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The Effect of a Dynamic Lens Structure on the Open Circuit Voltage of a Concentrated Photovoltaic Model

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Authors' contributions

This work was carried out in collaboration between both authors. Author MLH designed the model, carried out the experiments, and wrote the first draft of the manuscript. Author AH analyzed the performance and managed the research. Both authors read and approved the final manuscript.

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ABSTRACT

The current concerns of energy shortage and global warming have brought the development of strategies to utilize renewable energy resources at the forefront of public interest. Solar power is one of renewable energy's most promising sources. Concentrated photovoltaics can significantly improve a photovoltaic (PV) system's electricity production. This paper presents a novel approach of a CPV unit with a dynamic lens structure. Design and Implementation of both electrical and mechanical design in order to move the lens to achieve a better voltage output. Experiments had been carried out and measurements were taken according to the light source which was the sun in one case and the artificial light in the other. Based on the experimental results the effect of the dynamic lens was studied and compared to the fixed lens. The results showed that the dynamic lens CPV model was more effective and efficient than the fixed one.

Keywords: Solar energy; photovoltaic; concentrated PV; dynamic lens.

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1. INTRODUCTION

Although the conventional resources such as gas, oil, and coal are very effective and efficient in terms of power production, they have serious negative impact on the environment in addition to their limited quantities. Due to these reasons among with many others much attention was paid to the development of new renewable energy resources [1].

Renewable resources are unlimited natural resources that can be replenished in a short period of time. Renewable energy produces only small levels of carbon emissions and therefore, it is considered as environment friendly. The major sources of renewable energy include solar, wind, rain, biomass, geothermal, hydropower, wave and tidal energy.

The solar energy is the most abundant, reliable, and pollution-free energy source on our planet [2]. The cost of photovoltaic (PV) cells has been steeply declining, while their light-to-electricity conversion efficiency has increased which has boosted the PV industry [3].

Concentrated photovoltaic (CPV) can be considered as a branch of the PV industry in which the use of optical devices such as, collectors , reflectors ,and lenses to focus large quantity of sunlight radiation into a photovoltaic cell is applied [4] .

By concentrating sunlight onto a small area of photovoltaic, this technology provides an economic solution by replacing the expensive semiconductor photovoltaic cells with the cheaper optics. So only small area of PV cell is needed [5]. It also provides more efficient outcome by concentrating more light into the solar cell [6]. Since less semiconductor material is used in CPV systems, the PV cell must be highly efficient such as multi-junction cells, although this type of cells are extremely expensive, research show that using multi-junction cells with concentrated light can obtain higher efficiency [7].

Concentrating light, however, requires direct sunlight rather than diffuse light, limiting this technology to clear, sunny locations. It also means that, in most cases, tracking technology is required [8] .

When concentrated illumination is applied on photovoltaic cells, they experience a high heat load because the photons which are not converted to electrical energy are dissipated as heat in the cells. Thus, A cooling device that can effectively eliminate the dissipated heat while maintaining the cells at the desired temperature is an essential requirement for an effective photovoltaic concentrator [9]. The need for a cooling system was not a neccesity in the proposed design due to the approche that was taken, in which the CPV model was not exposed to the sun except when the data were being collected, hence, the system can eliminate the heat by not being used for a period of time.

Many research have already shown that applying CPV systems can be advantageous technically or economically according to the type of the system, nevertheless it is rare to find a study focusing on the lens being the dynamic part.

In this paper the effect of the moving lens on the open-circuit voltage was investigated in which results were obtained by using an artificial light as well as the sun as source of light.

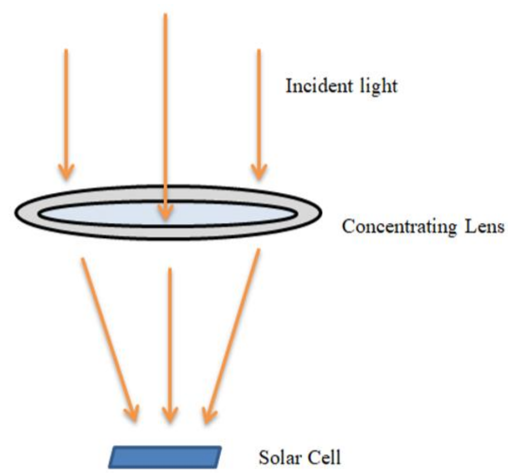

Fig. 1. Principle of CPV

2. MATERIALS AND METHODS

The purpose of the study is to find out whether the dynamic lens can provide an improvement to the PV cell’s open-circuit voltage. Many materials were used in order to complete this design. Those metrials can be falling under three categories: Measuring instruments, electronic components, and mechanical design.

Two measuring instruments were used for readings which are:

- Solar Power Meter: M206 solar power meter was used for the solar irradiance measurements.

- Digital Multimeter: UT136B Digital Multimeter was used to measure the open-circuit voltage of the PV cell..

Electronic components:

- DC Motors: in order for the design to work appropriately a motor with high torque(5 kg.cm) along with a revelation speed that does not exceed 120rpm has been chosen [10]. The motors is shown in Fig. 2. The motor specifications are listed in Table 1.

- LDRs: LDR which is a resistor whose resistivity decreases with increasing of light intensity were used as sensors.

- OPAMP: In order to amplify the variations of the LDR voltage, LM324 was used. LM324 is a quadruple OPAMP. It contains four OPAMPs. Nevertheless, only two of them were used.

- Variable resistors: two variable resistors (10 kΩ and 100 kΩ) were used in the suggested electrical circuit to restrain the motor from spinning when the LDRs are under the same amount of illumination.
- Resistors and capacitor: Resistors of 47 kΩ and 15 kΩ were used for the OPAMPs input lines. Also, a bypass capacitor of 100nF was used. • Transistors: Four transistors were used to build an H-bridge circuit.

- Diodes: The diodes were used in the H-bridge circuit to protect the transistors from damaging. Four 1N4001 model diodes were used in our circuits.

- Batteries: Two 12 voltage DC batteries were used to power the lens and the solar tracker's electrical circuit.

- Photovoltaic Cell: An ordinary solar cell was used with the following specifications:
- Open circuit voltage of 4.2. - Short circuit current of 100uA. - 0.55W.

Working principle: joining those electronic components together according to a specific design is what has been called here the control unit.

- The Control Unit: The electrical circuit that we used is shown in the Fig. 3. As long as the two LDRs are under the same level of illumination, the window comparator keeps the motor in non-moving state. When the level of the light irradiance is the same on both LDRs, the voltage is divided into two halves in which one half is applied to the inverting input of A1 and the other half is applied to the non-inverting input of A1. When the light falling on the LDRs changes, the input voltage for the comparator is no longer half of the supply voltage, therefor; the comparator's output produces orders for the motor to rotate the device until the LDRs are on the same level of illumination again.

Fig. 2. The DC Motor

Table 1. Specifications of the motor

Type	**22CL-3501PG**
Stall Torque:	1.6Nm (16Kg • cm)
Continuous torque:	0.5Nm (5Kg • cm)
Voltage	12VDC
Encoder:	67mm
Stall Current	1.8A
Reduction ratio:	80: 1 (metal planetary reducer)
Output speed	120 r / min (input voltage DC 12V)
Length	2 pulses per revolution.

The two variable resistors are calibrated in such way that the motor does not rotate when the LDRs are under the same amount of illumination. If the LDR1 is getting less light than the LDR2, the voltage in point A increases to more than half of the power supply voltage. Therefore the output of A1 is HIGH, consequently the concept of H-Bridge is applied in which the two transistors

T1 and T4 are open while the other transistors are closed and in this particular case the motor starts to rotate.

When the voltage at point A decreases to less than half of the power supply voltage, the output of A2 is HIGH, consequently the two transistors T2 and T3 are open while the other two transistors are switched off, hence the motor starts to rotate but in the opposite direction [11].

As it is known that the motor also generate electrical energy, when you switch off the transistors to stop the motor of spinning, this energy needs to be released on some way. adding diodes in the reverse direction for the transistors gives a path for the current to take and release this energy. Therefore ; diodes can help in the protection of the transistors and without them the damage of the transistors is a possibility due to the risk of the rises of the voltage [12].

Mechanical design:

The movement that is obtained from the electrical design is a rotational movement and since the desired lens structure movements must be up/down, we need to convert the rotational motion of the motor to linear motion hence, moving the lens up and down, a simple mechanical design was built using the following material.

- Two drawer slides
- Drilled bar
- Metal screw

Fig. 5 shows the overall mechanical design of the CPV unit. The two drawer slides are fixed into the wooden support structure of the design. The lens and the drilled bar are attached to the drawer slides. The metal screw is joined to the DC motor from one side, and from the other side it is passed through the drilled bar. keeping in mind that the drill was in the middle of the bar with a diameter that is equal to the diameter of the metal screw. Now when the DC motor rotates clockwise the motion of the lens is upward and when the motor rotates anticlockwise the motion of the lens is downward.

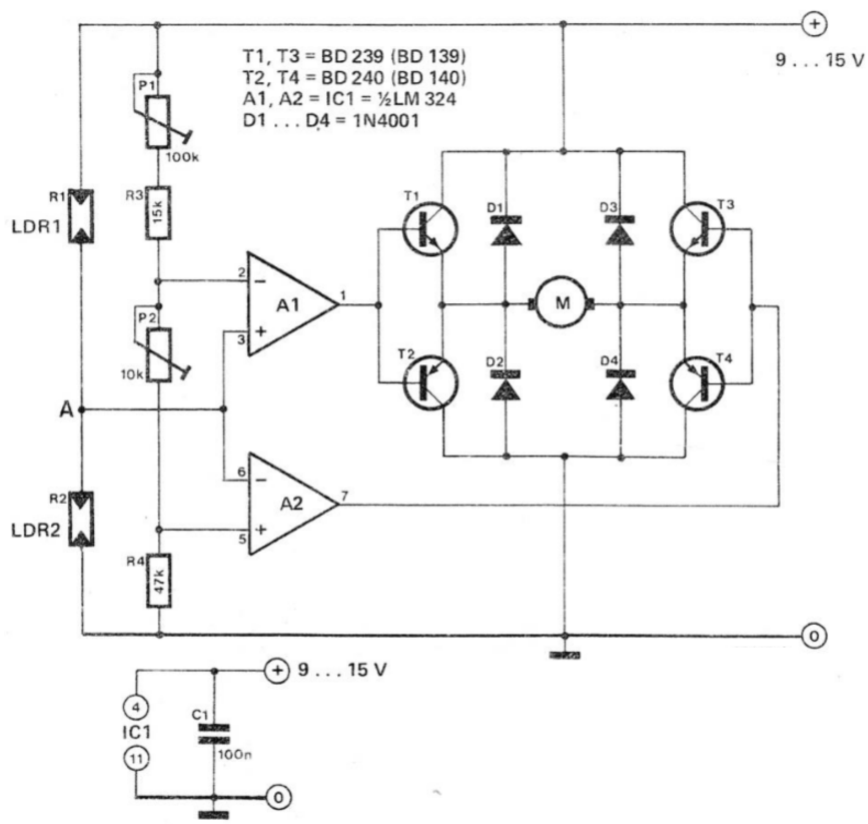

Fig. 3. Electrical design of the dynamic lens

Fig. 4. Drawer slides, The drilled bar, and the metal screw

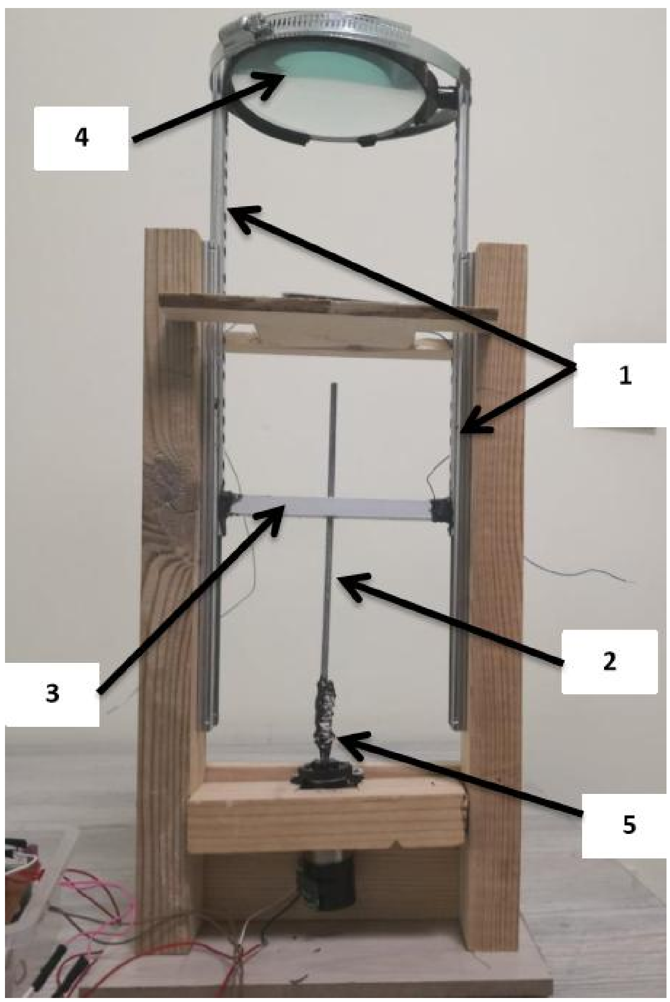

Fig. 5. Mechanical design of the CPV with dynamic lens. 1) Drawer Slides . 2) Metal Screw. 3) Drilled Bar. 4) Lens. 5) DC Motor

3. EXPERIMENTAL APPROACH AND RESULTS

Two experiments were conducted in order to investigate the performance of the design; the first experiment was conducted using the sun as a source of light and the second experiment was conducted using an artificial light.

1- Sun light as the source of power: In this case, the experiment was conducted in a sunny clear day on the 26th of July at the campus of Ankara Yildirim Beyazit university. The specific location is 39.969606 latitude and 32.818449 Longitude. Readings were taken instantaneously at different times throughout the day for both the fixed and the dynamic lens design taking in consideration in the case of the fixed lens readings, the lens was fixed at 10cm away from the PV cell. The following Tables show the taken readings.

   From Fig. 6 it can be noticed that the dynamic lens generates more voltage throughout the day than the fixed lens, it reached a peak of 4.7 V at midday. Both the fixed and the dynamic lens can achieve good results when the irradiance is direct; mostly between 11:00 and 15:00, but when the sun changes its position the direct light will not reach the lens, hence the Open Circuit Voltage decreases. An average of 2.17% gain in voltage was obtained throughout the day using the dynamic lens system.

2- Artificial light as the source of power: Unlike the first case, in this case the experiment was conducted in a dark room, a bulb light was used as an artificial light. The bulb (55A,230 V, and 70W) was attached to a stick of 100cm length. Also a goniometer was attached to the artificial light structure in order to measure the angle of the light source with respect to the PV cell as shown in Fig. 8. The reading were taken at 0, 30, 60, 90, 120, 150, and 180 degrees. Similar to the first case, the readings where the fixed lens system was applied were taken while the fixed lens was 10cm away from the cell.

   From the curve shown in Fig. 8 it can be observed that the dynamic lens can achieve better voltage at the whole degree domain than the fixed lens. From 60 degrees to 120 degrees the change in values of the voltage does not exceed 2%. On the other hand, when the degree is less than 60 or more than 120 we can see that the change in values of the open-circuit voltage increase rapidly, and that makes the dynamic lens more useful in the case of the dark room with the artificial light source. Using the dynamic lens in this case, increased the value of the average gain in voltage by 44.92%.

Table 2. Fixed lens readings

Time	Irradiance (W/m^2)	Open Circuit Voltage (v)
8:10	345.2	4.17
8:55	527.6	4.22
9:50	768.1	4.35
10:55	1007.8	4.53
12:05	1055.7	4.47
14:00	1237.1	4.49
15:45	916.4	4.4
16:50	496.8	4.09
17:45	354.7	4.1
18:50	50.1	3.94
19:40	16.1	3.55

Table 3. Dynamic lens readings

Time	Irradiance (W/m^2)	Open Circuit Voltage (v)
8:10	483.4	4.26
9:15	672.6	4.29
10:20	924.2	4.42
11:15	998.3	4.51
12:05	1695	4.7
14:00	1172	4.52
15:40	923	4.47
16:50	550.4	4.28
17:45	328.2	4.25
18:50	58.3	4.03
19:35	18.6	3.58

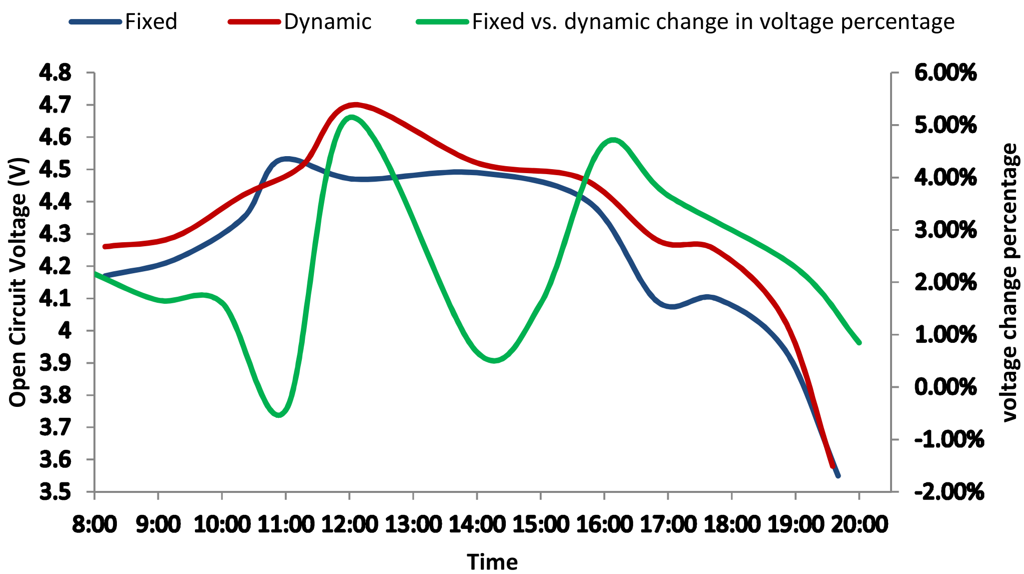

Fig. 6. Fixed vs. dynamic lens curve

Fig. 7. Artificial light structure in 3D

Table 4. Fixed lens readings (artificial light)

Degree	Irradiance (W/m^2)	Open Circuit Voltage (v)
0	1.2	0.883
30	1.5	1.3
60	8.8	3.15
90	64.1	4.08
120	14.2	3.37
150	3.1	1.76
180	1.74	1.022

Table 5. Dynamic lens readings (artificial light)

Degree	Irradiance (W/m^2)	Open Circuit Voltage (v)
0	1.9	1.586
30	2	2.0217
60	10.5	3.2
90	54.5	4.12
120	8.9	3.43
150	3.8	3
180	2.7	2.09

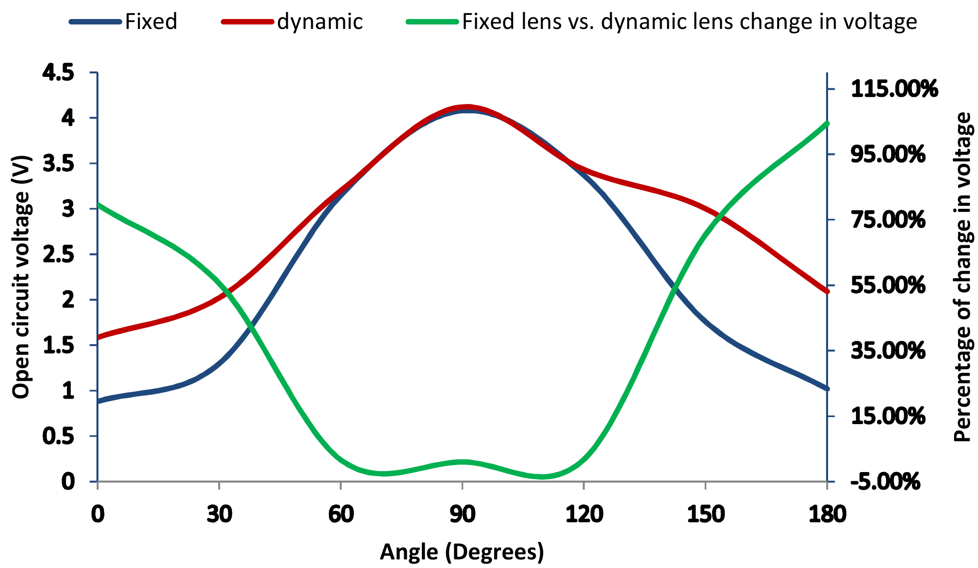

Fig. 8. Fixed vs. dynamic lens curve

4. CONCLUSION

This work reports the experimental effect analysis of a dynamic lens CPV module on open-circuit voltage and compare it to the fixed lens module. It has been observed that the open-circuit voltage from the CPV with dynamic lens is higher than that from the fixed lens module in both cases of light source. In the case of the sun as the source of light, it has been found that the average gain in voltage throughout the day for the dynamic lens is 2.17% higher than that from the fixed module. On the other hand for the artificial light as the source, based on the obtained experimental results, the average gain in voltage using the dynamic lens increased to 44.92%. The main reason behind this is as the irradiance was lower than the sun irradiance the saturation point was not reached. Giving us more reliable results to study. it can be concluded that CPV systems with the dynamic lens are able to obtain improved results comparing to those with fixed lens.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Shahzad U. The need for renewable energy sources. Int. J. Inf. Technol. Electr. Eng. 2012;16–18.
2. Kannan N, Vakeesan D. Solar energy for future world: - A review. Renew. Sustain. Energy Rev. 2016;62:1092–1105.
3. Sunny uplands - alternative energy will no longer be alternative; 2012. Available:https://www.economist.com/news/2012/11/21/sunny-uplands [Accessed: 10-Feb-2019]
4. Luque A, Andreev V. Concentrator Photovoltaics. Berlin: Springer-Verlag Berlin Heidelberg; 2007.
5. Pérez-Higueras P, Muñoz E, Almonacid G, Vidal PG. High concentrator photovoltaics efficiencies: Present status and forecast. Renew. Sustain. Energy Rev. 2011;15(4): 1810–1815.
6. SELİMOĞLU Ö. Design and realization of a new concentrating photovoltaic solar energy module based on lossless horizontally staggered light guide. Middle East Technical University; 2013.
7. Best research-cell efficiency chart photovoltaic research .NREL. Available:https://www.nrel.gov/pv/cellefficiency.html. [Accessed: 23-May-2019].
8. Apostoleris H, Stefancich M, Chiesa M. Tracking-integrated systems for concentrating photovoltaics. Nat. Energy. 2016;1(4).
9. Sayed S, Anis WR, Hafez IM. The effect of temperature on the performance of PV array operating under concentration. Int. J. Sci. Technol Res. 2015;4(8): 240–246.

10. ML Hennache Ş Erel. Performance of a CPV unit with a dynamic lens. In 3rd International Symposium on Innovative Approaches in Scientific Studies (Engineering and Natural Sciences). 2019;4(1):1–3.
11. DIY Solar Tracker System Circuit. Available:https://www.electroschematics.com/8019/diy-solar-tracker-system/. [Accessed: 23-Mar-2019].
12. What is an H-Bridge? - Build Electronic Circuits. Available:https://www.build-electronic-circuits.com/h-bridge/. [Accessed: 24-Nov-2019].

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