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Experimental investigation of the output power of PV panels combined with circular configuration TEG modules using LED bulb loads

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Abstract **– The purpose of this study is to optimize the potential of solar energy that releases light and thermal energy simultaneously by using a combination of PV and TEG technology. PV only absorbs photon light, where solar thermal is transmitted to the TEG module under the panel surface which is useful for maintaining temperature and increasing PV output power. The TEG module configuration was chosen to be circular with the diameter of the circle adjusting to the area of the solar PV panel. There are two PV panels used during the test, one panel is left without TEG and the other panel is installed with 12 TEG modules and on the cold side of the module is added a heat sink and circulating water fluid cooling to maintain the temperature of the cold side of the module. The test results show that the integration of PV-TEG increases the system output power by about 45% compared to PV alone. The PV surface temperature is more stable and tends to be even with the attachment of TEG and cooling with water, while without the hybrid, the PV temperature appears to be sinusoidal with a peak temperature of about 70°C compared to the hybrid only around 40 and 50°C. PV temperatures below 60°C are important to maintain PV performance for a long period.**

Keywords: PV-TEG-bulb, water circulation, power output, thingspeak

I. INTRODUCTION

Utilization of renewable energy sources is a promising alternative choice to overcome the limited availability of fossil energy sources. Not only that, the world's demand for clean and cheap green energy is increasingly needed. The development of solar panel (PV) technology is one that is able to generate electrical energy by utilizing solar radiation as the largest and free energy source of all time. The application of PV panel arrays can be directly connected to government-owned power plants (AC On-grid) or can stand alone as a harvester of renewable electrical energy from sunlight (Off-grid) [1][2]. The advantage of this solar power generation using PV (PLTS) whose main material is PV is that it is able to reach remote areas that are not supplied with electricity from the state, provided that the remote location point has sufficient solar radiation. In addition to these advantages, the problem experienced by the PV surface for a long period of time is the continuous exposure to solar heat, so that this will increase the surface temperature of the panel. As a result of the increase in the PV surface temperature, panel performance will decrease [3]. The task of researchers is to overcome this problem by maintaining the operational temperature of the solar panel no more than 60° C in stable performance conditions [4]. This can be done in various ways such as attaching the bottom surface of the panel with phase change material (PCM) [5][6], thermoelectric cooler [7][8], and TEG [9][10]. The focus of this study is the circular configuration of the TEG module in the integration of PV with TEG. This is important to maintain the temperature difference between the top and bottom surfaces of the PV which will affect the PV output power. This configuration was chosen to facilitate the circulation of the module cooler with a uniform water fluid flow rate for each TEG. Khan et al., [11] showed a similar rectangular configuration with 10 TEG modules attached to a 10 W polycrystalline PV compared to a PV without TEG as shown in Figure 1. It can be seen that the cold side of the module is left without the flow of cooling fluid with a forced convection system, but only natural air flows. The flowing air cooling system requires additional energy for the blower to work which is greater than the energy generated by the TEG. Meanwhile, Rahman et al., [12] who used a 50 W monocrystalline PV assembled the PV with a combination of 5 TEG modules (Figure 2). This configuration creates the same cooling constraints in each module due to the serpentine circulation of the water fluid, which can result in losses when the fluid moves from the first series of modules to the next series.

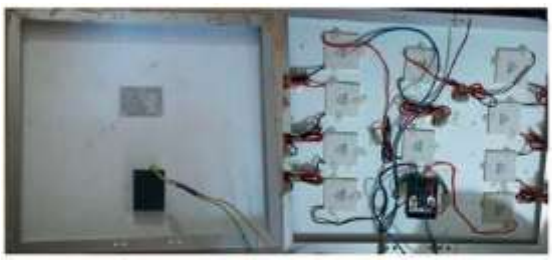
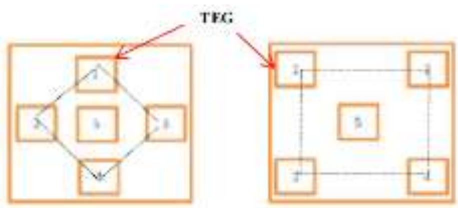


Figure 1. Hybrid of PV Poly 10 W and 10 TEG [11]



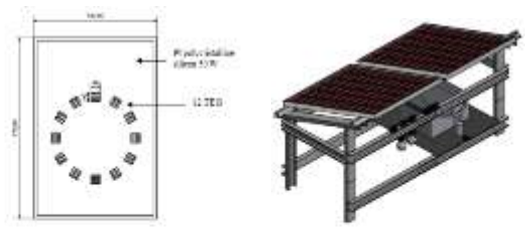
(a) rectangle (b) square

Figure 2. Hybrid of PV Mono 50 W and 5 TEG [12]

Rahman et al., [12] presented 2 different TEG module configurations; rectangle and square, where the hybrid PV-rectangle TEG had better power compared to PV-square TEG. The hybrid PV-TEG had a positive effect on the PV surface temperature which was maintained below 60°C. However, the configuration shown was less effective in circulating the TEG cooling fluid. Therefore, to overcome these obstacles, this study created a circular configuration which provided a smoother fluid flow space.

II. METHOD AND DESIGN

The test setup consists of two 50 W Polycrystalline solar panels, where one PV is integrated with 12 TEG modules connected in series. The other panel without TEG combination is placed on an aluminum frame at a 15° tilt as shown in Figure 3(b). The configuration of the 12 TEG modules placed on the back of the PV panel is shown in Figure 3(a).



(a) (b)

Figure 3. (a) Configuration of hybrid PV-12 TEG; (b) Experimental setup of PV combine TEG and PV stand-alone

During data collection, the PV used a 12 V, 50 W DC bulb load, while the TEG used a 3 V load with a current of 18-20 mA at a power of 0.1 W. The coolant fluid was circulated using a R385 12 VDC water pump, with fluid mass flow rates set at 0.085 m/s. The PV panel was positioned sitting on a C-channel light steel assembly at a fixed inclination angle of 15° to the north with the consideration that this elevation was sufficient to provide the effect of solar radiation to the PV surface, where the observation location was on the equator [13]. To evaluate the performance of the PV-TEG hybrid system, the setup was tested under climatic conditions in the city of Palu (5°09'04"S 119°27'08"E), Indonesia. The experiment was conducted from 9 am to 3 pm.

The temperature of the top and bottom surfaces of the PV, hot and cold sides of the TEG module, were measured using a K-type thermocouple as shown in Figure 4, which was read using the Thingspeak platform, an Internet of Things (IoT) application. Meanwhile, the current and voltage readings were measured manually every 5 minutes using a Pasco SF-9569A digital multimeter. The thermocouple sensor was placed in the center of the top surface of the PV at the center point of the TEG module circle to approximate the average value of the panel in the module circle.

Figure 4. IoT-based K-type thermocouple

An example of an IoT-based computer program code can be read on the Thingspeak.com link as in Figure 5.

```
#include "max6675.h"
#include <WiFi.h>
#include <ThingSpeak.h>
WiFiClient client;
const char* ssid = "GR47IO";        // Name yourWiFi
const char* password = "29102019";  // Password your WiFi
const char* myWriteAPIKey = "B1Q5PR7UGP4WN24B";  // your API Key
unsigned long counterChannelNumber = 2584220;    //your  ID Channel
// Timer variables
unsigned long lastTime = 0;
unsigned long timerDelay = 10000;
int thermoDO = 19;
int thermoCLK = 18;
int thermoCS = 5;
int calculate = 0;
MAX6675 thermocouple(thermoCLK, thermoCS, thermoDO);
void setup() {
  Serial.begin(9600);
  WiFi.mode(WIFI_STA);
  ThingSpeak.begin(client);  // Initialize ThingSpeak
  Serial.println("MAX6675 test");
  // wait for MAX chip to stabilize
  delay(500);}
void loop() {
  float temperature = thermocouple.readCelsius();
  if ((millis() - lastTime) > timerDelay) {
// Connect or reconnect to WiFi
    if (WiFi.status() != WL_CONNECTED) {
      Serial.print("Attempting to connect");
      while (WiFi.status() != WL_CONNECTED) {
        WiFi.begin(ssid, password);
        delay(1000);  }
      Serial.println("\nConnected."); }
    Serial.println("Suhu = ");
    Serial.println(suhu);
    ThingSpeak.setField(2, suhu);
    int x = ThingSpeak.writeFields(counterChannelNumber, myWriteAPIKey);
    if (x == 200) {
      Serial.println("Channel update successful.");
      hitung=0;
      Serial.println(calculate);
    } else {
      Serial.println("Problem updating channel. HTTP error code " + String(x));
      hitung++;
      Serial.println(calculate);
      if (calculate == 3){
        WiFi.disconnect(true);
        Serial.println("WiFi disconnected"); }   }
      lastTime = millis(); }}
```

III. RESULTS AND DISCUSSION

Figure 6 shows the PV and TEG temperature configurations for both PV panels without TEG modules and PV with TEG. Experiments have proven that the surface temperature of the panel without thermoelectric cooling has increased quite significantly, even exceeding the stability limit of the PV surface temperature above 60°C, reaching 70.188°C at around 10 am. Furthermore, the surface temperature decreases randomly due to changes in solar intensity which decreases towards the afternoon. Compared to the PV-TEG hybrid, the PV surface temperature ranges from 44 to 50.5°C followed by temperatures on the hot and cold sides of the TEG. The temperature of the cold side of the module tends to be constant at less than 40°C as a result of the flow of water cooling fluid whose temperature is maintained by adding ice blocks. The greater the differentiation of hot and cold temperatures of the TEG, the more effective the module is.

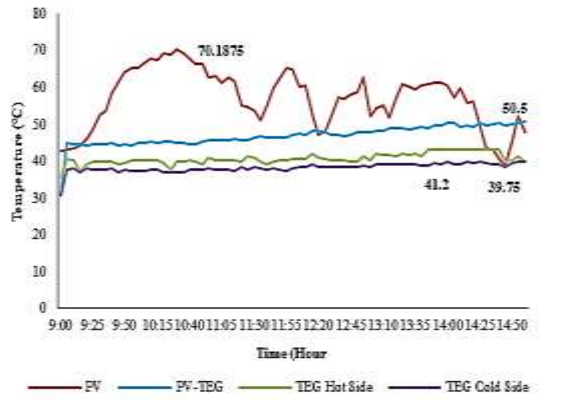


Figure 5. The temperature of PV and PV-TEG hybrid

Figure 5 shows the output power of PV and TEG separately, and the combined power of PV and TEG observed from 9am to 3pm. The test results prove that the integrated power of PV-TEG is on average above 40 Watts with a peak power of 80 Watts, while PV without TEG is only around 30 Watts. There is an average increase of 70% with the combination of circular TEGs. The hybrid power ranges between 70 and 80 W while without TEG, PV is only in the interval of 20 and 40 W. In contrast, the output power of TEG modules, even when connected in series, is still below 1 Watt. The positive trends is that there is an increase in electrical power under high solar intensity conditions of 0.015 Watts at the time interval of 11.45 to 12.00. This indicates that the temperature difference between the two sides of the module is optimal as investigated by Mustofa et al., [16] and Qasim et al., [17].

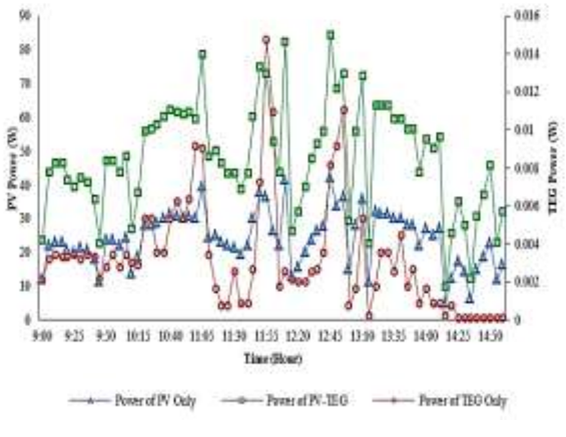


Figure 6. The output power of PV and PV-TEG hybrid

From the two Figures above, it shows a significant effect on the difference in PV surface temperature and its output power when combined with a TEG module in a circular configuration. Although the electrical power produced by the TEG module is still low, efforts to increase it are still wide open. Efforts that can be made are by using different TEG module specifications and nano-based cooling media [18][19].

IV. CONCLUSION

From this study, it can be concluded that the PV panel will stabilize its surface temperature if cooled. The cooling effect of the TEG module in a circular configuration has been in accordance with the needs of the PV device, hence the power generated also increases and lasts longer in changing solar irradiance conditions. The temperature measurement accuracy of the PV-TEG hybrid system is very good with the thinspseak application IoT platform. Further investigation is needed with different TEG cooling media or the use of a cascaded TEG model to increase the module's output power.

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