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Fully solar powered Raja Bhoj International Airport: A feasibility study ☆

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ABSTRACT

The atmospheric concentration of carbon dioxide (CO_2) has been increasing and it remained above 400 ppm throughout the year 2016 for the first time. The aviation industry is a main contributor towards green house gas emission. In this regard, aviation industry as a whole and airports in particular are trying to limit their carbon foot print. A feasible solution is to substitute the conventional electricity energy consumption of airport with clean energy sources. Solar PV route is considered as non polluting source of electricity but MW scale plant requires more land area. Since vast areas are mandatory in airport as buffer zones, this land can be effectively used for utility scale solar PV plant. A 2 MWp onsite solar PV power plant is proposed for Raj Bhoj International Airport (RBIA), India. An online PV simulation tool SISIFO, developed by Universidad Politécnica de Madrid (UPM), has been used to analyse the performance of the proposed plant. The PV module rating, inverter and transformer specifications etc. are provided as per manufacturer's datasheet. The plant is capable of generating 2733.122 MWh of electrical energy annually. The monthly averaged energy yield and performance ratio (PR) are 113.88 kWh/kWp and 85.54% respectively, which are best when compared to similar utility scale PV power plants. The economic and environmental benefits of the proposed plant are also discussed. The PV plant generation capacity can surpass the daily electrical energy consumption of airport. This paves way for RBIA to become second airport in the world to be energy self sufficient through solar power.

1. Introduction

The aviation industry is a major contributor towards greenhouse gases emission. The increase in concentration of green house gases is the main cause of global warming and climate change [1]. In aviation industry, airports are meant to be an interface between land and airside operations [2]. Normally vast and open areas of land are acquired for the construction of airports. Evacuation and preparation of land for airport definitely have environmental and ecological impact. Airports are energy intensive as the buildings on these lands are large, tall and air conditioned. Now it is seen that metropolis is being developed around airport premises. Usually the electrical energy requirement in any airport is met through conventional sources of energy, which are polluting [3].

Considering all these aspects, many airports around the world are trying to reduce its carbon footprint. Using power generated from renewable energy sources, the airports can indirectly reduce its pollution index [4]. Solar PV installed near the airport premises seems to be very successful in decreasing airport ground emissions [5]. The amount of power that can be generated by solar depends on the available area. Land area required for MW scale solar plant should be vast, shade free as well as low cost irrespective of solar irradiation. Though the efficiency of solar PV plant is low, the source of energy (sun) is freely available [6]. Airports have mandatory free spaces termed as sound buffer zone, which are ideal location for solar power plant. The 12 MWp grid connected solar power plant in Cochin International Airport has successfully completed its one year of operation. This airport has become energy neutral through this way. Similarly airports in Hyderabad, Kolkata and Calicut are using solar PV power for their daily operation [7].

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Birol Kilkis studied the connection between terminal buildings and landside and airside airport operations in terms of energy consumption. This paper analyses the sustainability of a new airport in the city of Istanbul in terms of CO_2 emission [8]. San Kilkis and Siir Kilkis developed Sustainability Ranking Index (SRI) for airports and included energy consumption as one of its dimension [9]. These measures will help airport authorities to incorporate sustainable practices in airports all over the world. Tullio et al. analysed the past energy consumption and framed an energy management system for the Leonardo da Vinci International Airport, Rome [10]. Solar power can be utilised to make airports sustainable. But the performance of solar PV plants in airports is to be analysed. Shivakumar and Sudhakar computed the performance of 10 MWp grid connected solar PV system in Ramagundam, India using the data obtained from site. The so obtained performance values were compared with values predicted using popular commercial PV softwares, PVSyst and SolarGis. The plant is operating with an average performance ratio (PR) of 86.12% and Capacity Utilisation Factor (CUF) of 17.68% and the annual energy generation was 15,798.192 MWh for the observed period of one year. Also the plant was operating at values nearer to the predicted values from PV simulation softwares [11]. Sundaram and Babu presented the annual performance analysis of 5 MWp grid connected photovoltaic plant, Sivagangai district in Tamilnadu, India with the monitored results. Annual average daily final yield was 4.810 h/day with an overall system efficiency of 5.08% was obtained. Performance comparison of present system with other grid connected PV system was also included in this paper [12]. Padmavathi and Arul Daniel analysed the performance of a 3 MW grid connected SPV plant, Karnataka, India using monitored data for year 2011. The plant was having good Capacity Utillisation Factor (CUF) value but it was influenced by peak load [13]. Rohith Goura studied the design and performance of a 1 MW grid tied solar PV plant after monitoring over a span of one year. The performance ratio of plant is found to be 77% [14]. Verma and Singhal studied various parameters that affect the performance of SPV plant and methods to optimise the power generation. A case study of 20 MW Solar PV Project in Gujarat, India to analyse and quantify the losses that can occur in a grid connected PV system was done. The variation in losses measured on actual site and that predicted by PVSyst software was negligible [15]. Sidi et al. analysed and compared the performance of two arrays (a-Si and μa-Si) of 15 MWp solar PV plant in Nouakchott, Mauritiana. PV plant exhibited performance seasonality among the sunniest and colder months over the recorded period [16]. All the above papers mentioned the design and layout of large scale power solar PV plants in India as well as rest of the world. Carrillo et al. describes SISIFO as a tool which uses parameters described by manufacturer as the input and provides energy yield, breakdown losses and financial analysis of solar PV plants [17]. Travis et al. calculated the Bird Hazard Index (BHI) for solar PV arrays located near to or on airport sites and found that PV arrays does not influence bird hazards [18]. Wybo analysed the safety issues on view of installation of large scale PV systems near to airport and also suggests remedial measures [19].

This paper is an attempt to study the effectiveness of MW scale solar farm at airport site using SISIFO PV simulation tool. In this paper, a utility scale grid connected solar PV system is proposed for Raja Bhoj airport. The performance of this proposed solar power plant is analysed using SISIFO analysis tool, in terms of monthly energy generation, performance ratio (PR), Capacity Utilisation Factor (CUF) etc. The feasible locations and the plant design have been identified. The economic burden and environmental benefits of proposed MW scale solar PV plant are also discussed.

2. Methodology

2.1. Geographical location of the site

Raja Bhoj International Airport (RBIA) is one of the busiest international airports in the state of Madhya Pradesh (MP) and spread over an area of 400 acres (Fig. 1). It is located in Gandhi Nagar area which lies 15 km (9.3 mi) north-west of Bhopal city centre on National Highway 12. Ample amount of solar insolation falls on these areas due to its closeness to equator. The latitude and longitude of airport site are at 23.29°N and 77.33°E. The average annual electricity consumption of the airport is about 3.6 million units which is equivalent to 10,000 per units per day [20].

2.2. Utility scale solar PV plant design

A grid connected solar PV plant mainly consists of

- Large number of arrays of solar PV modules: Convert solar energy into DC power
- Inverters: Convert DC power output into AC form
- Power transformers: Step up low voltage AC into high voltage for efficient transmission through grid

Along with these components, string combiner box is used for connecting a number of solar module arrays, switch gears used for transfer and control of power, bidirectional energy meters for calculating the net electrical energy evacuated to the grid. Some PV power plants employ Maximum Power Point Tracking (MPPT) separately to gain more energy out of sun. The overall system losses and maintenance are less in grid connected system as energy storage devices are absent.

The building blocks of a solar PV power plant are photovoltaic modules. Usually polycrystalline Si modules are used in large scale PV power plants due to its low cost and long life time (25 years). Metal structures are used to keep the solar modules in proper orientation and inclination so that maximum solar radiation may fall on the surface. Fixed tilt system is preferred for MW scale solar power plant because of its decreased economic and maintenance cost [11]. For a fixed tilt system, modules are inclined to the earth's latitude and oriented towards south [21]. The installed capacity (P) in kW of solar power plant on the basis of load requirement is calculated using the equation given below:

$$P = E_d/(H_s * E_s)$$

$$E_d = \text{daily energy requirement in kWh}$$

$$H_s = \text{average sunshine hours}$$

$$E_s = \text{system efficiency, taken as 80\%}$$

The number of PV modules required is found by dividing installed capacity (P) by peak rating of module. Since a MW scale solar plant consists of modules in the order of thousand, these are serially connected together to form a string which in turn is connected parallel to the input of inverter. String combiner box is used to connect a number of strings together. The number of modules per string depends on the maximum DC input voltage of inverter.

Inverters play an important role in grid connected solar PV system. Inverters are selected in such a way that its power rating

Fig. 1. Raja Bhoj Airport area.

is less than or equal to the rated PV output [22]. Nowadays inverters are designed exclusively for solar power plants. Inverters must have higher efficiency (98.0% or higher), lower current harmonics distortion (3% or lower) and must follow IEC 61683 standard [14]. The inverter must be able to detect ground fault detection and interruption. The inverter shall be provided with inbuilt MPPT and suitably rated air circuit breaker. The AC output of the inverter shall be purely sinusoidal (3 phase) of 50 Hz frequency. The inverter output is connected to electricity grid through step up transformer so that the energy generated can be fed into high voltage electricity grid. The three phase transformers shall be provided with bushings, undercarriage, current transformers, instrumentation, valves, piping, mounting plates, cable trays etc. The transformer rating depends upon the number of inverter used and its rating. Usually transformers are having high efficiency as it works on the principle of mutual induction. The energy generated is evacuated to nearby grid. Cable system is required for transfer of power from PV modules to grid through power conditioning system. XLPE power cables of different gauges are used depending on the voltage capacity. Usually 33/11 kV grade XLPE cables are used for connecting the transformer output and electric grid.

An integrated weather monitoring station is placed near the PV power plant for recording the solar irradiation data, wind speed, ambient temperature, humidity and rainfall [23]. A data logger server saves the solar irradiance, voltage, current and power at input and output of each inverter as well as wind speed and module temperature at regular interval. The values are recorded at a time interval between 1 min and 10 min as per the monitoring guidelines. The monitoring of the proposed solar PV power plant is important to analyse its proper operation. Usually Supervisory Control and Data Acquisition (SCADA) is employed for this purpose and it meets the guideline of IEC 61724. This monitoring system is capable of analysing the meteorological and electrical parameters such as Global irradiance, cell and ambient temperature, wind speed, DC voltage for PV arrays, DC current and DC power from PV, energy fed to grid and taken from grid etc.

2.3. Simulation using PV SISIFO tool

SISIFO is an open source, freely available design and simulation tool for grid connected PV system, developed by the Universidad Politécnica de Madrid (UPM). It provides the energy yield, analysis and breakdown of energy losses, as well as estimations of financial returns [24]. The step wise use of SISIFO is given below

Step 1: Site details: This software requires latitude, longitude and altitude of the site for resource calculation. These values can be given using virtual map tool.

Step 2: Meteorological data: SISIFO requires mean daily irradiation (Wh/m^2) and maximum and minimum daily ambient temperature (°C) for input solar energy calculation. These values can be given either manually or using PVGis softwares. The model considers three sky models – mean, clear and clear/cloudy.

Step 3: Models and algorithm: Once the weather data have been generated, the type of solar PV modules and static PV generators (on ground, roof or façade) are to be chosen. It also has option of solar trackers with the possibility of the backtracking mode of operation. It also considers the incident radiation on the plane of the PV generator and the impact of the angle-of-incidence, soiling, self-shading and solar spectrum. The technical parameters regarding the PV generators and inverters, provided by the manufacturers (datasheets), can be also included. There is an option to shift between basic and advanced simulation options depending on the technical expertise. Advanced options allow the selection of models to be used in the sequence of algorithms.

Step 3: Economics (optional): At first, SISIFO calculates the yearly incomes related to the simulated annual electricity production during the project lifetime, according to the indicated feed-in tariff. Secondly, the annual operating expenses, payment of the loan capital, interests, and annual cash flows are found. Finally, it evaluates the Levelised Cost of Electricity (LCOE), by considering the previously calculated global energy production and the overall expenses.

Step 4: Simulation: SISIFO analyses the times series of all the simulated variables that are integrated for obtaining and displaying daily, monthly and annual performance parameters (irradiations, electricity production, performance ratios, etc.).

Besides, SISIFO may provide a basic project finance analysis as well as generate a technical simulation report.

2.4. Performance parameters

Many parameters are used to define the overall system performance with respect to the energy production, solar resource and system losses. The performance parameters have been developed by International Energy Agency (IEA) for analysing the performance of solar PV grid interconnected system [14]. Energy quantities are evaluated and normalised to rated array power and are referred to as yields. System efficiencies are normalised to array area. The normalised performance indices allow us to readily compare PV systems of different configurations and at different locations. Yields indicate the actual array operation relative to its rated capacity. The significant among them are the following:

Energy generated (Eac): It is defined as the total value of AC power fed into grid daily/monthly or yearly and measured across the inverter output terminals by data logger for specific time interval (1 min/5 min) [15]. The energy generated by the PV system will be more than energy across the inverter output terminals for every minute. The energy generated by a PV system daily (Eac,d) and monthly (Eac,m) are given by

$$\mathrm{Eac,d} = \sum_{t=1}^{t=Trp} \mathrm{Vac} * \mathrm{Iac} * \mathrm{Tr} \tag{1}$$

$$\mathrm{Eac,m} = \sum_{d=1}^{d=N} \mathrm{Eac,d} \tag{2}$$

Vac – instantaneous AC voltage
Iac – instantaneous AC current
Tr – time interval

Energy yield (Y_e): It is defined as the net AC energy output of the system generated daily (annual, monthly) divided by the peak power of the installed PV array (Po) at STC of 1000 W/m^2 solar irradiance and 25 °C cell temperature. It indicates the number of hours of operation of the array required per day at its rated capacity to equal its monitored daily useful energy. Its units are kWh/kWp day.

$$Y_{e,day} = E_{ac,d}/Po \tag{3}$$

Performance ratio (PR): The performance ratio indicates the effect of losses on the power output of a PV power plant during DC to AC conversion [16]. The performance ratio is defined as the ratio of final yield (Yf) and reference yield (Yr) and quantifies the overall effect of losses on the rated output [25]. The PR, usually expressed as a percentage, is useful in comparing PV systems independent of its installed capacity and location. It can also be calculated as the ratio of AC output in kWh and DC output from PV array.

$$\mathrm{PR} = \mathrm{Yf}/\mathrm{Yr}$$

or

$$\mathrm{PR} = \mathrm{Eac}/(\mathrm{A} * \eta_{\mathrm{PV}} * \mathrm{Ht}) \tag{4}$$

A – area of PV array in m^2
Ht – solar irradiation in kWh/m^2
η_{PV} – PV module efficiency

Capacity Utilisation Factor (CUF): It is defined as real output of the plant compared to theoretical maximum output of the plant. The capacity factor of a fixed tilt PV plant in India is typically in the range of 18%–19% [26]. This means that a 1 MW PV power plant will generate the equivalent energy of a continuously operating 0.18 MW plant.

$$\mathrm{CUF} = E_{ac}/(\mathrm{Po} \times 24 \times 365) \tag{5}$$

3. Results

The average daily energy requirement in Raj Bhoj airport is around 10,000 kWh. Considering average sunshine hours (5.5) and 80% system efficiency, a 2 MWp solar power has to be installed so as to make the airport fully solar powered. It is also considered that the solar PV power plant is grid interactive.

3.1. Proposed feasible sites for PV power plant

According to CERC norms, 10 acres of plain and shade free land is required for 2 MW solar plant [27]. Since an area of 400 acre is acquired for the airport, the plot area for the solar plant can be easily located. Feasible sites have been chosen within the airport area for the proposed 2 MWp power plant (Fig. 2). The solar plant can be located adjacent to the terminal buildings and remote bays far away from the runaways. The land can be utilised in a better way and kept clear of bushes and grasses. All the chosen sites have an area of more than 10 acres. These sites are free of shading, away from runway and does not cause glare to pilots. The vast spaces in the airport terminal buildings are also suitable for installing solar PV systems.

3.2. Design and specification of the PV power plant

The proposed solar PV power plant consist of 7692 poly c Si PV modules of peak rating of 260 W. All the PV modules are fixed at a tilt angle of 23° from horizontal and oriented towards south so as to maximise incidence of solar irradiation. It is suggested to purchase PV modules from Tier 1 manufacturer, marked by Ministry of New and Renewable Energy (MNRE). The PV modules are to be erected at optimum angle with the help of galvanised steel structures. Twenty-five modules are serially connected together to form a string. A total of 308 strings are needed to include all the 7692 solar modules. In this power plant, two inverters of 1 MWac rating are to be installed for power conversion and must have an efficiency of 98.8% at full load operation. The AC output voltage of each inverter is 400 V. This voltage has to stepped up to 11 kV using a power transformer of 2MVA. The output of transformer is directly fed to nearby grid with help of switchgear and protection (Tables 2–4).

3.3. Performance analysis

From the performance analysis of 2 MWp solar power plant, using SISIFO software, it is found that the annual energy yield and performance ratio (PR) are 1367 kWh/kWp and 85.54% respectively. The detailed analysis is as follows.

3.3.1. Solar irradiation, temperature and wind speed

The output from PV generator mainly depends on solar insolation and the module temperature. The proposed site is receiving ample amount of sun light throughout the year except winter.

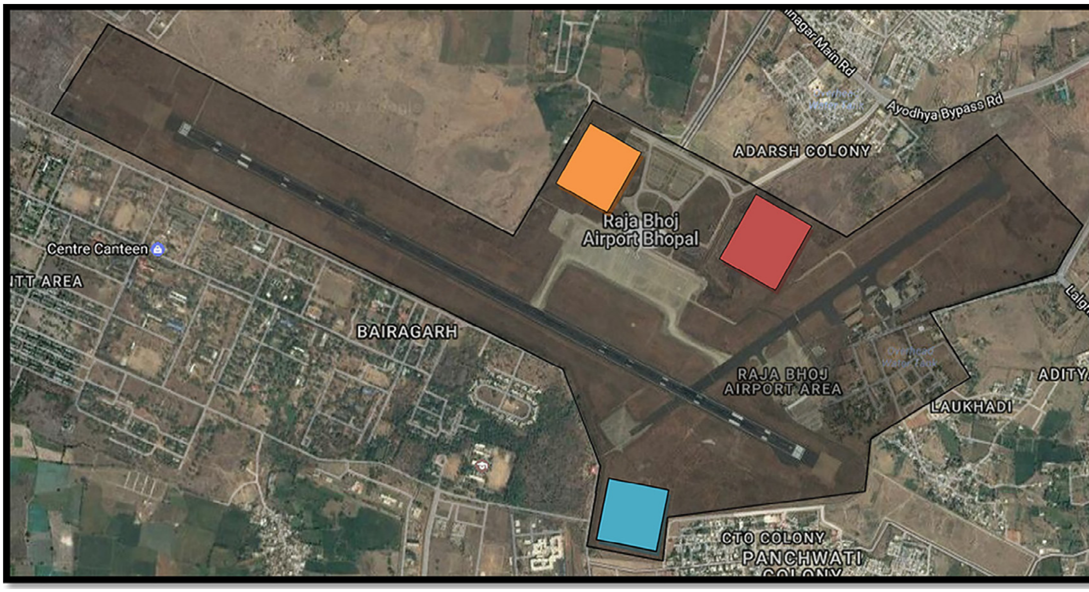

Fig. 2. Proposed sites for 2MWp PV power plant.

The percentage of beam radiation received is higher in Bhopal because of its closeness to equator. The solar insolation reaches its peak value of 200 kWh/m^2 in July. From Fig. 3, it can be concluded that temperature varies widely throughout the seasons in line with solar irradiation. The region experiences minimum temperature of 3 °C in the month of January and increases to a maximum of 31 °C during June and July. The wind speed influences the module temperature as well as the strength needed for metallic structure. The wind speed is very low at an average of 2.7 m/s. The variation in temperature value is found to be deviated from real values.

3.3.2. Energy generated and final yield

The effect of solar irradiation on the energy generated can be clearly seen from Fig. 4. Since the solar insolation is low during winter season, power generation also reduces. The solar power plant generates maximum electrical energy of 326,029 kWh (July) while minimum of 95,729 kWh during December. The energy generated can be directly fed to Madhya Pradesh state electricity board (MPSEB) grid. At the same time, electricity can be imported from the MPSEB grid when the energy consumption is more than generated, especially after sunset. The plant is showing good value of energy yield, generating an energy yield up to 163 kWh/kWp in the month of July. Since energy yield indicates the units generated per kWp, its value depends on the power output from the plant.

3.3.3. Performance ratio and capacity utilisation factor

The annual average performance ratio of the plant is 85.54%. The peak value (near to 90%) is obtained in the months of January and February while lowest value is during July and August. It can be concluded that the system losses are high during June and July though the power output is more. The performance ratio of the plant is varying inversely with the power generated. This proposed plant is having good value of PR when compared to similar PV plants in India (Table 1).

Table 1
Comparison of MW scale solar PV power plants in India.

Location	Installed capacity (MW)	PV technology	Performance ratio	Reference
Ramagundam (18.75°N , 79.46°E)	10	Poly c-Si	86.12	[11]
Kolar (12.53°N, 78.09°E)	3	Mono c-Si	65.47	[13]
Raichur (16°19 N, 77°42E),	1	Mono c-Si	77	[14]
Raj Bhoj Airport (23.29°N , 77.33°E)	2	Poly c-Si	85.54	Proposed

Table 2
PV module specifications.

Peak watt rating	260 W
Short circuit current (I_{SC})	8.95 A
Open circuit voltage (V_{OC})	37.6 V
Energy efficiency	15.8% to 16.2%
Operating temperature	−40 °C to +85 °C

Table 3
Solar inverter specifications.

Power output	1 MW ac
DC input	600 V–850 V
AC output	400 V, 1445 A
Efficiency	98.8%
Total harmonic distortion (THD)	<3%

Table 4
Transformer unit specifications.

Power output	2 MVA
Rating	400 V/11 kV
Current rating	5000 A/1.82 A
Efficiency	97%

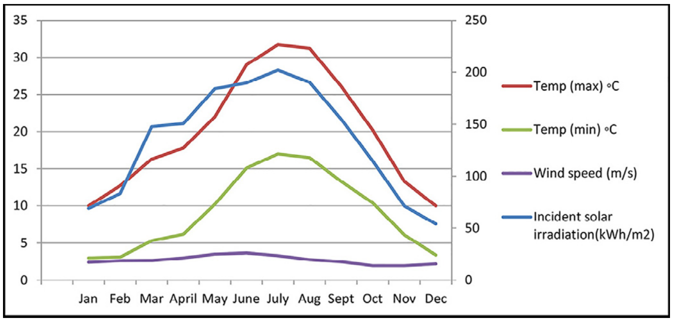

Fig. 3. Monthly variation of solar irradiation and temperature.

The capacity utilisation factor of the plant changes from 6.65% to 22.64%. The maximum CUF is obtained in the month of July because of high energy generation. The plant is having very low CUF during winter due to reduced solar insolation. The average CUF of the plant is around 15.82% which is less than the value specified by MNRE (19%) (Fig. 5).

4. Economic and environmental benefits

According to CERC norms, the total investment needed for 2 MWp grid connected solar PV system is around 10.1 Crores. The cost breakup of this project is given in the table below. The purchasing of PV modules requires more investment as compared to other items.

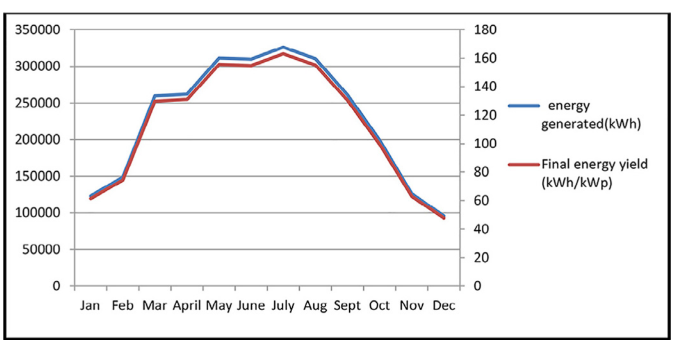

Fig. 4. Monthly variation of energy generated and final energy yield.

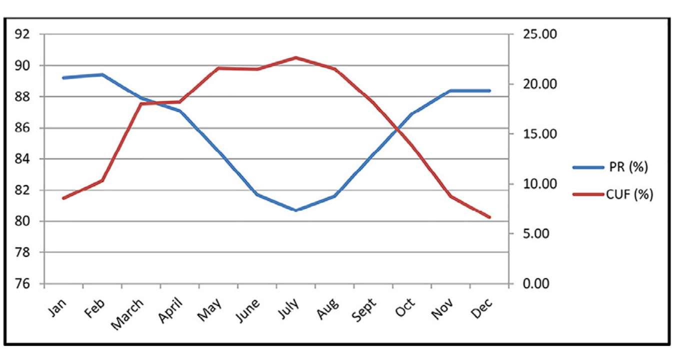

Fig. 5. Monthly variation of performance ratio and capacity utilisation factor.

Sl.No:	Particulars	Capital cost (Cr)	Percentage of total cost (%)
1	PV modules	6.26	61.96%
2	Land cost	0.474	4.7%
3	Civil and general works	0.66	6.6%
4	Mounting structures	0.66	6.6
5	Power conditioning units	0.66	6.6%
6	Evacuation cost up to interconnection point (cables and transformers)	0.84	8.3%
7	Preliminary and pre operative expenses	0.53	5.21%
	Total capital cost	10.1	100%

The economic analysis is carried out by considering 70:30 equity ratio. The interest rate for debt part is taken as 11.50% and loan term of 15 years. The project is expected to have a lifetime of 25 years at a degradation rate of 0.2%. From Renewable Energy (RE) Tariff Regulations formulated by CERC, levelised electricity tariff for solar PV is around 5.68 INR/kWh [28]. The annual energy generation of 2 MWp solar PV power plant is around 2733.122 MWh. The cash inflow in the first year of operation is about 1.55 Cr. Considering PV life time of 25 years, the amount obtained by airport authority will be around 38.81 Cr. The payback period of the project is 4.56 years if only capital cost is considered. For the proposed plant, tax deductions as well as debt interest are involved. As the debt amount decreases, the net cash flow also increases. Aviation sector not only caters to faster movement but also reduces the usage of petrol and diesel. In this airport, the conventional source of electricity is substituted with solar power. About 56,029 tonnes of CO_2 emissions can be mitigated during the life time of the proposed PV plant operation. The 2 MWp solar power plant at Raja Bhoj airport is equivalent to planting 89,646.41 teak trees over the life time [29]. The environmental impact caused during airport construction can be compensated through this solar power plant.

General guidelines for solar powered airport

- The location of solar plant should be chosen in the view of future airport development. Solar PV installations can become barrier to nearby airport terminal expansion, runway extension etc. The PV site construction can be of 'reversible' type, so that the site can be easily restored for building purpose. The height of machines and equipment used during construction should not affect aircraft landing and takeoff. The possible soil stripping should not flow towards the runway.
- Computer aided glare analysis must be carried out before fixing the tilt of PV module orientation. Solar PV modules chosen for PV plants in airports must be anti reflective. Sun tracking of solar modules should be employed with utmost care and precision.
- The solar plant site should not attract birds as it can cause flight hazards. The vegetation growing in the plant site was taken care off. The plant must be isolated from the airport operational area.
- Proper lightning protection is needed through the plant site. Electronic security systems such as CCTV must be installed in the plant site so as to prevent intruders.
- The landscape/visual impact due to the solar PV farm is a significant concern of such projects. The loss of ecology during site levelling must be minimal

5. Discussions

In this paper, the feasibility study of land based solar PV in Raja Bhoj is carried out. As of now, few Indian airports have installed solar PV power plants in their own land. So there is much untapped solar energy potential considering the many airports and airfields in India. Since PV output is more during summer, the increase in air conditioning load can be compensated. It is to be noted that the reduction in cooling load is marginal during winter. So the HVAC loads in airport buildings and solar power production profiles are often synchronised. The solar power plants in airports must be grid connected as solar power is intermittent in nature. The net metering system reduces the energy generated from the total units of electricity taken from grid. Moreover, PV system requires less maintenance, have life up to 25 years and can be recycled.

Out of 449 airports and airstrips in India, around 70 are having regular commercial flights. Assuming that an average of 2 MWp capacity was installed in all these 70 airports, the overall contribution in solar energy capacity would be 140 MW. Sixteen airports under Airports Authority of India (AAI) are already generating 5.4 MW of solar power. Government of India (GoI) wants to improve its underutilised airports through cheaper solar power in view of growing middle class travellers. These measures also help to achieve 100 GW solar power target under Jawaharlal Nehru National Solar Mission (JNNSM). The main achievement of JNNSM is that the electricity generated from solar PV has reached grid parity. Another advantage with solar PV power plant is the relatively short period of implementation time. The 12 MWp power plant in Cochin airport was completed within 8 months.

However the economical feasibility and safety aspects need to be studied in detail. The glare caused to the pilots by solar panels is a matter of concern. Another barrier in the acceptance of solar PV plants is the huge initial investment required. Airports can take on long term loans for executing the project as it will be coupled by lower electricity cost. Since this kind of airports helps public and policy, taxes can be levied from the passengers. This polluter payers approach helps to easily finance the solar power projects. In the coming future, a number of airports will be solar powered and help to mitigate green house gas emission.

Solar PV power plants have become economically attractive and environmentally desirable. This can be attributed to falling solar panel prices and increased environmental concern. Airports and airfields are favourable sites for the both land based and building PV installation. The vast and shade free buffer zones near airport site are suitable for land based projects. Buildings consume a considerable energy in an airport [30]. The Building Integrated Photo Voltaic (BIPV) and Building Applied Photo Voltaic (BAPV) technology can be integrated with the terminal building of airports. Zero Energy Building concepts are successful in airports if the buildings are modified as energy efficient as well as integrated with PV.

6. Conclusions

Airports are ideally suited for utility scale solar PV power plants due to the presence of vast and shade free mandatory buffer zones. On these lines, a 2 MWp PV power plant is proposed for Raja Bhoj International airport so that its daily energy requirement can be met. The performance of the solar PV power project is predicted with the help of SISIFO online PV tool and economic- environmental benefits are analysed. The following conclusions were formulated

- The proposed 2 MWp solar power plant consist of 7692 PV modules of 260 W, 1 MW inverter (2 nos) and 2MVA transformer, covering an area of 10 acres.
- The airport site location receives an average monthly solar irradiation of 134.27 kWh/m^2. The proposed plant is capable of generating 2733.122 MWh of energy per year at a performance ratio of 85.54% and energy yield of 133.88 kWh/kWp.
- Approximately 10.1 Crores of investment is needed for the project. The airport authorities will be able to recover the investment within 5 years.
- This plant also mitigates CO_2 emissions (59,200 tonnes) to a greater extent.
- Proper site planning including solar PV glare analysis has to be carried out to avoid impact on flight movement.

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