Study of Oscillatory Flow Heat Exchanger Used in Hybrid Solar System Attached with Fixed Reflectors

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Abstract- Simple hybrid photovoltaic/thermal or PV/T solar water systems are commercially unattractive due to its less combined efficiency, low concentration ratios, long payback period etc. The augmentation of solar radiation on module surface is the easy and cost effective method to increase concentration ratio and combined PV/T efficiency of simple hybrid solar system. This can be accomplishing by design, fabricating and attaching the aluminum reflectors to module sides of hybrid solar system. This paper offers design and performance analysis of oscillatory flow heat exchanger used in hybrid system fitted with aluminum reflectors. The investigational results such as performance efficiencies of photovoltaic, thermal, and combined PV/T system over a range of operating conditions are determined and assessed for latitude of Mumbai. At solar radiation of 929W/m^2 and water flow rate of 0.042 kg/sec, the present hybrid system has generated combined PV/T efficiency of 65.10 % with PV efficiency of 12.50%. Recommendations for enhancing performance of hybrid system with reflectors have discussed in the paper.

Keywords-Low concentration ratio, Long payback period, Combined PV/T efficiency, Flat reflectors, Oscillatory flow heat exchanger.

1. Introduction

Photovoltaic module absorbs solar radiation to generate electricity, which increases its temperature. Cooling of module improves generation of electrical power, efficiency and its operational life. In general, module has cooled by flowing cold/tap water through heat exchanger has attached at bottom side of module. This heat exchanger is termed as PV absorber surface that absorbs heat from heated module, and cools it at reasonable temperature. In hybrid solar system, simple PV module and thermal collector unit are mounted together to facilitate simultaneous conversion of solar radiation to electrical and thermal energy from single system. This discussion has showed that, hybrid solar system generates higher combined energy per square meter area of module, and could improve cost effectiveness of simple PV modules if the cost of thermal element is low.

In the present scenario, materials cost of photovoltaic cell constitutes 50 % to 60% of total cost of commercial PV module [1]. As result of technological developments and market competition, PV module prices have started declining since the last few years [1]. Currently, the cost of mono crystalline PV module is as high as US dollar 1.12/watt to 1.70/watt. Significant measures are required to reduce the cost of PV power, for the widespread and commercialization of PV technology, by reducing cell material.The different techniques such as use of thinner wafer, thin-film solar cell technologies, and concentrator techniques have incorporated by many module-manufacturing companies to reduce the overall price of PV modules. As per information obtained from manufacturing companies, these techniques have found useful to reduce PV cell material consumption per watt of generated output power. In the concentrator technology, optical reflectors could replace expensive PV cell area by the use of cheaper reflector materials such as glass mirror, aluminum sheets or foils, and acrylic mirror sheets. Executing these techniques, performance of simple module will enhanced due to more solar radiation striking module surface during operational period. The idea to use solar concentrator with modules is simple, but it is difficult to achieve high level of concentration ratio using the said technology. The high concentration ratio puts stringent constraints on solar cell's heat dissipation capacity during its service life. However, it is possible to use low concentration optics with simple modules in static mode to eliminate continuous module tracking. Based on this idea, flat reflectors are attractive selection to reduce price of photovoltaic output power. Flat reflectors are static concentrators, where solar intensity has enhanced by fitting reflectors to module sides.

Kostic et al. [2] have carried out investigational studies using sheet and tube type heat exchanger used in PV/T water collector, fitted with aluminum concentrators. In this study, it had found that with aluminum sheet concentrators fixed at 10^0 and 56^0 to vertical plane of PV module, the electrical and thermal energy were increased by 8.6% and 39% compared to simple module. Aluminum foil concentrators added with simple PV/T system had produced 17.1% surplus PV energy and 55% additional thermal energy than conventional module.

Othman et al [3] have designed and studied seven types of heat exchangers namely, direct flow, oscillatory flow, serpentine flow, web flow, spiral flow, parallel-serpentine flow, and modified serpentine-parallel flow by simulation techniques. After simulation, the results showed that spiral flow PV absorber surface was produced highest thermal efficiency of 50.12%, with module efficiency of 12.8%, than other configurations.

The performance of simple module has improved by passing water over its top surface to cool it, as noted by Hosseini, et al [4]. Due to cooling effect, the operating temperature of water-cooled PV module declined as against the simple module. The heat transferred from the top side of module to the water film flowing over its surface increased the water temperature. Due to cooling effect, the experimental result showed that electrical performance of the combined system increased 33% higher than simple module.

In the research work of Kamaruzzaman, et al [5], three PV/T water collectors, namely, direct flow, parallel flow and split flow had designed and their thermal performance compared for various tilts of collectors. The experimental result showed that the split flow PV/T collector produced the highest thermal power of 51.4% than 50.8 % and 50.6% for direct flow and parallel flow respectively.

Tripanagnostopoulos et al [6] have performed experimental studies on hybrid systems, with and without glazing, and with and without reflectors at operating temperatures of 25^0C, 35^0C, and 45^0C respectively. This study has shown that hybrid system, with glazing and flat reflectors at operating temperature of 25^0C were generated highest annual electrical energy of 167.98 kWh/ m^2 y with electrical efficiency of 10.21% respectively. At same period, modified hybrid system generated highest annual thermal energy of 831.75 kWh/m^2 y with thermal efficiency of 50.57%.

Palaskar and Deshmukh [7, 8] have reviewed the literature on research, development and selection of various PV absorber designs, materials and use of concentrators for higher energy output of hybrid solar systems. The review showed that overall system performance of hybrid system could improve by applying above discussed techniques to simple hybrid systems. After critical review and analysis, it was found that the spiral flow heat exchanger made from copper and fitted with reflectors was produced higher combined PV/T efficiency than simple hybrid systems. This system will have better commercial viability in future.

Sangani and Solanki [9] have designed and fabricated V-trough PV concentrator system to estimate performance and PV electricity cost ($/W) reduction than conventional one-sun concentration module. V-trough concentrator system was designed which mentioned two-sun concentration ratios. This V-trough concentrator system was generated 44% additional output power compared to one-sun concentration module. The cost/unit watt of electricity was reduced by 24% using V-trough concentrator system as compared to one-sun concentration.

Burkhard Donald et al [10] have derived different formulas analytically to calculate geometrical concentration ratios and irradiance distribution at the base of flat-sided linear trough design. The outcomes obtained from this derivation had presented graphically for optimal configuration of system, which required minimum material to attain optimum concentration ratios. The results showed that the exact concentration ratios had obtained in a range of 1.5 to 4 depending on geometry and coefficient of reflection.

Tripanagnostopoulos [11] has studied low concentration solar energy configuration techniques to determine its effect on PV electrical output. During experimental work, it was found that flat diffuse reflectors provided a uniform distribution of solar radiation over the module surface. The linear fresnel lenses also used to achieve additional solar control of interior spaces than diffuse reflectors. The compound parabolic collector with reflectors had effectively combined with PV strips that act as solar thermal absorbers. Photovoltaic cell temperature had increased because of absorption of solar radiation, and reduced its efficiency accordingly. Different heat extraction modes were design and developed, and most appropriate one selected according to the required applications and configuration of absorber surfaces.

Djilali Rizk and Nagrial [12] have carried out investigational studies on simple module attached with reflectors made from different materials and designs. Experiments performed on aluminum, stainless steel, and chrome film reflectors to determine efficient type of reflectors that produced highest PV power output. The practical results showed that, chrome reflectors produced of 27.65% additional PV power output than aluminum foil, and 34.05% extra PV power output against stainless steel reflectors.

Palaskar and Deshmukh [13] have designed and fabricated a pair of aluminum flat reflector, and attached shorter sides of module to study its effect on performance of simple module for latitude of Mumbai. For different tilts and reflector orientations, photovoltaic power, efficiency, and highest working temperature of modified module had discussed and analyzed for PV peak power point. The modified module at 25^0 tilt and 24^0 reflector orientations normal to its surface could generate PV power and efficiency of 161 Wand 13.8% respectively. During experiments modified module was found heated at maximum operating temperature of 66 ^{0}C.

In the present study, performance analysis of simple module and oscillatory flow heat exchanger used in hybrid solar system added with reflectors have compared based on different technical parameters for latitude of Mumbai. Simple module was transformed to hybrid system by fixing oscillatory flow heat exchanger at bottom of module. This heat exchanger was designed and fabricated using aluminum tubes of square cross section. Aluminum material was used due to its high thermal conductivity and easy in fabrication. Hollow square shape tubes used to fabricate heat exchanger to enhance surface contact between bottom of module and top surface of heat exchanger. A pair of aluminum reflector had designed, fabricated, and fixed toshorter sides of module of hybrid system. This modified hybrid system with reflectors was produced more current & electrical power and efficiency, with thermal power and efficiency respectively. Increase in photovoltaic power, thermal power, photovoltaic, thermal, and combined PV/T efficiency and decrease in module temperatures at different flow rates for highest PV power point have discussed and analyzed in current experimental work.

2. Experimental

2.1. Commercial PV Module with Stand

Tata Bp India made PV module of rated capacity of 180 watts used to conduct experiments on un-cooled and cooled PV module without and with reflectors. The module had its length and width of 1.587m and 0.79m respectively with area of 1.25m^2. The open circuit voltage and current at STC condition of the module had noted 44.8 V and 5.40 Amps respectively. The maximum voltage and current of the module had quoted by manufacturer as 36.60 V and 4.99 Amps respectively. As per technical specifications of the module at STC, its efficiency was specified 14.52%. Photovoltaic module with its parts mounted on mild steel stand facing south direction on the terrace of the main building of the Institute.

2.2. PV Heat Exchanger Design and Its Fabrication

After a comprehensive literature review and analysis, it was decided to validate the simulation results published in research paper [3] with experimental work. A special design heat exchanger called as oscillatory flow made from circular stainless steel material was selected to validate its simulation results with practical one. In current experimental work, aluminum square section tubes preferred for this application, which had provided good surface contact and thermal conductivity to absorb heat from module, and cools it at reasonable temperature.To attain highest combined efficiency and better cooling of module, oscillatory flow heat exchanger design was selected which provides uniform surface contact at bottom side of module.

After designing heat exchanger, its characteristic details are as given in Table1. The fabrication of this heat exchanger was done in house; the total bottom area of module occupied by heat exchanger was calculated and found to 37% with pitch of 34 mm. This surface area can increase by minimizing pitch between two consecutive square tubes. Figure 1 shows the detailed drawing of PV module and heat exchanger assembly with important dimensions and necessary features. Figure 2 shows the actual installation of oscillatory flow heat exchanger at bottom side of simple module.

Table 1. Heat exchanger characteristics

Size of square Aluminum tube	Pitch between two consecutive square tubes	Total length of heat exchanger	Module bottom area occupied by heat exchanger
12x12x1 mm thick	34 mm	36 mts	37 %

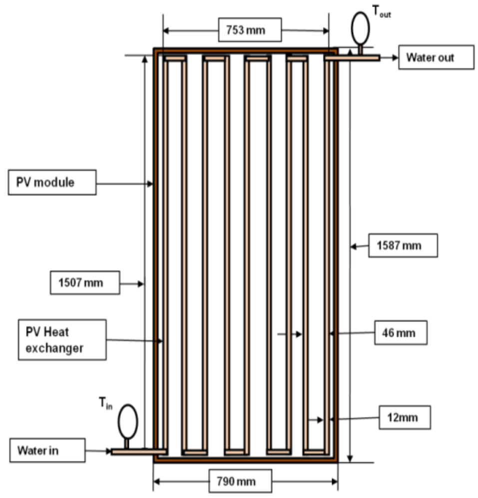


Figure 1. PV module and heat exchanger assembly with important dimensions and necessary features

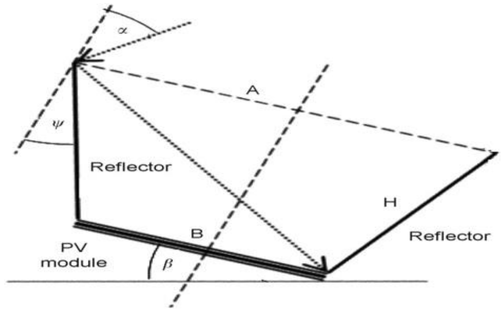
Figure 2. Installation of oscillatory flow heat exchanger at bottom side of PV module

2.3. Design and Fabrication of Aluminum Flat Reflectors

The highest PV power has generated by PV module depends on local climate, season of year, ambient temperature, wind velocity, latitude of location, tilt of module and intensity of solar radiation. After studying and analyzing these parameters, it has found that performance of module has strongly influenced by intensity of solar radiation, striking normal to its surface. In general, intensity of solar radiation does not remain constant over a day. The value of solar radiation has recorded less during morning and afternoon, and highest during solar noon period. This fluctuation of solar radiation causes variation in PV power generation and efficiency of module at different time of day. Due to this, module could generate fluctuating power as compared to rated power specified by manufacturers. Different methods have described in introduction section, which can use to increased PV power of module during day. These methods have found helpful in reducing PV material consumption/watt generated PV power output. In current experimental work, reflectors have designed, fabricated, and fitted to hybrid system as a cost effective method to increase concentration ratio and overall performance of modified hybrid system.

Aluminum sheet of 0.5 mm thickness was used for fabrication of flat reflectors available in market. The reflectivity of aluminum sheet measured by Albedo meter and was recorded 82%. The amount of solar radiation reflected from reflectors on module surface has strongly influenced by its concentration ratio and position of reflectors. Due to increase in concentration ratio, power output and efficiency of module have enhanced because of striking additional solar radiations on normal to its surface. The concentration ratio and reflector slant height of reflectors were calculated using formulas as given in table 2. Using this data, a pair of reflector was fabricated in house from aluminum sheet with its size equal to module dimensions and fitted to shorter sides of module as shown in figure 3[Burkhard Donald et al., 1978].

Table 2. Analytical relations to calculate concentration ratio and reflector height by Burkhard Donald et al [9]



Where: α-acceptance angle; *ψ*-trough angle; A-collector aperture width; B-receiver base width; H- reflector slant height; CR- concentration ratio; n-number of reflections and ρ- reflectivity of reflectors.

$CR = \frac{\sin[(2n+1)\,\psi + \alpha]}{\sin(\psi + \alpha)}$	(1)
$\frac{H}{B} = \frac{\sin[(2n+1)\psi + \alpha] - \sin(\psi + \alpha)}{2\sin(\psi + \alpha)\sin\psi}$	(2)

2.4. Measuring Instruments

A Dynalab Pyranometer used to measure global and diffuse solar radiations on horizontal surface. K-type thermocouples were used to measure ambient temperature and temperatures on top and bottom of PV module during experiments. A 16-channel temperature data logger was used to scan and record thermocouple temperatures at specified time intervals during experiments. A DC voltmeter and ammeter used to measure voltage and current for various loading conditions for a day. A DC load bank of 36Volts and 180-Watt capacity was design and used to measure voltage and current across load applied to module during experimental process. A 500 LPH Rota-meter was used to measure flow rate of water at the inlet of the oscillatory flow PV absorber surface. Dial type temperature gauges were used to measure water temperature at the inlet and outlet of the heat exchanger. Electrical water pump was used to circulate tap water through heat exchanger surface to trap heat and cool the PV module during tests. The complete, assembled experimental setup with all components as shown in figure 3.

Figure 3. Hybrid PV/T solar water system with measuring instruments

2.5. Experimental Observations

The main objective of this investigational work was to compare performance of un-cooled module and hybrid solar system with reflectors for latitude of Mumbai. Experimental work performed during months of March-April 2014. Experiments were conducted on un-cooled and cooled PV module with reflectors to determine their overall performance, which runs for 7 hours per day between 9.30 AM and 4.30 PM. The slope for simple module and hybrid system was selected and maintained 20^0 for all experimental days for latitude of Mumbai in months of March-April 2014. Experiments were conducted on distinct days for peak PV power point condition. Entire experimental work was divided in four parts as explained in following paragraphs.

In first observation set, experiment conducted on simple module to know its performance at ATC condition at selected slope. For this experiment, different observations were recorded manually such as global and diffuse radiations, voltage, and current at corresponding loading conditions at every 30 minutes time interval. K-type temperature sensors with data logger were used to scan and record the ambient temperature and the temperature at top and bottom of the PV module at an interval of one minute.

During second observation set, experiments performed on hybrid solar system with heat exchanger attached at bottom side of module. For this set, different readings were recorded manually and automatically as procedure explained in first observation set as explained in above paragraph. Few additional readings were collected manually in terms of water flow rate, and inlet and outlet water temperatures flowing though heat exchanger at every 30 minutes of time interval.

In third observation set, experiments conducted on module fitted with a pair of flat reflector to shorter sides of simple module as shown in figure 3. On modified module different tests were conducted on distinct days by changing orientations of reflectors manually from 100^0 to 135^0 (90^0+45^0) normal to PV surface with an interval of 5^0. This was done to determine the optimum orientation of reflectors for peak PV power point. At 24^0 orientations of reflectors with normal to module surface was able to generate highest photovoltaic power and efficiency.

During fourth observation set, different experimentations were performed on heat exchanger used in hybrid solar system fitted with fixed reflectors maintained at 24^0 orientations normal to module surface. At water flow rate for peak PV power point on distinct days, different readings recorded manually, and automatically as procedure explained in second experimental set.

2.6. Equations Used to Calculate Various Technical Parameters

The different equations from books such as Sukhatme and Nayak [14]; Solanki [15] and Duffie and Beckman [16] were used to calculate different technical parameters such as photovoltaic power, thermal power, input solar power, performance ratio, photovoltaic, thermal and combined PV/T efficiency for latitude of Mumbai as explain under:

Electrical power (P_{PV}) and thermal power (P_T) produced by hybrid system at ATC condition (W) as given by:

$$P_{PV} = V \times I \quad (1)$$

$$P_T = \dot{m} \times C_P \times (T_{we}-T_{wi}) \quad (2)$$

Where: V and I are voltage (V) and current (Amp) produced by module of hybrid system. $\dot{m}$ and C_P are mass flow rate (kg/sec) and specific heat of water (J/kg ^{0}K). T_{we} and T_{wi} are water inlet and outlet temperature of heat exchanger (^{0}K).

Direct solar radiation (I_T) on normal to module surface (W) and solar radiation (I_t) calculated on normal to module surface (W/m^2) as calculated using following formulas:

$$I_T = I_t \times A_{PV} \quad (3)$$

$$I_t = I_g \times r_g \quad (4)$$

Where: I_g is global radiation measured by pyranometer on horizontal surface (W/m^2) and A_{PV} is the area of PV module (m^2).

Tilt factor (r_g) for global radiation and elevation angle (α) as calculated follows:

$$r_g = \sin(\alpha + \beta)/\sin\alpha \quad (5)$$

$$\alpha = 90-\Phi+ \delta \quad (6)$$

Where: Φ and δ are the latitude of location (^{0}) and declination angle (^{0}) respectively.

Solar radiation reflected by considering both reflectors (I_{2ref}) on PV module surface (W) and solar radiation reflected from one reflected surface (I_{ref}) on PV surface (W/m^2) as given by

$$I_{2ref} = 2 \times I_{ref} \times A_{PV} \quad (7)$$

$$I_{ref} = \{[I_b \times r_b + (1-F_{C-R})\, I_d] \times \rho \times A_{ref} \times F_{C-R}\}/ A_{PV} \quad (8)$$

Where: I_b and I_d are the beam and diffuse radiation (W/m^2) measured on horizontal surface. A_{ref} is the area of any one reflector (m^2) and F_{C-R} is the View factor.

Total radiation on module surface ($I_{T\,ref}$) by considering direct plus reflected radiation (W) as given via:

$$I_{T\,ref} = I_T + I_{2ref} \quad (9)$$

Electrical efficiency (η_{PV}) and thermal efficiency (η_T) of hybrid system (%) as found by following equations:

$$\eta_{PV} = P_{PV} / I_{T\,ref} \quad (10)$$

$$\eta_T = P_T / I_{T\,ref} \quad (11)$$

Combined photovoltaic and thermal (PV/T) efficiency and performance ratio (%) of hybrid solar system as calculated under:

$$\eta_{PV/T} = \eta_{PV} + \eta_T \quad (12)$$

$P_R = P_{PV}/P_{STC}$ (13)

Where: P_{STC} is the electrical power produced by module (W) at STC condition.

3. Results and Discussion

3.1. Performance Analysis of Un-cooled PV Module

As experiments were conducted in March-April, the intensity of solar radiation and ambient temperature recorded during these months significantly higher than it values measured in winter. Figure-7 shows the maximum operating temperature of module that was recorded 61.20 ^{0}C during experiment at peak PV power point. Due to this high temperature of module, the operating voltage, and current produced by un-cooled module were recorded at 31.60 Volts and 4.36 amps respectively at 12.30 PM. Using these values of parameters, the electrical power and efficiency were calculated and found as137.80 W and 11.50 % respectively with performance ratio of 76.60 % as shown in figures 4 and 5 respectively. These results and its analysis for un-cooled module shows, that electrical power generating capacity of module decreases by 0.4% for every 1°C raise in temperature above 25 ^{0}C [Solanki C S, 2011]. The module could produce peak power of 137.80 W at 61.2^{0}C module temperature by using intensity of solar radiation of 924 W/m^2 as shown in figure 4.

3.2. Performance Analysis of Water Cooled PV Module

The cooling of module by extracting heat from its bottom side by oscillatory flow heat exchanger resulted in the rise of open circuit voltage (40.60 Volts) and voltage (32.40 Volts) at peak power point at 1 PM than un-cooled module. Due to this cooling effect, electrical power (146.12 W), performance ratio (81.20%), and efficiency (13.30 %) were increased as shown in figures 4 and 5 respectively. Figure 5 has shown low PV efficiencies in morning and late afternoon for both cooled and un-cooled cases.This mainly happens due to decrease in angle of incidence of solar rays from morning to noon and increase to late afternoon. At solar noon sun rays strike normal to module surface generating peak electrical power and efficiencies and for other periods like morning and late afternoon, the Power generated and efficiency of system has observed minimum.

Extracting waste heat from module, the hybrid solar system generated 572 W thermal power at flow rate of 0.042 Kg/sec. Water temperature recorded at outlet of heat exchanger was 34.25^{0}C, which is suitable for low grade applications such as swimming, pre-heating etc. The combined PV/T efficiency for this hybrid system was calculated and found 65.3 % as shown in figure 6. After fixing heat exchanger at bottom side of module, its operating temperature dropped to 48.70^{0}C than 61.20 ^{0}C of un-cooled module as shown in figure 7.

3.3. Performance Analysis of Un-cooled PV Module with Flat Reflectors

By fitting aluminum flat reflectors to shorter sides of module, the performance of simple module improved drastically due to concentration effect. Due this, modified PV module could generate maximum voltage of 32.50 V at 1 PM. This maximum voltage produced by module with reflectors has more than voltage produced by hybrid system as explained in sub-section 4.2 by considering peak PV power point. This could happen, as highest value of ambient temperature measured during this test was less than hybrid system as discussed in above sub-section. Because of this reason, module could produce more voltage despite of increase in module temperature due to boosting of solar radiation on its surface. In actual operation, the voltage produced by a PV module is a logarithmic function of intensity of solar radiation and solar intensity is directly proportional to rise in module temperature [Solanki C S, 2011]. The modified module produced highest operational current of 4.65 Amp at 1 PM. The current was found improved considerably as an effect of enhancing solar radiation on module surface. This happened, as the current produced by PV module is linear function of intensity of solar radiation [Solanki C S, 2011]. As a combined effect of these working parameters, photovoltaic power, and efficiency were found improved to 151.10 W and 14.40 % as shown in figure 4, and 5, and performance ratio raised to 84%.

It was found that sunrays striking on module were not fully reflected at normal to its surface over a day, due to fixed position of reflectors with module surface as discussed in experimental procedure. Between 11.30 AM to 2 PM when angle of incidence was nearly normal to PV surface and reflectors reflecting all receiving rays on module surface produced highest PV power of 151.10W. For other timings, unused reflections did not hit the module surface and directly went to atmosphere. To utilize these unused reflections, reflectors are required to be tracked continuously from morning to evening along East-West direction. Due this, angle of incidence may maintain constant over a day, producing PV power and efficiency equal to or more than its rated output power quoted at STC condition.

3.4. Performance Analysis of Water Cooled PV Module Fitted with Fixed Flat Reflectors

The co-generation solar system with oscillatory flow heat exchanger and flat reflectors resulted in rise open circuit voltage (40.60 Volts), operating voltage (35.65Volts) and current (4.70 Amps) at peak PV power point at 1 PM. Due to this, photovoltaic power (167.60 W), performance ratio (93 %) and efficiency (12.50 %) of hybrid system increased as shown in figures 4 and 5 respectively. Utilizing waste heat from module, the hybrid solar system generated 704 W of thermal power at flow rate of 0.042 Kg/sec. The temperature of water at the outlet of heat exchanger was measured 35.75^{0}C, which has found suitable for swimming, pre-heating etc. Combined PV/T efficiency of 65.10% was found for hybrid system as shown in figure 6. The forced water circulation system was in operation from 10 AM to 3 PM to supply tap water to hybrid system. Due to this, enhancement in system performance and reduction in operating temperature observed from 10.30 AM to 3 pm as shown in figures 4 to.7. By fixing heat exchanger at bottom of PV module and fitting flat reflectors, the operating temperature dropped to 56.70^{0}C than 76.25^{0}C of un-cooled module fitted with reflectors as shown in figure 7.

Use of thermal grease compound between top side of heat exchanger and bottom of module will minimize the air gap between these surfaces, improving the rate of heat transfer. This will reduce operating temperature of module, improving the overall performance of hybrid system. The operating temperature of cooled module may further reduce by lowering inlet water temperature, enhancing the overall performance of PV/T system. Sufficient water head maintained in storage of cooling water can lead to use of thermo-siphoned hybrid system. This will be the ideal solution for electrical power generation and hot water production used in rural areas.

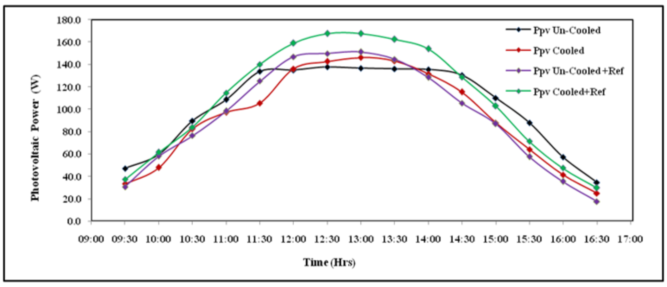


Figure 4. PV power produced by un-cooled module without and with reflecors, cooled module without and with reflectors

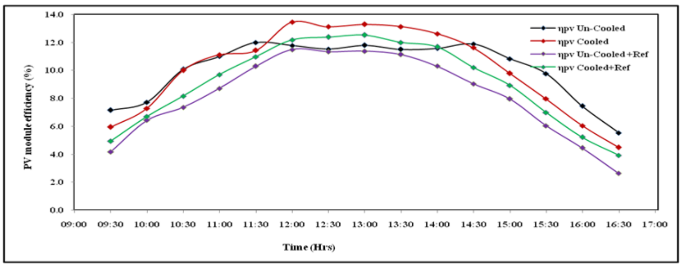


Figure 5. PV efficency generated by un-cooled module without and with reflecors, cooled module without and with reflectors

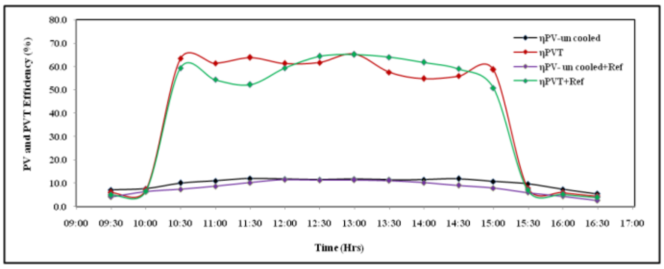


Figure 6. PV efficincy produced by of un-cooled module without and with reflectors, combined PV/T efficency of cooled module without and with reflectors

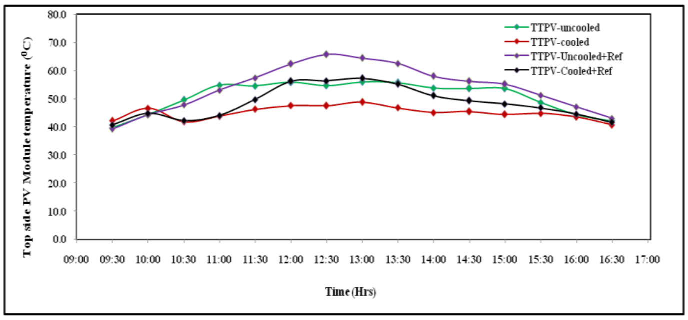


Figure 7. Top side PV temperature (TTPV) attended by un-cooled module without and with reflectors , cooled PV module without and with reflectors

4. Conclusion

The experimental result shows, that PV power and efficiency of hybrid water system with reflectors have enhanced by 21.62 % and 8.70 % respectively at 1 PM as compared to un-cooled module. The performance ratio of cooled module by adding reflectors has augmented by 16.40 %. Due to cooling effect, hybrid system has produced 704 W of thermal power with 52.60 % efficiency, achieving a combined efficiency of 65.10 %. The present hybrid solar system has exhibited combined PV/T efficiency of 65.10 % as compared to 54.10 % efficiency obtained by simulation [Othman et. al., 2008]. This experimental result has found be close fit to the simulation results.

The hybrid solar water system harnesses 65.10% of total solar radiation falling on earth and was converted 52.60 % of waste heat to thermal energy. Thus, on a yearly basis, hybrid system can produce 1255 KWh of combined energy and 242 KWh of electrical energy per m^{2}module area. With these experiments, it can be concluded that the hybrid solar water system with reflectors has a potential substitute for electrical power generation and hot water production use in rural regions.

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