# EXPERIMENTAL INVESTIGATION ON ONE KW GRID-CONNECTED PV SYSTEM

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***Abstract***
*This study analysed the performance of a 1-kW grid-connected photovoltaic (PV) system. The PV system was located at a latitude of 12°15'N, longitude of 79°07'E, and an elevation of 9 m in Tiruvannamalai, Tamil nadu, India. The system was monitored between September 2014 and August 2015; the generated electricity was fed into the application devices, and the excess was transmitted into the grid connexion. The area requirement of the PV system was 12 $m^2$/kW on a rooftop space. The front and back temperatures of the photovoltaic panel were measured for every month, and the results exhibited that the temperature levels of May and June were maximal and those of the other months were comparatively low. The dc and ac power deviation at 30 °C and 40 °C was 16.85% and 16.2%, respectively. The high and low values of the energy output were 4.59 and 4.23 kWh at 30 °C and 40 °C, respectively. When the estimated and measured values of the energy output of the 1-kW system were 1950.39 and 1622.4 kWh, the deviation was 16.8%. This deviation was observed when using power converters and transmission system of cables with the influence of derating factors. The converted ac energy was directly transmitted to the required part of application device, and the excess was transmitted to the grid system. During and non-sunny days, the energy was received from grid to application devices whenever the energy generated did not reach the required level. This system is most suitable for easily accessible areas in the grid system and for commercial installation in a PV power plant. This study may facilitate in determining the thermal effect of a PV connected to a grid system.*

***Keywords:*** *Grid-connected photovoltaic system, thermal effect, DC power, AC power.*

## 1. Introduction

A Photovoltaic (PV) system is a device used for converting solar energy into electrical energy. It is pollution free and does not require regular maintenance. It can be implemented in remote areas such as in hilly regions because of the easy availability of solar radiation. In India, the energy requirements are fulfilled through fossil fuels and nuclear power plants. However, the fossil fuels may deplete in the future. Therefore, PV energy is vital in providing electricity and a hazardous-free environment, but its initial investment is comparatively higher than nonrenewable energy sources. The PV system is effective in producing electrical energy with low impact on the environment. This electrical energy might be stored in a battery (for standalone PV system), which was used in our application devices based on our requirement. Instead of an energy storage technique, the generated electrical energy can be directly used for end-user applications and the remainder is transmitted to the grid system. The operations are easy and the generating cost is low (Grid-connected system).

The PV grid-connected system is well known to the society. Being entirely dependent on grids connected system based fossil fuel energy generating systems is highly risky. Therefore, the implementation of a PV grid is more reliable because the excess amount of energy generated from the system is transmitted to the grid, and a reverse process is also possible. Nowadays, PV materials with different characteristics are available in the market. Among these, crystalline materials (mono, poly, and amorphous-thin films) are majorly used in the PV field of study because they are easily available and cheap. Based on the requirements, mono and poly-crystalline materials can be used for generating electricity in standalone and grid-connected photovoltaic systems. Although, the technique of using crystalline silicon is outdated, many PV plants are installed through the crystalline module. The main advantage of this technique is that it requires less space; however, thin film-based panels occupy double the amount of space required by the same capacity of PV plant.

The electricity generation by using a PV system reduces the dependence of fossil fuels and controls the global warming [1]. Recent studies have focused on investing in renewable energy sources to reduce the use of fossil fuels in electricity production and avoid the emission of $CO_2$ into the atmosphere [2]. The performance of PV arrays has decreased with losses of 14% or more due to the mismatch and descent of PV sub arrays [3]. In any PV system, the effect of temperature and soiling losses contribute to a total of 5% losses from the normalised power output. These power losses can contribute to PV panel degradations [4]. By comparing and selecting mono and poly-crystalline PV modules with the same electrical configuration, the results exhibited that polycrystalline modules produce more electricity in higher ambient and PV module temperature. These results will facilitate the installation of a PV system in dry climatic conditions, such as in Iran and India [5]. The two PV materials (crystalline and thin film) produce different amounts of energy. The crystalline material produce maximum energy in summer and the energy decreases significantly in winter resulting in declining performance [6].

The crystalline silicon module is widely used in PV installation, and the operating temperature remains an imperative parameter. The PV modules are connected horizontally to reduce temperature differences among them [7]. The PV system was operated in an extremely humid region, and the amorphous thin-films exhibited better performance ratio compared with poly and mono-crystalline PV modules. Under high temperature operating conditions, polycrystalline produces the most satisfactory performance compared with amorphous silicon and monocrystalline silicon PV modules [8]. During the first year of operation, the power production from the PV system is high, whereas it reduced gradually during the remainder of the period because of the system condition and environmental circumstances [9]. The energy produced from the PV system is monitored in hourly, daily, and monthly bases through the website (http:// enerji.kocaeli.edu.tr) of the Kocaeli University, Kocaeli [10]. The maximum energy demand and increase in the electricity supply from a PV system play a vital role in decreasing the price per kilowatt of a system [11]. A microgrid transmission system provides reliability and power quality, which enables it to operate in both grid-connected and standalone systems. In future, all the PV systems will be developed as microgrids to provide full supply of electricity to the end users [12]. Because inverters change the electrical parameters, that is, the power factor and harmonic distortion value, their proper selection and operation can transmit high energy levels to the grid system [13]. The functioning of inverters coupled with the grid-connected system may prevent the frequent disconnection and improve the energy production, and thus be advantageous in the PV installation [14]. India exhibits various climatic conditions. In coal-based climatic conditions (Dhanbad), amorphous silicon is both technically and environmentally feasible; however, in hot climatic regions such as Thiruvannamalai, polycrystalline silicon materials are best suitable [15]. A hybrid power system modeled in combinations of Air breathing fuel-cell and PV system for providing the energy source for the LED lamp based industrial lighting applications. In this Air breathing fuel-cell and PV system have been achieved the overall efficiencies of 69.4% and 27.3% respectively [16].

According to literature reviews, few studies have reported on the experimental and performance investigation of a grid-connected PV system. This paper provides the estimated and measured energy outputs for a period September 2014 to August 2015; the deviation is maximum at non-sunshine periods. The comparisons in the DC and AC energy output were measured for different PV panel temperature ranges. In general, the climatic conditions of India are more suitable for installing the PV system. For increasing the energy demand in the country, the grid-connected system must be implemented, which is more reliable in Indian climates.

## 2. The amenities

The system is located in an area with hot climatic conditions, which is surrounded by hilly regions. The PV system is installed on the roof top of a building.

### 2.1 System location

The average energy production of the system is 6–6.5 kWh/m$^2$/day during normal sunny days (Fig. 1). The installed PV system is located near Chennai, and the average estimated value of the energy production is 5.6 kWh/m$^2$/day. The PV panel system is located at latitude 12°15’N, longitude 79°07’E, and elevation 9 m. The distance between the roof's edge and mounting structure is maintained at a minimum of 0.6 m. In India, the tilt angle is maintained at 11–13° north–south facing [19].

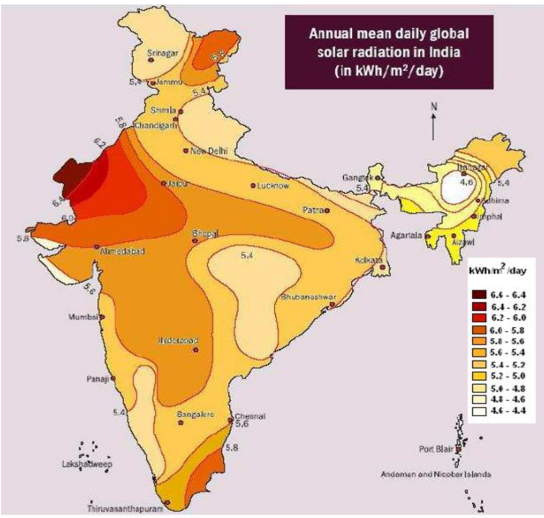


Fig. 1. Annual mean daily global solar radiation in India [18].

### 2.2. Grid-connected PV system

The grid-connected PV system includes a solar PV array and support structure, solar grid inverter, net-metre, protection devices and cables. The block diagram representation of the grid-connected PV system is shown in Fig 2. The PV system is installed on the rooftop of a residential building in Tiruvannamalai in India. The PV system consists of a 4-polycrystalline PV module, and covers a total of 12-m$^2$ area, with an installed capacity of 1 kW. The Yingli Yl245P-29B-PC solar polycrystalline module specification details [19] are provided in Table 1. The properties of the PV panel are given in Table 1. The panel array, solar grid inverter, net-metre, and DC distribution box used to fulfill the requirement of 1-kW grid-connected PV system are shown in Figs. 3 (a)–(e).

### 2.3 Grid-connected inverter

The inverter is used to convert the AC power from the solar PV output DC power. This inverter starts functioning from morning and synchronises with the grid to feed the power. It automatically shuts off in the evening or non-sunny periods. The inverter displays the PV system power feed into the grid, system voltage, and total amount of energy production value on the screen. The electrical parameter fluctuation is synchronised through the inverter, and the standard value is exported into the grid system.

Fig. 3. (a) solar photovoltaic panel array

Fig. 3. (b) DC distribution box


Fig. 3. (c) solar grid inverter

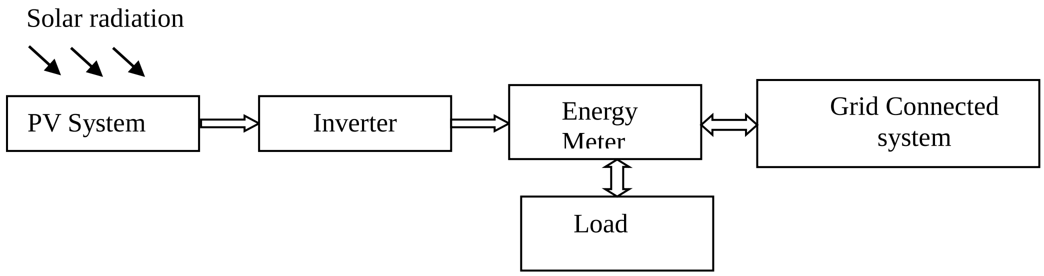


Fig. 2. Block diagram of a grid-connected photovoltaic system

Table 1. Properties of the PV panel

| Manufacturer | Model Number | Type of solar cell | $P_{max}$ (W) | $V_{max}$ (V) | $I_{max}$ (A) | $V_{oc}$ (V) | $I_{sc}$ (A) | η (%) | Dimensions (Inches) |
|---|---|---|---|---|---|---|---|---|---|
| Yingli Solar | Yl245P-29B-PC | Poly crystalline | 245 | 30.2 | 8.11 | 37.8 | 8.63 | 15 | $64.9 \times 38.98 \times 1.57$ |

Fig. 3. (d) solar generation metre

Fig. 3. (e) Bidirectional metre (net metre)

## 3. Methodology

The standalone PV system is useful for generating electricity during sunny days. During non-sunny days, storage devices or other energy producing techniques must be used. To avoid this problem, the PV system is connected with the grid system for transferring excess energy during non-sunny days and to obtain backup energy for the electrical load. In this study, 1 kW of the PV system is connected with the grid to provide the electrical supply for devices (Household applications). The entire system was monitored for measuring the atmospheric temperature, panel temperature, dc and ac power and energy generation during September 2014 to August 2015.

## 4. Results and discussion

The temeperature difference in the panel greatly influences the dc and ac output power (Fig. 4). A 30 °C, the dc and ac power are 953.72 and 799 W, respectively and the total difference in output is 16.85%. Similarly, at 40 °C, the difference in the output of dc and ac power is 16.2%. The derating factors play a vital role in decreasing the ac output power during the converting process. Each connecting cable and auxiliary item dominate the output values.

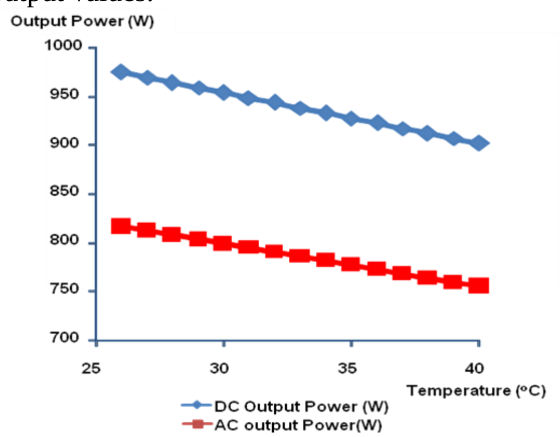


Fig. 4. DC and AC output power changes with Temperature.

Fig. 5 plots the variations in the energy output with varying temperature in a PV panel. The maximum and minimum energy outputs are 4.59

and 4.23 kWh, respectively. The difference in the devation level is 7.43% with varying temperature alone. Thus, the effect of tempareture on the PV panel decides the performance outputs, and this occurs in summer and winter seasons.

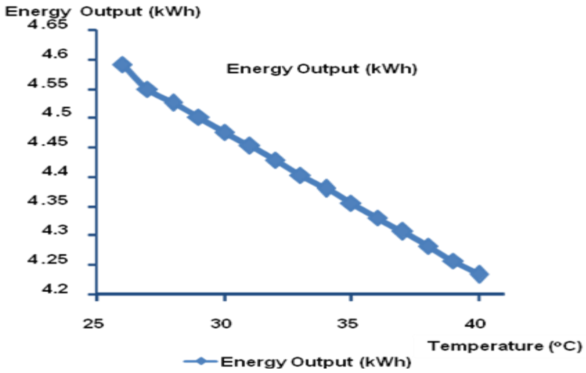


Fig. 5. Energy output for various temperature range.

On the basis of the empirical relation, the solar irradiation on the PV panel changes the output power with the influence of temperature (Fig. 6). When the solar irradiation on the panel is increased, the temperature level increased significantly. The obtained devaition level of the estimated and generated values gap is due to the temperature and behaviour of the PV panels. The modelling is estimated throughout of that year.

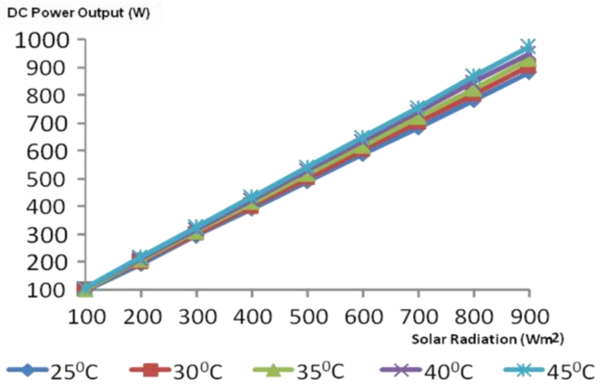


Fig. 6. DC output power with varying solar radiation

Fig. 7 depicts the month-wise temperature rate of the front and back of the PV panel at a specified location. The peak temperature value 34 °C of the front side is observed in May and June and the lowest 28 °C is observed in December. Similarly, the backside temperature is 32 °C in May and 26 °C in December.

The total power electrical production is 1950.39 kWh, whereas the measured value of production 1622.4 kWh. These results show a total difference of 16.8%. Fig. 8-9 illustrates the daily average and month-wise comparitive analysis of both the data.

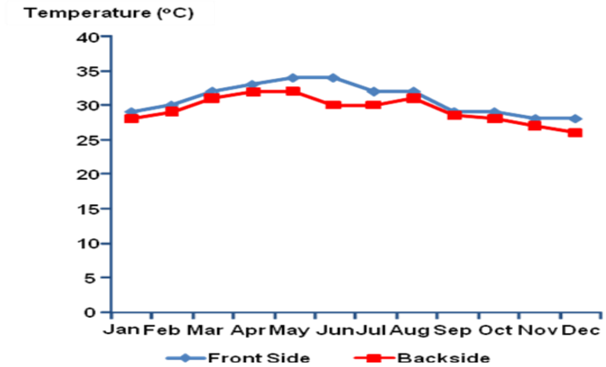


Fig. 7. Temperature profile of the front and back side of the PV panel for the entire period of the experiment.

A considerable difference is observed during summer, when sunshine period and day length are maximum. The estimated amount of energy does not signficantly differ with the measured value during the colder months and which is about 12.44%. This highlights that the measured energy value is always lesser for all the months. The panel's electrical paramters decide the system output.

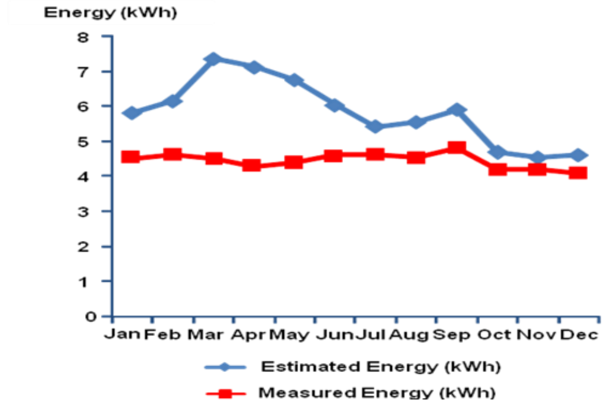


Fig. 8. Estimated and measure values of energy on daily average for the entire year of the experiment.

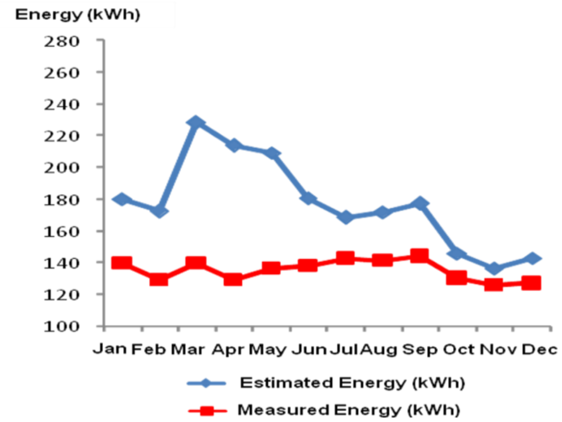


Fig. 9. Estimated and measure values of energy on monthly average for the entire year of the experiment.

## 5. Conclusion

The dc and ac power deviations of a particular temperature were 16.85% and 16.2%, respectively, and the estimated energy output were 4.59 and 4.23 kWh at temperatures of 30 °C and 40 °C, respectively. The overall energy production of the estimated and measured values of the 1-kW system between September 2014 and August 2015 were respectively 1950.39 and 1622.4 kWh, and the deviation is 16.8%. During the experiment period, the front and back side temperatures of the PV panels, dc and ac power, estimated and measured output energy with the effect of temperature variations in the PV system were recorded. During the experimental period, the monthly average temperature was highest in May and June. Despite the high insolation levels, the average relative humidity and suitable selection of solar cell materials can improve the system performance in Indian climatic conditions.

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