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Design and Simulation of Dye Sensitized Solar Cell as a Cost-Effective Alternative to Silicon Solar Panel

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Abstract

The continuous research in the area of renewable energy technology to substitute the unsustainable nature of fossil fuel in terms of it future availability and negative environmental impact created by fossil fuel has ensure the explore of solar energy as a good alternative. Dye sensitized solar cells (DSSCs) serve to be a good alternative means of producing photovoltaic solar cell. This work reports the working principle and construction process of dye-sensitized solar cell. A synthesized dye (Ruthenium oxide) and an iodide electrolyte were used for better performance based on already researched work. Also, this work reports the evaluation process with results recorded by the produced solar cell within 6:00am (GMT) and 6:00pm (GMT) for selected days. The results from the evaluation process show a better performance of a dye-sensitized solar cell in low and normal sunny day. The solar cell has a good performance at 12:00noon with a 0.5V output.

Keywords: Design; Simulation; Dye sensitized solar cell; Silicon solar panel.

1. Introduction

The unsustainable nature of fossil fuel as a cogent source of energy from the point of view of future availability and negative environmental impart, has energized interest in diversification of energy sources, with particular interest in renewable energy. This is indeed helping us to confront climate change by ending the world's dependence on fossil fuels, by tapping the power of new sources of energy like the wind and sun. The photovoltaic (PV) industry is a player in the renewable energy segment and the electricity generation from photovoltaic (solar cells) is deemed to be one of the key technologies of the 21st century [1]. Photovoltaic solar electricity remain a classy means of electricity generation, as there are no moving parts, clean and zero emissions and no noise.

The dominant material used in PV cells is silicon, particularly multi-crystalline silicon [2]. Further research has evolved new method of producing solar cell such as dye sensitizing solar cell. Since the invention of dye- sensitized solar cells (DSSCs) in 1991, they have been studied extensively as an alternative to silicon-based solar cells, owing to their simple structure, transparency, flexibility, low production cost, and wide range of application. Despite these advantages, the low efficiency of DSSCs compare to that of silicon-based cells has limited their commercial implementation [3]. Consequently there is a critical need to improve the efficiency of state-of-the-art DSSCs in order to realize next generation solar cells.

DSSCs are composed of four parts as follows:
1. The electrode film layer.
2. The conductive transparent Titanium oxide layer that facilitates charge transfer from the electrode layer.
3. The counter electrode layer made of platinum or carbon.
4. The redox electrolyte layer for reducing the level of energy supplied from the dye molecules [4, 5].

Recently, titanium dioxide (TiO_2) has attracted attention from researches worldwide due to its potential applications in environmental potential and energy generation [6], and has been applied largely in DSSC due to its nanocrystalline mesoporous nature that translates to high surface area for dye adsorption. The absorbed dye molecules can then be excited by the solar energy to generate electron-hole pairs that are subsequently separated and transported within the lattice of TiO_2 [7]. The absorption spectrum of the dye and the anchorage of the dye to the surface of TiO_2 are important parameters in determining the efficiency of cell [8].

2. Literature Review

A Dye Solar Cell is composed of two electrodes, the anode and the cathode. These electrodes are made from a specific glass that has a Transparent Conductive Oxide (TCO) coating on one side. The transparent conductive oxide

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material is a thin layer of fluorine-doped tin oxide, also called FTO. The transparency of the substrate allows sunlight to enter the cell while its conductive surface collects charges.

The anode is the negative terminal of the solar cell. It essentially bears a continuous network of sintered titanium dioxide nanoparticles. This porous network offers an inner surface that is a thousand times greater than the equivalent flat area, and acts like a "light sponge" in which sunlight can get trapped.

Among the various types of third generation solar cells, dye-sensitized solar cells are promising as they are cost effective, relatively easy to fabricate on large panels, lightweight and flexible; they also offer transparency compared to the first two generations of solar cells [9-11].

Due to their unique transparency [12], dye-sensitized solar cells have also shown superior performance under indoor lighting [13] and have been developed extensively on flexible substrates [14]. Dye-sensitized solar cells provided a technically and economically credible alternative concept to present day p-n junction photovoltaic devices. Unlike the conventional solar cell systems in which semiconductors functions as both photon absorber and charge carrier, dye-sensitized solar cells separate these two functions to two different materials. A light sensitized organic dye functions as the photon absorber, leaving the charge carrier function to the semiconductor.

Dye-sensitized solar cells are promising due to their low cost fabrication compared to the first two generations of solar cells; however, their efficiency is much lower than commercially available thin silicon solar modules. Although efficiency values up to about 13% have been reported in dye-sensitized solar cells [3].

The mechanism of dye-sensitized solar cells is similar to that of silicon solar cell. Photo excitation at a monolayer of organic dye results in the injection of an electron into the conduction band of oxide. Then, organic dye restores its original electron configuration by electron donation from the electrolyte, usually an organic system containing redox couples [15].

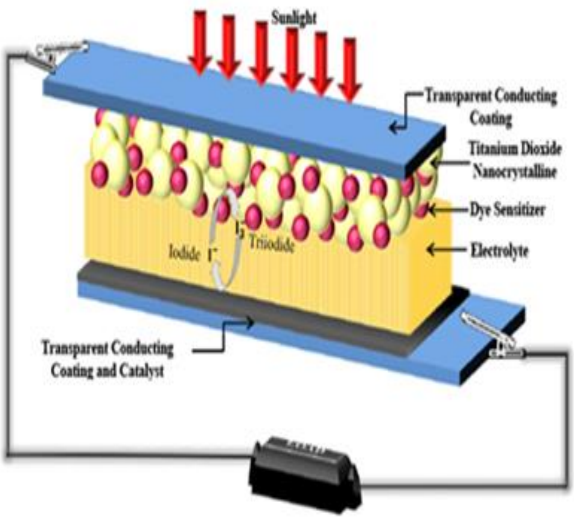
The heart of this solar cell is composed of nano-particles of meso-porous (with the pore width of 2-50 nm) oxide layer, which allows electronic conduction taking place. Since inorganic nano-particles have several advantages such as size tenability and high absorption coefficients, it is always the first choice when considering the cost and performance, etc. The material choice is mainly Titanium dioxide TiO_2 (Anatase), but an alternative choice such as Zinc oxide (ZnO) and Niobium pentoxide (Nb_2O_5) have been investigated as well [16].

Titanium dioxide was recognized as semiconductor of choice due to its great properties in photochemistry and photo-electrochemistry; it is a low-cost, widely available, non-toxic and biocompatible semiconductor material. Besides, experimental results showed meso-porous TiO2 layer has a highly efficient charge transport [17]. Titanium dioxide which is a white semiconductor that is not sensitive to visible light. The Titania particles have to be sensitized with a layer of dye molecules absorbing light in the visible spectrum. Some natural dyes can be employed, but the most efficient pigments were synthesized after intense scientific investigation [18].

3. Working Principle of a Dye-Sensitized Solar Cell

A single layer of dye molecules acts as a light absorber and is interspersed between TiO_2 particles. A drop of liquid electrolyte containing iodide is placed on the film to percolate into the pores of the film to complete the device. Conductive glass that has been coated with a thin catalytic layer of platinum or carbon as a counter electrode is placed on top of the cell, and light is illuminated from the TiO_2 side, as illustrated in Figure 1.0. A thicker coating of organic dye for solar cells has been tested; however, electric charges do not move easily within most organic materials, and it was reported that an active charge for charge injection is only effective with extremely thin layers. Thus, thick organic films do not transfer photo excited charges as well as thin films, absorbing all of the light, and a solar cell made from an interconnected series of thin film layers would be more effective than a cell made from a single thick layer of dye**.**

Figure-1. Working principle of a dye-sensitized solar cell [19]



Dye-sensitized solar cell components are:

- Transparent Conductive Oxide (TCO)

- Semiconductor Oxide Material
- Dye Sensitizer
- Electrolyte
- Counter Electrode

3.1. Transparent Conducting Oxide (TCO)

Dye sensitized solar cell are constructed with two sheets of TCO material as current collectors for the deposition of the semiconductor and catalyst. The Transparent conductive oxide material characteristics determine the efficiency of Dye sensitized solar cell [20] due to the efficient charge transfer of electrical conductivity to minimize energy losses.

Fluorine tin oxide (FTO) and indium tin oxide (ITO) are typical conductive oxide substrates consisting of soda lime glass coated with fluorine tin oxide or indium tin oxide, respectively. The fluorine tin oxide is the most common TCO used for the production of dye-sensitized solar cell.

3.2. Semiconductor Oxide Material

The central part of a Dye sensitized solar cell device consists of a thick nanoparticle film that provides a large surface area for light-harvesting absorption molecules to accept electrons from the excited dye [21], such as TiO_2, ZnO [22], SnO_2 [23], Nb_2O_5, WO_3, Ta_2O_5, CdSe, CdTe, and CdS. These molecules are interconnected to allow electronic conduction [24]. The efficiency of DSSCs depends on the electron transfer rates, which in turn depend on the crystallization, morphology and surface area of the semiconductor.

3.3. Dye Sensitizer

An efficient solar cell sensitizer must be able to adsorb strongly to the surface of the semiconductor oxide via anchoring groups, exhibit intense absorption in the visible part of the spectrum, and possess an appropriate energy level alignment of the dye excited state and the conduction band edge of the semiconductor. The performance of dye sensitized solar cell mainly depends on the molecular structure of the photosensitization. The best photosensitization can be attained using metal transition materials [25].

Three classes of dye sensitizers are used in DSSCs: metal complex sensitizers, metal-free organic sensitizers and natural sensitizers.

Ru (II) is the most efficient dye due to its numerous advantageous features, such as good absorption, long excited-state lifetime, and highly efficient metal-to-ligand charge transfer. Tris(***bipyridine***)ruthenium(II) complexes are excellent photosensitizers due to the stability of the complexes' excited states and the long-term chemical stability of oxidized Ru (III) [26].

The standard dye used in traditional DSSCs is tris(2,2'-bipyridyl-4,4'-carboxylate) ruthenium (II) (N_3 dye) [27]. Natural dyes are a viable alternative to expensive organic-based DSSCs. The overall solar energy conversion efficiency of natural dye extracted from pigments containing anthocyanins and carotenoids has been demonstrated to be below 1% [28]. Different parts of the plant, including the flower petals, fruits, leaves, stems, and roots, typically have different pigments. The advantages of natural dyes are their low cost, easy extraction, non-toxicity and environmentally benign nature [29].

3.4. Electrolyte

Electrolytes are used to regenerate the dye after electron injection into the conduction band of the semiconductor and also act as a charge transport medium for the transfer of positive charge toward the counter electrodes [30]. The liquid electrolyte is based on an organic solvent with a high ionic conductivity and distinctive interfacial contact properties; nevertheless, the leakage and volatility of the solvent affect the long-term performance of DSSCs [31]. Therefore, the electrolyte must have the following characteristics [32, 33]: (i) high electrical conductivity and low viscosity for faster electron diffusion; (ii) good interfacial contact with the nanocrystalline semiconductor and counter electrode; (iii) no tendency to induce the desorption of the dye from the oxidized surface or the degradation of the dye; and (iv) no absorption of light in the visible region.

3.5. Counter Electrode

Counter electrodes are mainly used to regenerate the electrolyte, with the oxidized electrolyte diffusing towards the counter electrode [30]. The counter electrode transports the electron that arrives from the external circuit back to the redox electrolyte system. Hence, for efficient charge transfer, the counter electrode should exhibit a high catalytic activity and high electrical conductivity [29]. Thus, the catalyst must accelerate the reduction reaction. Based on this consideration, platinum (Pt) is considered a preferred catalyst. Pt is a superior catalyst for use as a counter electrode for I^{3-} reduction because of its high exchange current density, good catalytic activity and transparency. The performance of the counter electrode depends on the method of Pt deposition on TCO substrates, such as the thermal decomposition of hexachloroplatinic in isopropanol [27], electrodeposition [34], sputtering [35], vapor deposition [36], and screen printing.

4. Silicon Solar Cell versus Dye-Sensitized Solar Cell

Table-1. Comparison between silicon solar cell and the dye-sensitized solar cell [30]

Function/ Performance	Silicon Solar Cells	Dye-Sensitized solar cells
Transparency	Opaque	Transparent
Pro-environment (material and process)	Normal	Great
Power generation cost	High	Low
Power generation Efficiency	High	Normal
Colour	Limited	Various
Manufacturing costs	High	Moderate
Performance in Diffuse Light	Low	Better
Performance at high temperature	Normal	Great

5. Methodology

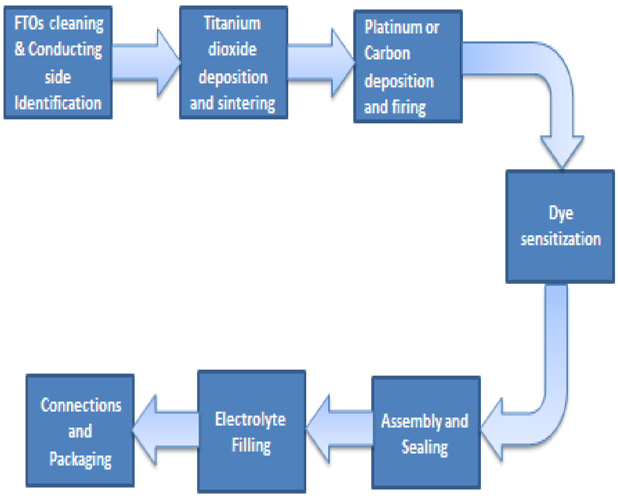
1. A piece of transparent glass that conducts electricity is used as an electrode in the solar cell.
2. It is tapped down, with the conducting side facing upwards using two pieces of tape.
3. The gap between the tape is covered with a paste containing small particles of titanium dioxide using a process called doctor blading. A blob of paste is put onto the glass and spread over the surface using a glass rod.
4. The tape is removed and the electrode is heated at a high temperature.
5. The electrode is removed and the electrode is heated at a high temperature.
6. The Titanium side of the electrode is socked or inserted into a dye. The dye molecules get attached to the surface of the titanium dioxide particles with a chemical bond.

This process is called 'sensitization' which is why these solar cells are called Dye-sensitized solar cells.

7. When the electrode is removed, the titanium dioxide is now coloured which allow it to adsorb sunlight better.
8. Another piece of conducting glass is used to make the other electrode of the cell. Two holes are drilled into it and then platinum metal is sprayed onto one side to help the cell conduct electricity better.
9. The two electrodes are now put together with a square of easy-melt plastic (meltonix film to seal cell).
10. They are then heated. When heated, the plastic melts and glues the two electrodes together.
11. The cell is filled with a liquid electrolyte by injecting it through the drilled holes.
12. A piece of sticky tape then seals the holes and stops the electrolyte leaking out.
13. The solar cell production is completed and can thereby be tested in the sun.

The figure 2 below summaries the step involve in manufacturing of dye sensitizing solar cell.

Figure-2. Block diagram of dye sensitizing solar cell production procedure



When sunlight falls on the cells, a flow of small particles called electrons (e) is created. This is called a current and can power an electrical device. Inside the cell, a particle of light called a photon hits the dye molecule. This gives an electron enough energy to escape the molecule and move to the titanium dioxide nanoparticles.

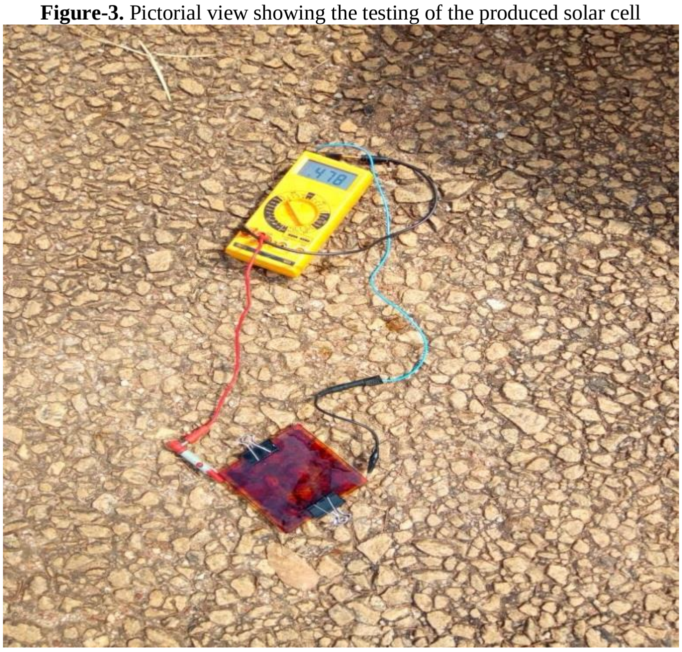
When this happens, a hole is left behind. A mediator (M), for example iodide, in the liquid electrolyte fills the hole with one of its own electron. The electrons travel in a big circle and create an electrical circuit, which powers a device. All that is required is a bit of energy from the sum to start it off.

6. Evaluation of the Dye-Senitizing Solar Cells

6.1. Evaluation Equipment

- Light source (Sunlight)
- Cables
- Variable resistance (or switchable fixed resistances) Voltmeter

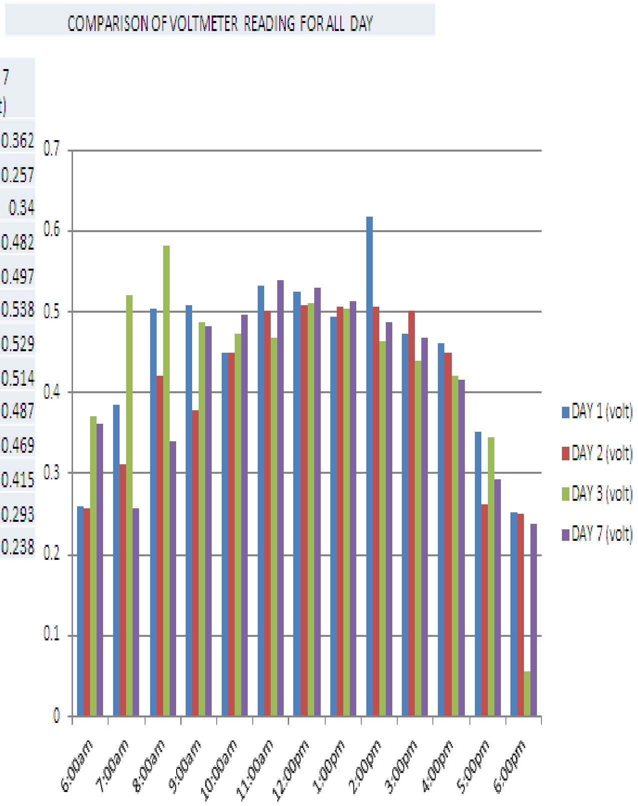
Figure-3. Pictorial view showing the testing of the produced solar cell



6.2. Results and Evaluation of the Dye-Sensitized Solar Cell

6.2.1. Chart Comparing the Voltmeter Reading At Different Day

Time	DAY 1 (volt)	DAY 2 (volt)	DAY 3 (volt)	DAY 7 (volt)
6:00am	0.259	0.257	0.371	0.362
7:00am	0.386	0.311	0.519	0.257
8:00am	0.503	0.42	0.582	0.34
9:00am	0.509	0.377	0.486	0.482
10:00am	0.449	0.45	0.472	0.497
11:00am	0.532	0.5	0.468	0.538
12:00pm	0.524	0.509	0.51	0.529
1:00pm	0.495	0.506	0.503	0.514
2:00pm	0.618	0.507	0.464	0.487
3:00pm	0.473	0.501	0.439	0.469
4:00pm	0.462	0.449	0.42	0.415
5:00pm	0.352	0.262	0.344	0.293
6:00pm	0.252	0.249	0.056	0.238



Observations from Section 6.2.1 are summarized with the Table 2 and 3 shown below.

Table-2. Harvested voltages of 0.5V and above

Time	Day 1	Day 2	Day 3	Day 7
6:00am				
7:00am			✓	
8:00am	✓		✓	
9:00am	✓			
10:00am				
11:00am	✓			✓
12:00pm	✓	✓	✓	✓
1:00pm		✓	✓	✓
2:00pm	✓	✓		
3:00pm		✓		
4:00pm				
5:00pm				
6:00pm				

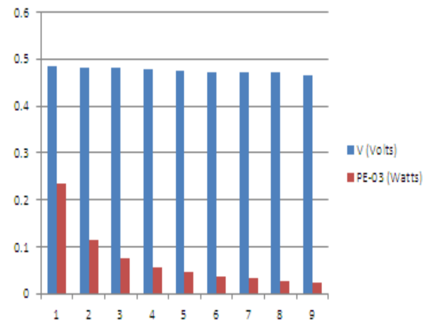
Table-3. Showing voltages of 0.4Volt and above

Time	Day 1	Day 2	Day 3	Day 7
6:00am				
7:00am			✓	
8:00am	✓	✓	✓	
9:00am	✓	✓	✓	✓
10:00am	✓	✓	✓	✓
11:00am	✓	✓	✓	✓
12:00pm	✓	✓	✓	✓
1:00pm	✓	✓	✓	✓
2:00pm	✓	✓	✓	✓
3:00pm	✓	✓	✓	✓
4:00pm	✓	✓	✓	✓
5:00pm				
6:00pm				

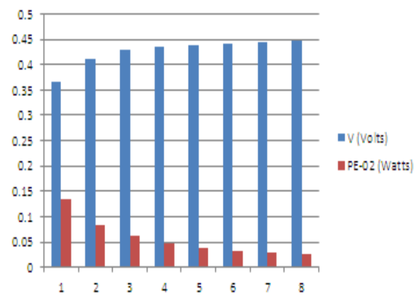
Table 2 shows the performance of the dye-sensitized solar cell with a voltage output of 0.5V and above. This table show that the best electricity harvest occurs at 12:00noon and 1:00pm. Also, Table 3 shows an output of 0.4V and above with a clear indication that dye-sensitized solar cell performs effectively between the hour of 8:00am and 4:00pm.

6.2.2. Chart Relating the Average Voltage and Power for R X103 and R X102 Ohms at 12:00pm

	RX1000 (Ohms)	
R (Ohms)	V (Volts)	PE-03 (Watts)
1	0.486	0.236
2	0.482	0.116
3	0.482	0.077
4	0.479	0.057
5	0.475	0.045
6	0.473	0.037
7	0.471	0.032
8	0.47	0.028
9	0.466	0.024



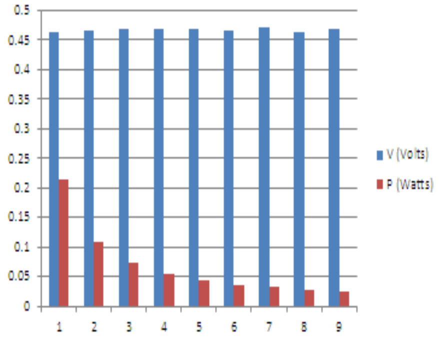
	RX100 (Ohms)	
R (Ohms)	V (Volts)	PE-02 (Watts)
1	0.367	0.135
2	0.41	0.084
3	0.429	0.061
4	0.434	0.047
5	0.438	0.038
6	0.441	0.032
7	0.444	0.028
8	0.446	0.025
9	0.447	0.022



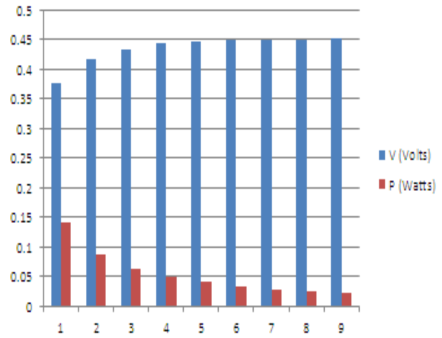
The chart in section 6.2.2 shows the relation of average voltage and power of the two selected ohmic value of load at 12:00noon indicated clearly how power decreases with corresponding increase in load. This satisfies the power law equation;

6.2.3. Chart Relating the Voltage and Power for R X10^3 and R X10^2 Ohms at 2:00pm

RX1000 (Ohms)		
R (Ohms)	V (Volts)	P (Watts)
1	0.463	0.214
2	0.467	0.109
3	0.468	0.073
4	0.468	0.055
5	0.468	0.044
6	0.466	0.036
7	0.471	0.032
8	0.462	0.027
9	0.469	0.024



RX100 (Ohms)		
R (Ohms)	V (Volts)	P (Watts)
1	0.377	0.142
2	0.417	0.087
3	0.434	0.063
4	0.443	0.049
5	0.446	0.04
6	0.45	0.034
7	0.451	0.029
8	0.451	0.025
9	0.453	0.023



The chart in section 6.2.3 shows the relation of average voltage and power of the two selected ohmic value of load at 2:00pm also correlated with the observation in section 6.2.2 by satisfying the power law equation.

$$P = \frac{V^2}{R}$$

Hence, the increase in the value of the load leads to corresponding decrease in the power output of the dye-sensitized solar cell.

7. Conclusion

This project was considered successful resulting from the result derived from the analyses done on the measured data at different hours of the day. The great performance and efficiency of dye-sensitized solar cell as compare to it cost in relation to silicon solar cell gave it an effective alternative to silicon solar cell.

This project has made it also possible to study the behavior and performance of dye-sensitized solar cell in Nigeria since solar cells depends on the amount of irradiate which varies with geographical region.

Also, due to the remarkable performance of DSSCs under low levels of light and compact fluorescent lamps through study, there is strong interest in both glass-based products and even more so in thin flexible dye-sensitized solar modules, which can be easily integrated in fixed or portable electronic products such as sensors in the home and personal computer peripherals. The commercialization of these products with integrated DSSs has been enabled by the fact that their efficiencies are particularly high indoors, their flexibility and light weight characteristics permit easy integration (and portability), their degradation rates are reduced in less-harsh indoor conditions.

Dye-sensitized solar cells can be used excellently as energy-harvesting electrochromic window (EH-ECW). This helps to boast the energy generation rate.

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