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Energy Yield Analysis of a Grid Connected Solar PV Power Plant

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ABSTRACT: Electrical energy became essential commodity in the present day lively hood. There is a rapid demand for its generation both by conventional and renewable energy recourses. To address the environmental concerns and for overall economic development of the country, addition of major renewable sources of energy and transition from conventional energy systems to those based on renewable resources became necessary. Among several renewable energy resources, solar is identified as the main source for reliable power generation. In terms of cost of energy photo voltaic solar plants located in high solar radiation zones will have a greater economic and logistical advantage. In India about 58% of total land area (1.89 million km2) receives average Global Horizontal Incidence (GHI) above 5kWh/m^2/day and can generate at least 77 W/m^2. Andhra Pradesh State is one of the suitable locations in India for installing solar power plants due to the availability of about 300 sunny days in a year with solar insolation of about 5.5 to 6 KWh/m^2/day. The proposed paper presents feasibility and energy yield analysis for a 5 MW photo voltaic based solar plant that can be erected at Rentachintala, one of the solar hotspot regions in Andhra Pradesh. This may attract investments and independent power producers for the establishment of solar power plant at that area and to some extent meets the objective of Indian solar power policy.

KEYWORDS: Solar insolation, Photovoltaic, Poly crystalline technology, Energy yield.

I.INTRODUCTION

One of the important components of India's energy planning process is renewable energy. The importance of transition of renewable energy sources to a sustainable energy base was recognized in the early 1970s. In this connection Department of Non-Conventional Energy Sources was established in 1982, which was then upgraded to a full-fledged Ministry of Non-Conventional Energy Sources (MNES) in 1992 and subsequently renamed as Ministry of New and Renewable Energy (MNRE) [1]. Resource-wise targets have been formulated by MNRE for the period 2011-17, keeping in view the estimated total potential, the progress made so far, the targets that were set for the 11th plan period & corresponding achievements and the general constraints in different sectors. Table 1 shows year-wise targets for grid-interactive solar power for the period 2011-17.

Renewable Energy Certificate (REC) mechanism was introduced by Central Electricity Regulatory Commission (CERC) to ease the purchase of renewable energy by the state utilities and required entities, and also to create a national level market for renewable power generators to recover their investment. Under this mechanism a power producer can generate electrical energy in any part of the country through the available renewable resources. He can sell that produced power based on the number of units generated and the environmental aspect. For the generated units, he can receive the cost equivalent to that from any conventional resource and for environment aspect he can receive the cost depending upon the exchanges at the market determined price. The required entity can purchase these RECs from any part of the country to meet its Renewable Purchase Obligation (RPO) compliance. Main objectives of the solar power policy [2] are presented in table 2.

India receives annual sunshine about 2600-3200 hours, i.e., 7 hours/day. Indian solar hotspots cover 58% of the total land area (1.89 million km2) that receives average Global Horizontal Incidence (GHI) above 5 kWh/m^2/day. Regions that receive GHI of 5kWh/m2/day and above can generate at least 77 W/m^2 at 16% efficiency and even 0.1% of the land area of the identified solar hotspots (1897.55km2) could deliver nearly 146 GW of solar electricity. Under Jawahar Lal Nehru (JNN) Solar Mission 10000 MW was planned by 2017 and 22000MW by 2022.

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Table 1: Year-wise targets for grid interactive RE power for the period 2011-17

S. No	Year	Solar Power Target (MW)
1	Total Targets Cumulative (anticipated upto 31.03.11)	35
2	2011-12	300
3	2012-13	800
4	2013-14	400
5	2014-15	400
6	2015-16	1000
7	2016-17	1100
8	Total Target for the 6-year period	4000
9	Cumulative Total Target	4035

Table 2. AP Power policy

S. No	Main objectives of the Solar power policy
1	To encourage, develop and promote solar power generation in the State with a view to meet the growing demand for power in an environmentally and economically sustainable manner
2	To attract investment in the state for the establishment of solar power plants.
3	To promote investments for setting up manufacturing facilities in the State, which can generate gainful local employment
4	To promote the Off-Grid Solar applications to meet the power needs on Stand-alone basis
5	To contribute to overall economic development, employment generation and improvement in public services by provision of electrical energy for various needs.
6	To encourage Decentralized, Distribution Generation System in the State to reduce T&D losses.

In India, Andhra Pradesh (AP) state is one of the suitable locations for installing solar power plants [2]. In AP annual sunny days are about 300, with solar insolation of 5.5 to 6 KWh/m². Power plants can be easily connected to the grid due to the availability of widespread electric grid network and also due to growing energy demand in the State.

II.PHOTOVOLTAIC (PV) TECHNOLOGY

Photovoltaic (PV) technology is a solar power technology that is developed based on Photovoltaic effect, discovered by Becuerel in 1839. PV technology uses solar cells to convert sunlight irradiated directly into electricity without any emissions. As on now, PV technology established, itself as a best, flexible and long term solutions for electrifying poorest rural areas of the world. Solar cells are made of semiconductor materials. In solar cells, an electric field is developed within a thin semiconductor wafer existing between a positive type layer (Boron doped) on one side and negative type layer (Phosphorus doped) on the other side. When light energy strikes the solar cell, electrons will be knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current and can be then used to power a load. The solar cell generates voltage about 0.5 to 0.6V DC under open circuit condition. Silicon is the basic raw material for the PV industry.

The primary source of silicon is quartzite, which is found in the ordinary sand. Solar cells are grown on silicon wafers. The thickness of the wafer decides the cost of a solar cell. Silicon will be purified, melted, and crystallized into ingots. The ingots will be then sliced into wafers to make individual cells. The Indian PV industry now makes use of silicon wafers in the thickness range of 210-240 microns as against 350 microns till a few years back.

Lot of energy is to be incurred in making a pure silicon wafer thus creating very expensive market for pure silicon material. So, continuous efforts are to be incurred in developing a PV technology, particularly thin film technology, that uses a very little or no quantity of expensive silicon. Thin film modules are fabricated by depositing very thin layers of photosensitive materials on a low-cost backing. Substrates used for this purpose will be made of glass, stainless steel or even plastic, which are inexpensive. Commercially available thin film types are amorphous silicon,

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cadmium telluride and copper indium diselenide. Table 3 shows the available solar cell and module efficiencies [3] and fig. 1 shows spot PV module price trends in Europe. At present crystalline cell technology is the most dominant PV technology.

Table 3 Currently available cell and module efficiencies

Technology	Cell efficiency (%)	Module efficiency (%)
Single crystal silicon	16-17	13-15
Polycrystalline-silicon	14-15	12-14
Amorphous silicon		6-7
Cadmium telluride		8-10
Copper indium		10-11

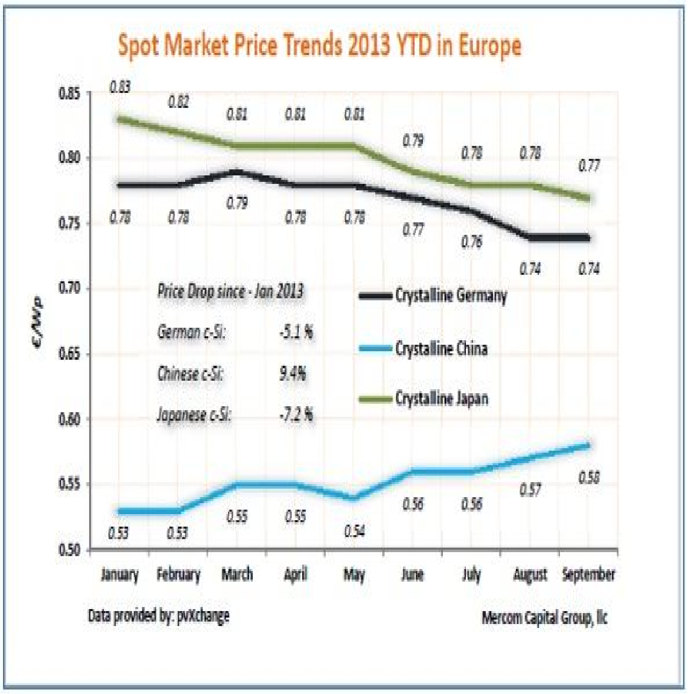

Fig. 1 Spot PV Module price trends in Europe (Source: Mercom's Solar Market Intelligence Report (Sept, 2013)

III. MAJOR COMPONENTS OF SOLAR POWER GENERATING SYSTEM

PV module is the basic component of a solar power system (SPS). Solar cells are building blocks of a PV module. All components in the SPS, other than the module are termed as Balance of System (BoS). The BoS of a grid connected solar PV system generally comprises Power Conditioning Unit (PCU) referred as inverter compartment, mounting structure, AC and DC cables, earthing material, junction boxes or combiners, String Monitoring Box (SMB), weather station, instruments and protection equipments. However the final configuration of a PV SPS normally depends upon the location of the site and specified load requirements.

A. String Monitoring Box (SMB)

PV strings are connected to SMB. SMB consists of string connection compartment, string monitoring compartment and main inverter compartment.

B. Weather Station

It consists of pyranometer for measuring solar radiation, temperature sensor for measuring ambient temperature, humidity & air pressure, rain gauge for measuring rain fall inside the plant, anemometer for measuring wind speed & wind direction , polycrystalline solar panel for charging 12V Battery and RS232 to RS 485 converter.

C. Inverter and its Components

It converts the DC power to AC power. It is made of Insulated Gate Bipolar Transistor (IGBT). It has high current, low saturation voltage capability and self grid synchronizing capability. It is provided with overload, heat sink over temperature protections. It is facilitated with auto run & auto shutdown features.

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D. Other Components

Grid monitoring device is used for monitoring of voltage, frequency, and phase failure and phase sequence. It is connected at output of AC breaker. Earth Fault Locator (EFL) monitors the insulation resistance of grounded PV generator, DC cable and internal wiring. It has memory to store alarm massages with date & time and RS 485 interface for data exchange. It is provided with Iso-meter disconnecting relay for the operation of multiple A-isometer in coupled floating systems. Electro Magnetic Compatibility (EMC) Filter eliminates the electromagnetic interferences to protect other electronic or electrical equipments. It is connected before the IGBT inverter. Sinusoidal Filters are low pass filters that convert inverter pulse width modulated (PWM) voltage to sine wave. It suppresses the high frequency components from inverter output. It is connected at output of IGBT inverter. Line Reactor reduces the harmonic distortion and burden on upstream electrical equipments. It aabsorbs the line spikes and adding sags, prevents overvoltage and under voltage tripping problems. It reduces the interferences with the electronic equipments
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IV. GRID CONNECTED SOLAR PV POWER PLANT AT RENTACHINTALA-A CASE STUDY

Rentachintala is one of the best hotspot regions in Andhra Pradesh, with a daily horizontal surface solar irradiation incidence between 5 and 6 kWh / m^2. The Solar PV Power Plant (SPVPP) with proposed capacity of $5MW_P$ will be connected to the nearby grid for feeding generated power. The proposed grid connected SPVPP would be a demonstration project to exploit renewable energy and analyse various aspects of plant operation.

The energy yield forecasting involves sourcing of average monthly global horizontal irradiation; wind speed and temperature data from a variety of sources from land based meteorological stations. NASA –SSE Satellite data (1983-2005) is considered for this case. The other tasks include calculating the global incident radiation on the collector plane, estimating the losses that may occur during the power production process. This step uses PV module characteristics [4], inverter specifications [5] and the site geography. Owing to the relative economy and availability in the market poly crystalline PV module is considered for the energy yield estimation.

Table 4. Salient features of proposed grid connected PV plant at Rentachintala

S. No	Salient features	Description		S. No	Salient features	Description
1	**Location**			2	**SPV Power Plant**	
	Locality	RENTACHINTALA			Output	5MW
	State	ANDHRAPRADESH			Total No. of modules	20000
	Latitude	16.6 deg N			No. of modules in series	20
	Longitude	79.5 deg E			No. of parallel combination	1000
	Altitude	83 m				
3	**Proposed technical details of a SPV Module**			4	**Electrical Parameter**	
	PV Module type	Poly crystalline			Maximum Power Rating	250Wp
	Considered Physical Dimensions				Rated Current	8.27A
	Length with frame	1.652 Sqmm			Rated Voltage	30.3V
	Width with frame	0.994 Sqmm			Short Circuit Current	8.65A
	Thickness	45mm			Open Circuit Voltage	38.2V
5	**Mounting Arrangement**			6	**Inverter/ Power Conditioning Unit (PCU)**	
	Mounting	Fixed Type			Number of units proposed	10
	Surface azimuth angle of PV Module	0			Ratings	500kWac, (320-700) DC V, 400V AC, 50Hz
	Tilt angle(slope) of PV Module	22			Efficiency	97.50%

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V. RESULT AND DISCUSSION

The possible energy generation at Rentachintala for 5 MW SPVPP is estimated using PV SYST V6.10 simulation software. PVSYST is a photovoltaic simulation software that simulates the energy yield considering site resources, PV module, Inverter and mounting structure specifications.

The proposed grid connected SPVPP at Rentachintala, Guntur District, Andhra Pradesh State would utilize vacant area of about 101172 Sqm. The SPVPP is estimated to cost Rs. 30.60 Crores based on the normative cost of Rs.6.12Crores per MW adopted by CERC Suo-motu order dated 7th January 2014 [6]. The tariff for sale of electricity has been worked out adopting the parameters given in the CERC notification and energy generation as presented in this report. Adopting normative cost estimate and capacity utilization factor, the levellised tariff works out at Rs 6.99 per kWh. Salient features of proposed grid connected SPVPP at Rentachintala are presented in table 4.

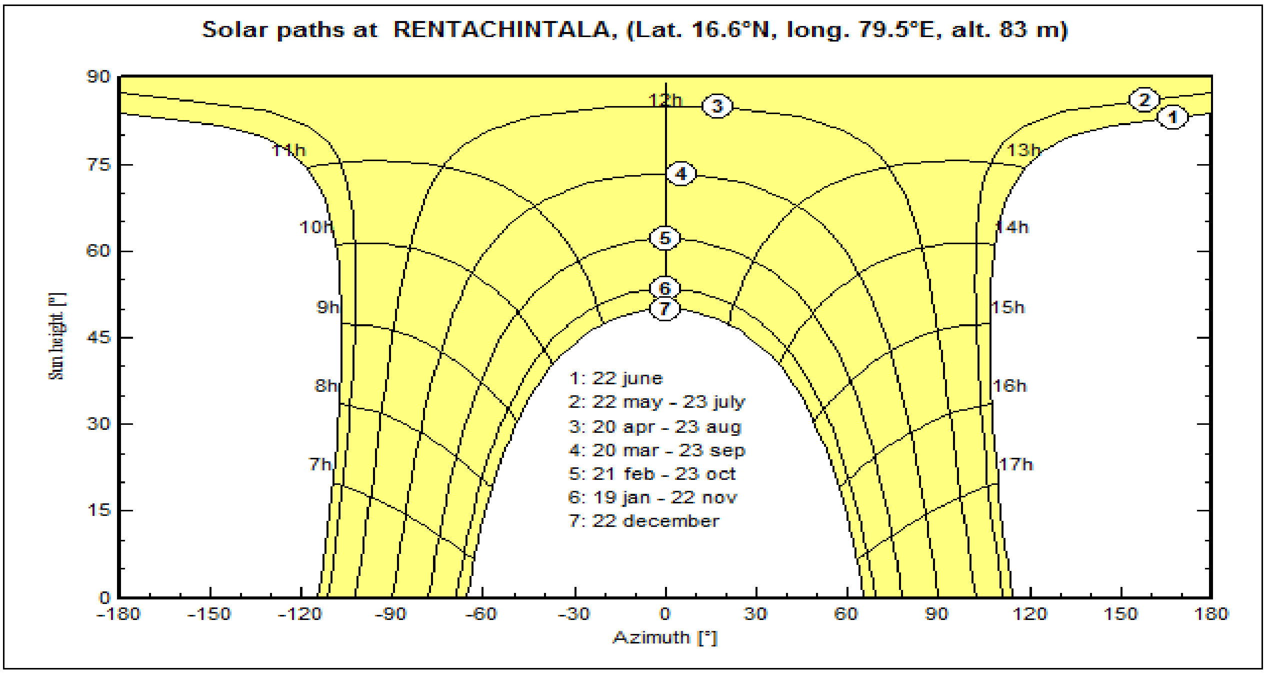

Fig. 2 Solar paths at Rentachintala

Possible solar paths at Rentachintala, at latitude 16.6^{0}N and longitude 79.5^{0}E are depicted in fig. 2.

Fig. 3 shows the characteristics of 250Wp PV module and fig. 4 shows 500kWac inverter efficiency characteristics considered for analysis.

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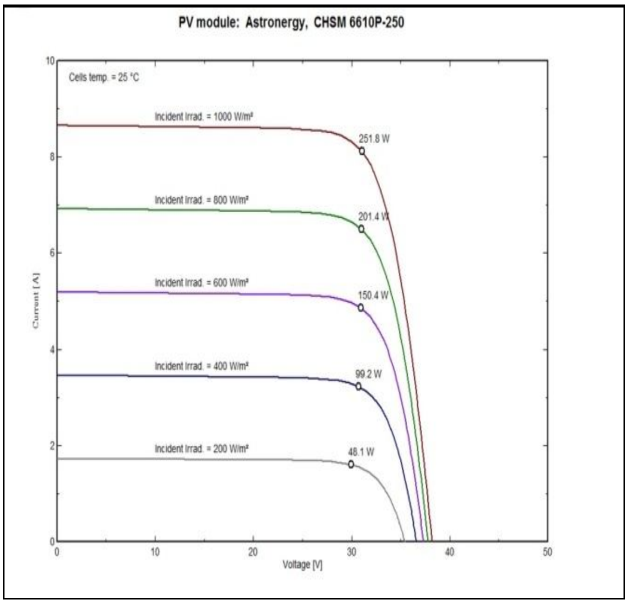

Fig. 3 Characteristics of 250Wp Poly crystalline PV Module

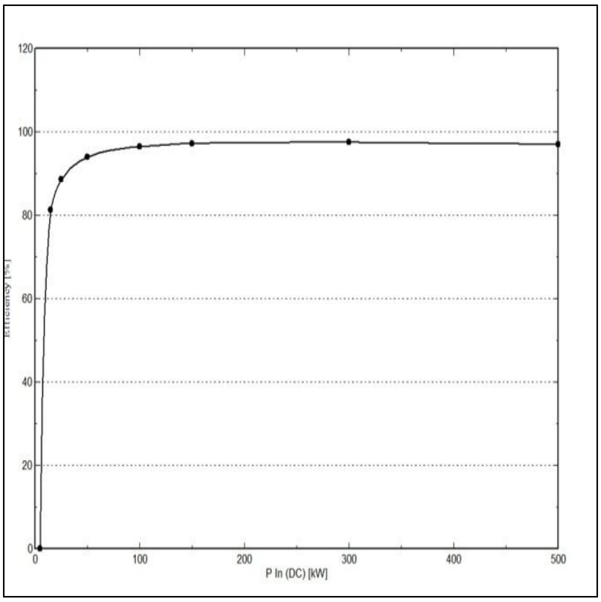

Fig. 4 Efficiency profile versus input power characteristics of 500kWac Inverter

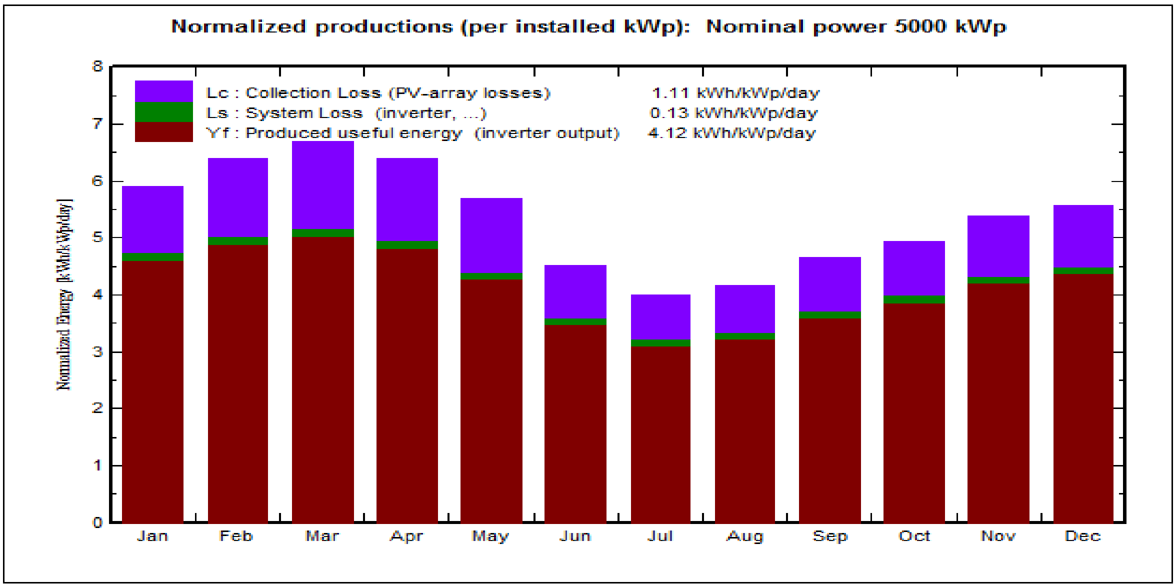

Fig. 5 Normalized power production per installed kWp

In fig. 5 the net output energy at the inverter terminals is estimated as 4.2kWh/kWp/day considering the system loss about 0.13kWh/kWp/day for proposed installed capacity of 5MWp.

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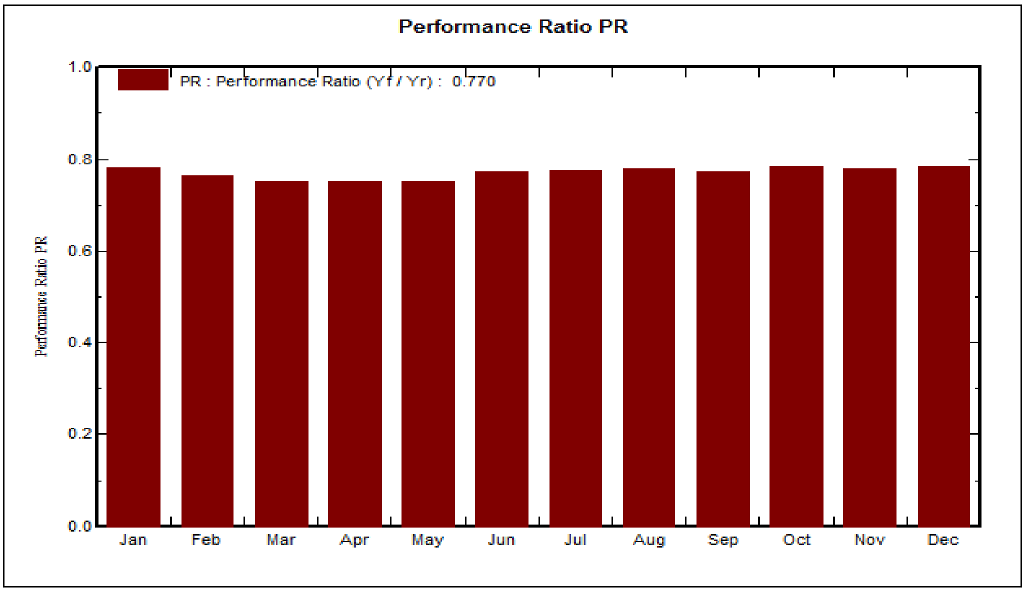

Fig. 6 Monthwise performance ratio

From fig.6 average month wise performance ratio of the system is estimated at 0.770.

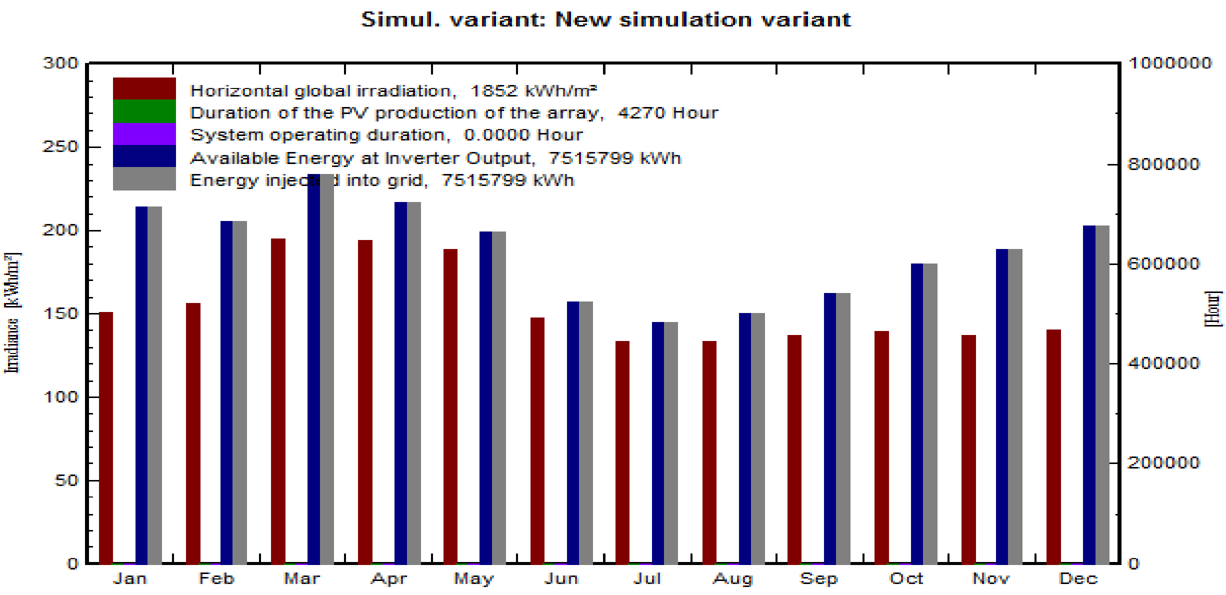

Fig. 7 Month wise irradiance and energy yield estimate

Month wise irradiance and energy yield estimate is shown in fig. 7. The 5MW$_P$ SPVPP is estimated to afford annual energy feed of 7515799 kWh considering efficiency of the solar module as 15.34%, PCU as 96.8% and losses as 3% in the DC and AC system. The plant would operate at an annual capacity utilization factor of 19%. The energy available from the plant would vary from a minimum of 715.012 MWh during the month of January to a maximum of 779.438 MWh during the month of March.

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VI. CONCLUSION

Based on NASA –SSE Satellite data (1983-2005) and using PV SYST V6.10 simulation software, the energy yield analysis for 5MW PV Solar power generation was performed for geographical site Rentachintala, which is located at latitude 16.6^0 N and longitude 79.5^0E at legal time zone UT +5.5. And it was found that, for a horizontal global irradiation of 1852kWh/m^2, duration of PV production of the array is 4270 hours with performance ratio about 77%. The available energy at the inverter output which can be fed to the nearby grid is 7515799kWh with a specific power production about 1503kWh/kWp/year. This much amount of energy, which can be generated by establishing 5MW SPV plant at Rentachintala, to some extent shares the generation demand at Andhra Pradesh and meets the objective of Indian solar power policy. In these context independent power producers willing to establish the said SPV plant, will be encouraged by MNRE with REC Mechanism under the regulatory direction of CERC.

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