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Case Study of Solar Photovoltaic Power Plant in PES Campus Shivamogga- A: Analysis of Technology and Cost

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Abstract

As the market for solar power is relatively, it is not understood completely. The technology providers for solar power generation are limited, and access to technical data is quite restricted. Before any technology could be implemented on a large scale, there is a need to analyze the energy impact. In this paper, the reanalysis of the cost effectiveness of using solar photovoltaic power plant to meet the energy demands of PES campus in Shivamogga is presented. Levelized cost of energy is calculated with a plant life of 25 years.

Keywords: *Power Generation, Technology, Energy, Demand, Solar Power.*

INTRODUCTION

The energy demand of the campus has been estimated(159kW)and the design of the solar photovoltaic power plant of 200 kW capacities has been proposed which requires about 1.85 acres of land area. Looking at the available roof top area, the onsite rooftop plant has been proposed. Levelized cost of energy was found to be Rs 5.69 per kWh for onsite solar power plant, considering 25 years of plant life @10% discount rate, with simple payback period of 15 years. The development of renewable energy sources (RES) is necessary for the sustainable development of any country due to depleting fossil fuel level, climbing fossil fuel prices across the world and more recently pressure for reduction emission level. Among various renewable energy sources based technologies, the solar photovoltaic technology (PV) for power generation is considered well-suited technology particularly for distributed power generation. The large introduction of PV systems may replace or postpone the extension of conventional central stations of electricity production and the

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investment in grid reinforcement having a positive overall economic impact. The PV system electric power is of particular value when it coincides with the peak demand, as during the summer afternoon peak due to the use of air conditioning units. In addition to this, solar photovoltaic (PV) systems can also increase the reliability of the system to which they are connected, can also reduce transmission and distribution losses as they generate the electricity close to the point where it is consumed.

PV systems are designed and sized to meet a given load requirement. PV system sizing exercise involves the determination of the size and capacity of various components, like PV panels, inverter, batteries, etc. PV system design also involves a decision on which configuration is to be adopted to meet the load requirement. Once the system configuration is decide then the size or capacity of the various components are calculated. A low quality component (charge controller, for instance) may be cheaper initially but probably will be less efficient and may not last longer. On the other hand, a relatively expensive but higher quality component is more likely to perform better(saving energy and thus cost) and may be able to recover its cost in the longrun. Most parts of India receive solar energy of 5Kwh/m2 per day over 280 clear days per annum. Even if 1% of this land is used to harness solar energy at an overall efficiency of 10%, as much as 429 × 109 KWh/year of electricity can be generated. One of the states of India, Karnataka is rich in solar resources and solar energy will complement the conventional sources of energy in a large way .The state of Karnataka is blessed with about 240 to 300 sunny days with good solar radiation of 5.4 to 6.2 KWh/m2/day . To harness the potential of solar resources in the state, Government of Karnataka had issued a solar policy for the period2014–2021withtheobjectiveto achieve 3% contribution from solar source out of total energy consumption. All solar power projects (solar PV and solar thermal) established in the state of Karnataka shall be eligible for benefits under the policy. The different projects applicable under this policy are:

- Grid connects utility scale projects.
- Grid connects roof top projects.
- Off grid projects.

In grid connect roof top project, all residential/institutional/commercial/government building owners, industrial units are eligible to set up solar power plant within the prescribed capacity limit.

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The solar market for power generation is still relatively new and not completely understood. There are a limited number of technology providers and access to technical data is restricted. There is a need to analyze the energy impact of these systems before large scale implementation of the technology. In the ongoing work the potential and the cost-effectiveness of a solar photovoltaic power plant for meeting the energy demand of PES campus, one of the educational institutions situated near Shivamogga (Karnataka) was analyzed. PES campus comprises of seven blocks of buildings. Electricity is needed for lighting gadgets, fan and air conditioners and to run various equipments and machineries.

These days getting a continuous and uninterrupted supply of energy has become the largest problem for institution. The backup diesel generators have a very high operation cost and are not a clean source of energy either. So there is great need for a sustainable and clean source of energy. Solar energy is the largest available carbon-neutral renewable energy source which can meet the energy demand of institution.

LITERATURE SURVEY

A 5MW SPV power plant was designed for 50cities of Iran, using RET Screen software and the highest capacity factor was found at Blusher and lower at Anal, i.e., 26.1% and 16.5% respectively with a mean capacity factor of 22.27% [1]. A computer program was designed for quick evaluation and optimization of fuel saving, battery life time, investment costs and the total annual cost of the project or a 35kW hybrid PV-diesel power plant along with the feasibility study under climatic conditions of southern Algeria [2].

A viability analysis of a 10 MW PV-grid connected power plant taking 29 metrological sites in Egypt was carried out [3]. Renewable energy production and capacity factor was found to be minimum at Savage and maximum at What Charge, i.e.,24.202GWh/year,27.6%and 29.493GWh/year, 33.7%, respectively. Another viability analysis was conducted to find the option of PV power plant in the Gulf Corporation Council(GCC) countries and study showed that the at present PV technology is not a cost-effective option for the GCC countries because of existing lower electricity tariff, higher PV system cost and lower system efficiency [4]. A solar power plant situated in the Kingdom of Bahrain produced 12MW (32 kW per

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day) from PV panels installed at the windows and roofs of two buildings along with annual CO2reductionof48,000t and revenue generationof€4,800,000annually [5].

Studies were conducted in Serbia to find out possibilities of generating electrical energy through 1MW PV power plants by taking different types of solar PV modules available and it was concluded that higher electricity is generated using Cite solar modules [6]. Researchers developed a computer software tool which integrates different types of PV power plants parameters into a single system to verify/compare the performance and dynamic behavior of other researchers' experimental, theoretical and simulation work for PV power plants [5, 6]. In one study a modular approach was adopted to meet the energy demand of six majorcities in India up to year 2025 and solar PV electricity was suggested as the viable solution for meeting future energy demands [7]. Other studies also found solar PV system as a reliable substitute to be considered in the Indian process industries, particularly in the garment industry [8, 9]. A 2.5 MW capacity solar PV power plant has been proposed to meet the energy demand of stature industrial area Raipur Rajasthan and a capacity factor of 35.23% were found [10].

OBJECTIVES

In the present work the potential and the cost-effectiveness of a solar photovoltaic power plant for meeting the energy demand of PES campus, one of the educational institutions situated near Shivamogga (Karnataka) was analyzed. The main objectives of the proposed work were:

- To conduct questionnaire based survey during the specified study period for energy demand estimation at the PES campus.
- To design a suitable rated photovoltaic power plant which consists PV modulesizing, Inverter sizing, battery sizing and module circuit design.
- To estimate the total cost of the installation.
- To carry out Economic feasibility analysis.

SOLUTION METHODOLOGY

The solution methodology includes:

Energy Demand in PES Campus

A questionnaire based survey was conducted during specified study period for energy demand estimation in PES campus. The questionnaire comprised of

$$\text{Total Watt peak rating for PV modules} = \frac{\text{Energy required from PV modules}}{\text{Panel generation factor}}$$

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the monthly energy demand in terms of heat and power for each electrical installations, number of different type of machines, their energy consumption and duration of operation, etc.

Design of Solar Photovoltaic Power Plant

The design methodology and technical specifications of the PV power plant are;

- **Panel Generation Factor**

Panel generation factor (PGF) is a key element in the size determination of solar photo voltaic cells on the basis of total watt peak rating and then for estimating the number of panels required for a particular SPV plant, which varies with the solar intensity and sunshine period of the site

$$\text{Panel generation factor} = \frac{\text{solar irradiance} \times \text{sunshine hours}}{\text{standard test conditions irradiance}}$$

- **Energy Required from PV Modules**

Energy required from PV modules can be calculated by multiplying peak energy

$$\textbf{Number of Inverters reqired} = \frac{\textbf{Inverter size}}{\textbf{Rating of Inverter}}$$

requirement in kWh/day times 1.3(considering 30% energy loss in the system) to get the total kWh/day which must be provided by the panels. Energy lost in the SPV system = 30% Energy required from PV modules = 1.3 X kWh/day.

- **Total Watt Peak Rating for PV Modules**

Total Watt peak rating is calculated using the energy required to be produced from the solar PV modules and the panel generation factor.

- **Number of PV Modules Required**

Total numbers of PV modules required in the power plant are estimated by using the

$$\text{Number of PV modules required} = \frac{\text{Total Watt peak rating}}{\text{PV module peak rated output}}$$

total watt peak rating required and the PV module peak rated output.

- **Inverter Sizing**

Size of the inverte used in PVpowerplant depends on the total peak watts requirement. The inverter must be large enough to handle the total peak watt requirement of the zone at any time. The inverter size should be 25–30% bigger than the total wattage of the appliances and machines.

- **Battery Sizing**

Considering battery loss of 10% and depth of battery discharge of 80%,

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$$\text{Battery Capacity(Ah)} = \frac{\frac{\text{Total watt-hours per day}}{\text{used by appliances}} \times \text{Days of autonamy}}{0.9 \times 0.2 \times \text{Nominal battery voltage}}$$

- **PV Modules Circuit**

Number of PV modules to be connected in series= (Maximum open circuit voltage of the system) / (Open circuit voltage of each PV module) Total number of PV arrays to be used=(Number of PV modules)/ (Number of PV modules to be connected in series)

- **Area Required**

Total width of each PV array=(Number of PV modules to be connected in series) X (Width of one PV module) Width of the solar field= (Number of PV modules to be connected in series) X(Total width of each PV array) Number of rows in solar field= (Total number of PV arrays to be used) /(Number of PV modules to be connected in series)

Length of the solar field= [(Number of rows in solar field – 1) X (Pitch distance between two arrays)] + [Length of one PV module] Area required= (Length of the solar field) X (Width of the solar field)

Installation Cost

For the purpose of analysis, installation cost is classified into module and inverter cost, design engineering and management cost, installation labor cost and operation and maintenance cost.

Economic Feasibility Analysis

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 level zed cost of energy is used to correlate the utilization of the power plant.

Capacity Factor(CF)

CF = (Annual kilowatt hours generated for each kilowatt AC peak capacity) /(Number of hours in a year)

Levelized Cost of Energy (LCOE): LCOE is equivalent to the average price consumers would have to pay to exactly repay the invest or forth capital, O&M and fuel costs with aerate of return equal to the discountrate. In addition present worth analysis is to be carried out to determine payback period.

CASESTUDYANDRESULTS

In the present study the potential and the cost-effectiveness of a solar photovoltaic power plant for meeting the energy demand of PES campus, one of the educational institutions situated near Shivamogga (Karnataka) was analyzed.

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The PES Campus comprises of various departments of engineering, management studies, polytechnic and public school. The engineering departments consumes much of the load so as to run various equipments and machineries including 3-phase and 1-phase induction machines, Lathe machines, drilling machines, universal testing machines etc. and electricity is required to provide lightning to the whole campus.

QUESTION NAIRE BASEDS URVEY

Based on the survey conducted during the 3 months of study period the Energy demand in the campus is determined which is shown in Table 1.

Solar Irradiance

From the prospective of design consideration of the solar Photovoltaic power plant, the solar irradiance available during different seasons in the study area has to be known. As per the data obtained from "Centre for Ecological Sciences, Application of Science and Technology to Rural Areas (ASTRA), Indian Institute of Science, Bangalore, India" the average solar irradiations available during different seasons are at shivamogga is tabulated in Table 2.

Table 1: Energy Demand in Campus.

Month	kWh Consumed	Average kWh/month	Average kWh/day
January	2143	63913.2	2130.44
February	2025		
March	2223		

Table 2: Solar Irradiance Data.

Seasons in a Year	Solar Irradiance in w/m^2
Summer	604–624
Monsoon	435–492
Winter	503–530
Average	531

Design of Solar Photovoltaic Power Plant

Panel generation factor=
(531*9.32)/1000=4.94

Energy required from PV modules:
1.3X2130.44=2769.57kWh/day

Total Watt peak rating for PV modules= (2769.57)/4.94= 560.64

Number of PV modules required=
(560.64*1000)/180= 3115(app.)

Number of inverters required=
(200*1.3)/100=3(app.)

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Battery Capacity(Ah)= (2130*1000*1)/(0.9*0.2*12)=986111Ah

Number of batteries required =

986111/1500=657

Maximum open circuit voltage=

System voltage–VadjVadj=VocX

{(100%+(Tmod–250)XTcVoc)}=

44.97X{(100%+(-30-250)X-0.117)}=

192VdcMaximum system voltage =

1000 Vic

Maximum open circuit voltage=1000-192 = 808Vdc

Open circuit voltage of each PV module =44.97V

Number of PV modules to be connected in series = (808/44.97) =17.96 ~ 18

Total number of PV arrays to be used= (3115/18)=173 arrays

Area required:

Number of PV Modules required = 3115 Dimensionof1PVModule=1.58X0.809 m

Number of modules in an array connected in series = 18

Number of arraysm in PV field=173

Number of arrays in a row = 18

Total width of each PV array=18X0.809 =14.56m

Width of the solar field= 18 X 14.56 = 262.08m

Number of rows in solar field=(173/18)= 9.61 ~ 10

Length of the solar field=[(10 -1) X (3)] + [1.58] = 28.58m

Area required= (28.58 X 262.08) = 7490.24m2 (7490.24m2 = 1.85 acre)

Total Cost of Project Module, inverter and battery cost Cost of each PV module = 7097 Rs

Number of PV modules required = 3115

Total cost of PV module = 3115 X 7097 = 2, 21, 07,155 Rs

Inverter cost (100kw each, 3 numbers)

Cost of one inverter = 38160 Rs

Total cost of inverter = 38160 X 3 = 1, 14,480 Rs Battery cost (12v, 1500Ah)

Total number of batteries required = 657

Cost of one battery = 9540 Rs

Total cost of batteries = 9540 X 657 = 62, 67,780 Rs

Total cost of Module, Inverter and Battery =2, 84, 89,415 Rs

Design Engineering and Management Cost

Labor cost for design, engineering and project management = 200 Rs/man-hour.

Design, engineering and project management hours per kWp = 2 Hours= 200 X 103 kip X 2 = 400 kip hours Total design engineering and management cost = 400 X 200 = 80, 000 Rs Installation Labour Cost Labour cost for installation= Rs 50/man-hour.

Installation man-hour required per kip = 12 Hours.

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Totallabourcostforinstallationof200kW PV power plants=200X12X50=1,
20,000 Rs

Operation and Maintenance Cost Fixed operation and maintenance cost =5480000 Rs/MHz

Fixed operation and maintenance cost= 5480000 X 0.200 MHz = 10, 96, 000 Rs.

Variable operation and maintenance cost= 4950000 Rs/MHz

Variable operation and maintenance cost= 4950000 X 0.200MWh = 9, 90, 000 Rs.

Total O &M cost = 20, 86, 000Rs.

Total Project cost of PV power plant of 200 kW capacity=3, 07, 75, 415

Economic Feasibility Analysis Capacity Factor

Energy required to be generated from the plant = 2130.44 kHz/day

Annual energy to be generated from the plant=2130.44x365=0.7776106x106
kHz

Peak capacity requirement of the Volant
=0.200x103kwhCapacityfactor=
(0.777610 *106/0.200*103)/8760=0.4438
=44.38%

Levelized Cost of Energy (LCOE)

Levelized cost of energy is equivalent to the average price consumers would haveto pay to exactly repay the investor for the capital, operation and maintenance and fuel costs with a rate of return equal to discount rate. For this SPV power plant LCOE is Rs 5.69/kWh for the plant life of 25 years and at a discount rate of 10%.

Present Worth Analysis

The present worth analysis for the proposed project is carried out by using Mi-power simulation package. The result of present worth analysis is shown in Table4.

Table-4

Interest Charges	12.0 %
O and M Charges	0.0 %
Project Life	15 Years
Capital Investment	30775415
Unit Charge	6.00Rs /kWh
Annual Expenses	0
Present Worth of Annual Expenses	0
Present Worth of Cash Outflow	30775415
Annual Saving in Energy	777610.6 kWh
Cost of energy	4665666
saving	
Present Worth of Cash Inflow	31777218
Net Present Worth	708918
Net Benefit	31777218
Benefit to Investment Ratio	1.023
Project is Feasible	

CONCLUSION

Study has been carried out to assess the technical feasibility and economic viability of a 200 kW capacity solar photovoltaic power plant for meeting the energy demand of PES campus, Shivamogga

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considering on-site options. For this power generation total 3115 PV modules are required with 18 modules in each row. Three inverters with MPPT controller of 300kWcapacityandbatterybankof9,86, 111 Ah are required to supply the power and the total land area required is 1.85 acres. The power plant can generate 1.12GWh electricity in first year at44.38% plantcapacityfactor.After25years,consideringcumulative degradation of 11.01%,electricitygenerationfromthe plantwillbei.e.,0.996GWhLevelised cost of energy (LCOE) is Rs.5.69 per kWh for on-site, considering 25years of plant life @ 10%d iscount rate at a simple payback period of 15 years.

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