DESIGN AND DEVELOPMENT OF A COST EFFECTIVE URBAN RESEDENTIAL SOLAR PV SYSTEM

A REPORT SUBMITTED TO DR. ABDUL HASIB CHOWDHURY OF ELECTRICAL AND ELECTRONIC ENGINEERING DEPARTMENT OF BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLODGY IN FULFILLMENT OF THE REQUIREMENTS FOR THESIS WORK

Fahim Hasan, ID: 09221114,

Jakir Hossain, ID: 09221109,

Maria Rahman, ID: 09221110,

And

Sazzad Ar Rahman, ID:09221199

December 2010

Table of Contents

1. Introduction

1.1. Power shortage problem in Bangladesh

Bangladesh has been facing electricity shortage for many years. But in last few years this problem has exceeded the common people’s patient. Bangladesh is located in tropical region. So except for few months in winter most of the part of a year is summer. In summer the temperature rises up to 40 degree Celsius, when it is nearly impossible to stay without electricity. In this modern world electricity is the main and fundamental demand for common people. Bangladesh is an over populated country, where on an average more than 1617 people live in per square mile. But we cannot ensure 24 hours electricity supply to our people.

Every summer Bangladesh faces huge load shedding problem. According to the official statistics, our electricity shortage has gone up 1000 MW to 1259 MW in 2006, whereas the electricity demand was 4806 MW. In 2009 the country faces a shortage of around 1400 MW to 1800 MW. Every summer we face an uncertain condition due to power.

Power Development Board (PDB) sources informed that the officially estimated power demand is now 5000MW against a generation of around 3500 MW. Only the capital Dhaka needs around 2000 MW of power to run. Here in this highly populated country only 40% of the people have access to electricity with a per capita availability of 136 kWh per annum. Problems in the Bangladesh's power sector include high system losses, delays in completion of new plants, low plant efficiencies, erratic power supply, electricity theft, blackouts, and shortages of funds for power plant maintenance. Overall, the country's generation plants have been unable to meet system demand over the past decade.

1.2. Instant Power Supply (IPS)

IPS is a power back-up system for continuous power supply during electricity failure. It incorporates the latest inverter technology and a built-in microprocessor based control unit that continuously monitors and controls the functions of the IPS. This is designed to meet emergency power requirements for home and office appliances like tube light, fan, television, fax, PABX, energy saving lamp, etc. and can be plugged in directly with the main electric supply. IPS uses grid power to charge its battery and supplies this stored electric energy when power cut occurs. In Dhaka city most of the families use IPS to lessen the power shortage problem. All the IPSs installed throughout Dhaka city are consuming huge electricity from grid. Only here in Dhaka city around 100 mW of IPS is installed. So in one hand IPSs are increasing the comfort level of some people, in the other it’s a burden to those who cannot afford to buy them. These people are actually being deprived of the power, which IPS’s are consuming to charge their batteries.

1.3. Renewable energy to fight power shortage problem

Renewable energy is the energy that comes from natural resources such as sunlight, wind, tides, rain and geothermal heat, which are all renewable. These energies are derived from natural processes that are restored constantly. Electrical energy is derived from solar, wind, ocean, hydropower, biomass, geothermal resources, biofuels and hydrogen. If we can use renewable energy to produce power, we can certainly reduce the power shortage to some extends. Bangladesh government and engineers are also concentrating on using renewable energy. Bangladesh has planned to produce 5% of total power generation by 2015 and 10% by 2020 from renewable energy sources like air, waste and solar energy.

1.4. Solar as the best form of renewable energy

Bangladesh is situated between 20.30 - 26.38 degrees north and 88.04 - 92.44 degrees east which is an ideal location for solar energy utilization. Here daily average solar radiation varies between 4 to 6.5 kWh per square meter. Maximum amount of radiation is available on the month of March-April and minimum on December-January. There is a good prospect of harnessing solar power in Bangladesh. Solar energy is derived from the sun through the form of solar radiation. Power generation with solar energy depends on Photovoltaic and heat engines. In our case as we are finding a solution for urban power shortage problem. Here in urban area wind, ocean, hydropower etc. are not possible to be used as a form of renewable energy to generate power. And among the rest we are going to work with Solar, as it is already being popular in our country but in a very narrow span.

1.5. Solar PV system to replace IPS

The working principal of Solar PV system is similar to IPS. Solar PV system also stores DC energy in battery and when needed converts that to AC for home usage. The main difference is IPS uses grid power to charge the batteries and PV system uses solar power. Using solar to charge batteries will not only save on expenses but also removes a huge load from the grid system, which will definitely be a step to reduce the power shortage of our country. Above all the longevity of most of the elements of PV system is very high. So using solar PV system instead of IPS will allow us to fight against the power shortage problem more reliably and effectively. In case of any problem with the solar power generation like bad weather condition we will have backup grid connection to charge the batteries ensuring 24 hours power backup.

1.6. Solution for a whole residential building

Solar PV system is already becoming very popular in our country. We have 15 mW solar energy capacity through rural households. But solar system is mostly being used in rural areas, where the load is very little. Solar is hardly found in urban areas where the load requirement of the people is very high. So if solar can satisfy urban residential loads in cases of load shedding that will be very helpful to fight the power shortage. So to prove the PV system to be a prime weapon against the power shortage of our country we are developing a design that will provide backup power system to a whole residential building with more than 20 families. Here we are trying to design a cost effective and efficient alternate power supply system that will instantly give backup when any power failure occurs.

1.7. Avoid grid power supply

The most interesting part of our design is that we are introducing an intelligent system that will some time use the solar power to satisfy our load requirement in the morning even if there is proper grid supply. That is how we can contribute to save our grid power using solar instead of grid supply. It will also be economically beneficial for us as we are using the free sun power, rather than using the expensive grid connection. Though it is possible only in morning hours and when the sun will be shining well.

2. Challenges and solutions

From the beginning of our project work we are studying on adding more and more features in our PV system design which will make the system efficient and economic enough to replace the conventional IPS system of our country. We had initially set several challenges that would lead us towards our goal, and found out solutions for those. Some of the prime challenges coming in our way is described briefly here.

2.1. PV system for more than 20 families

Setting up a PV system is very easy. All that someone needs to do is setting up a PV module and store the solar energy to batteries. And supply that energy when required. But the challenge comes when we were trying to set up this PV system in any urban area where the load requirement is very high. Moreover we are designing a common system for a whole residential building having more than 10-20 families living in it. Designing a common system for a whole building instead of designing for each family is proved to be an economically effective system that is shown later. Using a common system also reduces the maintenance cost and space requirement. Because if we go for individual system for each flat than we would need to set up almost each component of PV system in each family which will defiantly become a trouble for maintenance and off course the cost will rise. Whereas in our designed system every single element of PV system will be set up in common and only a wire will go to each flat which be connected to the desired loads.

2.2. Instant power supply

The prime objective of our project is to design a system that will provide a solar photovoltaic system which will supply instant power as soon as the grid power cuts off. The system will keep on checking the availability of grid power supply continuously, and whenever the grid power is not found available the system will immediately connect loads to the PV system. So here in this system if load shedding occurs the system will automatically starts giving backup power.

2.3. Power supply at night

The biggest problem with a solar PV system is that it cannot supply power if there is no sun ray falling on the solar cells. So if anyone wants power supply from PV system while there is no generation of power one must have power storage device (battery) attached to the system. The batteries will store the electric energy coming from the solar cells and supply that energy to load when required. So the system will have to have batteries to ensure power supply in no generation condition and other equipment that will be controlling the charging and the supply from the batteries.

2.4. Charging at night and bad weather condition

In Bangladesh there are heavy clouds for several consecutive days in rainy seasons. This cloud condition may prevent the system to produce enough power to charge the batteries for that period of time. In that case the batteries will not be properly charged and as a result the system will not be able to support the required load. So an alternative charging option is essential to be attached with the system that will help to charge the batteries if necessary. On the other hand in summers as we face too much load shedding it is also possible that giving backup for a long time the batteries get discharged at night time. Now at that time there is no sun outside to charge those batteries. So here also we can use that alternative charging option to charge the batteries. And in this design the alternative source is the grid supply. That means if the battery charge gets too low and the solar power generation is not satisfactory but the grid supply is available the system will use the grid connection to charge the batteries just like the typical IPSs available in Bangladesh. This design is developed in such way that ordinary grid connection will not be required. But exception may occur so the alternate grid charging system is integrated with this design.

2.5. Intelligent system to minimize power consumption

Even when the grid power is available, if the batteries are well charged the PV system can support the loads connected to it directly without touching the battery. That is how the design can save some grid power, because when battery bank is well charged and the grid is connected but the solar cells will not stop generating electricity, which will be totally wasted as the batteries are already charged. So here we will be using this excess power to reduce grid power consumption. On the other side in winters there is almost no load shedding in Bangladesh, or the amount of load shedding becomes very little. In that case if the PV system is designed in such a way that it can avoid grid connection we can certainly reduce the grid usage with the help of this system.

3. Developing the Designs

At the beginning of the project we have developed several possible design topologies shown in figure 4.1a, which are suitable to serve our purpose. The difficult part is to select a design. While selecting a design it is necessary to keep the efficiency and economic factor into account.

3.1. Designed Topologies

In design A and B there are both AC and DC load connected to the system and in C and D only AC load is connected. A common inverter is used for the whole system in design A and C, where in B and C each family will have their own inverter. For all cases battery storage system is common.

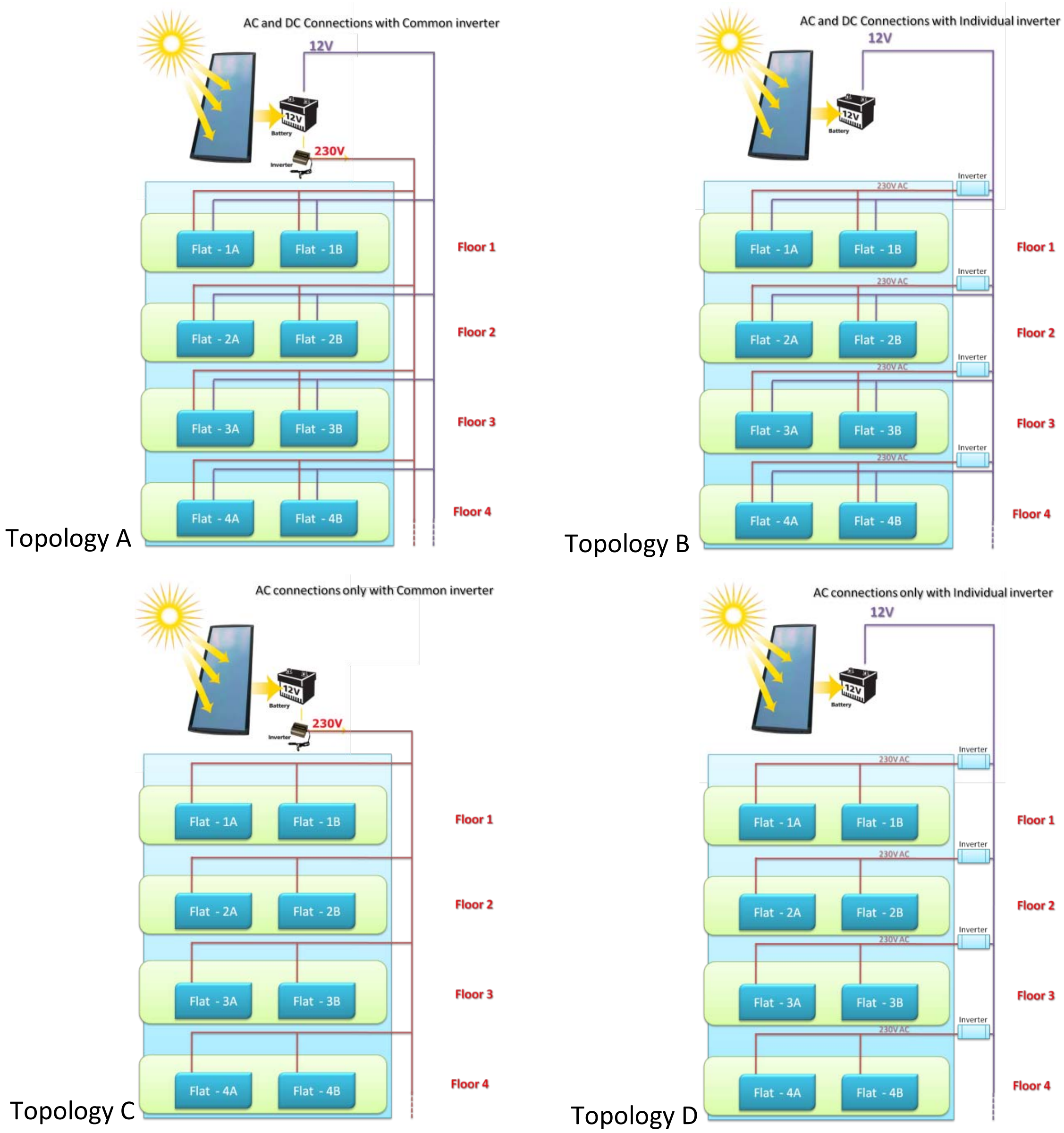


Figure 4.1a Design Topologies

3.2. Comparison of Topologies

3.2.1. Design Comparison

Connecting both will AC and DC load will make the design complicated. Use of only DC appliance is not possible so to simplify the setup we can chose to use only AC appliance. Now coming to the inverter section using a common inverter is easier to implement. If we are setting up inverters in each flat then the maintenance will be a huge issue.

3.2.2. Economic Comparison

As an engineer we also have to consider the economic factors. Like using both AC and DC loads may increasing the complicacy of the design but DC loads will need less energy than AC ones. At least we can use DC lights in our system, which are very popular in our rural areas. After all, those will not need any inverter. Those lights can directly be connected to the batteries. So adding DC loads with the system will defiantly decrease the size of inverter as well as the whole system. And using the common inverter for whole building, instead of using one each flat, will be economically beneficial.

3.3. Selecting a Design

As working with DC load is complicated, though that is economically beneficial, we will not be using DC loads in our system right at this moment. We will be working on DC loads later. So for now we will be designing our system taking Design C as our base topology.

4. Load Calculations

While designing a PV system the first and foremost task is to determine the approximate load that will be connected to the system. Each and every part of the PV system will be designed according to that load requirement. Designing a PV system will need loads in terms of ampere hour (AH) and watt hour (WH). The total wattage and peak current is also necessary for further calculation.

In this PV system we are developing a design that provide backup power for 20 families, each family having four 75W fans, three 15 W CFL bulb and one 23 W CFL bulb connected to the system. So the total wattage and peak current can easily be found. The process of finding the ampere hour load is divided into several stages.

As this system is a backup power system it will be used to supply power to the loads in cases of disconnection of grid power supply. This load shedding time in a day defers form month to month. While in summer Bangladeshi people suffer from load shedding for around 6-10 hours in winters there is load shedding less than 2-3 hours every day. So load requirement for this PV system can be spited in two seasons. Now the daily load shedding hours and daily home appliance usage during load shedding period for both the season is necessary for calculating the total load in Amp-hours. Here the fact will also be considered that the entire load will not be connected at a time.

4.1. Summer Load Calculations

Summer and winter load calculation processes are same. Only difference is in dally load usages. As in summer there are more load shedding the load shedding time usages will be larger than winter.

4.1.1. AC loads

A certain amount of load is allocated for each family in this system. An example of the total load is shown in table 4.1 with various household appliances. Here the total load will be around 4360 W.

Table 4.1 Description of the loads connected to the system.

LOAD DESCRIPTION	QTY		LOAD Current (A)		LOAD Voltage (V)			AC LOAD POWER (W)
Drawing/Dining room light	20	x	0.1	x	230		=	460
Dining room fan	20	x	0.326	x	230		=	1500
Bedroom light	20	x	0.065	x	230		=	300
Bedroom fan	20	x	0.326	x	230		=	1500
Kitchen light	20	x	0.065	x	230		=	300
Toilet light	20	x	0.065	x	230		=	300
TOTAL			**18.94**					**4360**

4.1.2. Hourly load characteristics

This is an approximation of the dally usages of loads connected to the PV system. This approximation is made as a 24 hours basis. Table 4.2 is Daily load usages table that shows which load is used for what span of time. Usages of the load are marked with 'X'. And Table 4.3, the load shedding hours in per 6 hours, shows the estimated time of load shedding happening in our urban areas both in summer and winter.

Table 4.2 Dally Load Usages.

LOAD DESCRIPTION	Dally hours																								
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**Total**
Drawing/Dining room light																			X	X	X	X	X	X	6
Dining room fan	X	X	X	X	X	X	X	X	X	X				X	X					X	X	X	X		16
Cld bedroom light																			X	X	X	X	X	X	6
Cld bedroom fan	X	X	X	X	X	X	X	X											X	X	X	X	X	X	14
Kitchen light																			X	X	X	X	X	X	6
Toilet light																			X	X	X	X	X	X	6
Total Load Watts	150	150	150	150	150	150	150	150	75	75	0	0	0	75	75	0	0	0	143	218	218	218	218	143	

Table 4.3 Load shedding hours in per 6 hours

Season	0 - 5 hours	6 - 11 hours	12 - 17 hours	18 - 23 hours	Total
Winter	0	1	0	1	2
Summer	2	2	2	3	9

4.1.3. Dally average load usages in summer

Analyzing table 4.2 and table 4.3 the average load shedding run time of the loads in summer are determined which is shown in table 4.4.

Table 4.4 Dally average load shedding usages of the loads in summer

LOAD DESCRIPTION	Dally Avarage Load shedding Usages
Drawing/Dining room light	3
Dining room fan	6
Cld bedroom light	3
Cld bedroom fan	5.66
Kitchen light	3
Toilet light	3

From table 4.4 it is seen that all the lights has a dally usage of 3 hours, and the average fan usages is around 4 hours every day. This dally average usage hours will be used to determine the total AC load of summer for the system. Multiplying the dally usage hours with the Load wattage (form Table 4.1) Amp-hour load per day is found, as shown in table 4.5. Power conversion efficiency is assumed to be 80 % and the nominal system voltage is 230 V as all the working loads are in AC.

Table 4.5 Dally average load shedding usages of the loads in summer

LOAD DESCRIPTION	AC LOAD POWER (W)	DAILY DUTY CYCLE (hrs/day)		WEEKLY DUTY CYCLE (%)		POWER CONVERSION EFFICIENCY (%)			NOMINAL SYSTEM VOLTAGE (V)		Amp-Hour LOAD Per Day (AH)
Drawing/Dining room light	460	X	3	x	7 ÷ 7	÷	.8	÷	230	=	7.5
Dining room fan	1500	X	5.5	x	7 ÷ 7	÷	.8	÷	230	=	44.84
Cld bedroom light	300	X	3	x	7 ÷ 7	÷	.8	÷	230	=	4.9
Cld bedroom fan	1500	X	5.5	x	7 ÷ 7	÷	.8	÷	230	=	44.84
Kitchen light	300	X	3	x	7 ÷ 7	÷	.8	÷	230	=	4.9
Toilet light	300	X	3	x	7 ÷ 7	÷	.8	÷	230	=	4.9
TOTAL	**4360**										**111.88**

Hence the amp-hour load per day in summer is found to be 111.88 AH/day which is 25732.4 WH/day. Considering ohmic loss factor 0.9966 (13.2.5) the final amp-hour load comes to 111.88 AH/day which is 25732.4 WH/day.

4.2. Winter Load Calculations

In winter the loads will be the same and the normal usages will also remain the same. The only change will be in the load shedding hours, which certainly will decrease. So the average load shedding time usages of the connected loads will decrease.

4.2.1. Dally Average load usages in winter

Analyzing table 4.2 and table 4.3 the average load shedding run time of the loads in winter are determined which is shown in table 4.6

Table 4.6 Dally average load shedding usages of the loads in winter

LOAD DESCRIPTION	Dally Avarage Load shedding Usages
Drawing/Dining room light	1
Dining room fan	2
Cld bedroom light	2
Cld bedroom fan	2
Kitchen light	2
Toilet light	1

From table 4.6 the amp-hour load for winter is found just like the summer calculations, which is shown in table 4.7.

Table 4.7 Dally average load shedding usages of the loads in winter

LOAD DESCRIPTION	AC LOAD POWER (W)		DAILY DUTY CYCLE (hrs/day)		WEEKLY DUTY CYCLE		POWER CONVERSION EFFICIENCY		NOMINAL SYSTEM VOLTAGE		Amp-Hour LOAD Per Day (AH)
Drawing/Dining room light	460	X	1	x	7 ÷ 7	÷	.8	÷	230	=	2.5
Dining room fan	1500	X	2	x	7 ÷ 7	÷	.8	÷	230	=	16.3
Cld bedroom light	300	X	2	x	7 ÷ 7	÷	.8	÷	230	=	3.26
Cld bedroom fan	1500	X	2	x	7 ÷ 7	÷	.8	÷	230	=	16.3
Kitchen light	300	X	2	x	7 ÷ 7	÷	.8	÷	230	=	3.26
Toilet light	300	X	1	x	7 ÷ 7	÷	.8	÷	230	=	1.63
TOTAL	**4360**										**43.25**

Hence the amp-hour load per day in winter is found to be 43.25 AH/day which is 9991.2 WH/day. Considering wire loss factor 0.9966 (13.2.5) the final amp-hour load comes to 43.25 AH/day or 9991.2 WH/day.

4.3. Average Approximate Load for Further Calculation

It is clear that if the system is designed considering the loads of summer the system will easily work in winters as the load requirement is less in winter. So we are using the amp-hour load calculated for summer as the final load of the system, so that the system works properly throughout the year. So bottom line is that we have to design a PV system that supports 111.88 AH/day which is 25732.4 WH/day load connected to the system.

4.4. Load Calculation using PVSyst 5.21

We have also conducted the whole load calculation process in PV system simulation software, PVsyst 5.21. Calculations done in PVSyst are shown here.

Figure 5.6a shows the PVSyst 5.21 User's need window. Here inputs are the number of appliance, wattage and dally usage hour. As the design is being developed combined for 20 families, we have calculated the loads together. Fluorescent lamps of the software used as 23 W CFL bulb, TV loads are used for calculating 75 W fans and domestic appliances are used for calculating 15 W CFL bulbs. The power conversion efficiency is not calculated here for software limitations [11.4]. In figure 5.6b the hourly distributions of the loads are defined so that the software can understand what amount of load is used in which period of time in a day.

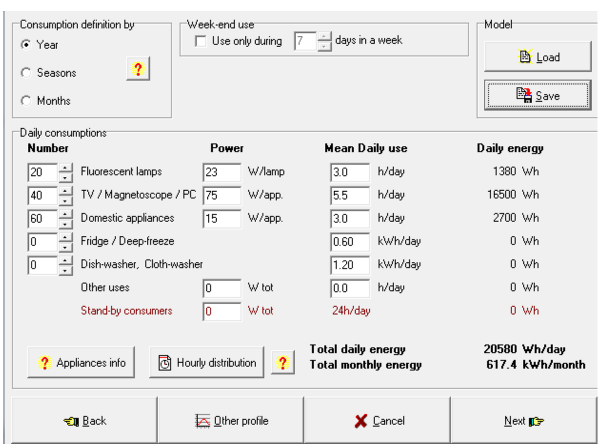


Figure 5.6a PVSyst 5.21 User's need window

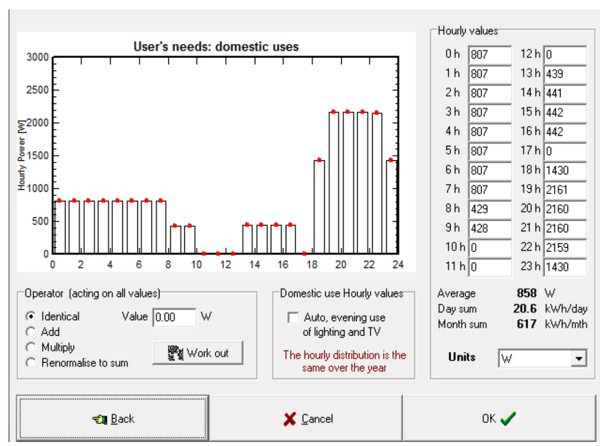


Figure 5.6b PVSyst 5.21 Hourly Load distribution window

This shows a total daily energy requirement is 20580 Wh/day and 617.4 KWh/month. Now calculating 80% power conversion efficiency we have 25725 Wh/day which is almost the same as our mathematical calculation that gives us 25732.4 Wh/day.

5. Roof Spacing Survey

The most important part of setting up a PV system is the establishment of the PV modules which is to be set up somewhere, where the sun light reaches directly without any obstacles. The only such space available in any urban residential building is the rooftop of that building. The rooftop is generally used for various purposes. Most of the buildings have some space allocated for drying clothes, gardening and playing in its roof. Some of the building also has community space at the roof. So naturally the building settlers will not allow us to use the whole roof for establishing the PV modules. In most cases we can use the top portion of the water storage tank, roof of the lift and community space. In case of no such space found an extra shade can be made at the roof top for setting up arrangement of the PV modules.

To have a proper idea of how much space we will have at the roof top of any urban building we have gone through several stages of survey. We have surveyed at almost every part of the Dhaka City, using software applications and physically, analyzing those surveyed data came to a conclusion. To visually understand the spacing more clearly we have created 3D Version of several buildings, which will help us for further procedure of establishing the PV modules.

5.1. Procedure of Survey

The actual task of the survey was to determine the approximate free space available at the roof top of the buildings and the space that will be allowed for solar establishment. For this purpose with the help of Google maps and Google earth we determined the available space at rooftop of most urban buildings. Considering other usage of the roof we assumed the approximate space that will be allowed for our PV system setup. To cross check the spacing we physically surveyed several building roofs from each area. For a clear and understandable view we have created 3D models for several buildings.

5.1.1. Google Map Survey

With the help of Google's distance measuring tools in Google Earth the area of the Roof of any building can be determined easily. Figure 5.1 shows the Satellite view of Dhanmondi Road 8-A. From this figure roof design of the building of this road can easily be understood. Surveying this road we found the number of families living in these buildings and from that the approximate load requirement is assumed. Considering the roof design and other usages of the roof we approximated available space for PV System establishment for each building of this road.

From the measuring tool the straight distance can be measured. Area is found as the length and width of roof is found. A close view of house no. 63 of that road is shown in figure 5.2, where each part of the roof is marked with numbers. How the approximate space is determined is described clearly in Physical Survey Point [5.1.2].

Figure 5.1 Satellite View of Dhanmondi Road no. 8/A (House no. 48-81)

Figure 5.2 Satellite View of House no. 63 (Dhanmondi Road no. 8/A)

5.1.2. Physically Roof Spacing Survey

We have surveyed different building across the Dhaka city. Each building has different roof design, but rooftops of the most building have similar functions. We have taken House no. 63 of Road no. 8/A, Dhanmondi R/A as an ideal one. Surveying this building physically we have seen that the whole rooftop of that building is split into several parts, as shown in figure 5.2. Each of those parts is shown very clearly in figure 5.3. Dimension of each part is listed in Table 5.1. Now analyzing the parts of this building the approximate roof spacing is found.

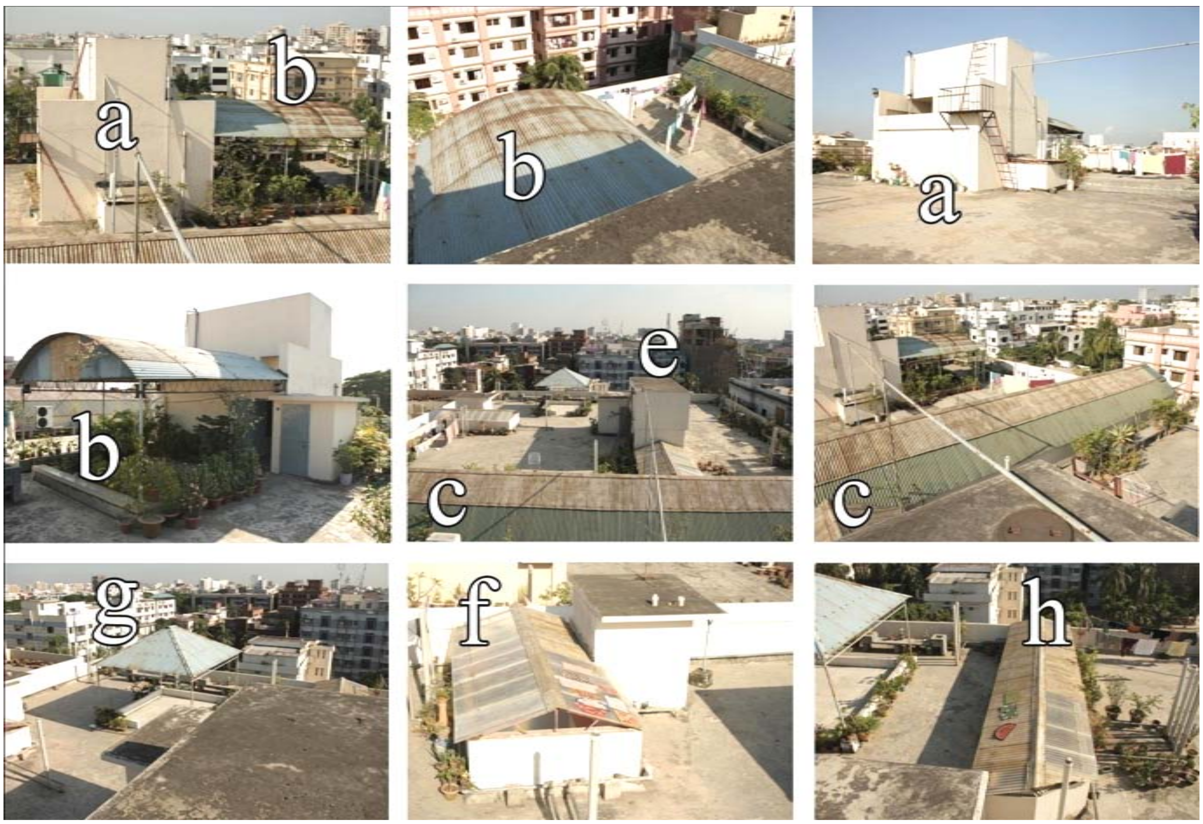


Figure 5.3 Partial Roof Photo of House no. 63 (Dhanmondi Road no. 8/A)

In the case of this building the portion shown in figure 5.3 can be used for solar establishment. Part ‘a’ is the water storage of that building. It is of 200 sq. ft. Part ‘e’ is the elevator maintenance room which is also 200 sq. ft. The total usable space combining part ‘a’, ‘c’, ‘d’, ‘f’, ‘g’ and ‘h’ is around 1000 sq. ft. these entire portion of the roof can be allowed to establish PV modules.

We have conducted the same procedure for some more buildings from different areas to cross check with the data we have got from Google.

5.2. Analysis with 3D Model

Having a look at the figure 5.4 will make the view clear. Here in this figure it is seen that combining Part 'a' and 'e' it is around 400 sq. ft. flat surface. And this can be easily used for PV module set up. The half portion of part 'c' is south facing this portion can also be used for module set up. Now full portion of the south facing c is also not possible to use as it has shedding in the western part, which is shown in the shedding analysis part [9.2.5]. To have a better idea go to section 9.2.4. So sufficient space can be found in any building designed like this.

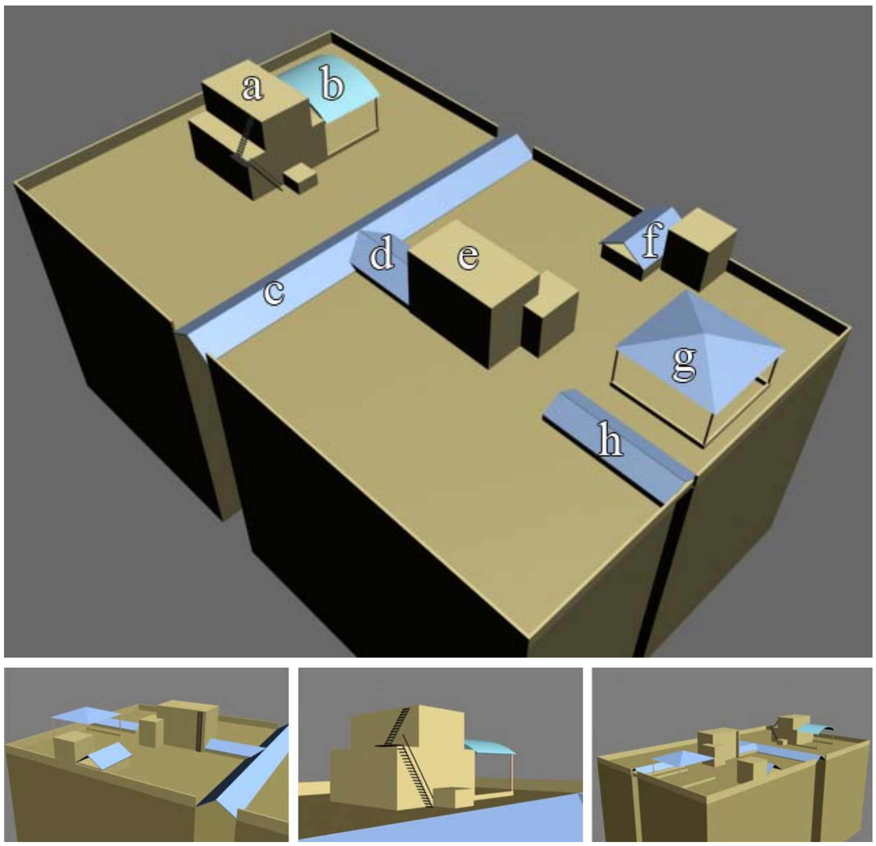


Figure 5.4 3D perspective of the roof of House no. 63 (Dhanmondi Road no. 8/A)

5.3. Roof Spacing Analysis

Considering all the facts mentioned before we assumed the usable area for solar establishment. As an example roof spacing analysis data of Dhanmondi road no. 8/A is shown in table 6.3a. Where it is found that in a building with 20 families more than 1500 sq. ft. area is usable for PV set up. We have conducted this survey at all most every area of Dhaka city. In some areas it is found that total area of buildings is smaller than Dhanmondi area. But the load requirement also decreases with size of the building as the number of families' decreases.

Table 5.1 Roof Spacing Analysis of Dhanmondi Road no. 8/A

Sl No.	Road No	Holding No.	No. of Families	Total Space			Usable for Solar Establishment			%
				X	Y	Sq Ft.	X	Y	Sq Ft.	
1	8/A	62	15	65.421	78.421	5130.38024	78.42	25.27	1981.6734	**38.63**
2	8/A	63	20	146.61	85.85	12586.4685	50	37	1850	**14.70**
3	8/A	64/A	5	61.23	36.19	2215.9137	33.59	18	604.62	**27.29**
4	8/A	64/B	10	62	37	2294	36.74	23.04	846.4896	**36.90**
5	8/A	65	15	81.22	88.63	7198.5286	48.26	67.74	3269.1324	**45.41**
6	8/A	66	20	89	79.37	7063.93	46.46	24.87	1155.4602	**16.36**
7	8/A	67	20	70.11	35.5	2488.905	70.11	20.54	1440.0594	**57.86**
8	8/A	70	20	77.97	80.63	6286.7211	41.62	77.97	3245.1114	**51.62**
9	8/A	71	20	144.57	78.18	11302.4826	78.18	56.96	4453.1328	**39.40**
10	8/A	73	10	83.75	57.93	4851.6375	57.68	38.31	2209.7208	**45.55**
11	8/A	78	20	157.2	85.37	13420.164	44.12	84.61	3732.9932	**27.82**
12	8/A	79	20	144.44	78.67	11363.0948	78.67	47.15	3709.2905	**32.64**
13	8/A	UIU	Commercial	152.27	78.74	11989.7398	94.11	49.12	4622.6832	**38.56**
14	8/A	ALMAS	Commercial	81.95	84.11	6892.8145	77.17	32.01	2470.2117	**35.84**
15	8/A	61	15	59.38	68.01	4038.4338	47.04	27.68	1302.0672	**32.24**
16	8/A	59	20	149.52	86.23	12893.1096	86.23	59.29	5112.5767	**39.65**
17	8/A	57	20	93.97	87.79	8249.6263	78.24	49.59	3879.9216	**47.03**
18	8/A	55	10	64.55	56.06	3618.673	64.05	29.34	1879.227	**51.93**
19	8/A	50/A	20	100.76	53.96	5437.0096	53.96	50.44	2721.7424	**50.06**
20	8/A	50/B	15	78.29	52.52	4111.7908	52.52	33.73	1771.4996	**43.08**
21	8/A	49	20	177.66	81.97	14562.7902	81.97	76.20	6246.114	**42.89**
									Avarage:	**38.83**

5.4. Result of the Roof Spacing Survey

At the end of this roof spacing survey it is found that in a building with 20 families more than 1500 sq. ft of area can be found at roof top for Solar Panel establishment. And as the building size increases or decreases the number of families and load requirement also changes according to building size.

6. Primary Elements

The whole system is designed consisting of various elements. Starting from the beginning the solar radiation drops on the solar cells of the PV modules, which produce DC power. This DC power is supplied to the load but as the household loads run in AC, the DC power, from the solar cells need to be inverted to AC. So here we need an inverter. But as the system can generate electricity only when there is bright sun light, a storage device is necessary here to store the solar energy in electrical form. Now batteries will take the charge of storing energy in this system. To control the charging system we need a charge controller. An intelligent controller is used here which will control when to connect the system with the loads, how to charge the batteries when there is no sun light available and to prevent charging with grid connection while it is not needed. These primary elements discussed in this chapter.

6.1. PV Modules

This is the prime element of a PV system. This is magic wand which produces electricity from Sun light. PV module has many solar cells in it connected in series and parallel varying from model to model. The main task of PV module is to convert the solar energy to electrical energy. The photovoltaic effect is the basic principal process by which a PV cell converts sunlight into electricity. When light shines on a PV cell, it may be reflected, absorbed, or pass right through. The absorbed light generates electricity. (1)

6.1.1. Solar Cells and how it works

A single PV cell is a thin semiconductor wafer made of two layers generally made of highly purified silicon. The layers have been doped with boron on one side and phosphorous on the other side, producing surplus of electrons on one side and a deficit of electrons on the other side.

When the wafer is bombarded by sunlight, photons in the sunlight knock off some of excess electrons, this makes a voltage difference between the two sides as the excess electrons try to move to the deficit side. In silicon this voltage is .5 volt.

Metallic contacts are made to both sides of the semiconductor. With an external circuit attached to the contacts, the electrons can get back to where they came from and a current flow through the circuit. This PV cell has no storage capacity; it simply acts as an electron pump.

The amount of current is determined by the number of electrons that the solar photons knock off. Bigger cells, more efficient cells, or cells exposed to more intense sunlight will deliver more electrons.

6.1.2. Photovoltaic Modules

A PV module consists of many PV cells wired in parallel to increase current and in series to produce a higher voltage. 36 cell modules are the industry standard for large power production.

The module is encapsulated with tempered glass (or some other transparent material) on the front surface, and with a protective and waterproof material on the back surface. The edges are sealed for weatherproofing, and there is often an aluminum frame holding everything together in a mountable unit. In the back of the module there is a junction box, or wire leads, providing electrical connections.

6.1.3. Types of PV Modules

There are currently four commercial production technologies for PV Modules:

Single Crystalline
This is the oldest and more expensive production technique, but it's also the most efficient sunlight conversion technology available. Module efficiency averages about 10% to 12%.

Polycrystalline or Multicrystalline
This has a slightly lower conversion efficiency compared to single crystalline but manufacturing costs are also lower. Module efficiency averages about 10% to 11%.

String Ribbon
This is a refinement of polycrystalline production; there is less work in production so costs are even lower. Module efficiency averages 7% to 8%.

Amorphous or Thin Film
Silicon material is vaporized and deposited on glass or stainless steel. The cost is lower than any other method. Module efficiency averages 5% to 7%.

6.1.4. Module Selection

Single crystalline and polycrystalline module's efficiency is very high but expense is high as well. But the expense is very crucial in our design. As we are designing a system with a large load, the number of solar panel will also be large. So the expense of the panels will rise. So using these high quality modules will go beyond the reach of the common people. In this circumstances considering the economic facts we have decided to use polycrystalline, which will not be too costly and but efficient.

6.1.5. Photovoltaic Panels

PV panels include one or more PV modules assembled as a pre-wired, field-installable unit. The modular design of PV panels allows systems to grow as needs change. Modules of different manufacture can be intermixed without any problem, as long as all the modules have rated voltage output within 1.0 volt difference.

6.1.6. Photovoltaic Array

A PV Array consists of a number of individual PV modules or panels that have been wired together in a series and/or parallel to deliver the voltage and amperage a particular system requires. An array can be as small as a single pair of modules, or large enough to cover acres.

12 volt module is the industry standard for battery charging. Systems processing up to about 2000 watt-hours should be fine at 12 volts. Systems processing 2000 - 7000 watt-hours will function better at 24 volt. Systems running more than 7000 watt-hours should probably be running at 48 volts.

In our system we will be using 12 volt modules because we have batteries connected to our system store energy. So the nominal DC voltage of our system will be 12 volt. And before supplying to load this 12 volt DC will be inverted to 230 volt AC.

6.2. Inverter

An inverter is an electrical device that converts direct current (DC) to alternating current (AC) at any required voltage and frequency with the use of appropriate transformer, switching and control circuits. Inverter is one of the main elements of PV system if AC load is connected to the system. Because the current produced in cells and stored in batteries is DC and as we are using AC loads we need to convert DC to AC with inverters.

6.2.1. Inverter's Basic

Batteries produce power in direct current (DC) form, which can run at very low voltages but cannot be used to run most modern household appliances. Utility companies and generators produce sine wave alternating current (AC) power, which is used by most commonly available appliances today. Inverters take the DC power supplied by a storage battery bank and electronically convert it to AC power.

In our system inverter is used in a backup Solar PV system in a grid connected building where power, coming from solar cells will be used to keep the batteries charged. And when grid power fails, the system will start drawing power from the batteries and supplying it to the building electrical system. Most modern inverters also include overvoltage and under voltage protection, protecting sensitive equipment from dangerous power surges as well.

Now the problem arises when there is electricity available the AC power, coming from the grid connection will try to charge the batteries converting from inverter. Here the intelligent controller used in our system will control the Grid Charging system, which is described in [9.6]

6.2.2. Inverter Types

Different types of Power inverters are found. These inverters differ in sizes, efficiency and the quality of AC power supplied. Some types of inverters available for usage in solar PV system are detailed here.(2)

True Sine Wave Inverters

True sine wave inverter actually generates the wave shape closely to sine wave, as shown in figure 6.1. They are most efficient for our home appliances and also effective. Because these kinds of inverters can produce wave shapes which is very close to the wave shape of grid supply. True sine wave will run practically any type of AC equipments. And appliance will draw less power with a true sine wave. But in terms of cost this type of inverters are very expensive.

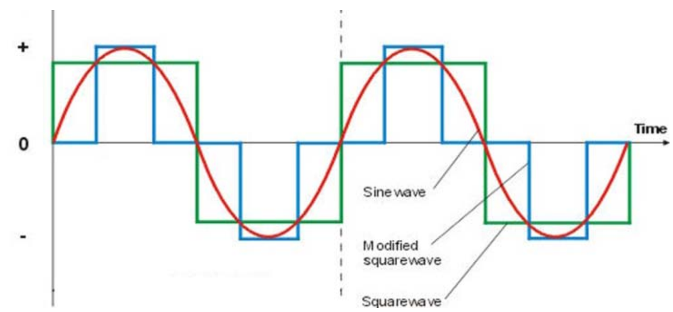


Figure 6.1 Types of Waves Supplied from Various Inverters

Squire Wave Inverters

This is the least expensive and least desirable type. The square wave it produces is inefficient and is hard on many types of equipment. These inverters are usually fairly inexpensive, 500 watts or less. It is not even considered as power inverters for a home system.

Modified Sine Wave Inverters

Modifies sine wave inverter produces wave between square wave and sine wave, shown in figure 7.2a. Modified sine wave inverters are most popular and economical inverters. These inverters will work with our most of the home appliances but the equipment which uses motor speed controls or timer will not work well with modified sine wave inverter. These inverters are not efficient like true sine wave inverter and also increase power loss but they are less expensive than true sine wave inverters.

6.2.3. Selection of Inverter

We cannot choose squire wave inverters for our system because this kind is not suitable as power inverters. On the other hand true sine wave inverters being the best as power inverter are very hard to use because these are too expensive. So we are left with only the last type, the modified sine wave inverters. This modified sine wave can run almost all kinds of household appliance we are using in our system.

6.3. Battery

Battery is the heart of our system. Without the battery in our system the system will not be able to provide 24 hours support. This is the device that stores the DC energy from PV panel in chemical form, and when needed converts the stored chemical energy to electrical energy.

6.3.1. Basic of Battery in PV System

In solar PV system batteries are charged and discharged randomly. Life time of battery is depends on charging and discharging of battery. The popular unit to measure charging capacity of battery is Amp-hour. Battery ratings are depended according to cycle. Car battery is shallow cycled which types of battery have cycles between 10% - 15% of batteries total capacity. In other hand solar energy system has deep cycle batteries which have up to 50% - 80% of total battery's capacity. Deep cycle batteries are capable of many repeated deep cycles and best for solar power system.

6.3.2. Available Types of Batteries

There are many types of batteries found all around the world but only these four types of batteries are commonly used with the appliances we are using in our system.

RV or Marine type deep cycle battery
These are basically used for boats and camps where small loads are needed to get powered. These types of batteries do not have capacity for continuous service with charger or discharger.

Lead- acid battery
Lead acid batteries can be used for solar energy storage. These types of batteries are deep cycled and have long life time for charging and discharging. Typical life time of lead- acid batteries is 3- 5 years. Life time of Battery actually depends on the charging and discharging cycle. Lead acid batteries releases some gas while charging. That's why these batteries are needed to be kept outside or cross ventilated place, where air circulation is good enough.

AGM battery
Absorbed glass material (AGM) batteries are another type of battery which allows the electrolyte to be suspended in close proximity with the plate's active material. The AGM batteries are special batteries that typically cost twice as much as a premium wet cell. However they store very well and do not tend to sulfate or degrade as easily as wet cell. There is little chance of a hydrogen gas explosion or corrosion when using these batteries. The larger AGM batteries are typically good deep cycle batteries and they deliver their best life performance if recharged before allowed to drop below the 50% discharge rate. When Deep Cycle AGM batteries are discharged to a rate of no less than 60% the cycle life will be 300. AGM batteries are used in airplanes and hospitals where large charging time is needed.

Gel battery

The Gel Cell is similar to the AGM style because the electrolyte is suspended, but different because technically the AGM battery is still considered to be a wet cell. The electrolyte in a Gel Cell has a silica additive that causes it to set up or stiffen. The recharge voltage on this type of cell is lower than the other styles of lead acid battery. This is probably the most sensitive cell in terms of adverse reactions to over-voltage charging. Gel Batteries are best used in VERY DEEP cycle application and may last a bit longer in hot weather applications. If the incorrect battery charger is used on a Gel Cell battery poor performance and premature failure is certain.

6.3.3. Local Survey

Surveying some local companies we found a list of batteries that are mostly available throughout our country. Most of these batteries are being imported from other countries table 6.1 shows the list of batteries available.

Table 6.1 List and description of locally available batteries.

Sl. No.	Battery Type	Volts	AH @20 Hr.	Dimension (mm)			Approximate Market Price (Tk)	Container Type
				Length	Width	Height		
1	AP50	12	50	258	170	221	4,625.00	PP
2	AP70	12	70	302	170	227	6,480.00	PP
3	AP100	12	100	415	178	255	9,495.00	PP
4	AP120	12	120	500	182	255	11,070.00	PP
5	AP150	12	150	505	221	255	13,420.00	PP
6	AP200	12	200	514	275	255	14,980.00	PP

Studying the catalogs and brochures provided by the battery selling companies we came to know that these batteries are sold with free after sales services for all over Bangladesh through their own outlets, authorized dealers and registered retailers. These batteries are specially made for battery driven TV, VCR, DVD player, fan, light and mainly for IPS or Inverter, which we will be using in our system.

6.3.4. Battery Selection

Selecting a type of battery for a PV system like ours depends on various facts like, Battery price, efficiency, charging and discharging factor, etc. Considering the economic factor and availability in our country we will be using Lead acid batteries, which are being widely used as a solar system storage device. These batteries are comparatively cheap, efficient in power storing and have a life time of 3 – 5 years. Though these types of batteries release some hydrogen gas while charging and needs some maintenance but still for large solar energy storage system lead acid battery is very popular.

Here we will be using batteries of 200 Ah and 12 V, as our systems nominal voltage is 12V. Considering the prices of the locally available batteries we have decided to use batteries of 200 Ah, which will be the most economic battery for our system.

6.4. Charge Controller

Charge controller is and equipment which controls the charging system of the battery. Since the brighter the sunlight, more voltage the solar cells produces. Here if we don’t have any charge controller, the excessive voltage can damage the battery. So the charge controller is a vital component in our system so that we have an extended life time of the batteries.(3)

6.4.1. Basics

A charge controller is used to maintain the proper charging voltage on the batteries. As the input voltage from the solar array arises the charge controller regulates the charge to the batteries preventing any overcharging. And when the battery is fully charged the charge controller prevent the system to charge the battery more. Charge controller also prevents backward current flow, because some time at night when the panels are not generating any electricity, the current from battery can try to move towards the panels. Charge controller prevents this kind of backward flow. The charge controller is installed between the solar panel and the batteries where it automatically maintains the charge on the batteries using the three stage charge cycle.

7. Local Weather Study

Bangladesh is situated between 20.30 - 26.38 degrees north and 88.04 - 92.44 degrees east which is an ideal location for solar energy utilization. Another thing is that the sunlight falls directly in summer and transversely in winter. In Bangladesh, most of the modern building in urban area have flat roof. This roof is normally exposed to the direct solar radiation. After that, the Bangladesh receives about 300 clear sunny days per year, and this is enough to produce an enormous amount of solar energy in a sustainable way. Here daily average solar radiation varies between 4 to 6.5 kWh per square meter. The yearly direct solar energy available in the country of Bangladesh is estimated to be 25610 million tons of coal equivalents. Maximum amount of radiation is available on the month of March-April and minimum on December-January. There is a good prospect of harnessing solar power in Bangladesh. In a recent study conducted by Renewable Energy Research Centre, it is found that average solar radiation varies between 4 to 6.5 kWhm-2day-1. Data in Table 8.1 has illustrated prospect of solar radiation in Bangladesh.

Table 8.1 Average monthly Solar Radiation in Bangladesh

MONTH	SOLAR RADIATION (KWh/m2-day)
Annually	(4-4.5)
January	(3-3.5)
February	(4-4.5)
March	(4-4.5)
April	(5-5.6)
May	(5-5.6)
June	(4-4.5)
July	(4-4.5)
August	(4-4.5)
September	(3.5-4)
October	(3.5-4)
November	(3.5-4)
December	(3.5-4)
Average	(3-3.5)

Table 8.2 Average monthly Solar Radiation in Dhaka

MONTH	SOLAR RADIATION (KWh/m2-day)
January	4.03
February	4.78
March	5.33
April	5.71
May	5.71
June	4.80
July	4.41
August	4.82
September	4.41
October	4.61
November	4.27
December	3.92
Average	4.73

Apart from the different sources, few other organizations or institutes have also measured time series of global radiation, direct or beam radiation, diffuse radiation, sunshine hours and temperatures of different parts of the Bangladesh. Monthly Global Solar Insolation at Dhaka city of Bangladesh and Daily Average Bright Sunshine hour at Dhaka city are presented in tables 8.2.

The solar radiation map of Bangladesh was jointly prepared by Renewable Energy Research Center (RERC), Dhaka, Bangladesh and National Renewable Energy Laboratory (NREL); Shown in figure 8a.

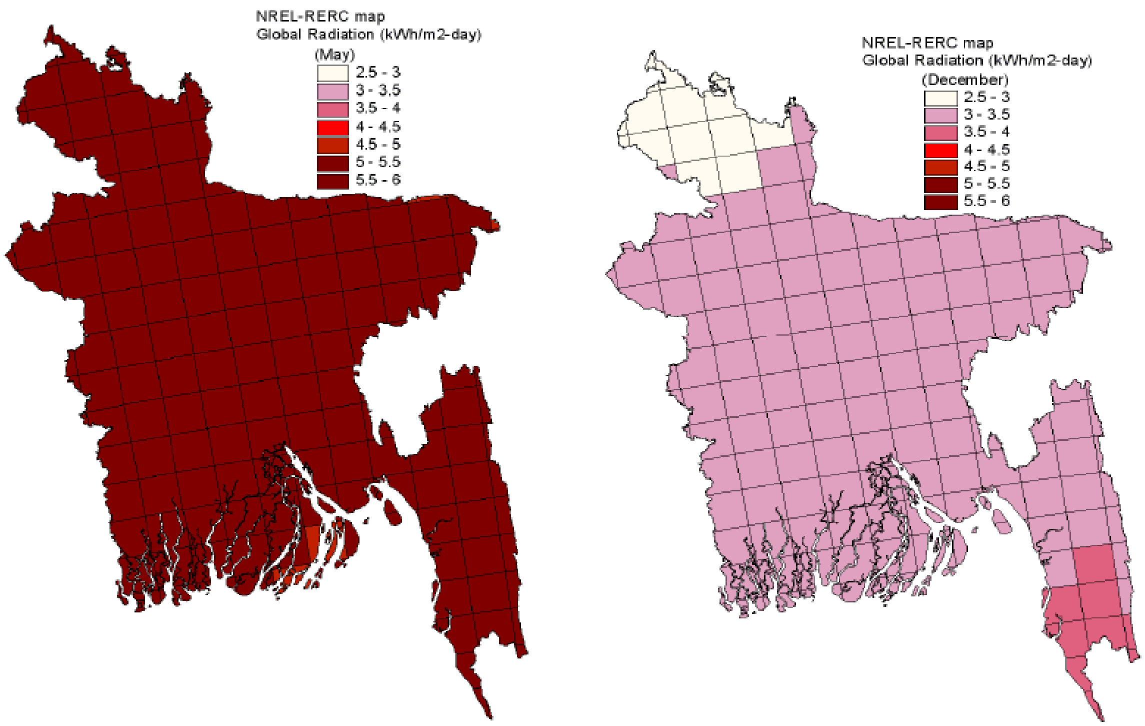


Figure 8.1 The Solar Radiation Map of Bangladesh

From the maps and geographical Information System (GIS) data sets of monthly and yearly sums of Global Radiation it is seen that the data in an effective manner to facilitate solar technology investment.

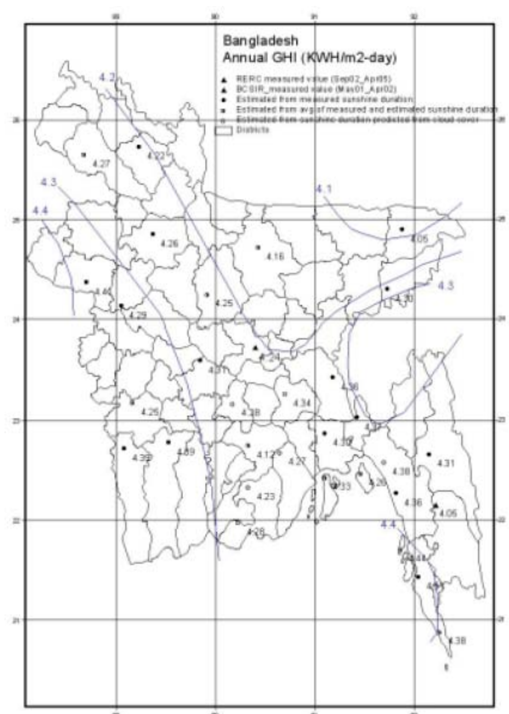


Figure 8.2 Bangladesh Annual global horizontal (GHI) map

9. Basic Design and Calculations

9.1. Basic Design

The basic design can be understood easily from the figure 9.1 the total sizing and calculations of the system is described here.

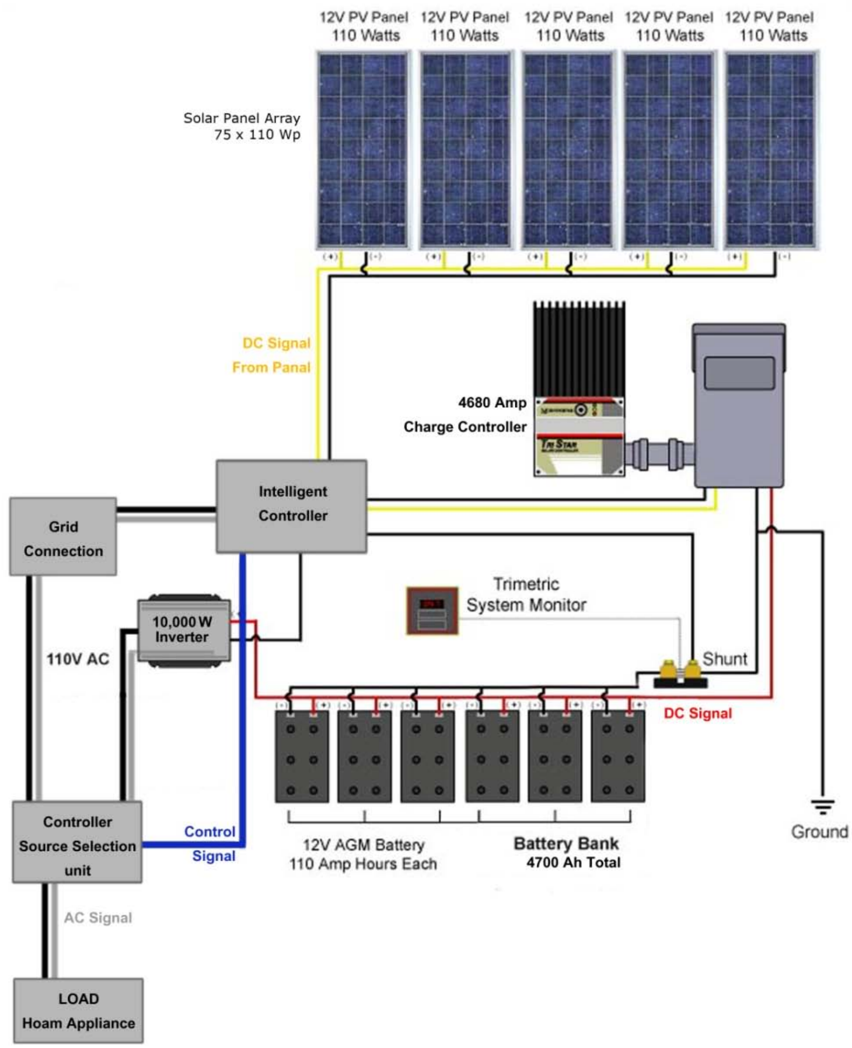


Figure 9.1 Types of Waves Supplied from Various

When in the morning time sunlight is available the charge controller will keep on charging the Battery bank and when load shedding occurs the system will supply the stored energy to loads. But in the morning when the grid is connected if the battery is fully charged the system will directly connect the load to the PV modules so that the solar power can run the load avoiding the grid supply. It is possible because in the morning household load requirement is comparatively low and if we have excess energy available from solar why not use it to avoid utility supply. At night or in rainy seasons if the energy getting from the sun is not satisfactory for battery to charge the system will take the help of utility supply to charge. To satisfy all this condition the intelligent controller is used.

9.2. PV Module Setup Procedure

The first stage of PV module setup is to determine the size of the PV module required to support the whole system. Than we need to assume the total approximate size required for PV module setup. Array configuration is a very important fact here in PV setup. That will describe how the modules will be arranged. While setting up the PV modules we also have to consider the shading effect and building categorization as the array configuration will change with the building roof design. In section 6.1.4 we have considered that we will be using polycrystalline Modules.

9.2.1. PV Module Sizing according to the Load Calculation

As we already know the approximate load requirement we can determine the size of the PV module for our design. But the size of the module depends on which kind of module we are using. As an example we are considering SF 160 module(4) of 190 Wp to be an ideal module. The specification is shown in figure 9.2.

SF 160 Polycrystalline Module

Wattages available: 155, 160, 165, 170, 175, 180, 185, 190, 195

Average cell efficiency: 15.7%

Electrical characteristics chart:

Maximum Power (P_{max})	155W	160W	165W	170W	175W	180W	185W	190W	195W
Open Circuit Voltage (V_{OC})	43.3V	43.5V	43.7V	44.1V	44.5V	44.7V	44.9V	45.0V	45.2V
Short Circuit Current (I_{SC})	4.95A	5.03A	5.14A	5.17A	5.20A	5.23A	5.37A	5.48A	5.55A
Maximum Power Voltage (V_{mp})	35.2V	35.3V	35.5V	35.5V	35.7V	35.8V	35.9V	36.0V	36.2V
Maximum Power Current (I_{mp})	4.40A	4.51A	4.65A	4.78A	4.90A	5.03A	5.16A	5.28A	5.38A
Module Efficiency (%)	12.2%	12.5%	12.9%	13.3%	13.7%	14.1%	14.5%	14.9%	15.3%
Cell Efficiency (%)	13.8%	14.3%	14.8%	15.3%	15.8%	16.6%	16.8%	17.0%	17.2%
Tolerance	+/-3%								
Temperature Coefficients of (P/V/I)	-0.48%/K / -0.34%/K / +0.05%/K								
Maximum System Voltage (IEC/UL)	1000V / 600V								

Electrical characteristics at Standard Test Conditions (STC), defined as: Irradiance of 1000W/m2, Spectrum AM

Figure 9.2 SF 160, 190Wp PV Module Specification

Total PV panels energy needed	= 25732.4 Wh/day.	
Total Wp of PV panel capacity needed	= 25732.4 / 4 hours	= 6,433.1 Wp
Number of PV panels needed	= 6,433.1 / 190	= 33.858 modules
Having 10% extra modules we need	= 40 modules.	

So this system should be powered with at least 40 or more modules of 190 Wp.

9.2.2. Array Configurations

As Dhaka city is situated at 23° 43' 23" N / 90° 24' 31" E so we will be setting up the panels at 30^{o} angle so that our fixed arrays can give us maximum possible output.

9.2.3. Approximation of the Required Space

The PV module shown in figure 9.2 SF 160 polycrystalline has a dimension of 1580 x 808mm which is 5.18 x 2.65 ft.

On an average in Dhaka City the Sun ray falls in 60^{o} angle, and we are setting up our PV Modules at 30^{o} angle with the ground, where the northern part of the module will be at height.
Here, in the figure 9.3 the 'E' arm is PV module and 'A' arm is considered to be the Sun ray.

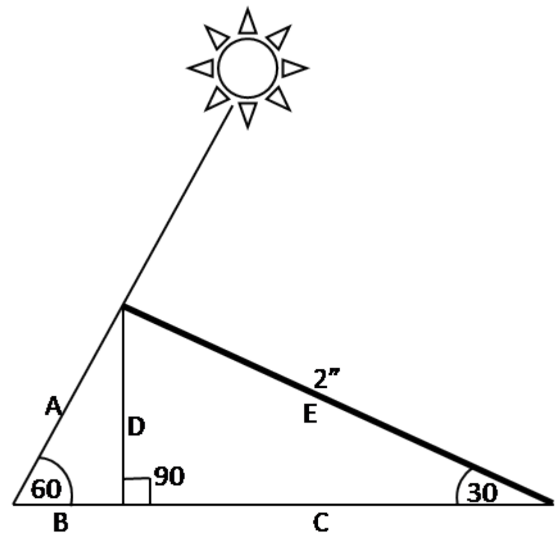


Figure 9.3 Space Determination

From here we get

E = 2.65 ft

D = 2.65Sin30 = 1.325

D = ASin60

A = 1.325/Sin60 = 1.53

B = ACos60 = 1.53 x Cos60 = .765 ft

C = ECos30 = 2.65 x Cos30 = 2.3ft

So the total Space required for the Panel in Y-axis is (2.3 + .765) ft = 3.1 ft and as the Length (X-axis) of the Panel is 5.18 ft, it will need 5.18 ft x 3.1 ft Space for each panel to set up, which will be 16.058. So the total space required for 40 modules to setup is around 642.32 sq. ft. In Roof spacing survey [6.4] we have seen that in a building with 20 families we will easily have 1500 sq. ft of space at the roof for PV establishment.

9.2.4. Set up Explanation with 3D model

Figure 9.4 explains, with a 3D example of house no. 63, Dhanmondi 8A, how the panels will be set up in 30^{o} angel. 3D views of that building's different portions are shown here.

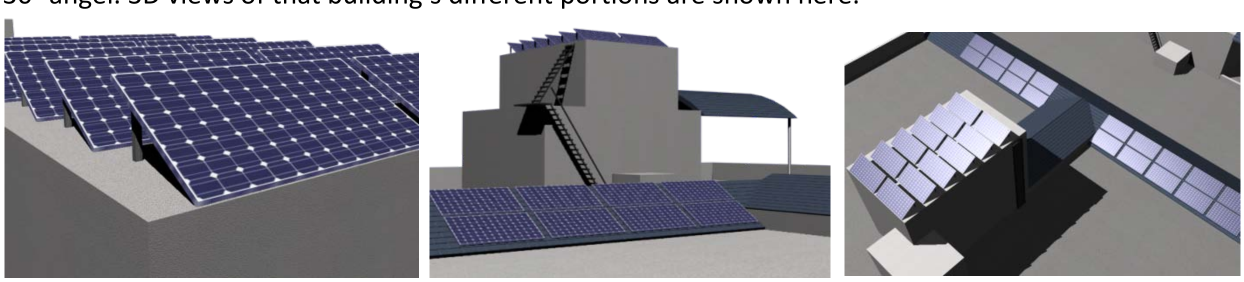


Figure 9.4 3D PV array setup explanations

9.2.5. Shading Analysis

Shading effect will be very little in our system because most of the buildings with 20 or more families are of 6 storied or more. So at the rooftop of a 6 story building the shading will have very little effect. Some shading can happen and we have to avoid those place. Few possible example of shading of the building, shown in figure 5.2, is shown in figure 9.5. as we can see here due to the water storage tank of the building situated west to this building after 3/4 pm there will be some shedding in some portion of this building

Figure 9.5 Example of shading at House no. 63 (Dhanmondi R/A)

9.3. Inverter Configuration

9.3.1. Inverter Sizing According to the Total Wattage

Inverter should be large enough to handle the maximum possible wattage of the system. It is recommended to use an inverter having the rated wattage 20% larger than the possible maximum wattage of the system, so that we can keep the inverter out of any kind of accidental damage.

Our system will draw a maximum current of 18.24 Amp, when the entire load will be working. That indicates the wattage will be 4195.2 W or 4.1952 kW. In this case we have to use an inverter rated more than 5 kW or 5000 W.

9.4. Battery Sizing

Coming to the part of battery backup we have to think more critically. Till now we were calculating the load on dally basis but while we will be working with the batteries we will not be considering 24 hours battery backup because in the morning if there is a bright sunlight than we will not be using the batteries. So we should consider autonomy from afternoon to the next morning, which will be around 15-16 hours.

9.4.1. Number of Battery Required

To calculate the battery backup time load, we have to consider the usage of loads from afternoon to next morning when the bright sun shine will not be there. Considering that we will have the battery backup load calculations shown in table 9.1. The battery size will be then determined according that. We are not considering the raining effects in this case because if we have continuous rain fall and if that disturbs the panels to generate sufficient electricity, we have alternate grid charging system. So we will not need extra battery to store extra energy.

Table 9.1 Load calculation in battery back time

LOAD DESCRIPTION	AC LOAD POWER (W)	CONTINIOUS DUTY CYCLE (Aprox) (hrs)		ENERGY NEEDED (WH)
Drawing/Dining room light	460	3		1380
Dining room fan	1500	4		6000
Cld bedroom light	300	3		900
Cld bedroom fan	1500	4		6000
Kitchen light	300	3		900
Toilet light	300	2		600
TOTAL	**4360**			**15780**

Total Energy need for whole building = 15780 Wh.

It isn't good to run a battery all the way down to zero during each charge cycle. It is recommended to leave the battery 20% charged. So we are considering that 85% of the battery charge is usable.

So usable amount of charge = $\frac{15780}{0.85}$ = 18564.71 Ah.

For lead acid batteries the rated capacity (i.e. the number of AH stamped on the side of the battery) is typically given for a 20 hour discharge rate. If you are discharging at a slow rate you will get the rated number of amp-hours out of them. However, at high discharge rates the capacity falls steeply. Drawing current at a rate of 60% of the rated number of amp-hours will give the best performance.

If the nominal battery voltage is 12 V
The battery should be rated $\frac{18564.71}{(0.6 \text{ x } 12)}$ Ah = 2578.43 Ah.

By using 200 AH 12 Vdc Battery we will need 13 batteries or more.

9.4.2. Battery Setup Configuration

As we know that the nominal voltage of our system is 12 V and the batteries we are using will be connected in parallel. 13 200 Ah 12 Vdc batteries in parallel will make a 2600 Ah 12 Vdc battery bank, which is enough to support our system with 20 families. To confirm the reliability we can even use 15 batteries, considering 15% extra.

9.5. Charge Controllers sizing

From the PV module specification in figure 9.2 it is seen that we are using a PV Module having the peak wattage o f 110 Wp and the short circuit current of 2.5 Amp. We need to calculate the minimum controller current. So the solar charge controller rating = (40 strings x 5.48) x 1.25 = 274 A at 12 V or greater. The multiplier of 1.25 over sizes the controller by 25 percent to allow for current production at highest solar irradiance conditions.

9.6. Intelligent Controller

Intelligent controller is a smart addition to our system. This device will serve most of the prime goals of our system. This device will be connected with almost all the elements of our system like modules, charge controllers, inverters etc. This device will decide how the inverter will actually work, how the batteries will be charged and the loads will be connected to which source of electricity.

This controller will check whether the charge controller is charging the battery or not. It will also check the battery charging condition and module electricity supply availability. Depending on these the controller will work.

9.6.1. Major Aspects of Intelligent Controller

The purpose of using this controller in our system is to confirm several prime services. These are explained bellow.

9.6.1.1. Instant Power Supply

The controller will be checking if the grid connection is available or not. As soon as the controller reports that the grid is disconnected, it will connect the load to battery so that the user will get backup power instantly.

9.6.1.2. Avoid the Grid Connection

As the controller is monitoring the system, when it finds that the grid is connected, batteries are well charged and the sun is shining with bright rays, the controller cutting of the grid connection connects the load to the batteries. Because while the batteries are fully charged in the morning we can use the rest of the energy produced from solar panels to support the loads directly.

9.6.1.3. Alternate Backup Battery Charging System

While we were working with a solar PV system the question we were asked by most of the people is how your system will serve while there is heavy cloud for several days, or how will you charge your battery if those get discharged at night? This intelligent controller will give answer to those questions. If the controller finds the battery is not well charged and there is also no sun power to charge the battery the controller will set the inverter in reverse order so that the grid supply can charge the battery.

9.6.2. Working Principal Flowchart

The flow chart shown in figure 9.6 will help to understand how the controller will actually work.

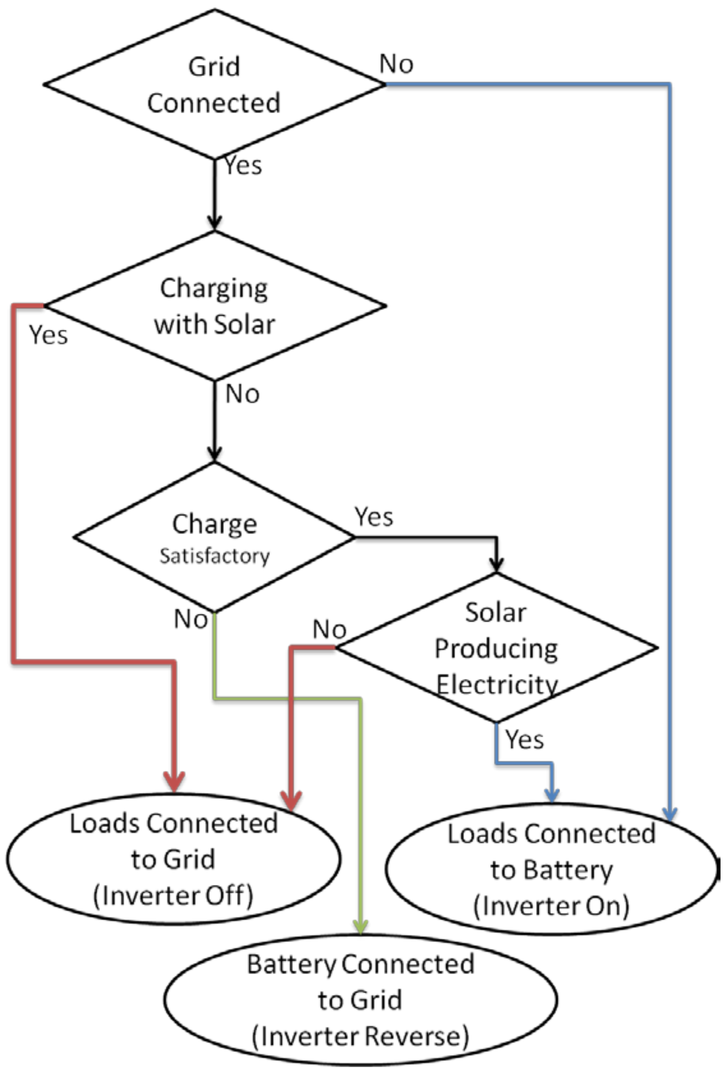


Figure 9.6 Working principal flowchart of the intelligent controller

10. Grounding, Surge Protection & Disconnects

All most all the urban buildings have built in surge protection system attached to those. But we have to make sure that the surge protection rod is at a sufficient height as we are establishing our panels at the rooftop. And our system grounding should never be attached to the building surge protection grounding system.

Figure 10a Grounding Lugs

The other electrical safety issue of the PV system is to securely ground all the solar panels and inverters. This can be done in various ways. The conventional method is to use the ground bond screws on each solar panel and connect all the panels together with heavy gauge bare copper wire. But dressing all the copper wire around the roof is a very risky installation. So to avoid the risk a neat scheme was developed by a company named Wiley Electronics LLC. Their scheme allows the panels to be directly ground bonded to the aluminum mounting rails. The rails then connect to each other and ground. Grounding lugs used to connect the rail to each other with copper wire are shown in figure 10a. A slice of a mounting rail with a bonding jumper partly attached is shown at figure 10b. To provide sufficient reliable ground path a flexible cable is used to 0connect the 2 rails via washers. The bolt and clip shown in figure 10c secures 2 solar panels to the rail, as the clip at top bridges both the panels. As the panels are tightened down, the washer on the rail connects the panels to the rail electrically. A 6 gauge copper wire is installed for grounding as shown in figure 10d. We can connect this grounding wire with the building's own grounding wire. The figure also shows the end clip in place ready to secure the solar panels.(5)

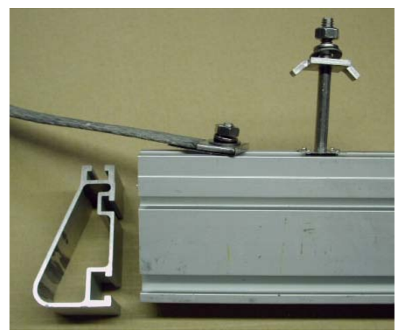


Figure 10b Mounting rail and Jumper

Figure 10c grounding bolt and clip

Figure 10d Mounting rail

Figure 10e Grounding copper wire

11. Design Simulation

11.1. Simulation Tool

The designed system is simulated using PVSyst. It is a PC software package for the study, sizing, simulation and data analysis of complete PV systems.

This software is oriented towards architects, engineers, and researchers, and holds very helpful tools for education. It includes an extensive contextual Help, which explains in detail the procedures and the models used. It offers an ergonomic approach, with a "greenline" guide, and several project levels.(6)

The new PVSyst Version 5.0 represents a major modernization of the software, resulting of more than 2 years of development. In particular, this version provides:

- Designing stand alone, grid connected, pumping and DC grid system.
- the possibility to define multi PV fields
- an improved definition of the inverters, allowing to take into account Multi-MPPT devices
- the simulation of PV systems with heterogeneous orientations

11.2. Methodology

PVSyst 5.21 needs the weather data to be set by the user. We are designing the system for Dhaka, Bangladesh. But there is no data for Bangladesh in PVSyst. But they have data for Dhaka and Chittagong which will be found under India region. The longitude and latitude is already set for Dhaka their as shown in figure 13.2a. The user has to fill up graph and date portion as they desire.

Load requirement or the user's need part is shown in [4]. From where we found our total load is around 20580.5 Wh/day that is 617.4 KWh/month. For better performance in simulation hourly load distribution is also possible in this simulation software.

Setting the weather and load data PVSyst automatically determines the Module and battery size and configuration. These configurations can also be set manually. Then comes the loss factors (array losses). These losses are also can be determined with the help of PVSyst.

11.2.1. Weather Data

In PVSyst to work in the region Dhaka we have to select Dacca, which will be found under INDIA. The latitude and longitude will be set by default as Dacca is selected. Dhaka is situated at 23.5’N and 90.2’E, its altitude is 8 m and is in +6 time zone. Figure 11.1 shows the weather data window of PVSyst 5.21.

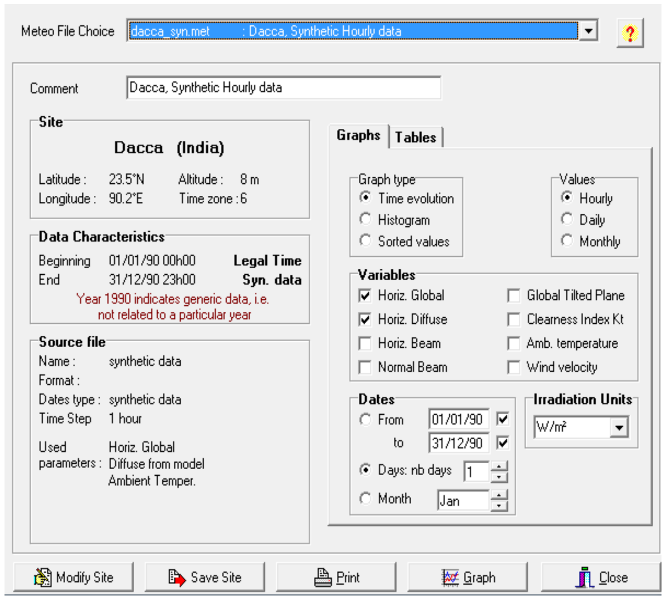


Figure 11.1 Weather data window of PVSyst 5.21

11.2.2. PV modules and Battery Configurations

PVSyst having all the necessary information regarding weather and user’s desired load can automatically calculate the approximate size of PV module and Battery in personalizing help window which is shown in figure 11.2. The information that user needs to give are the array configuration, shedding information, model and unit size of PV modules and Batteries. Before starting the simulation process PVSyst also gives a System Summary shown in figure 11.3.

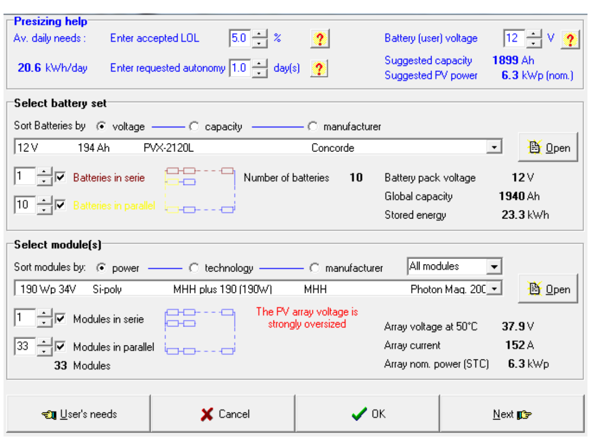


Figure 11.2 Personalizing help window.

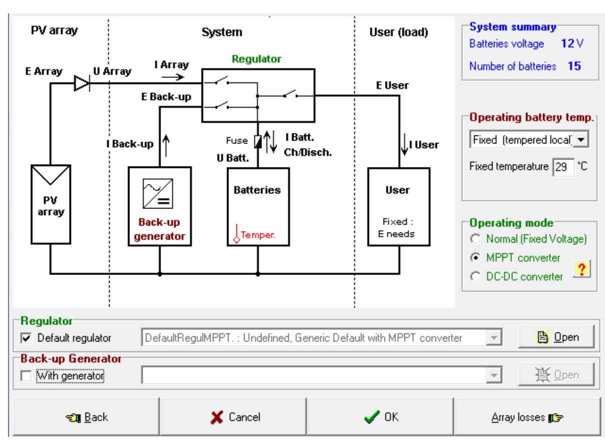


Figure 11.3 System summary Window.

11.2.3. Loss Factors

While simulating PVSyst keeps all the obvious losses in consideration. There are some losses where the users have access to change the loss factors according to their own design. They can also leave the losses to be as default so that PVSyst simulates considering the losses set to default of the simulator. How these losses are defined is described here in this chapter.

11.2.3.1. Temperature Loss

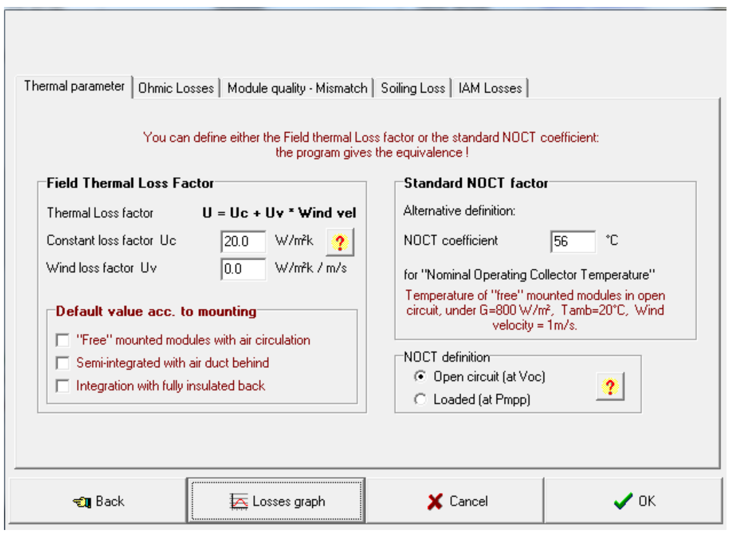


Figure 11.4Array Loss Window

This is also known as the thermal loss. The user can define either the field thermal loss factor or the standard NOCT coefficient. The program gives the equivalence. Figure 11.4 shows the thermal parameter of losses.

11.2.3.2. Ohmic Loss

Ohmic loss actually occurs because the wire we practically use has some internal resistance. In PVSyst the ohmic loss is defined in two separate parts DC Circuit (ohmic losses for the array) and AC circuit (inverter to injection point). Detailed computation is possible by defining the system configuration, setup and distance of equipments.

11.2.3.3. Module Quality – Mismatch

Module quality deviation of the average effective module efficiency is specified by the manufacturer. Negative value indicates over-performance. In mismatch losses section power loss at MPP and loss when running at fixed voltage can be defined. Graphical tool for determining the effect of parameter mismatch, for the cells in module or the modules in an array can also be found in detailed computation of mismatch losses. But this will not be effective in practical life if we use charge controller or MPPT.

11.2.3.4. Soiling Loss and IAM Losses

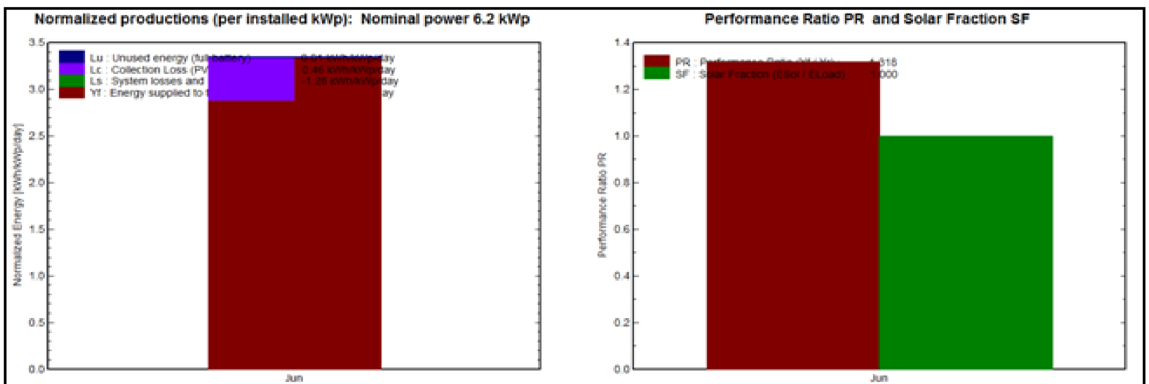
PVSyst also takes soiling and IAM losses in consideration. SunPower has extensive empirical data that support a simple rule of thumb for estimating soiling loss across a range of climates. IAM stands for Incident Angle Modifier. The incident angle modifier (IAM) functions describe the optical response of the glass laminate surface to the incoming solar beam at a given solar position for two different glass surfaces.

11.3. Results and Discussion

Using PVSyst simulation the results we get for our system is mentioned here.

11.3.1. Main system parameters

System type	: Stand Alone
PV Field Orientation	: 30 Tilt and 0 Azimuths
No of modules	: 56 (Total 6.2 kWp)
Battery Pack	: 15 Units (12V and total 1860 Ah)
User Needs	: 7512 kWh/year



Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E Avail kWh	EUnused kWh	E Miss kWh	E User kWh	E Load kWh	SolFrac
June	2.696	2.428	11.61	0.068	0.000	20.58	20.58	1.000
Period	2.696	2.428	11.61	0.068	0.000	20.58	20.58	1.000

Legends:				
	GlobHor	Horizontal global irradiation	E Miss	Missing energy
	GlobEff	Effective Global, corr. for IAM and shadings	E User	Energy supplied to the user
	E Avail	Available Solar Energy	E Load	Energy need of the user (Load)
	EUnused	Unused energy (full battery) loss	SolFrac	Solar fraction (EUsed / ELoad)

Figure 11.2e Main Result Window

11.3.2. Loss Diagram

As it is already known that PVSyst considers various losses that are obvious in PV system. All the losses considered in simulation is shown in a diagram in PVSyst, which is here in figure 11.2f

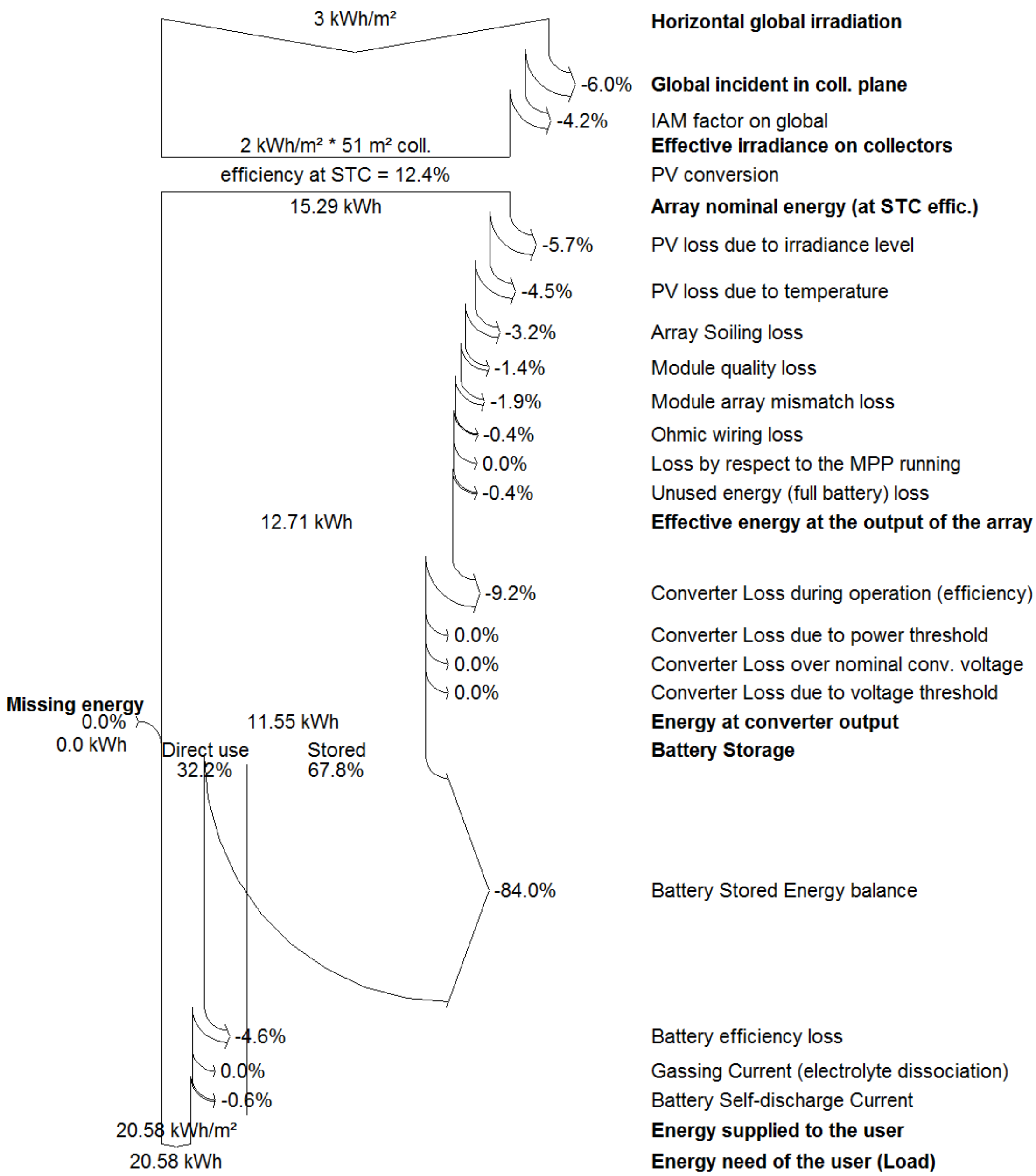


Figure 11.2e Main Result

11.4. PVSyst Limitations

Everything has some draw backs and so do PVSyst. Though almost everything that are necessary in a PV system can be configured in PVSyst for simulation but there is still something that is not yet available or that is completely new, PVSyst cannot deal with those. The limitations of PVSyst are given bellow.

- PVSyst stand alone project don't allow the users to configure the ohmic loss of wire in AC side. But here in our design we have long AC side wires to connect to the loads from inverters, which will defiantly have a voltage drop that causes a loss. Now this loss cannot be determined in PVSyst.
- In PVSyst we can work with our own designed equipments' like charge controller and intelligent controller that we will be using in our design as we are designing the system as a backup power system where PVSyst is considering it to be a normal PV system.
- The Parameters of PV modules and batteries we are using in this simulation don't matches with our practical ones that we will be using in our design.
- PVSyst simulation only works in between January to December of the year 1990. But from 1990 to now in these 20 years the climate has changed, though the change is very little.

12. Environmental Impact and Different Toxic Emission Analysis

Solar energy is the energy produced by the sun, which warms the earth, affects our weather and makes life possible. Here we are producing electricity by using this solar energy. But at the same time when we produce the solar cells we are using toxic heavy metals, the cells themselves contain such material and batteries that store solar energy contain toxic lead acid.

The primary environmental concern arising from solar technologies is the disposal of batteries. Batteries are required to store electricity produced by solar panels so the power can be used at load shedding hours. They are an essential component of any passive solar installation. These batteries contain lead acid, which makes them difficult to recycle and a threat to the environment if they are disposed of improperly. As a result, environments are greatly threatened day by day.(7)

Again, the use of heavy metals to produce solar cells, and the eventual disposal of those cells, is another environmental concern related to solar power technology. Most photovoltaic solar cells contain the heavy metals cadmium and selenium, according to the U.S. Department of Energy. They are known to be toxic. Improper disposal of solar cells could result in the leeching of cadmium and selenium into the environment. Cadmium is being used at an increasing rate in the production of solar cells, which is one of the most important environmental issues for destroy. (8)

After that, based on PV production data of 2004-2006, we see that this presents the life-cycle green house gas emission, criteria pollutant emission and heavy metal emission from four types of major commercial PV system: multicrystalline silicon, ribbon silicon, and thin film cadmium telluride. But at the same time, after the prospective analysis it was found that from a new paper by M. Vasilis, V. Fthenakis, H.C. Kim and E. Alsema, published in the January 2008 *Environmental Science & Technology*, finds yet again that PV technologies generate far less life-cycle atmospheric emissions per GWh than conventional fossil-fuel generation technologies. It states that at least 89% of the harmful emissions into the atmosphere could be prevented if conventional grid electricity was to be replaced by photovoltaic electricity.

Another important thing is that, Greenhouse gas emissions in PV life-cycle. The GHG emissions over the life-cycle of a PV panel are strongly related to the EPBT (Energy Payback Time). They can mainly be allocated to the use of electrical energy during the manufacture of PV panels. Consequently, those emissions differ for the same PV panel according to the energy mix that is used for generating electricity in that particular location.

The findings in the *Environmental Science & Technology* paper were calculated with three different energy mixes and for four different types of PV panels: multichrystaline silicon (Multi-Si), monochrystaline silicon (mono-Si), ribbon silicon (ribbon-Si) and thin film cadmium telluride (CdTe). In the UCTE energy mix, the CO2 emissions vary between 21 g CO2-eq/kWh for the thin film CdTe to 43g CO2-eq/kWh for Mono-Si. (9)

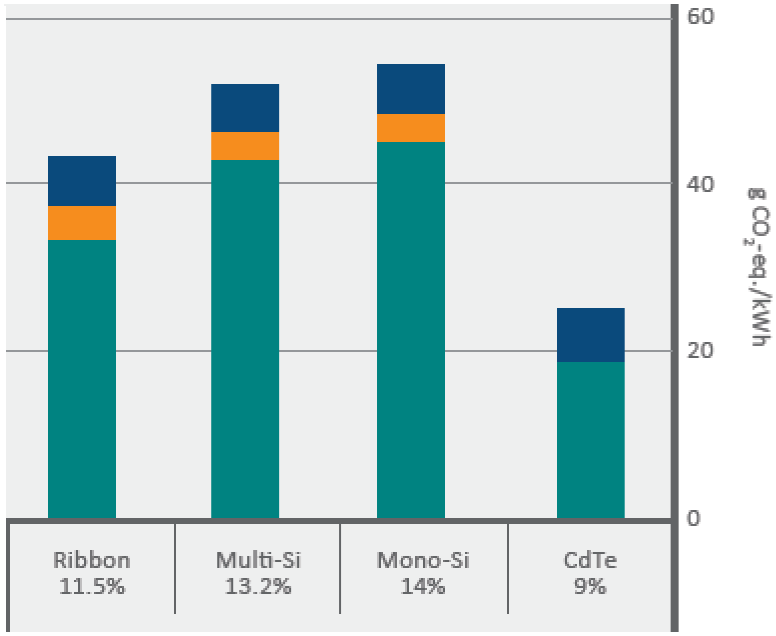


Figure 12: life cycle GHG emissions from silicon and CdTe PV modules

Now a day, there is a tremendous change in PV technology over the last five years. The movement in the environmental impact of PV manufacturing is decreasing even further and the energy efficiencies are increasing. As a result, the EPBT and the life-cycle environmental profile of PV panels can be expected to continue to improve in the upcoming years.

13. Loss Calculation

13.1. Global Loss

13.1.1. IAM factor on global

Performance measurements are normally taken with the solar insolation level measured perpendicular to the collector plane (i.e. facing the same direction as the collector). When the light shines on the collector from an angle the performance changes and this is what the IAM (Incidence Angle Modifier) values provide us, an angular performance factor. A value of 1 is achieved when the collector is perpendicular to the sun's rays, and therefore receiving maximum radiation. For flat plate collectors, 1 is the maximum value, dropping off in both morning and afternoon. Evacuated tube collectors, however, often provide values in excess of 1 during these periods, as factors such as reflective panels and reflection off neighboring tubes can influence the relative performance. (10)

13.2. PV Array Losses

13.2.1. Loss due to Irradiance Level

Solar cells experience daily variations in light intensity, as the irradiance level is not the same throughout the day. At low light levels, the effect of the shunt resistance becomes increasingly important. As the light intensity decreases, the bias point and current through the solar cell also decreases and the equivalent resistance of the solar cell may begin to approach the shunt resistance. When these two resistances are similar, the fraction of the total current flowing through the shunt resistance increases, thereby increasing the fractional power loss due to shunt resistance. Consequently, under cloudy conditions, a solar cell with a high shunt resistance retains a greater fraction of its original power than a solar cell with a low shunt resistance.(11)

13.2.2. Loss due to Temperature

The operating temperature of a PV module is equilibrium between the heat generated by the PV module and the heat loss to the surrounding environment. There are three main mechanisms of heat loss: conduction, convection and radiation.

Conductive heat losses are due to thermal gradients between the PV module and other materials (including the surrounding air) with which the PV module is in contact. The ability of the PV module to transfer heat to its surroundings is characterized by the thermal resistance and configuration of the materials used to encapsulate the solar cells.

Convective heat transfer arises from the transport of heat away from a surface as the result of one material moving across the surface of another. In PV modules, convective heat transfer is due to wind blowing across the surface of the module.

A final way in which the PV module may transfer heat to the surrounding environment is through radiation. The net heat or power lost from the module due to radiation is the difference between the heat emitted from the surroundings to the module and the heat emitted from the PV module to the surroundings.(12)

13.2.3. Soiling Loss

Array soiling is the accumulation of dirt on solar panels. Soiling can have a significant impact on the performance of PV systems. Due to the soiling on array the sun light cannot reach to the solar cells properly. This won’t have much problem in rainy seasons because in rainy days raining will automatically clean the arrays for us. But in winter we hardly have any rainfall in our country so we have to option but to manually clean the arrays. Studying our neighboring countries’ Solar establishments we are assuming to have a soiling loss of around 3.2%

13.2.4. Module Array Mismatch Loss

Every solar cell wafer produced has a slightly different I-V characteristic. Cells are often sorted to ensure that a typical 36 series cell module has the correct I-V profile. Connecting a ‘strong’ and a ‘weak’ module together constrains the output of the ‘strong’ module to the level of the ‘weaker’ one. This creates a problem: increasing the length of strings inevitably leads to a greater level of mismatch and therefore, energy loss. (13)

Taking into account the difference in inverter efficiency and inverter internal power consumption the effect of mismatch loss can be quantified. Analysis indicates that mismatch typically represents a power loss of less than 3% between a central inverter and a string inverter configuration.(14)

13.2.5. AC Ohmic Wiring Loss

AC ohomic wiring loss is the loss due to the AC circuit wire resistance. So to determine the AC Ohomic wiring Loss we need to find out the total wiring resistance.

The wires being used from Inverter to Load

purpose	**AWG** (gaug)	**Diameter** (inch/ mm)	**Area** (mm^2)	**Resistance** (Ω)	**Handling Current** (Amp)	**Maximum Current** (Amp)
Inverter to Node	6	0.162/4.115	13.3	0.3951	32.3	37
Node to Load	19	0.0359/0.912	.653	8.051	1.65	1.7

R_6 and R_{19} are the total total inverter to node and node to load wire resistance. Figure 15.5a will say how these are determined.

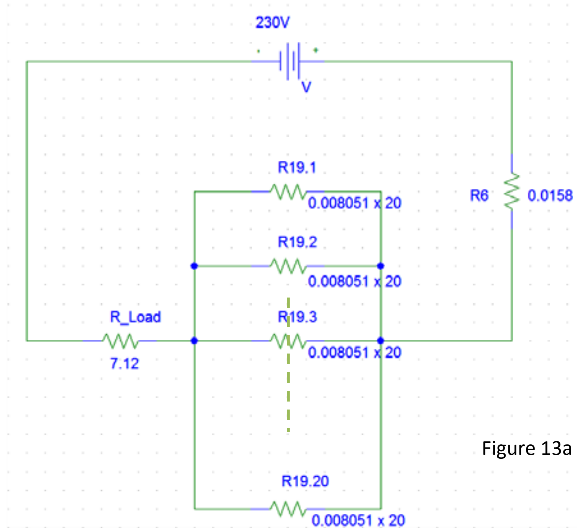


Figure 13a

$R_6 = 3.95 \times 10^{-4}$ Ω/ft x 40 = 0.0158 Ω

$$R_{19} = \frac{1}{\frac{20}{0.008051 \times 20}} = 8.051 \times 10^{-3}\ \Omega/\text{ft}$$

= 0.008051 Ω

So the total wire resistance is,

R_{eq} = (0 .0158 + 0.008051) Ω = 0.023851 Ω

Form the load calculation we found out that if all the appliance are connected to the system at a time all together they will draw 18.24 Amp.

So , I_{R_Load} = 18.24 Amp

So, R_{load} = V/I = 230V/18.24 = 12.6096Ω

So from Figure 15.5b,

$$I = V/R = \frac{230\ V}{(.023985 + 12.6)\ \Omega} = 18.22\ \text{Amp}$$

$V_{R_{eq}}$ = 18.22 x 0.023851 = 0.4346V

$V_{R_{load}}$ = 18.22 x 12.6096 = 229.7469 V

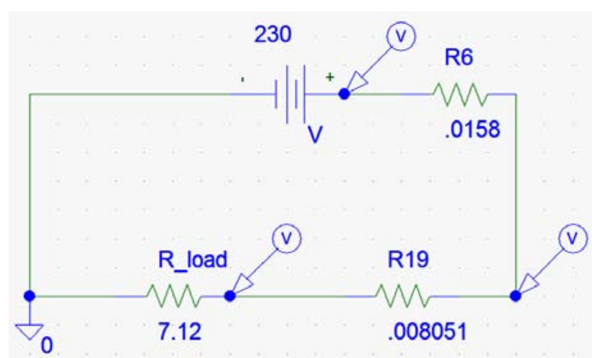


Figure 13b

So Loss due to R_{eq} (Wire) is = 0.253/230 x 100% = 0.11%.

So the total AC wiring loss for our system will be around 0.11%.

14. Conclusion

The first and foremost part of designing a PV system is to know the electricity need. So in the first step of our study we have gone through the load calculations, where we have found that we have to produce around 25 kWh of energy. Now to generate and store this huge amount of energy we will need around 40 PV module of 190 W_P and 15 batteries of 200 AH. Here in our system we will be using an inverter of 5000W rating.

Most the people of Bangladesh are using IPS or fuel generator as a backup power system to get rid of the power shortage problem. But these systems are very expensive to buy and run, where we can use PV system for the same purpose. Here using the PV system the initial cost may rise a little but for rest of the life we will be generating electricity for free of cost. Most of the PV modules come with 40-50 years guarantee and battery with 5 years.

15. Further works

Maximum Power Point Tracking (MPPT) Controller

A MPPT, or maximum power point tracker is an electronic DC to DC converter that optimizes the match between the solar array (PV panels), and the battery bank. They convert a higher voltage DC output from solar panels down to the lower voltage needed to charge batteries. This is mostly used in the charge controllers.(15)

Designing the Intelligent Controller

Here it is clearly shown that how the intelligent controller will work, that means what is the purpose of the intelligent controller. The flowchart shown in figure 10a describes the working principle of this controller very well. We will be designing the controller and physically implement.

Detailed Economic Analysis

We will be analyzing the economic factors of the whole system that includes which elements should be used in which parameters, why the system is economically better than other backup power system and what is the economic benefits will be if this system can be used.

Addition of DC loads to the system

Using DC loads will make the system little complicated but it will definitely reduce the load requirement. Because DC loads will draw less energy from battery. At least we can Change the lights we are using in DC.

Addition of Possible Large loads

Till now we were working with only household lights and fans, but we are planning to introduce large loads to the system like TV, Computers, etc.

Effective and Efficient Design to reduce the losses

In Efficiency and losses part [13] we have already seen the losses of in our system. We will be studying on finding some way to lessen those losses in our system so that we can use the maximum possible energy coming from the sun.

16. References

1. **Solar Wholesale Products.** How Solar Energy Works. *Solar Wholesale Products.* [Online] http://www.solarwholesaleproducts.com/Page5.html.

2. Power Inverter. *Solar Drop Shipping.* [Online] http://www.solardropshipping.com/power_inverter.php.

3. **Rightsol Services Network.** Solar energy, a wise choice. *rightsolservices.* [Online] http://www.rightsolservices.com/Charge-controller.htm.

4. High-efficiency polycrystalline solar modules. *solarfun-power.com.* [Online] http://www.solarfun-power.com/en/products/modules/polycrystalline-modules.

5. Solar Power-System Grounding. *www.arttec.net.* [Online] July 5, 2009. http://www.arttec.net/SolarPower/5_Grounding/index.htm.

6. PVsyst 5.30. *pvsyst.com.* [Online] ISE-Group Energy, University of Geneva. http://www.pvsyst.com/5.2/.

7. The Effects of Solar Energy for teh Envirionment. *ehow.com.* [Online] http://www.ehow.com/list_6375269_effects-solar-energy-environment.html.

8. *Emissions from Photovoltaic Life Cycles.* **Vasilis M. Fthenakis, Hyung Chul Kim, and Erik Alsema.** s.l. : Environ. Sci. Technol [Downloaded from http://pubs.acs.org on February 13, 2009], 06 February 2008. 42 (6), 2168-2174, DOI: 10.1021/es071763q.

9. **Wachter, Bruno De.** Emissions from Photovoltaic Manufacturing. *leonardo-energy.org.* [Online] May Thu, 29 , 2008. http://www.leonardo-energy.org/emissions-photovoltaic-manufacturing.

10. **Institute of the Environmental Sciences, Group of Energy.** *Modeling Systems Lossess in PVSyst.* [PDF Presentation] Geneva : University of Geneva.

11. Effect of Light Intensity. *pvcdrom.pveducation.org.* [Online] http://pvcdrom.pveducation.org/CELLOPER/LIGHT.HTM.

12. Heat Loss in PV Modules. *pvcdrom.pveducation.org.* [Online] http://pvcdrom.pveducation.org/MODULE/HeatLoss.htm.

13. **James P.A.B., Bahaj A.S. and Braid R.M.** PV array < 5kWp + Single inverter = Grid connected PV system: are multiple inverter alternatives economic? *Solar Energy.* September 2006, Vol. 80, 9.

14. **Sustainable Energy Research Group, School of Civil Engineering and the Environment.** Solar Photovoltaics Research of the Sustainable Energy Research Group. *www.energy.soton.ac.uk.* [Online] University of Southampton. http://www.energy.soton.ac.uk/solar/mismatch.html.

15. **Northern Arizona Wind & Sun.** Maximum Power Point Tracking Charge Controller. *windsun.com.* [Online] http://www.windsun.com/ChargeControls/MPPT.htm.

16. **Silvestre, Luis Castafier and Santiago.** *Modelling Photovoltaic Systems using PSpice.* The Atrium, Southern Gate, Chichester, West Sussex PO19 SSQ, England : JOHN WILEY & SONS, LTD, 2002.

17. *Design and Simulation of a Distributed PV System for Pennsylvania State University.* **Oladipo Ositelu, Ruveyda Cetiner, Mesude Bayrakci,Charith Tammineedi, Vasudev Jagarlamudi.** s.l. : EME 580, May 3, 2010.

18. **U.S Department of Energy.** *A Consumer's Guide: Get your Power from the Sun.* s.l. : Energy Efficiency and Renewable Energy, U.S Department of Energy.

19. **Meteotest Dern,.** *Global radiation, annual mean 1981-2000.* Switzerland : s.n.

20. *Effect of Soiling in PV Concentrators: mechanisms of light dispersion and real field performance of soiled flat modules and CPV's.* **M. Vivar, R. Herrero, F. Martínez-Moreno, R. Moretón, I. Antón, G. Sala,.** Valencia, Spain : 23rd European Photovoltaic Solar Energy Conference, 1-5 September 2008.

21. *Electricity Industry in Bangladesh: Problems and suggested solutions.* **Engr. Shamsul Islam, F/669, Former Chairman, BPDB.**

22. **Sunpower Corporation.** *Basic Explanation and PVSyst default edit Instructions.* 17-Aug-09.

23. *Changing photovoltaic array interconnections to reduce mismatch losses: a case study.* **D. Picault, B. Raison, S. Bacha, J. Aguilera, J. De La Cas.** Prague, Czech Republic : EEEIC 2010 (International Conference on Environment and Electrical Engineering), 2010. hal-00485197.

24. *A SIMPLE MONITORING METHOD FOR ESTIMATION OF SHADING LOSS OF PHOTOVOLTAIC SYSTEMS.* **Kenji Otani, Koichi Sakuta and Kosuke Kurokawa.** Portoroz, Slovenia : EuroSun98 The Second ISES-Europe Solar Congress, September 14-17, 1998.

25. *THE EFFECT OF SOILING ON PHOTOVOLTAIC SYSTMES LOCATED IN ARID CLIMATES.* **A. Kimber, L. Mitchell, S. Nogradi, H. Wenger.** Waikoloa, Hawaii, USA : Proceedings of the 4th World Conference on Photovoltaic Energy Conversion, May 7-12, 2006.

26. *UNDERSTANDING TEMPERATURE EFFECTS ON PV SYSTEM PERFORMANCE.* **Thomas Nordmann, Luzi Clavadetscher,.** TNC Consulting AG, Seestrasse 141, CH-8703 Erlenbach, Switzerland : s.n.

27. *Analysis of Photovoltaic Systems, Report IEA-PVPSIEA PVPS Task 2 Report T2-01: 2000.* April 2000.

28. *Environmental Impacts of Crystalline Silicon Photovoltaic Module Production.* **ErikA.Alsema1, Mariska J. de Wild-Scholten.** Petten, The Netherlands : The Netherlands 2Energy research Centre of the Netherlands (ECN), http://www.ecn.nl/docs/library/report/2006/rx06041.pdf.

29. *Concentrating photovoltaic multijunction (cpvm) module electrical layout optimisation by a new theoretical and experimental "mismatch" analysis including series resistance effects.* **A. Minuto, G. Timò, P. Groppelli and M.Sturm.** s.l. : SolarTec International AG, Uhlandstr 13, Aschheim 85609, Germany.