Performance Investigations of Hybrid Solar Photovoltaic – Thermoelectric (Hybrid PV-Te) System

Yogesh N. Nandanwar1 Sandeep S. Joshi2 Rahul S.Dixit3
1G. H. Raisoni College of Engineering, Nagpur 2,3Shri Ramdeobaba College of Engineering and Management, Nagpur

Abstract— The performance of the solar cell is strongly depends on it’s operating temperature. The high operating temperature of the solar cell causes the thermal agitation and in turns the loss of free carriers in the crystalline PV modules. The electrical conversion efficiency and the power output of the solar cell decreases with an increase in the working temperature. Exhaustive work based on the performance improvement of PV modules using various cooling methods is reported in many literatures so far. In the present work, an experimental work to harvest the heat from solar PV module and to use it in the thermo-electric converter is described. In the designed system, the series connected solar cells are mounted on an aluminum base and Bi-Te thermoelectric modules are attached to the dark side of the base. The aluminum base creates the hot junction for the thermo-electric (TE) modules and the cold junction is achieved by circulating water. The temperature of PV cell reduces as the heat is transferred from the PV module to the circulating water via TE modules. This also creates the temperature difference across the two junctions by Seebeck effect. In this study, the performance of solar photovoltaic cells, PV – TE hybrid system is studied. The net efficiency of the system was found to be around 23%. The constructional details and the performance analysis are presented in this article.

Key words: Hybrid Photovoltaic – Thermoelectric System, PVT System

I. INTRODUCTION

To quench the voracious energy thirst today, solar energy is emerging as the most reliable source of renewable energy. Many researchers around the world are developing the system based on solar energy. Since long, solar energy is used to produce the electricity by solar photovoltaics (PV). The current research is focused on the cost reduction and efficiency improvement of the PV. The operating temperature of solar cell is identified as one of the performance influencing parameters in the photovoltaic conversion process. The output of the PV cell decreases as the cell temperature increases. In addition, there could be permanent structural damage of the module if thermal stresses remain in for longer periods. Significant work is documented in the literature showing the dependency of operating temperature on the output of PV cells. Review papers of Swapnil Dubey et al. [1] and E. Skoplaki et al. [2] gives a comprehensive review of different correlations showing temperature effect on PV performance investigated by many researchers. Keeping low operating temperature of solar PV cells could improve its performance and life. This leads to the discovery of combined photovoltaic-thermal systems (PVT). Combined photovoltaic - thermal system (PVT) is considered as appealing invention in solar technology. In the mid of 1970s the concept was documented and Wolf [3], Florschuetz [4, 5], Kern and Russell [6] reported theoretical and experimental studies in their publications. At the beginning, thermic fluid, especially water and air were being used in different arrangements to extract the heat from the solar cell.

In the recent past, a new technique known as a combined photovoltaic thermal system with integrated thermoelectric generator (PVT-TEG) has been invented. In this technique, the hot junctions of the thermoelectric (TE) modules are attached to the solar cells thereby removing some heat from the solar cell. The cold junctions of these modules are maintained at lower temperatures by some cooling method. Along with PV, the electricity is also produced by these modules proportional to the temperature difference across the two junctions by Seebeck effect. Beside increase in the electricity generation, this technique helps to keep the solar cell at low operating temperatures thereby improving its efficiency too. In addition, in the effort to keep the cold junction of TE modules at low temperature, some heat is also recovered from the system for separate utilization. Thus the net output of the system would be PV electricity + TE electricity + recovered heat.

In the recent past, many such systems have been studied, developed and reported in the literature. Some of the recent work in this context is described in the subsequent text. The combined use of photovoltaic cell and thermoelectric power generator modules (PV-TEG) is modeled and analyzed by, Hamidreza Najafi et al. [7]. A comprehensive heat transfer model is prepared to simulate the performance of the PVT –TEG air based system. The air was used as a medium to extract the heat from both solar cells and cold junction of the TE module. The performance of the system is simulated considering various operating conditions and different meteorological data. 4% improvement in the electrical efficiency was reported in this study. W.G.J.H.M. van Sank [8] reported a model of roof mounted PV-TE system for the meteorological conditions of Spain and Netherlands. In this system, the TE modules were directly attached to the PV modules and only focus was given to the combined electrical output. Considering the typical figure of merits of 0.004 K-1 of thermoelectric material, the researchers claimed the annual energy yield of 14.7–11% in this system. Wei He et. al. [9] investigated the performance of the heat pipe assisted PV-TE system. The specially designed heat pipes were used to transfer the heat from PV to TE and from TE to the working fluid. The electrical efficiency of 16.7% and the thermal efficiency of 23.5% were reported in the experimental study. Apart from these systems, some researchers also studied the possibility of concentrated solar power for PVT-TEG system. E.A. Cha’vez-Urbiola et al. [10] experimentally investigated the performance of the concentrated solar PVT-TEG system.

All rights reserved by www.ijsrd.com
operating in the temperature range of 50-200°C. The study concludes that, for temperature difference of 155°C, the TEG efficiency was about 4% and as compared to separate systems, the efficiency of combined system was found better. In the present work, the experimental set up is designed to investigate the performance of the PVT-TEG system.

II. METHODOLOGY

The principal objective was to check the performance of PV system using attached TE modules. Series connected thirty poly C-Si solar cells of size 52mm × 30 mm × 400μm were used as PV module. All the solar cells were mounted on the Aluminum plate. Eight thermoelectric modules of Bismuth Telluride of size 40mm × 40mm were thermally connected to the bottom of the aluminum plate. To extract more heat from the cold junction of the thermoelectric modules, specially designed aluminum heat sinks are attached. The top side of the PV cells was covered with the glass material. The cold junctions of the TE modules were achieved by immersing the attached heat sinks in a water flowing channel. The block diagram of the whole assembly is shown in fig.1. Whereas fig.2 shows the actual photograph of the experimental set up.

III. EXPERIMENTATIONS

The experiments are conducted to investigate the performance of the system with and without cooling. The system performance is determined on the basis of power output of PV and TE systems combined and separated. For the estimation of power output, the parameters like, open circuit voltage of PV, short circuit current of PV, I-V characteristics of PV, power output of TE modules, Temperatures at Various locations in the system, flow rate of water through cooling channel etc. are measured using calibrated measuring instruments. The experiments are conducted for following three conditions.

Case – I Without attachment of TE modules: This condition is used as the reference condition to compare the performance of the PVT-TEG system. No TE module is attached to the aluminum base plate of PV. The cell temperature, Voc, Isc of the PV module were recorded. By plotting the I-V curve, the maximum power output of the PV module was determined.

Case – II With the attached TE module (PV –TEG system) without cooling: The TE modules are attached to the aluminum base plate of the PV module. The similar experimentations were performed. Along with PV, the power output of TE modules was also recorded. Case – III With attached TE modules with cooling (PVT-TEG system): Here, the heat sink is attached to the cold junction of the TE modules. The other end of heat sink is embedded in the water cooling channel. The power output of PV, TE was recorded. In addition the cell temperature, and the heat gained by the cooling water is also recorded.

The experimentations were carried out for more than fifteen days in the month of April 2015. The average value of solar radiation intensity was considered for the calculations. The reflection losses from PV, convective heat losses from the walls of cooling channels were not considered in the calculations.

Efficiency of PV is calculated using

\[ \eta_{pv} = \frac{\text{Power output of PV (W)}}{\text{Radiation intensity (W)}} \]

The output power of PV is measured using the appropriate circuit arrangement of I-V curve generator. On the similar lines the efficiency of TE modules was calculated. While calculating the net system efficiency, the heat gained by the cooling water is also considered. This heat gained by the water is determined using the energy balance relation,

Heat Gained by cooling water = \( m \times C_p \times \Delta T \)

The tap water under natural circulation is used for the cooling purpose. The mass flow rate is kept constant throughout the experimentation. In fact a good analysis is possible if the mass flow rate is varied to keep the PV cell temperature at some constant low temperature.

IV. DISCUSSIONS AND CONCLUSIONS

As stated in the previous texts, the power output of the system is recorded in three different conditions. The variations of power output of PV, TE separated and combined over an entire day are shown in the subsequent texts. Fig 3 shows the power output of PV in all the three cases.
Fig. 4: Power output of TE module alone over a day
Fig 4 the performance of the TE modules improves significantly if the cold junction is cooled. Fig. 5. Shows the net electrical power output of the PV-TE system in all the three cases. The total power output of the PV-TE system is maximum when the cold junction of the TE modules is continuously cooled using water.

Fig. 5: Total Power Output of the PV-TE systems over a day
In the first case, the performance of PV module alone was investigated. In this case the average power output of the PV module is found to be 11.8 W and the net efficiency of 13.9% was recorded. In this case the average PV cell temperature of 48°C was recorded. In the second case, the hot junctions of the TE modules were attached to the PV modules. Some of the heat from the PV modules was transfer to the TE modules. In this case, the reduction of 5°C average PV cell temperature was recorded. In this case the output of PV module recorded was 12.5 W. The difference of (12.5 – 11.8 = 0.7 W) was observed in the output of PV modules. In addition, the thermoelectric power generation of 0.11 W was also recorded. The net efficiency of 14.8% was recorded in this case. In the third case, the heat sinks were attached to the TE modules at the cold junction and are immersed in the water channel. In this case, the average PV cell temperature reduced to 38°C. The average power output of 13.9 W and 0.38 W of PV and TE were recorded respectively. The net electrical efficiency of 16.8% was recorded in this case. In addition, keeping mass flow rate of cooling water as 1 lph, an average 5 W of heat gain was also achieved in this case. Considering this additional heat gain and common energy input of average solar radiations on the system, the net efficiency of 23.7 % was recorded.

In summary, it can be concluded that the PVT-TEG systems are feasible and if properly designed, good net efficiency of the system may be achieved. Use of high thermal conductivity materials for PV cell substrate, heat sink can improve the performance. Also, instead of water some other heat transfer fluid or specially designed heat pipes can gives best results. Such systems are reliable and can be constructed for domestic applications in large scale.

REFERENCES