Design of Flyback Converter by Obtaining the Characteristics of Polymer Based R2R Organic PV Panels

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Abstract- Organic solar cells are cheaper and easier to produce than inorganic solar cells. In addition, organic solar cells have a wide range of applications due to their flexible structure. However, since the efficiency of organic solar cells is lower than that of inorganic solar cells, studies are carried out to increase efficiency. Maximum power point monitoring studies in solar systems provide improvement in the efficiency of these systems. DC-DC converters are needed for the application of maximum power point tracking algorithms to solar systems. Due to the high output voltages of organic panels, specially designed converters should be used to apply maximum power point algorithms to these panel types. Flyback converters are preferred in high voltage applications because their output circuits are isolated from the input circuits. In this study, considering the advantages and deficiencies in the literature, a polymer-based organic panel produced by the R2R method was used. Considering the high output voltage of the organic panel, characteristic curves were obtained and flyback converter design was carried out depending on the values in these characteristic curves. In this way, with the smaller, more powerful, and portable converter, compact devices such as mobile phones and smart watches will be able to be charged with portable, foldable, lightweight organic panels in their environment or in open air environments.

Keywords- Solar Energy, Organic PV Characteristics, Polymer based Organic PV Panels, R2R, Flyback Converter.

1. Introduction

Solar energy is an endless source of electrical energy. Energy generation from solar cells is a noiseless, non-toxic, maintenance-free technology. Especially in recent years, organic solar cells have become a popular type of solar cell. Polymer-based organic panels produced by the R2R (roll-to-roll) method are preferred among organic panels due to their easy and fast production techniques, and their development has continued in recent years [1]. In addition to the high efficiency in inorganic solar cells, the production costs are also quite high. For this reason, the advantages of Organic Photovoltaic (OPV) cells such as being easy to produce compared to inorganic solar cells [2], and having wide usage areas thanks to their low cost and flexible structure [3] are the main reasons which is count for increase to research on organic solar cells. For this reason, efforts to reach higher yields have been accelerated by using methods such as different production techniques [1], the use of different materials [4] to increase efficiency in organic panels [5].

By using maximum power point tracking methods, solar panels can be utilized with high efficiency [6, 32]. In line with these studies, Maximum Power Point Tracking (MPPT) methods performed on organic solar panels can improve their efficiency [7,33].

DC-DC converters are the basic circuits of MPPT applications in renewable energy systems [34, 37]. DC-DC converters have the ability to convert DC input voltage value to DC output voltage values at different levels [8, 36]. DC-DC converters are structurally examined in two main groups as non-isolated and insulated. Flyback converters are included in isolated DC-DC converters. Flyback converters are also preferred in MPPT circuits in solar systems due to their advantages such as the small number of circuit elements, wide input voltage range, isolation of the output circuit from the input circuit, and having more than one output voltage value [6, 7].

We can examine the publications related to the work we have carried out under 3 headings. These are publications involving organic panel structures, those related to flyback converter design, and studies involving maximum power point tracking methods.

When the studies on organic panels are examined; examination of organic semiconductors in terms of commercialization and market [3], portable Current-Voltage monitor design of roll to roll (R2R) OPV modules with low current and high voltage [10], comparison of material, cost, production techniques, environmental effects and sustainability aspects of organic and inorganic panels [2], maximum power point tracking using RTO optimization algorithm in OPV cells [7], investigation of the level of efficiency of organic panels according to studies conducted in recent years [5], investigation of indoor characteristics in case of using wide range non-fullerene acceptor in high performance OPV cells [4], production techniques of polymer-based organic panels produced by roll to roll (R2R) method [1], comparison of open circuit voltages in organic panels of different structures produced by roll to roll (R2R) method [11], evaluation of indoor efficiency of encapsulated organic panels coated with roll to roll (R2R) method [12], high efficiency flexible organic panel design in indoor applications [13], investigation of stability, yield and synthetic complexity of photoactive material in high efficiency organic panels [14], investigation of recent developments in terms of material, device and processing method in thick-film organic panels [15] studies have been carried out.

When the studies on flyback converter design are investigated; planar flyback transformer design for LED lighting powered by PV source [16], flyback converter design simulation and experimental studies for solar system [17], flyback converter based MPPT simulation study for a photovoltaic system [18], closed loop controlled flyback converter design for a PV system [19], advanced Flyback converter design for PV applications [20], design of an MPPT-based grid-connected photovoltaic system using flyback converter [21], push-pull Flyback converter design for photovoltaic systems [22], application of low cost P&O (Perturb & Observe) and INC (Incremantal Conductance) MPPT algorithms for Proteus software-based flyback converter [9], high gain flyback DC-DC converter design for PV systems [8], multi-output isolated flyback converter design and implementation [24], various studies have been carried out.

When the studies including MPPT tracking applications are examined; modeling the whole photovoltaic system as sub-modules and applying MPPT to each sub-module separately [25], simple structure and low cost P&O based maximum power point tracker design [26], Design of an MPPT-based grid-connected photovoltaic system using flyback converter [6], application of low-cost P&O and I&C MPPT algorithms for Proteus software-based flyback converter [9], simulation study for flyback converter based maximum power output control for photovoltaic system [18] studies have been carried out.

When the studies on the radiation characteristics of organic panels were evaluated, it was observed that the cell size characteristics were examined in general [4,5]. On the other hand, in the literature, there is a deficiency in examining the characteristics of organic solar cells, panel sizes, and radiation-related characteristics.

In addition to these studies, publications in which organic photovoltaic panels and DC-DC converters are used together are detailed. Accordingly, Valverde et al. In their study, they designed a current-voltage monitor for organic photovoltaic panels larger than 5kV. In order to isolate the load side from the output of the organic photovoltaic panel in the current-voltage monitor electronic circuit design, a ready-made DC-DC regulator module with an output voltage between 12V and 3.3V is used [10]. Wu et al. In their study, they designed a buck-boost converter for an organic photovoltaic panel with a maximum output voltage of 5V. Since the organic photovoltaic panel used in the study has a low output voltage, there was no need for a converter design to isolate the load side from the organic photovoltaic panel output. It has been observed that the output voltage changes in the range of 2V-4V in response to the change of the input voltage in the range of 3V-5V [29]. Prasad et al. In their study, performance analysis was made for dye-sensitive organic photovoltaic panels using buck-boost converter and maximum power point algorithms. The switching frequency on Buck-Boost can switch up to 20 KHz [30]. Venkateswari and Sreejith investigated the basic materials affecting the efficiency of solar panels, the maximum power point tracking algorithms and the basic DC-DC converters used for power conversion. When the features of the converters examined here are detailed, it is shown that while the buck converter works only in the decreasing direction and the boost converter works only in the increasing direction, flyback, push-pull, half bridge, full bridge converters provide DC-DC conversion in both directions. When the DC-DC converters evaluated in the study are evaluated in terms of complexity in their electronic circuit designs, it has been shown that buck, boost and buck-boost converters have a low level, flyback converters have a medium level, push-pull, half bridge and full bridge converters have a higher level of complexity. Among these converters, only flyback converters do not need a choke coil since a transformer is used [31]. When the studies in which organic panel and DC-DC converters are used together are evaluated in general, buck-boost converters are used because there is no need for load-side isolation for small-sized organic photovoltaic panels .

There is no study on flyback converter design based on the characteristic analysis of organic panels.

In this study flyback converter design was carried out for polymer-based high output voltage organic panels produced by roll to roll (R2R) method, considering the deficiencies in the literature and the advantages it provides. The characteristic features of organic panels differ depending on the material from which they are produced. Therefore, the organic panel used in the study; current-voltage (I-V) and power-voltage (P-V) characteristic curves were obtained in accordance with the size, properties and different radiation levels. Depending on the characteristic curves and datasheet information, which is obtained, the parameters of the flyback converter were determined and the design was carried out.

Since the organic photovoltaic panel used in the study has the feature of high output voltage, it is ensured that the organic photovoltaic panel output side and the load side are isolated from each other with the flyback converter design. In addition, the designed flyback converter can be used in a wide input voltage range. A clamp circuit has been added to the converter input in order to eliminate the leakage current on the coil on the primary side of the transformer used in the flyback converter. Thus, the leakage current caused by the coil on the primary side of the flyback converter is eliminated. A diode with fast response feature has been added to the converter output so that the flyback converter can respond quickly to radiation changes in the system. In addition to these, the MOSFET used in the converter design has a switching feature up to 100 KHz.

It is foreseen that a similar design is applicable for organic panels with different characteristics. In outdoor environments where access to electricity is difficult, small powerful, portable, compact devices such as mobile phones, smart watches and tablets can be charged with the OPV supported flyback converter. In addition, the realized flyback converter structure is designed to work in harmony with MPPT algorithms. In this way, the use of flyback converter circuit and MPPT algorithms together will improve the efficiency of organic panels, which have many advantages as mentioned above.

2. Flyback Converter Design

DC-DC converters are used to obtain the maximum power output of photovoltaic panels [26, 21]. Types of DC-DC converters such as buck, boost, buck-boost, flyback, push-pull, half-bridge, full-bridge are used in studies on photovoltaic panels. While buck and boost converters provide a one-way DC-DC conversion, flyback, push-pull, half bridge, full bridge converters provide DC-DC conversion in both directions. In terms of design simplicity, buck, boost and buck-boost converters have a more easily applicable structure, while half-bridge and full bridge converters have more complex structures. In buck, boost and buck-boost converters, there is no isolation between the converter input side and the output side. Flyback converters, on the other hand, are not very complex in terms of being applicable and have an isolated design [31]. Organic panels are photovoltaic structures with high output voltage. High voltage poses a problem in charging low power loads. Therefore, DC-DC converters are needed for organic panels to be used in low-power systems. Due to the high output voltage of the organic panels, a flyback converter design has been carried out in which the load can be isolated from the panel. Compared to other DC-DC converters, flyback converters are primary side isolated from the load. It can also produce a regular output voltage despite wide input voltage variation. Due to the high output voltage of the organic panel, flyback converter design has been carried out.

As seen in Fig.1, there is a transformer used in flyback converters to provide isolation, energy storage and voltage conversion between the input voltage and the load connected to the output side. The polarities of the primary and secondary windings on the transformer are designed in such a way that while current flows from one of them, no current flows from the other [9,35].

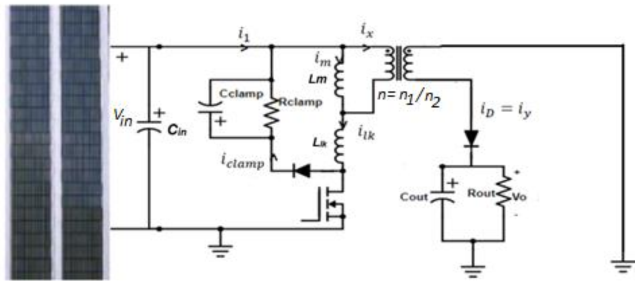


Fig. 1. OPV Assisted Flyback Converter Circuit Diagram

During the design of flyback converters, parameters such as switching frequency, transformer conversion ratio, output resistance, magnetic inductance should be determined [8].

The first parameter to be determined is the switching frequency, it has a very important value in determining other parameters and an optimum switching frequency should be selected. This value has been determined as 100KHz for the designed flyback converter.

In determining the transformer conversion ratio, it is necessary to determine the relationship between the primary and secondary windings of the transformer used [9]. Transformer conversion ratio n is calculated as $n_1/n_2 = 9/1$.

$$\frac{V_o}{V_{in}} = \frac{n.D}{1-D} \tag{1}$$

In Eq. (1), $n=n_1/n_2$ is expressed as transformers ratio and duty cycle as *D*. V_o represents the output voltage, and V_{in} (V_{mpp}), represents the voltage value of the maximum power point obtained for the organic panel.

Equivalent resistance *Req* and output resistance *Rout* are calculated using Eq. (2) and (3) with determined *n*, *D*, V_{in} , current of the maximum power point obtained for the organic panel I_{in} (I_{mpp}) values [17].

$$R_{eq} = \frac{V_{in}}{I_{in}} \tag{2}$$

$$R_{out} = \frac{R_{eq}.D^2.n^2}{(1-D)^2} \quad (3)$$

The magnetic inductance L_m, used in the circuit is a very important element for flyback converters. The value of L_m should be an acceptable value for modeling the transformer. Voltage V_{Lm} and magnetic inductance L_m values on magnetic inductance are calculated using Eq. (4)-(5), respectively [25].

$$V_{Lm} = V_{in} = L_m.\frac{dI_m}{dt} \quad (4)$$

$$L_m = \frac{V_{in}.D}{\Delta I_m.f_{sw}} \quad (5)$$

While calculating L_m inductance value, magnetic inductance current change ΔI_m, switching frequency f_{sw}, panel input voltage V_{in} and duty cycle value D, are taken into account.

The parameters to be considered while choosing the MOSFET in the flyback converter circuit are the current flowing through the MOSFET and the voltage value that the MOSFET can withstand. Calculations should be made considering the maximum voltage value on the MOSFET while the MOSFET is in cut-off . The maximum voltage that will fall on the MOSFET V_{FET} voltage can be calculated by Eq. (6) [17].

$$V_{FET} = V_{in} + \frac{V_{out}}{n} \quad (6)$$

In order to avoid safety problems due to MOSFETs, the MOSFET withstand voltage should be used greater than twice the calculated value .

As with the MOSFET, the rectifier diode is determined by the maximum voltage V_D it will calculated in Eq. (7) [27].

$$V_D = V_{in}.n + V_{out} \quad (7)$$

The clamp circuit on the flyback converter ensures that the current on the leakage inductance is eliminated. In order to protect the MOSFET, we should make our calculations according to the maximum voltage that the MOSFET can withstand, V_{sw}, and the maximum value of the input voltage, V_{inmax}. According to this, the voltage on the clamp circuit is calculated according to V_{clamp} Eq. (8).

$$V_{clamp} = V_{sw} - V_{in_{max}} \quad (8)$$

R_{clamp} value in clamp circuit is calculated by Eq. (9) by using power loss P_{loss} and voltage V_{clamp} value in clamp circuit.

$$R_{clamp} = \frac{V_{clamp}^2}{P_{loss}} \quad (9)$$

After obtaining the R_{clamp} value, the capacitor range value of the clamp circuit, C_{clamp}, can be calculated in Eq. (10).

$$R_{clamp}.C_{clamp} > 10.T_{sw} \quad (10)$$

The output capacitor in the flyback converter circuit is the element that limits the ripple value in the output voltage. In order to create the desired voltage fluctuation at the output, we must calculate the output capacitor C_{out} value. We can calculate the output capacitor value by using Eq. (11) with output voltage V_{out}, duty value D, switching frequency f_{sw} and output resistance R_{out} values [25].

$$C_{out} = \frac{D.V_{out}}{f_{sw}.R_{out}.\Delta V_{out}} \quad (11)$$

3. Organic Panel Characteristics and Calculation of Flyback Converter Parameters

Polymer-based organic panels produced by the R2R (roll-to-roll) method have the advantages of being easy and cost-effective, being flexible, and are preferred among organic panels [1]. In this study, polymer-based organic panel produced by roll to roll (R2R) method was preferred considering the advantages it provides.

For the organic panel, Current-Voltage (I-V) and Power-Voltage (P-V) characteristic curves depending on the radiation falling on the panel to be used for the design of flyback converters are needed. For this reason, in this part of our study, primarily characteristic curves of the organic panel were obtained, and flyback converter design was carried out depending on the values in the characteristic curves.

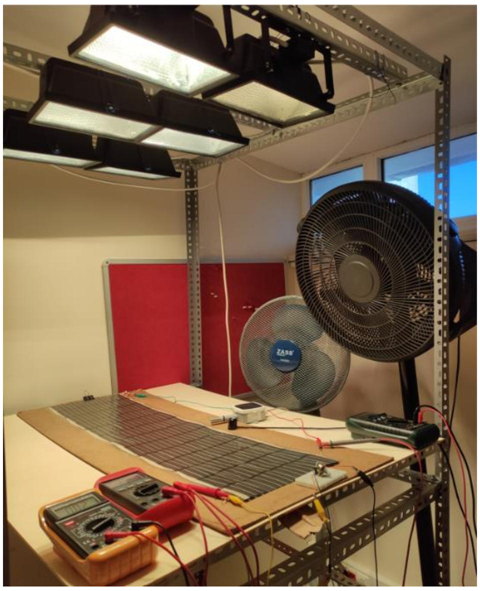


Fig. 2. Experiment Setup for Organic Panels

The experimental setup set up to obtain the characteristic of the Organic Panel at different radiations is shown in Fig. 2. The organic panel used in the study belongs to Infinity PV company and consists of polymer-based organic cells measuring 305mm x 1000mm. I-V and P-V curves suitable for the panel dimensions used in the experimental setup are not included in the catalog and related literature. Therefore, in order to determine the characteristic properties, first of all, the I-V and P-V characteristic curves of the organic panel were obtained under different radiation conditions, at T=25ºC. During the experimental studies, 6 halogen projector lamps with 1000 watts of daylight feature were used. Halogen lamps are placed on the organic panel in such a way that there is homogeneous radiation distribution. The amount of radiation was adjusted by the distance of the organic panel to the projectors. The radiation value was measured with the Apogee SP-215 pyranometer and the panel surface temperature was measured with the IOSENSE IO-TRH-INDR temperature transmitter. When halogen lamps are turned on, the panel surface temperature increases. In order to prevent the structural deterioration of the organic panels as a result of temperature and to keep the panel surface temperature constant, a cooling fan was used.

During the experimental measurements, different irradiance values were obtained by changing the distance between the panel and the halogen lamps. The temperature value is fixed at T=25 ºC. Depending on the measurement results, the I-V characteristic curves obtained on the MATLAB program are shown in Fig. 3. Accordingly, when the organic panel characteristic curves were examined, it was observed that the open circuit voltage decreased with the amount of radiation. However, the short-circuit current value also decreases with the amount of radiation.

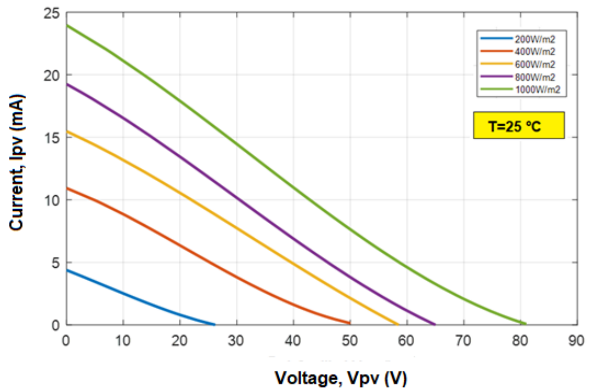


Fig. 3. Organic Panel I-V Characteristic Curve

The P-V characteristic curves obtained as a result of the measurements are shown in Fig. 4. When the graphic values are examined, it is observed that the power value of the maximum point decreases with the radiation. In addition, the voltage values of the maximum power points decrease with radiation.

After obtaining the characteristic curves of the organic panel, the parameters of the flyback converter can be calculated. For safety purposes, the flyback converter parameters were calculated considering the maximum irradiance value G=1000W/m^2 for the organic panel and shown in the P-V characteristic curve in Fig. 5. Accordingly, flyback converter parameters were calculated based on the voltage V_{mpp} and current I_{mpp} values of the maximum power point for the maximum radiation G=1000W/m^2 and the measurements determined for the organic panel during the experimental studies.

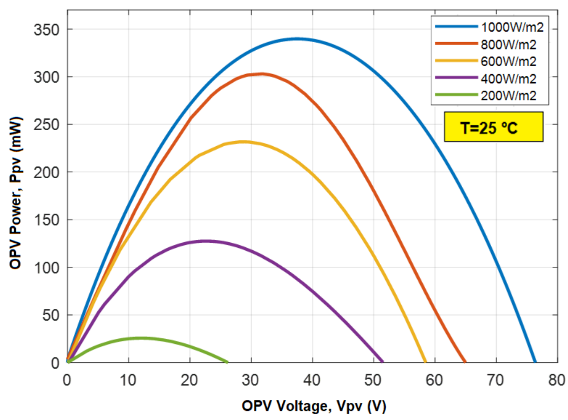


Fig. 4. Organic Panel P-V Characteristic Curve

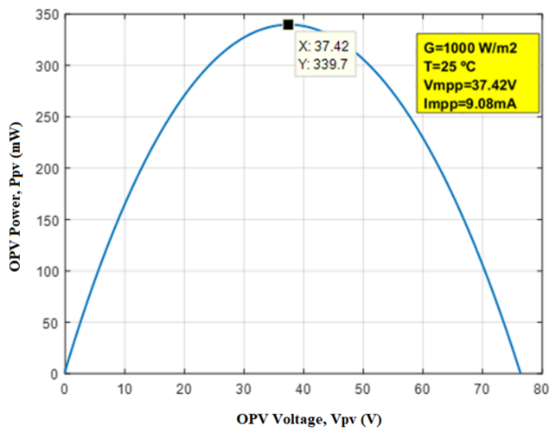


Fig. 5. Maximum Irradiance P-V Characteristic Curve

Organic panel and flyback converter parameters to be designed were obtained as a result of experimental measurements and given in Table 1. In the calculations, the voltage V_{mpp} and current I_{mpp} values of the maximum power point are accepted as 40V and 12mA in order to be in a safer area.

Table 1. Organic Panel and Flyback Specification

ORGANIC PANEL and FLYBACK FEATURES	
Photovoltaic Panel Input Voltage (Vinmax)	85V
Flyback Load Voltage (Vout)	5V
Flyback Load Current (Iout)	0.2A
Flyback Load Power (Pout)	1Watt
Panel Open Circuit Voltage (Voc)	82V
Panel Short Circuit Current (Isc)	35mA
Voltage Value of Maximum Power Point (Vmpp=Vin)	40 V

By using the flyback converter design equations given in Chapter 2 and the values of the organic panel in Table. 1, the parameters and component values of the flyback converter were calculated. While calculating the design parameters, 100KHz was chosen considering the switching frequency, operating frequencies of the MOSFET and the transformer used. In the study, the duty cycle value was taken as 0.5 max. Diode 1N4148 with fast response feature is used on the clamp circuit. After this stage, simulation studies were carried out.

4. Flyback Converter Simulation Studies

During the simulation design of the flyback converter, first of all, the organic panel parameters in Table 1 were obtained as a result of experimental measurements. By using the organic panel parameters obtained afterwards, the parameters of the flyback converter design were calculated. Depending on the final calculations, the flyback converter MATLAB/Simulink model design has been carried out. The realized simulation model is shown in Fig. 6.

While determining the flyback converter parameters, calculations were made according to the standard test conditions [28] for the radiation and temperature value, considering the organic panel measurements at the maximum radiation value G=1000W/m^2 and the temperature value at T=25ºC, which is accepted as the optimum temperature. The voltage value of the maximum power point at this radiation and temperature was measured as 37.42V and the current value as 9.08 mA. However, while designing, the voltage of the maximum power point is accepted as 40V and the current as 12mA for safety purposes. The maximum duty cycle value (D) accepted in the calculations for these values is 0.5.

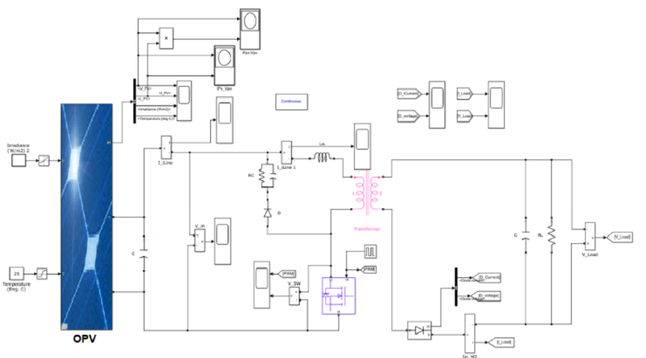


Fig. 6. Flyback Converter MATLAB/Simulink Model

The radiation value is G=1000 W/m^2, the temperature value is T=25ºC, applied to the panel input, and the 0.5 duty cycle value accepted in the calculations for this temperature and radiation is applied to the MOSFET input on the simulation model. When the simulation is run, the current and voltage values observed at the panel output coincide with the current and voltage values in Table 1 of the maximum power point. The results of the simulation are shown in Figure 7.

However, in Fig. 7.b, when the radiation value is G=1000 W/m^2 and the panel surface temperature value is T=25 ºC, it is observed that the load voltage is V_L=4.7V and the load current is I_L=0.2A on average. It has been observed that these values coincide with the load current and load voltage values in Table 1 determined during the design. After the simulation results, experimental studies were started for flyback converter design.

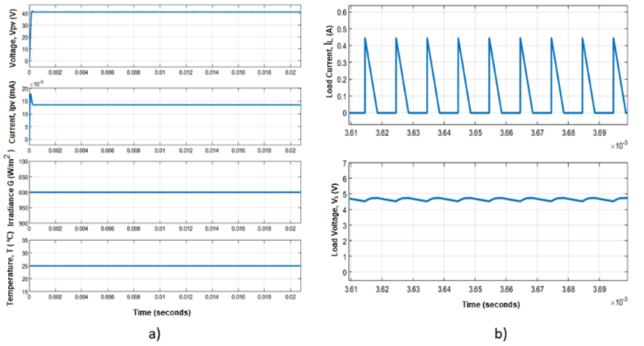


Fig. 7. a) Panel Voltage, Current, Radiation and Temperature Curves **b)** Load Current and Load Voltage

5. Experimental Studies

The flyback converter circuit design for the organic panel is shown in Fig. 8.

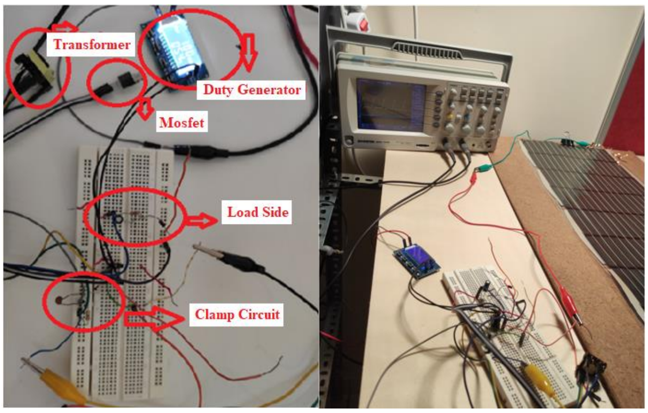
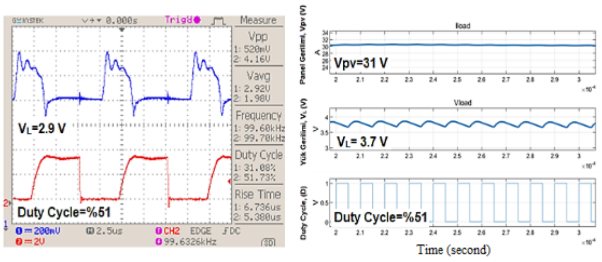


Fig. 8. Flyback Converter Circuit Design and Experimental Studies

During the experimental study, the performance of the converter was analyzed with the potentiometer used as a load under the radiations of 300W/m^2 and 100W/m^2. The panel voltage was measured as V_{pv}=31V for 300W/m^2 radiation value and as V_{pv}=10V for 100W/m^2 radiation value. In the study, it has been shown that the load voltage and current values of the Flyback converter can be controlled depending on the change in the organic panel voltage and the change in the duty cycle. When the load resistance changes in the flyback converter, the duty value should be automatically adjusted to a new optimum value in order to control the power transferred from the converter. Therefore, MPPT must be applied in order to transfer the converter input power to the output at the maximum rate. For this reason, the operation of the system was investigated under single load condition under different radiations.

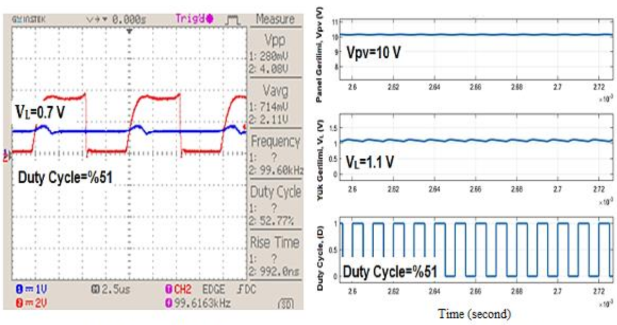
In the experimental results of the designed circuit, the voltage at the panel output when is measured as V_{PV}=31V depending on the radiation, according to the oscilloscope outputs, in Fig. 9a, when the switching frequency is f=100KHz, the duty cycle value is D=0.51, the voltage on the load is at V_L=2.92V has been observed. However, as a result of the simulation in Fig. 9b, the voltage on the load is V_L=3.7V for the same panel output voltage and duty cycle value.



a) Experimental Result b) Simulation Result

Fig. 9. Load Voltage (V_L) and Duty Cycle (D) **a)** Experimental Result **b)** Simulation Result

In addition, considering the results given in Fig. 9, f=100KHz, duty cycle value D=0.51 was kept constant in this stage of the experimental study, and it was observed on the oscilloscope outputs that the average value of the load voltage decreased from 2.92V to 0.7V by decreasing the panel voltage from V_{pv}=31V to V_{pv}=10V. As a result of the simulation, the load voltage was observed at 1.1V. The results obtained with these values are given in Fig. 10.

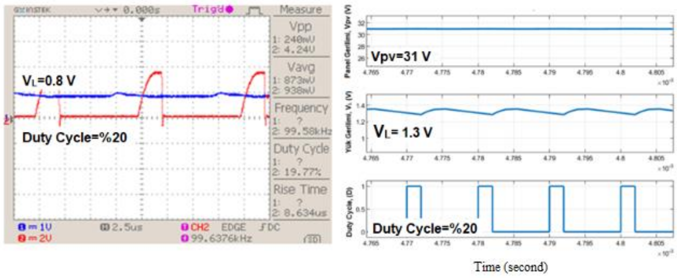


a) Experimental Result b) Simulation Result

Fig. 10. Load Voltage (V_L) and Duty Cycle (D) **a)** Experimental Result **b)** Simulation Result

Similarly, in Fig. 9, considering the experimental results, the panel voltage and switching frequency were kept constant, and it was observed that the average value of the load voltage decreased from 2.92V to 0.87V as the duty value was reduced from D=0.5 to D=0.2. Results of this experimental study given at Fig. 11.

Considering the environmental factors and losses during the application, it was observed that the simulation and experimental results were compatible. It has been observed that the flyback converter output voltage can be controlled in accordance with the duty cycle and panel input voltage.



a) Experimental Result b) Simulation Result

Fig. 11. Load Voltage (V_L) and Duty Cycle (D) **a)** Experimental Result **b)** Simulation Result

6. Conclusion

In this study, current-voltage (I-V) and power-voltage (P-V) characteristic curves were obtained for polymer-based organic photovoltaic panel produced by R2R (roll to roll) method, whose properties are given under different irradiance values. These characteristic data will contribute to the studies of organic panels in the simulation environment. In addition, flyback converter design has been carried out for the organic photovoltaic panel depending on the current-voltage (I-V) and power-voltage (P-V) characteristic curves. In addition, with the flyback converter design for organic panels, small powerful, mobile compact devices will be able to be charged in the open-air environments. The designed flyback converter is designed to be controlled by the output voltage, panel input voltage and duty value, and its accuracy has been observed through experimental studies. Thus, the designed flyback converter circuit can be used integrated with the maximum power point algorithms.

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References

[1] R. Søndergaard, M. Hösel, D. Angmo , T. T. Larsen-Olsen, F. C. Krebs, ‘‘Roll-to-Roll Fabrication of Polymer Solar Cells ’’, mateiralstoday, Volume 15, Number 1-2, Jan-Feb 2012

[2] K. Orgil, ‘‘Comparison of Organic and Inorganic Solar Photovoltaic Systems’’, Senior Project, Electrical Engineering Department California Polytechnic State University San Luis Obispo ,December 2018.

[3] X. Yang and L. Ding ‘‘Organic semiconductors: commercialization and market’’ J. Semicond., 42(9), 090201,2021.View online: https://doi.org/10.1088/1674-4926/42/9/090201.

[4] Y. Cui , Y. M. Wang , J. Bergqvist,H. Yao, Y. Xu, B. Gao, ... & J. Hou, ‘‘Wide-gap non-fullerene acceptor enabling high-performance organic photovoltaic cells for indoor applications’’,Nat Energy, 4, 7, 2019.

[5] A. Distler , C. J. Brabec, H. J. Egelhaaf , ‘‘Organic photovoltaic modules with new world record efficiencies’’, Prog Photovolt Res Appl, 29, 24, 2021.

[6] MD. Modassir Masoom, DR. Narendra Kumar, Ashish Rajeshwar Kulkarni., ‘‘MPPT Based Grid Connected Photovoltaic System Using Flyback Converter’’ IEEE International Conference for Innovation in Technology (INOCON) Bengaluru, India, Nov 6-8, 2020.

[7] Labsi R., Laiche L., ‘‘Maximum Power Point in Organic Photovoltaic cells by using RTO Optimization Algorithm’’, A thesis submitted for the fulfillment of The degree of Master Memory Project, 2019.

[8] R. Hasan, W. Hassan, W. Xiao, “A High Gain Flyback DC-DC Converter for PV Applications”, IEEE REGION 10 CONFERENCE (TENCON) Osaka, Japan, pp. 522-526, November 16-19, 2020.

[9] A. L. Saleh , A. A. Obed , Z. A. Hassoun , S. J. Yaqoob, “Modeling and Simulation of A Low Cost Perturb & Observe and Incremental Conductance MPPT Techniques In Proteus Software Based on Flyback Converter”,3rd International Conference on Sustainable Engineering Techniques (ICSET), Vol. 881. No. 1,p. 012152, 2020.

[10] R.G. Valverde, S.C. Almagro, M. Corazza, N. Espinosa, M. Hösel, R.R. Søndergaard, M. Jørgensen, J.A Villarejo and F.C. Krebs, ‘‘Portable and Wireless IV-curve Tracer for 45 KV Organic Photovoltaic Modules ’’, Solar Energy Materials & Solar Cells, 151, 60–65, 2016.

[11] F. Tintori, A. Laventure, J.D.B. Koenig, G.C., ‘‘Welch High Open-Circuit Voltage Roll-To-Roll Compatible Processed Organic Photovoltaics’’, J. Mater. Chem. C, 8, 13430-13438, 2020. DOI: 10.1039/d0tc03614e.

[12] B.H.S. Miranda, L de Q. Correa , G.A. Soares , J. L. Martins ,P. L. Lopes , M. L.Vilela , J. F. Rodrigues , T.G. Cunha , R de Q. Vilaça , S.C. Hermosa , L. Wouk, D. Bagnis , “ Efficient fully roll-to-roll coated encapsulated organic solar module for indoor applications ”, International Solar Energy Society, 2021, https://doi.org/10.1016/j.solener.2021.03.025.

[13] M. Ylikunnari ,M. Välimäki, K.-L. Väisänen, T. M. Kraft, R. Sliz, G. Corso, R. Po,R.Barbieri, C. Carbonera, G. Gorni and M. Vilkman ‘‘Flexible OPV modules for highly efficient indoor applications’’, Flex.Print.Electron. 5,014008, 2020,https://doi.org/10.1088/2058-8585/ab6e73

[14] C-Y. Liao, Y-T. Hsiao , K-W. Tsai ,N.-W. Teng , W-L. Li , J-L. Wu, J-C. Kao , C-C. Lee , C-M. Yang, H-S. Tan , K-H. Chung , and Y-M. Chang , “Photoactive Material for Highly Efficient and All Solution Processed Organic Photovoltaic Modules: Study on the Efficiency, Stability, and Synthetic Complexity”Sol. RRL , 5, 2000749, 2021.

[15] D. Zhang, B. Fan , L. Ying , N. Li , C. J. Brabec , F. Huang, Y. Cao, “Recent progress in thick-film organic photovoltaic devices: Materials, devices, and processing”,SusMat., 1:4–23, 2021

[16] Mamizadeh A., Mustafa B. A. , Genc N., “Planar Flyback Transformer Design for PV Powered LED Illumination”, International Journal of Renewable Energy Research., Vol.11, No.1, March, 2021.

[17] D.P. Quesada “Design and Construction of An Isolated Dc-Dc Flyback Converter for Solar MPPT Purposes”, Senior Thesis in Electrical Engineering University of Illinois at Urbana Champaign, pp.1-100, 2018.

[18] V. Mohanapriya, V. Manimegalai, ve J. Manoj, “MPPT Control of Photovoltaic System Using Flyback Converter ” International Journal of Current Trends in Engineering & Research, e-ISSN 2455–1392 Volume 3 Issue 6, pp. 66 – 71, June 2017.

[19] R. Singh, S. Bose ve P. Dwivedi, ‘‘Closed Loop Control of Flyback Converter with PV as a Source’’*IEEE 9th Power India International Conference (PIICON)*, pp. 1-6, February, 2020.

[20] S. Devi , Dr. K. Krishnamoorthib and T. Ilakkiac , ‘‘Design of Enhanced Flyback Converter for PV Application ’’ , Turkish Journal of Computer and Mathematics Education, Vol.12 No.9 ,2864-2868, 2021.

[21] MD. M. Masoom, N. Kumar, A. R. Kulkarni., “MPPT Based Grid Connected Photovoltaic System Using Flyback Converter”, IEEE International Conference for Innovation in Technology (INOCON) Bengaluru, India. Nov 6-8, 2020.

[22] B. Bose, S. Kumar, Ruchira., “Design of Push-Pull Flyback Converter interfaced with Solar PV System”, First International Conference on Power, Control and Computing Technologies (ICPC2T), 2020.

[23] A. L. Saleh , A. A. Obed , Z. A. Hassoun , S. J. Yaqoob “Modeling and Simulation of A Low Cost Perturb & Observe and Incremental Conductance MPPT Techniques In Proteus Software Based on Flyback Converter”, 3rd International Conference on Sustainable Engineering Techniques (ICSET 2020),Vol. 881, No. 1, p. 012152, 2020.

[24] S.A. Hashjin, “Design And Implementation of A Multi Isolated Output Flyback Converter”, M. Sc. Thesis, Gazi University Graduate School of Natural and Applied Sciences, 2017.

[25] M.E. Başoğlu, ‘‘Analyzes of Flyback DC-DC Converter for Submodule Level Maximum Power Point Tracking in Off-grid Photovoltaic Systems’’, Balkan Journal of Electrical & Computer Engineering, Vol. 7, No. 3, July, 2019.

[26] S. J. Yaqoob , A. R. Hussein , A. L. Saleh ,“ Low Cost and Simple P&O-MPP Tracker Using Flyback Converter” , Solid State Technology Volume: 63 Issue: 6, 2020.

[27] N. Mohan, T. M. Undeland, W. P. Robbins,“Power Electronics: Converters, Applications, and Design, 3rd Edition ”, ISBN: 978-0-471-22693-2, 832 Pages, 2002.

[28] Photovoltaic, C.S.T. Modules—Design Qualification and Type Approval; International Electrotechnical

Commission: Geneva, Switzerland, Volume 1215, p. 2005-05, 2005.

[29] T. Wu, et al. "A flexible and wearable energy harvester with an efficient and fast-converging analog MPPT." 2016 IEEE Biomedical Circuits and Systems Conference (BioCAS). IEEE, 2016.

[30] S. Prasad, et al. "Fabrication, device performance, and MPPT for flexible dye-sensitized solar panel based on gel-polymer phthaloylchitosan based electrolyte and nanocluster CoS2 counter electrode." Materials Science for Energy Technologies 2.2 (2019): 319-328.

[31] R. Venkateswari, and S. Sreejith. "Factors influencing the efficiency of photovoltaic system." Renewable and Sustainable Energy Reviews 101 (2019): 376-394.

[32] Lawan, M., Aboushady, A., & Ahmed, K. H. (2020, September). Photovoltaic MPPT techniques comparative review. In 2020 9th International Conference on Renewable Energy Research and Application (ICRERA) (pp. 344-351). IEEE.

[33] Kayisli, Korhan, et al. "A Review of Hybrid Renewable Energy Systems and MPPT Methods." International Journal of Smart Grid-ijSmartGrid 6.3 (2022): 72-82.

[34] Vadi, Seyfettin, et al. "Optimization of pi based buck-boost converter by particle swarm optimization algorithm." 2021 9th International Conference on Smart Grid (icSmartGrid). IEEE, 2021.

[35] Orikawa, Koji, and Jun-ichi Itoh. "Analysis and optimization design of snubber cricuit for isolated DC-DC converters in DC power grid." 2012 International Conference on Renewable Energy Research and Applications (ICRERA). IEEE, 2012.

[36] Jaber, Shahd Fadhil, and Amina Mahmoud Shakir. "Design and simulation of a boost-microinverter for optimized photovoltaic system performance." Int. J. SMART GRID (ijSmartGrid) 5.2 (2021): 94-102.

[37] Guenounou, Ouahib, et al. "Optimization of fuzzy logic controller based maximum power point tracking using hierarchical genetic algorithms." 2021 9th International Conference on Smart Grid (icSmartGrid). IEEE, 2021.