupation after Palestinian election, Power Generation Sector faced several obstacles starting with destroying main generators of Gaza Power Plant in June 2006 through blocking fuel entry into Palestinian Territories in 2008 ending to unknown and horrible situation. So the need of alternative and urgent power source to supply hospitals and medical centers is very important issue especially in situation we live in Gaza Strip; imposed siege, shortage in fuel supplies, and increasing in the mortality rate. Palestine is considered one of the sunny countries with marvelous solar radiations over the year. In this paper a PV-lighting system for small houses in Gaza Strip has been evaluated, all PV system components have been measured and designed.

Keywords: PV-Solar Energy, Gaza Strip, renewable energy.

1. Introduction

Renewable energy sources have been important for humans since the beginning of civilization. For centuries and in many ways, biomass has been used for heating, cooking, steam rising, and power generation, hydropower and wind energy, for movement and later for electricity production. Renewable energy sources generally depend on energy flows through the Earth's ecosystem from the insolation of the sun and the geothermal energy of the Earth.

Furthermore, many renewable technologies are suited to small off-grid applications, good for rural, remote areas, where energy is often crucial in human development. At the same time, such small energy systems can contribute to the local economy and create local jobs. The natural energy flows through the Earth's ecosystem are immense, and the theoretical potential of what they can produce for human needs exceeds current energy consumption by many times. For example, solar power plants on one percent of the world's desert area would generate the world's entire electricity demand today [1].

2. Electricity Crisis in Gaza Strip

The Gaza Strip's needs range between 240 and 280 megawatts (MW), of which at least 42 percent is purchased from Israel. Gaza is connected from north to south by eleven connection points with Israeli power network, via transmission lines with 22 Kilovolt and total capacity of 115MW. In Gaza, the power supply comes from three sources, Israel, Egypt and generated by its own Gaza power plant (GPP). Currently, the Gaza Strip's needs range 350 megawatts (MW), of which at least 42 % is purchased from Israel, distributed in separate feeder lines along the Gaza Strip, and 6-7 % is purchased from Egypt, distributed mainly to the Rafah area.

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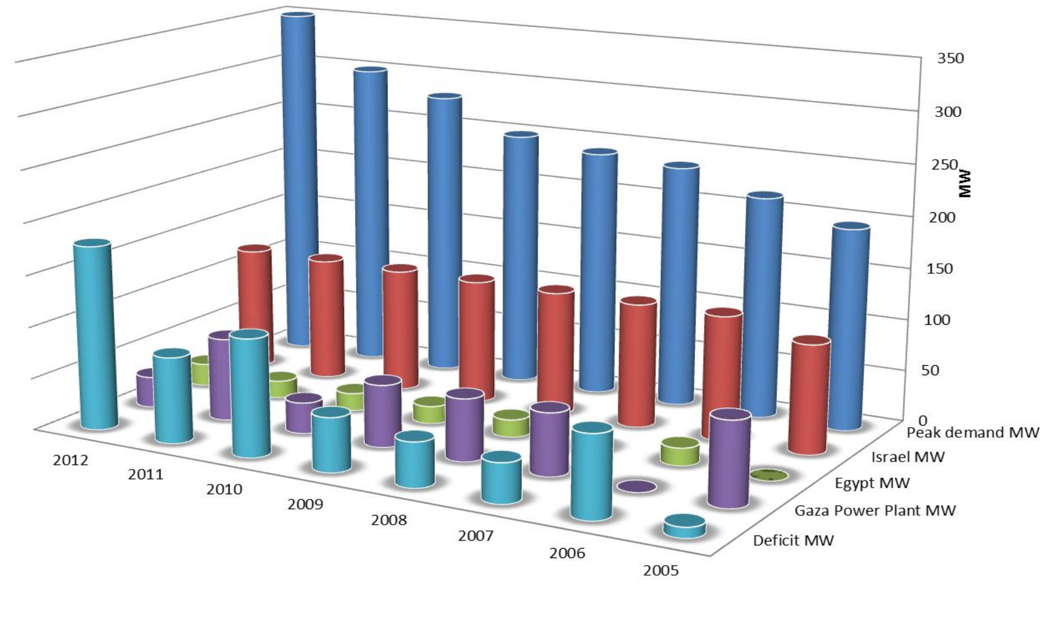
The remaining electricity need is supposed to be met by the GPP. Following the latest decline in production, however, the GPP is able to meet less than 13 % of the electricity needs. This is resulting in a deficit of up to 51 %, compared to 21% in 2009. Figure 1 shows the various electricity suppliers with its related shares in Gaza between 2005 and 2012 [2].



	2005	2006	2007	2008	2009	2010	2011	2012
Peak demand MW	195	215	235	240	249	280	300	350
Israel MW	105	120	120	120	120	120	120	120
Egypt MW	0	17	17	17	17	17	17	22
Gaza Power Plant MW	80	0	60	60	60	30	80	30
Deficit MW	10	78	38	43	52	113	83	178

Fig. 1: Electricity supply in Gaza Strip between 2005 and 2012 [2]

2.1. Usage of PV-Solar Systems in Gaza Strip

The use of the Photovoltaic technologies in Gaza Strip has much more advantages, so that man cannot ignore. In Gaza case, it is independent from Israel supply of fuels and electricity that have the opportunity to cut it under any circumstances, and according to the political situation and the mandatory siege since 2006 by the Israeli occupation after Palestinian election, the power generation sector faced several obstacles starting with destroying main generators of Gaza Power Plant in June 2006 through blocking fuel entry into Palestinian Territories in 2008 ending to unknown and horrible situation. So the need of alternative and urgent power source to supply hospitals and medical centers is very important issue especially in situation we live in Gaza Strip; imposed siege, shortage in fuel supplies, and increasing in the mortality rate. In addition, the direct conversion of solar radiation into electricity, solar panel converts solar radiations into electricity directly and immediately when they fall on it. The energy source, the sun, is free, ubiquitous, and in exhaustible, no mechanical moving parts, no noise, no high temperatures, and notably no pollution.

Palestine is located within the solar belt countries and considered as one of the highest solar potential energy; the climate conditions of the Palestinian Territories are predominantly very sunny with an average solar radiation on a horizontal surface about 5.4 kWh/m2 days. Gaza Strip is in the average of overall potential of Africa. According to the U.S. National Aeronautics and Space Administration NASA, Gaza Strip receives high radiation levels ca. 5.5 kWh/m2 per day annually, see Figure 2.

The total annual sunshine is approximately 3400 h. These are excellent conditions for harnessing solar energy for both large-scale and stand-alone applications. Indigenous energy resources are quite limited to solar energy for photovoltaic and thermal applications, mainly for water heating. Utilization of solar energy for water desalination is still the subject of research and investigation in Palestine, and of course in Gaza Strip [2]-[5].

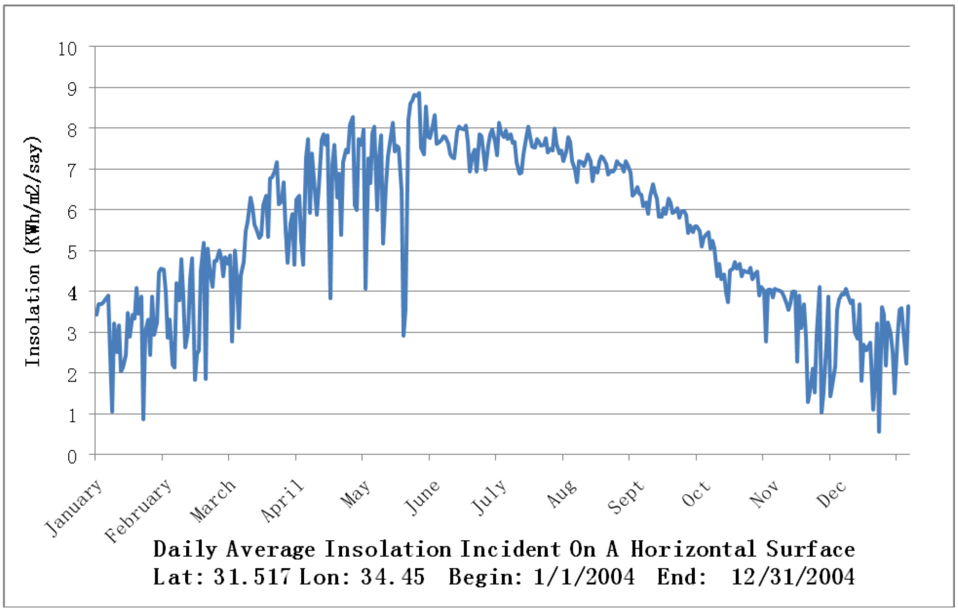


Fig. 2: Solar Irradiance in Gaza, 2004 [2]-[4]

3. Designing of a Standalone PV System

3.1. System Sizing

System sizing is the process of evaluating the adequate voltage and current ratings for each component of the photovoltaic system to meet the electric demand at the facility and at the same time calculating the total price of the entire system. The average power demand in Watt-hour per day that can be obtained by itemizing all appliances and their hours of use each day, which is referred to as the load profile. Geographical location that indicates, radiation amount the tilt angel, panel orientation, and the average sun hours per day.

3.2. Measuring Electricity Consumption

The most important and complex stage in sizing a stand-alone PV system is providing a carefully worked out breakdown of the daily electricity consumption. First, we need to estimate the consumption of all the individual electric loads .All intended electric loads and their respective power consumption are listed with their probable daily operating times and their daily consumption amounts [6].

3.3. Sizing the PV Array

After the daily electricity demand has been ascertained, the correct size of the PV array needs to be determined. There are different approaches to determining the yields of the diverse solar module types available on the market. The most sensible procedure would be to base this on the nominal power of a module at STC (Standard Testing Conditions) [6]. Table 1 lists the monthly mean totals for the daily Gaza Strip radiation on a horizontal plane Z2 for a range of Gaza Strip location. If the values are normalized to the irradiance at STC, then the factor Z2 has the unit hours per day.

Table 1: The monthly mean totals for the daily Gaza Strip radiation

Month	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Radiation (Z_2)	2.70	3.12	3.67	4.25	4.87	5.27	5.43	5.38	4.67	3.87	2.94	2.61

For tilted areas, these values must be converted with the factor Z3 . The necessary factors for the location are provided in Table 2. According to Al Barqouni research the suitable tilt angle for Gaza Strip location is 31.464 and its factor Z3 is 0.9586 [7].

Table 2: Mean values of solar angles for different tilt and azimuth angles

Tilt Angles	55	8	45	28	50	13	25	50	35	31.464
Mean Value Of Solar Angle	0.823	0.7442	0.849	0.542	0.3945	0.9092	0.903	0.5256	0.8896	0.9586

The deviation of the cell temperature from the standard value must be taken into account. With the exception of the winter months, this is, on average, over 25 ℃, which reduces the power. The corresponding factors Z4 are listed in Table 3. In July the factor is 0.99 [6].

Table 1: deviation of the cell temperature

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.03	1.01	0.95	0.91	0.88	0.87	0.99	0.99	1.00	1.01	1.02	1.02

The ideal energy yield for the PV array is derived from the product of the nominal power of the PV array and the factors. We can summarize the yield calculation for a PV array in the following equation:

Eideal =Ppv × Z2 × Z3 × Z4

3.4. Cable, Conversion and Adjustment Losses

With the data for daily electricity consumption of the intended loads, we are able to calculate the daily yield of a solar array in accordance with the geographical location the season and the orientation of the array. The PV array, load and battery are connected with electrical wiring. In particular, the cables and battery reduce the electricity yield. Voltage losses occur in the cables, and the battery causes conversion and adjustment losses. It is only when we take these losses into account will we know the quantity of electrical energy that is actually available to power the loads. When sizing the cables, we will ensure that the total losses will be 6 per cent: 3 per cent in the array to charge controller cable and 3 per cent in the battery to charge controller. Therefore, we will apply 6 per cent for the cable losses. This means that we must reduce the array yield by a factor of VL = 0.94. The conversion of electrical energy into chemical energy and back again into electrical energy, which takes place in the battery, is a process that is difficult to calculate in energy terms since this involves construction details, age, temperature depth of discharge, and the charge and discharge amperage. Here, it is only possible to make use of experience values. In practice, an average loss of 10 per cent is acceptable. This reduces the PV array yield by another factor of Vu = 0.9 [8].

3.5. Summary of the Design Outcome

The PV array is designed around the assumed daily energy consumption W in kWh/day. Depending upon requirements, the average value for summer or winter can be used.

$$P_{PV} = \frac{W}{Z_2 \times Z_3 \times Z_4 \times V} \tag{1}$$

With

$$V = V_L \times V_a \times V_u \tag{2}$$

Corresponding to the statements above, the results for overall losses are:

V= 0.94×0.9=0.846.

Required Data:

Daily energy consumption from Table 1:

Factor Z2 from Table 2 for the horizontal radiation at the relevant location (Gaza Strip). Select the month in which we want to operate the PV system.

The month we choose to operate the PV system is July with Z2 factor =5.43 hours/day.

Factor Z3 from Table 3 for the orientation of the PV array , (less than 45 ° tilt angle, facing east): In this case Z3 =0.9586

Factor Z4 from Table 3 for taking the cell temperature into account: For the month (July): Z4 = 0.99.

Overall factor V for cable, and conversion losses: V = 0.846.

The equation for calculating the required array power Ppv is as follows:

$$P_{PV} = \frac{W}{Z_2 \times Z_3 \times Z_4 \times V}$$

3.6. Sizing of Battery

The battery's task is to compensate for the non-simultaneity of energy supply and energy consumption. The battery capacity is stated in AMP hours (Ah). So far, we have stated the energy consumption in watt-hours (Wh). To be able to relate the values Ah and Wh to each other, we convert the consumption figures into Ah by dividing the Wh by the system voltage (e.g. 12V). In order to gain a sufficiently long service life with fluid electrolyte batteries, we may not plan for the total capacity as specified by the manufacturer. Instead, we can only plan with 50 per cent of this value. We therefore need to select the battery capacity Cn, which is calculated as follow:

- Calculate total Watt-hours per day used by appliances.
- Divide the total Watt-hours per day used by 0.9 for battery loss.
- Divide the answer obtained in item 2 by 0.6 for depth of discharge.
- Divide the answer obtained in item 3 by the nominal battery voltage.
- Multiply the answer obtained in item 4 with days of autonomy (the number of days that you need the system to operate when there is no power produced by PV panels) to get the required ampere-hour capacity of deep-cycle battery.

Battery Capacity (Ah) = Total Watt-hours per day used by appliances x Days of autonomy (0.9 x 0.6 x nominal battery voltage).

The battery type recommended for using in solar PV system is deep cycle battery. Deep cycle battery is specifically designed for to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years. The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days.

3.7. Sizing of the Voltage Regulator

According to its function, it controls the flow of current. A good voltage regulator must be able to withstand the maximum current produced by them array as well as the maximum load current. Sizing of the voltage regulator can be obtained by taking the short circuit current (Isc) of the PV array, and multiply it by 1.3 [6]-[9]. Solar charge controller rating = Total short circuit current of PV array x 1.3. The factor of safety is employed to make sure that the regulator handles maximum current produced by the array that could exceed the tabulated value. And to handle a load current more than that planned due to addition of equipment, for instance. In other words, this safety factor allows the system to expand slightly.

3.8. Sizing of the Inverter

An inverter is used in the system where AC power output is needed. The input rating of the inverter should never be lower than the total watt of appliances. The inverter must have the same nominal voltage as your battery. For stand-alone systems, the inverter must be large enough to handle the total amount of Watts you will be using at one time. The inverter size should be 25-30% bigger than total Watts of appliances. In case of appliance type is motor or compressor then inverter size should be minimum 3 times the capacity of those appliances and must be added to the inverter capacity to handle surge current during starting. For grid tie systems or grid connected systems, the input rating of the inverter should be same as PV array rating to allow for safe and efficient operation [10].

4. Experimental Model: Stand-Alone Photovoltaic System for Home Lighting

4.1. Load Consumption

This model has been developed to be alternate solution for the drop of Grid electricity due to the Siege, shortage of fuel supplies, and maintenance problems. The designed solar model should meet the lighting load for an apartment of 180m2; it consists of 2 bed rooms, 3 living rooms, kitchen and bathroom. The system will be powered by 12 Vdc, 80 Wp PV module.

4.2. PV Size (Results)

$$\text{Total Wp of PV panel capacity needed} = \frac{540}{5.43*0.9586*0.99*0.846} = 123.87 \text{ Wp.}$$

Number of PV panels needed = $\frac{123.87}{80}$ = 1.55 modules.

Actual requirement = 2 modules

So this system should be powered by at least 2 modules of 80 Wp PV module.

4.2.1. Inverter sizing

Total Watt of all appliances = 30 W

For safety, the inverter should be considered 25-30% bigger size.

The inverter size should be about 50 W or greater.

4.2.2. Battery sizing

Total appliances use = (5 Lamps x 15 W x 6 hours) =540 Watt

Nominal battery voltage = 12 V

Days of autonomy = 1 days

Battery capacity= $\frac{540}{0.9*0.6*12} \times 1 =$ 83.3 Ah

Total Ampere-hours required 83.3 Ah

So the battery should be rated 12 V 100 Ah for 1 day autonomy.

Solar charge controller sizing

PV module specification

Pm = 80 Wp

Vm = 16.7 Vdc

Im = 6.6 A

Voc = 20.7 A

Isc = 7.5 A

Solar charge controller rating = (2 strings x 7.5 A) x 1.3 = 19.5 A

So the solar charge controller should be rated 20 A at 12 V or greater.

4.2.3. System summary

Total Watt-hour requirement:	45 Ah/day
PV array size:	160 W—two 80-W modules
Nominal system voltage:	12 V DC
Battery bank capacity:	one battery 100 Ah
Battery type:	deep cycle 12 V at 100 Ah
Autonomy:	1 days
Inverter:	12 V DC; 50 W
Charger	12V DC, 20A

5. Economic Analysis

The need of economic feasibility study is to compare estimated costs of the PV system to other alternatives. The most common alternative to off-grid PV is a line extension from an electric utility company. Other alternatives include on-site diesel generators, each alternative comes with its own benefits and drawbacks, many of which are difficult to quantify. For example, daily period of electricity cutting, the cost of purchasing and delivering diesel should be considered in an economic analysis of alternatives, as well as the noise and exhaust generated as byproducts of the energy production [11].

In Figure 3 shows the complete system, which is represented as finished design. In a photovoltaic system, the investment costs essentially determine the production costs of the generated solar power since no costs are incurred for fuels and the actual running costs (insurance, maintenance, etc.) are low. Via the power production costs, the photovoltaic system can be compared with other energy systems It varies. Depending on the PV and battery sizing, the amount of required electricity, the particular solar energy system, how much sunshine received in our area [12]. Table 4 shows the electricity consumption of a middle-income family in Gaza Strip. Table 5 shows the comparison between the available energy sources in Gaza Strip, Palestine, and the cost estimation per kilowatt-hour ($/KWhr). Unfortunately, price of solar system components is very expensive compared to those outside Gaza Strip, Palestine, which increases the cost of solar energy, another factor is the availability of solar components, which restricts the designer to particular components that increases the cost of solar system. Here are the outlined equations for cost estimation:

Table 4: Apartment Electrical Load

Electrical Load	Wattage (Watt)	Daily operating time(hrs)	Daily consumptions in watt hours (WH)	Lighting (Watt)
Lamps(6 units)	15	6	540	540
TV	85	2	170	-
DVB Digital receiver	18	2	36	-
Laptop	80	2	160	-
ADSL Router	15	2	30	-
Total load			936	540

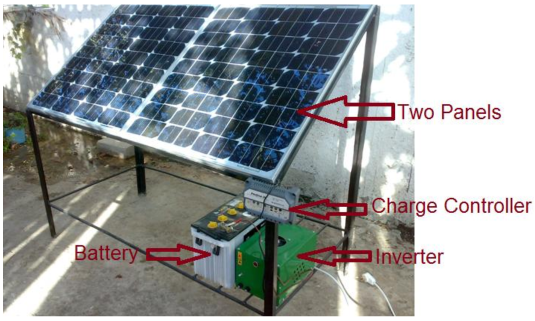


Fig. 3: The ready-built used PV-solar system

$$\text{Cost (\$ / KWhr)} = \frac{\text{Total Cost over 25 years}}{\text{Total Load for 25 years}}$$

Total Cost for 25 years

= installation Cost + Accumulative Running cost for 25 years

+25 years *(Maintenance Cost + Parts Replacement).

Accumulative Running Cost for 25 years

= (Total Yearly cost *Yearly Running Cost) + Previous Year Cost

Yearly Running Cost

= Previous Year Running Cost * (1+ Increment Cost Percentage)

Table 5: Comparison for cost estimation between available source energy for home user

Items	Solar Energy	Grid Network	Diesel Generator
Average Daily Load/Day (KWhr)	1 KWhr	1 KWhr	1 KWhr
Total Yearly Load (KWhr/year)	360	360	360
Expected Liftime (years)	25	100	25
Total Load for Expected PV Lifetime (KWhr)	9,000	9,000	9,000
Installation Cost ($)	2,500	300	150
Running Cost ($/KWhr)	-	0.17	0.5
Yearly Maintenance ($/Year)	-	-	30
Parts Replacemnts ($/Year)	35	-	53
Cost/KWhr	0.38	0.21	0.75

Previous Table 5 shows that the three available resources of electricity in Gaza Strip are ordered according to the cost of KW as the following, electricity from grid is the first, electricity from Photovoltaic is the second, and third is the electricity from Diesel Generators. Solar power takes the second because of the price of solar system components is very expensive compared to those outside Gaza Strip, Palestine, which increases the cost of solar energy, another factor is the availability of solar components, which restricts the designer to particular components that increases the cost of solar system.

6. Conclusions and Recommendations

Gaza strip is considered as one of the poorest areas of energy natural resources around the world, it has not petrol, coal, rivers, and nuclear resources. The Gaza Strip presently experiences 8-12 hours of scheduled power outages per day, which disrupt the normal functioning of humanitarian infrastructure, including health and education institutions and water and sewage systems, as well as the agricultural sector. The power outages also take a toll in human lives of people killed or injured by using generators, which are brought into Gaza through the tunnels, are of poor quality, and are not always used according to safety instructions. The geographical location of the Gaza Strip at 31.3o latitude and 34.3o longitude makes it a relatively sun rich region with an annual solar irradiance of about 2000 kWh.m2. This implies that solar energy systems would be very efficient in this part of the world. Some areas in the Gaza Strip are still beyond utility grid reach especially those along the east border line. The study has presented the components required for the design of a stand - alone photovoltaic system that will light a home in Gaza. The factors that affect the design and sizing of every piece of equipment used in the system have also been presented. The governmental has to present and influential in encouraging people to turn to such alternative energy systems. The government should encourage and support renewable energy research and should provide technical assistant to potential users.

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