How To Use Solar Energy Conversion Equipment Effectively To Reduce House's Power Energy Bill

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Abstract *— Access to affordable electricity price is one of the major factors that causing socio-economic problems in the island of Puerto Rico. At the present, most of the clients require the service from the only Power Company provided by the government of PR "Autoridad de Energía Eléctrica" (AEE). Saying this, the possible opportunities to find a better price for the same utility is limited. At this moment, the use of alternative energy is the only option provided to the client. Inside this alternative energy program, we have the solar energy system that can even be installed in distant area in which the local electrical power cannot afford it.*

Key Terms *— Inverter, Battery, Panel, Photovoltaic.*

PROBLEM STATEMENT

Load management for electricity is a need to develop the sector in a sustainable manner which can provide more benefit to our citizens and environment. Solar power is an increasing market for more developed countries, which can benefit from less electric expense over time and good for the environment. There are other renewable energy sources besides solar, but it is especially practical for sunny areas which have less wind and water resources.

Reasons for choosing solar energy are also clearly indicated by the growing number of projects conducted by various organizations and governments. Application for this energy source can be from single houses and large electrical grids to cars, exhibiting a versatility perfect for the needs of a developing country.

The present energy demand is increasing day by day in Puerto Rico due to various reasons such as the aspiration for improved living standard and general economic and industrial growth. The power generation system is principally depended on imported petroleum oil and natural gas. It may be mentioned that concern for environment is now a universal issue and conventional energy gives rise to greenhouse gases with adverse consequences for health and climate. Communities in rural areas and mainly in remote areas of Puerto Rico have very little possibilities to participate on the national electricity supply. Therefore, and in the context of environment protection, renewable energies can contribute substantial to the delivery of alternative energy to the customers are some of the key issues that determine the need for technological inventions in solving energy problems in the rural areas.

RESEARCH DESCRIPTION

Electricity has given modern and sophisticated life in the world. It is impossible to imagine the civilized world without electricity. In Puerto Rico the crisis of power is the common phenomena. Now a day it has become a serious problem. The reasons for lower availability are:

- Some plants are out of operation for maintenance, rehabilitation & overhaul
- Capacity of some plants are de-rated due aging
- Gas shortage

Power crisis is the result of transmission loss (technical loss and non-technical loss), machinery loss, distribution loss and corrupt management. Non-technical losses are Consumption loss, billing loss and collections loss. As the demand of electricity is increasing so it is essential to set up new power stations to overcome the excess demand.

But in our country being short of huge fund it could not be possible to build up new power stations. On the other hand, the lifetime of the old

power stations is over. In that case sometimes some of the units or whole station collapsed.

This research will try to explain the possible benefits on the implementation of solar systems to help the community to understand how this type of equipment could help on their regular living styles without affecting their power energy consumption bills that typically are highly costs provided from traditional source of power production.

RESEARCH OBJECTIVE

The following describe the objectives of this research work:

- provide details on how the solar energy could be converted into electrical power that could be use on customer's houses;
- provide information on how the sun will be a very important source of energy without have to spend too much money for its acquisition benefits;
- Equipment and electrical diagrams will also provide for visual interpretation;
- Conclude with results that justify correct initial decisions.

RESEARCH CONTRIBUTIONS

Better descriptions on Solar Home System will be detailed in this study research. Cost and Benefits Comparison between actual Power source provided by AEE and Solar Home System will be presented for better knowledge on how the alternative energy system could help to the customer in Puerto Rico.

SUN AND ENERGY

Light striking a silicon semiconductor causes electrons to flow, creating electricity. Solar power generating systems take advantage of this property to convert sunlight directly into electrical energy.

Solar panels also called "solar modules" produce direct current (DC) which goes through a power inverter to become alternating current (AC) – electricity that we can use in the home, like that supplied by a utility power company.

There are two types of solar power generating systems: grid-connected systems, which are connected to the commercial power infrastructure: and stand-alone systems, which feed electricity to a facility for immediate use, or to a battery for storage. Grid-connected systems are used for homes, public facilities such as schools and hospitals, and commercial facilities such as offices and shopping centers. Electricity generated during the daytime can be used right away, and in some cases surplus electricity can be sold to the utility power company. If the system doesn't generate enough electricity, or generates none at all (for example, on a cloudy or rainy day, or at night) electricity is purchased from the utility power company. Power production levels and surplus selling can be checked in real time on a monitor, an effective way to gauge daily energy consumption. Stand-alone systems are used in a variety of applications, including emergency power supply and remote power where traditional infrastructure is unavailable.

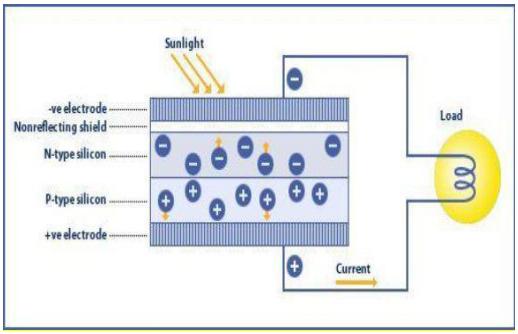

Figure 1
Conversion of Sunlight into Electricity

In Figure 1 when sunlight hits the semiconductor, an electron springs up and is attracted to the n-type semiconductor. This causes more negative electrons in the n-type semiconductor and more positive electrons in the p-type, thus generating a flow of electricity in a process known as the "photovoltaic effect".

Solar Power System

Solar power is the conversion of sunlight into electricity. Electric energy is to the kinetic energy

of moving electrons, the negatively charged particles in atoms. Sunlight can be converted directly into electricity using photovoltaics' (PV), or indirectly with concentrated solar power (CSP), which normally focuses the sun's energy to boil water which is the used to provide power. They are an important and relatively inexpensive source of electrical energy where grid power is inconvenient, unreasonably expensive to connect, or simply unavailable.

Photovoltaic systems (PV system) (Figure 2) use solar panels to convert sunlight into electricity. A system is made up of one or more photovoltaic (PV) panels, a DC/AC power converter (also known as an inverter), a tracking system that holds the solar panels, electrical. interconnections, and mounting for other components.

Solar or photovoltaic (PV) cells are made of semiconducting materials that can convert sunlight directly into electricity. When sunlight strikes the cells, it dislodges and liberates electrons within the material which then move to produce a direct electrical current (DC).

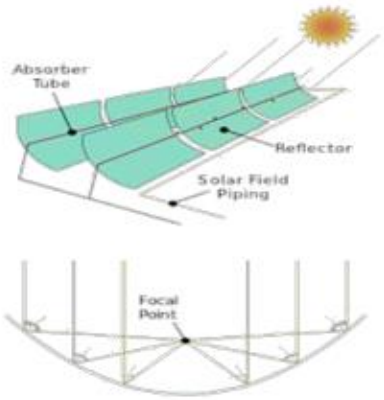

Figure 2
Application of Solar Power System Photovoltaic System

Figure 3
Solar park or PV farm Advantage Photovoltaic System

Photovoltaic systems offer substantial advantages over conventional power sources (Figure 3):

- Reliability: Even in harsh conditions, photovoltaic systems have proven their reliability. PV arrays prevent costly power failures in situations where continuous operation is critical.
- Durability: Most PV modules available today show no degradation after ten years of use. It is likely that future modules will produce power for 25 years or more.
- Low Maintenance Cost: Transporting materials and personnel to remote areas for equipment maintenance or service work is expensive. Since PV systems require only periodic inspection and occasional maintenance, these costs are usually less than with conventionally fueled systems.
- No Fuel Cost: Since no fuel source is required, there are no costs associated with purchasing, storing, or transporting fuel.
- Reduced Sound Pollution: Photovoltaic systems operate silently and with minimal movement.
- Photovoltaic Modularity: PV systems are more cost effective than bulky conventional systems. Modules may be added incrementally to a photovoltaic system to increase available power.
- Safety: PV systems do not require the use of combustible fuels and are very safe when properly designed and installed.
- Independence: Many residential PV users cite energy independence from utilities as their primary motivation for adopting the new technology.
- Electrical Grid Decentralization: Small-scale decentralized power stations reduce the possibility of outages on the electric grid.
- High Altitude Performance: Increased insulation at high altitudes makes using photovoltaic advantageous, since power output is optimized. In contrast, a diesel generator at

higher altitudes must be de-rated because of losses in efficiency and power output.

Photovoltaic Module

Due to the low voltage of an individual solar cell (typically ca. 0.5V), several cells are wired in series in the manufacture of a "laminate". The laminate is assembled into a protective weatherproof enclosure, thus making a photovoltaic module or solar panel. Modules may then be strung together into a photovoltaic array.

Photovoltaic Array

A photovoltaic array (or solar array) (Figure 4) is linked collection of solar panels.

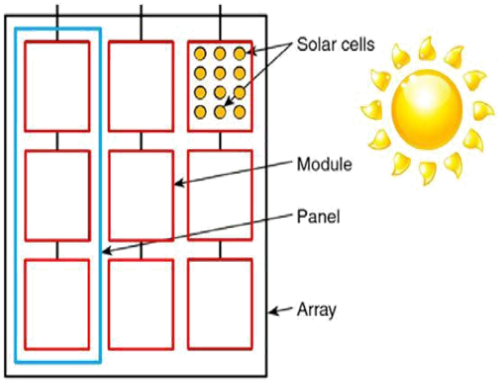

Figure 4
Basic Photovoltaic Components Used to Capture Solar Energy

The power that one module can produce is seldom enough to meet requirements of a home or a business, so the modules are linked together to form an array. Most PV arrays use an inverter to convert the DC power produced by the modules into alternating current that can power lights, motors, and other loads. The modules in a PV array are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more current. Solar panels are typically measured under STC (standard test conditions) or PTC (PV USA test conditions), in watts. Typical panel ratings range from less than 100 watts to over 400 watts. The array rating consists of a summation of the panel ratings, in watts, kilowatts, or megawatts.

Module Circuit Design

The voltage of a PV module is usually chosen to be compatible with a 12 V battery (Figure 5).

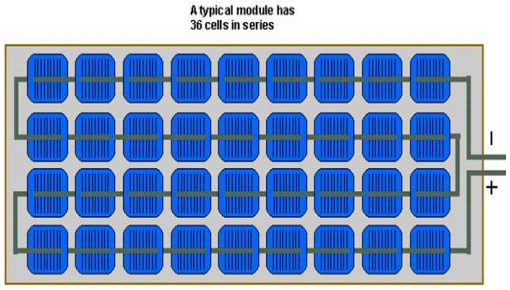

Figure 5
In a Typical Module, 36 Cells are Connected in Series to Produce a Voltage Sufficient to Charge a 12 V Battery

- While the voltage from the PV module is determined by the number of solar cells, the current from the module depends primarily on the size of the solar cells and also on their efficiency.

Solar Cell

A solar cell (also called a photovoltaic cell) (Figure 6) is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect.

The operation of a photovoltaic (PV) cell requires 3 basic attributes:

1. The absorption of light, generating either electron-hole pairs or exactions.
2. The separation of charge carriers of opposite types.
3. The separate extraction of those carriers to an external circuit.

Figure 6
Solar Cells Arrangement

Solar Cell Manufacture

Solar cells are semiconductor devices, they share some of the same processing and

manufacturing techniques as other semiconductor devices such as computer and memory chips.

Anti-reflection coatings, to increase the amount of light coupled into the solar cell, are typically next applied. Silicon nitride has gradually replaced titanium dioxide as the anti-reflection coating (serve to increase the amount of light coupled into the cell).

Some companies use an additional electro-plating step to increase the cell efficiency. After the metal contacts are made, the solar cells are interconnected by flat wires or metal ribbons and assembled into modules or "solar panels". Solar panels have a sheet of tempered glass on the front, and a polymer encapsulation on the back.

Solar Cell Materials

Materials for efficient solar cells must have characteristics matched to the spectrum of available light. Silicon remains the only material that is well-researched in both bulk and thin-film forms.

Solar Cell Theory

The solar cell works in three steps:

1. Photons in sunlight hit the solar panel and are absorbed by semiconducting materials, such as silicon.
2. Electrons (negatively charged) are knocked loose from their atoms, causing an electric potential difference.
3. An array of solar cells converts solar energy into a usable amount of direct current (DC) electricity.

Solar Energy

Solar energy is the radiant (light and heat) energy produced by the sun. The solar energy that reaches the earth can be used to produce electricity or heat through the use of solar collectors.

Solar Energy From The Sun

The sun and its energy are the starting point. They can be seen as the engine that drives the weather and the climate. The earth receives energy from the sun. 50% of this energy is absorbed by the earth and 30% is reflected back into space by the atmosphere. The hydrological cycle is powered by the remaining 20% and only 0.6% of this amount is going into photosynthesis. Photosynthesis is the basis of all life forms on Earth and created the reserves of fossil fuel.

Solar Energy Uses

Solar energy uses in various respects. Such as:

- Generate electricity using photovoltaic and concentrated solar cells.
- Generate electricity by heating trapped air, which rotates turbines in a solar updraft tower.
- Heat buildings, directly, through passive solar building design.
- Heat foodstuffs, through solar ovens.
- Heat water or air for domestic hot water and space heating needs using solar thermal panels.
- Heat and cool air through use of solar chimneys.
- Generate electricity in geosynchronous orbit using solar power satellite.
- Solar air conditioning.

Solar Energy Advantages

The following are advantages when solar energy is used into solar home system:

- The power source of the sun is absolutely free.
- The production of solar energy produces no pollution.
- The technological advancements in solar energy systems have made them extremely cost effective.
- Most systems do not require any maintenance during their lifespan, which means you never have to put money into them.
- Most systems have a life span of 30 to 40 years.
- Most systems carry a full warranty to 20 to 30 years or more.
- Unlike traditional monstrous panel systems, many modern systems are sleeker such as Uni-solar rolls that lay directly on the roof like regular roofing materials.

- Solar energy can be fed back to the utilities to eliminate the need for storage system as well as eliminating or dramatically reducing electric bills.
- Solar energy systems are now designed for particular needs. For instance, you can convert your outdoor lighting to solar.

Solar Radiation

This renewable energy comes from the sun. The sun emits radiant energy as a result of nuclear fusions inside it. The radiant energy that is not absorbed or reflected by clouds, ozone and dust is called direct radiation and is noticed as daylight and heat. The amount of this kind of energy depends on location and altitude. It also depends on the position of the sun, which is related to the reason, the time of the day and the geographic latitude.

Light is a composition of elementary particles that are called photons. A photon is the carrier of electromagnetic radiation of all wavelengths that includes gamma rays, X-rays, ultraviolet light, visible light, infrared light and microwaves, as well as radio waves. Depending on the conditions, the sunlight can reach a maximum of 1 kW (kilowatt) per square meter.

SOLAR POWER SYSTEM

Before concentrating on energy issues and related socio-economic impacts, it is essential to draw a general picture of the situation and conditions within villages and households in focus of this investigation [1]. The following paragraphs will present some basic information on the socio-economic context, problems and expectations of rural Puerto Rico households.

Household Income Group

The average overall monthly household income was $1,160 (Hourly rate of $7.25, working 40 hours weekly). Therefore, it can be stated that the customers were poor, and thus represented well the economic situation of an average rural community. To get a better impression of income reality for the rural households, income distribution must be taken into account.

Household by Occupation Groups

The rural people are directly and indirectly involved in all phases of agricultural and commercial activities. The maximum percentage of the respondents (33%) was agriculture, while about 67% of the total respondents were business.

Owners Decided to Purchase A Solar Home System

We asked owners to list up to three reasons exampling why they made the purchase. The top two responses, improved quality of light (keep refrigerator running to maintain their food) and an increased ease of studying (families with children). The third most common response was TV for personal use (elderly people).

Solar Home System Design

The Basic Components for Solar Home System Design are: Module, Battery, Charge Controller and Load (Figures 7 & 8).

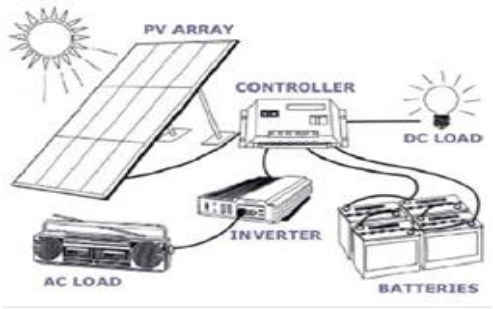

Figure 7
Design of Solar Home Systems

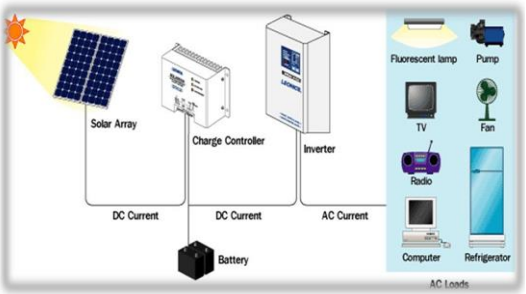

Figure 8
Solar Home Systems to Produce Light [2]

Block Diagram of Solar Home System Design Process

The process of solar home system design is shown in the Figure 9. The process is started with the site screening. It means that it must be located in a place where there is enough sunlight. Then first stage is load estimation and after that battery sizing. Then other components of the system such as charge controller unit and voltage converter (if needed) are selected. In this way, the whole system design is processed.

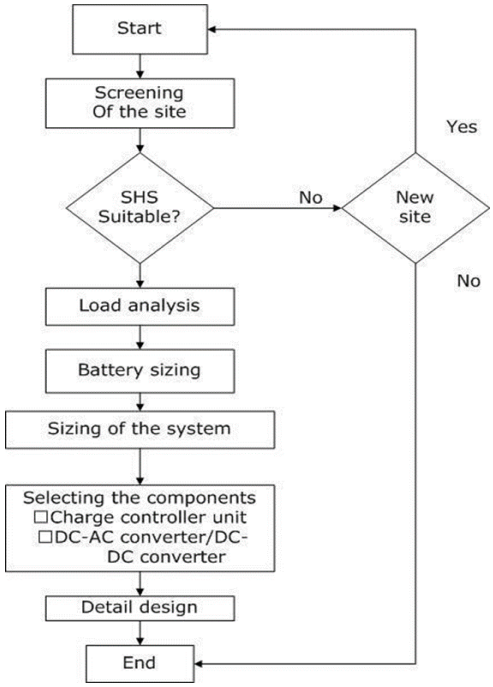

Figure 9
Block Diagram of Solar Home System Design Process

RESULTS AND DISCUSSION

In this part of the design, we will first analysis the location of the installation of the solar system where there is available sunshine. As we know, sunshine isn't equal in all places, so this part is very important because the price of the whole system depends on it [3].

Load Determination

Customer Power consumption - Load Analysis for one-month period for a family of 4 members (Table 1).

Table 1
Electrical Power Consumption on Electric Equipment

Electric Equipment	Potency Consumption (kW)	Daily Use (h)	Electrical Consumption per day (kWh)	Monthly Use (h)	Electrical Consumption per month (kWh)
Ceramic Top Stove	1.2	2	2.4	60	72
Refrigerator	0.89	24	21.36	720	640.8
Washing Machine	0.33	1	0.33	30	9.9
Oven	0.79	5	3.95	150	118.5
TV	0.156	8	1.248	240	37.44
Lights	0.24	6	1.44	180	43.2
Internet / Laptop / Computer	0.17	6	1.02	180	30.6
Microwave	1.2	3	3.6	90	108
A/C	1.35	4	5.4	120	162
Fans	0.06	8	0.48	240	14.4
Total			41.228		1,236.84

Solution

The daily energy needed for the given family = 41.228 kWh

The monthly energy needed for the given family = 1,236.84 kWh

The yearly energy needed for the given family = 14,842.08 kWh

Battery Sizing

The following characteristics are needed for a solar home system battery:

- For deep cycle, long lifetime
- Low maintenance
- High charging capacity
- The ability of completely discharge
- Low internal discharging rate
- Reliability
- Minimum change under excessive temperature

Array Sizing

Array sizing of a PV system means the calculation of the number of PV modules.

Selection of Charge Controller

Functional parameters of solar home system charge controller

- Maximum current receives from PV panel
- Ability of maximum power supply on the load
- Mark its low voltage level

- Mark its high voltage level
- Electric protection from thunder
- Good regulation
- Protection from reverse polarity
- Adjust with system voltage

Selection of Converter

A solar home system use for appliance needs AC and DC voltage. As Solar module output voltage is DC, so this system DC-DC converter or DC-AC converter needed. Some of the load is connected necessary converter.

System Wiring

From PV module up to system component electric wiring is needed. Voltage drop occurs in internal resistance of the wire and should keep under a limit. Wire cost is very important and wire length must be small size. Connection the solar component under dement must be fulfill.

- System must be safe
- These wires are not making defect for system components performance
- Each component works according their maximum performance
- If possible, use centralized 12volt DC system
- If possible, use centralized 24volt DC system

A small size 12 volts Home System Design

The following criteria are required to develop a solar home system:

Let, Load determination for 41,228 Wh/Day design a 12 volts solar home system.

Here 85Wper module (Isc = 7.9A, Imp = 7.00A & nominal voltage=12), 2,000 Ah battery (DOD = 60%, Efficiency=80%) will use.

- Cabal voltage drop maximum 5%
- Maximum power loss 5%
- Inverter efficiency 90%

Battery Size

Required calculation to determine the necessary amount of batteries on a solar home system:

DC Wh/day = 41,228 Wh÷ (0.9*0.95) =48,219.88Wh

Daily load = 48,219.88 Wh ÷ 12V =4,018.32Ah

Battery efficiency = 80%

DOD (Depth of Discharge) = 60%

If autonomy of battery 3 day

Therefore, Amp-hour for battery = (4,018.32*3) ÷ (0.6*0.8) = 25,114.5Ah

Each battery is 2,000Ah.

Number of batteries required = 25,114.5 ÷ 2000 = 12.56 ≈ 13

Therefore, 13 batteries are needed.

Array Sizing

Required calculation to determine the necessary array size on a solar home system:

Module nominal voltage = 12V

Daily avg. pick insulation = 6 hours

Daily PV module output = Module nominal voltage x Imp x Daily avg. pick insulation = 12*7.00*6= 506 Wh/day

Summarizing 15% loss PV Array Sizing= 506*0.15 =75.6Wh

DC watt-hours Available = 506-75.60Wh = 430.4Wh

Therefore, no. of module = Daily consumption / DC watt-hours Available =

41,228 /430.4 = 95.78 ≈ 96

Inverter Size

Required calculation to determine the necessary inverter size on a solar home system:

Size of the inverter = 14,842.08 / (.9) *1.25 = 20,614W ≈ 21,000W

Therefore, 21 kW inverter is needed.

Cost of Solar Power System (Approx. 15,000 kW-h)

Required calculation to determine the amount of money spent on a solar home system (Table 2):

Table 2

Cost of Solar Power System

Item No.	Description of items	Quantity	Unit Price ($)	Price ($)
1	Solar Panel (440W)	36	380	13,680
2	Battery	13	400	5,200
3	Charge Controller	1	500	500
4	Wire	1	430	430
5	Inverter	1	3,150	3,150
6	Panel Mounting	1	1,250	1,250
7	Miscellaneous	1	245	245
8	Maintenance Cost (Labor & Others)	1	3,067	3,067
Total				**27,522**

Cost of Power from AEE (14,842.08 kW-h)

Required calculation to determine the amount of money spent on AEE electrical power for 20 years:

Per Unit Cost of power from AEE ≈ $0.27 / kWh

Per year cost of power from AEE= 14,842.08 kWh x $0.27 / kWh = $4,007.36

Total cost for 20 Years (without considering any maintenance cost)

= $4,007.36×20 = $80,147.20

Comparison Between Solar Home System and Power from AEE

Table 3 provides a summary of costs, advantages and disadvantages between Solar Home System and Power from AEE.

Table 3

Comparison Between Solar Home System and Power from AEE

Comparison	Solar Home System	Powered from AEE
Cost	Total cost for 20 Years = $27,522	Total cost for 20 Years (without considering any maintenance cost) = $80,147.20
Load Shedding	No	Yes
Cost Variation Due Time	No	Yes
Utility Bills	Low	High
Backup Capability	Around 4 day	No
Source of Production	Sunlight (No greenhouse gases)	Coil, Gas, Water, Oil, etc.

Identifying Direct Costs

Direct costs items are classified into two types:

- **Capital Costs**:
  - Land and other natural resources that have current alternative uses
  - Detailed engineering and design
  - Preparatory installation work
  - Cost of equipment, raw materials and supplies for construction
  - Cost of building and auxiliary installations
  - Engineering and administrative cost during construction
  - Organization costs
  - Expenses of running in periods
  - Contingencies
- **Operating and Maintenance Costs**:
  - Raw materials and other supplies
  - Energy and Fuels
  - Labor
  - Rent and Insurance
  - Depletion of natural resources
  - Contingencies

Advantage of Solar Home System

The following are advantages obtained by using a Solar Home System:

- Save Money on Electric Bills Immediately
  - Installing a home solar system make many homeowners save 30% or even eliminate their electric bills.
  - A typical Puerto Rico household uses 41.228 kWh of electricity per day. A residential solar installation of 1,236.84 kWh per month from Renewable Energy Corporation would almost entirely offset your electricity costs.
  - Your actual savings will depend on your home's energy needs, available space for a photovoltaic system, and your PV system orientation. Contact Renewable Energy Corporation for an analysis and estimate.
- Protect Yourself Against Rising Energy Costs

    - Electricity costs have climbed more than 21% during the past five years.
    - Rates jumped 10.3% in 2006 alone.
    - Fossil fuel supplies are dwindling, which will lead to higher energy costs.
    - Solar power locks in your electrical costs and protects you from escalating utility costs.
- Reduce Your Carbon Footprint
    - Reduce of Carbon Dioxide on solar panels preparation which prevents global warming, which is dramatically affecting our climate causing glacier loss, shoreline erosion, and endangering many animals around the world.
- Conserve Our Natural Resources
    - Putting the sun to work reduces the amount of water, coal and nuclear energy needed to power your home which helps preserve the earth's supply of non-renewable resources.
- Increase Your Home Value
    - Studies show that solar systems can increase your home value by 20 times the annual electricity savings.[4]
- Minimal Environmental Impact

The technology produces none of the carbon, methane or particulate emissions that fossil fuels emit.

Limitation of Solar Home System

The following are disadvantages obtained by using a Solar Home System:

- Limited number of supplier & lack of experience in the solar technology market, resulting the high price of Solar Home System.
- During Rainy season sometimes, sunlight isn't available.
- Initial costing is high that's why some middle-class family can't afford it.
- If Solar panel is damaged, then have to change the panel.

CONCLUSION

In the short word we can say the growing rate of Solar Home System (SHS) is around the middle-class family & the poorest are still unable to afford it. One thing we can suggest increasing their research & development sector for having more new ideas. Some strategies could include:

- Offer small system, so that initial investment amount is reduced.
- Cross subsidies may make SHS more accessible to the poor people.
- Installing SHS in school, college, market may increase working hour.
- At the present there are limited number of suppliers, lack of experience and no availability or difficult to obtain the components in the solar technology market, resulting the high price of SHS.

Nowadays with the increasing number of SHS installation health issue is adding new dimension. Battery recycling process is compulsory project for each organization to ensure the health and environmental issue. Approved specification, guidelines & technology should be updated frequently to run with modern energy world. Need increases their technical training to ensure the proper maintenance service and provide a better-quality product. So, we can hope that by increasing their service they will put a real impact on the national power generation.

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