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OPTIMIZATION OF SOLAR ENERGY UTILIZATION USING CONCENTRATED SOLAR HYBRID ENERGY HARVESTER (CSHEH) BASED ON SMART SOLAR PANEL AND CONCENTRATED THERMOELECTRIC GENERATOR

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Abstract

Many forms of community activities and national industrial sector are highly dependent on the availability of electrical energy. Unfortunately, at the end of 2014 the electrification ratio in Indonesia is only 80.5%. On the other hand, Indonesia is a tropical country that has high intensity of sunlight almost 10 hours per day throughout the year. Indonesia has a solar energy intensity of 4.0-4.9 kWh/m2. This condition is potentially to be used as an alternative source of electrical energy to cover the electricity shortage, particularly in areas which is difficult to reach by existing electricity power. This paper will discuss about optimization of solar energy utilization through Concentrated Solar Hybrid Energy Harvester (CSHEH). CSHEH consists of Smart Solar Panel and Thermoelectric Generator. CSHEH is able to convert the two energy

generated by the sun into electrical energy that is photon energy through the photovoltaic effect of solar panel and heat energy through Seebeck effect of thermoelectric. In case, CSHEH is able to provide an alternative solution to produce electricity, especially in isolated areas. As well as being stand alone, the advantages of CSHEH also does not require operating costs, and environmentally friendly because it just utilize solar energy as a source.

Keywords

Concentrated, Optimization, Smart Solar Panel, Thermoelectric

1. Introduction

The sustainability of community activities and national industrial sectors are highly depending on the availability of electrical energy. The demand of electrical energy also increases every year. Unfortunately, electrification ratio of Indonesia is only 80.5% at the end of 2014. There are 19.5% Indonesian people that doesn't have electricity supply yet. For the household, there are 12.5 million household whom doesn't have electricity. The 19.5% people of Indonesian that doesn't have the electricity is spread out all over the country except Jakarta, the capital city (Jarman, 2014). Furthermore, majority power plants in Indonesia are using fossil fuel as the primary sources. As we know that the availability of fossil fuel is decreased every year and this energy is not good for environmental, because it emission is consist of high carbon monoxide, and the other chemical element.

On the other side, Indonesia is tropical country that has high intensity of sunlight almost ten hours per day throughout the year. Based on Word Solar Insolation Values data, Indonesia has sun energy intensity up to 4.0-4.9 kWh/m^2. This condition is potentially to convert as alternative electricity energy (Anonym, 2015). Utilization of solar energy for alternative electricity energy to reduce the using of fossil fuel especially gasoline has high attention all over the world and also in Indonesia. The solar energy can converted to electrical energy using solar panel technology.

Nowadays, Indonesia Solar Panel Energy Power Plant (SPEPP) already has strong base in wisdom and implementation (Anonym, 2014). But, conventional SPEPP has several problem especially in Indonesia. Indonesian SPEPP using Balance of System (BOS) which integrated with grid system and need a lot of space. Besides that, solar panel component also has several problems such as only optimally work when the module is perpendicular with sunlight and the heat effect causes the voltage drop. The recent SPEPP in Indonesia is also not suitable to

implementation for several isolation areas/downtown areas which difficult to reach by existing (grid) electricity because this areas load are less than 2200 VA, so to reach them need more cost and doesn't have beneficial at all (Anonym, 2015).

There are several developing technology to utilize solar energy such as Australian Concentrated Solar Power (CSP) which utilize the sun thermal energy as primary thermal resources to replace the burning coal energy in the *Rankine* cycles of Steam Power Generation (SPG) or utilization of solar photon energy through solar panel which integrated with single axis solar tracker or double axis (Azevedo et al, 2008). In this paper Concentrated Solar Hybrid Energy Harvester (CSHEH) will utilize both photon energy and thermal energy from solar energy, so the efficiencies of this solar power plant will increase significantly. CSHEH using solar panel equipped with single axis solar tracker (timer) called Smart Solar Panel (SSP) to utilize photon energy and Concentrated Thermoelectric Generator (CTG) inspired by CSP to utilize thermal energy of solar power.

Therefore, CSHEH will give an alternative solution to fulfil electricity energy demand especially in isolation/downtown areas which difficult to reach by existing electricity. CSHEH designed as independent power plant for household. Besides using stand-alone topology, the beneficial of this device are costless in operational and environmentally friendly because this device is only utilizing solar energy as the source.

2. Materials and Methods

Smart Solar Panel

Solar panel is electrical generator component made from diode. Conversion solar energy into electricity energy through solar panel occurs with photovoltaic process which depends on solar radiation. The capacities going maximum when it's daylight and the position of solar and solar panel module is perpendicular. Some of solar panel have maximum efficiency around 10% and 22W/m^2 in average.

Solar panel consists formation of photovoltaic cells, either in series or parallel which convert solar radiation into electricity. Solar panel will occur voltage and current drop when solar panel module could not get sunlight perpendicularly. The effective control which is used to set solar panel module in perpendicular position with sunlight continuously is solar tracker method or maximum power point tracker (Zhou et al, 2014).

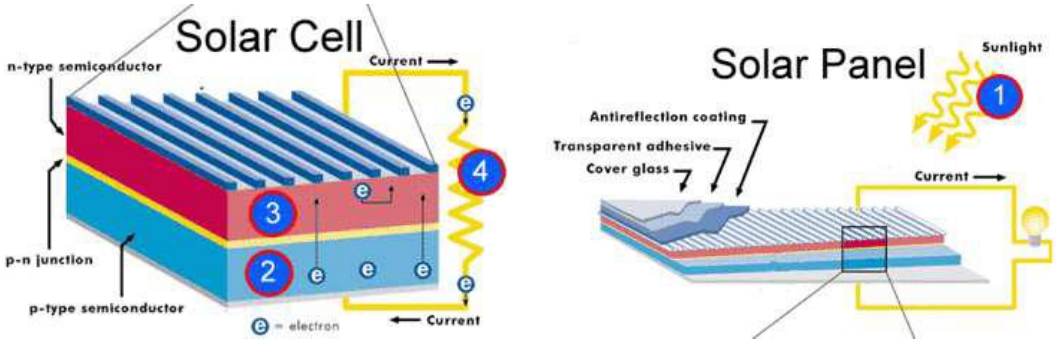

Figure 1: *Solar Panel Structure*

Smart Solar Panel System is solar panel that integrated with solar tracker to overcome the problem of voltage drop that occurs at a certain time conditions. Based on the research journal of Li Guihua about solar tracker, 2012 stated that the solar panel's efficiency using solar tracker horizontal axis type, increased by 10-24%.

Concentrated Thermoelectric Generator

Thermoelectric is electrical power producing systems which utilize waste energy that is heat energy based on Seebeck effect. The Seebeck effect is occur when one end of two different metals are connected, then given different temperature into connection, the difference voltage at one end with another end occurs (Hun et al, 2010).

Concentrated thermoelectric generator using system of Concentrated Solar Power (CSP) which is shown on Figure 2, utilize medium for focusing sun's heat onto one point. That medium is parabolic mirror. Parabolic mirror is a mirror which able for focusing the accepted light towards onto one point. Parabolic mirror has concave surface (Kocic, 2010). The mirror works based on reflection law that stated the angle of incidence equals the angle of light reflection, so that light come to be focused at one point because it has a different degree of slope on all sides (Exergy, 2015). Concentrated thermoelectric generator using thermoelectric as medium of utilization solar energy which concentrated by parabolic mirror. The usage of thermoelectric also can minimize sound emission than using steam turbine as in CSP.

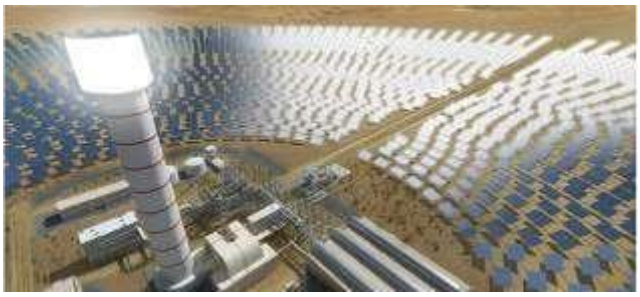

Figure 2: *Concentrated Solar Power (CSP) Concept*

Stand-Alone Topology

The CSHEH using stand-alone topology to overcome the problem of isolated areas. Isolated areas are not suitable with grid system electricity due to the load is less than 2200 VA. This condition make some dilemma for governor because if the decide to supply it, it will not gave them beneficial because the cost is too expensive. So, independent power plant is more suitable to be the solution of lack electricity in isolated areas. The stand-alone topology of CSHEH is shown on Figure 3 below.

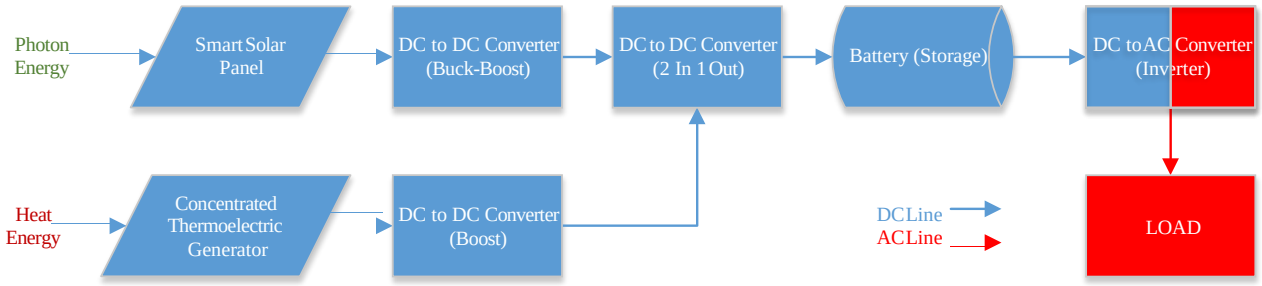

Figure 3: *The CSHEH Stand-Alone Topology*

3. Results and Discussion

Design of Concentrated Solar Hybrid Energy Harvester

The CSHEH design consist of several parts which build for utilize two energy from solar power, photon energy and thermal energy. The photon energy will be utilize by smart solar panel and the thermal energy was utilized by concentrated thermoelectric generator. Design of CSHEH is shown on (Figure 4).

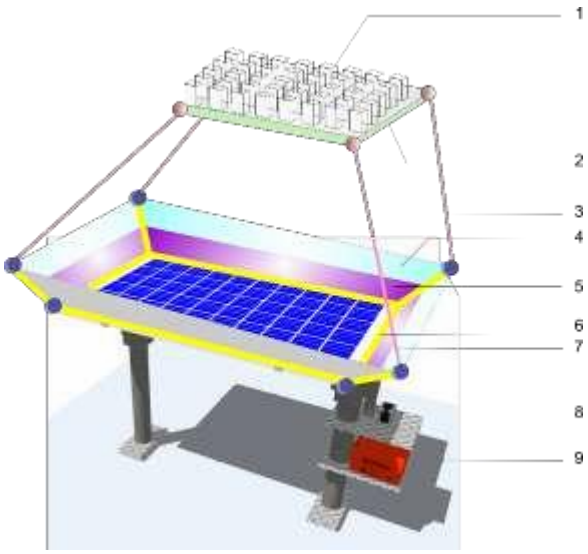

Figure 4: *Design of Concentrated Solar Hybrid Energy Harvester Figure Description*

- Heat sink as heat absorber.
- Thermoelectric generator as converter of thermal energy to electricity energy.
- Supporting pole.
- Parabolic mirror as sun heat concentrator to thermoelectric generator module.
- Flat mirror as biasing sun light to solar panel module.
- Frame of smart solar panel.
- Solar panel module as converter of photon energy to electricity energy.
- Smart solar panel module an electrical system.
- Battery as electricity energy storage.

Electricity Energy Result of Smart Solar Panel

Based on the measurement experiment of smart solar panel and conventional solar panel with 10 Watt peak (WP) solar panel module, we get data of harvesting photon energy to electricity energy from both methods in (Table 1).

Table 1: *Result of Smart Solar Panel and Conventional Solar*

Time Zone	*Smart Solar Panel*		*Conventional Solar Panel*	
	Vt (Volt)	**Energy (Wh)**	**Vt (Volt)**	**Energy (Wh)**
07.00	18.50	8.364	7.60	3.518
08.00	19.90	9.212	8.24	3.819
09.00	20.80	9.628	16.92	7.836
10.00	21.60	10.000	21.20	9.814
11.00	21.60	10.000	21.40	9.906
12.00	21.60	10.000	21.60	10.000
13.00	21.60	10.000	21.50	9.954
14.00	21.60	10.000	21.00	9.722
15.00	21.20	9.802	20.90	9.674
16.00	19.90	9.166	15.23	7.054
17.00	18.80	8.704	7.49	3.472
Average	**20.63**	**9.534**	**19.12**	**7.706**
Energy Total (Wh)		**104.876**		**84.769**

From Table 1, the conclusion is smart solar panel produce 23.7% more energy than conventional solar panel.

Figure 5: *Measuring of Smart Solar Panel at 4.00 pm, electricity current (top right), voltage (bottom right)*

Smart solar panel still produce quite high energy from photon energy even in 4.00 pm when the sun is near completely set, the measurement is shown on Figure 5. On the other side, there is voltage drop on conventional solar panel at the same time. This condition happen because conventional solar panel is not perpendicular with sun light every time. The difference electricity energy which is produce by both of them is shown on graphic in Figure 6.

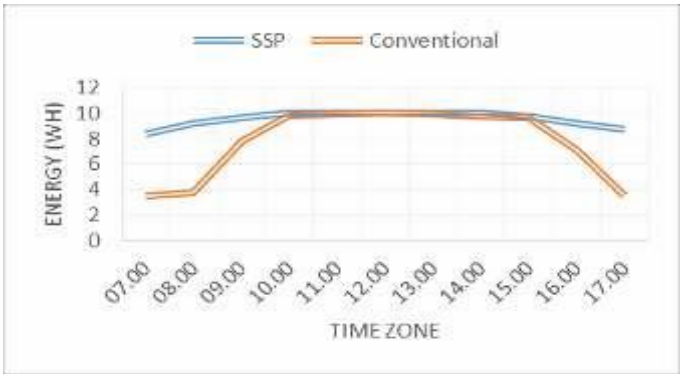

Figure 6: *Graphic Comparison of Electricity Energy from Smart Solar Panel and Conventional Solar Panel*

From the graphic above, we can conclude that there is energy dropping in conventional solar panel at the morning. Even it happens again in the evening at 03.00 pm till 5.00 pm. On the other side, on the smart solar panel the electricity energy dropping was a little bit because the effect of single axis solar tracker module which make solar panel module always close to perpendicular with sun light every time.

Electricity Energy Result of Concentrated Thermoelectric Generator

Besides using smart solar panel to utilize the photon energy from solar power, CSHEH is also using concentrated thermoelectric generator to utilize thermal energy from solar power. The specification of thermoelectric generator from our experiment is below:

L x W x H = 40mm x 40mm x

3.8mm Maximum Power = 40 Watt

Working Temperature = -18º C – 180º

C Efficiency = 40%

CSHEH system using two module of thermoelectric generator and based on our measuring experimental, the optimal temperature (up to 70º C) is between 10.00 am to 2.00 pm or four hours per day. So, the electricity energy from concentrated thermoelectric generator is:

$$E = \text{Efficiency} \times P_{max} \times n \times t \quad \text{.....(1)}$$

$$= 40\% \times 40 \times 2 \times 4$$

$$= 128 \text{ WH}$$

Efficiency and Cost of Concentrated Solar Hybrid Energy Harvester

Planning of CSHEH model is using solar panel with 100 Wp capacity and thermoelectric generator with 575 Watt. However, the prototype of CSHEH that has been already test by us is using solar panel 10 Wp and thermoelectric generator 40 Watt. Based on experimental data of CSHEH prototype, the mathematics result of energy from large scale CSHEH is as follows

L x W x H = 62mm x 62mm x 3.8mm

Maximum Power = 575 Watt

Working Temperature = -20º C – 262º C

Efficiency = 30%

$$E = \text{Efficiency} \times P_{max} \times n \times t \quad (2)$$

$$= 30\% \times 575 \times 2 \times 4$$

$$= 1380 \text{ Wh}$$

Result of smart solar panel using solar panel with 100 Wp capacity based on prototype experimental result is shown on Table 2.

Table 2: *Result of Smart Solar Panel Using 100 Wp Solar Panel*

Time Zone	***Smart Solar Panel***	
	Vt (Volt)	**Energy (Wh)**
07.00	18.50	83.64
08.00	19.90	92.12
09.00	20.80	96.28
10.00	21.60	100.00
11.00	21.60	100.00
12.00	21.60	100.00
13.00	21.60	100.00
14.00	21.60	100.00
15.00	21.20	98.02
16.00	19.90	91.66
17.00	18.80	87.04
Average	**20.63**	**95.34**
Energy Total (Wh)		**1048.76**

So, the total energy from CSHEH is:

$$E_{total} = E_{ssp} + E_{ctg} \quad (3)$$

$$= 1048.76 + 1380$$

= 2428.76 Wh

From the electricity energy, the CSHEH can turn on four lamps with 20 Watt capacity up to 28 hours nonstop, or turn on 200 Watt television up to eleven hours nonstop, or both of them up to 8 hours nonstop. This result is significantly increase than using a conventional solar power plant.

CSHEH is a renewable energy conversion system which is quite expensive to have it. But, the operational and maintenance fee is almost costless. The cost to have one CSHEH is shown on Table 3.

Table 3: *Total Cost to Build CSHEH*

No	Components	Quantity	Unit Price (IDR)	Total Price (IDR)
1	Solar Panel 100 Wp	1	1.800.000	1.800.000
2	Thermoelectric 575 Watt	2	600.000	1.200.000
3	Motor Stepper	1	300.000	300.000
4	Flat Mirror	4	60.000	240.000
5	Concave Mirror	4	70.000	280.000
6	Frame	1	300.000	300.000
7	Battery 200 Ah	1	1.500.000	1.500.000
8	Arduino Uno Module	1	180.000	180.000
9	Heat sink	1	100.000	100.000
10	Maintenance	10%	590.000	590.000
Total (IDR)				**6.490.000**

The CSHEH living time is about ten years from mathematical calculation and several solar panel warranty. So, we know the total efficiencies if we compare with existing electricity in Indonesia. CSHEH is for household family, so we compare it with household electricity price. To have 1 kWh electricity energy, we should pay IDR 1.300,-. If one household need energy as big as energy from CSHEH 2.5 kWh, they should paid IDR 3.250, - a day or IDR 1.186.250,- a year. On the other hand, with investment IDR 6.490.000,-, we can get CSHEH for and has ten years electricity energy for free. To get same amount electricity energy with existing electricity, we should pay for IDR 11.862.500,-. Such a big value for little household. So, using the CSHEH can safe IDR 5.732.500,- than using existing electricity. Moreover, the efficiencies of using CSHEH as follows:

$$\eta = [(Cost_{start} - Cost_{csheh})/(Cost_{start})] \times 100\% \quad (4)$$

= (5.732.500/11.862.500) x 100%

= 45%

4. Conclusion

This paper has presented a new method to utilize solar energy using Concentrated Solar Hybrid Energy Harvester (CSHEH). CSHEH is a new technology about utilization of solar energy to electricity energy which more efficient by utilize both solar photon energy using Smart Solar Panel and solar thermal energy Concentrated Thermoelectric Generator inspired by CSP. Smart Solar Panel using single axis solar tracker that suitable for tropical country such Indonesia and Concentrated Thermoelectric Generator was inspired by CSP but it use thermoelectric generator to replace steam turbine in CSP to reduce sound emission. Based on experiment using prototype model of CSHEH, known that CSHEH is able to produce more electrical energy than kind of solar power plant that already exist. The using of Smart Solar Panel was increasing utilization of solar photon energy through solar panel up to 24% and the addition of Concentrated Thermoelectric Generator made CSHEH produce energy twice more than the conventional solar panel power plant. Besides that, using Concentrated Solar Hybrid Energy Harvester can minimize the usage cost up to 45% throughout ten years. Furthermore, concentrated Solar Hybrid Energy Harvester is suitable as electrical energy alternative particularly for household and isolated areas because it use stand-alone electricity topology that less expensive than using grid system electricity topology.

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