Experimental Study on Solar Parabolic Dish Thermoelectric Generator

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***Abstract*-The applications of solar dish and thermoelectric generator have the research potential as green and clean energy generation from solar thermal route. In this paper, an attempt has been made to conduct an experimental study on small scale solar parabolic dish thermoelectric generator. The solar parabolic dish collector is fabricated using an unused satellite dish antenna fitted with polished aluminum sheet as concentrator surface. Thermoelectric generator consists of commercial thermoelectric modules embedded between the receiver plate and water cooled heat sink which is placed on the focal plane of manual tracking parabolic dish collector. The concentrated solar radiation and water cooled heat sink is the driving potential to generate electricity, various operating parameters like receiver plate temperature, power output and conversion efficiency with respect to solar radiation are studied. It is found that the receiver plate temperature is significantly affecting the power output. Also, in this study it is identified to reuse the unused dish antenna for solar collector and coupled with commercial thermoelectric module is simple fabrication method easy to adopt in the rural techno craft for small scale power generator to meet the isolated energy demands.**

Keywords- Solar Parabolic Dish Collector; Thermoelectric Generator; Power Output; Heat Sink

I. INTRODUCTION

Green and clean energy providing technology main focuses on the world problems of green house gas emission and energy shortage. Solar energy is attractive to substitute for the conventional fuels due to its abundant availability, clean and safe source of energy in its conversion processes. Thermoelectric generator (TEG) is solid sate direct energy conversion device, it is simple in construction and easy to fabricate by sintering process. It has many advantages such as highly reliable, having no moving parts and environmentally friendly, when compared with conventional power generators. There have been considerable emphases on the development of small capacity TEGs for variety of applications such as aerospace, military, medical, and self sufficient energy system over the last few years. More recently, there is a growing interest for standalone power generation system combining TEG using concentrating and non-concentrating type solar thermal collector (Ono and Suzuki, 1998; Rowe, 1999). Thermodynamic analysis of solar parabolic dish thermoelectric power generator studied for design parameters and a operating parameters and found that exergy loss found maximum at thermoelectric generator due to its lower figure merit value of thermoelectric generator (Eswaramoorthy and Shanmugam, 2010).

In the case of TEG for combination of solar thermal collector for power generation, there have been many conceptual designs of power conversion system which are potentially capable of obtaining application in this area (Suzuki and Daisuke Tanaka, 2003; Suzuki, 2004). These designs involve the consideration of the maximum power output and conversion efficiency with different thermoelectric heat exchanger. The performance evaluations of TEG have been theoretically carried out by modeling approach (Douglas and Gregory, 2004). The results show that TEG promising options for waste heat recovery and solar thermal collectors. The economic viability of a TEG may be improved significantly when used for solar thermal collector that could reduce the device cost and increase the conversion efficiency of the device. Therefore, one of the more attractive options for solar dish collector is to construct the TEG device by incorporating the relatively simple water cooled heat sink with commercial thermoelectric modules. The developed TEG unit with commercial thermoelectric modules made of bismuth telluride alloys for an anticipated maximum generation of about 60-85 *W.* In this work an experimental investigation to be made on the solar parabolic dish thermoelectric generator for small scale power generation and its performance characteristic over the beam radiation to be made at Tiruchirappalli (Latitude 78.43E and Longitude 10.45N).

II. EXPERIMENTAL SETUP

The system consists of the thermoelectric modules, the heat sink device, the receiver plate, and manual tracking arrangement for the solar parabolic dish collector. The stainless steel box acts as heat sink and their flat surface having its surface area of 0.08 m^2 and sheet thickness of 2 *mm* which is opposite to the lid which is attached to cold side of thermoelectric modules. The cold water is circulated to the heat sink to maintain the cold side temperature at minimum; the cold water is drawn from the over head tank. The flow rate of cold water is adjusted manually by the valve arrangement in order to maintain the constant outlet temperature of the water. So, we can maintain the mean temperature of water is considered as the heat sink temperature. The receiver plate is made aluminum sheet have 3 *mm* thickness, its surface area of 0.1 m^2 and its surface was coated with dull black paint to absorb the concentrated solar radiation from concentrator, the receiver plate as heat sources is attached to the hot side of thermoelectric modules.

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A. Solar Parabolic Dish Collector

The higher cost of present solar dish concentrator system is limiting the users for utilization of solar thermal system. The reductions in the system cost become possible by using outdated satellite dish antenna. An unused satellite dish made of aluminum frame has been adopted from the Campus Communication Network of NITT. The aluminum wire mesh was replaced by polished aluminum surface. The receiver plate was placed at the focus. A manual tracking mechanism arranged at the bottom of the dish helped to track the sun. The dish has the open mouth diameter of 3.56 *m*, focus of 1.11 *m*, height of 70 *cm*, and aperture angle of 69°. A rectangular sheet of thickness 0.3 *mm*, width 0.61 *m*, and length 1.524 *m* was cut diagonally into two pieces. The reflector surfaces were made by 20 triangular pieces of aluminum sheet polished on one side, fixed on the aluminum rib by a set of bolts and nuts by keeping the polishing side facing the sun. The flat receiver plate made of aluminum sheet with 30 *cm* square in size with thickness of 3 *mm* to absorb the concentrated solar radiation from the *PDC*. The absorbed heat energy in the receiver plate is transmitted to the hot side of thermoelectric modules after the convection, radiation, and conduction losses. The receiver assembly, which comprises heat sources, thermoelectric modules and heat sink is attached to the cross base of two mild steel plates 5 *mm* thick and 32 *mm* long, which in turn is fixed to one end of steel pipe of 24 *mm* as outer diameter and 1.12*m* long.

B. Thermoelectric Generator Unit

The TEG unit consists of the receiver plate made of aluminum sheet; thermoelectric modules are made of bismuth telluride and the heat sink made of stainless steel materials as shown in the pictorial view (Figure 1).

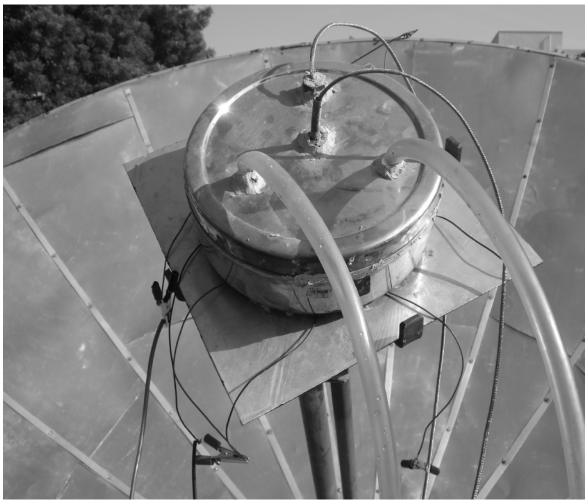

Figure 1 The arrangement of TEG setup

Four thermoelectric modules with total rated power generation of 58.8 *W* are embedded between the receiver plate and the heat sink. Commercial thermoelectric modules having the dimension of 56 *mm* x 56 *mm*, a matrix of one hundred and twenty six thermoelectric couples (p-type and n-type), generate electric power of 14.7 *W* when the temperature of 230℃ and 30℃ and heat supplied is 350 *W*. Thermal grease is placed between all of the thermoelectric modules /receiver plate and heat sink interfaces in order to minimize the thermal contact resistance. In order to reduce the side heat losses from TEG unit, insulation board with thickness of 9 *mm* is provided. The receiver unit has diameter of 1000 *mm* and thickness of 280 *mm*.

C. Instrumentation

Operating parameters such as receiver plate temperature, heat sink temperature and ambient temperature are measured by using *K* type thermocouples made chromel-alumel having an accuracy of 0.1˚*C* connected to the measuring points. Solar beam radiation is measured by the pyranometer instrument (Make: Energy and Environmental Ltd, Cochin) with an accuracy of 0.1% and the wind velocity is measured by the wind anemometer (Model: FESTO 45). The water flow rates in the heat sink are measured by volume of the collection over the time methods in a closed vessel. The circulating water in heat sink draws from the over head tank and its pressure loss and pumping power is not considered in our primary interest of this study. The generated voltage, electrical current and connected electrical load of TEG are measured by using the digital multimeter (Make: MASTECH, China) with an accuracy of 0.2% of each electrical parameters.

III. RESULTS AND DISCUSSION

Solar parabolic dish thermoelectric generator was tested at outdoor condition on clear sun days at Tiruchirappalli, India. The main operating parameters like receiver plate temperatures, solar beam radiations and electrical powers (current x voltage) are recorded. The performances of the TEG are evaluated in terms of the electrical power output and the conversion efficiency from the following relations. The electrical power output from thermoelectric generator for connected load resistance and

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voltage generated between the two terminals is given by

$$P = \frac{V^2}{R_L} \tag{1}$$

$$\eta = \frac{P}{Q_h} \tag{2}$$

where *P* is Electrical power output from TEG, *V* is generated voltage from TEG, R_L is the connected electrical load, and Q_h is heat input to TEG from the solar parabolic dish collector which can be computed from the following relation,

$$Q_h = \eta_o C_R A_r I_b \tag{3}$$

Where η_o is the optical efficiency of the solar dish collector, A_r is the surface area of the receiver plate. I_b is the beam radiation, and C_R is the concentration ratio. Experiments are conducted for a range of operating conditions as follows; the receiver plate temperature is varying between 350 *K* and 650 *K* and the mean temperature of heat sink 300 *K* to 310 *K*. The overall measurement uncertainty of the power output is 3.2%, and that in calculating the heat rate through the heat exchanger is 3.5%. The maximum uncertainty in the conversion efficiency is 6.7%. In addition, the relative heat loss from TEG is estimated to be approximately 3.5% or less based on the insulation conductivity and thickness. Experimental performance evaluation of the TEG system is carried out on the basis of data derived from tests.

The experiments conducted on 14.7.2010. Figure 2 shows the variation of receiver plate temperature over the measured solar beam radiation. The receiver plate temperature obtained was maximum 602 *K* at the solar beam radiation of 950 W/m^2. The minimum temperature of the receiver plate obtained was 375 *K* at solar beam radiation value of 430 W/m^2. The following correlation with R^2 = 0.98 was obtained to compute the receiver plate temperature for any solar beam radiation that can be computed using the correlations developed from the experimental data,

$$T_p = 0.0002 I_b^2 + 0.0231 I_b + 324.14 \tag{4}$$

The electrical power output from the solar parabolic dish thermoelectric power generator over the beam radiation is illustrated in Figure 3.

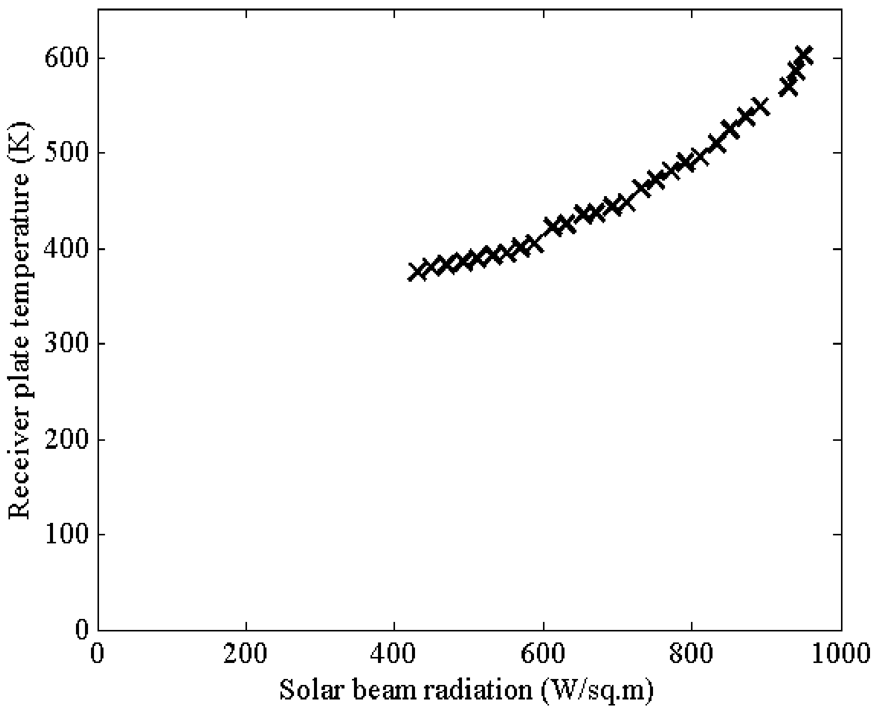

Figure 2 Receiver plate temperatures as function of solar beam radiation

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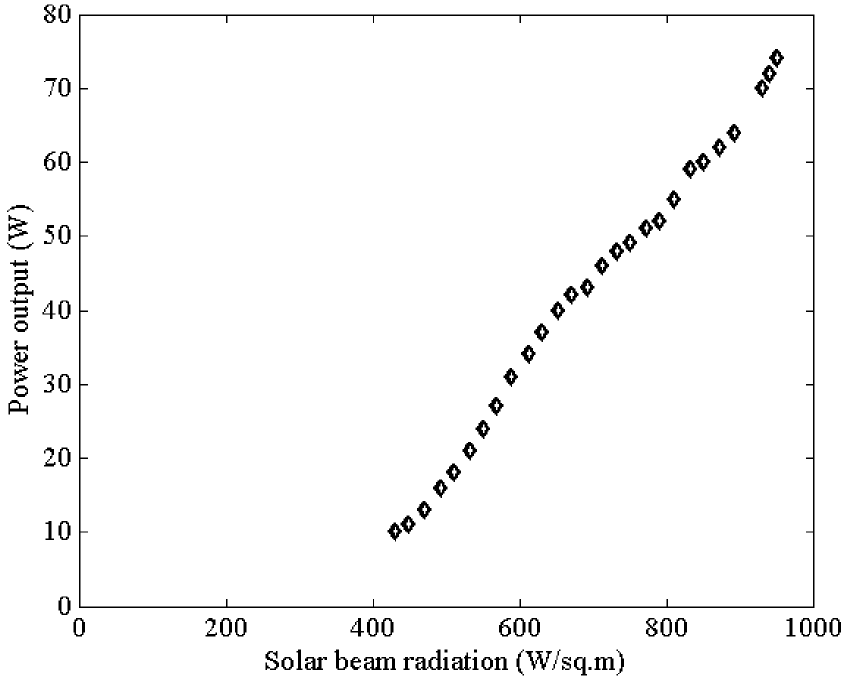

Figure 3 Maximum power output as function of solar beam radiation

The measured current and voltage for constant resistance of 4 Ω in terms of electrical power generation. The maximum power output of 68 *W* obtained when the solar beam radiation the maximum value at 950 W/m^2 with the receiver plate temperature of 602 *K.* The minimum power output of 11 *W* was obtained when the solar beam radiation value at reaches 430W/m^2 with the receiver plate temperature of 375 *K.* with R^2=0.96 was electrical power output over the beam radiation, can be computed from the following model

$$P_{teg} = -0.0002I_b^2 + 0.3304I_b - 103.31 \quad \textbf{(5)}$$

Figure 4 illustrates the overall efficiency of the solar parabolic dish thermoelectric power generator over the beam radiation values.

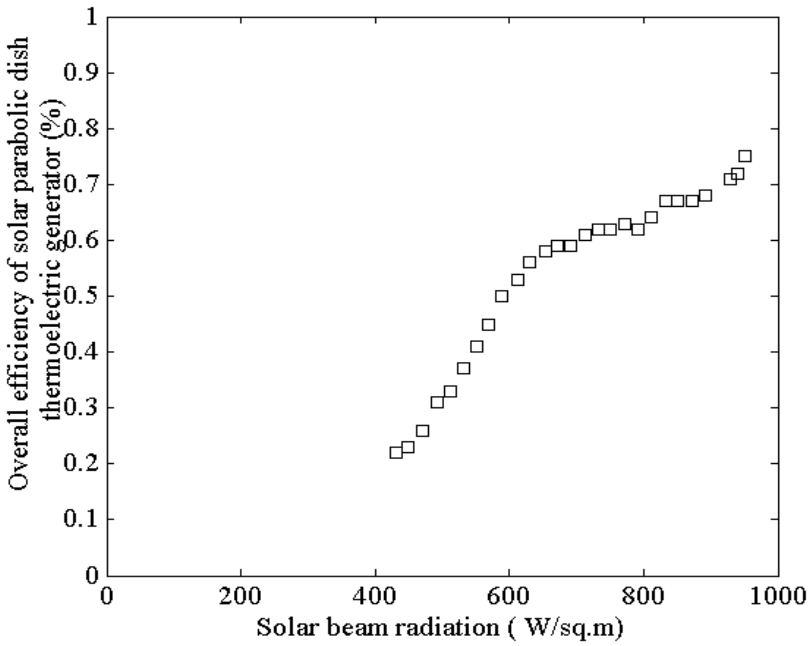

Figure 4 Overall efficiency of solar parabolic dish thermoelectric generator as function of solar beam radiation

The maximum efficiency of 0.78% was obtained when the solar beam radiation is maximum value at 950 W/m^2. The minimum overall efficiency of 0.22% obtained when the solar beam radiation had the value of 431 W/m^2. The overall

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efficiency of the solar parabolic dish thermoelectric power generator over the beam radiation can be computed from the following model 0.99.

$$\eta_o = -2e^{-6I_b^2} + 0.004I_b - 1.0649 \tag{6}$$

The Equation (6) can be used to compute the overall performance of the solar parabolic dish thermoelectric generator.

IV. CONCLUSIONS

The power generation from the combined system of solar parabolic dish collector and commercial thermoelectric modules was developed. The results of absorber plate temperature, power output and overall conversion efficiency are derived from the experimental investigation are reported for the different solar beam radiations. The performances of the systems are greatly affected by the heat sink temperature. Correlations for determining the plate temperature, electrical power output and overall conversion efficiency have been developed in terms of solar beam radiation. The experimental investigation shows that the generation of electricity from the low cost solar parabolic dish collector and commercial thermoelectric modules is a feasible option and also it is highly suitable for isolated energy demand where the conventional grid is not feasible or available.

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