TECHNICAL NOTE

Performance of a megawatt-scale grid-connected solar photovoltaic power plant in Kolar District in Karnataka

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A megawatt scale grid-connected photovoltaic power plant was commissioned on 27 December 2009 in Yalesandra in Kolar district in Karnataka. The Yalesandra plant is one among more than 20 such Megawatt size solar power plants in India during the past few years. The performance of this plant during its first year of operation has been discussed. The total electrical energy generated by the Yelasandra plant during 2010 was 3.34 million kWh. Although the performance of photovoltaic modules was good, there were problems associated with the inverters which led to reduction in energy generation. The impact of temperature variation of modules on their performance has been highlighted.

Karnataka Power Corporation Limited (KPCL) has established the first large-scale grid-connected solar power plant using photovoltaic panels near Yalesandra village, Kolar District. The plant was commissioned on 27 December 2009 with an installed capacity of 3 MW_{peak} (MW_P). Two other plants with same capacity were constructed later in Belgaum and Raichur. India has an ambitious plan to build large grid-connected solar power plants with a cumulative installed capacity of 20,000 MW_P by 2020, under the National Solar Mission. Hence it is essential to document the performance of the large-scale grid-connected solar power plants in Karnataka. In this note we discuss the performance of the photovoltaic solar power plant in Kolar during 2010.

The Yalesandra power plant is located at 12°53′ lat. and 78°09′ long. The area occupied by the photovoltaic modules is 10.3 acres. The plant has three segments, with each segment having an installed capacity of 1 MW_P. Each segment has four inverters with a capacity of 250 kW each. There are 13,368 modules (557 arrays with 24 modules per array) that contain mono-crystalline silicon solar cells. The solar photovoltaic modules are connected such that a voltage of 415 V is generated at the output of each inverter. This is stepped up to 11 kV by a step-up transformer and connected to the existing 11 kV grid. The nominal operating temperature of the cell is 45°C. The modules are mounted on a mild steel structure and are inclined (towards south) by 15° (Figure 1). This ensures that yearly average solar radiation falling on the module is higher than that on a horizontal surface. The modules were installed by Titan Energy Systems Limited. After the site preparations were completed, the first segment was installed in 4 months, and the second and third segments in the next two months. The total cost of the plant was Rs 60 crores, which works out to be Rs 20 crore per MW_P installed. The cost break-up is solar modules 72.5%, power conditioning units 9%, mounting structure 5%, and erection and commissioning 5%. Hence reduction of the cost of the system is possible only when the cost of the solar modules decreases substantially.

Performance

The total electrical energy generated by the Yalesandra power plant during 2010 was 3.34 million kWh and 3.30 million units were sold to the grid. The performance of all the three segments is shown in Figure 2. Since segment 3 was not working satisfactorily for a few months, we will restrict our analysis to the first two segments. Based on the performance of the first two segments, we estimate the mean output to be 6655 kWh per day. The plant was running effectively for about 4085 h during the entire year. The large decrease in power generation during August to November was both on account of cloudiness and malfunctioning of the grid or inverters. It was found that failure in the inverter is the most frequent incident. This is mostly caused by the lack of experience in the initial production stage, or some unexplained inverter failure might be caused by disturbance from the grid and other interconnected issues[1]. The Belgaum power plant generated 3.90 million units in 2010. This is larger than the Yalesandra power plant (for the same installed capacity) because this plant faced less problems related to performance of inverters. The problems associated with inverters and related protection equipment used in the grid-connected photovoltaic power systems have been discussed[2]. The performances of some of the similar grid-connected PV plants installed in India and other parts of the world[3–5] have been listed in Table 1. The

Figure 1. A view of the solar panels in the Yalesandra photovoltaic power plant, Kolar District, Karnataka.

Table 1. Grid-connected solar photovoltaic power plants[3–5]

Plant	Commission year	System size (MW_P)	Annual energy production (million kWh)	No. of panels	Covered surface area (acres)	Developer	Annual plant load factor (PLF in %)
Sarnia, Ontario, Canada	2009	80	120	1,300,000	950	First Solar	17.1*
Montalto di Castro, Italy	2010	84	140	276,156	410	SunPower	19.0*
Olmedilla de Alarcon, Spain	2008	60	87.5	270,000	–	Nobesol	16.6*
Moura, Portugal	2010	62	93 (approx.)	376,000	618	Acciona	17.1*
Jamuria, West Bengal	2009	1	1.13 (September 2009–August 2010)	–	–	WBGEDCL#	12.29
Khimsar, Rajasthan	2010	5	7.5 (July 2010–June 2011)	–	–	Reliance	18.80

*Approximate estimates; #West Bengal Green Energy Development Corporation Limited.

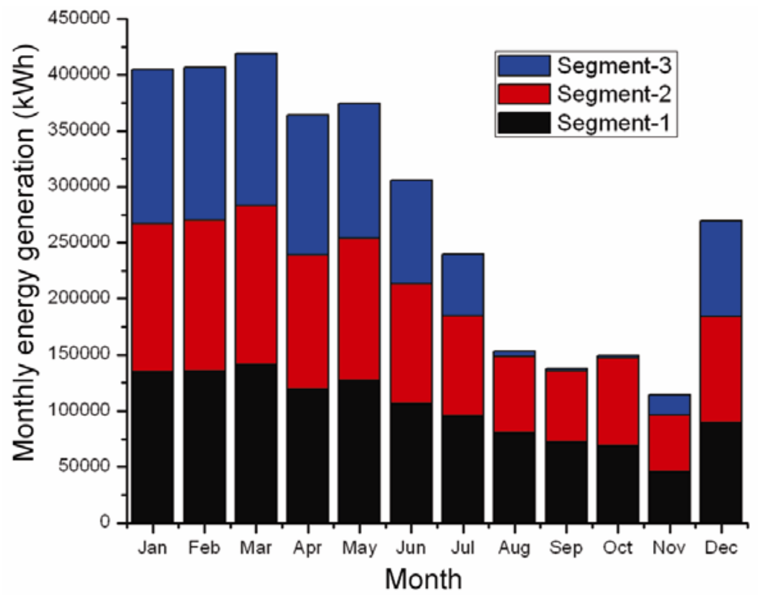

Figure 2. Contribution of all the three segments in the total power generation during 2010.

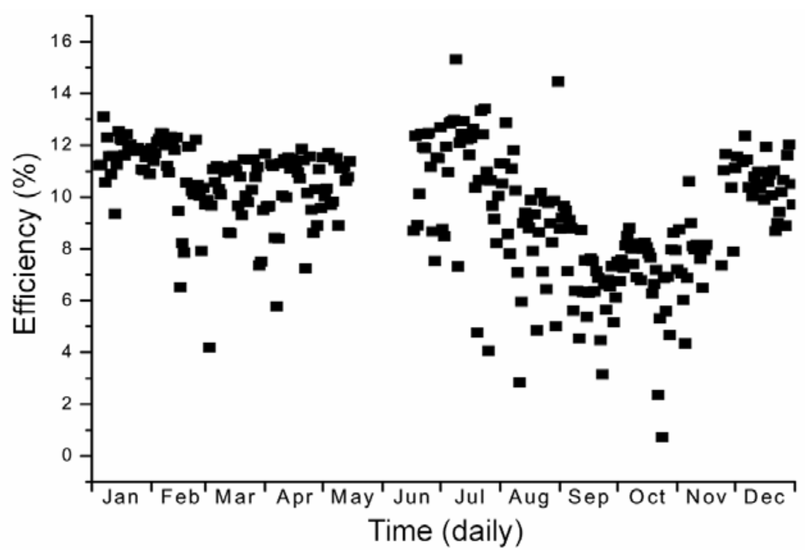

Figure 3. Daily efficiency of segments 1 and 2 for the year 2010.

annual plant load factor (PLF) of Yalesandra plant is 12.7%, which is lower compared to the plants in Table 1, except the West Bengal plant. This is on account of teething troubles associated with inverters and the grid encountered in the first year of operation of the plant.

A pyranometer has been installed at Yalesandra to measure the total solar radiation incident on the solar modules. The daily efficiency of solar power generation is shown in Figure 3. The efficiency was between 10% and 15% on good days (i.e. clear sky, and no grid or inverter problems). The daily efficiency fell below 10% on account of malfunctioning of the grid or inverters during the day. The normal trend is that the efficiency of the plant is high during morning hours, but low during the middle of the day and again starts increasing from late afternoon. This is on account of the impact of temperature variation on the performance of the solar cells. The variation in efficiency of the solar modules (5 min average) with variation in module temperature is shown in Figure 4. The efficiency of the mono-crystalline solar cells decreases from 14.5% at 30°C to 11.5% at 55°C. Hence cooling of the solar modules may be desirable to increase the efficiency. There is a need to evaluate whether additional energy required for cooling the solar modules will be less than the additional energy generated due to higher efficiency and the economics associated with the same.

Discussion

The performance data from the photovoltaic power plants in Kolar and Belgaum provide us an opportunity to evaluate the potential for solar energy to

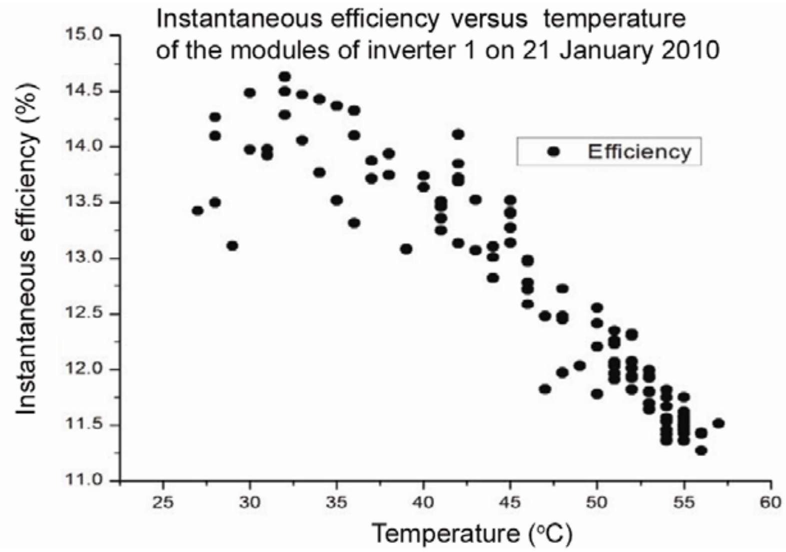

Figure 4. Effect of variation in module temperature on efficiency.

provide the future energy needs of Karnataka. During 2009–2010, KPCL generated about 26,000 million kWh. Based on the data from Kolar and Belgaum, we can assume safely that a photovoltaic power plant rated at 3 MW will generate around 4 million kWh per year if there is no inverter failure. Hence we will need 6500 Yalesandra-type photovoltaic power plants to meet the present electricity needs of Karnataka. The approximate area that would be required is around 70,000 acres. This may seem large, but is less than the area of forests submerged by hydroelectric power plants in Karnataka. There is a need to look for some ways to reduce the area that is required. This can be done by increasing the efficiency of the photovoltaic modules. The nominal efficiency of the monocrystalline silicon cells used in Yalesandra power plant was 15%. The efficiencies for different types of solar cells and modules documented recently are given by Green *et al.*[6]. During the last few years, in new multi-junction solar cells with high efficiency have been manufactured. These solar cells have an efficiency approaching 40%. The high-efficiency solar cells are expensive and hence are used in conjunction with concentrators[7]. These concentrators are mounted on towers to facilitate two-axis tracking and reduce the amount of solar cells required by a factor of 500. Hence, this provides more opportunity to make use of the same land for multiple purposes, for example, the same land can be utilized for grazing, power generation and shading purposes. The major challenge, however, will be with regard to the cost of the solar photovoltaic power plants. The cost of these plants will come down if the economies of scale are brought into play. If a policy decision is taken to install about 1000 MW of photovoltaic power plants in the Karnataka in the next 10 years, the cost can be brought down below Rs 10 crore per MW. This is still about twice as expensive as a coal-based thermal power plant. The effective cost of photovoltaic power plants can be brought down even further if subsidy is sought from international agencies under the Clean Development Mechanism (CDM). Karnataka cannot build more coal-based thermal power plants unless there is an assured supply of coal that has to be imported from other states in India or abroad. Hence photovoltaic power plants may be a better option for Karnataka than using thermal power plants or diesel generators or gas turbines. The generation of electricity by photovoltaic power plants during the day can be used to reduce the demand on hydroelectric power generation, which meets more than 50% of the state's demand presently. Hence the energy from hydropower can be used for a longer period. More detailed analysis of the performance of the Yalesandra plant can be found in Mitavachan *et al.*[8].

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