Watt Peak Meter of Solar Panel

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Abstract. The design of a watt peak meter of solar panel has been carried out using an LDR sensor to obtain the strongest light as the sun moves. The electronic circuit used includes LDR KY018, WEMOS ESP32, servo motor, Solar Charger Controller, INA219 Power Sensor, Battery and 10 A / 5V Relay. The mechanical structure uses angle iron construction which is assembled in such a way as to support solar panels with the SUNLITE Model 156P-20 type. Solar panels are positioned on 2 poles and attach the bolts as the rotary axis. LDR that gets sunlight will provide input to the WEMOS ESP32 to drive the servo motor in line with the direction of the sun in the east - west direction. The result led to an average 93.7% close to number as stated in the data specification of solar panel.

1. Introduction
Electricity has become the most important part that cannot be separated from human life today. Almost all human activities, both at home, offices and industry depend on electricity. Electricity can be generated with an electric generator and more than 99% of the electrical energy used today is generated by electric generators in the form of alternating current which is easily distributed over long distances [1].

The kinetic energy to drive a turbine generator is obtained from energy or steam power generated from the combustion of fossil energy sources (petroleum, coal, and natural gas). Most of the sources of electrical energy in Indonesia are supplied from fossil energy, but in the next 20 years, this energy source will run out and other energy sources are needed to continue to produce electrical energy. Currently there is one form of unlimited energy (non-conventional), namely energy produced from sunlight. This energy is an alternative source that can be converted into environmentally friendly electrical energy which is processed using solar cell panels or photovoltaic [2].

The sun has more than enough energy to supply the world's energy requirements, and unlike fossil fuels, it will not run out anytime soon. Solar power's main constraint as a renewable energy source is our capacity to convert sunlight into electricity in an efficient and cost-effective manner.

A typical question is how to calculate the solar panel output. Given the influence solar panel manufacture has on the overall system, it makes logical. There are a few variables and stages to calculating the power output of your solar panels. Of course, it's hard to anticipate how much electricity a photovoltaic system will generate in advance. There are a lot of things to consider. There are many elements involved such as the location, panel orientation, the direction of shade, the weather, the presence of clouds and the temperature on the roof. The watt-peak (WP) is therefore an indication based on a standard. It corresponds to the maximum electrical power that can be supplied by a photovoltaic panel under standard temperature and sunlight conditions.

The solar panel efficiency number indicates how many watts your solar panel can generate under ideal conditions. These ideal conditions, known as Standard Test Conditions (STC), are simulated in a laboratory/Manufacture where solar panels are tested. Standard test conditions for solar panel wattage would imply that your solar panel is operating at 77 degrees Fahrenheit with 1000 watts of sunlight per square foot [3].

In these ideal conditions, a 200-watt solar panel will generate 200 watts of electricity. This standard is a good way to ensure that when solar panels are manufactured, they meet specific criteria. Efficiency, how much sunlight shines on the solar panels, and which direction your solar panels are facing are the
main factors in determining solar panel output. The WP listed by manufacturers makes it possible to compare different photovoltaic panels. The main issue for implementor is they cannot sure how many WP can be in the same surface area, the higher the WP, the better the panel performs.

They are several research on new energy alternative especially in solar Panel or photovoltaic, the trend is to optimize the power generated by the photovoltaic itself and to measure the characteristic of the photovoltaic. The following paragraph, we will summarize what we have been done before.

The real-time solar energy monitoring system was one of the papers we reviewed. The proposed work employs a 125-watt Poly Crystalline silicon solar panel as a monitoring system. The voltage and current sensors are used to measure the voltage and current from the panel, respectively. The temperature sensor is installed on the solar PV module to measure the current temperature, which greatly affects the efficiency of the photovoltaic system. A pyranometer measures the amount of solar irradiance in a planar surface in terms of W/m². The Microcontroller is critical in processing the measured data and forwarding it to the cloud platform via the Wi-Fi module for concurrent observation and decision making.[3]. We found that it was done in this paper and result can be accessed from smartphone or PC. They way to develop IoT using microcontroller A CC3200 system-on-chip (SoC) with inbuilt Wi-Fi connectivity. This is the efficient way to make real time result.

A virtually reliable Solar PV monitoring system [4] is developed with LABVIEW software for computing the performance of a 5-Watt Solar Module. The electrical parameters like voltage, current, temperature, humidity and irradiance are measured using sensors and store the data in the DAQ (Data Acquisition) unit, which provide an interface to the PC. LABVIEW tool plot the I-V and P-V graph based on the data acquired and compute the Maximum voltage, Maximum current, Fill factor and efficiency of the solar panel. The watt peak calculation is still not measure on this research. [4].

Other papers we referred to is the solar tracking system. Solar tracker is a solar cell propulsion device that is made to automatically move at an angle of 0-180 degree and vice versa. Where the driving work is carried out by motors and sensors that function to track the receipt of solar energy by the solar cell panels. [5]. This paper is solving the issue about how much sunlight shines on the solar panels and Which direction your solar panels are facing.

It was expected that system can reduce the power load generated to drive the solar tracker motor and solar panels can produce maximum power. This research [6] found that solar tracker it has problems with the power generated to drive the motor has a large power to rotate the solar panel to always follow the movement of the sun. From the results of the study, the minimum power consumption occurs at 17:00 at 690.8 kg weight 8.12 voltage 0.11 when the solar panel is cross sectioned.

The developed prototype [7] was composed of current sensor type ACS-712 5A, voltage sensor, LM35 temperature sensor, LDR sensor, servo motor, and 11cmx11cm sized solar panel. The data of solar horizon coordinate system will be connected to the Arduino Uno software; therefore, the microcontroller works as the servo motor's controlling to drive the solar panel. Two pieces of servo motor allow the solar panel to rotate horizontally and vertically in the direction of the sun. Physical parameters, i.e., voltage, electric current, light intensity, and temperature, are measured using sensor modules, then stored in a personal computer (PC) using the PLX program – DAQ. This paper is still used PC and DAQ to collect data.

Other paper presents how to improve the photovoltaic (PV) system efficiency by using a method to integrate the solar tracker and the maximum power point tracking (MPPT). The integrated system provides a closed-loop solar tracker without the sensors. Instead of using the solar sensor, the output power of the MPPT is employed as the feedback signal to the solar tracker. The solar tracker estimates the solar azimuth and elevation angles using an astronomical algorithm based on the latitude, longitude, and the date-time of the local site. To improve the solar tracking accuracy, the fuzzy logic controller is employed to adjust the angle according to the power slope of maximum power with respect to the solar tracker angle. From the simulation results, the proposed method increases the PV energy by 23.23% compared to the fixed PV panel. It improves the efficiency of the existing integrated solar tracker by 0.25% based on the simulation models[8].

The last researcher presents real-time measurement of grid connected photovoltaic system using Zigbee sensor networks. The measurements were performed using sensors that are chosen based on their simplicity and lower price. [9]. The advantage of the solution of this paper had developed the network
by installing the sensor on every PV while they can collect all the information about the weather parameters were measured using OPT101 photodiode for irradiance sensors and DHT22 for temperature and humidity sensors[9]. However, there is no watt peak calculation involve on this solution. 

Having said above explanation form several papers reviewed, Therefore, in writing this paper the author tries to provide new innovations by designing a prototype circuit for solar tracker which combine with Internet of things, called Watt Peak Meter of Solar Panel. So that it is expected that the system that will be ensure the value of watt peak compared to datasheet of manufacture, aside it will make easy to have real time measurement without facing or sitting in front of the solar panel. In this research we would cover the three main factor that influence the solar panel. This watt peak meter is based on a solar panel tracker which can solve the issue about direction or facing of solar panel and to absorb the optimum sun shines. Another concern is giving an easy way to measure wattage peak as a real time measurement.

2. Method

The SUNLITE Photovoltaic was selected to be measured in this research. The nameplate from the manufacture state is the 20-Watt Peak, please refer to Figure-1 for further detail technical specification. Solar panel I-V Characteristic Curves are used to give a visual representation of the current and voltage (I-V) characteristics of a particular photovoltaic panel (cell or array) giving a detailed description of its solar energy conversion ability. Knowing the electrical I-V characteristics of a solar panel is critical in determining the output performance and therefore its efficiency. Measuring the output power of a solar panel, for example the 20W – SUNLITE Solar Panel is not that difficult if we apply some simple steps.[10].

![Figure 1. SUNLITE Photovoltaic 20 WP](image)

The product label of the SUNLITE 20-Watt 12 Volt Polycrystalline Solar Panel gives us the electrical characteristics of the panel, according to the manufacture SUNLITE when it is exposed to an irradiance of 1000 W/m².

The electrical data label states that the panels Open Circuit Voltage, (V_{OC}) is 20.64 volts and that its Short Circuit Current, (I_{SC}) is 1.3 amps. We can use Ohm’s Law then to find the output power of the solar panel, right. But V times I gives us 20.64*1.3 = 26.83 watts, which is a lot more than the 20 watts quoted by SUNLITE.
Further explanation will refer to Figure 2. The open-circuited voltage, $V_{OC}$ means that the PV panel is not connected to any load, so its terminals are therefore open (infinite resistance) resulting in maximum voltage, in this case 20.64 volts, at its terminals. As its terminals are open there will be no current flow ($I = 0$) because there is no electrical circuit or load for the current to circulate through. Then the output power of the solar panel in this instance is $P = V*I = 20.64*0 = 0$ watts. No generated electrical power.

Likewise, the short-circuited current, $I_{SC}$ means that the PV panel terminals are shorted or connected (zero resistance) creating a fully closed electrical circuit allowing the maximum panel current, in this case 1.3 amps, to flow. However, as the terminals are shorted together there will be no output voltage drop ($V = 0$), so the output power of the solar panel will be $P = V*I = 0*1.3 = 0$ watts. No generated electrical power.

![Figure 2. Conventional Method to measure watt peak](image)

We said previously that the output power of a solar panel mainly depends on the electrical load connected to it. This load can vary from an infinite resistance, ($\infty \Omega$) to a zero resistance, (0Ω) value thus producing an open-circuit voltage, $V_{OC}$ at one end and a short-circuit current, $I_{SC}$ respectively, at the other. Then we need to be able to find an external resistive value somewhere in between these two extremes.

As the theoretical maximum power, $P_{max}$ was shown to be 26.83 watts, and the maximum open-circuit voltage, $V_{OC}$ as 20.64 volts. If we assumed the panel has a maximum wattage of 150 watts and a maximum terminal voltage of 30 volts, this would give us the panels dynamic resistive value of:

$$R = \frac{V \cdot V}{P} = \frac{(20) \cdot (20)}{30} = 13.3 \ \text{Ohm value using rheostats resistors}.$$ 

Thus giving us a fully variable resistance between a minimum value of zero Ohms (0Ω) and the maximum value of 13.3Ω. We know that our solar panel has a manufacturer rating of 20 watts, so this would be the minimum power rating of our rheostat.

As we do internet of things, to measure the voltage across the terminals of the PV panel we would require a voltage sensor and current sensor or Power Sensor (INA219) as input for WEMOS ESP32 to calculate.
2.1. System Concept
The overall block diagram of a Watt Peak meter on the Solar Panel system is shown in Figure 3. The working principle of the system can be seen as follows:

1. The component of the LDR # 1 module detects the sun's rays,
2. LDR # 1 then provides input to the WEMOS ESP32 microcontroller,
3. WEMOS ESP32 drives the servo motor towards the strongest beam of sunlight,
4. When LDR # 2 gets sunlight, it will then provide input to the WEMOS ESP32 microcontroller to stop so that the position of the strong sunlight is between LDR # 1 and LDR # 2.

5. After knowing the position or direction where the strong sunrays are, the servo motor mechanic will move the solar cell panels,
6. The sun rays detected by the LDR will be forwarded to the solar charge controller module.
7. Voltage, current and power measurement data is generated by the INA219 sensor which is then sent via an internet connection to the Blink server where the data was previously received by the WEMOS ESP32 microcontroller.
8. Solar Charge Controller is used for charging the battery which is used as backup power when sunlight can no longer be obtained.
9. The output of the Solar Charge Controller is also used to supply LED light power using a 10 A / 5 V relay which then turns ON and OFF via Blink for operation.

2.2. Software Design
The Watt Peak Meter of Solar Panel system based on the internet of things, mainly includes transmitter software and receiver software. The transmitting terminal program mainly includes that the WEMOS ESP32 receives the data sent through the Wi-Fi port, furthermore the program flow chart of the sending end is shown as in Fig. 4. The main issue in case of delay due to the Wi-Fi limited connection only, it really depends stability on internet connection, however the delay is still can be tolerated since the data also only showing the result not have some action to drive any actuator.
2.3. API Setting
An internet connection-based remote-control system is made by requiring an intermediary software that connects the microcontroller and the controlled device or known as the API (Application Programming Interface). Of the many APIs, researchers chose to use Blink. Blink functions as a medium for connecting internet connections with microcontroller devices such as Arduino, MCU Nodes or Mini CPUs such as the Raspberry Pi. The value of the Blink application is the ease of use and the source code for each command in the application.

Each API includes an entry access in the form of a token key which we then copy to our source code via Sketch Arduino. This application is used to control relay 1 (one) and relay 2 (two) as well as to monitor sensor data, visualization, and others. In the Blink application there are 3 (three) main components, namely applications, servers, and libraries.

Blink server functions to handle all communication between hardware and smartphone. Blink is not tied to several types of microcontrollers, but must still be supported by the selected hardware.

3. Result and Discussion
In this section, we divide in two subsection namely electronic and mechanic part and measurement output.

3.1. Electronic and Mechanical Part
Solar panels are components that convert light energy into electrical energy. Electrical energy generated by a panel depends on the intensity of the light produced by the solar panels used are 6 volts per cell or panel. While Maximum output power is 20 watts. In the figure 5 and 6, we may see the schematic and a prototype of the proposed watt peak meter.

The Watt peak solar panel consists of electronic parts, and mechanical part. The electronic part aside of software, we implemented the WEMOS ESP32 controller, Relay, Motor Servo, Voltage and Current
sensors, LDR sensor and SCC (solar charge controller). The whole system diagram can be seen in Figure 5. The sensor used in this design is a sensitive sensor light or so-called light sensitive resistance (LDR). The components are a component that is a variable resistance where the resistance These components depend on the intensity of the light. On Generally, the stronger the infrared light, the smaller the resistance of the resistor and vice versa the less the intensity of the light the larger resistance resistor. In this design the LDR sensor is used to distinguish the intensity of light in the two cardinal directions, namely east and west. By using these two light sensors, we can compare to the angle of light. The sensor output is connected to controller input, wherein the light sensitive resistance (LDR) is coupled with one fixed resistance to form a divider resistor voltage. Thus, the output of the circuit is a voltage magnitude which depends on the light intensity. The controller reads voltage the two sensors and compare them. To find useful R for motor movement.

The controller used is Arduino WEMOS ESP32. The controller functions to control the motor in the direction of the beam of light the sun is by reading the light sensor then compare it to get the difference or error and use to drive the motor or panel. When the sensor voltage the east is smaller than the west the controller will move the motor and panel to the west until the position is balanced, namely the east sensor same as western sensor.

![Figure 5. Mechanical and Electronic System Schematic](image)

The motor driver is a circuit that serves to amplify the current and drive the motor. The amplifier used is a type of amplifier H bridge is IC L293D. The advantages of the H bridge amplifier can reverse the motor current so that the motor can reverse direction. The amplifier can amplify a current of 200 mA. Direction of motion and direction determined by the microcontroller. There are 2 inputs from the amplifier to motor for setting on/off and direction of rotation.

Motor is a component that converts electrical energy into mechanical energy. The type of motor used is a gear motor permanent magnet. The function of the motor is to move the panel to the position in the direction of the sun, the motor is controlled by the controller through the current amplifier.
3.2. Measurement Output

The measurement output can be seen in the smartphone or personal computer. Figure 7 shown the value result of Voc and my search along together we can see the watt peak meter result.
Using the data from the table-1 below, we can plot a graph of the measured voltage against the panels current as shown. The high voltage and current are popping up around 13.00 PM. The Voltage open circuit is 16.41 Volt and Current short circuit is 1.12 A

### Table 1. Voc, Isc conventional measurement during best weather condition

| Time  | Voc (Volt) | Isc (Amp) | Rated Current SSC (Amp) |
|-------|------------|-----------|-------------------------|
| 08.00 | 13.36      | 0.98      | 10.0                    |
| 09.00 | 13.86      | 1.01      | 10.0                    |
| 10.00 | 14.24      | 1.02      | 10.01                   |
| 11.00 | 15.13      | 1.05      | 10.02                   |
| 12.00 | 16.35      | 1.09      | 10.02                   |
| 13.00 | 16.41      | 1.12      | 10.02                   |
| 14.00 | 15.74      | 1.06      | 10.02                   |
| 15.00 | 14.59      | 1.02      | 10.01                   |
| 16.00 | 13.62      | 1.00      | 10.00                   |

Having taken our readings and tabulated the results in the above table 1, we can clearly see that the maximum power occurs when a panel voltage of about 16.41 volts producing 1.12 amperes thus giving a calculated output power of 18.38 watts.

This value closely matches the manufactures data label for an operating voltage ($V_{mp}$) and operating current ($I_{mp}$) of 17.2V and 1.16A respectively, giving a dynamic panel resistance at maximum power on $V_{mp}/I_{mp} = 17.2/1.16 = 14.8$ ohms and we could if so, wished fine-tuned our measurements to get even closer to the 20-watt, 14.8 ohms target.

#### 3.3. Analysis

Figure 8 present the voltage vs time. We can see from the measurement that the 16.41 is the high voltage around 13.00 PM in the noon. While the highest current is 1.12 Ampere at same time. This value we obtain from the blink dashboard without sitting in front of the solar panel itself. With integrated the IoT will help PV manufacture to be faster to testing the PV. We might conclude that the peak time would be around 12.00 – 13.00 PM with clear sky condition (best weather day).
The I-V characteristics graph for all typical PV solar panels can be seen in Figure 10. Measuring the power of other types and ratings of solar panels will yield similar results; the only difference could be in the voltages and current values. Also, for an open-circuit (zero current condition) and a short-circuit, power is zero (zero voltage condition).

The maximum power output of a PV panel is defined as its peak DC output, which is calculated by multiplying the voltage and current. The optimum operating point for our photovoltaic panels has been identified here at the midpoint of the bend in the character traits curve (or knee). In other words, the maximum power point, or MPP, is the point at which a solar panel produces more power.

Fill factor (FF) is the ratio of actual maximum attainable power (represented by the green, blue box) to the product of short circuit current Is/c and open circuit voltage Vo/c (represented by the light blue box).
The Fill Factor is essentially a measure of a PV module’s efficiency, with the theoretical maximum value depending on factors such as the type of silicon used to build the module. However, deviation from the expected value or changes in Fill Factor can provide an indication that a fault is present.

The I-V characteristic curve demonstrates an important property of a photovoltaic solar panel, or cell, in that it demonstrates that it is a current source device rather than a voltage source device, such as a battery. Unlike a battery, which has a fixed terminal voltage (12V, 24V, etc.) and delivers variable amounts of current to a connected load, for a given amount of solar insolation, a photovoltaic cell or panel provides a constant supply of current over a wide voltage range.

Measuring the power of a solar panel is no longer difficult, as it no longer necessitates a slew of multimeters, power resistors, or a single rheostat capable. Thank you to IoT technology for making life easier.

The maximum power or maximum production power of solar panels that can be obtained is 18.37-Watt peak when direct sunlight hits the solar panel without any obstructions in the form of shadows of trees, houses, or sunlight obscured by a cloud collection. If a continuous solar panel receives sunlight for 5 hours and has a productive power of 18.37 Watt, it will produce 91.85 Watt-hour. This stored energy of 91.85 Watt-hour can be used to turn on a 10-Watt lamp for 9 hours or other devices. It is necessary to add solar panels if you need more power according to operational needs.

In the figure 8 and 9, some data related to the best time and best power result during testing in sunny weather conditions. The highest power analysis obtained from solar tracker test data can be calculated by the following formula:

\[
P_{\text{max}} = V_{\text{mp}} \cdot I_{\text{mp}}
\]  

Where:

- \(P_{\text{max}}\): Maximum Power (Watt)
- \(V_{\text{mp}}\): Maximum Power Voltage (Volt)
- \(I_{\text{mp}}\): Maximum Power Current (Ampere)

Then the Maximum Power of the Solar Panel is (datasheet source):

\[
P_{\text{max}} = V_{\text{mp}} \cdot I_{\text{mp}}
\]

= 17.2 Volt \cdot 1.16 Ampere

= 19.95 Wattpeak round up to 20 WP.

However, to produce maximum power can be obtained from:

\[
P_{\text{max}} = V_{\text{o}} \cdot I_{\text{sc}} \cdot FF
\]  

Where FF (Fill Factor) formula:

\[
FF = \frac{V_{\text{mp}} \cdot I_{\text{mp}}}{V_{\text{o}} \cdot I_{\text{sc}}}
\]  

So at the peak of the highest measurement at 13.00 with Voc equal to 16.41 Volt and Isc equal to 1.12 A then the results is:

\[
FF = \frac{V_{\text{mp}} \cdot I_{\text{mp}}}{V_{\text{o}} \cdot I_{\text{sc}}} = \frac{17.2 \cdot 1.16}{20.64 \cdot 1.3} = \frac{19.95}{26.83} = 0.74
\]

The maximum power generated based on the datasheet is:

\[
P_{\text{max}} = V_{\text{oc}} \cdot I_{\text{sc}} \cdot FF
\]
\[ V = 20.64 \text{ Volt} \cdot 1.3 \text{ Ampere} \cdot 0.74 \]
\[ = 19.86 \text{ Watt} \]

So that the maximum power generated at 13.00 hours is:

\[ P_{\text{max}} = V_{\text{oC}} \cdot I_{\text{sc}} \cdot FF \]
\[ = 16.41 \text{ Volt} \cdot 1.12 \text{ Ampere} \cdot 0.74 \]
\[ = 13.6 \text{ Watt} \]

Thus, by involving the Fill Factor (FF) the maximum of Power would be 13.6 Watt.

The use of Blink as an application for power monitoring is also quite helpful in the data collection process, but the data obtained is only real time data, because the database contained in the application platform is stored directly on the Blink server and researchers cannot access the database making it difficult for researchers to create. Further analysis of the peaks in the voltage and current obtained during the test period.

4. Conclusion

On this basis, to sum up, everything that has been stated so far, our design is successful in measuring watt peak result which is very close to datasheet form PV manufacture. The prototype of watt peak meter has been successfully made including the Mechanical and Electrical with a maximum power of 19.84 Watt from the maximum power of 20 Watt-peak PV. By using the WEMOS ESP32, we tested the performance of our circuit and proved its portability. The modification of the Blink mobile application was successfully carried out and functioning properly but is limited to a-Wi-Fi connection only.

The overall performance fit the aim of this work which is to design a watt peak meter portable. Future research should be devoted to the development to add another several sensors to measure more characters of PV. The future research should focus to enhance and play with data measured which can be shared as part of big data. With the help of Computer Engineering, the watt peak meter collected can be better analysed to provide practical help for the PV manufacture.

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