Design and Implementation of P&O Maximum Power Point Tracker Algorithm Based Solar Charge Controller

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Abstract: Solar energy is one of the main sources of renewable energy. In photovoltaic systems, energy is obtained from photovoltaic batteries. In photovoltaic batteries, the current and voltage do not increase linearly. This causes the power to take different values. There is a point where power reaches its peak. Detecting this point called the maximum power point and transferring the energy to the load at this point, reduces the losses and increases the efficiency. In order to track maximum power point, various circuits with microcontroller have been designed algorithms have been developed. The most widely used algorithm is the Perturb and Observe. In this study; Maximum Power Point Tracker Algorithm Based Solar Charge Controller is designed. Arduino microcontroller board was used as it has easy programmability and rapid prototype development. Developed charge regulator determines the maximum power point by measuring the current voltage values and charge the battery at this point. The current, voltage, battery charge rate and charge status information obtained from the charge controller can be monitored by android mobile devices. The developed charge control circuit has been tested using a 50 Watt photovoltaic panel under different weather conditions. It has been observed that it followed the maximum power point.

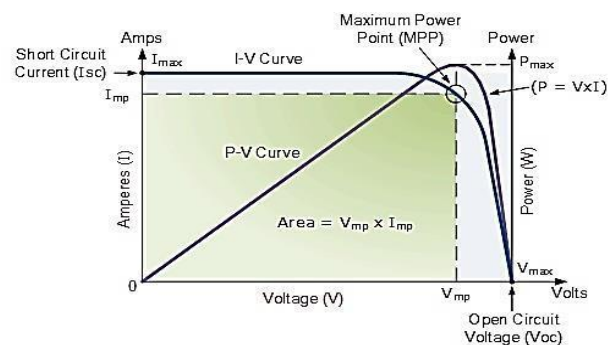*Keywords: Maximum Power Point, Mppt Tracking, Solar Charge Regulator, Solar Charge Controller*

1. Introduction

This Energy needs are increasing day by day due to the developments in the industry. Environmental pollution caused by traditional energy sources, health problems and limited resources increase the importance of renewable energy. Where energy transmission is not possible with the electricity grid, energy needs can be met with renewable energy sources [1].

Solar energy is one of the main sources of renewable energy. Photovoltaic systems; It has an important place among the renewable energy sources with the lack of fuel costs, lack of moving parts and consequently not being exposed to abrasions and not requiring any maintenance [2]. Photovoltaic panels are used to provide direct energy from the sun's rays [3].

Non-linear current and voltage are obtained from photovoltaic panels. In this respect, the energy obtained from the sun differs with the energy obtained from the power sources such as the battery [4]. The current value received from the panel causes changes in the voltage value.

Photovoltaic systems; cannot produce energy at full efficiency when exposed to disturbing effects such as clouding, partial shading, contamination, physical deformation [5]. The maximum power point monitoring system (MPPT) allows to obtain maximum power from the PV panel under varying conditions such as temperature, light level using an algorithm. Figure 1 shows the current voltage characteristics and maximum power point of the photovoltaic cell.

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Fig. 1. Current-voltage (I-V) characteristics of a typical silicon photovoltaic cell [6]

By regulating the current and voltage obtained from the PV panel, the power transferred to the load is maximized [7]. The current and voltage values of solar cells are calculated periodically and the point at which the maximum power can be obtained from the panel is determined. Maximum power point tracking algorithm; it provides energy from the solar cell at the detected point [8]. Traditional charge controllers can only protect the battery from overcharging. MPPT provides maximum power by varying the ratio between voltage and current given to the battery and converts it to current when excessive power is generated on the photovoltaic panel [9]. Thus, the loss of power and shorten the life of the battery is prevented.

Different algorithms have been developed for maximum power point tracking. The most commonly used of these; perturb and observe (P&O) algorithm in which the duty cycle of the controller is controlled. [10]. Studies related to MPPT can be performed using various microcontrollers.

In this study, it is aimed to design and implement a maximum power point tracker working with P&O algorithm using Arduino microcontroller board.

2. Maximum Power Point Tracking

Maximum power point tracking is the method of determining the peak value of the power obtained from the panel under varying conditions and transferring the maximum power to the load. Maximum power point tracking methods can be examined in two groups as direct and indirect control. In the direct control method, the power from the photovoltaic panel is continuously measured and compared to the previous state. In the indirect control method; values such as short circuit current, temperature and open circuit voltage are measured at certain intervals and maximum power point is tracked [11]. Maximum power point tracking methods are listed below.

- Constant voltage method
- Short circuit current method
- Open circuit voltage method
- Perturb and observe method
- Incremental Conductance

The most commonly used of these methods is the perturb and observe algorithm. P & O; design costs, software ease, cost-benefit is considered as the most appropriate algorithm when evaluated with features [12].

3. Perturb and Observe Algorithm

When the studies about MPPT are examined, various control algorithms are found. In choosing the appropriate algorithm; simplicity, speed, compatibility with sensors used and cost factors should be taken into account [13]. P&O is widely used because it can be easily applied and requires a small number of parameters. However, this algorithm has the disadvantages of not being fast enough and causing oscillations around the maximum power point. In order to determine the maximum power point by this method, PWM is slightly increased and the power of the system is measured. The measured power is compared to the power measured in the previous step. If there is a positive change in power, the controller will increase the PWM again. If the direction of the change is negative, it is understood that the power point is moved away. PWM is reduced to approach the power point. The purpose of the P&O method; to run the system in the direction of increased power [14].

In a sudden changing atmosphere, it has negative properties such as not being able to look for the maximum power point in the right place, not being able to react quickly to change, not being fixed at the maximum power point and causing oscillations [15].

4. Materials and Method

In this study, a maximum power point tracker was designed and implemented by using the Arduino and the P&O algorithm. The project is divided into two parts: hardware and software.

4.1. Hardware

The main components of this project are; Arduino Nano, Lm2596 voltage regulator, Acs 712 current sensor, buck converter circuit, voltage divider circuit, lcd character display and bluetooth module. The system works with photovoltaic cell and batteries. Although the tablet computer is not the main element of the system, it was added to the system to display the data. The block diagram showing the connections of the hardware elements used in the system is shown in Figure 2.
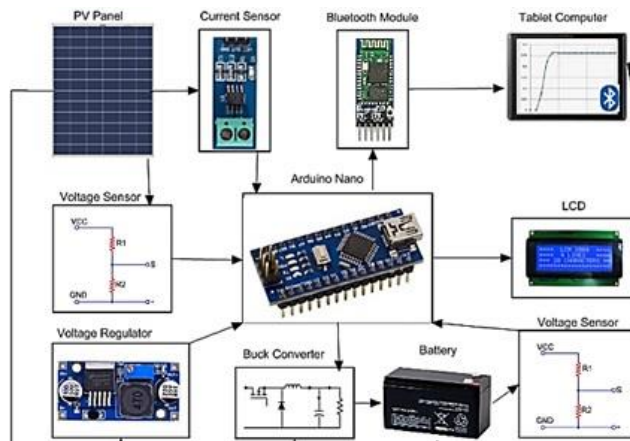

Fig. 2. Block diagram of MPPT circuit

4.1.1. Arduino

Arduino is an open source microcontroller board. It has an Atmega 328 microcontroller. No external hardware is required to program the card. The powerful features of Arduino are that it is compatible with all operating systems, it is cheap and has a user-friendly coding structure. The programming language of Arduino is open source and open to development. It allows to produce prototypes easily and quickly [17].

Arduino Nano was preferred considering the number of analog and digital input-output pins to be used in the study and the size of the circuit. Arduino calculates power using current and voltage values measured with current sensor and voltage sensor. Determines the maximum power point using the P&O algorithm. Arduino determines the PWM signal rate to be applied to MOSFETs and controls the switching of MOSFETs.

4.1.2. Buck Converter

Buck converter is a DC-DC converter with a simple structure and a high efficiency which reduces DC voltage. It is possible to control the output voltage of the Buck converters using the PWM method. PWM method works with the principle of constant frequency and variable occupancy rate. The duration of a signal being active in a period is defined as the occupancy rate [16].

The PWM signal applied to the Buck converter input reduces the effective value of voltage by keeping the circuit intermittently in transmission. These PWM signals are generated by Arduino in the solar charge controller circuit. In order to strengthen the PWM signals obtained from the Arduino and to perform the switching operation, mosfets are driven by an IR2104 MOSFET driver. The adjustment of the voltage obtained from the panel to the desired ratio to be transferred to the battery is provided by the buck converter. In Figure 3 the Buck converter diagram is shown.
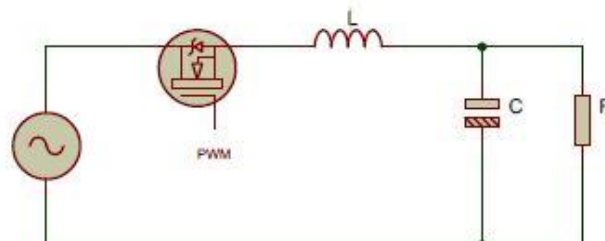

Fig. 3. Buck converter diagram

IRFZ44N mosfet was used as the switching element in the project. MOSFETs enable switching of high frequency. The relation of the

switching ratio and the output voltage in Buck converters is the same as expressed in equations 1 and 2.

$$D = \frac{T_{0N}}{T_{0N+}T_{0FF}} = \frac{T_{0N}}{T_S} \qquad (1)$$

$$V_{out} = D.V_{in} \qquad (2)$$

Where, V_{out} is the output voltage. V_{in} is the input voltage, D is the duty cycle, T is the period of the function. Equations; shows that the output voltage is dependent on the transmission time and that the output voltage in buck converters will always be smaller than the input voltage

4.1.3. Current Sensor

Acs712 current sensor was used to measure the value of the current taken from the output of the photovoltaic panel. Acs712 is a sensor that can measure electrical current with high precision by hall-effect method. An output voltage value proportional to the measured current value is generated by the current sensor. The current value is calculated by the microcontroller using this voltage value. Figure 4 shows the connection of the Acs712 to the circuit
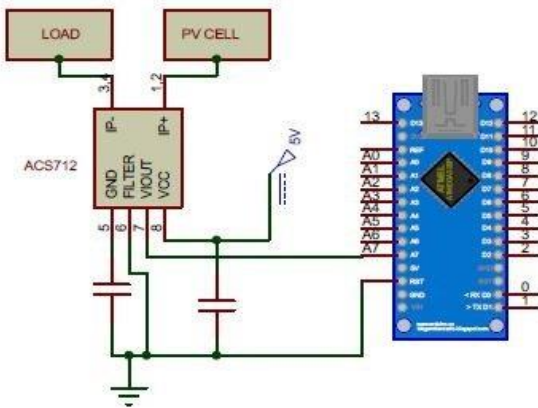

Fig. 4. Connection ACS712 to the circuit

4.1.4. Voltage Divider Circuit

Resistors were used as voltage divider to measure the voltage of the photovoltaic panel and battery. Measuring the voltage directly with Arduino is possible at low values, but it causes damage to the circuit at high voltage values. The voltage divider consists of 2 resistors connected in series. The voltage is distributed on the resistors in proportion to the resistance values. The Arduino calculates the voltage of the photovoltaic panel and the battery using the reference voltage value. Figure 5 shows the wiring diagram of the voltage divider used to measure the voltage of the photovoltaic battery.
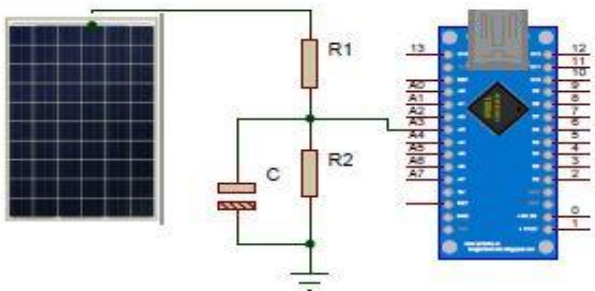

Fig. 5. Voltage sensor

Figure 6 shows the wiring diagram of the voltage divider used to measure the voltage of the photovoltaic battery.
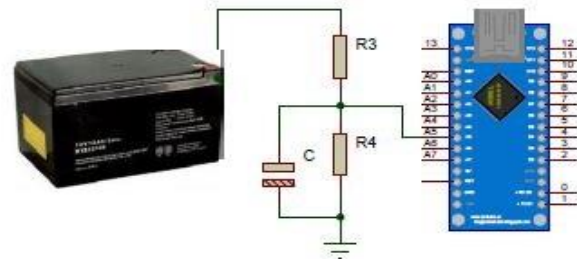

Fig. 6. Battery voltage sensor

4.1.5. Bluetooth Module

The data and signals obtained from the charge controller can be displayed using mobile devices with Android operating system. Data transfer is provided by the Bluetooth module. HC-05 Bluetooth module was used in the system. HC-05 transmits the data to the android application using serial communication method. Figure 7 shows the Fritzing drawing of the HC05 bluetooth module connection to Arduino Nano.
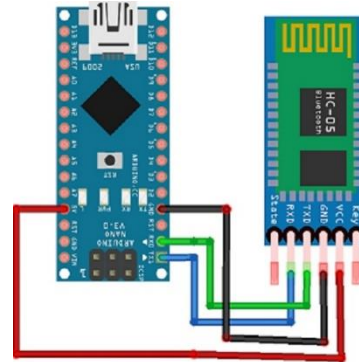

Fig. 7. Connection bluetooth module to the circuit

4.2. Software

The software development phase of the study consists of two parts: Arduino software and mobile application software.

4.2.1. Arduino Software

Arduino IDE was used in the programming of Arduino. The 1.8.8 version of the Arduino IDE software was used for programming the microcontroller. Figure 8 shows a screenshot of the program in which the code for the P&O MPPT algorithm was written.
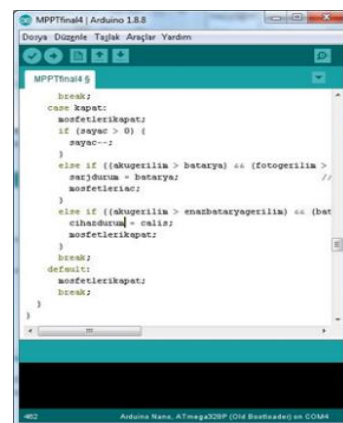

Fig. 8. Screenshot of the program

In accordance with the operating logic of the system, the processing steps were determined and the algorithm was created. Figure 9 shows the general structure of the P&O algorithm.
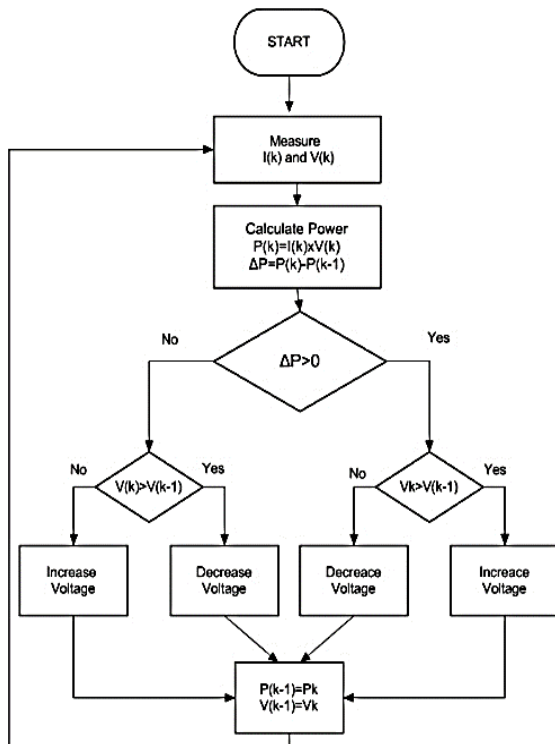

Fig. 9. The general structure of the P & O algorithm

The power obtained from the panel is calculated by using the voltage value measured by the current value obtained from the current sensor and the voltage divider resistors. If the power obtained from the photovoltaic panel is at a very low level, the mosfets are closed and the charging process is interrupted. If the power obtained from the panel is medium to high and the battery charge level is low; mosfets are opened, charging is started.

The power is recalculated periodically according to the changing current and voltage values. The last calculated power value is compared with the power value calculated in the previous step. The amount of change in power and the direction of change are determined. The voltage value is increased and the power is calculated. If there is an increase in power compared to the previous step, the voltage continues to increase. If the increase in power is due to the reduction of the voltage, the voltage is reduced slightly. The change in power is indicated as ΔP and is expressed in equation 3. Where ΔP is the change of power, $P(t-1)$ is the perturbation, $P(t)$ is the next perturbation,

$$\Delta P = P(t) - P(t-1) \tag{3}$$

The P&O change table summarizing this is shown in Table 1.

Table 1. P&O change table

P(t-1)	ΔP	P(t)
+	+	+
+	-	-
-	+	-
-	-	+

The information on the measured current, voltage, charge rate of the battery, whether the charge is on or off is displayed on the LCD screen in the circuit. With these values, current-time and voltage-time graphs can be monitored via mobile phone or tablet computers using Android operating system. For this purpose an android application has been prepared. The MPPT circuit and mobile devices communicate with bluetooth technology.

4.2.2. Mobile Application Software

The Android application is prepared with MIT App Inventor. App inventor is an easy to use, web-based programming tool. Coding is carried out by combining the blocks with drag and drop. The data calculated by Arduino are transmitted to the mobile device via the HC-05 bluetooth module. The application screen shows the data. Current, voltage graphs are converted to graphics by App Inventor and displayed on screen. The code block for displaying the voltage-time graph on the display is shown in Figure 10.
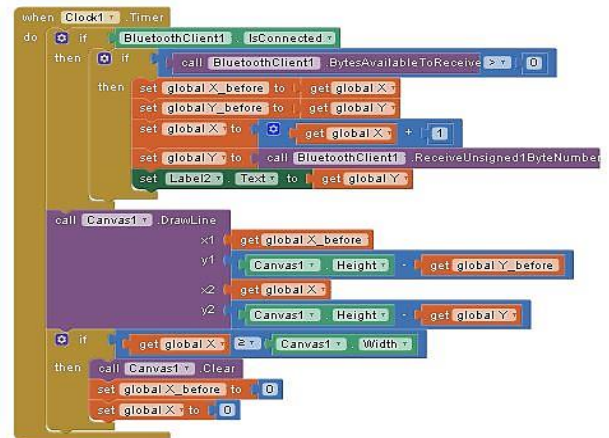

Fig. 10. Screenshot of the program

The maximum power point tracker android application user interfaces are shown in Figure 11.

Fig. 11. Android application user interfaces

After the Android app and mobile device are connected to bluetooth, their data is displayed by selecting one of the graphical display options or reading the measured values from the menu.

5. Experimental Result

MPPT Charge controller is tested with different current-voltage of the panel and battery. 12V 7Ah lead acid battery and polycrystalline solar panel were used in the experiment. The data of the solar panel are shown in the Table 2.

Table 2. Electrical characteristics of the PV Panel

V_{mp}	Nominal Voltage	18,3 V
I_{mp}	Nominal Current	2,75 A
V_{oc}	Open Circuit Voltage	22,7 V
I_{sc}	Short Circuit Current	2,93 A
P_{max}	Maximum Power	50 W

The charge status according to the battery voltage and the panel voltage is shown in Table 3.

Table 3. Charging status of mppt circuit

No	V_{in}	I_{in}	V_{bat}	PWM	Charge State
1	3,2 V	0,03 A	11,2 V	%0	Off
2	10,3 V	0,48 A	9,1 V	%99	On
3	12,48 V	0,47 A	10,9 V	%78	On
4	17,2 V	0,80 A	11,4 V	%85	Bulk
5	17,4 V	0,78 A	14.1 V	%5	Float

The system has been tested in different weather conditions. The results of the experiment are shown in Table 4.

Table 4. Test results in different weather conditions

No	Weather	Temperature	V_{in}	V_{out}	P_{max}
1	Cloudly	8 C	12,3 V	12,1 V	22 W
2	Partly cloudly	12 C	13,3 V	12,4 V	30 W
3	Partly cloudly	15 C	13,2 V	12,2 V	28 W
4	Sunny	23 C	17,4 V	12,6 V	39 W
5	Sunny	25 C	16,8 V	12,5 V	38 W

Conclusion

In this study, a maximum power point tracker has been performed by using the Arduino board. The power of the photovoltaic panel has been calculated in the system using the perturb and observe algorithm. The battery has been charged at the maximum power point. The circuit protects itself from overload, short circuit and reverse power flow. In the designed system; current, voltage, power, battery occupancy rate can be displayed on the lcd display. By the bluetooth connection, data and signal flow can be monitored from mobile devices Charge controller; it is compatible with photovoltaic panels in the range of 12-24 Volts, providing a maximum current of 5 amps. The circuit has been tested with a photovoltaic panel of 50 watts. It was seen that the designed circuit trackers the maximum power point and performs charge regulation. The circuit determines the appropriate charging type depending on the state of charge of the battery. In the experiments, it has been observed that the maximum power point has been directly proportional to radiation and inversely proportional to temperature. This is similar to the results of other studies in the literature. The Android application developed for monitoring the information has been designed for short distances. In later studies, it would be useful to add an internet connection to the system. This circuit is a prototype developed for low-power photovoltaic panels. It is expected to be a model for the circuits to be developed for high power photovoltaic panels. The use of Arduino in the circuit facilitated the prototyping process. As a result of this study a charge controller with low-cost, low-power, high-efficiency, applicable has been obtained.

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