

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 6, June 2014

# Performance Evaluation of 5MW Grid Connected Solar Photovoltaic Power Plant Established in Karnataka

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**ABSTRACT:** The favorable climate conditions of the place called Belakavadi of Mandya district in the state of Karnataka and the recent legislation for utilization of renewable energy sources provide a substantial incentive for installation of photovoltaic power plants. In this paper, the grid connected solar photovoltaic power plant established by Karnataka Power Corporation Limited, is presented, and its performance is evaluated. The photovoltaic power plant has a solar radiation of 5.26 kWh/sq.mt/day spread over 25 Acres of land. Operating module temperature varies from 15 to 40 degree centigrade, with a tilt angle of module 15 degree and guaranteed energy generated is 8.3224MU/Annum with 19% CUF. The plant has been in operation since 2012. The power plant is suitably monitored during 7 Months, and the performance ratio and the various power losses (temperature, soiling, internal, network, power electronics, grid availability and interconnection) are calculated. The final yield (YF) ranged from 1.96 to 5.07 h/d, and the performance ratio (PR) ranged from 58 to 73%, giving an annual PR of 67.36%.

**KEYWORDS:** Photovoltaic, Grid connected, SCADA system, PVsyst software.

### I. INTRODUCTION

Photovoltaic is the field of technology and research related to the devices which directly convert sunlight into electricity. The solar cell is the elementary building block of the photovoltaic technology. Solar cells are made of semiconductor materials, such as silicon. One of the properties of semiconductors that makes them most useful is that their conductivity may easily be modified by introducing impurities into their crystal lattice.

Photovoltaic's offer consumers the ability to generate electricity in a clean, quiet and reliable way. Photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity. It is anticipated that photovoltaic systems will experience an enormous increase in the decades to come. However, a successful integration of solar energy technologies into the existing energy structure depends also on a detailed knowledge of the solar resource. But to note it is essential to state the amount of literature on solar energy, the solar energy system and PV grid connected system is enormous. Grid interconnection of photovoltaic (PV) power generation system has the advantage of more effective utilization of generated power. However, the technical requirements from both the utility power system grid side and the PV system side need to be satisfied to ensure the safety of the PV installer and the reliability of the utility grid.

Souvik Ganguli et al. [1] presented a Estimation of Grid Quality Solar Photovoltaic Power Generation Potential and its Cost Analysis in Some Districts of West Bengal. A.S. Elhodeiby et al. [2] presented a performance analysis of 3.6 kW Rooftop grid connected solar photovoltaic system in Egypt. The system was monitored for one year and all the electricity generated was fed into the 220 V, 50 Hz low voltage grid to the consumer. D.Picault et al. [3] presented an over view of current architectures used in grid connected systems, five key points for comparison based on topology upgradeability, performance under shaded conditions, degraded mode operation, investment costs and ancillary service participation. These evaluation guidelines may assist grid-tied PV system users to choose the most convenient topology for their application by weighting the evaluation criteria Phil Bolduc et al. [4] presented a paper about performance of a grid-connected PV system with energy storage. One kilowatt amorphous photovoltaic system has been operated in a grid-connected mode with energy storage. R. Ramkumar et al. [5] presented a paper of photovoltaic systems including

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a discussion of major U.S. and international activities. After a brief review of system types and output characteristics, various system configurations were discussed and a classification based on photovoltaic (PV) system rating was provided. Eduardo Roman et al. [6] presented a performance of a grid connected PV system with energy storage. Three kilo watt amorphous photovoltaic system has been operated in a grid-connected mode with energy storage. The purpose of the system development and performance experiment is to investigate the additional value a grid connected system garners with dispatch able battery energy storage. Evert Nieuwlaar et al. [7] presented an over view of current power generation used in grid connected systems, the points for comparison based on, performance under shaded conditions, degraded mode operation, investment costs and ancillary service participation. Kosuke Kurokawa et al. [8] presented paper about the cost analysis of very large scale PV system on the world desert, a 100 MW very large scale photovoltaic power generation (VLS-PV) system was estimated assuming that it is installed on the would deserts, which are Sahara, Negev, Sonora, Great Sandy and Gobi desert.

An electrical grid is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centres, and distribution lines that connect individual customers are power systems energized by photovoltaic panels which are connected to the utility grid. Grid-connected photovoltaic power systems consist of Photovoltaic panels, MPPT, solar inverters, power conditioning units and grid connection equipment. Unlike Stand-alone photovoltaic power systems, these systems seldom have batteries. When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load to the utility grid.

To find out the performance of grid connected solar photovoltaic power plant work in this paper is divided in two stages. 1) Manually extract the parameters for generation of power through SCADA system. 2) Compare with the PVSYSY software. PVSYSY is a PC software package for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid (public transport) PV systems, and includes extensive meteorological readings and PV systems components databases, as well as general solar energy tools. This software is geared to the needs of architects, engineers, researchers. It is also very helpful for educational training.

Paper is organized as follows. Section II describes manually extracted readings from SCADA system, relative graphs, those results are compared with the PVSYSY software package that is given in Section III. Section IV presents experimental results and comparisons. Finally, Section V presents conclusions.

### II. MANUALLY EXTRACTED PARAMETERS THROUGH SCADA SYSTEM

A draft procedure for the design of grid-connected systems was prepared which will be updated from time to time (in the course of the design of the MW grid-connected system) until a standard procedure is developed which can be used to replicate the design of large-scale grid-connected solar PV systems in other institutions.

The draft procedure comprises the following steps;

1. Assessment of the solar radiation data for the location from various institutions such as the American Space Agency (NASA), the Joint Research Commission (JRC) of the European Commission and UNEP which helps to estimate the amount of electricity generated. Most simulation software packages also have inbuilt solar radiation data which can be used for this same purpose.
2. Obtain a land use map of the location showing the various sites that can be used for the project.
3. Confirm the various locations on the land use map and update where necessary.
4. Identify various building roofs and car parks that can be used for the project based on a minimum roof area.
5. Identify grid access and requirement for grid connection
6. Obtain the dimensions of the lands or roofs of the selected buildings and car parks to be used.
7. Assessment of lands or roof properties such as roof type, roof area, roof orientation, pitch/slope, strength of roof and the effect of shading on the roofs.
8. Selection of suitable lands or roofs and collation the total area available PV system design.
9. Obtain solar PV information from various solar dealers both locally and internationally. This information should include; type, cost, size, weight, etc
10. Design the layout of the system for each of the selected building roofs or lands.

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### TOTAL OUTPUT

The Energy generated from photovoltaic power plant are tabulated using SCADA System on a daily basis and for the calculation purpose those readings taken on an average, here the average yearly energy output is calculated by multiplying average monthly energy output with total number of months in a year. The daily energy output also calculated for various months shown in 2nd column. Monthly energy output is calculated by multiplying the number of days of month with the daily energy output shown in 3rd column for various months. Kilowatt-Hour (kWh) means 1,000 watts acting over a period of 1 hour. The kWh is a unit of energy. 1 kWh=3600 kJ.

| Months         | Avg. daily energy o/p [MWh] | Monthly energy o/p | Avg. monthly Energy o/p [MWh] | Avg. yearly energy o/p MWh |
|----------------|-----------------------------|--------------------|-------------------------------|----------------------------|
| November- 2013 | 18.96                       | 568.8              |                               | 7416.12 MWh                |
| December- 2013 | 17.14                       | 528.3              |                               |                            |
| January- 2013  | 17.61                       | 612.7              |                               |                            |
| February- 2013 | 19.35                       | 599.9              | 618.01                        |                            |
| March- 2014    | 23.03                       | 714                |                               |                            |
| April- 2014    | 21.88                       | 531.5              |                               |                            |
| May- 2014      | 24.86                       | 770.9              |                               |                            |
| Total          |                             | 4326.1             |                               |                            |

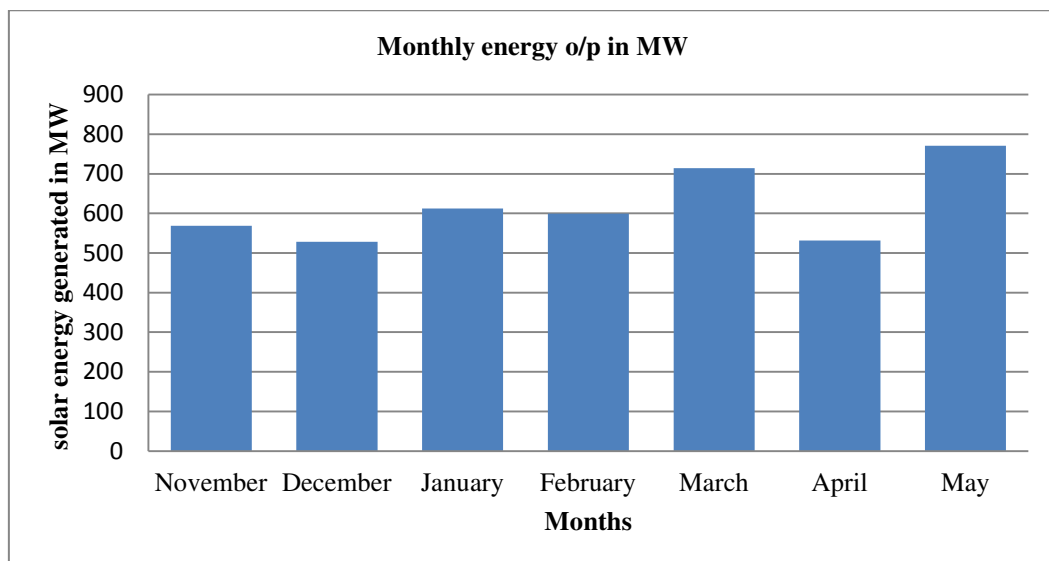


Fig. 1 Month wise Energy generated

The above graph shows that during the month of May recorded the highest solar energy generated, by taking 7 months into consideration from November 2013 to May2014.

### PEAK VARIATION AND POSSIBLE PLANT RATING

Average peak solar radiation for the month is 166.8926MWh/m<sup>2</sup>. We assume that 100m<sup>2</sup> areas are available for installation of solar power plant. Above we calculated the average peak solar radiation for the different months. So the possible plant rating can be calculated by multiplying average peak solar radiation value 166.8926 MWh/m<sup>2</sup> with available area 100 m<sup>2</sup>, we get 4.63590 mega watt. So predicted plant rating in megawatt is 5 MW.

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| Months         | Monthly avg. peak output<br>MWh/m <sup>2</sup> | Avg. peak Output<br>MWh/m <sup>2</sup> | Avg. peak per 100 mtr <sup>2</sup> area<br>MWh | possible plant<br>MWh |
|----------------|--|--|--|-----------------------|
| November- 2013 | 130.873  |  |  | 5 MWh                 |
| December- 2013 | 147.340  |  | (166.8926*100) / (60*60)                       |                       |
| January- 2013  | 155.329  |  |  |                       |
| February- 2013 | 180.665  | 166.8926                               | 4.63590 MW                                     |                       |
| March- 2014    | 190.579  |  |  |                       |
| April- 2014    | 166.140  |  |  |                       |
| May- 2014      | 197.322  |  |  |                       |
| <b>Total</b>   | <b>1168.248</b>                                |  |  |                       |

### III. COMPARING WITH PVSYSST SOFTWARE

By using the PVsyst version 6.2.4 it is possible to have preliminary and as well as post evaluation test data for the feasible power generation. The total system performance and efficiency of each systems of plant are evaluated by entering the make and specifications of a particular plant design. In this paper the main parameter is to concentrate on average energy output by comparing with the software package.



Fig. 2 System Specification generated using PVsyst Software.

Specifications obtained from a PVsyst software package, for a 5MW Solar Power Plant:

Site Information:- Proposal site for the Plant is Shivanasamudra, Mandya district, Karnataka, India. Its co-ordinates are:

Latitude : 12.29° N  
Longitude: 77.16° E

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### Grid Specification:-

|                |              |
|----------------|--------------|
| No. of Phases  | 3- $\phi$    |
| Voltage rating | 400 Volts AC |
| Frequency      | 50 Hz.       |

### Solar Photovoltaic Power Plant Specification:-

|                |                      |
|----------------|----------------------|
| Plant Capacity | 5 MW                 |
| Voltage Output | 864 Volts dc o/p OCV |
| Current Output | 25 A dc              |
| No. of Modules | 22560 nos.           |
| Area           | 100m <sup>2</sup>    |

GEC [Grid Export Condition] inverters are used here for suppressing the harmonics produced after DC to AC conversion. The calculation for finding the output voltage of inverter is shown below:

### Inverter Specification:-

|                   |   |
|-------------------|---|
| KVA rating        | 250 KVA   |
| Input DC voltage  | 864 Volts DC  |
| Input dc current  | 500 A   |
| Output AC voltage | 240 V ac (phase voltage)<br>240 V ac (line voltage) |
| No. of Phases     | 3- $\phi$   |
| Type              | GEC [grid export condition]                         |
| Efficiency        | Almost 90-93%                                       |
| No's              | 20  |

### Transformer Specification:-

|                          |   |
|--------------------------|---|
| KVA rating               | 1250 KVA  |
| No of phases             | 3- $\phi$   |
| Frequency rating         | 50 Hz   |
| Primary voltage rating   | 11 kVA  |
| Secondary voltage rating | 440 V   |
| Primary current rating   | 64.18 A + (10-15% extra)  |
| Secondary current rating | 27.27 A + (10-15% extra)  |
| Connections              | Primary - delta (for suppressing<br>Secondary - star 3rd harmonics)<br>10 to 25 taps in secondary |
| Efficiency               | Almost 95 %   |
| Extra features           | Air cooled  |
| No's                     | 5   |

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### Solar Panel Specification:-

|   |  |
|---|--|
| Watt  | 220 Watt   |
| Voltage   | 360 Volts  |
| Current   | 7.6 A  |
| Type  | Monocrystalline  |
| No's of module                                    | 22560 no's   |
| No's of modules per MW                            | 4512 no's  |
| Detail of series/parallel combination             | 24 nos in series, 940 nos in parallel string.  |
| Efficiency  | 14.3%  |
| Temperature                                       | Min 15 ° and Max 40 deg c  |
| Dimensions of single module (mm)                  | 1655(L) × 995(w) × 50(T) mm<br>Area of single panel = 1646725 (mm)<br>Area of single panel = 1.64 meter <sup>2</sup> |
| Tilt angle(slope) of PV Module                    | 15°  |
| Wind speed rating                                 | 150 Km/h   |
| Mounting  | Fixed Type   |
| Output of the PV array to be connected to the PCU | Nominal 250 KW   |

|                   |                               |
|-------------------|-------------------------------|
| Protective device | 400 Volts under voltage relay |
|-------------------|-------------------------------|

Others: Junction boxes, meters, distribution boxes, wiring materials, mounting materials etc.

### IV. EXPERIMENTAL RESULTS

Target obtained from PVsyst software and Actual generation for the months in MWh for the year of 2013 - 2014

| Sl no | Month          | Target generation [MWh] | Actual generation [MWh] | Difference in generation [MWh] | % generation [a/t*100] |
|-------|----------------|-------------------------|-------------------------|--------------------------------|------------------------|
| 1     | November- 2013 | 684                     | 568.8                   | 115.2                          | 83.16                  |
| 2     | December- 2013 | 684                     | 528.3                   | 155.7                          | 77.24                  |
| 3     | January- 2013  | 638.4                   | 612.7                   | 25.7                           | 95.97                  |
| 4     | February- 2013 | 706.8                   | 599.9                   | 106.9                          | 84.88                  |
| 5     | March- 2014    | 706.8                   | 714                     | 7.2                            | 101.02                 |
| 6     | April- 2014    | 706.8                   | 531.5                   | 175.3                          | 75.20                  |
| 7     | May- 2014      | 706.8                   | 770.9                   | 64.1                           | 109.07                 |
| Total |                | 4833.6                  | 4326.1                  | 507.5                          | 89.50%                 |
| Loss  |                |                         |                         | 507.5                          | 10.5%                  |

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Above results shows that minor difference between Analytical method and results obtained using PVsyst software package but the results are within the acceptable range. The differences are due to some of the unavoidable errors occurred during data interpretation, loss in cell efficiency, transmission losses and errors in some of electrical systems.

### V. CONCLUSION

The maximum monthly energy output out of seven months is obtained during the month of May. Solar photovoltaic generation potential during November 2013 to May 2014 is assessed for Mandya district of Karnataka. It is found that the month of December produced the lowest solar radiation. Monthly and yearly outputs were calculated on the basis of 100 m<sup>2</sup> area. Considering the monthly peaks, the average peak output is calculated from where an estimate of the possible plant rating is made. The methodology adopted seems satisfactory for determining the possible plant capacity for an arbitrarily chosen area. As a conclusion the comparison between the analytical method of manually extracted data and results obtained from the PVsyst software package are feasible.

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