Characterization of Electrical Quantities of a Grape Dye-Sensitized Solar Cell

S C See¹, M M Mercado¹, J Z Corpuz¹, J Balbin¹ and E Chua¹

¹ School of Electrical, Electronics and Computer Engineering, Mapua University, Philippines
Email: seesherwin@gmail.com

Abstract. A significant solution to the current global energy demand worldwide is the advancement of renewable energy, and one of these major renewable resources is the conversion of solar energy to electricity that is made possible by solar cells. In this study, the electrical quantities of a dye-sensitized solar cell were characterized to determine its efficiency, which is usually the main basis for this prototype. The researchers used a grape dye-sensitized solar cell composed of conductive glass as the photo-electrode, titanium dioxide (TiO2) sensitized with grape anthocyanin ethanol-based dye, KI3 electrolyte, and conductive glass with carbon as the counter-electrode. In characterizing the electrical quantities, the room temperature, lux level, and cell size were held constant at 23°C, 1500 lux, and 2.032cm x 1.524cm as controlled testing parameters. The researchers determined the voltage (Voc) and current (Isc) by using open and short circuit tests. The measured values were: 0.43 V; 0.40 V; 0.40 V; 0.45 V; 0.41 V; 41 µA; 38 µA; 35 µA; 41 µA; 39 µA respectively. The computed efficiency of the cells were 1.22%, 1.05%, 0.94%, 1.29%, and 1.11% respectively.

1. Introduction
The increasing global energy demand due to various energy-intensive industries and the rapid development of technology has been the biggest problem of many power distributors [1]. Fossil fuel, the major contributor of energy in the world, is not sufficient these days. For this reason, there is an urgent need to harness the renewable energy sources that will serve as alternative energy solutions. One renewable resource that supplies renewable energy worldwide is the conversion of solar energy into electricity. Solar Radiant energy can provide stable energy no matter what the conditions are at present [2]. However, its main disadvantage is the expensive construction of a solar panel and the use of toxic materials such as silicon, even though it is one of the most abundant elements in the world [3]. Therefore, further development of solar cells is being studied [4-6]. Gratzel and O’Regan studied and created a prototype of a dye-sensitized TiO2 solar cell that has made it an attractive and cheap device for the conversion of light into useful electrical energy [7]. A dye-sensitized solar cell (DSSC) is another type of solar cell that also converts visible light into electricity but is primarily based on the sensitization of wide band gap semiconductors, and its performance mainly depends on the dye used to sensitize the surface of TiO2 which determines the efficiency of the cell [8,9]. Dye-sensitized solar cells caught the attention of many innovators as these may be a potential alternative to the Silicon Solar cells because of their low cost, efficiency, and easy manufacturing. [10]
A variety of dyes was applied to dye-sensitized solar cell designs, ranging from ruthenium-based dyes to natural dyes [11]. So far, several organic dyes and organic metal complexes were employed to sensitize nanocrystalline TiO2 semiconductors, and one of the most efficient sensitizers was the...
transition metal coordination compound (ruthenium polypyridyl complex). Though the Ruthenium complex provided the best result as a sensitizer, its preparation was difficult, and toxicity was high compared to a natural dye [12-14].

This research focuses on characterizing the electrical quantities of a solar cell with a grape skin based light-absorbing material as an alternative to the silicon-based cells. Through a dye-sensitized solar cell (DSSC), the researchers were able to determine the short-circuit current (Isc), open-circuit voltage (Voc), charging time, discharging time, the voltage at maximum power (Vmp), current at maximum power (Imp), fill factor (FF) and efficiency (ɳ).

This study emphasizes on the renewable energy source that can be made available and can be provided not only to places that are unreachable by electricity distribution companies but also to those who are willing to help in preserving the Philippines’ natural resources.

The scope of this study centers on the characterization of the electrical quantities of grape skin dye-sensitized solar cells. Anthocyanin is the absorbent dye with light intensity, while the temperature is the controlled variable. Also, since the set-up was more of a mock-up than a marketable product, the expected output that was obtained might not be the most optimal set of results. Moreover, the researchers did not acquire the power output due to the small availability and time frame in the utilization of testing equipment. This study did not consider the lifespan of a grape dye-sensitized solar cell. Also, the researchers only focused on the angle of the surface of the cell that is perpendicular to the incident ray. Other angles for testing were not considered.

2. Methodology
As shown in Figure 1, the mechanical process is the main focus of this study. The mechanical process directs its attention to the output of the dye-sensitized solar cell as well as the tests involved in gathering the data.

![Figure 1. Conceptual framework for the mechanical process of DSSC.](image)

Figure 2 shows the final hardware output that the researchers used for testing.

![Figure 2. DSSC Output.](image)

2.1. Light
Table 1 shows the specification of the light source used in the experiment. The intensity of the light source (lux) was obtained by using “light meter” and “lux light” mobile application. The researchers used both mobile applications for the reliability of the data.
Table 1. Specifications of the Light Source

| Model  | Light Source | Battery Capacity | Charging Input | Material       | Finish | Performance Time |
|--------|--------------|-----------------|----------------|----------------|--------|-----------------|
| AEL-300| 21pcs SMD LED, 6000mAh | 5V 1A | ABS Plastic | Gloss | 12 hours |

2.2. Testing for Voltage (Voc), Current (µA), Resistance (Rth)

A Digital Multimeter (DMM) was used to obtain the open-circuit voltage (Voc) and the short-circuit current (Isc). As shown in Figure 3 and Figure 4, the probes were connected to the Anode and Cathode of the dye-sensitized solar cell, and the function was set into dc voltage and current in microamperes. Ohm's law was then used to acquire The Rth. The results of batch 1 and batch 2 for testing are found in Table 1 and Table 3 of this paper.

2.3. Testing for Voltage (Vmp), Current (Imp), Power (Pmp)

Figure 5 shows the circuit used to obtain the Vmp and Imp. The researchers used the value of Rth as the load and measured the voltage and current that pass through the load. Table 2 and Table 4 present the measured data of Maximum Voltage (Vmp) and Maximum Current (Imp) for the first batch and second batch.

2.4. Testing for Charging and Discharging Time

The researchers measured the charging and discharging time using a timer from no light condition to light condition. Charging refers to the rate of how fast the cell reaches its maximum voltage while discharging refers to the rate of time the cell loses its charged voltage. Table [2] presents the charging and discharging time of each cell for the first batch, and Table [4] for the second batch.
2.5. Equations

2.5.1 Fill Factor. The ratio of maximum obtainable power to the product of the open-circuit voltage and short-circuit current

$$\text{FF} = \frac{P_{\text{max}}}{P_{\text{theo}}} = \frac{E_{\text{mp}} \cdot I_{\text{mp}}}{E_{\text{oc}} \cdot I_{\text{sc}}}$$  \hspace{1cm} (1)

where \(I_{\text{sc}}\) = Short Circuit Current, \(E_{\text{oc}}\) = Open Circuit Voltage, \(P_{\text{max}}\) = Maximum power

2.5.2. Power Conversion Efficiency. An assessment of how well time and effort are used to accomplish a specific task. If that task is the conversion of one form of power to another, the efficiency of the conversion indicates how well the power conversion is implemented [15].

$$\eta = \frac{V_{\text{oc}} \cdot J_{\text{sc}} \cdot \text{FF}}{P_{\text{in}}}$$  \hspace{1cm} (2)

where \(J_{\text{sc}}\) = Short Circuit Current Density, \(V_{\text{oc}}\) = Open Circuit Voltage, \(P_{\text{in}}\) = Power Input from the Light Source

3. Results and discussion

Table 2. Data for indoor testing (1st batch) at 1500 lux.

| Trial | Voltage (Voc) | Current (µA) | Resistance (Rth) | Charging Time (Seconds) | Discharging Time (Seconds) |
|-------|---------------|--------------|------------------|-------------------------|---------------------------|
| 1     | 0.43          | 41           | 10488            | 26                      | 130                       |
| 2     | 0.40          | 38           | 10527            | 34                      | 245                       |
| 3     | 0.40          | 35           | 11429            | 28                      | 196                       |
| 4     | 0.45          | 41           | 10976            | 39                      | 205                       |
| 5     | 0.41          | 39           | 10513            | 32                      | 225                       |

Table 3. Continuation for Data for indoor testing (1st batch) at 1500 lux.

| Trial | Maximum Voltage (Vmp) | Imp (µA) | Pt (µW) | Pmax (µW) | FF | %\(\eta\) |
|-------|------------------------|----------|---------|-----------|----|-----------|
| 1     | 0.30                   | 27.61    | 8.283   | 17.63     | 0.4698 | 1.22%    |
| 2     | 0.30                   | 23.85    | 7.155   | 15.2      | 0.4707 | 1.05%    |
| 3     | 0.27                   | 23.73    | 6.4071  | 14        | 0.4577 | 0.94%    |
| 4     | 0.31                   | 28.24    | 8.7544  | 18.45     | 0.4745 | 1.29%    |
| 5     | 0.28                   | 26.86    | 7.5208  | 15.99     | 0.4703 | 1.11%    |

The data in Table 2 shows the measured voltage and current having 0.43V and 41µA respectively. The charging and discharging time of the cell is also shown in Table 1 with 26s as its charging time and 130s as its discharging time. Table 3 shows the computed values for the Pt. wherein the formula used is Pt=IscVoc (Power Formula), maximum power (Pmax), current density (Js) that is current over the surface area of the light-absorbing material (A= 0.8in x 0.6in or A= 2.032cm x 1.524cm) that is equal
to 13.23µA/cm², the fill factor (FF), and the %efficiency (%η). For the Pin, the researchers converted 1500 lux into Watt/cm² that is equal to 0.00021 W/cm². The fill factor, 0.4698, was obtained using Equation (1) wherein the Pt is 8.283µW, and Pmax is 17.63µW for trial 1 of the first batch. For the efficiency, the researchers used equation (2) having the Voc = 0.43V, Jsc= 3.0968µW, FF= 0.4698, and Pin= 0.00021W/cm² that resulted to 1.22% efficiency.

**Table 4.** Data for indoor testing (2nd batch) at 1500 lux.

| Trial | Voltage (Voc) | Current (µA) | Resistance (Rth) | Charging Time (Seconds) | Discharging Time (Seconds) |
|-------|---------------|--------------|------------------|-------------------------|---------------------------|
| 1     | 0.423         | 39           | 10846            | 26                      | 210                       |
| 2     | 0.416         | 38.5         | 10805            | 30                      | 225                       |
| 3     | 0.412         | 38           | 10804            | 25                      | 205                       |
| 4     | 0.425         | 39.3         | 10814            | 32                      | 215                       |
| 5     | 0.39          | 41           | 10488            | 27                      | 235                       |

**Table 5.** Continuation of Data for indoor testing (2nd batch) at 1500 lux.

| Trial | Maximum Voltage (Vmp) | Imp (µA) | Pt (µW) | Pmax (µW) | FF | %η  |
|-------|------------------------|----------|---------|-----------|----|-----|
| 1     | 0.2952                  | 26.255   | 7.7505  | 16.497    | 0.4698 | 1.14%|
| 2     | 0.2902                  | 25.922   | 7.5226  | 16.016    | 0.4697 | 1.11%|
| 3     | 0.2875                  | 25.5816  | 7.3547  | 15.656    | 0.4698 | 1.08%|
| 4     | 0.2965                  | 26.46    | 7.8454  | 16.7025   | 0.4697 | 1.16%|
| 5     | 0.30                    | 27.6     | 8.28    | 17.63     | 0.5178 | 1.22%|

Batch 2 of dye-sensitized solar cell was constructed and characterized to test the data for repeatability and additional accuracy. The data obtained in the second batch are close to the data in the first batch. With that, at 99% degree of confidence, the mean open-circuit voltage ranged from 0.3977V to 0.4335V; the mean short-circuit current ranged from 37.09µA to 40.87µA; the mean maximum voltage ranged from 0.2811V to 0.3047V; the mean maximum current ranged from 24.6522µA to 27.7694µA; the mean theoretical power ranged from 7.01µW to 8.37µW; the mean maximum power ranged from 15.033µW to 17.7212µW; the mean charging time ranged from 25.369s to 34.431s; the mean discharging time ranged from 176.6671s to 241.5329s; the mean fill factor ranged from 0.4576 to 0.4904; and the mean efficiency ranged from 1.03% to 1.234%.[16]
Table 6. Data for I-V Curve from Batch 2 Trial 5.

| Voltage (V) | Current (µA) |
|------------|--------------|
| 0          | 0.2          |
| 0.2        | 2.5          |
| 0.23       | 3.1          |
| 0.24       | 3.5          |
| 0.265      | 4.7          |
| 0.271      | 5.3          |
| 0.313      | 10.8         |
| 0.36       | 20           |
| 0.43       | 41           |

Figure 6. Sample I-V Curve of Batch 2 Trial 5 Indoor Testing.

Figure 6 shows the current and voltage curve (IV curve) for trial 5 of indoor testing (second batch). The researchers used the point plotting method to generate the IV curve. The dye-sensitized solar cell (DSSC) was exposed to different light intensity to get the voltage and current. Based on the graph, the current increased dramatically at point 0.313V to 0.43V. Light intensity is directly proportional to the voltage and current. The graph also shows that higher intensity received from light results in higher current and voltage output.
Figure 7 shows the charging and discharging of each trial for the first batch of indoor testing. Each trial showed that the solar cells produced tend to charge quickly and discharge for a long period of time. With this, the researchers can claim that the dye-sensitized solar cell produced maximizes the solar/light energy. The stored energy does not immediately discharge. With this representation, the solar cell stores and releases energy efficiently.

4. Conclusion

The researchers were able to characterize the dye-sensitized solar cell using open and short circuit tests, Ohm’s law, Fill Factor Formula, and Power Conversion Energy formula. This study obtained a measured data of \( V_{OC} = 0.43 \text{V}, \text{I}_{SC} = 41 \mu\text{A}, \text{V}_{MP} = 0.3 \text{V}, \text{I}_{MP} = 27.61 \mu\text{A}, \text{and Area} = 3.0968 \text{cm}^2 \) and computed data of \( \text{FF} = 0.4698 \) and percent efficiency of 1.22%. Also, having 26 seconds as charging time and 130 seconds as discharging time showed that the solar cell maximizes the stored light energy.

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