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Development of a Solar Photovoltaic and Solar Thermal Co Power Generation for Domestic Use

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ABSTRACT
A solar photovoltaic and solar thermal co-power generation (SPSTCPG) system is attracting more awareness in sustainable development. This study investigated an SPSTCPG system which consists of PV panel sandwiched with continuous flow of water in a 3mm copper pipe. The heat energy produced is conserved using a well lagged 20 liters silver primary storage tank. This was aimed to maximize the usage of natural energy from sun light (photo light and heat), the research has revealed that, the efficiency of electricity generated increases by cooling the PV panel , the design was modelled to fabricate a system with local materials, with low production cost and relatively low maintenance cost. The SPSTCPG developed system produced 20 liters of water at 37 °C in 6hours of sunlight with system efficiency of 73% and able to rotate through 270°, at NO SUN period, the system was connected to a DC auxiliary heater to compensate for heat loss for the operation period.

Key words: Solar, Photovoltaic, Thermal, Power

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1. INTRODUCTION

The is Earth facing the threat of extinction due to energy driven industrial, commercial and domestic activities that support modern society, researchers around the world have in recent times intensified efforts in developing new methods of generating cleaner, safer and sustainable energy. The solution to these problems has been largely linked to renewable energy technologies. Available statistics, however, show that approximately 80% of the global energy consumption is still dependent on fossil fuels, while renewable energy accounts for the remaining 20%. Like many other countries, Nigeria depends heavily on fossil fuel, especially oil and gas, which are not renewable sources, to meet its energy needs. Even with the abundant oil and gas reserves in Nigeria, insufficient energy (electricity) supply remains a strong barrier to industrial and economic growth of the country.

In Nigeria; the electricity supply from all sources (conventional and renewable) was projected to be 14 and 29GW in 2015 and 2025, respectively to match the countries demands [1]. At present the installed capacity is 10.396GW and available capacity 6.056GW, which is less than 44% of the 2015 electricity demand and exposes shortcoming in energy delivery. Most of the electricity generation plants are based on fossil fuel (oil and gas), accounting for 81% (8.457GW) of the installed to total capacity and an available capacity of 4.996GW (83% of the total available). The three major hydropower plants contribute 1.938GW (19%) of total installed and an available capacity of 1.060GW [2]. The Nigeria Energy Policy Report estimate that less than 40% of Nigeria's population are connected to the national grid

Nigeria being blessed with abundant sunshine due to its proximity to the equator (estimated between latitude $4^{0}00$ - $13^{0}30$N and longitude $2^{0}30^{1}$ - 14^{0} 30^{1}E), it has been shown that Nigeria has one of the highest potentials for solar thermal energy sources (STES) amongst other renewable energy sources, which includes offshore wind-waves, and ridal energy [1]. This potential can be adequately harnessed to comfortably satisfy the energy needs of the country.

The concept of solar PVT system is design to integrate major renewable energy technologies to provide energy needs of the country. The project comprises of solar photovoltaic power system for provision of electrical energy and solar thermal collector for provision of hot water for domestic use. The research is the development of a solar photovoltaic and solar thermal co-generation power plant which would be considered as hybrid solar system (or PVT system for simplicity). The PVT technology is a combination of photovoltaic (PV) and solar thermal component or system. In other words, PV is used as (part of) the thermal absorber PVT (Road map 2006). To improve the electrical efficiency of the PV module, water would be used as a coolant to cool the PV module.

2. LITERATURE REVIEW

Theoretical and experimental studies of PVT were documented as early as in mid 1970s. Wolf [3], Florschuetz [4], Kern and Russell [5] and Hendrie [6] on different occasions presented the key concept and the data with the use of either water or air as the coolant (i.e. the PVT/a and PVT/w systems in abbreviation). The technical validity was soon concluded. Their search works that followed were mainly on flat-plate collectors, like the contributions from Raghuraman and Cox [7], Braunstein and Kornfeld [8] and Lalovic [9] in the 1980s. The works of O'leary and Clements [10], Mbewe and others [11], Al-Baali [12] and Hamdy and others [13] included performance analysis on light concentrating PVT systems.

Garg and his co-workers carried out detailed analytical and experimental studies on hybrid PVT air and liquid heating systems from late 1980s for about 10 years [14]. Working with a steady state PVT/a model, they pointed out that the increased transmission losses due to the addition of a second front cover do not justify the heat loss reduction –beyond the critical point the single-glass cover collects more heat than double-glass. Based on the weather of New Delhi, their transient simulation analysis found that in terms of overall energy performance, the double- glass configuration is better than the single-glass option for conventional PVT/a collectors [15-16]. For mechanical operated system, Bhargava and others found that the PVT/a system can be self-supported within a certain range of design parameters like packing factor and air flow rate [17]. They also developed a steady state model to analyze the system performance of a PVT/a collector with integrated compound parabolic concentrator (CPC) troughs [14-16]. The parametric study showed that the thermal and electrical outputs increase with increased absorber length, air mass flow rate and packing factor, but decrease with increased duct depth. The final design is then subject to the cost-performance analysis.

Sopian and others developed a steady–state model for comparing the performance of single and double-pass PVT/a collectors; the better performance of the double-pass design was found attributed to the productive cooling of the solar cells and the reduction in front cover temperature. An experimental unit was introduced accordingly [18]. Prakash [19] carried out transient analysis on a conventional PVT collect or designed for air-and water-heating, respectively. Compared with water heating, the lower thermal efficiency of the air-heating design as a result of poor heat transfer between the absorber plate and the flowing air was concluded.

Bergene and Lovvik [20] proposed a detailed physical model of a flat-plate PVT/w collector system for performance evaluation. The fin width to tube–diameter ratio was investigated and the total efficiency was found in the range of 60–80%. As for thermosyphon systems, Agarwal and Garg showed that the thermal efficiency depends on the packing factor, but this is not the case for cell efficiency [21]; the quantity of water in the storage tank also has an effect. Their study was extended to acquire experimental data on a flat-plate PVT/w collector system equipped with simple parabolic reflectors [22].

The use of modified Hottel–Whillier model, De Vries [23] investigated the steady–state long-term performance of various PVT collector designs in Netherland. The single-covered design was found better than the uncovered design (of which the thermal efficiency is unfavorable) or the double covered design (of which the cell efficiency is unfavorable). Nevertheless, the energy analysis performed by Fujisawa and Tani [24] indicated that the energy output density of the uncovered design is slightly higher than the single-covered design, taking the fact that the thermal energy contains much unavailable energy. For some low-temperature water-heating systems, like swimming pool applications, the low-cost unglazed PVT/w system is recommended. During some severe cold days in winter, anti-freeze liquid can be used but then the drawback would be as light drop in summer performance [25].

Experimental tests on PVT/w systems in Riyadh (at 24.60N), Saudi Arabia (1998) showed that the high ambient temperature in summer could lead to 30% drop in PV efficiency, though the thermal efficiency remains good. In winter time the PV modules show improved performance yet the thermal side performance deteriorates.

On the other hand, Rockendorf et al [26] constructed prototypes of thermo electric collector (first generating heat and subsequently electricity) and PVT/w collector (with solar cells on aluminum-absorber and copper-tubing combination); the TRNSYS simulation results showed that the electrical output of the PVT/w collector is significantly higher than that of the thermo electric collector. In the above studies of flat-plate collectors, the calculated thermal efficiency of PVT/liquid systems are generally in the range of 45–70% for unglazed to glazed panel designs. For PVT/a systems, the thermal efficiencies can be upto 55% for optimized collector design.

3. MATERIALS AND METHOD

The (SPSTCPG) system is designed for the purpose of generating electricity and heating water for domestic use. The system components include working fluid pump (WFP), photovoltaic panel (pvt), storage tank (STk), battery (B), water heater (WH), valves (V1, V2, V3, V4, V5) and a thermostat (TM) as shown in Figure 1. The TM senses the temperature difference in the storage tank and at 32 ^{o}C, enables the start up of the WFP to circulate the working fluid through the system continuously, from the thermal collector and back to storage tank. The working fluid continuously carry heat away from the pvt collector thereby increasing the output of electricity generated concurrently, as the water in the STk attains a temperature range of 55 to 60 ^{o}C the water is open for domestic use. At maximum temperature of 70^{o}C, the working fluid pump stops as this is the set temperature on the thermostat to stop the pump. The refill valve is opened to fill fresh water into tank invariable to the system in case of low water level in thank. In the case of no Sun, the WH in the storage tank is switched on to heat up the water to required temperature. Photo electric emission from the sun is absorbed by the pvt collector stored in form of direct current in the battery (B), with the amount of voltage stored in B is controlled by a solar controller, (SC). The direct current is further converted to alternating current by the inverter device, (INV), which provides electricity for domestic appliances including the electric heater, heat pump and other appliances as designed.

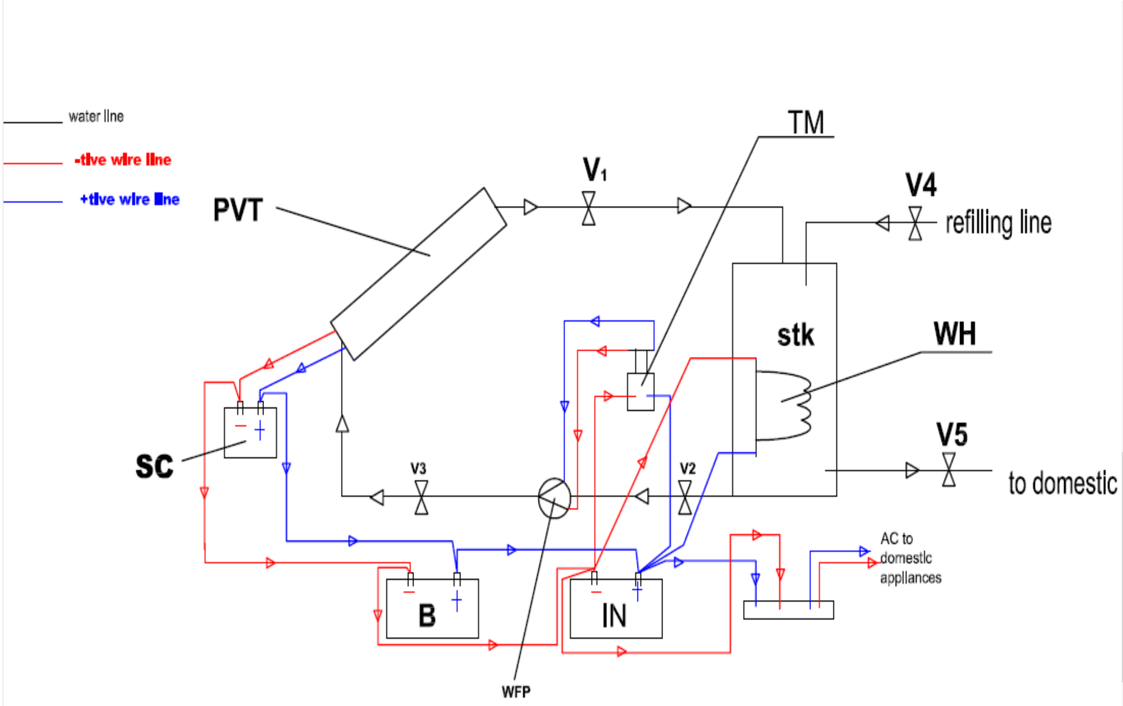

Fig. 1 Combined system schematic diagram of the PVT design

Fig. 2 Developed solar photovoltaic and solar thermal co power generation for domestic use

Design of Solar Thermal Collector Base on Hot Water Demand

The heat requirement is modeled as in Equation (1.1)

$$Q = m\, C_{PW}(T_{out} - T_{in}) \quad (1.1)$$

Where

Q (W/m^2) is the actual quantity of heat,

m (kg) is mass of water ,

$C_{pw}\,(J/kgK)$ Specific capacity of water

$T_{out}\,(o_C)$ Temperature of hot water desired

$T_{in}\,(o_C)$ Temperature of cold water

Mass (m) = density (ρ) X total volume (V) (1.2)

$$Q = \rho\, V\, C_{pw}(T_{out} - T_{in}) \quad (1.3)$$

Pipe Sizing

Copper pipe diameter 12.7mm

$$Q = \bar{h} A_p \theta_m \quad (1.4)$$

Where

$\bar{h}(w/m^2 o_C)$ is heat transfer coefficient

$A_P(m^2)$ is area of pipe,

Θ_m (^{0}C) is the mean temperature difference

$$\bar{h} = \frac{Nu\ k}{D} \quad (1.5)$$

Nu (3.657) is Nusselt number for tube

k $(W/mK)$is thermal conductivity of water (0.638)

D (m) is diameter of pipe

$$A = \pi\ D\ L \quad (1.6)$$

π (3.142), is Pie

L (m) is length of pipe

$$\Theta_m = \frac{\theta 1 - \theta 2}{in\ [\frac{\theta 1}{\theta 2}]} \quad (1.7)$$

$$\Theta_m = \frac{(\theta o - \theta 1) - (\theta o - \theta 2)}{in\ [\frac{(\theta o - \theta 1)}{(\theta o - \theta 2)}]} \quad (1.8)$$

Where

Θ_1 (^{0}C), is the initial temperature of water in pipe

Θ_2 (^{0}C), is the desire water temperature (final temperature)

Θ_0 (^{0}C), is the direct temperature heating the pipe

Design of Thermal Collector Area

The solar collector area is modeled using Equation (1.9)

$$A_C = \frac{Q}{\eta t\, G_a} \quad (1.9)$$

Where

Ac (m^2) is area of solar collector,

Q (w/m^2) is quantity of heat,

η(%) is the solar collector efficiency (0.5)

Thermal Heat Load $(\dot{Q}_U)$

$$\dot{Q}_u = A_c F_R\,[(\alpha\tau)G_a - Q_L] \quad (2.0)$$

Where

Q_u (w/m^2) is thermal heat load.

F_R(-) is heat removal factor,

$\alpha\tau$(-) average transmittance of absorptance of collector (0.9),

G_a(w/m^2) is solar irradiation 700,

Q_L (w/m^2) heat loss rate

Heat Loss Rate (Q_L)

$$Q_L = U_{L1}(T_{in} - T_o) \quad (2.1)$$

Where U_L (w/m^{2}k) is overall collector heat loss coefficient (4.67)

Heat Removing Factor (F_R)

$$F_R = \frac{\dot{m}_f C_p}{U_{L1 A_c}}\,[1 - e^{-\frac{F' U_{L1} A_c}{\dot{m}_f C_p}}] \quad (2.2)$$

Where

m_f (kg/s) is mass flow rate,

F' (-) is collector efficiency factor (0.91)

Thermal Efficiency of the Flat Plate

η_{th} = $F_R \tau\alpha - F_R U_L \left(\frac{T_i - T_a}{G_a}\right)$ (2.3)

where η_{th} (%) is thermal efficiency

Design of PV Panel Based On Load Estimation

The load estimation of the PV depend on size of the PV panel and number of pv module required to match the required load

Size of PV Panel (SPV)

Total appliance =
$\sum$ (No. of unites X Watt rating of equipment X No. of hours) (2.4)
Total PV panels energy needed = Total Appliances (Wh/day) x 1.3 (2.5)
SPV = $\frac{\text{Total PV panels energy needed}}{3.4}$ (2.6)

Number of PV Modules (NPM)

The system will be power by 12Vdc, 220Wp PV module
NPM = $\frac{\text{SPV (Wh/day)}}{220}$ (modules) (2.7)

Inverter Sizing (IS)

IS = $\sum$ (Watt rating of equipment) (2.8)
Factor of safety for inverter selection (FOS) = $\frac{25}{100}$ x IS (2.9)

Battery Sizing (BS)

The battery discharge life autonomy = 3days
Nominal volt = 12
BS= $\frac{\text{Total appliance (Wh/day)}}{0.85\ X\ 0.6\ X\ 12}\ X\ 3days$ (2.10)

Electrical Efficiency of Pv Panel

$\eta_e = \frac{Im\ Vm}{Ga}$ (3.0)
Where $I_m V_m$ are current and voltage of the PV module operating at maximum power.

Total Efficiency of the System (η_0)

$\eta_0 = \eta_{termal} + \eta_{elect}$ (3.1)

Design of Storage Tank

The storage tank is model by
$V = \pi r^2 h_t$ (3.2)
V (m^3) is the volume of thank
h_t(m) is the height of tank

Bill of Engineering Material and Evaluation (BEME)

Bricks Moulding

Table -1 Material Selection and Cost Estimate

S/N	Parts	Material	Dimension(mm)	Reason for choice	Cost (Dollars)
1	Collector absorber plate	Copper plate	120mm by 55mm	High thermal conductivity	14
2	Heat transfer tube	Copper	5mm diameter	Higher thermal conductivity	60
3	Storage tank	Plastic flask tank	20litres		44
4	Frame	Angle bar	2mm	Strength and availability	22
5	Fluid passage	Pvc pipe	13mm diameter	Corrosion resistance , cheaper and easy coupling	14
6	Union connection	Pvc	14mm diameter	Tight connector fitness	3
7	Elbow joint	Pvc	14mm diameter	Tight as connector fitness	3
8	valves	Pvc	14mm diameter	Effectiveness in flow control	7
9	Pv solar panel		3kva	To accommodate the require power	109
10	Solar controller		80watt	Based on size of battery	55
11	Battery		100amp 12v	Base on load	109
12	pump		0.5hp		30
13	Wire	2.5mm			20
14	Miscellaneous				82
15	Labor cost				109
	TOTAL				681

4. RESULTS AND DISCUSSION

This seek to give specifications and do a performance evaluation on solar photovoltaic power generation co solar thermal panel that was developed to generate hot water for domestic use, the analysis was done in the month of February through 17th to 19th, 2018.

Input Data

Table -2 input data

S/N	Parameter	Symbol	Unit	Value
1	Nusselt Number	Nu	-	3.657
2	Thermal conductivity of water	k	W/mK	0.638
4	Solar collector efficiency	η	-	0.5
5	average transmittance of absorptance of collector	$\alpha\tau$	-	0.9
6	is solar irradiation	G_a	w/m^2	750
7	overall collector heat loss coefficient	U_L	w/m^2K	26.5
8	collector efficiency factor	*F'*	-	0.91
9	Ambient temperature	T_o	o_C	36
10	Battery discharge days			2 days

Results Computation

An excel spread sheet was used for result computation for three days data collections from the equipment setup. The tables of result, charts and graphs showing the relationship between the parameter are shown below.

Day 1 Results and Analysis

Table -3 Result for Day 1

Time (Hour)	Inlet Temp (°C)	Outlet Temp (°C)	Vm (Volt)	Im (ampere)	Elect Eff. (ηelect)	Thermal Eff. (ηth)	Total Eff (η_0)	Total Eff. % (η_0)%
7	27	28	6	0.2	0.0016	0.81	0.81	81
8	28	29	10	0.5	0.0067	0.79	0.79	79
9	29	30	14	0.7	0.0131	0.76	0.78	78
10	30	31	17	0.9	0.0204	0.74	0.76	76
11	32	33	21	1.3	0.0364	0.70	0.73	73
12	34	35	23	1.5	0.046	0.65	0.70	70
13	34	35	24	1.7	0.0544	0.650	0.71	71

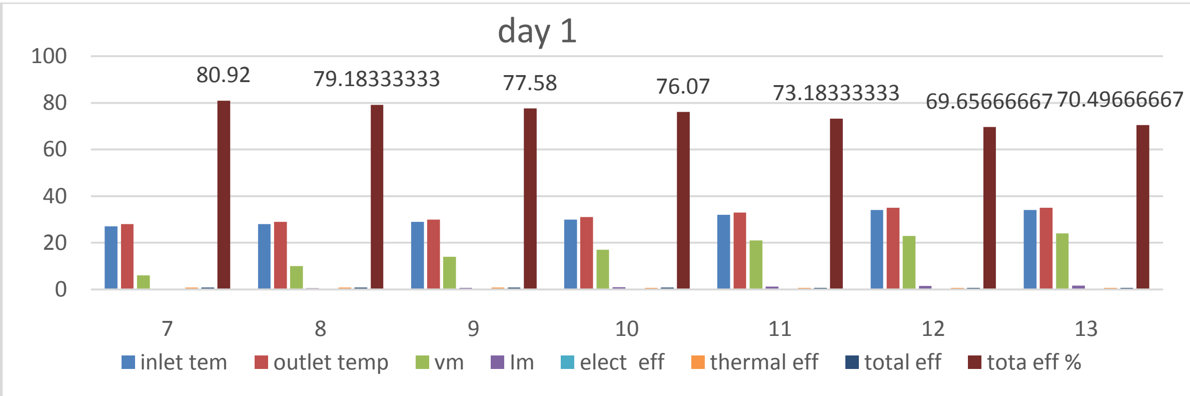

Fig. 3 Chart of Inlet Temperature, Outlet Temperature, Electrical Efficiency, Thermal Efficiency and Total Efficiency on Day 1

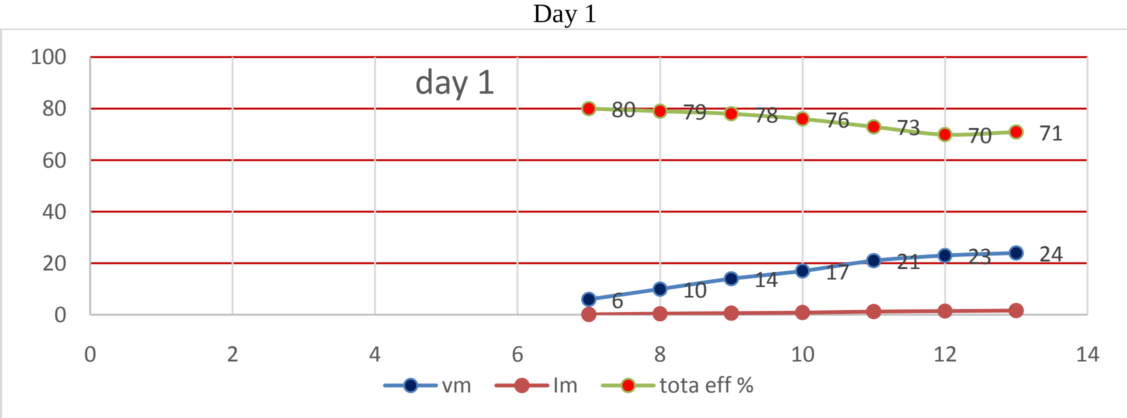

Fig. 4 Graph of Maximum Voltage, Ampere and Total Efficiency on day 1

Day 2 Results Analysis

Table -4 Result for Day 2

Time (Hour)	Inlet Temp (°C)	Outlet Temp (°C)	Vm (Volt)	Im (ampere)	Elect Eff (ηelect)	Thermal Eff (ηth)	Total Eff (η_0)	Total Eff % (η_0)%
7	29	30	8	0.3	0.0032	0.76	0.77	77
8	29	31	13	0.6	0.0104	0.76	0.77	77
9	32	33	20	1.4	0.0373	0.70	0.73	73
10	33	35	22	1.6	0.0469	0.67	0.72	72
11	35	36	24	1.8	0.0576	0.63	0.69	69
12	36	37	27	2.1	0.0756	0.61	0.68	68
13	37	38	31	2.4	0.0992	0.58	0.68	68

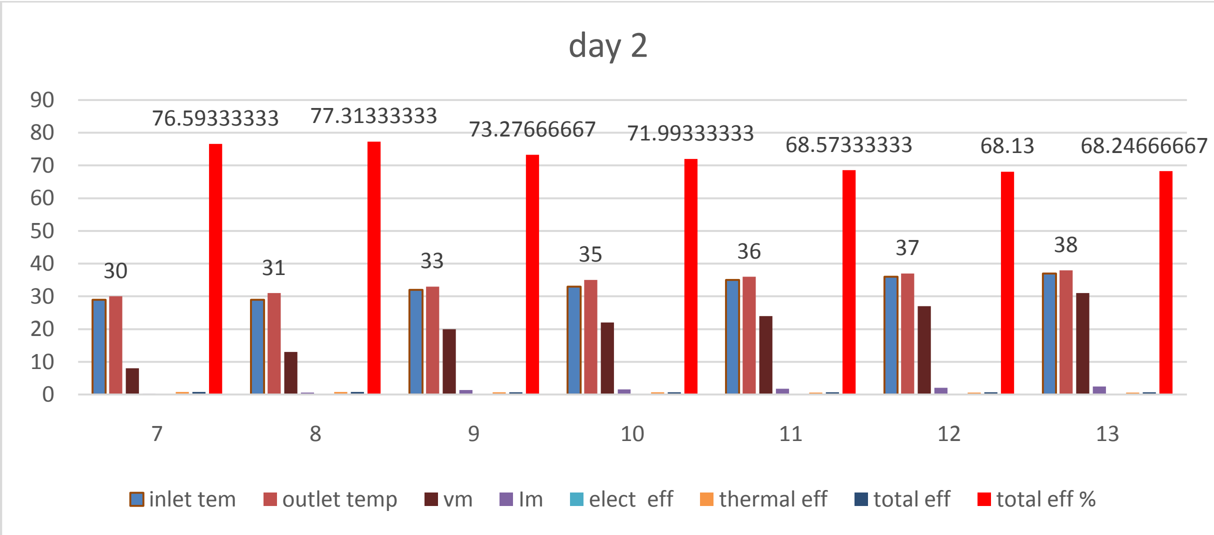

Fig. 5 Chart of Inlet Temperature, Outlet Temperature, Electrical Efficiency, Thermal Efficiency and Total Efficiency on Day 2

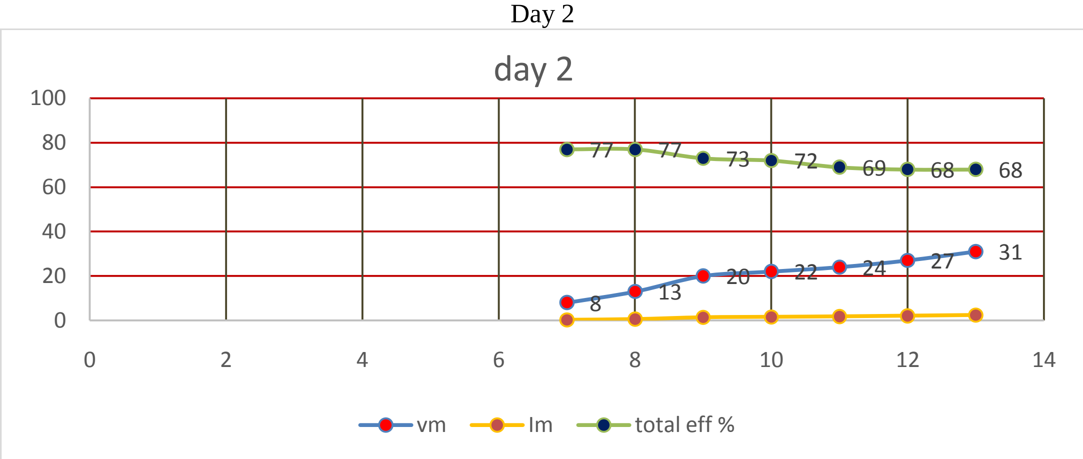

Fig. 6 Graph of Maximum Voltage, Ampere and Total Efficiency on day 2

Day 3 Results and Analysis

Table -5 Result for Day 3

Time (Hour)	Inlet Temp (°C)	Outlet Temp (°C)	Vm (Volt)	Im (ampere)	Elect Eff (ηelect)	Thermal Eff (ηth)	Total Eff (η_0)	TotalEff (η_0)%
7	28	29	7	0.25	0.0023	0.79	0.79	79
8	29	31	14	0.6	0.0112	0.76	0.77	77
9	31	32	16	1.0	0.0213	0.72	0.74	74
10	32	34	21	1.3	0.0364	0.70	0.73	73
11	34	36	22	1.4	0.0411	0.65	0.69	69
12	36	38	28	2.0	0.0747	0.61	0.68	68
13	37	39	32	2.5	0.1067	0.58	0.69	69

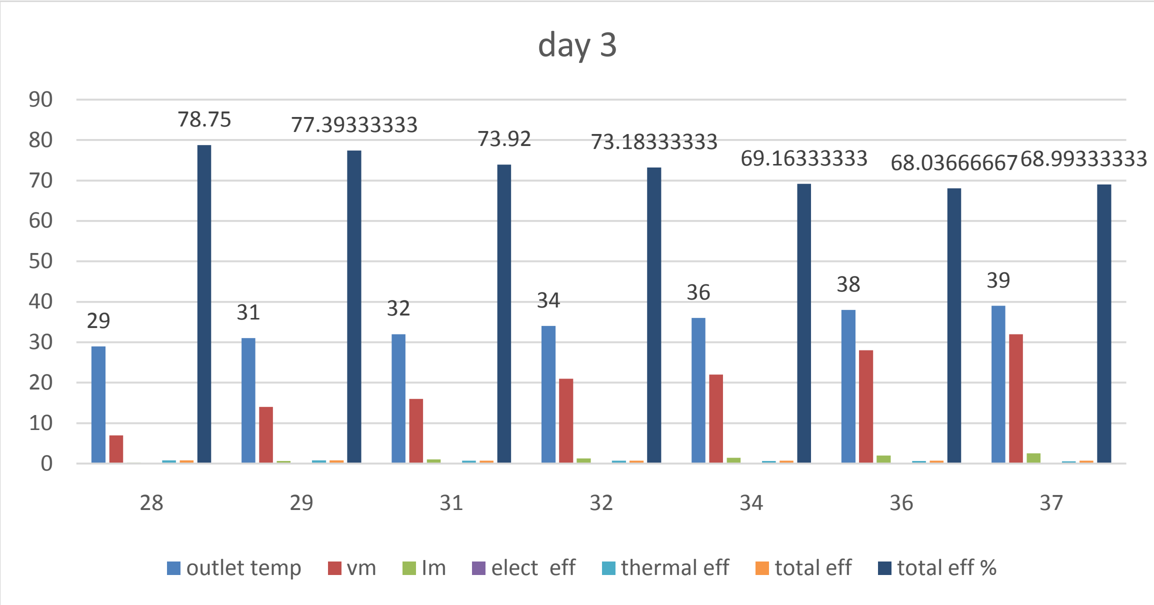

Fig. 7 Chart of Inlet Temperature, Outlet Temperature, Electrical Efficiency, Thermal Efficiency and Total Efficiency on Day 3

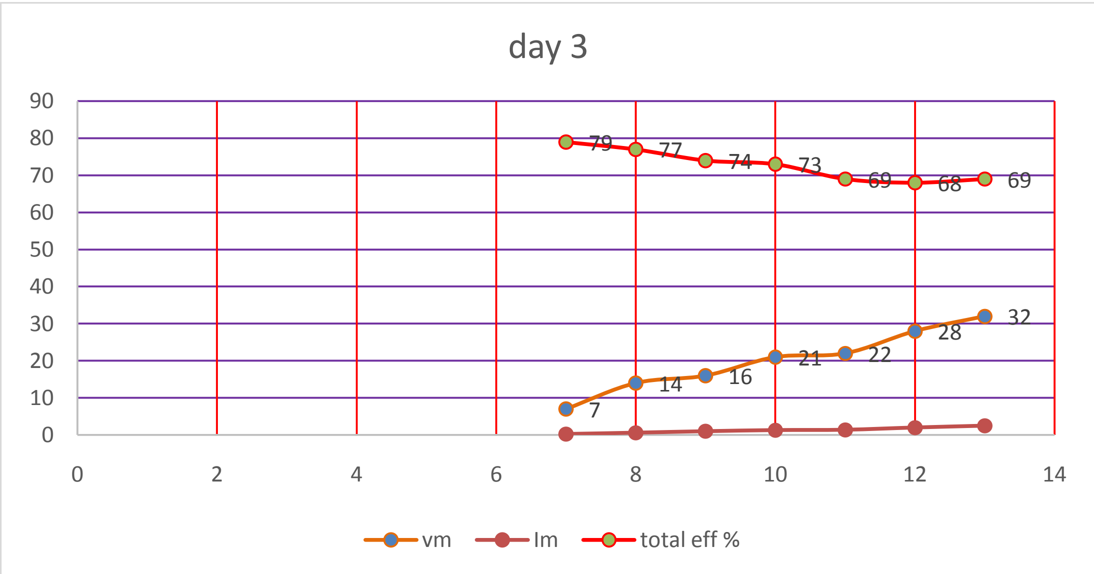

Fig. 8 Graph of Maximum Voltage, Ampere and Total Efficiency on day 3

Table -6 Cumulative Result Analysis for Day 1, 2 and 3

Days	**Inlet Temp (°C)**	**Outlet Temp (°C)**	**Vm (Volt)**	**Im (ampere)**	**Pm (Watt)**	**Elect Eff (ηelect)**	**Thermal Eff (ηth)**	**Total Eff (η_0)**	**Total Eff (η_0)%**
1	28	29	7	0.25	1.75	0.0023	0.79	0.79	79
2	29	31	14	0.6	8.4	0.0112	0.76	0.77	77
3	31	32	16	1.0	16	0.0213	0.72	0.74	74
Mean of the average mean(M of m)	32	34	21	1.3	27.3	0.0364	0.70	0.73	73

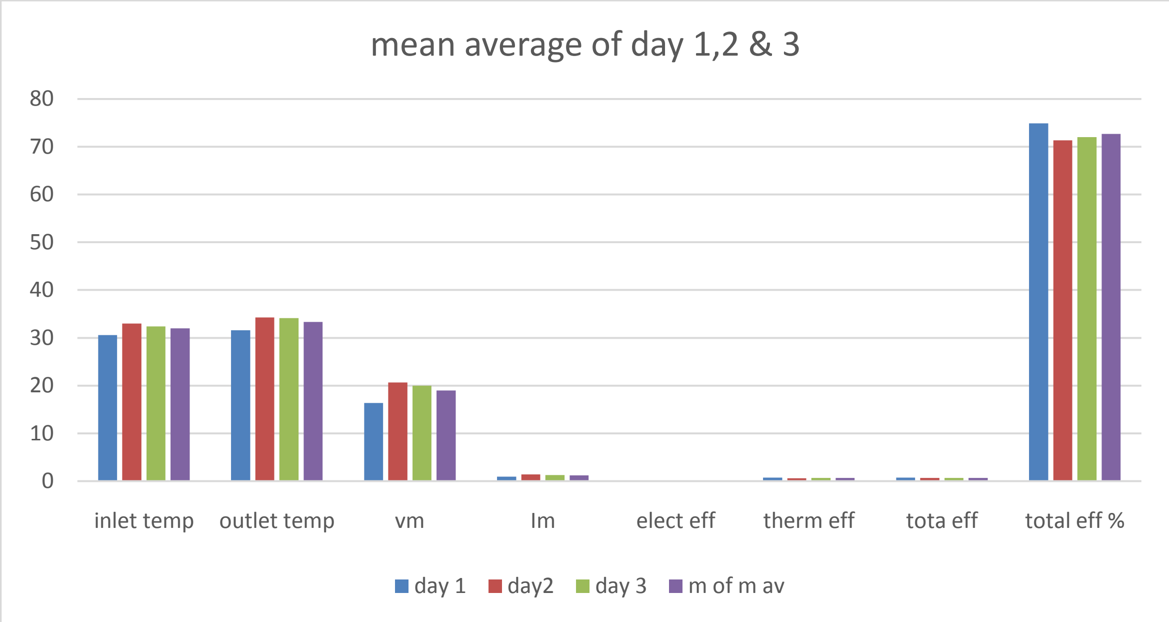

Fig. 9 Chart of Inlet Temperature, Outlet Temperature, Electrical Efficiency, Thermal Efficiency and Total Efficiency for Average Mean of the Three Days

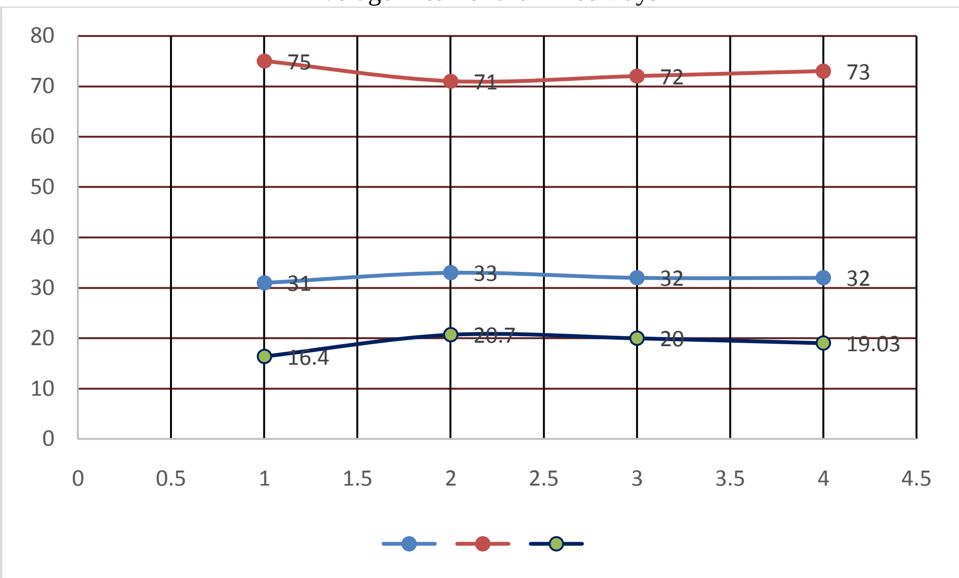

Fig. 10 Graph inlet temperature, Total Efficiency and maximum velocity for average mean of the three days

Table -7 Summary of Results

S/N	Parameter	Symbol	Unit	Value
	Solar Pannel Size			
1	Average solar power required in (DC)	P_s	Watt	27.3
2	Number of solar panel module	NMP		1
3	Average current produce	Im	A	1.3
4	Average voltage produced	Vm	V	21
5	Average Pv electrical efficiency	η_{elect}	-	0.0364
6	Average total efficiency	η_o	%	73
	Solar Thermal			
7	Area of solar collector	A_C	m^2	2
8	Heat removing factor	F_R	-	0.673
10	Thermal load	Q_u	w/m^2	17.73
11	Thermal panel efficiency	η_{th}	-	0.7

Performance Evaluation of the PVT Panel

Once the mechanical and the electrical components of the system were completed and coupled, the entire device was tested, the current and voltage value were recorded using multimeter and also voltage value were also read on solar controller and the outlet, inlet temperature were measured by laser jet thermometer rate of one hour interval from 7000hr to 13000hr for three days as shown in table 3, 4 and 5 respectively. The total efficiency of the system is calculated to 73%, the initial voltage generated was use to operate the pump to circulate water round the pipe, it was expected to increase the voltage drop efficiency as more heat is carried away by cooling water in pipe by convection heat transfer.

5. DISCUSSION

The efficiency of the system increases at the beginning of the early hour of the day 1, 2 and 3 as shown in figure 3 to 8. But drop from 80% to 71% as shown in figure 4 for day 1, the efficiency also drop from 77% to 68% as shown in figure 8 for day 2, it also drop from 79% to 69% as shown in figure 8 for day 3 while for cumulative value the efficiency drop from 75% to 73% as shown in figure 1.8, this proves that, increase in temperature slow down the efficiency of the PVT system. The cooling water system was able to arrest the efficiency not to drop below 73% as shown in figure 9 and 10 above respectively.

The voltage increases drastically at the early hour of 7000 hrs from 6 volts to 24 volts at maximum at 1300 hrs on day 1, on the day 2 the voltage increases from 8 volt at minimum to 31 volts at maximum while the voltage increase at 7 volts to 32 volts this translate that the photo electric emission on day 2 is higher than the other two days as shown on cumulative voltage graph in figure 10, as well as but the total efficiency at cumulative graph on day three (72%) is higher than day two(71%) because of better cooling on day three due less ash weather.

The cumulative efficiency is calculated to 73% which is considered as the overall efficiency of the system.

6. CONCLUSION

The design was achieved as an efficient and cost competitive system configuration so that the hybrid solar system can improve the life of people especially in rural areas where electricity is not stable and efficient. The efficiency of this system is about 73% in the day and during No rain season. The hybrid solar system is environmentally friendly and easy to maintain.

REFERENCES

[1]. http://www.ecowrex.org/sites/default/files/repository_old/2005%20RE%20Master%20Plan%20-%20Min%20Power.pdf

[2]. Onochie, U. P., Egware, H. O., & Eyakwanor, T. O. (2015). The Nigeria Electric Power sector (opportunities and challenges). *Journal of Multidisciplinary Engineering Science and Technology*, *2*(4), 494-502.

[3]. Wolf, M. (1976). Performance analysis of combined heating and photovoltaic power systems for residences. Energy Convers; 16 PP: 79–90.

[4]. Florschuetz, L.W. (1979). Extension of the Hottel–Whiller model to the analysis of combined photovoltaic/thermal flat plate collectors. Sol Energy; 22 PP: 361–6.

[5]. Kern, J.E.C. Russell, M.C. (1975). Combined photovoltaic and thermal hybrid collector systems. In: Proceedings of the 13th IEEE photovoltaic.

[6]. Hendrie, S.D. (1979). Evaluation of combined photovoltaic/thermal collectors. In Proceedings of the ISES international congress, Atlanta, USA, (3); PP: 1865–1869.

[7]. Raghuraman, P. (1981) Analytical prediction of liquid and air photovoltaic/thermal flat plate collector performance. J Sol Energy Eng; 103 PP: 291–298.

[8]. Braunstein, A. Kornfeld, A. (1986). On the development of the solar photovoltaic and thermal (PVT) collector. IEEE Trans Energy Convers; EC-1 (4) PP: 31–33.

[9]. Lalovic, B. (1986–1987). A hybrid amorphous silicon photovoltaic and thermal solar Collector. Sol Cells; (19) PP: 131–138.

[10]. O'leary, M.J. Clements, L.D. (1980). Thermal–electric performance analysis for actively cooled, concentrating photovoltaic systems. Sol Energy; (25) PP: 401–406.

[11]. Mbewe, D. J., Card, H. C., & Card, D. C. (1985). A model of silicon solar cells for concentrator photovoltaic and photovoltaic/thermal system design. Solar energy, 35(3), 247-258.

[12]. Al-Baali, M., & Fletcher, R. (1986). An efficient line search for nonlinear least squares. Journal of Optimization Theory and Applications, 48(3), 359-377.

[13]. Hamdy, H. I., Mukhopadhyay, N., Costanza, M. C., & Son, M. S. (1988). Triple stage point estimation for the exponential location parameter. *Annals of the Institute of Statistical Mathematics*, *40*(4), 785-797.

[14]. Garg HP, Adhikari RS. System performance studies on a photovoltaic/thermal (PV/T) air heating collector. Renew Energy 1999; 16: 725–30.

[15]. Garg HP, Adhikari RS. Conventional photovoltaic/thermal (PV/T) air heating collectors: steady state simulation. Renew Energy 1997; 11(3):363–85.

[16]. Garg HP, Adhikari RS. Transient simulation of conventional hybrid photovoltaic/thermal (PV/T) air heating collectors. Int J Energy Res 1998; 22: 547–62.
[17]. Bhargava, A.K., Garg, H.P., Agarwal, R.K., 1991. Study of a hybrid solar-system solar air heater combined with solar-cells. Energy Convers. Manage. 31 (5), 471–479.
[18]. Sopian K, Yigit KS, Liu HY, Kakac S, Veziroglu TN. (1996). Performance analysis of photovoltaic thermal air heaters. Energy Convers Manage; 37(11) PP: 1657–1670.
[19]. Prakash, J. (1994). Transient analysis of a photovoltaic thermal solar collector for cogeneration of electricity & hot air/water. Energy Convers Manage; 35(11) PP: 967–72.
[20]. Bergene, T. & Lovvik, O.M. (2001). Model calculations on a flat-plate solar heat collector with integrated solar cells. Sol Energy; 55 PP: 453–462.
[21]. Agarwal, R.K. Garg, H.P.(1994). Study of a photovoltaic-thermal system thermosyphonic solar water heater combined with solar cells. Energy Convers Manage; 35(7), PP: 605–620.
[22]. Garg, H.P. Agarwal, R.K. Joshi, J.C.(1994) Experimental study on a hybrid photovoltaic thermal solar water heater and its performance predictions. Energy Convers Manage; 35(7) PP: 621–33.
[23]. De Vries, D.W., 1998, "Design of a photovoltaic/thermal combi-panel", PhD thesis, Eindhoven University.
[24]. Fujisawa, T. & Tani, T. (1997). Annual exergy evaluation on photovoltaic-thermal hybrid collector. Sol Energy Mater Sol Cells; 47(1–4) PP: 135–48.
[25]. Norton, B. Edmonds, J.E.J. (1991). Aqueous propylene–glycol concentrations for the freeze protection of thermosyphon solar energy water heaters. Sol Energy; (47) PP: 375–82.
[26]. Rockendorf, G. Sillmann, R. Podlowski, L. Litzenburger, B. (1999). PV-hybrid and thermoelectric collectors. Sol Energy; 67 PP: 227–237.