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The monitoring of monthly, seasonal and yearly optimum tilt angles by Raspberry Pi card for Bilecik city, Turkey

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Abstract

Solar energy is extracted from photovoltaic (PV) panels by semiconductor materials used in the system. However, the PV panel efficiency is low. Moreover, inaccurate determination of optimum fixed tilt angle of the panels, some environmental factors such as dirt and dust and solar radiation level and temperature variations depending on the seasonal changes decrease the panel efficiency. In the study, PV panels were placed at 10º, 20º, 30º, 40º, 50º and 60º tilt angles and the monthly, seasonally and yearly optimum tilt angles for Bilecik city were determined. Therefore, it was determined at which tilt angle the maximum power is extracted from PV panels. The record and the storage of the voltage, current and the power data obtained from PV panels is provided by Raspberry Pi card. Moreover, the obtained data is open to access on the internet by a web server set up on Raspberry Pi. Therefore, the data can be watched live in any computer with an internet access. Annual measurements were performed by the designed system and the data was recorded with the date and time data.

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Keywords: PV panel; Raspberry Pi; tilt angle; microcontroller; yearly

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1. Introduction

The need for electricity has increased due to rapidly improving technology and increasing population with the industrial revolution. Today, mostly fossil fuels such as oil, natural gas are used in obtaining electrical energy. Some renewable energy sources such as solar, wind, geothermal and biomass have been used recently as an alternative to fossil fuels since they give harm to the environment and they will be exhausted in the near future. There have been many investments on energy sector recently and obtaining electrical energy from solar energy has become more attractive [1, 2].

The systems used to obtain electrical energy from solar energy are called as photovoltaic (PV) systems. In PV systems, solar energy is directly converted to electrical energy by the semiconductor materials used in the system. However, the efficiency of PV panel is low depending on the semiconductor materials. There are many factors affecting the PV panel efficiency. The location of the PV panel is the most important parameter affecting the efficiency. Sun lights should fall on the PV panels with direct angle in order to have a power at maximum level [3–5]. Therefore, solar tracking systems are used. However, the drawbacks of the power tracking systems are that the devices such as motor, driver, etc. used in the system consume energy continuously and they have high cost. Therefore, the panels are placed monthly seasonally and annually at optimum fixed tilt angles to benefit from sun light at maximum level. In fixed tilt angle systems, the angle varies according to the geographic position of PV panels. As a result, the monthly, seasonally and annually variations of PV panel optimum tilt angles are determined by experimental studies [6, 7].

In literature, Ulgen [8] carried out a study for Izmir city, Turkey and determined that the optimum tilt angle for solar collectors varies between 0–61˚ throught the year. He indicates that the tilt angles of the solar collectors should be 55.7˚ for winter, 18.3˚ for spring, and 4.3˚ for summer and 43˚ for autumn. He presented that annually average tilt angle of fixed systems is 30.3˚. In the study conducted by Beringer et al. [9] eight PV panels are placed between 0°–70° by 10° increase. The optimum tilt angle for winter and summer seasons are found to be between 50°–70° and 0°–30°, respectively. The annual optimum tilt angle is found to be equal to the tilt angles of summer period. Jafarkazemi and Saadabadi [10] found the annual optimum tilt angle as 22°. This value is very close to the latitude angle found by Abu Dhabi. The monthly optimum tilt angle varied between –9 and 52° starting from June to December months. Khorasanizadeh et al. calculated the monthly, seasonal, semiannual and annual optimum tilt angles for Tabass city, Iran. The monthly tilt angle was found to be 0° for June and July and 64° for December months. The annual tilt angle was calculated as 32° and this value is very close to the latitude angle of Tabass city. Kacira et al. [11] conducted a study for Sanlıurfa city and presented that the monthly optimum tilt angle of the city varies between 13°–61° through the year.

In this study, PV panels with same properties were placed at 10º, 20º, 30º, 40º, 50º and 60º tilt angles and the voltage data was measured and recorded in the computer environment. The monthly, seasonal and annual optimum fixed tilt angle was determined for Bilecik city. Firstly, the obtained analog data was converted to numerical data by a microcontroller. The average of the numerical data was taken in every 10 minutes by Raspberry Pi and was stored on a SD card placed on Raspberry Pi and in computer environment as well. Then, the current, voltage and power values of PV panels could be watched alive by the web server set up on Raspberry Pi in every hour of the day. Only the voltage values of PV panels could be measured in the system. The current and power values of the PV panels are calculated by an algorithm written by Phyton programming language. The measurements were conducted between May 2015 and April 2016. The data was taken hourly between 06:00 and 21:00. The daily average voltage, current and power values are shown in line chart, the daily voltage and current values of each panel placed at different angles are shown in bar chart and the annual power values expressed in percentages are shown in a bar chart.

This paper is organized as follows: Section 2 presents the designed system. In Section 3 and 4, hardware development and architecture of the system are presented, respectively. In the results section, the annual power values of the panels expressed in percentages placed are given and the monthly, seasonal and annual optimum tilt angles are determined.

2. The experimental setup of the designed system

In fixed angle systems the panels should be placed in a way to form a certain angle with the horizontal surface. The tilt angle varies depending on the geographical position of the PV panels. The panels should be placed to form a tilt angle with the horizontal surface, as shown in Fig. 1 [12].

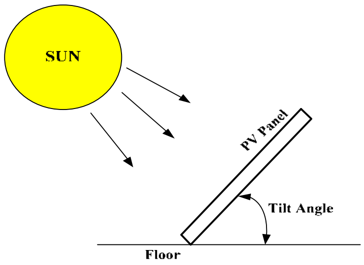


Fig. 1. The fixed tilt angle of PV panel.

In the study, six PV panels with same properties were placed at 10º, 20º, 30º, 40º (city's latitude), 50º and 60º angles to determine the monthly optimum tilt angle of PV panels for Bilecik city and the experimental setup of the panels were constructed. The setup of the panels is shown in Fig. 2.

Fig. 2. Experimental setup of the PV panels.

In this system, polycrystalline 100 Wp Perlight PLM-100P/12 PV panels are used. Firstly, 14 Ω load voltage is connected to each PV panel. Voltage breaker circuit is formed in order to measure the voltage of the panels and voltage data is obtained by 1 Ω load resistor. The experimental setup of the load and voltage data of each PV panel are shown in Fig. 3.

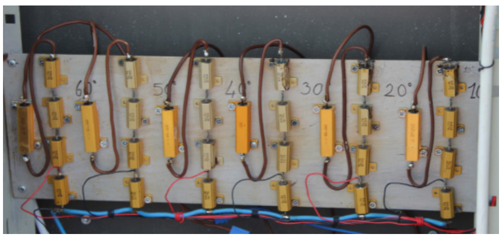


Fig. 3. Loads connected to PV panels.

The circuit connection schema of the microcontroller providing the transformation of the voltage values of the panels to numerical data by analog-digital converter is shown in Fig. 4.

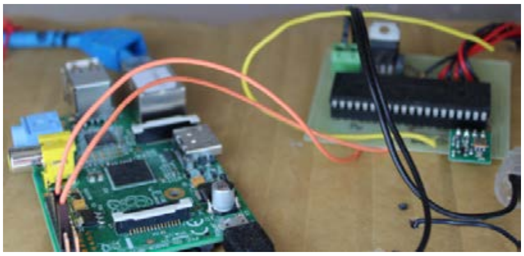


Fig. 4. The connection scheme of microcontroller and Raspberry Pi.

Data logger devices are used to measure the current, voltage, and daily radiation level and the temperature of the PV panels and to monitor and store the values of these parameters. However, in the designed system microcontroller and Raspberry Pi were used instead of the data logger device to since the data logger devices on the market are expensive.

3. Hardware development of system

3.1. The specifications of Raspberry Pi

Raspberry Pi is a small size single board computer developed in order to teach basic computer science in schools. Single Board Computer is the name of the concepts which combines all the necessary equipment for the operation of a computer in a single card. The RPI used in the study features a Broadcom BCM2836 microchip which includes 900 MHz quad-core ARM Cortex-A7 central processing unit (CPU). It has a video Core IV 3D GPU graphics processing unit, 1 Gigabyte LPDDR2 SDRAM memory, 4 USB (Universal Serial Bus) ports, 40 GPIO pins, HDMI (High Definition Multimedia Interface) port, Ethernet port, 3.5 mm audio jack, camera interface (CSI), the display interface (DSI), micro SD (Secure Digital) memory card slot. The Raspberry Pi used in the experimental study are shown in Fig. 5 [13].

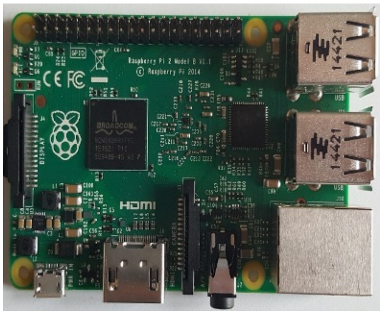


Fig. 5. Raspberry Pi card.

3.2. Configuration of Raspberry Pi

The operating system of Raspberry Pi is set up on the SD card installed on the Raspberry Pi. Raspbian Jessie operating system has been set up on SD card. Among the programming languages, Python is available on Raspbian Jessie operating system. Therefore, the Python programming language is preferred when the software of the system is designed. Software development processes can be programmed by C, Perl and Java programming languages, as well [14, 15]. There is a tool on Raspbian Jessie operating system on which the configurations are made. By using this tool; the extension of the file system, regulation of user passwords, booting operation from GUI or CLI, the overclocking operation, regional languages, and time settings and the activation of the serial communication protocols and SSH services are performed.

4. Architecture of system

The analog voltage values taken from PV panels are converted to digital data by a microcontroller. Microcontroller and Raspberry Pi communicated with UART serial communication protocol. Open source MySQL relational database was used to record the data. The Python programming language on the Debian Linux-based database was used to read the data and record them on the database. Php was used for dynamic monitoring of the data stored in the database in a web environment. Informing the administrator in case of failure in the system was carried out by swatch application. NTP server was configured for the consistency of the data since there is no unit in Raspberry Pi controlling the time [16, 17].

4.1. Data Monitoring

The measurements were conducted during a year (between May 2015 and April 2016). The recorded data was analyzed and the graphics were created. 25.04.2016 date in April was chosen randomly to set an example. Daily average voltage, current and power values obtained during the mentioned dates are shown with a line chart in Fig. 6.

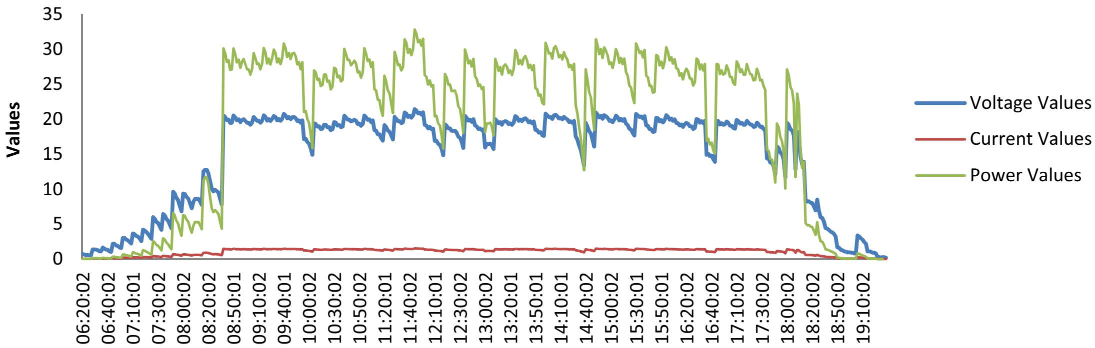


Fig. 6. The values obtained from PV panels.

Daily voltage and current values obtained from panels placed at different angles are shown in bar chart in Fig. 7. and Fig. 8.

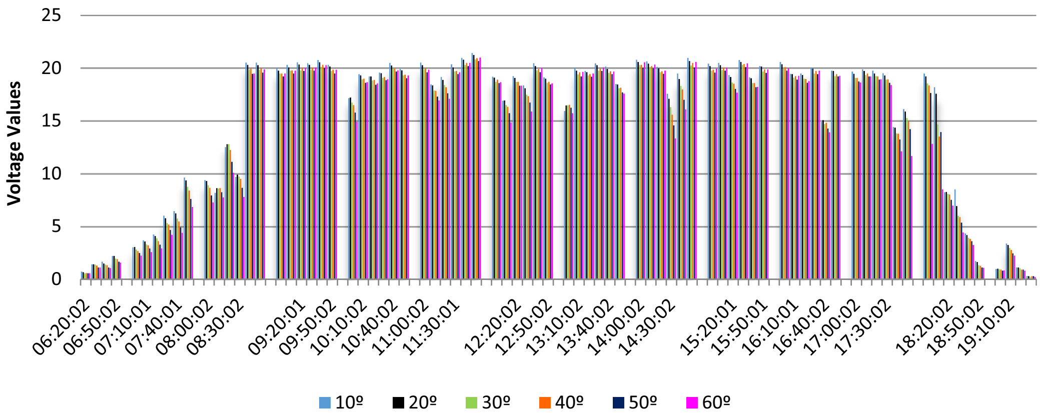


Fig. 7. Daily average voltage obtained from each panel.

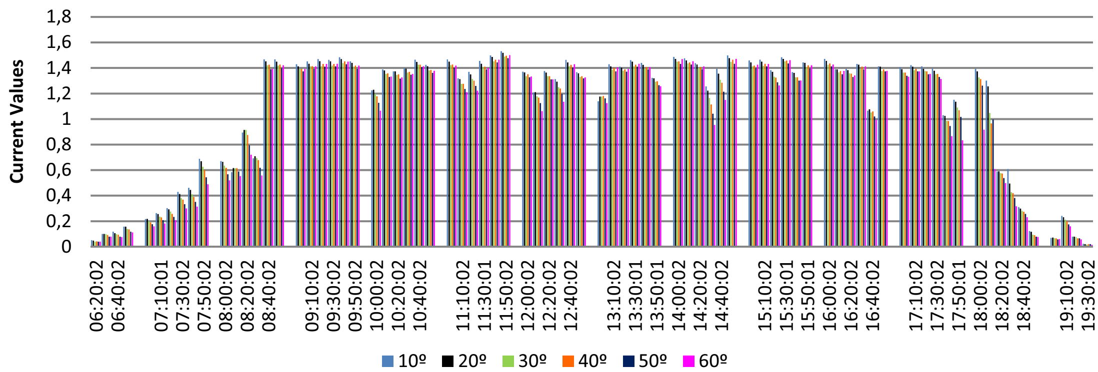


Fig. 8. Daily average current values obtained from each panel.

The annual average power values expressed in percentages are shown in a bar chart in Fig. 9.

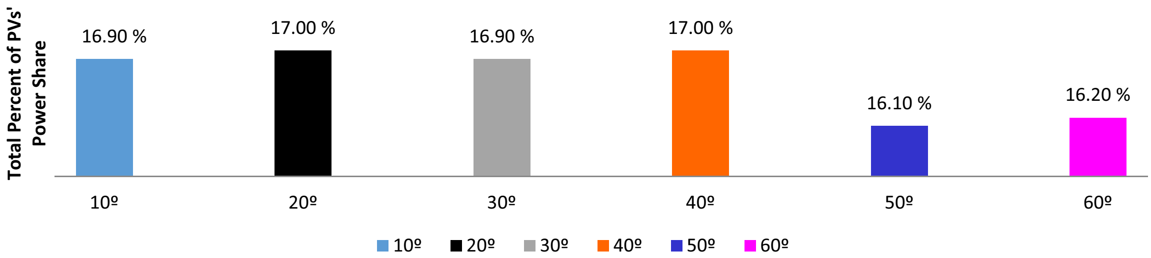
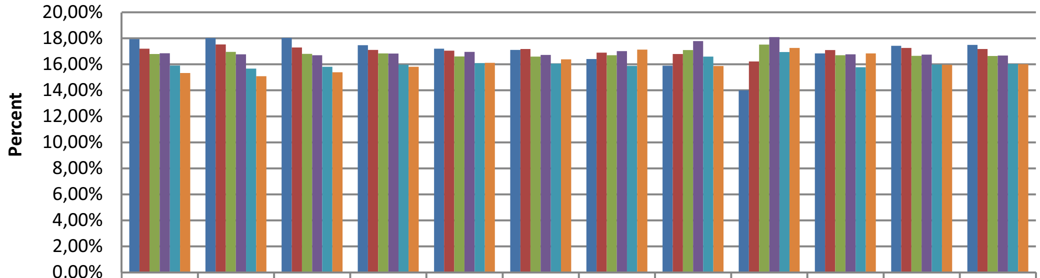


Fig. 9. The annual average power values of PV panels.

The total power of the panels for 12 months duration between May 2015 and April 2016 is shown in Table 1 in percentages.



	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
10º	17,93%	18,01%	18,03%	17,47%	17,20%	17,10%	16,40%	15,89%	13,99%	16,84%	17,42%	17,49%
20º	17,20%	17,52%	17,29%	17,10%	17,04%	17,17%	16,89%	16,79%	16,21%	17,09%	17,25%	17,17%
30º	16,79%	16,95%	16,80%	16,84%	16,60%	16,59%	16,70%	17,09%	17,51%	16,70%	16,65%	16,63%
40º	16,85%	16,76%	16,70%	16,82%	16,95%	16,72%	17,01%	17,78%	18,09%	16,77%	16,74%	16,67%
50º	15,90%	15,67%	15,80%	15,97%	16,09%	16,05%	15,87%	16,59%	16,94%	15,77%	15,98%	16,03%
60º	15,33%	15,08%	15,38%	15,80%	16,11%	16,38%	17,13%	15,86%	17,26%	16,83%	15,96%	16,01%

Fig. 10. The total power of the PV panels.

The power amount of each panel through the year calculated by the average monthly power amounts is given in Table 1 in percentages.

Table 1. The annual average power values.

	10°	20°	30°	40°	50°	60°
Annual	16.9 %	17.0 %	16.9 %	17.0 %	16.1 %	16.2 %

5. Conclusion

It was concluded from the total power amount of each panel expresses in percentages that while the panel with 10º tilt angle produced more power compared to other panels in June, July and August months, the panel with 60º tilt angle produced less power. Therefore, the best tilt angle for summer season is found to be 10º and the worst tilt angle was found to be 60º. The power difference between these tilt angles was found to be 7.25 %. While the panel with 20º tilt angle produced more power compared to other panels in September, October and December months, the panel with 50º tilt angle produced less power. As a result of this, the power difference between the best and the worst tilt angle for autumn season was found to be 3.09 %. While the panel with 40º tilt angle produced more power compared to other panels in December, January and February, the panel with 10º tilt angle produced less power. Therefore, the power difference between the best and the worst tilt angle for winter season was found to be 5.92 %. While the panel with 10º tilt angle produced more power compared to other panels in March, April and May months, the panel with 60º tilt angle produced less power. As a result of this, the power difference between the best and the worst tilt angle for spring season was found to be 1.85 %. When the annual average power amount obtained from each panel is examined, it was seen that the panels with 20º and 40º tilt angles produced the highest power amount. On the other hand, the panel with 50º tilt angle was found to produce the least power amount. The power difference between the best and the worst tilt angles was 0.9 %. The results showed that the fixed tilt angle of PV panels should be 20º or 40º for Bilecik city. This study is regarded as an example for the studies on high power solar energy applications which will be conducted in this region.

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