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Techno-Economic Feasibility of Stand-Alone Solar PV System for an Educational Institution

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***Abstract*— Rapid industrialization, depletion of fossil fuel reservoirs and the global warming crises led to the consideration of using clean and inexhaustible energy sources. Harnessing the solar energy to feed the electrical appliances starts by converting the energy coming from the sun into electricity directly is known as photovoltaic. Building a photovoltaic system is the process of designing, selecting and calculating the ratings of the equipments employed in the system. It is found that providing electricity to a site in a remote zone using photovoltaic systems is very beneficial and competitive with the other types of conventional energy sources, especially considering the decreasing prices of these systems and their increasing efficiency and reliability, they also have the advantage of maintaining a clean environment. It is recommended that solar photovoltaic-based dump site electrification application should be encouraged by the government, especially for those rural sites without easy access to a grid supply. The economic feasibility of the system in a small industrial/residential area of Faridabad (India) is investigated. The aim of the proposed PV system is to reduce the grid energy consumption and promote the use of renewable energy. In this paper, the emphasis is also laid on the reduction of greenhouse gases emission. The results of the study encouraged the use of the PV systems to electrify the rural/urban and remote sites in India.**

***Index Terms*— Photovoltaic, techno-economic feasibility**

I. INTRODUCTION

Solar energy is the light and radiant from the Sun that influences earth's climate and weather. It is the source of energy that sustains life on the earth planet. Solar radiation along with secondary solar resources such as wind and wave power, hydroelectricity and biomass accounts for over 99.97% of the available flow of renewable energy on earth. According to this source, the earth receives 174 peta watts (PW) of incoming solar radiation known as isolation at the upper atmosphere out of which approximately 30% is reflected back to space and rest is absorbed by the clouds, oceans and masses on the land. The amount of solar energy reaching the surface of the planet is vast. The annual average solar radiation is 5.7 KW/m^2/day. Solar energy has been harnessed for centuries as early as the 7th century B.C. people have used magnifying lenses to concentrate the light into beam so hot that could cause wood to catch fire (Zweibel 1990). Harnessing solar energy is one of the renewable energy sources, which has potential being domestically or/and commercially used today. It is non-depleting source, non-polluting, economic, high reliability and abundantly frees in its original radiation form, hence a suitable solution for energy requirements especially in rural areas. In numerous remote and rural areas in the world, a large number of domestic consumers, farms and small business are not connected to main electrical grid system. This is especially in the developing countries, where large distances and the lack of techno-economic feasibility are some of the obstacles to the development of a grid system (Elhadidy and Shaahid, 2000; Elhadidy, 2002; Tay *et al.*, 2011; Nakata *et al.*, 2011).

Rapid advance researches and developments in the solar photovoltaic technologies in recent years have made it a competitive alternative to the conventional energy systems whose cost has reached to an alarming stage. Photovoltaic systems have made a significant contribution to daily life in developing countries where one third of the world's people live without electricity even today. New researches emphasizes the share of photovoltaic as an encouragingly high in near future having a major contribution of 25% of the world energy up to 2050 and about 58% in turn of the century i.e.2100.

Table 1:Insolation Location Delhi Rural Area

Months	**Value (H_m)**
January	4.15
February	5.19
March	6.34
April	7.13
May	7.51
June	6.76
July	5.66
August	5.45
September	6.07
October	5.50
November	4.60
December	4.02

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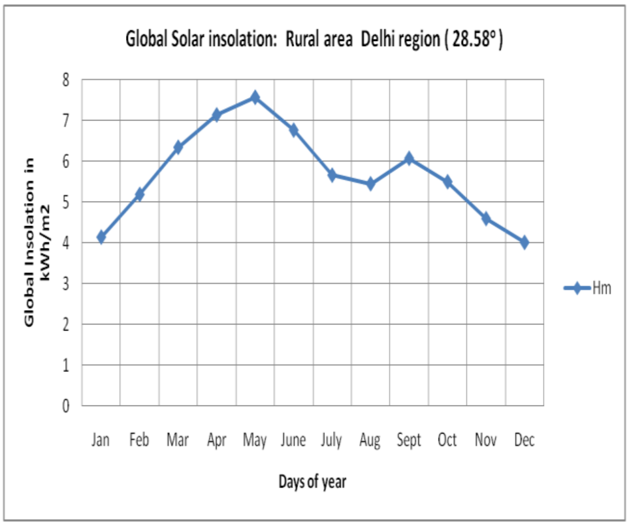

Figure 1: Global Solar Isolation

In this paper, an economic analysis is performed for realizing the advantage of the stand-alone system versus constructing a line ex-tension from the nearest existing distribution line for supplying the load with conventional power. The study suggests that different system configurations (a combination of PV module and battery capacities) can be used for different load patterns and different applications. Technological development in solar photo- voltaic technology and economic production of batteries would make rural electrification even in the isolated locations more promising and demanding.

II. RETSCREEN AND HOMER TOOLS

Renewable Energy Technologies Screen (RET Screen), software developed by the Ministry of Natural Resources, Canada, is the leading tool for facilitating the feasibility analysis of clean energy technologies. The core theme of this tool is to provide standardized and integrated project analysis software which can be used to evaluate the energy production costs, life cycle costs and GHG emission reduction for various types of proposed energy efficient [8]. An optimization computer tool that simplifies the task of evaluating design option for both grid and off-grid connected power systems is HOMER, that is used to optimize and evaluate the economic and technical feasibility of a large number of technology options and account for variation in technology costs and energy resource potential.

III. TECHNO ECONOMIC EVALUATION

The assessment of a particular energy system for its techno-economic feasibility is of utmost importance if the system has to function satisfactorily at a given location. The techno-economic feasibility assessment of a particular technology begins with evaluating the techno-logical appropriateness, economic viability and other financial incentives of a technology for it to get successfully disseminated at a given location. [3]

Load profile:-

Table2: Load profile of the Institution.

S.No.	**Load**	**Watts**	**No.**	**Hrs.**	**Total Wh**
1	CFL	10	72	4.5	3240
2	CFL	18	48	2	346
3	Fan	65	72	24-4.5 48-2	4680 1248
4	Sockets	100	10	4-2	160
5	Exhaust Fan	45	4	4-4	208
Total load	9880Wh or 9.9 kW or Say approx. 10 kW or 10 Units/ Day				

The electricity production of the most feasible system showed that higher electricity production is possible during the summer months (May-September) as compared to other months. This is a favorable characteristic of the system because this trend closely matches the load trend which is higher during the summer months.

A. Principle of PV supply system

In case of the solar PV system load profile depends upon a number of factors, viz the weather conditions, time dependency and the geographic location of PV System installation. In most of the cases amount of energy consumption is concentrated in the evening, when the lighting, TV and refrigerator etc. are working. It is expected that most of these locations will have electrical loads as shown in Table 1.It is estimated that the average daily energy consumption for the location is about 10 kWh/day or the total energy consumption per year is 3650 kWh or Units. In the areas, where the solar radiation is of appreciable magnitude, the stand-alone photovoltaic systems are becoming cost-effective for the widely scattered homes and villages in remote and rural electrification purposes with the minimum attention and maintenance (Gordon, 1987; Markvart, 1997)

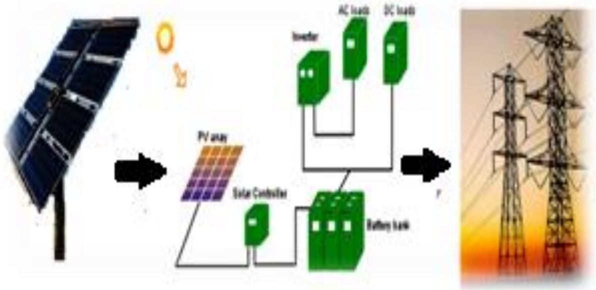

Fig 2: Solar PV Generation

The solar PV array size can be obtained successfully by using the following equation :(Ahmed, 2002; Mahmud and Ibrik, 2006; Mahmud *et al*., 1991):

$$\text{PV (Area)} = \frac{EL}{H_{av} \times \eta_{pv} \times \eta_{out} \times TCF} \quad \text{………} \quad \text{(i)}$$

Where,
E_L = the daily electricity consumption kWh/day
H_{av} = the average solar radiation kWh/m^2/day
η_{pv} = the efficiency of the module
η_{out} = the output efficiency of the system components,
$= \eta_{bat} \times \eta_{inv.}$ ($\eta_{bat} = 0.9$, $\eta_{inv.} = 0.92$)
TCF = Temperature correction factor

If the temperature of the cell is likely to reach up to 60^0 C the TCF is on the safer side as 0.8, and let the PSI-peak solar radiation for this situation as 800 W/m^2
The total electrical consumption of the system is 10Wh /day or 10 kWh/Day i.e.10 unit/day.
The area of PV array can be calculated as;

$$\text{PV (Area)} = \frac{EL}{H_{av} \times \eta_{pv} \times \eta_{out} \times TCF}$$

So the PV area is

$$= \frac{10000}{5700 \times 0.17 \times 0.9 \times 0.8 \times 0.92}$$

$$= 14.714 \text{ m}^2$$

The array area 14.714 m^2 can produce PV power as indicated;
$PV_{\text{Peak power}} = PV_{\text{area}} \times PSI \times \eta_{PV}$ Wp

$P_{pv} = 800 \times 14.714 \times 0.18 = 2118.82$ Wp

A 220W mono-crystalline PV module type is selected. According to (Al-Mehaidat, 2003; Mahmoud and Ibrik, 2006), now the number of modules needed (Npv) to meet the demand is the peak power of solar generator (Ppv) divided by the power of one module (Pm), i.e.:

$$\text{Number of modules} = \frac{Ppv}{Pm} = \frac{2118.82}{220} = 9.631 \approx 10$$

So ten numbers of modules of 24V 220W are needed to meet the load demand and to supply the site for the required energy. The modules can be assembled to give the desired voltage according to the design of the other components of the PV system and the load specifications. Stand-alone power systems often store energy generated during the day in a battery bank for use at night. The photovoltaic system is equipped with a battery bank, the storage capacity of which can be obtained.

B. Battery, size and capacity

The energy converted is required to be stored in any of the device so that it could be used at the time of necessity. There are several ways but the very common is to use the battery, a collection/group of cells in a particular fashion to suit the requirement of use.
The storage capacity of the battery can be calculated according to the following relation

$$\text{Storage capacity} = \frac{N_C \times E_L}{DOD \times \eta_{out}}$$

Where,
E_L = The Electrical load in Wh.
N_C = Number of continuous cloudy days on the site.
DOD=Permissible depth of discharge of the battery.

The possibility of largest number of continuous cloudy days $N_{C,}$ at the selected place of use, is about 2 days. Thus, for a maximum depth of discharge of the battery keeping 0.75 as the depth of discharge because the batteries have to take care of the connected electrical load to work satisfactorily during these days the storage capacity becomes

$$\text{Storage capacity} = \frac{10000 \times 2}{0.765 \times 0.75} = 34858.3878 \text{ Wh.}$$

The Ampere-hour capacity of the battery can be calculated as the DC voltage for the bus is kept 24V. There is a possibility of using the batteries of 12 V each, two in series to make 24V and number of rows to suit the requirement of the load current. The selected bus voltage is 24V, so the capacity will be
= 34858.3878/24 = 1452.433 Ah.
If the system is designed for the cloudy days when the sun shine is not available, that is the autonomy to supply the load even when no supply is generated by the PV system, the battery size is increased .Here for two days of autonomy the total Ah are designated as
Total Ah = X + nX
Where
n = The number of days of autonomy,
X = Total daily Ah requirement.
Total requirement = 1452 + (2 x 1452) = 4356 Ah.
Thus the battery size will be three times as that of the calculated one.
The total numbers of the batteries are
= (3 x 2) x 3 = 18 Nos. of 12V, 704 Ah capacity.
Generally more numbers of days of autonomy more storage capacity, more numbers of batteries and hence more cost, but results better reliability and dependability such as in the cases of medical applications a high reliability is required. The places where the reliability is not of so importance, the number of days of autonomy may even be reduced to zero reducing the overall cost of the PV system.
The battery Model Enersol 250, Exide classic 24V having normal capacity 704Ah having Maxi/EURO efficiencies as 96.0/94.0% are used. The 18 numbers of batteries having an arrangement two in series and 9 in parallel are arranged to meet the demand requirements of the cloudy day's duration.
In battery sizing some other factor like maximum depth of discharge, temperature correction, rated, battery capacity and battery life are considered (Bhuiyan and Asgar, 2003). The charge controllers are required in renewable systems to regulate the battery charge and to control the operation of the load.

C. Design of the battery charge controller

It is an inherent procedure of charging the battery if the array is being connected and exposed to sunshine, but that charging should be in a controlled and safe mode. This ideal charging will maintain longer service life and better conditions without much maintenance cost, moreover it governs the capability of carrying the short circuit current of the PV Array.[6].

D. Design of Inverter

The used inverter must be able to handle the maximum expected power of AC loads; therefore it can be selected as 20% higher than the rated power of the total AC loads that presented in Table 1. Thus the rated power of the inverter becomes 12000 W, 24 VDC, 220 VAC, and 50 Hz

The regulator and inverter with maximum efficiency and Euro efficiencies as 96.0 & 94.0 % ,the Model generic default with MPPT inverter with battery management threshold charging 27.4 & 26.3 V and discharging 23.5 & 25.2 V with back up is preferred. The dust, temperature rise will degrade the output but keeping all these factors negligible and the number of hours of sunshine in different parts of India specially in Delhi, and its surroundings ranges from 5 to 7 hours a day corresponding to 5000 to 7000 Wh/ m2/day , but having an average of 6 hrs a day. The total Amperes that would be produced, keeping 6 hrs of sunshine are 40 A. Keeping this range of current and capacity of module, let us take a module of 24 V and 220W that having 9.166 A or say 9 A per module, the number of modules required are 40/9 = 4.4 or say 5 modules are required.(the current will be 9.166*5 = 45.83 ≅ 46A. which is on the safer and convenient side and will be preferred.

Excessive discharge is avoided by monitoring the battery voltage and disconnecting the load from the battery if the voltage falls below a pre-set minimum value (Markvart, 1997). The battery charge controller is chosen to maintain a longer lifetime for the batteries (Ahmed, 2002; Mahmoud and Ibrik, 2006). For this system the required rated power of charge controller is 10000 W.. Inverters convert Direct Current (DC) voltage to Alternating Current (AC). Therefore, the input power is the DC power from the renewable energy system or battery, and the output is AC power used9 to run AC appliances or fed into the utility grid (Markvart, 197). The input of inverter has to be matched with the battery block voltage while its output should fulfill the specifications of the electric appliances.

Although different authors have quoted different prices for different PV components which seem to be on higher side according to the present market scenario, we made a market survey and concluded that the most probable cost are as follows:

Table 3. The Used Cost Data of All Items.

S.No.	**Items**	**Cost**
1	PV Array	Rs.45/W_p
2	Battery	Rs.100/Ah
3	Charger	Rs.130/A
4	Inverter	Rs12/W
5	Installation	10% of PV cost
6	M & O / Year	2% of PV cost

The LCC of the PV system includes the sum of all the present worth (PWs) of the costs of the PV Modules, storage batteries, battery charger, inverter, the cost of the installation, and the maintenance and operation cost (M&O) of the system. The details of the used cost data for all items are shown in Table **2** [7]. The lifetime N of all the items is considered to be 25 years, except that of the battery which is considered to be 5 years. Thus, an extra 4 groups of batteries (each of 2 batteries in series) have to be purchased, after 5 years, 10 years, 15 years, and 20years assuming inflation rate 'i' of 3% and a discount or interest rate 'd' of 10%. Therefore, the PWs of all the items can be calculated as follows [10]:

$$F_{\text{PW one}} = \frac{\text{Future cost}}{\text{Future value}}$$

Let there be,

Cs_1 = Cost of PV array,

Cs_2 = Initial cost of batteries,

Cs_3 = Cost of subsequent change of batteries,

The PW of the 1st extra group of batteries (purchased after N = 5 years) CB1PW can be calculated,

$$C_{B1PW} = C_B \times \left(\frac{1+i}{1+d}\right)^N$$

The PW of the 2nd extra group of batteries (purchased after N = 10 years) CB2PW and that of the 3rd extra group (purchased after N = 15 years) CB3PW are calculated.

$$ALCC = LCC \times \left[\frac{1-\left(\frac{1+i}{1+d}\right)}{1-\left(\frac{1+i}{1+d}\right)^N}\right]$$

The PW of the maintenance cost CMPW can be calculated per year (M/yr) and the lifetime of the system (N = 20 years)

$$C_{MPW} = \left({}^{M}/_{yr}\right) \times \left(\frac{1+i}{1+d}\right) \times \left[\frac{1-\left(\frac{1+i}{1+d}\right)^N}{1-\left(\frac{1+i}{1+d}\right)}\right]$$

Cs_4 = Charger cost,

Cs_5 = Inverter cost,

Cs_6 = Installation cost,

Cs_7 = Operation & Maintenance cost per year.

Total cost of the system will be,

$Cs = Cs_1 + Cs_2 + Cs_3 + Cs_4 + Cs_5 + Cs_6 + Cs_7$

$$\text{Unit. cost of electrical energy} = \frac{ALCC}{365E_L}$$

Therefore, in remote sites that are too far from the Indian power grid, the PV installers are encouraged to sell the electricity of their PV systems at a reasonable moderate price to earn a marginal profit. It is to be noted, here, that although this price is very high compared to the current unit cost of electricity in India, this price will drop down further if the future initial cost of the PV modules drops to \$0.1/W_P[13,14] .These costs drop down to 60% straight way resulting a net saving of approx.40% (subjected to market risks and not taken into consideration the benefits of earning carbon credits, environmental benefits, space savings and Govt subsidies etc, if all parameters are taken into account the value will be considerably down, which will further encourage the acceptability of the solar PV System.) At the same time, if the future unit cost of electricity in India becomes many more times its present market value, due to the rapid increase in the conventional fuel prices (as the trend approaching higher and higher, therefore PV energy generation will be promising in the future household electrification (in India) due to its expected future lower unit electricity cost, efficiency increase, and clean energy generation compared to the conventional utility grid. The lifetime N of all the items is considered, the details of cost & data of auxiliaries and accessories/items are shown in Table 2, to have their life expectancy be 25 years, except that of the battery which is considered to be 5 years. Thus, an extra 4 groups of batteries (each of 2 batteries) have to be purchased, after 5 years, 10 years,15 years, and 20 years assuming inflation rate 3% and a discount or interest rate 10%. Therefore, the present worth's (PWs) of all the items can be calculated as follows [10, 11]:

$$LCC = C_o + (O \& M)_{pv} + R_{pv}$$

Life-Cycle Costs = Total initial cost of installations
+Life cycle O & M costs +Total replacement cost.

The initial capital investment C_0 is the sum of the investments of each part of the photovoltaic system, i.e. photovoltaic array, DC/AC converter (maximum power point trackers), storage batteries, electric control and battery charger, miscellaneous (electric cables, outhouse, etc.), packaging, transportation and installation, etc. Operation and maintenance costs include taxes, insurance, maintenance, recurring costs, etc. (Kolhe *et al.*, 2002)

The life-cycle maintenance for a lifetime of N years is:

$$O \& M_{pv} = O \& M_0 \times N$$

Where $O \& M_m$ is taken as: $O \& M_0 = m (C_0)$

The battery replacement cost (R_{pv}) is mainly a function of the number of battery replacements over the System lifetime, without taking the salvage value of replaced batteries (Kolhe *et al.*, 2002).

IV. CONCLUSION

The cost of solar energy systems were analyzed, solar technologies were compared economically with conventional technologies of power generation considering present socio-economic environment to emphasize the need to supplement with and eventually replace existing power generation systems with available, abundant and inexhaustible solar energy system.. The costs of a stand-alone PV system include acquisition costs, operating costs, maintenance costs, and replacement costs. All these costs have the significance advantage, the initial capital cost of the system is high but the raw material is absolutely free, the maintenance costs are low, replacement costs are low (mainly for batteries) [7] all these factors encourage the suitability and effective use of solar system. The use can further be attractive if the best possible use of energy efficient apparatuses are preferred and the Govt, provide sufficient subsidy to encourage the consumers and young scientists to come forward for new and effective innovations in this field, though the present researches and their results inculcate the hope of solar PV system ahead.

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