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Feasibility study and design of a grid-tied low-cost solar system to replace IPS for a residential building

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***Abstract*— In recent years, a densely populated country like Bangladesh has experienced severe electricity shortages. The use of the finite mineral resources to generate power is nearing its conclusion. So it's past time to switch to renewable energy sources like solar, hydro, biomass, wind, etc. Avoiding power outages in major cities is becoming more difficult. Generators and instantaneous power supplies (IPS) are commonly employed to combat this, however, they are unable to reduce the demand on mineral resources, as well as being inefficient and unreliable owing to significant fuel fluctuation. However, the country is located in a hotspot. Because of its long length of existence, sunlight may be employed as a stable supply of verse energy. Installing a rooftop solar photovoltaic (PV) system is simple. However, it must be concerned about the high expense of installation. The major goal of this project was to construct a cost-effective solar PV energy system for an urban building to address power shortages and to replace expensive IPS. This device will be linked to practically every component of our system, including modules, charge controllers, inverters, and so on. This device will determine how the inverter will operate, how the batteries will be charged, and which power source the loads will be linked to.**

Keywords*— *Solar PV, IPS, Load shedding, Energy demand

I. INTRODUCTION

Bangladesh has had an electrical scarcity for a long time. However, in recent years, this problem has outgrown the patience of the general public. Bangladesh is situated in the tropics. So, except for a few months in the winter, the majority of the year is spent in summer. In summer the temperature rises to 40 degrees Celsius when it is nearly impossible to stay without electricity [1], [2]. Electricity is the most basic and important requirement for most individuals in today's globe. Bangladesh is a densely populated nation, with an average population density of 3416 persons per square mile. However, we are unable to provide our people with power 24 hours a day, seven days a week. Every summer, Bangladesh suffers from severe load shedding. Our power shortfall increased by 1000 MW to 1259 MW in 2006, despite a demand of 4806 MW, according to government figures. In 2009 the country faces a shortage of around 1400 MW to 1800 MW. Every summer, we are faced with an unpredictable situation owing to power outages. According to sources at the Power Development Board (PDB), the officially estimated power demand is currently 11000MW, with a generation capacity of roughly 8500MW [3]-[5]. Only Dhaka, the capital, requires roughly 3000 MW of power to function. Only 62 percent of the population in this densely populated country has access to electricity, with a per capita availability of 321 kWh each year. High system losses, delays in the construction of new plants, low plant efficiency, unpredictable power supply, electricity theft, blackouts, and a lack of cash for power plant maintenance are all issues in Bangladesh's power industry. Over the last decade, the country's power plants have been unable to fulfill system demand.

Most homes in Dhaka city utilize IPS to alleviate the problem of electricity shortages. All of the IPSs that have been put around Dhaka city are taking a significant amount of power from the grid. Around 100 MW of IPS has been installed in Dhaka city alone. On the one hand, IPSs improve the comfort of some individuals, but they are a financial burden for those who cannot afford them. A generator is another option for load shedding. It is a widely used and well-liked energy source. However, a nation with few natural resources, such as Bangladesh, which lacks oil, is continually plagued by huge fluctuations in imported fuel prices. The cost of a generator is significant, and the cost of operation is also not cheap. Renewable energy is energy derived from renewable natural resources such as sunshine, wind, tides, rain, and geothermal heat. This energy comes from natural processes that are continually renewed. Solar, wind, ocean, hydropower, biomass, geothermal resources, biofuels, and hydrogen are all sources of electrical energy. We can surely lessen the power constraint to some extent if we can create power using renewable energy. Bangladesh's government and engineers are focusing on renewable energy as well. Bangladesh has planned to produce 10% by 2020 and 30% by 2030 from renewable energy sources like air, nuclear, waste, and solar energy [6]-[8].

The world is inflowing in the new era, which is acknowledged to technology lovers, with the encroachment of cutting-edge technology such as wireless communications [9]-[13], internet of things [14], [15], antenna design [16]-[18], remote sensing [19], bio-sensing [20]-[24], advanced optics [25]-[28], health sector [29], [30], reliable power system [31]-[33], renewable energy [35]-[37]. Energy harvesting from local renewable energy sources (RES) is growing more widespread and is now considered an established technique for numerous reasons. First and foremost, it lowers dependency on fossil fuels. Second, renewable energy sources are widely available around the world. Third, a considerable amount of green energy may be created from renewable sources of energy by lowering the cost of generating power and lowering the carbon content [38]-[40]. Despite the potential benefits noted above, there are several hurdles to collecting energy from RES, including weather conditions and the dynamic nature of renewable energy sources, which can produce energy shortages or outages [41]. As a result of the interruption, the quality of services (QoS) may suffer. However, combining multiple renewable energy sources or incorporating renewable energy sources into non-renewable energy sources/electricity grids or renewable energy sources supplies with appropriate energy storage devices can improve QoS [42]-[43]. The fundamental goal of renewable energy sources is now to construct a long-term, sustainable, and dependable supply system with the lowest net current cost possible [44]-[46].

We have been investigating adding more and more elements to our PV system design from the beginning of our project work to make the system efficient and cost-effective enough to replace our country's traditional IPS system. A PV system is simple to install [47]. All that is required is the installation of a PV module and the storage of solar energy in batteries. And make sure that energy is available when it's needed. However, the difficulty arises when attempting to install this PV system in any metropolitan region with a high load need. Furthermore, we are developing a shared system for a residential complex with more than 10-20 households. Creating a standard system for a whole building rather than designing for each household is a cost-effective solution. The cost of maintenance and the amount of space required is also reduced by using a shared system. Because if we go with a unique system for each flat, we'll have to install practically every component of a PV system in each household, which would inevitably cause maintenance issues and, of course, raises the cost. In our proposed method, every component of the PV system will be installed in the same location, with simply a cable connecting each flat to the appropriate loads.

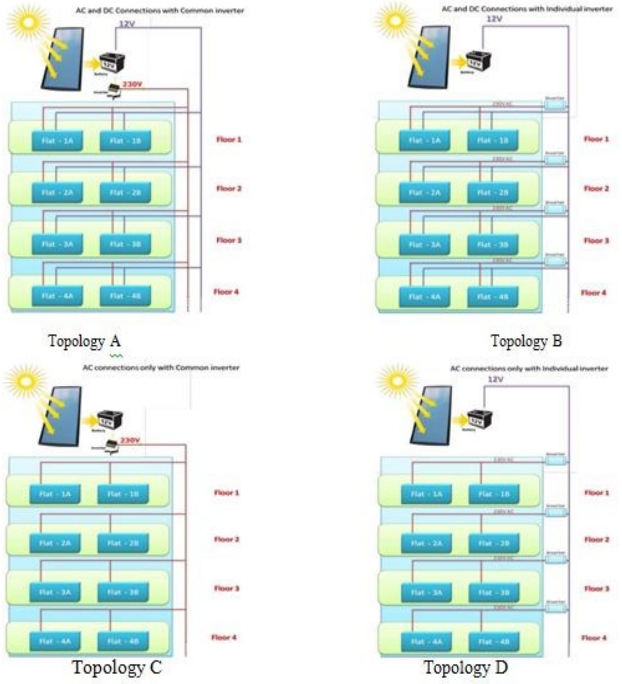
The prime objective of our project is to design a system that will provide a solar photovoltaic system that will supply instant power as soon as the grid power cuts off. The system will keep on checking the availability of grid power supply continuously, and whenever the grid power is not found available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

II. DEVELOPING A DESIGN

Figure 1 shows a comparison of several alternative design topologies. The most challenging element is deciding on a design. Both AC and DC loads are linked to the system in designs A and B, but only AC load is linked in designs C and D. In designs A and C, a single inverter serves the whole system, but in B and C, each household will have its inverter. The use of a battery storage system is widespread in all circumstances.

A. Comparison of Topologies

The design will be difficult if both AC and DC loads are connected. Because using just DC appliances is not viable, we might opt to utilize just AC appliances to simplify the setup. It is now easy to create a common inverter in the inverter section.



Topology A
Topology B
Topology C
Topology D

Figure 1: Design topologies.

If we install inverters in each apartment, upkeep will be a major concern. As engineers, we must also think about the financial aspects. Using both AC and DC loads may add to the design's complexity, although DC loads need less energy than AC loads. At the very least, we may incorporate DC lights into our system, which are quite popular in rural regions. After all, they won't require an inverter. Those lights may be linked directly to the batteries. As a result, including DC loads in the system will significantly reduce the size of the inverter as well as the overall system. It will also be more cost-effective to use a single inverter for the entire building rather than one for each apartment. We will not be employing DC loads in our system at this time due to the complexity of working with them, although they are more cost-effective. Later on, we'll work on DC loads. As a result, for the time being, we will design our system using Design C as our basis topology.

B. Load Calculation

The first step in constructing a PV system is to calculate the estimated load that will be connected to the system. Each component of the PV system will be built to meet that load demand. Loads in ampere-hour (AH) and watt-hour (WH) are required when designing a PV system. For subsequent calculations, the total wattage and peak current are also required. We're working on a design for this PV system that will supply backup power for 15 homes, with four 75W fans, three 15 W CFL lamps, and one 23 W CFL lamp linked to the system for each home. As a result, finding the total wattage and peak current is simple. The procedure for determining the ampere-hour load is broken down into many steps.

Because this is a backup power system, it will be used to give electricity to loads in the event of a grid power outage. The amount of time spent shedding loads in a day varies from month to month. Throughout the summer, Bangladeshis are subjected to 3-4 hours of load shedding per day; however, during the winter, load shedding is limited to less than 2 hours per day. As a result, the PV system's load requirements may be separated into two seasons. The total load in Amp-hours must now be calculated using the daily load shedding hours and daily home appliance consumption during the load shedding period for both seasons. The fact that the complete load will not be connected at the same time will also be taken into account.

C. Load Determination for the Time of Load Shedding Usages

We determined certain tiny loads for load shedding usages and designated them "load shedding usages loads" at load termination during the time of load shedding. This system does not support larger loads such as a television, refrigerator, or washing machine. Table I shows the load shedding usages loads.

Table 1. Load determination for the time of load shedding usages

Load description	Quantity	Load current (A)	Load voltage (V)	Load power (W)
Drawing/Dining room light 23 W	15	0.1	230	345
Drawing room fan 75 W	15	0.326	230	1124.7
Bedroom light 15 W	15	0.065	230	224.25
Bedroom fan 75 W	15	0.326	230	1124.7
Kitchen light 15 W	15	0.065	230	224.25
Toilet light 15 W	15	0.065	230	224.25
TOTAL		15*0.947= 14.205 A		3267.15 W

D. Hourly Load Characteristics for Daily Load

Table 2. Load shedding hours per 6 hours

Season	0-5 hours	6-11 hours	12-17 hours	18-23 hours	Total hours
Summer	1	1	0	2	4
Winter	1	0	0	1	2

Table II shows the load shedding in the summer and winter seasons. This is a rough estimate of the daily utilization of the PV system's loads. This estimate is based on 24 hours. The daily load usage table (Table III) displays which load is used during which time. Usages of the load are marked with '*'. The daily average load usages in the summer season are shown in Table IV.

Table 3. Hourly load characteristics for the daily load.

Load description		Drawing /dining room light	Drawing room fan	Bedroom Light	Bedroom Fan	Kitchen light	Toilet light
Daily 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		6	16	6	14	6	6

E. Daily Average Load Usages in Summer

Table 4. Daily average load usages in summer

Load Description	Daily average load shedding usages
Drawing /Dining room Light	1
Drawing room fan	3
Bedroom light	1
Bedroom fan	3
Kitchen light	1
Toilet light	1

According to the chart above, all of the lights are used for one hour per day, and the average fan is used for three hours per day. Because all of the working loads are in AC, the power conversion efficiency is estimated to be 80%, and the nominal system voltage is 230 V.

F. Current Determination for 15 Families of Load Shedding Usages

Table 5. Daily average load shedding usages of the loads in summer

Load Description	AC load power (W)	Daily duty cycle hrs/day	Power conversion efficiency	Nominal System Voltage (V)	Amp-hour Load per day (AH)
Drawing /Dining room light	15*23	1	0.80	230	1.875
Drawing room fan	15*75	3	0.80	230	18.34
Bedroom fan	15*75	3	0.80	230	18.34
Bedroom light	15*15	1	0.80	230	1.22
Kitchen light	15*15	1	0.80	230	1.22
Toilet light	15*15	1	0.80	230	1.22

So, the energy required for "Load Shedding Usages Loads" is: 42.215*230= 9709.45wh/day

G. Winter Load Calculation

The loads will be the same in the winter, as will the typical consumption patterns. The only difference will be in the load-shedding hours, which will very definitely be reduced. As a result, the associated loads' average load shedding time utilization will reduce. Here is the table VI for daily load shedding usages in winter.

Table 6. Daily average load usages in winter

Load Description	Daily average load shedding usages
Drawing /Dining room light	1
Drawing room fan	1
Bedroom light	1
Bedroom fan	1
Kitchen light	1
Toilet light	1

H. Current Determination for 15 families of Load Shedding USages

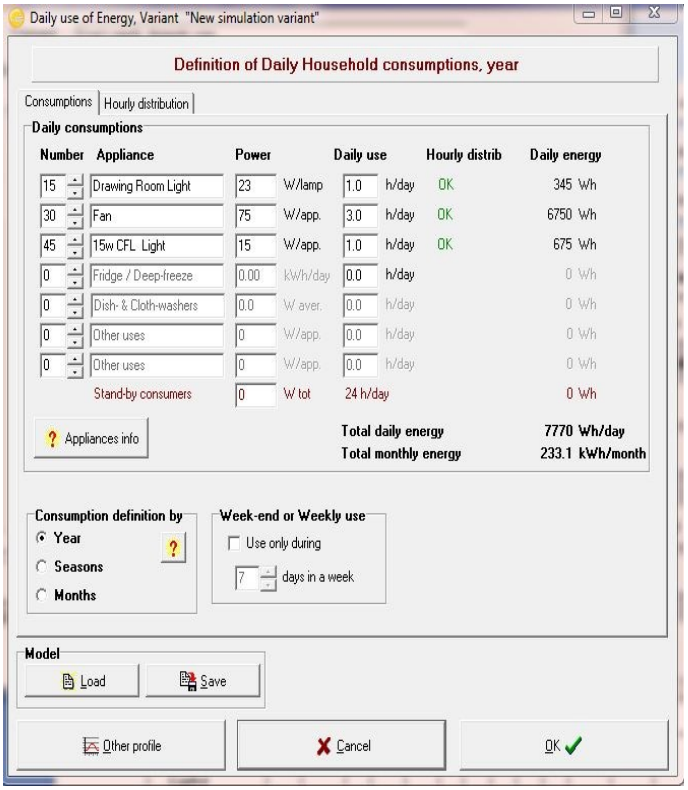
Dally average load shedding usages of the loads in winter. Here, the energy required for "load shedding usages loads" is 17.755*230= 4083.65 wh/day.

Table 7. Daily average load shedding usages of the loads in winter

Load description	AC load power (W)	Daily duty cycle hrs/day	Power conversion efficiency	Nominal system voltage (V)	Amp-hour load per day (AH)
Drawing /Dining room light	15*23	1	0.80	230	1.875
Drawing room fan	15*75	1	0.80	230	6.11
Bedroom fan	15*75	1	0.80	230	6.11
Bedroom Light	15*15	1	0.80	230	1.22
Kitchen light	15*15	1	0.80	230	1.22
Toilet Light	15*15	1	0.80	230	1.22
Total	3267.15 W				17.755AH

I. Load Calculation with PVSYST Software

We have also conducted the whole load calculation process in PV system simulation software, PVSyst 6.4.0. Calculations done in the PV system are shown here.



Daily use of Energy, Variant "New simulation variant"

Definition of Daily Household consumptions, year

Consumptions | Hourly distribution

Daily consumptions

Number	Appliance	Power		Daily use		Hourly distrib	Daily energy
15	Drawing Room Light	23	W/lamp	1.0	h/day	OK	345 Wh
30	Fan	75	W/app.	3.0	h/day	OK	6750 Wh
45	15w CFL Light	15	W/app.	1.0	h/day	OK	675 Wh
0	Fridge / Deep-freeze	0.00	kWh/day	0.0	h/day		0 Wh
0	Dish- & Cloth-washers	0.0	W aver.	0.0	h/day		0 Wh
0	Other uses	0	W/app.	0.0	h/day		0 Wh
0	Other uses	0	W/app.	0.0	h/day		0 Wh
	Stand-by consumers	0	W tot	24 h/day			0 Wh

Total daily energy 7770 Wh/day
Total monthly energy 233.1 kWh/month

Consumption definition by
● Year
○ Seasons
○ Months

Week-end or Weekly use
☐ Use only during
7 days in a week

Figure 2: Load calculation using PVsyst

It is a simulation of Energy required for "load shedding usages loads" By PVsyst 6.4.0. This shows the total daily energy requirement in summer is 7770 Wh/day and 233.1 KWh/month. Now calculating 80% power conversion efficiency we have (7770/0.80) = 9712.4 Wh/day which is almost the same as the mathematical calculation that gives us 9709.45 Wh/day.

J. Roof Spacing Survey

The most crucial aspect of installing a PV system is locating the PV modules, which must be placed where sunlight can reach them straight without being obstructed. The only such place available in any urban residential building is on the building's rooftop. We went through numerous steps of the survey to get a good estimate of how much room we'll have on the rooftop of any urban building. We have inspected practically every portion of Mirpur City, both electronically and physically, and have completed an analysis of the data collected.

The survey's main goal was to figure out how much open space was available on the roofs of the buildings and how much area would be accessible for solar installation. We determined the available space on the rooftops of most metropolitan structures using Google maps and Google earth for this purpose. We physically examined numerous building rooftops from each location to double-check the spacing. The area of any building's roof may be readily measured using Google's distance measurement tools in Google Earth. Figure 3 depicts a satellite image of the BUBT rooftop from Route 7. The roof design of the buildings on this route may simply be deduced from this diagram.

Figure 3: Result of the roof spacing survey

After conducting this roof spacing study, it was discovered that in a building with 15 households, more than 5000 sq. ft. of rooftop space is available for the installation of solar panels. And if the size of the structure grows or shrinks, the number of households and the load requirements alter as well.

K. Local Weather Survey

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. 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. The maximum amount of radiation is available on the month of March-April and the 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 kWh/m2-day [3]. Data in Table VIII has illustrated the prospect of solar radiation in Bangladesh.

Table 8. Solar radiation profile in Bangladesh

Month	Solar radiation (KWh/m^2-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
Septemer	4.41
October	4.61
November	4.27
December	3.92
Average	4.73

III. SYSTEM PARAMETERS

The entire system is made up of several components. Solar radiation falls on the solar cells of the PV modules, which create DC electricity, from the beginning. The load is supplied with DC power, but because home loads are powered by AC, the DC electricity from the solar cells must be reversed to AC. In this case, an inverter is required. However, because the system can only create power when the sun is shining brightly, a storage device is required to store the solar energy in electrical form. In this approach, batteries will now be in charge of storing energy. A charge controller is required to regulate the charging system. When there is no sunlight available, an intelligent controller is used to regulate when the system is connected to the loads, how to charge the batteries when there is no sunlight accessible and to avoid charging with the grid connection when it is not needed. In this part, the major elements are discussed.

L. Module Selection

The efficiency of single-crystalline and polycrystalline modules is quite high, but the cost is also quite high. However, in our design, the cost is really important. We'll need a lot of solar panels because we're constructing a system with a lot of loads. As a result, the cost of the panels will climb. As a result, employing these high-quality modules will be out of reach for the average person. In light of the economic realities, we have chosen polycrystalline, which is both cost-effective and efficient.

M. Photovoltaic Panels

PV panels are made up of one or more PV modules that are pre-wired and ready to be installed in the field. PV panels' modular architecture allows systems to expand as needs change. Intermixing modules from various manufacturers is not an issue as long as all of the modules' rated voltage outputs are within 1.0 volts of each other.

N. Selection of Inverter

Squire wave inverters are not suited for power inverters, thus we can't utilize them in our system. True sine waves inverters, on the other hand, are the best power inverters but are difficult to employ due to their high cost. So we're down to the modified sine waves inverters as the only option. This modified sine wave can power nearly all of the household appliances in our system.

O. Battery Selection

Choosing a battery for a PV system like ours is based on a variety of factors such as battery pricing, efficiency, charging and discharging factor, and so on. We will employ lead-acid batteries, which are commonly utilized as a solar system storage device, due to the cost aspect and availability in our nation. These batteries are very inexpensive, efficient in power storage, and have a 3–5 year lifespan. Even though lead-acid batteries emit hydrogen gas while charging and require some maintenance, they are nonetheless quite popular for big solar energy storage systems.

Because our system's nominal voltage is 12V, we'll need batteries with a capacity of 200 Ah and a voltage of 12 V. Based on the pricing of locally accessible batteries, we've opted to utilize 200 Ah batteries, which will be the most cost-effective option for our system.

P. Charge Controller

The charge controller is a piece of equipment that regulates the battery's charging system. Because the solar cells create a greater voltage when the sun is brighter, the solar cells create greater voltage. If we don't have a charge controller, the battery will be damaged by the high voltage. As a result, the charge controller is a critical component in our system for extending the battery life.

IV. SYSTEM MODEL

The schematic diagram of grid-connected solar PV system is shown in Figure 4. The solar panel uses the sun's rays to create electricity. PV modules use a charge controller MPPT to store electricity in a parallel linked battery bank. MPPT can protect batteries from extremely high or extremely low voltages. The inverter is powered by the battery bank, and the inverter converts DC to AC. In our system, three ICs are employed for an intelligence operation. The following are the operations of these integrated circuits:

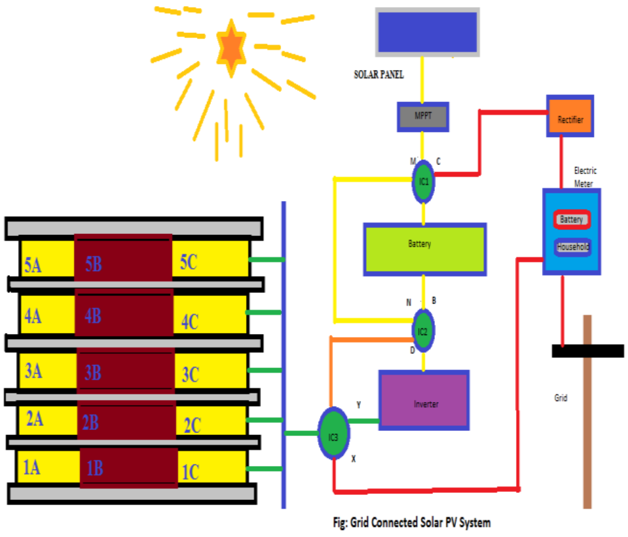


Figure 4: Schematic diagram of grid-connected solar PV system

IC1: For adverse weather or night-time charging, the IC1 intelligence controller is linked to the battery, MPPT, and grid-linked battery charging rectifier. It also communicates with IC2. MPPT will examine the battery once it has been charged. It will not charge the battery if it is already completely charged. It will transfer its excessive MPPT charge N to the inverter through IC2 instead of charging the battery. When MPPT is unavailable, it will wait five minutes for MPPT to become available before allowing rectified grid power to charge the batteries.

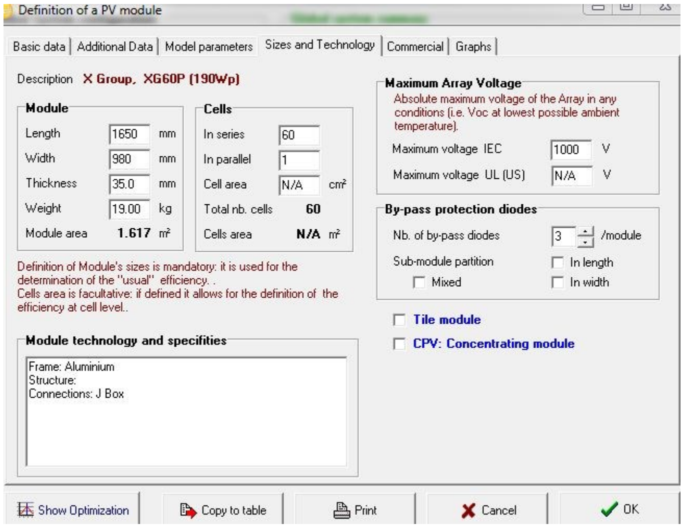
IC2: Between the battery and the inverter lies IC2. It can also communicate with IC1 and IC3. When IC1 detects that the battery is completely charged and that the battery MPPT can still provide power, it sends N to the inverter through IC2. If battery power B and MPPT excessive power N are present, IC2 will check. It will provide MPPT surplus charge N to the inverter's priority.

IC3: The inverter, grid, and domestic load are all connected via IC3. If MPPT excess charge N or battery charge B is arriving at the inverter, IC3 will inform IC2. If N arrives, the inverter will be able to give power to the home. If N is not there, grid power X will be lost. If both grids X and N are unavailable, only battery B power will be sent to the homeowner via the inverter.

Q. PV Module Sizing

We can calculate the size of the PV module for our design because we already know the anticipated load required. However, the size of the module is determined by the type of module we are employing. We believe the 190 W XG60p module to be ideal as an example. Figure 4 depicts the specification.

We came to know that Energy our load requirement is 3267.15 watts. For our grid-tied system, when the battery is fully charged then PV will run the load without draining the battery out in non-load shedding conditions. So, PV power needed to be equal to the load power. Considering 80% conversion efficiency PV capacity required = 3267.15/.80 =4083.97 kW or 4.1 kW.



Description **X Group, XG60P (190Wp)**

Module
Length 1650 mm
Width 980 mm
Thickness 35.0 mm
Weight 19.00 kg
Module area **1.617** m²

Cells
In series 60
In parallel 1
Cell area N/A cm²
Total nb. cells **60**
Cells area **N/A** m²

Definition of Module's sizes is mandatory: it is used for the determination of the "usual" efficiency. .
Cells area is facultative: if defined it allows for the definition of the efficiency at cell level..

Module technology and specifities
Frame: Aluminium
Structure:
Connections: J Box

Maximum Array Voltage
Absolute maximum voltage of the Array in any conditions (i.e. Voc at lowest possible ambient temperature).
Maximum voltage IEC 1000 V
Maximum voltage UL (US) N/A V

By-pass protection diodes
Nb. of by-pass diodes 3 /module
Sub-module partition ☐ In length
☐ Mixed ☐ In width

☐ **Tile module**
☐ **CPV: Concentrating module**

Figure 5: XG 60p, 190Wp PV module specification

We used a polycrystalline PV solar panel of 190 wp. The detailed parameters are shown in Figure 5. So, for each module being 190wp, the total module needed: 4100/190=21.57 or 22. As Dhaka city is situated at 23° 43' 23" N / 90° 24' 31" E so we will be setting up the panels at a 30o angle so that our fixed arrays can give us the maximum possible output.

The PV module shown in figure 5 XG60p polycrystalline has a dimension of 1650 x 980mm which is 5.41 x 3.21 ft. On average, in Dhaka City, the Sunray falls at a 60^o angle, and we are setting up our PV Modules at a 30^o angle with the ground, where the northern part of the module will be at a height. Here, in Figure 6 the 'E' arm is the PV module and the 'A' arm is considered to be the Sunray.

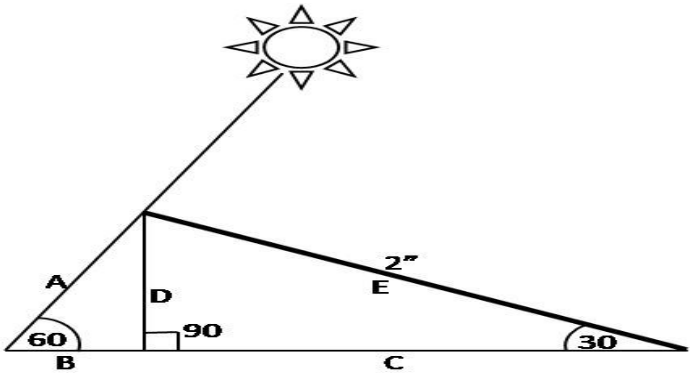


Figure 6: Principle of sun tracking.

From Figure 6 it is seen that, E = 3.21 ft,

D = 3.21Sin30 = 1.605, D = ASin60,

A = 1.605/Sin60 = 1.853.

B = ACos60 = 1.853 x Cos60 = 0.9265 ft

C = ECos30 = 3.21 x Cos30 = 2.77 ft

So the total space required for the Panel in Y-axis is (2.77 + .9265) ft = 3.69 ft and as the Length (X-axis) of the Panel is 5.41 ft, it will need 5.41 ft x 3.69 ft Space for each panel to set up, which will be 19.99. So the total space required for 22 modules to set up is around 439.78 sq. ft. In the Roof spacing survey [6.4] we have seen that in a building with 15 families we will easily have 439.78 sq. ft. of space at the roof for PV establishment.

R. Inverter Configuration

The 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 14.205A when the entire load will be working. That indicates the wattage will be 3267.15W or 3.267 kW. In this case, we have to use an inverter rated 4.2kw or 4200 watts. We used one low price modified sine wave inverter of 4.2 kW 200-500V. For being rated in KVA, our inverter with a 0.80 power factor will be needed to be 4.2/0.80 =5.25KV

S. Battery Sizing and Calculations

We need to be more careful when it comes to battery backup. We were estimating the loaded daily up until now, but now that we'll be working with batteries, we won't be considering a 24-hour battery backup since we won't be utilizing the batteries in the morning if there's strong sunlight. As a result, we should contemplate autonomy from late afternoon until early dawn the next day, a period of 15-16 hours. We must include the utilization of loads in load shedding time in two hours to compute the battery backup time load. We'll use the following table to calculate the battery backup load. As seen from Table IX, the total energy needed for the whole building is 6540 Wh.

Table 9. Load calculation for battery backup time

Load Description	AC load power (W)	Continuous duty cycle hours	Energy needed (Wh)
Drawing/Dining room light	345	2	690
Drawing room fan	1125	2	2250
Bedroom light	225	2	450
Bedroom fan	1125	2	2250
Kitchen light	225	2	450
Toilet light	225	2	450
Total	327 W		6540 Wh

It isn't good to run a battery 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 = 6540/0.85 =7694.12Wh.

For each batter being 12V dc, battery energy needed 7694.12/12 =641.17 AH. Here we used a 200AH heavy Duty Cycle Battery. Being 200 Ah Battery needed for our system is 3.20. So, it will be profitable if we use three 200Ah and one 50Ah battery. Hence, the amount of battery is 4.

T. Battery Charging time determination

Battery Charging time = (Energy required for the whole building in backup time) / (system power generation capacity)

(1)

Battery Charging time =7694.11wh/4100w =1.87 hours =112.2minutes= 1hour 52 minutes

U. Charge Controller MPPT

The charge controller is a regulator which limits the rate of current that goes to and from the battery pack. Charge controllers are essential to prevent overcharging or completely draining a battery. Such action can reduce battery performance and the lifespan of a battery dramatically.

V. Calculating the Controller Array Current

The x group xg60p 190 W solar panel has a short circuit current of 7.5 Amp. Module Short Circuit Current x Modules in parallel x Safety Factor = Array Short Circuit current 7.5 Amp x 2 x 1.25 = 18.75 Amp (minimum Controller input current). This is the input current that comes from the solar array. The number of parallel strings in the array increases the current. To be on the safe side, it is advised to multiply the result by a safety factor of 1.25. Total DC connected Watts / DC System Voltage = Max. DC Load Current 4100 W / 12 V = 341.66 Amp (minimum Controller output current)

W. Intelligence Controller Design

Our system would be incomplete without the intelligent controller. This gadget will help us achieve the majority of our system's primary objectives. This device will be linked to practically every component of our system, including modules, charge controllers, inverters, and so on. This device will determine how the inverter will operate, how the batteries will be charged, and which power source the loads will be linked to. This controller will determine whether or not the charge controller is properly charging the battery. It will also examine the battery charge status and the availability of module power. Depending on these the controller will work. We used IC1, IC2, and IC3 as intelligence controllers in our system. The truth table, Boolean expression, and final expression are shown in Table X, XI, and XII respectively. Finally, the Boolean expression circuit implementations and PLC ladder diagrams for the system is shown in Figure 6 and 7 respectively.

Table 10. Truth table for IC1

M	C	Out M	Out C
0	0	0	0
0	1	0	1
1	0	1	0
1	1	1	0

M=MPPT charge

C=Grid charge

Out M=Solar to charge the battery

Out C=Grid to charge the battery

Table 11. Boolean expression using k-map: Fm:

Fm	C′	C
M′	0	0
M	1	1

So, function Fm=M

Table 12. Boolean expression using k-map: Fc:

Fc	C′	C
M′	0	1
M	0	0

Fc=M′ C

Now, Fic1=Fm+Fc=M+M′ C

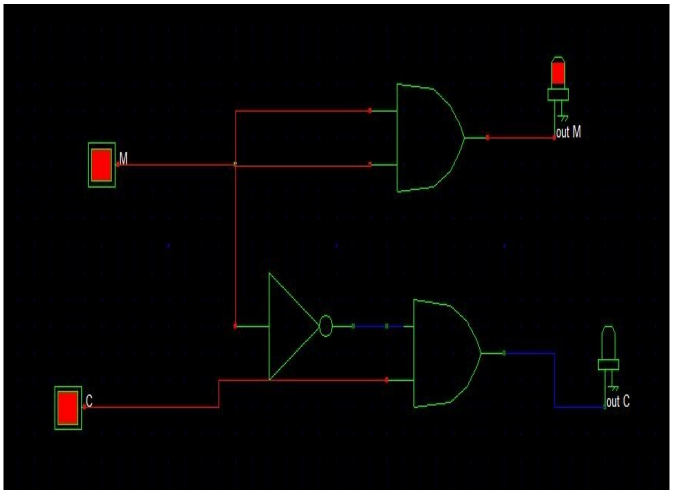


Figure 6: Boolean expression circuit implementation by Dsch3 for IC1

PLC Ladder diagram:

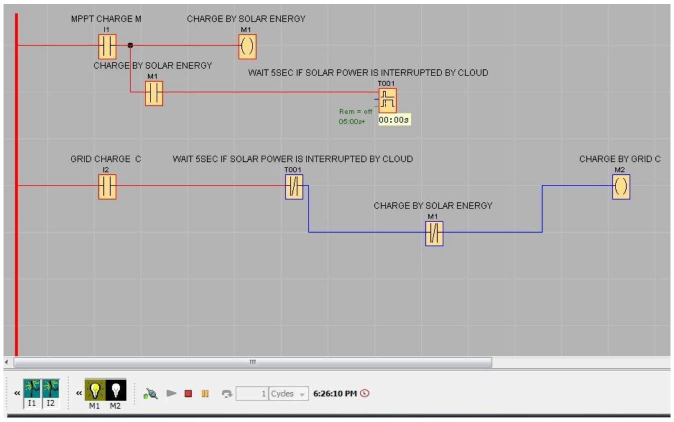


Figure 7: PLC Ladder diagram by Logosoft comfort v7.0 for IC1

For IC2:

Table 13. Truth table for IC2

N	B	Out N	Out B
0	0	0	0
0	1	0	1
1	0	1	0
1	1	1	0

N= MPPT excessive charge

B=Battery charge

Out N= MPPT excessive charge to inverter

Out B= Battery charge to inverter

Table 14. Boolean expression using k-map: Fn

Fn	B′	B
N′	0	0
N	1	1

Fn=N

Table 15. Boolean expression using k-map: F

Fc	C′	C
M′	0	1
M	0	0

Fb=N′ B

So, Fic2=Fn+Fb=N+N′ B

The truth table, Boolean expression, and final expression for IC2 are shown in Table XIII, XIV, and XV respectively. Finally, the Boolean expression circuit implementations and PLC ladder diagrams for IC2 is shown in Figure 8 and 9 respectively.

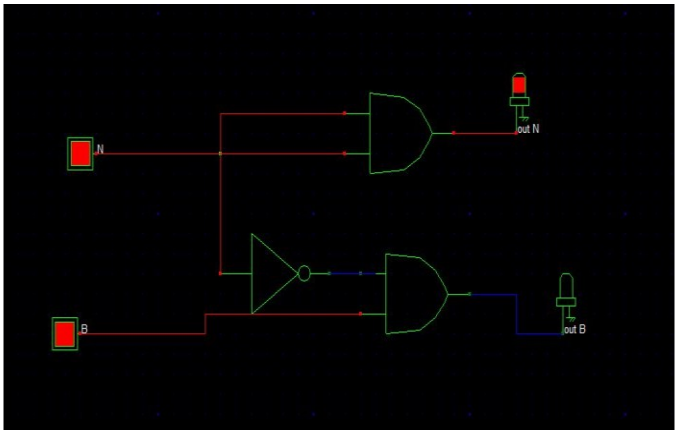


Figure 8: Boolean expression circuit Implementation for IC2

PLC Ladder diagram:

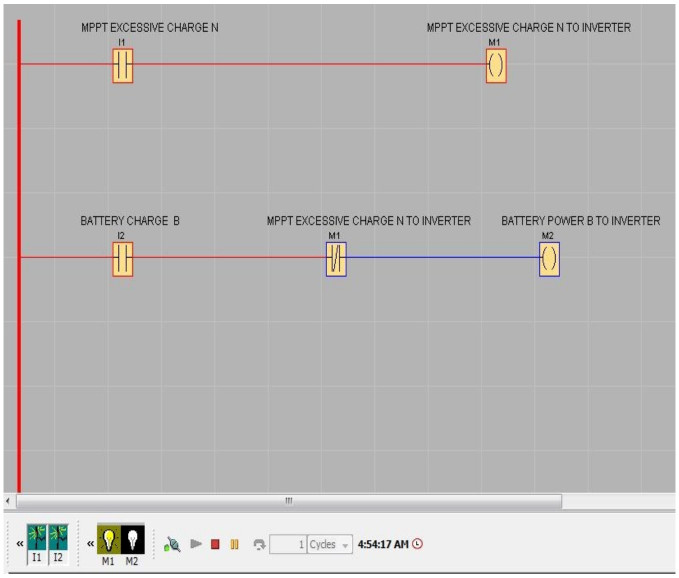


Figure 9: PLC Ladder diagram for IC2

For IC3:

Table 16. Truth table for IC3

N	X	B	Out Y	Out X
1	1	Xx	1	0
1	0	Xx	1	0
0	1	Xx	0	1
0	0	1	1	0
0	0	0	0	0

N=MPPT Excessive Charge

B=Battery Charge

X=Grid power

Y=solar power (N or B)

Table 17. Boolean expression: Fx

Fx	X′B′	X′B	XB	XB′
N′			1	1
N				

Fx=N′ X

Table 18. Boolean expression: Fy

Fy	X′B′	X′B	XB	XB′
N′		1		
N	1	1	1	1

Fy=N+X′ B

Fic3=Fx+Fy=N′ X+N+X′ B

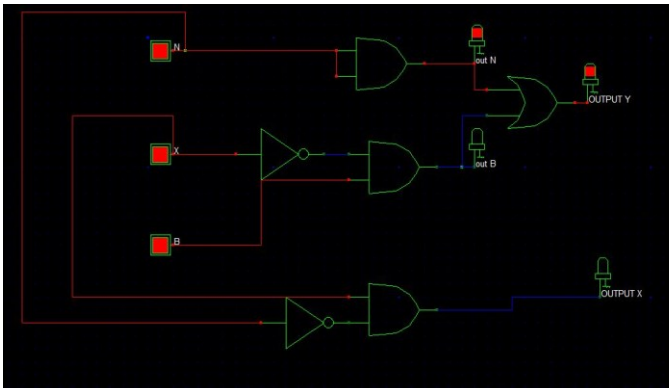


Figure 10: Boolean expression circuit Implementation for IC3

The truth table, Boolean expression, and final expression for IC3 are shown in Table XVI, XVII, and XVIII respectively. Finally, the Boolean expression circuit implementations and PLC ladder diagrams for IC3 is shown in Figure 10 and 11 respectively.

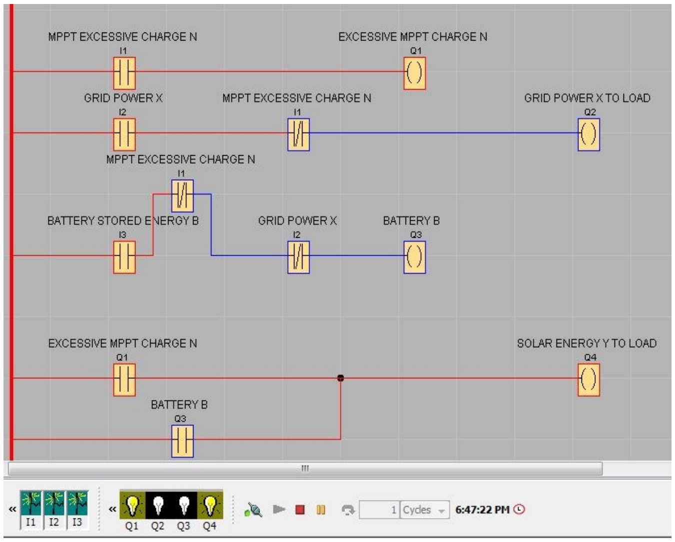


Figure 11: PLC Ladder diagram for IC3

X. *Grounding and surge protection*

Surge protection systems are installed into almost all metropolitan structures. However, when we install our panels on the rooftop, we must ensure that the surge protection rod is at a proper height. Our system grounding should never be connected to the grounding system for the building's surge protection. The PV system's other electrical safety concern is safely grounding all solar panels and inverters.

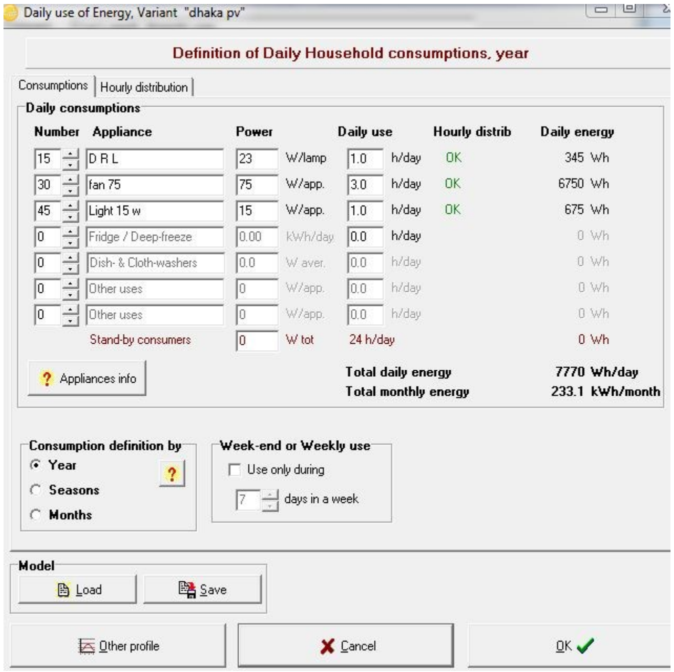
Y. *IPS System Sizing*

The IPS system has to be scaled based on a single-family load calculation. The system settings may be altered here, but each family's power requirements will remain the same. Our solar system is taking the place of IPS. As a result, the following is the computation for individual IPS:

If the power requirement for 15 families is 4100 W, for each family it will be = 4100/15=273.33 w. For an inverter with 0.80 pf, inverter capacity needed 273.33/.80 =341.66VA. Battery capacity needed 641.17/15= 42.75 Ah or one 50Ah.

Z. *Simulation Procedure*

The user must set the weather data in PVSyst 6.40. The system is being developed for Dhaka, Bangladesh. However, PVSyst does not have any data for Bangladesh. They do, however, provide statistics for Dhaka and Chittagong, which may be accessed under the India category. Dhaka's longitude and latitude have previously been determined. The user must complete the graph and date sections as desired. Figure 12 depicts the load demand, often known as the user's need. Our overall load, according to our calculations, is roughly 7770 Wh/day, or 233.1 KWh/month. This does not include a conversion efficiency of 80%. Hourly load distribution is also feasible in this simulation program for improved simulation performance.



Definition of Daily Household consumptions, year

Daily consumptions

Number	Appliance	Power		Daily use		Hourly distrib	Daily energy
15	D R L	23	W/lamp	1.0	h/day	OK	345 Wh
30	fan 75	75	W/app.	3.0	h/day	OK	6750 Wh
45	Light 15 w	15	W/app.	1.0	h/day	OK	675 Wh
0	Fridge / Deep-freeze	0.00	kWh/day	0.0	h/day		0 Wh
0	Dish- & Cloth-washers	0.0	W aver.	0.0	h/day		0 Wh
0	Other uses	0	W/app.	0.0	h/day		0 Wh
0	Other uses	0	W/app.	0.0	h/day		0 Wh
	Stand-by consumers	0	W tot	24 h/day			0 Wh

Total daily energy 7770 Wh/day
Total monthly energy 233.1 kWh/month

Consumption definition by
● Year
○ Seasons
○ Months

Week-end or Weekly use
☐ Use only during
7 days in a week

Figure 12: Load requirement part using PVSyst

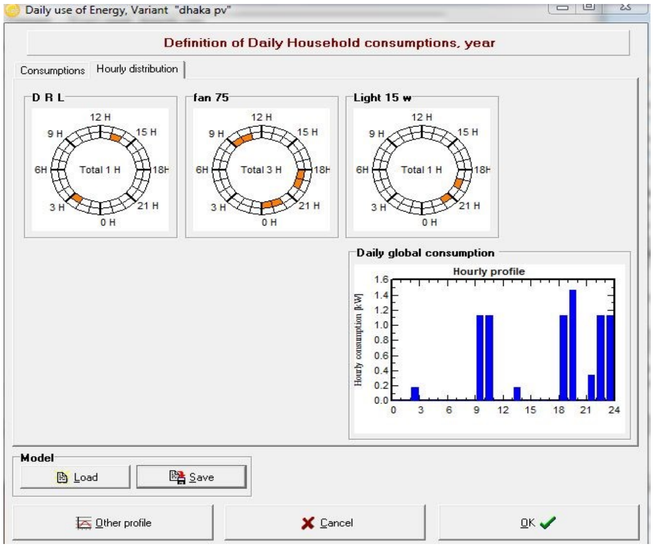
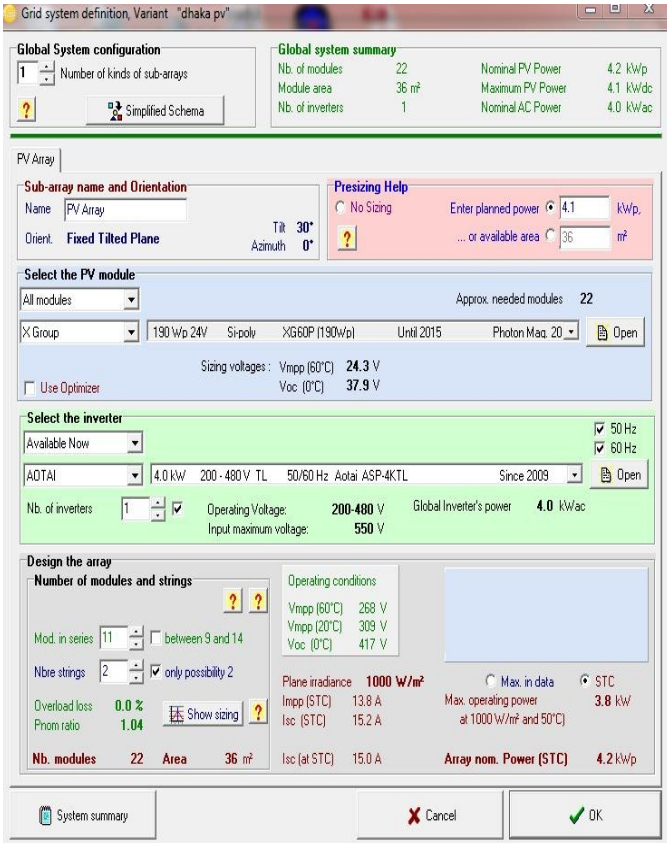


Figure 13: Hourly load duration using PVSyst

Hourly load duration using the PVSyst is shown in Figure 13. 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. System parameters is shown in Figure 14.

AA. System Parameters In PVSyst



Grid system definition, Variant "dhaka pv"

Global System configuration
1 Number of kinds of sub-arrays

Global system summary
Nb. of modules 22
Module area 36 m²
Nb. of inverters 1
Nominal PV Power 4.2 kWp
Maximum PV Power 4.1 kWdc
Nominal AC Power 4.0 kWac

Sub-array name and Orientation
Name PV Array
Orient. Fixed Tilted Plane
Tilt 30°
Azimuth 0°

Presizing Help
○ No Sizing
Enter planned power ● 4.1 kWp,
... or available area ○ 36 m²

Select the PV module
All modules
Approx. needed modules 22
X Group
190 Wp 24V Si-poly XG60P (190Wp) Until 2015 Photon Mag. 20
Sizing voltages : Vmpp (60°C) 24.3 V
Voc (0°C) 37.9 V
☐ Use Optimizer

Select the inverter
Available Now
☑ 50 Hz
☑ 60 Hz
AOTAI
4.0 kW 200 - 480 V TL 50/60 Hz Aotai ASP-4KTL Since 2009
Nb. of inverters 1 ☑
Operating Voltage: 200-480 V
Input maximum voltage: 550 V
Global Inverter's power 4.0 kWac

Design the array
Number of modules and strings
Mod. in series 11 ☐ between 9 and 14
Nbre strings 2 ☑ only possibility 2
Overload loss 0.0 %
Pnom ratio 1.04
Nb. modules 22 Area 36 m²

Operating conditions
Vmpp (60°C) 268 V
Vmpp (20°C) 309 V
Voc (0°C) 417 V

Plane irradiance 1000 W/m²
Impp (STC) 13.8 A
Isc (STC) 15.2 A
Isc (at STC) 15.0 A

○ Max. in data ● STC
Max. operating power at 1000 W/m² and 50°C) 3.8 kW
Array nom. Power (STC) 4.2 kWp

Figure 14: System parameters

V. COST ANALYSIS

Here a cost analysis between our PV systems concerning IPS is given below. This is due to show the cost-effectiveness of our system.

A. PV System Cost Determination

PV solar panel price: Our PV system is Polycrystalline. PV solar panel price is according to per watt generated cost. Parameters of costing have been taken from [45]. Our PV Cell per watt Generation cost is 0.53 dollars =42.4 Tk.

Each solar panel is 190 watts will cost 190*42.4 =8000 Tk

For 22 panels, the total cost will is 22*8000=176000 Tk

Battery Price: Each 200AH battery will cost 15000 Tk in the BD market. So, for three 200Ah and one 50Ah batteries, it will cost 15000*3+6785=51785 Tk

MPPT price: MPPT can be made very easily. One MPPT making cost is less than 500 Tk

Inverter Price: 5000 Tk, according to BD market

Power Rectifier Price: lesser than 100 Tk

Intelligence Controller Price: It is made by ourselves with an 8051 Microcontroller. Each controller with 70 Tk. let the three intelligence system price be 500tk

Total system installation cost: (PV panel cost + Battery price+ MPPT Price+ Inverter price+ power rectifier price + Intelligence price) = (176000+51785+500+5000+100+500) = 2,33,885 Tk

B. IPS Cost Determination

From the Rahimafrooz IPS Price list, we can see from the above picture that our IPS of 350VA will cost 19050 Tk for each family.

Total system installation cost: For each family having their own IPS system at 19050 Tk,

Total installation cost will be 15*19050k= 2, 85,750 Tk

C. Our System Saving

It can be divided into three classes.

***a) Capital saving**:* (IPS system installation cost – Solar system installation cost)*=2, 85,750- 2, 33,885 Tk =51,865 Tk.*

b) Load shedding saving: For 4 hours load shedding schedule on a particular day, it can generate that amount of energy that is free of grid cost.

"Load Shedding Usages Loads" is = 9709.45 Wh/day=9.71 kWh/day. According to DESCO per kWh price, per kWh price is 5.63 Tk [Collected from DESCO]. A price list of DESCO is given below [51]. So, according to the DESCO price list, Per day saving is =9.71*5.63=55 Tk. One-month saving is = 55*30=1630 Tk. Annual load shedding saving is=55*365=20,075 Tk.

c) Grid-Tied regular savings: This is the most important calculation of cost analysis and saving of any Grid-tied solar system. It is the saving that comes from (per day total generation – load shedding generation). We designed our system such that, when solar and grid power both are present then, our pre-determined "load shedding usages loads" will use solar power to run themselves. Here is today's sunray time given: *Daylight time for an average of 12 hours 34 minutes.* Let, 9 hours among them can suitable for solar energy production.

So, subtracting 4 hours load shedding time, it can have (9-4) = 5 hours to produce solar energy. These 5 hours per day are for our on-grid or grid-tied saving. For our system is capable of 4.1kw generation, for 5 hours it will generate 5*4.1=20.5 kWh

Annual Generation: 20.50*365=7482 kWh

Per day grid-tied saving =20.50*5.63=115.415 Tk

Per month grid-tied saving= 115.415*30=3462.45 Tk

So, Annual grid-tied saving =115.415*365=42,126.475 Tk

But, if we consider the seasonal effect on our system like the rainy season, the on-grid generation won't be the same. We know In Bangladesh June-July is mainly the rainy season. So, considering these two months of rainy days (2*30) =60 days. Finally, 60 days could generate 60*20.5 kWh = 1230 kWh.

Assume that in these two months' production is 50%. So, the production of these two months is 1230x50%=615 kWh. The non-saving amount from these two months is 615x5.64=3468 Tk. So, more appropriate grid saving = 42126-3468 = 38,658 Tk. And Annual unit generated is (365-60x50%)*20.5 kWh = 6867.5 kWh which is very close to our software calculation given below.

D. Cost Analysis Comprehension Between Solar And IPS

Cost analysis comprehension between solar and IPS is shown in Table XIX. It is seen that the solar PV system can save a significant amount of capital cost. As it is observed that Total Annual Saving is 38,658 Tk + 20,075 Tk = 58,733 Tk. The proposed system is warranted for 5 years on batteries and inverters and 10 years on the solar panel. According to 58,733tk per year saving, it will take (2, 33,885/58,733) years = 3.98 years lesser than 4 years to regain our capital investment.

Table 19. Cost analysis comprehension between solar and IPS

Cost analysis	**Solar**	**IPS**	**Solar capital saving**
Installation cost:	2,33,885 Tk	2,85,750 Tk	(2,33,885-2,85,750) Tk =51,865 Tk
Annual load shedding saving	+20,075 Tk	-20,075 Tk	Here, solar is generating so the value is positive and IPS are consuming so value negative
Annual grid-tied saving	+38,658 Tk	0	IPS has no Grid-tied savings because it doesn't produce energy

VI. CONCLUSION

A solar PV system's first and most important task is to determine how much power is required. As a result, this work performed various load computations to calculate the energy consumption to avoid a power outage. When the battery is completely charged and solar energy is available, we structured our system such that the surplus solar energy is used instead of the grid, leaving the battery alone. Only when both solar PV and the grid are off can the battery supply the load. The technology is cost-effective enough to serve middle-class households on a tight budget. Replacing an unreliable IPS system with a solar PV system is not only cost-effective, but it also helps to alleviate the current energy crisis. Solar PV systems have a longer service life, making them ideal for energy generation. It is quickly recoupable in terms of installation costs. For a poor nation like Bangladesh, solar energy production may be legendary.

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