TECHNO-ECONOMIC ANALYSIS OF SOLAR PV SYSTEM

Nikhil U. Kamble
Department of Mechanical Engineering,
Rajarambapu Institute of Technology,
Rajaramnagar, India.

Sharad D. Patil.
Department of Mechanical Engineering,
Rajarambapu Institute of Technology,
Rajaramnagar, India.

Abstract-

It has been largely observed that the traditional energy resources make damage to the nature. These energies are also called non nonrenewable. It is possible and easy to seek the alternative energy sources to save the environment. Solar energy, wind power, and geothermal heat can be the best alternatives.These energies are also called renewable energies.It is the solar energy that can be dominantly used at the lowest cost. The location for the Solar Power Plant is determined by solar isolation availability along with other essential factors and considerations. The solar system can be calculated in terms of panel generation factor, energy required from PV modules, total watt peak ratings,required PV modules, inverter andbattery sizing, PV modules circuit and land required. The project installation cost can be taken into consideration with the help of such important factors as module, inverter, design, engineering, management, installation labor, operation, maintenance coast,levelized cost of energy and capacity factor. The present paper is the study of the Solar Power system analysis presented with technical and economicalfeasibility to meet the load demand of 30kWh / day. The system requires 6 series arrays and 4 parallel plan 24 solar panels. The required area is 569.96 m^2. The levelized cost of energy 25 years will be 6.3327Rs. / kWh having 5% escalation.

Keywords—solar PV panel, battery,nonrenewable renewable energies, technical and economical feasibility

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I. Introduction

Most of the developing countries use coals, natural gases for electricity and other energy fields. These resources that are non-renewable expel such harmful gases as carbon-di-oxide, carbon-mono-oxide, carbon partials and NO_x. As a result this expels makes damage to the naturalenvironmental condition. It also results in global warming, acid rain, ozone layer depletion etc. In fact renewable energies are easily available. They can be used as the best alternative way to the earlier traditional resource energies in our life for long time duration without making damage to nature. These energies are renewable. They aresolar energy, wind powerand geothermal heat. The present paper is an honest attempt to focus mainly on the solar energy that can be easily used in the world in general and in India in particular.

It is the solar energy which is free to install at the initial position. It is helpful to reduce carbon dioxide and to bring in improvement in environmental balance. Renewable energy often provides power in four key areas: electricity, air and water heating or cooling, transportation and rural (off-grid) energy services.

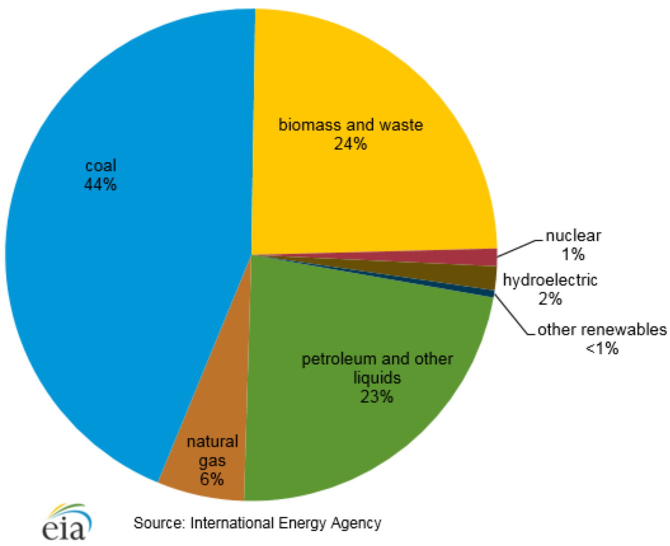

Fig. 1. Total energy consumption by india in 2013.

As shown in Figure 1, India's largest energy supply is followed by coal (44%), standard biomass and waste (24%) and petroleum and other liquids (23%). Alternative renewable fuel sources frame a tiny low portion of primary energy consumption, though the capability potential is important for many of those resources like solar, wind, and electricity. Since the start of New Policy in 1991, India's population has increasingly moved to cities, and urban households have shifted away from using traditional biomass and waste for cooking and lighting to using electricity sourced from other energy sources such as hydrocarbons, nuclear, biofuels, wind, and solar.

S. Manju, NetramaniSagar [1] observe the solar energy situation, Policies and constraints available for the development of solar energy. Also, some apps explained.BhubaneswariParidaa, S. Iniyanb, RankoGoic [2] works on various photovoltaic technologies such as silicon-based materials, thin film silicon, mono-crystalline silicon, amorphous silicon etc. The author explained where the technology has been applied.

FigenBalo and LütfüŞağbanşua [3]explain the method of selection for a solar PV panel. Parameters considered for selection process each panel has electrical, mechanical, financialand customer satisfaction capabilities to choose the most suitable panel.Diaf et al.[4] makes solar wind hybrid system suitable for generating more energy. They concluded that 40% more energy production on the high energy site after optimization and more than 20% of the energy production is at low energy sites.

Hassan Al Garni, Anjali Awasthi [5] done the techno-economic analysis using the HOMER software considering the factors such as Net Present cost, cost of energy and capital cost etc. at Saudi Arabia. ElieserTarigan et al. [6] simulated the solar power plant with the help of PVSyst and the RETScreen software. The system is designed for the small residential purpose. Authors were done the technical, economic and environmental aspect that need to design solar PV system. Hussein A. Kazem et al. [7] explains the feasibility analysis of the 1MW solar PV Power plant with grid-connected system. According to their result, the cost of the energy is 0.2258 USD/ kW h.

In present work study of Techno-economic analysis is carried for second floor of college building placed in Islampur town. The selected location includes desktop PC, fan, tube light and other accessories, which loads about 27 kW.

II. SITE SELECTION

The selected location for a Solar Power Plant is pre-dominantly determined by solar insolation availability. Equally important are other essential factors/considerations such as:

- Availability of adequate roof top space for Power Plant and green belt development
- Availability of water and power during construction
- Availability of labor force in the proximity
- Availability of load centers within vicinity
- Easy accessibility of the site

The proposed site where Power Plant is to be located is near Sangli city of Maharashtra state.

Proposed Location and Land Availability

Rajarambapu Institute of technology, Rajaramnagar (Islampur) is the Educational Site located in the Sangli District in the Maharashtra state.

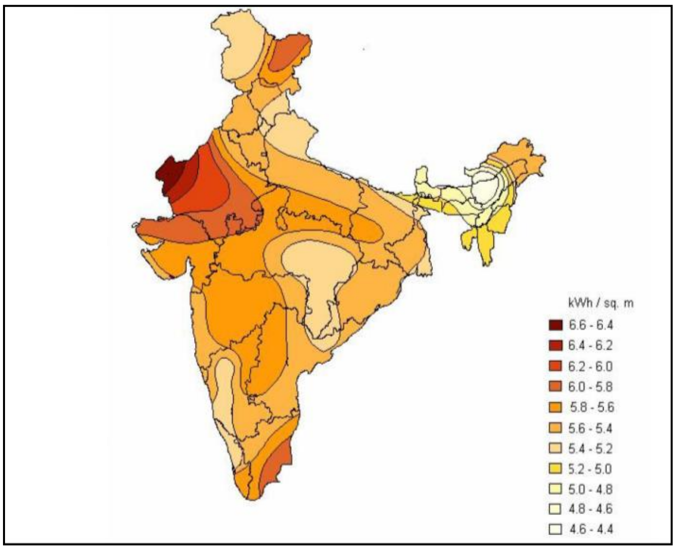

Fig. 2. Solar Irradiation for India [15]

Topographical & Geological Conditions

Rajarambapu Institute of technology is located 17.0500° N, 74.2652° E.

Building has an average elevation of 20 meters.

Electric Power

The power generated from the Power Plant will be off grid to become independent on the external power sources.

Fig 2 Implies that Irradiation level of the selected location is in the level of 5.4 to 5.6 kWh / m^2 and the following are the actual site co-ordinates.

A. *Solar irradiation and PV systems*

The location of the selected area is 17.0500° N, 74.2652° E. The annual average solar irradiation of the region is 5.39 kWh/m^2/day. The monthly average solar irradiation data (kWh/m^2/day) given in Table 1. The Data is collected from the National Renewable Energy Lab. The atmospheric cleanliness is defined by the clearness index which is found as 0.50 for the studied area. In this system, no tracking arrangements have been considered and 80% de-rating factor for each panel is taking into account due to varying effects of temperature and dust on the panels.

TABLE I. AVERAGE SOLAR IRRADIATION DATA [15]

Month	Clearness Index	Daily solar Radiations- Horizontal (kWh/m^2/day)
Jan	0.657	5.206
Feb	0.688	6.073
Mar	0.65	6.397
Apr	0.63	6.649
May	0.604	6.52
Jun	0.427	4.615
Jul	0.384	4.133
Aug	0.395	4.179
Sept	0.496	4.981
Oct	0.623	5.662
Nov	0.643	5.207
Dec	0.67	5.093
Annual Average solar irradiance		5.392917

III. SOLAR PV SYSTEM CALCULATIONS

The estimation of the required load was 27.360kW for the Building floor. This design is considered for the small size power plant for educational purpose. Solar PV Power plant is consists of PV module sizing, inverter sizing, battery sizing and module circuit design. The Methodology and the technical Specifications are given below:

A. *Panel generation factor*

Panel Generation factor is a maximum watt peak needed to meet the requirement of electricity from solar panels. The Panel generation factor calculated by using following equation (1)

$$\text{Panel generation factor} = \frac{\text{Solar irradiance} \times \text{sunshine hours}}{\text{standard test condition irradiance}} \quad (1)$$

$$= \frac{539.29 \times 8.13115}{1000} = 4.3$$

B. *Energy required from PV modules*

Energy required from PV modules can be calculated by multiplying peak energy requirement in kW h/day times 1.3 (the energy lost in the system) to get the total kW h/day which must be provided by the panels.

Peak energy requirement of the zone during the on-season period was 27.36kW h/day.

$$\text{Energy loss in the SPV system} = 30\%$$
$$\text{Energy required from PV modules} = 30 \text{ kW h/day}$$

C. Total watt peak rating for PV modules (2)

Total Watt peak rating is calculated using the energy required to be produced from the solar PV modules and the panel generation factor. It iscalculated by using equation (2).

$$\text{Total watt peak rating for PV module} = \frac{\text{Energy required from Modules}}{\text{Panel generation Factor}} = \frac{30}{4.32} = 6.944\text{kW}$$

D. PV modules

Canadian Solar CS6U-330M (330W) Solar Panels are chosen for the solar power plant. It is made up of the mono crystalline silicon material. Panel contains the 72 cell and Cost of 330w panel is 13750 INR.

E. Number of PV modules required (3)

Total numbers of PV modules required in the power plant are estimated by using equation (3)[11].

$$\text{No. of PV modules required} = \frac{\text{Total Watt peak rating}}{\text{PV Module peak rated output}} = \frac{6.944 \times 10^3}{330} = 21.042$$

F. Inverter sizing

Size of the inverter is depend on the peak watt of the requirement. Total wattage required was 30 kW. The inverter should be easy to handle. The inverter size should greater than it requires i.e. size should be 25–30% greater than the total wattage of the appliances and machines.

$$\text{Inverter size} = 30\text{Kw} \times 1.3 = 39 \text{ Kw}$$

Sukam10 kW Inverter is chosen for the solar power plant.

$$\text{No. of inverters required} = \frac{\text{Inverter size}}{\text{Rating of inverter}} = \frac{39}{10} = 3.9{\sim}4 \quad (4)$$

G. Battery sizing

For calculating the Battery capacity equation number (5) is used.

$$\text{Total battery watt hours used per day} = 27360 \text{ W h/day}$$
$$\text{Battery loss} = 15\%$$
$$\text{Depth of discharge for battery} = 40\%$$
$$\text{Nominal battery voltage} = 24 \text{ V [12]}$$

$$\text{Battery capacity} = \frac{\text{Total watt} - \text{Hours per day used by appliances} \times \text{days of autonomy}}{(0.85 \times 0.6 \times \text{Nominal Battery Voltage})} \quad (5)$$

$$\text{Battery Capacity} = \frac{27360 \times 1}{(0.85 \times 0.6 \times 24)} = 2235.29 \text{ Ah}$$

H. PV modules circuit

Maximum open circuit voltage=240 V_d
Open circuit voltage (VOC) of each PV module= 45.9 V_{dc}
Number of modules to be connected in series=240/45.9=5.22~6
Maximum power voltage of each PV module= 37.5 Vdc
Maximum power voltageat inverter input=37.5×6= 225 Vdc
Total number of PV arrays to be used for producing 225 Vdc = 21.042/6 = 3.507 ~ 4 arrays

I. Land required

Number of PV modules required=24
Dimension of one PV module = 1.96 m × 0.992 m
Number of modules in an array connected in series = 6
Total width of each PV array=6× 0.992m = 5.952 m
Length of one PV module=1.96 m
Number of arrays in PV field=4
Number of arrays in a row = 6
Width of the solar field = 6× 5.952 = 35.712 m
Number of rows in solar field= 4
Pitch distance between two arrays (including module length of 1.96 m) = 3.5 m [15]
Length of the solar field = 4 × 3.5 + 1.96 =15.96 m
Land required for PV field = 35.712 × 15.96 = 569.96 m^2
= 0.14 acres [1 acre=4047 m^2].

IV. PROJECT COST

A. Module and inverter cost

TABLE II. COST OF SYSTEM

Sr. No.	Name	No. of Units	Cost(₹)/unit	Total cost(₹)
1	Solar PV Panel	24	15371	368904
2	Battery	15	13750	206250
3	Inverter	4	79826	319304
	Total Cost			894458

B. Design engineering and management cost

Labor cost for design, engineering and project management = Rs. 200/man-hour
Design, engineering and project management hours per kWp = 2 h
Total design, engineering and project management cost for 30 kW = 12000 INR

C. Installation labor cost

Labor cost for installation = Rs. 50/man-hour
Installation man-hour required for per kWp = 12 h
Total labor cost for installation of 30kW PV power plant = 18000 INR

D. Operation and maintenance cost(O & M cost)

Fixed O and M cost = INR 980.76/kW h

E. Capacity factor

Capacity factor is a key driver of the solar PV plant's economics. Majority of the expenses for a PV power plant are fixed in nature and levelized cost of energy is used to correlate the utilization of the power plant.

$$\text{CF} = \frac{\text{Annual kilowatt hour generated for each kilowatt AC peak capacity}}{8760 \text{ hours in year}} \quad (6)$$

Energy required to be generated from the plant = 27.36 kW h/day

Annual energy to be generated from the plant = 27.36 × 365 = 9986.4 kW h
Peak capacity requirement of the PV plant = 6.994 kWp

Find the capacity factor using equation (6).

$$\mathrm{CF} = \frac{9986.4/6.944}{8760} = 16.47\ \%$$

F. Levelized cost of energy

The Levelized Cost of Energy (LCOE) is the cost which is paid by the consumers to the investors to repay the capital, O&M and fuel costs with a rate of return equal to the discount rate. For this Solar Photovoltaic power plant LCOE are Rs. 6.33270/kW h, taking the 25 year life of the power plant @ 5% escalator.

TABLE III. LEVELIZED COST OF ENERGY

Escalator	5%
20 Years	5.55681
25 Years	6.33270

V. Comparison between Different Loads

Designing the system at the different load and resultsare given in Table IV.

TABLE IV. DESIGN OF SYSTEMS AT DIFFERENT LOADS

Parameters	System Load			
	26.26 kW	60 kW	90 kW	120kW
Panel generation factor	4.32	4.32	4.32	4.32
Energy Required from PV panel (kWh/ Day)	30	78	117	156
Total peak rating of PV Module (kW)	6.944	18.06	27.08	36.11
No. of PV Modules required	21.3	54.73	82.06	109.42
Inverter size	4	11	16	21
Battery size in Ah (autonomy for 1Day)	2235.29	4901.96	7352.92	9803.92
No. of modules connected in series	6	6	6	6
No. of array to be used	4	10	14	19
No. of PV panel requirement	24	60	84	114
Area required (m^2)	569.96	1319.91	1819.88	2444.84
Total project cost (Rs.)	894458	2254096	3255880	4336140
Total Design and management cost (Rs.)	12000	24000	36000	72000
Total Labor cost (Rs.)	18000	36000	54000	72000
O & M Cost (Rs.)	980.76	1127	1086.26	1084
Levelized cost of energy at 5% Escalator	6.3327	6.25618	6.0208	6.01676

The number of panels required for 26.26 kW, 60 kW, 90 kW and 120 kW load are 21.3, 54.73, 82.06 and 109.42. For the same load, actual number of solar panels required are 24, 60, 84 and 114 by series and parallel combination. From the results obtained the levelizedcostsof energy decrease as system size increases.

VI. Conclusion

Technical and financial analysis has done in this paper.To meet the demand it requires the 24 panel (i.e. 6 series and 4 parallel configuration), 4 inverters of 10kW capacity and battery capacity required is 2235.29 Ah and area requirement is 569.96 m^2.The system can generate 9986.4 kW h electricity in 1st year with capacity factor of 16.47%. And theLevelized cost of energy for 25 years will be 6.3327 Rs. / kWh having 10% escalator.

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