Monitoring System for Solar Panel using Xbee ZB Module based Wireless Sensor Networks

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***Abstract*—Nowadays, due to the increasing need for electric energy, new production areas have emerged. Solar photovoltaic (PV) systems that convert sunlight into electricity are one of the most popular production areas. The definite part of the needed electricity has begun to be supplied by solar PV systems. These systems have some disadvantages such as high cost and low efficiency. In order to use the solar PV systems more efficiently, the current, voltage and power values should be continuously monitored in computer environment, and the measured values should be analysed hourly, daily and yearly. In this study, an electronic circuit with ATMega328P microcontroller was designed to monitor the power generation. In order to transmit the measured values, wireless sensor network based Xbee ZB modules have been used due to the advantages such as low power consumption, long battery life, reliability and low cost. An interface and a software have been created in C# to analyze the measured values by using tables and graphics. Also, the measured values have been monitored on the LCD screen on the designed circuit. The system was tested by considering both different panel angles and ambient conditions.**

Keywords—Xbee, Zigbee, Wireless sensor network, Photovoltaic system, Solar panel

I. INTRODUCTION

Solar photovoltaic (PV) systems convert sunlight into electrical energy. At the point of obtaining energy from the sun, the best-known system is to make use of PV cells. In order to benefit from the total energy of all PV units, all the cells are connected to each other by electrical network and converted into a photovoltaic module (solar panel). A PV module consisting of 36 photovoltaic cells is shown in Fig. 1. PV Modules can generate about 1000 W of energy per square meter [1]. When the panel is connected to a load, an electrical current flows.

Solar PV systems have many advantages such as being clean, harmless to the environment and not needing fuel. However, it also has some disadvantages such as high investment costs and low efficiency. Therefore, there are a lot of studies and efforts to increase the efficiency of systems using solar energy [2-8].

Today, wireless sensor network has become very popular. Because these systems are both cheap and safe. In addition, wireless sensor network can provide uninterrupted data transmission in urban and rural areas at low cost without any infrastructure and cable connection operations. In wired connection system, a certain number of cables are connected to each PC, but in a wireless network system, a wide area and more users can connect freely via many connection points. Wireless network points are programmed to communicate with other networks. So, the connection point selects the fastest and the most reliable way to transfer data.

This study introduces a control card design that enables data exchange between a computer and solar panel via Xbee ZB modules. It is the new generation of wireless sensor network, which offers the possibilities offered by similar samples on the market. This study offers more economic and ergonomic opportunities than similar studies, and the designed circuit is also developed as a system that allows various improvements according to the needs.

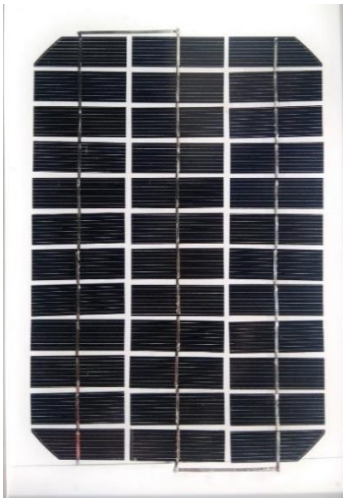

Fig. 1. Solar Panel

In the second and third section, the methods used during the design of the system are explained. In these sections, working principle of photovoltaic panel, maximum power point detection method, principles of choosing an efficient solar panel, microcontroller and wireless modules, algorithm and circuit design are explained comprehensively. The measurements made with the system designed in the third section were presented and discussed in the fourth section. Finally, the concise interpretation and conclusions were given in the last section.

II. METHODS

It is known that changes in operating temperature cause changes of current and voltage of PV modules and PV cells [13]. Therefore, in order to consider the temperature effects, a temperature sensor was connected to Atmega 328P in the design

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of the monitoring system which measures the current and voltage values generated by the solar panel, as shown in Fig. 2.

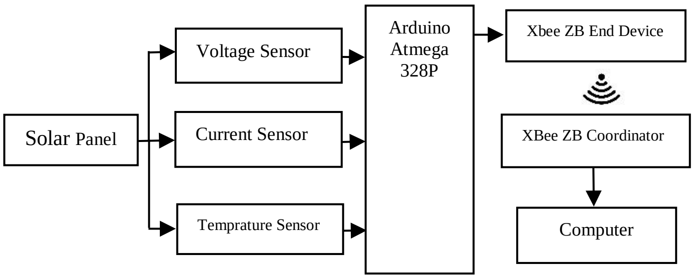

Fig. 2. Diagram block of monitoring system

A. Photovoltaic panel working principle

The equivalent circuit of a PV cell is shown in Fig. 3. This circuit includes a diode, a series of resistor and a shunt resistor. The electricity generated from the solar cell is symbolized by Iph the current drawn from a dependent current source on the circuit (Fig. 2). The solar battery is shown with a diode because it is a semiconductor material. The voltage obtained from the solar cell is shown as Vpv.

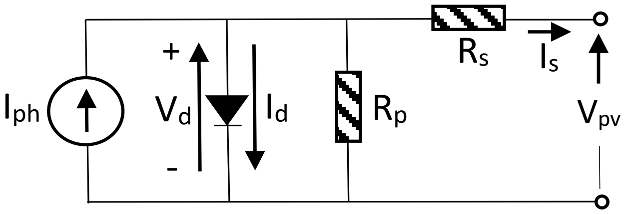

Fig. 3. Equivalent Circuit of the Solar Panel

According to [9-12] and based on the equivalent circuit (Fig. 3) of a solar PV panel, it determines the relationship between voltage and current supplied by a photovoltaic module. its characteristic equation is expressed as;

$$I = I_{ph} - I_s\left(e^{\frac{(V_{pv}+I\,R_s)q}{akT\,N_s}} - 1\right) - \frac{(V_{pv}+I\,R_s)}{R_p} \quad (1)$$

where N_s is the number of cells in series, It is the reverse saturation current, I_{ph} is the current produced by the photoelectric effect, R_s and R_p are inherent resistances in series and parallel associated with the cell, a is the ideality factor modified, q is the electron charge, k is Boltzmann constant.

B. Short circuit current and open circuit voltage

The most important characteristics, which should be considered in the analysis of a PV cell, are the current (A) and voltage (V) values produced by the cell. The current produced varies with the light intensity and the area covered by the PV module, but the voltage produced by the PV module does not vary much with the light intensity.

When a PV module is short circuit, it generates the maximum current. This is called as short circuit current (I_{SC}). When the PV module is open-circuit, the voltage measured at the terminals is called as the open-circuit voltage (V_{OC}).

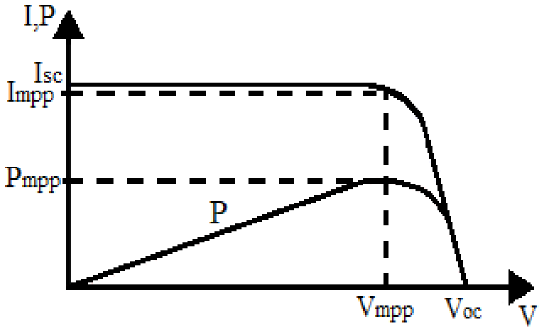

Fig. 4. I-V Curve and P-V Curve

It is observed that the current value obtained with the measurement made by keeping the sun rays constant is changed with working voltage. The $I - V$ curve and $P - V$ curve of a crystal cell are shown in Fig. 4 [13]. The maximum power point ($Pmpp$) where maximum power is taken from a PV cell can be seen in this curve. The current value and voltage value corresponding to $Pmpp$ are called as $Impp$ and $Vmpp$, respectively. This figure is drawn according to equation (1).

III. MATERIALS AND DESIGN

A. Solar panel selection

Two of the TT T-ECHN I-C solar panels were used in the project. This panel with 5W power is a convenient and cost-effective solar panel for various solar energy applications. It has a useful and durable structure thanks to the aluminum frame around it. It is composed of monocrystal cell lines. One of these panels was used to read the current and voltage values and the other one was used to supply the electrical energy required for the operation of the designed circuit.

B. Wireless module selection

Two Xbee series 2 communication modules were used in this study. This is because we need at least 2 Xbee ZB modules, the end device and the coordinator to be able to use the modules. Xbee series 2 modules operate at 2.4 GHz and use ZigBee Mesh communication. It makes serial communication reliably with computer and microprocessor systems. It supports communication within point-to-point or multi-point networks. The output power of the module is 2 mW, and the communication distance is 100 meters in open area.

While XBee ZB modules is ideal for some applications as stated in [14-16], it also has a few drawbacks. For example, XBee does not support high data rates [17,18]. Namely, it is not possible to exchange high-speed data with these modules. It is preferred in applications where data rate is not very important. However, it is possible to increase the data rate slightly by the configuration of settings. An important point is that an Xbee ZB module series 2 cannot communicate with an Xbee ZB module series 1, since series 1 and series 2 have different communication protocols. For this reason, modules with the same series are used.

Xbee USB Explorer module is used to connect Xbee ZB modules to the computer after the configuration of the settings of Xbee ZB module by using X-CTU program. One of the XBee ZB modules is configured as the Coordinator, while the other one is configured as the End Device [19].

Xbee ZB modules communicate with microcontrollers via Xbee breakout board. Xbee ZB module is not suitable for direct use of the pins, so Xbee breakout is required. A buffer circuit is available to reduce the communication pins from 5 volts to 3.3 volts in the integrated circuit. The reason for this circuit is that the Xbee ZB modules need 3.3 volts supply voltage.

C. Microcontroller selection

In the study, Atmega 328P microcontroller on Arduino Uno was used to view the data received from Xbee ZB module in computer environment and to make the necessary calculations. At the same time, supply voltage of the Xbee ZB module and the Xbee breakout board module were provided by the electronic circuit.

D. Algorithm and circuit design

The circuit developed in this study is shown in Fig. 5. Atmega328P microcontroller is used to execute functions of the circuit. All the system was controlled with the unique software developed for this study privately.

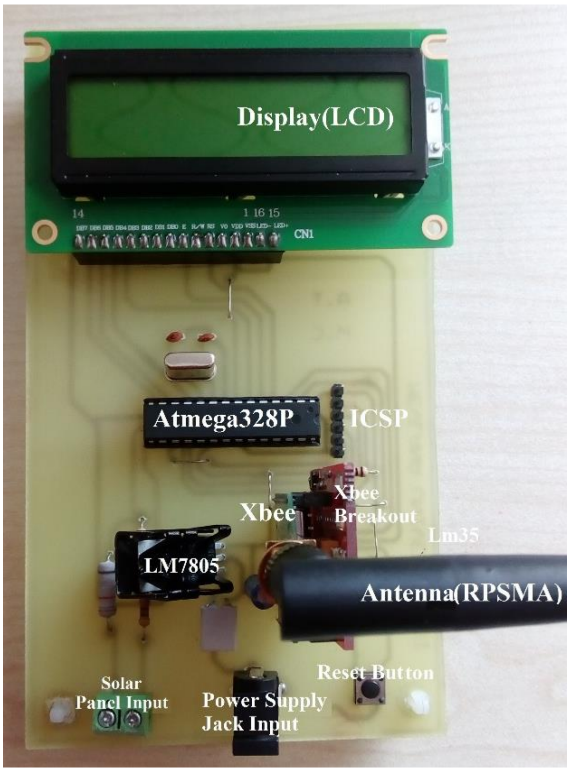

Fig. 5. Practical implementation of designed circuit

The flowchart of this software is shown in Fig. 6. First, the system is energized. Then the analog voltage values from the solar panel to the ADC0 pin of the microcontroller have been converted to the digital values between 0-1023 by means of the 10 bits ADC pin. These values were put into a string, and this process was repeated 100 times in 1 second. Then, the values were divided by 100 to obtain more stable results, and divided values were assigned to analog1 variable. Since the analog input

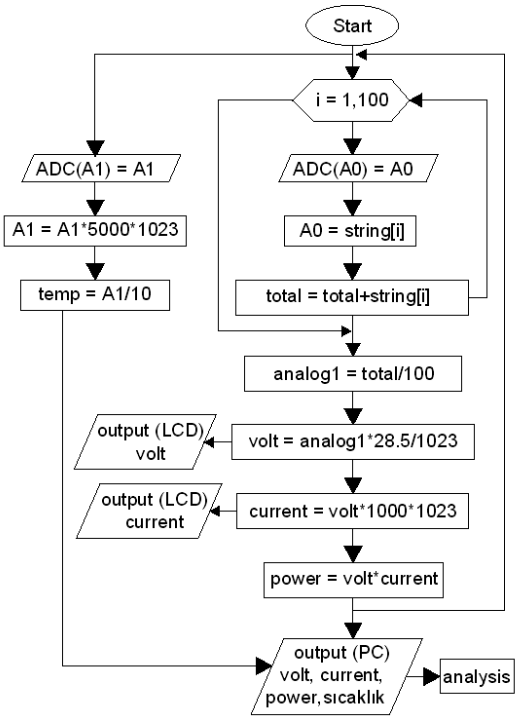

Fig. 6. Flowchart of the system

can take the maximum value of 5V, a voltage divider circuit shown in Fig. 7 was used to adjust the input voltage which is calculated as following:

$$V_{max} = (R_{eq} * 5)/R2 \quad (2)$$

As seen from Fig. 7 and obtained from equation (2), the maximum input voltage is 28.5 volts. Then, $volt = (analog1 * 28.5)/1023$ formula is used, and the digital voltage values are converted to the analog values. Then, to find the current value $current = volt / 5700 * 1000$ formula is used, and the current value is calculated in mA. The current and voltage values are multiplied ($power = volt * current$) to obtain power value in mW. In addition, the temperature sensor is connected to the ADC1 pin of the microcontroller, and the measured temperature value is expressed as Celsius by using required formulation and software. Finally, the temperature and power values have been transferred to both the Display (LCD) and PC, while the current and voltage values have been transferred only to the PC. Schematic diagram of designed circuit is shown in Fig. 8.

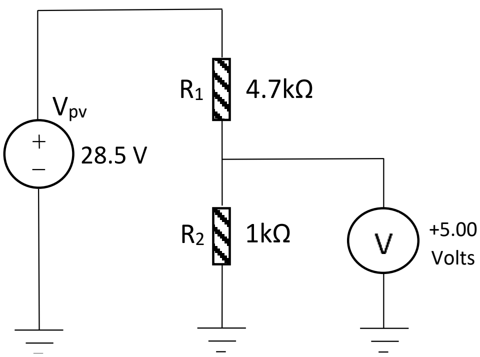

Fig. 7. Voltage Divider Circuit

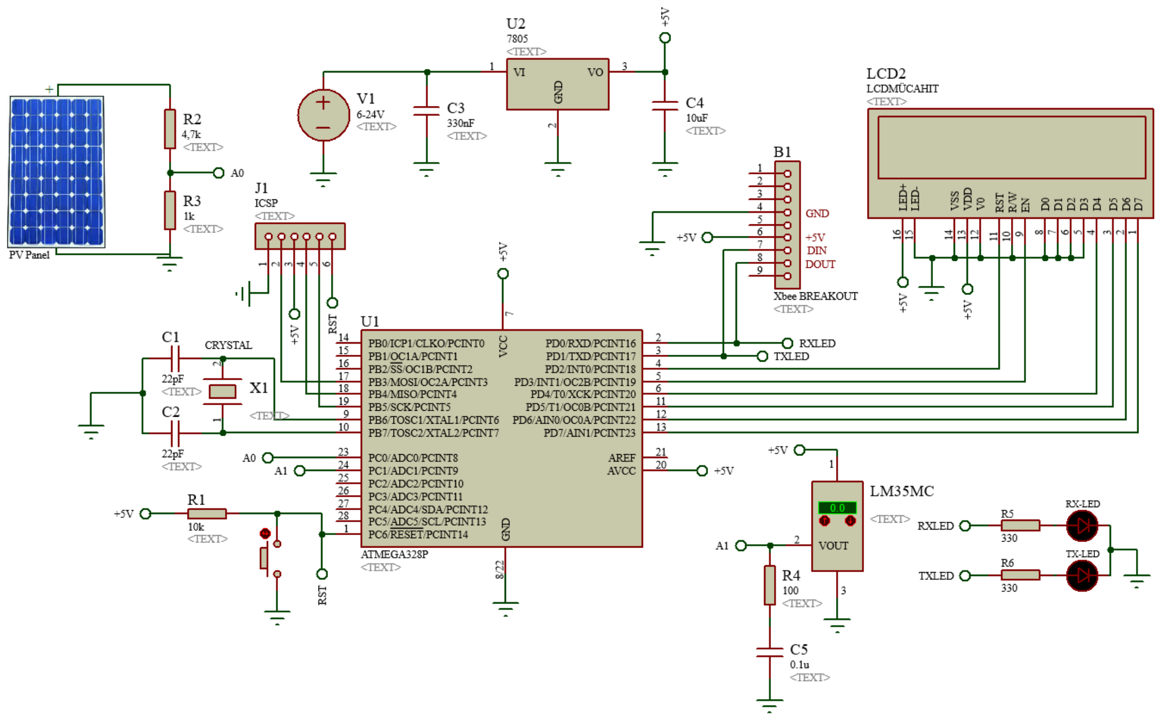

Fig. 8. Schematic Diagram of Designed Circuit

IV. RESULTS AND DISCUSSION

In order to explain the method of testing solar panels under environmental conditions; a solar PV panel with 5W power is used (Fig.1). The technical values on the solar panel used for the test are shown in Table I. This test was carried out on a sunny day the instantaneous change values of the temperature in the air on the test day are shown in Fig. 10 and Table II. As shown in the graph, the temperature varies between 19 °C and 28 °C. The average temperature during the day is 22.35 ° C.

TABLE I
SOLAR PANEL FEATURES

Features	Values
Rated Max Power	5 W
Short-Circuit Current (Isc)	291 mA
Open-Circuit Voltage (Voc)	22.6 V
Current at $Pmax$	285 mA
Voltage at $Pmax$	17.5 V
Cell Count	36
Sizes of Solar Panel	290x205x28mm

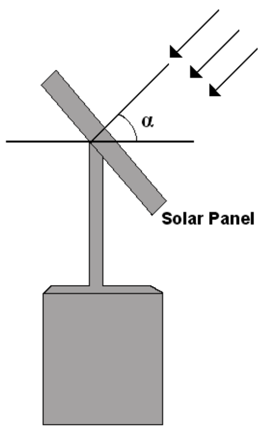

Fig. 9. The Surface Angle of the Panel: α

The solar panel is positioned as shown in Fig. 9 to make different α inclination angles with the horizontal surface: α = 0 °, 30 °, 45 °, 60 ° and 90 °, and it faces to south. The current, voltage and power values transferred from the solar PV panel to the computer were recorded hourly between 5 am and 7 pm. A table was formed with the hourly measured voltage, current, temperature and power values for different panel angles. Then, the data shown in Table II were analyzed graphically.

TABLE I I
POWER VALUES AND AVERAGES ACCORDING TO HOURLY ANGLES OF 21.06.2018

Time (hour)	Power(mW)					Temp. (°C)
	0°	30°	45°	60°	90°	
5 am	0,00	0,00	0,00	0,00	0,00	14
6 am	83,28	309,40	696,85	707,66	738,85	15
7 am	601,09	667,11	686,40	689,88	698,25	16
8 am	807,20	817,01	820,04	807,95	778,74	19
9 am	829,93	818,53	814,74	804,94	801,43	18
10 am	801,94	833,75	832,99	807,20	795,95	19
11 am	784,78	829,93	829,93	814,74	810,98	20
12 pm	**772,21**	**813,65**	**843,27**	**824,60**	**813,23**	**20**
1 pm	**663,69**	**702,46**	**733,49**	**706,82**	**700,75**	**25**
2 pm	654,85	699,65	733,69	720,36	722,83	26
3 pm	631,33	682,24	740,88	732,25	732,11	27
4 pm	629,34	673,96	743,81	738,72	738,51	28
5 pm	636,67	668,47	739,70	744,49	741,73	28
6 pm	43,51	36,96	27,79	10,88	5,75	20
7 pm	0,00	0,00	0,00	0,00	0,00	17
Avg:	610,76	657,93	711,05	700,81	698,39	22.35

As a result, the most efficient angle value was found to be α = 45° in this region, and the power value was found to be 711,05 mW as it seems in Table II. In other words, it is observed that the efficiency changes according to different angle values.

In addition, the graph in Fig. 10 was formed to examine the effect of temperature on efficiency. Here, in the most efficient angle value (45°), it is observed that the increase of 3-5°C in the panel temperature the power values decreases significantly between 12 pm and 1 pm. As a result, it has been determined that the high temperature increases the temperature of the panel and decreases the power value, it affects the efficiency badly.

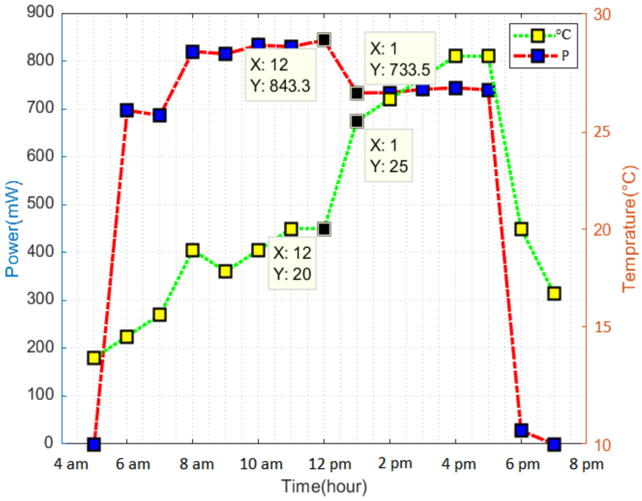

Fig. 10. Power and temperature change according to time

V. CONCLUSION

In this study, the current, voltage and power values obtained from the solar panel were measured by using the control card designed for this study. The obtained values were displayed both on PC and LCD located on the card. The measured data were transferred to PC by using sensor based wireless Xbee ZB communication network. Tables and graphs based on the measured data were created to analyze the effect of the panel angle and temperature on the performance of the monocrystalline PV cell. A unique software based on C# has been developed for this study and applied to control and test the PV cell.

As a result of the analysis, it was determined that the panel angle in which PV panel had maximum efficiency was 45 degree. In addition, it was observed that the increase of 3-5°C after a definite temperature of 20°C in the panel temperature affected the efficiency of PV panel negatively, although the light intensity didn't change considerably.

Xbee ZB based network was used due to the advantages such as low power consumption, long battery life for using lithium battery, reliability (128-bit encryption) and low cost. When Xbee ZB based networks are compared with other networks, it is seen that Bluetooth based networks can transfer data up to 10m with data transfer rates up to 1Mbps, while Xbee ZB based networks can transfer data from 10 to 100 meters with data transfer rates are up to 250Kbps. In addition, Bluetooth based network can be established in a point to point master-slave method, but Xbee ZB networks can be established in both point to point and point to multipoint method. Also, Wi-Fi networks defined under 802.11b Standard (ESP, etc.) have data transfer rates from 11 Mbps to 54 Mbps due to its version.

In this study, Xbee ZB modules-based networks was preferred among wireless sensor networks due to the its optimal efficiency by considering required communication distance, data transfer rates and ergonomic sides. Bluetooth module was not preferred because the communication distance was short as mentioned above. Wi-Fi module was not used since it is not cost effective for this kind of application. So, we conclude for the projects, where low data transfer rate is sufficient, that Xbee ZB modules based network is more practical and available in comparison with the mentioned data transfer methods.

VI. FUTURE WORKS

In the future works, such as more complex applications where the communication distance is higher, the communication distance can be increased by using Xbee Router modules, since Xbee ZB modules used in the project can exchange data up to 120 meters. Also, in order to increase the sensitivity, the current and voltage values can be measured by using sensors instead of reading these values from the resistor.

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