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THE THERMOELECTRIC SOLAR PANELS

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Abstract. In this study, load characteristics of thermoelectric and photovoltaic solar panels are investigated and compared with each other with experiments. Thermoelectric solar panels converts the heat generated by sun directly to electricity; while, photovoltaic solar pales converts photonic energy from sun to electricity. In both types, maximum power can be obtained when the load resistance is equal to internal resistance. According to experimental results, power generated from unit surface with thermoelectric panel is 30 times greater than the power generated by photovoltaic panel. From a panel surface of 1 m^2, thermoelectric solar panel has generated 4 kW electric power, while from the same surface, photovoltaic panel has generated 132 W only.

Keywords: thermoelectric, photovoltaics, solar panel, renewable energy.

1. INTRODUCTION

Today, fossil fuels such as coal and oil are used as sources of energy to obtain electrical power. These fossil fuels are limited sources and continuously omit greenhouse gases to environment. Efforts towards research use new and renewable energy sources increase due to greenhouse gas emission and increase in global warming. The world's population increases constantly and need for energy increases accordingly. In future, mankind needs to make maximum use of renewable energy resources such as solar, wind, biomass, geothermal and hydrogen to minimize the threats posed by energy sources and meet the energy requirement [1]. Solar energy, which is a renewable energy source, is infinite, clean and renewable. Solar energy emits as rays and heat. Photovoltaic panels (PV) and thermoelectric panels (TE) have been widely used especially in areas far from electric network due to their advantages such as converting the sun rays or thermal energy emitted from the sun directly into electrical energy. However, PV panels are more widely used compared to TE panels. Studies on thermoelectric panels show that TE panels could compete with PV panels and would even replace them. The cost per kW of the electrical energy obtained from PV and TE systems are higher compared to sources such as water, coal or oil. This unit cost is usually constituted by PV and TE panels and the battery group used in these systems. Recently, PV and TE systems directly connected to the network and reduced battery use have been developed in order to reduce the unit cost and make maximum use of solar energy. Today, PV systems work with approximately 20% efficiency. Thanks to the newly developed optical concentrators, this level of efficiency has been increased up to about 30% [2, 3]. TE panels have no moving parts, their structure is simple, they require no maintenance, they are long lasting, they allow temperature control, directly convert the electrical energy and work quietly, reliably and decidedly. Along with these advantages, the biggest drawback is that the efficiency drops to (5 -10) % when the temperature difference between thermoelectric modules used in panels is 100°C. However, even when the temperature difference increases slightly, the efficiency of TE panels can go up to (30-40) % [4]. Commercially, the unit cost of the electric power produced by a PV panel is 1.5 W/€, while it is 1.5 W/$ for a TE panel. Therefore, TE panels are more advantageous compared to PV panels in terms of electric energy production. They are also more advantageous given the space they take [5].

2. THE BASIC STRUCTURES OF PV AND TE PANELS

2.1. PVS AND THEIR CHARACTERISTICS

PV technologies, which are very common today, are semiconductor devices consisting of single crystal and polycrystalline silicon modules. PV cells consist of two n- and p-type semiconductor materials. Photons hit PV cells due to radiation effect and cause electrons to move and pass through load. The work efficiency of PV cells increases as the radiation intensity increases. PV cells work like a current source [6]. A PV cell can be modeled as in Figure 1a. PV cell model is made up of the current source, diode, parallel resistance Rp and serial resistance Rs. The PV cell completes its circuit through the diode when it is open circuit and through the external load when it is shorted. Although the value of parallel resistor is very high, the value of serial resistor is very low. The maximum power (MPP) is obtained when the resistance of the load connected is equal to the internal resistance of the PV cell. In order to capture the maximum power from the PV cell, solar inverter's maximum power point tracker (MPPT) control loops are used. As shown in Figure 1b, the PV cell shows different behaviours depending on the size of the PV panel or the type of the load connected and intensity of sunlight. The PV cell's characteristic is described as voltage and current change when different loads are connected. The maximum voltage VOC is measured on its ends when the PV cell is in the sunlight with open ends. This voltage is the open circuit voltage. When two ends of the PV cell is shorted, the maximum current ISC passes through, and in this case, the voltage is zero. This current is called the short circuit current. Temperature and light intensity affects the output characteristics of the PV cell. The current is directly proportional to the intensity of the light. Voltage varies depending on the level of light emitted, but this variation is very small. MPP is the point where the highest power is transmitted from the system to the receivers. PVs work in a wide range of voltage and current. Therefore, the power output changes constantly [7].

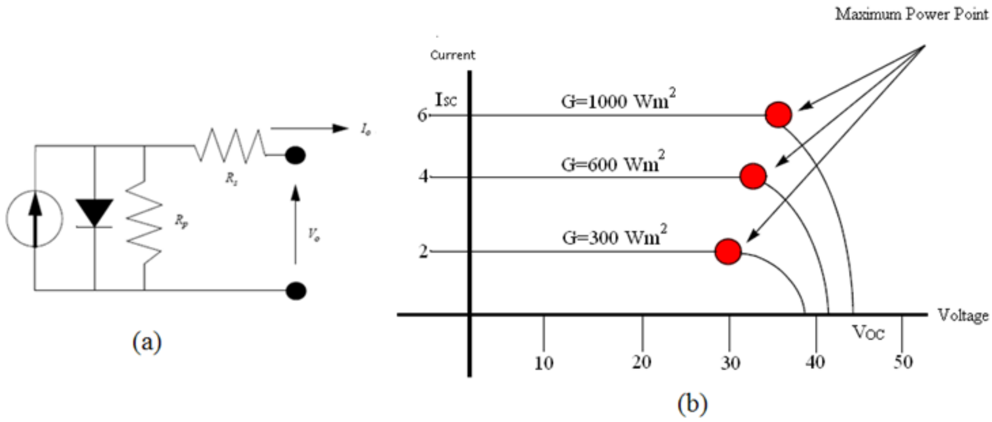

Fig. 1. (a) PV cells' electrical model, (b) V-I against illumination (36 cells set).

2.2. TEs and Their Characteristics

The basic structure of a thermoelectric module is made up of thermoelements. Thermoelements result from the combination of p- and n-type semiconductor and conductor. Thermoelements are connected electrically in series, and thermally in parallel. The modules operate with Seebeck effect. Seebeck effect was found by Thomas Seebeck in 1821. The electrical circuit model of the thermoelectric module is given in Fig. 2 (a). TE's electrical circuit model is similar to PV battery's electrical circuit model. The increase in the electric current causes an increase in the power spent in the internal resistance. If a temperature difference is created between the surfaces of the thermoelectric module and a load is connected to both ends, electrical current passes through the load and electric power is obtained [1].

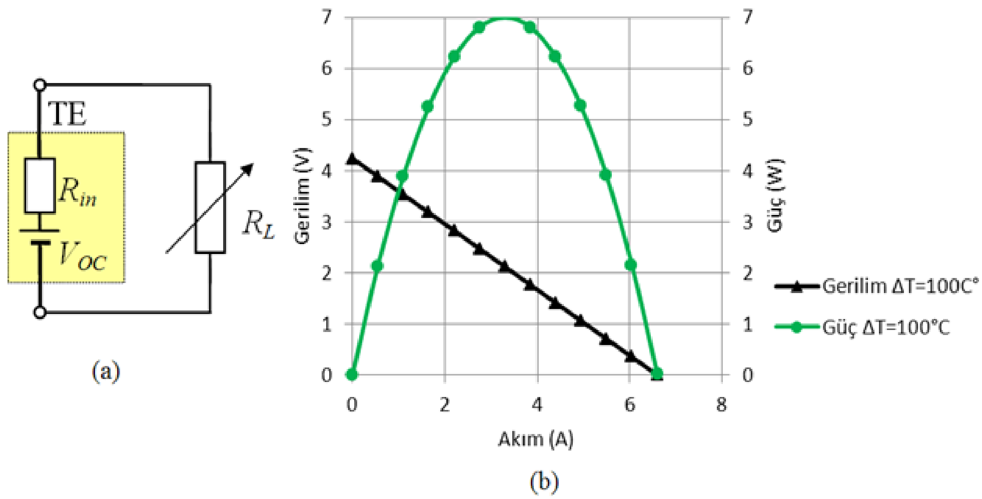

Fig. 2. (a) The electrical circuit model of the thermoelectric module, (b) TE V-I graph.

The open circuit voltage obtained from the thermoelectric module varies parabolically depending on the temperature difference between the surfaces ($\Delta T = T_H - T_C$). The maximum power is obtained from a TE when the resistance of the load connected is equal to the internal resistance of TE. The TE output characteristic is given in Fig. 2 (b). The power obtained changes when the temperature difference between the surfaces of TE is maintained at a constant value and the value of the load connected to the ends is changed. The maximum current is obtained when the load value is zero. The maximum voltage value is obtained when the load value is infinite. The maximum power is obtained when the resistance of the load connected is equal to the internal resistance of TE. If the temperature difference between the TE's surfaces is increased, the power value also increases parabolically [1].

3. Experimental Installation

3.1. Experimental PV Installation

The experimental PV installation as in Fig. 3 was carried out in Ankara on July 21st, 2014 at 12:00. The experimental installation involved solar panel, solar gauge, and electronic load.

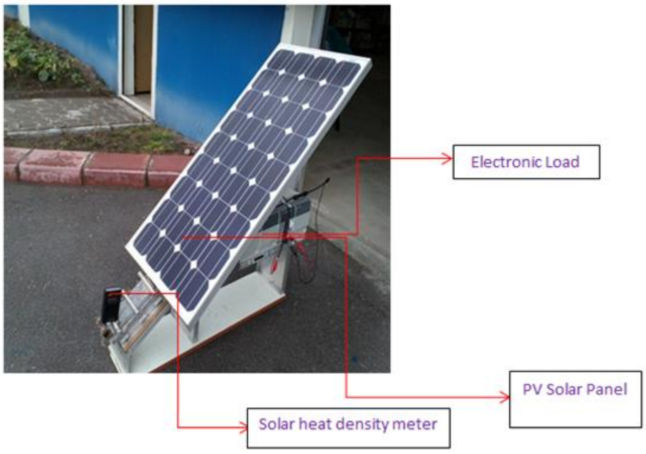

Fig. 3. PV system installation.

As the solar panel, a LCS Solar Strom AG type solar panel consisting of 40 PV cells and with the dimensions of 900x676x35 mm was used. The PV panel area was 0.61 m^2 and the maximum power was indicated to be 80 W on the label. Electronic load was used in order to obtain PV panel's characteristics. The intensity of the heat from the sun was measured with heat density solar meter, and the resistors were measured with the electronic load Mainframe device.

3.2. Experimental TE Installation

The experimental TE installation is given in Figure 4. This TE system was designed to be portable. It can be used anywhere. The TE system consists of four parts: TE panel, solar gauge, temperature gauge and electronic load. The temperatures were measured with CE 307 digital thermometer, the intensity of the heat from the sun was measured with heat density solar meter, and the resistors were measured with the electronic load Mainframe device.

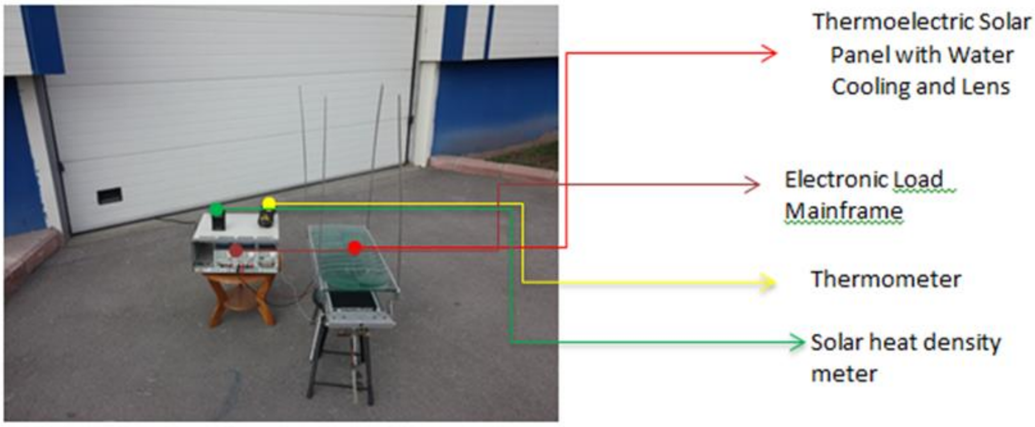

Fig. 4. The experimental portable TE installation.

For TE system, 10 thermoelectric modules 5x5x0.4 cm in size, which were custom produced by TES Ltd. company, were used and the surface area of the TE panel was 0.025 m^2. These were mounted on a flat surface using silicone gel between the module surface and mounted surface to increase the thermal transmittance. All modules were connected in series to increase output voltage. Since the electrical energy obtained from TEs depends on the temperature difference between the surfaces, two T-type point-tipped thermocouples were used to measure the temperature of the surfaces. Running water was used to cool the cold surface of TE and the water discharge was maintained at 30 ml/sec. The upper surface of the panel was painted black with a special paint to absorb the heat from the sun maximally and a special lens was used to increase the temperature of the surface. The height of the lens on the panes was kept constant at 20 cm, which is the focal length of the lens.

4. Evaluation of Experiment Results

The data obtained in PV and TE system experiments are given in Table 1. The experiments were conducted for 30°C environmental temperature value. The density of the power from the sun was measured to be 2 kW/m^2. It was measured as $\Delta T = T_H - T_C = 140°C – 40°C = 100°C$ on the TE panel with lens. For PV panel, the maximum power value was approximately 80.55 W, when the load resistance was 10 Ω, the current value was 4.5 A and the voltage was 17.9 V. The amount of electrical power obtained from unit area was 132 W/m^2.

R_L,Ω	U_{TE},V	I_{TE},A	P_{TE},W	U_{PV},V	I_{PV},A	P_{PV},W
∞	45	0	0	22,1	0	0
50	45	0	0	21	0.8	16.8
25	30	2	60	20.2	1.1	22.22
20	27	3	81	20	1.97	39.4
15	25	4	100	19.6	2.7	52.92
10	20	3,5	70	17.9	4.5	80.55
5	15	3	45	10.4	4.4	45.76
0	0	10	0	0	5.1	0

Tab. 1. Experiment data of PV and TE systems.

For TE panel, the maximum power value was 100 W, when the load resistance was 15 Ω, the current value was 4 A and the voltage was 25 V. The amount of electrical power obtained from unit area was 4000 W/m^2.

5. Conclusion

The characteristic behaviors of TEs' and PV panels in energy production were investigated. TEs produce electrical power from the heat generated by the sun, while PV systems produce electrical power from sun rays. According to the results obtained, the amount of electric power produced from the unit surface of thermoelectric panel was about 30 times more compared to photovoltaic panel. The amount of electric power produced from one square-meter of thermoelectric panel surface was 4 kW, while it was only 132 W for a photovoltaic panel with the same surface area. Since the cost of electrical energy produced by PV panel is more than 1.5 – 2 times of TE panel on average, TE panels are more advantageous compared to PV panels in terms of electric energy production. They are also more advantageous given the space they take. But both technologies are environment-friendly and renewable.

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У статті виконано порівняння експериментальних робочих характеристик термоелектричних та фотоелектричних сонячних панелей. Термоелектричні сонячні панелі перетворюють тепло, яке виділяється сонцем безпосередньо в електрику; у той час як сонячні фотоелектричні панелі перетворюють енергію фотонів від сонця в електрику. В обох типах може бути отримана максимальна потужність, коли опір навантаження рівні внутрішньому опору. Відповідно до результатів експериментальних досліджень, потужність, яка генерується із одиниці поверхні термоелектричної панелі у 30 разів вища, ніж потужність, яка генерується фотоелектричною панеллю. З поверхні термоелектричної сонячної панелі площею 1м^2 згенеровано 4 кВт електроенергії, у той час як з такої ж самої площі поверхні фотоелектричні панелі згенеровано лише 132 Вт.

Ключові слова: термоелектрика, фотоелектрика, сонячні панелі, відновлювальна енергетика.