

Maximum Power Point Technique Integrated Impedance Source DC to AC/DC Converter

R. Sivapriyan, D. Elangovan, G. Arunkumar



Abstract: The Impedance Source based DC to AC or DC (Z-source DAD) converter converts the given DC voltage to AC or DC. In a solar photovoltaic (SPV) system, the solar panel output voltage is DC voltage, and this voltage will be converted to AC or DC by Z-source DAD converter. To get maximum output power from the panel, a modified perturb and observe (P&O) maximum power point technique (MPPT) is implemented with a Z-source DAD converter. This single-stage MPPT integrated Z-source DAD converter eliminates the conventional multi-stage SPV system, and also, the output voltage of this SPV system is either AC or DC voltage. The simulations are performed with MATLAB-Simulink software, and the hardware circuit is constructed with a microcontroller-based SPV system. The MATLAB-Simulink simulation and hardware output shows the ability of the modified P&O algorithm based MPPT integrated Z-source DAD converter.

Keywords : P&O algorithm, maximum power point technique, Impedance Source DC to AC/DC converter, solar PV system, Shoot-Through.

I. INTRODUCTION

The solar photovoltaic (SPV) system is becoming increasingly important nowadays because of the reduction in solar panel cost and the large depletion in conventional energy resources. The SPV system is a non-pollutant and renewable energy source; therefore, it is considered more important than other non-renewable sources. Among renewable energy, the solar irradiation is available around the globe for an average of eight hours per day [1]. This makes the solar PV system the favorite among all other non-conventional energy sources. Solar panel output depends on many parameters—temperature, irradiation, age of solar cell, etc. Therefore, the MPPT is used with SPV module [2]. It is integrated in SPV module to get more energy from the panel at any given time. MPP tracking technique increases the SPV system’s operating performance but adds complexity to the operation of the SPV system [3–9]. Normally a DC to DC chopper circuit is utilized for MPPT.

Most of the residential application needs AC voltage to operate; therefore, it is necessary to add an inverter between the chopper circuit and load. This increases the volume as well as the cost. This conventional two-stage SPV system requires separate controllers to track the MPP and match the load voltage. Therefore, it increases the operation difficulty of the overall SPV system. Also, the voltage source inverter (VSI) load voltage will be always less than the given DC input voltage, and the current source inverter (CSI) load voltage will be higher than the input DC voltage. The Z-source inverter (ZSI) output AC voltage will be either more than or less than the given DC input [10]. Also, the ZSI output will always be AC voltage, whereas the Z-source DAD converter load voltage will be either DC AC voltage or DC voltage with increase or decrease in the load voltage [11]. This provides the flexibility to integrate the MPPT directly with this converter. The existing conventional photovoltaic system consists of two stages, as shown in Figures 1 and 2. Here, the first converter will track the solar panel MPP, and the other one will match the load voltage requirement. This increases the system volume, complexity and cost.

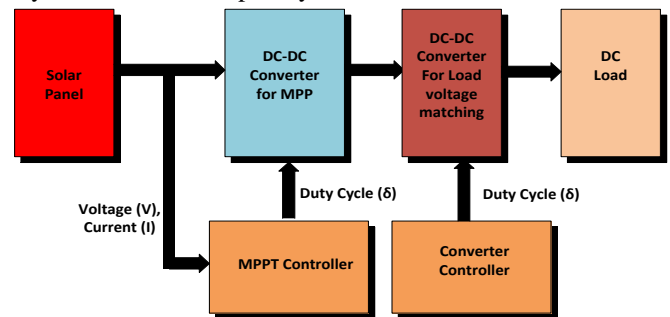


Fig. 1. Solar Photovoltaic System for DC load

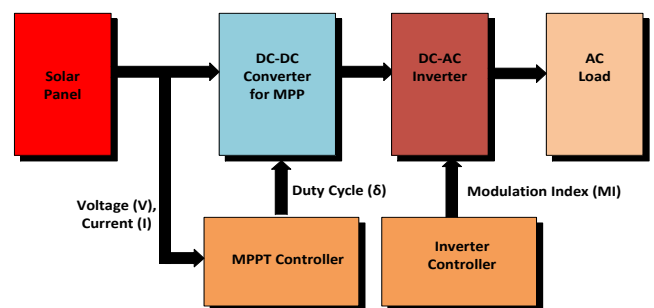


Fig. 2. Solar Photovoltaic System for AC load

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* Correspondence Author

R. Sivapriyan, Associate Professor, Dept of EEE, Sir MVIT, Bangalore, India.

D. Elangovan*, HoD, Dept of Energy and Power Electronics, SELECT, VIT, Vellore, India. Email:elangovan.devaraj@vit.ac.in

G. Arunkumar, Associate Professor, SELECT, VIT, Vellore, India.

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The single stage MPPT-integrated Z-source DAD converter for SPV is shown in Figure 3. It combines MPP tracking with converter or inverter control. Therefore, it reduces the overall system volume, complexity and cost.

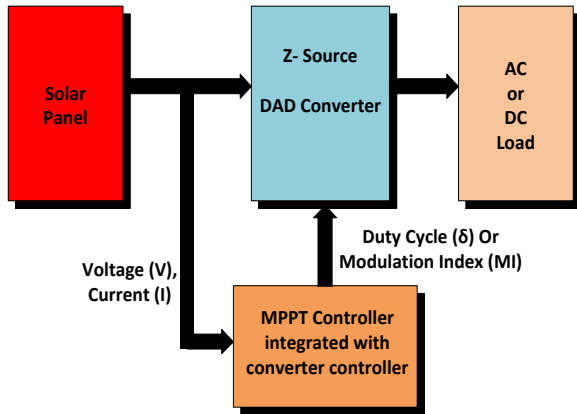


Fig. 3. Z-source DAD converter integrated SPV system for AC or DC load

II. Z-SOURCE DAD CONVERTER

It employs an impedance network inserted in middle of the input and the switching circuit. This network consists of L_1 and L_2 split inductors, and C_1 and C_2 split capacitors arranged in X-shape [12], as shown in Figure 4. This converter eliminates the drawbacks of the normal voltage source and the current source inverters, where the VSI is buck inverter and the CSI is a boost inverter. However, this converter is a buck-boost DC-AC inverter as well as a buck-boost DC-DC converter.

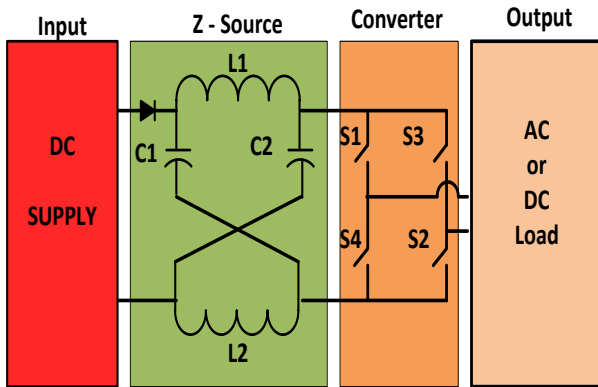


Fig. 4. Impedance source DC to AC or DC converter

This converter operates in three modes, (1) zero state (2) active/normal state (3) shoot-through (ST) state, as shown in Figure 5. In the active state, the input will be connected with the output and load current flows from the input side to output side. In zero state, all the switches are opened; therefore, the load will be disconnected from the input supply and no current will be flowing from input to output. In the ST state, switches present in the same leg will be turned ON, this initiates the short circuit of the Z-source, and now energy transfer occurs between capacitors and inductors [12]. In the normal active state, this voltage will be released across the load; therefore, the load voltage will be boosted to the

required level. The ST state will not be used for the buck mode of operation.

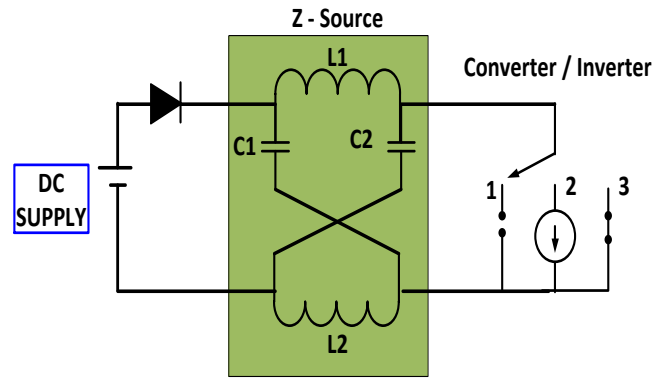


Fig. 5. Different modes of operation

For the chopper operation, the S1 and S2 will be turned ON and the switches S3 and S4 will be kept in the OFF position. Therefore, the load will receive a positive voltage. The output of the buck mode DC-DC converter will be purely based on the ON time of the control circuit of the converter, and in boost mode, DC-DC converter output will depend on the duty cycle and the boost factor. This boost factor will be adjusted by varying the ST duration of the converter circuit.

$$V_o = D \cdot V_{dc} \quad (1)$$

$$V_o = B \cdot \frac{V_{dc}}{2} \quad (2)$$

$$B = \text{Boostfactor} = \frac{T}{T_1 - T_0} \quad (3)$$

where V_o —output DC voltage, D —duty cycle, V_{dc} —DC link voltage, T_1 —active state period, T_0 —ST state period and T —Total duration.

For the DC-AC inverter operation, the S1 and S2 will be turned ON for a positive half cycle, and the S3 and S4 will be turned ON for a negative half cycle. The output of the buck mode DC-AC inverter will be dependent on the modulation index (MI), and the boost mode DC-AC inverter output will depend on the MI as well as the ST timing of the inverter [13,14].

$$V_{ac} = M \cdot \frac{V_{dc}}{2} \quad (4)$$

$$V_{ac} = M \cdot B \cdot \frac{V_{dc}}{2} \quad (5)$$

where V_{ac} —output AC voltage and M —Modulation Index. This ST state can be achieved in two methods in the Z-source DAD converter.

In the first method the two switches of the same leg is gated ON to achieve the ST state, and in the second method all four switches are closed to get the ST state, as shown in Figure 6. This ST state duration decides the boost mode output voltage.

The inductor and capacitor design will be same, like the normal Z-source inverter circuit element design [12].

$$C1 = C2 = C = \frac{I_L D_s T}{2 \Delta V_C} \tag{6}$$

$$V_{C1} = V_{C2} = V_C = V_{in} \frac{(1 - D_s)}{(1 - 2D_s)} \tag{7}$$

$$D_s = \frac{T_0}{T} \tag{8}$$

$$L1 = L2 = L = \frac{V_C D_s T}{2 \Delta I_L} \tag{9}$$

where I_L is the current in inductor, V_C voltage across the capacitor, ΔI_L is the change in the inductor current and ΔV_C —change in voltage across the capacitor.

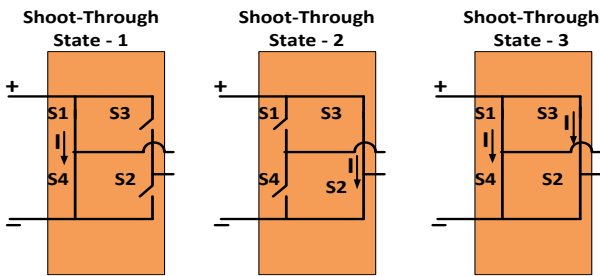


Fig. 6. Shoot Through Zero states

III. MAXIMUM POWER POINT TRACKING

MPPT is adopted to get the maximum power from the solar panel for the given environmental condition. The solar panel output will completely depend on solar irradiance, cell temperature and age of the PV module. There are many studies available that incorporate various MPPT techniques [15–20]. The perturb and observe (P&O) method is taken for its minimum parameter requirement and ease of implementation [16,17]. In this method, voltage will be varied by adjusting the ON time (D) of the converter, and it will be compared with the output power. If the new power is greater than the previous one, the perturbation will be in the same direction. If the new power is weaker than the previous one, the perturbation will be in the opposite direction. At peak power the perturbation will oscillate between the positive and negative direction.

A simple P&O MPPT technique is used in the Z-source DAD converter. Here, we need to specify the type of voltage (AC/DC) and then the algorithm will decide the duty cycle. In the P&O method, the change in voltage (dV) and the change in power (dP) is calculated for every cycle. Then, the dV and dP will be compared with the previous state and the algorithm

will decide the duty cycle. As shown in Figure 7, in the P&O method there are four cases. Case-1, change in power and change in voltage are positive, then the duty cycle will be decreased. Case-2, change in power is positive but change in voltage is negative, then the duty cycle will be increased. Case-3, change in power and change in voltage are negative, then the duty cycle will decrease. Case-4, change in power is negative but change in voltage is positive, then the duty cycle will be increased. The above four cases are implemented in the P&O algorithm, as shown in Figure 8.

This duty cycle (D) is used to decide the ST time and the active state time for the Z-source DAD converter.

$$T_0 = D \tag{10}$$

$$T_1 = 1 - D \tag{11}$$

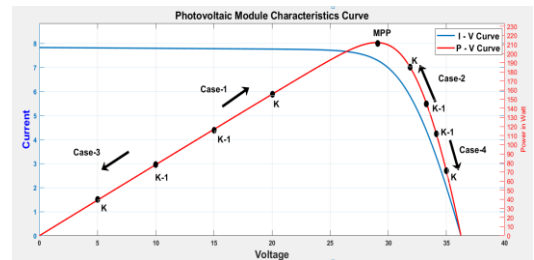


Fig. 7. Maximum Power Point Technique graph

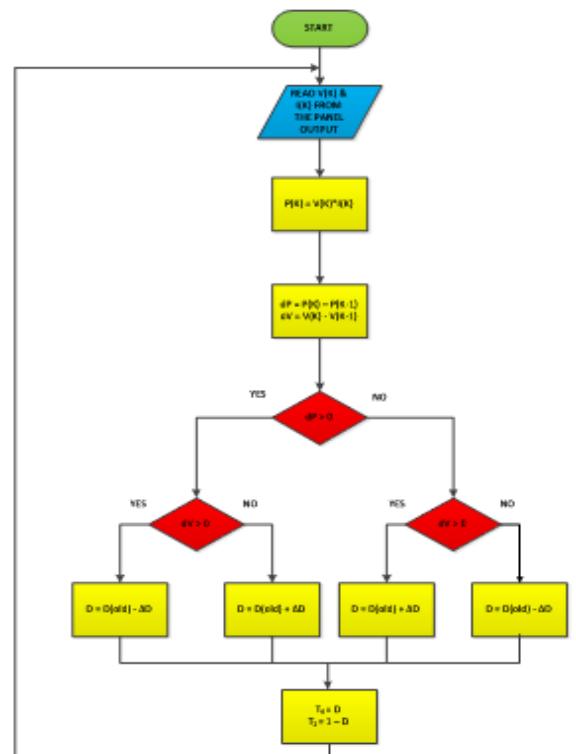


Fig. 8. Modified P&O algorithm for Z-source

Fig. 9. DAD converter

IV. MATLAB-SIMULINK SIMULATION AND HARDWARE IMPLEMENTATION

A 40 W, 12V solar panel is used in the simulation and in the hardware implementation. This panel maximum voltage and current at MPP is 18 V and 2.23 A, respectively. The open circuit voltage and short circuit current is 22 V and 2.42 A. A resistance of 50 Ω is connected in the load circuit, respectively. For the given SPV system, the values of the impedance source elements are $L1 = L2 = 120 \mu\text{H}$ and $C1 = C2 = 100 \mu\text{F}$. The switching frequency is maintained at 50 KHz. The detailed output analysis of the MATLAB-Simulink simulation is showing the ability of the proposed MPPT integrated converter. The simulation result has been verified with hardware circuitry. In the hardware implementation, Arduino microcontroller is used to generate the duty cycle and 4N35M optocouplers is used to give electrical insulation between the microcontroller and the IRFZ44 mosfet.

The MATLAB-Simulink simulation was conducted for both the inverter mode AC output as well as for the converter mode DC output (Figures 9 and 10). The input and output power were compared for various irradiance changes to show the converter ability to track the MPP of the given solar panel.

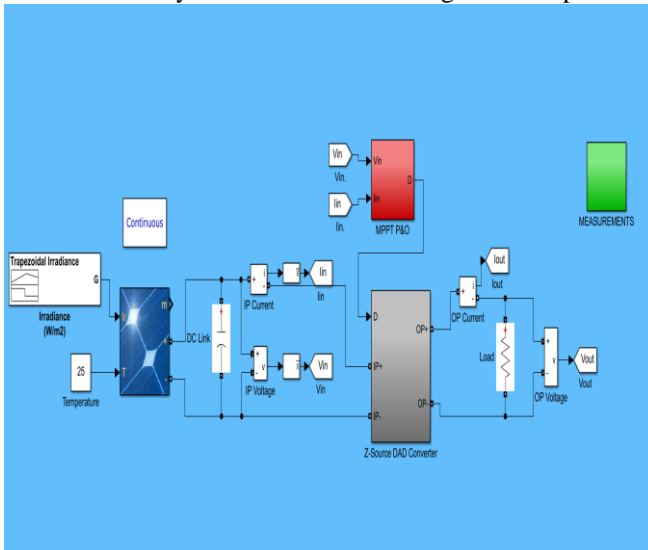


Fig. 10. Z-source DAD converter simulation model

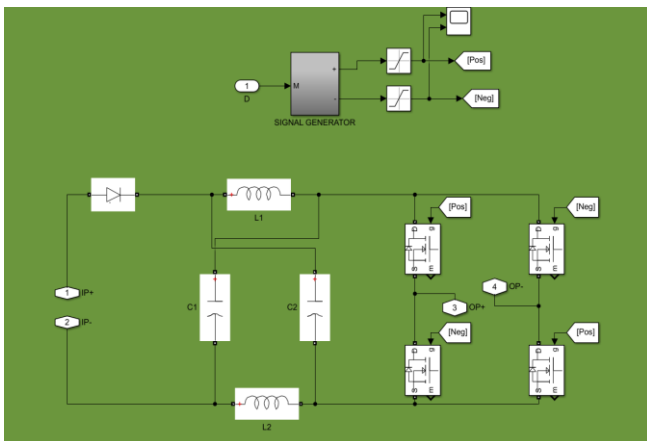


Fig. 11. Simulink internal block of Z-source DAD converter

The change in irradiance during simulation is shown in

Figure 11. The input and output power variation of the photovoltaic module with respect to the change in irradiance is shown in Figure 12. In simulation, the difference between the input and load power is a few milliwatts, which shows the efficiency of the proposed system. The input power and output power oscillations are negligible, as shown in Figure 13. The Root Mean Square (RMS) values of output power, voltage and current is shown in Figure 14. The AC output voltage of the Z-Source DAD converter in the inverter mode is shown in Figure 15.

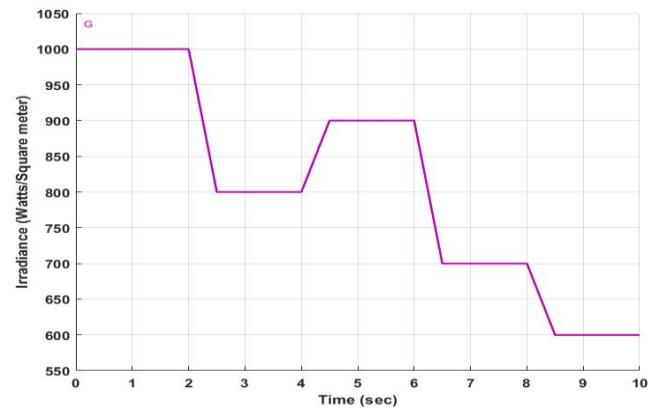


Fig. 12. Simulink simulation of change in irradiance

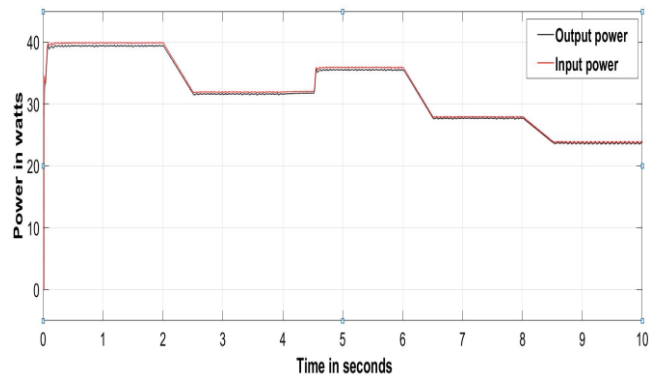


Fig. 13. Simulated output of input and output power for inverter mode

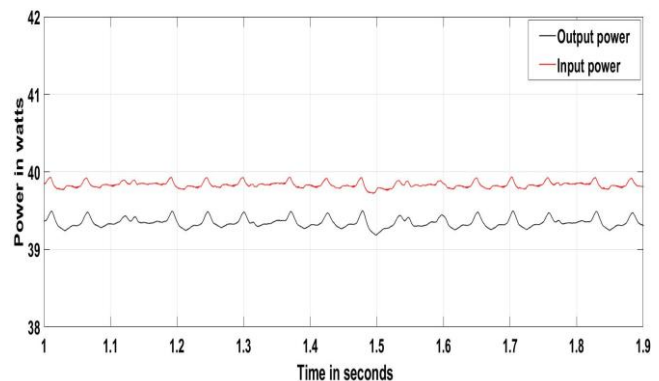


Fig. 14. Power oscillation for inverter mode

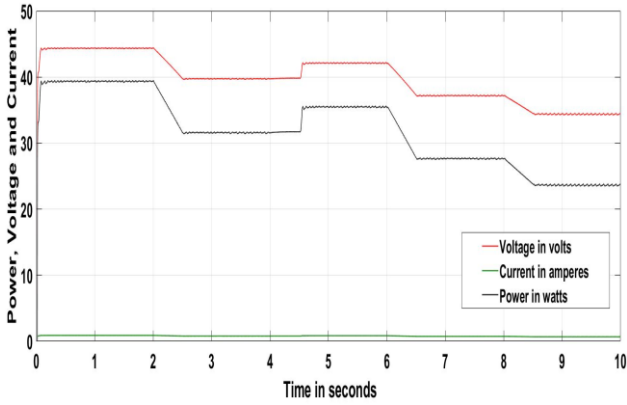


Fig. 15. Simulated output of Voltage, Current and Power in inverter mode

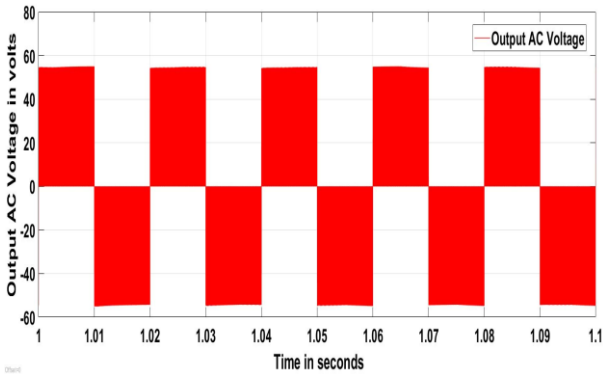


Fig. 16. Simulated inverter mode output voltage

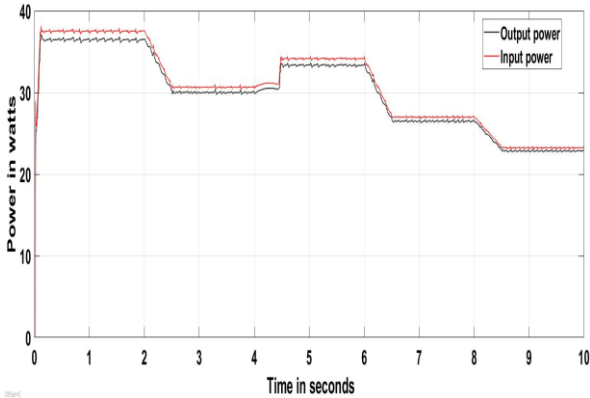


Fig. 17. Simulated output of output and input for converter mode

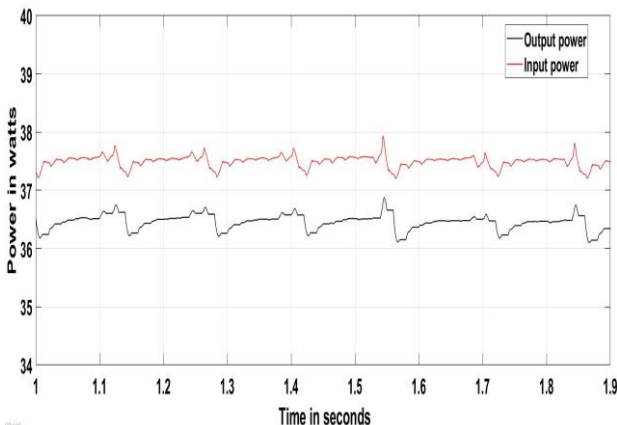


Fig. 18. Simulated output of power oscillation

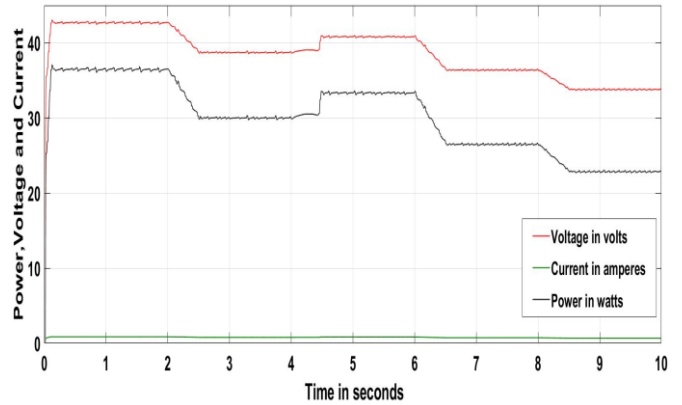


Fig. 19. Simulated output of Voltage, Current and Power in converter mode

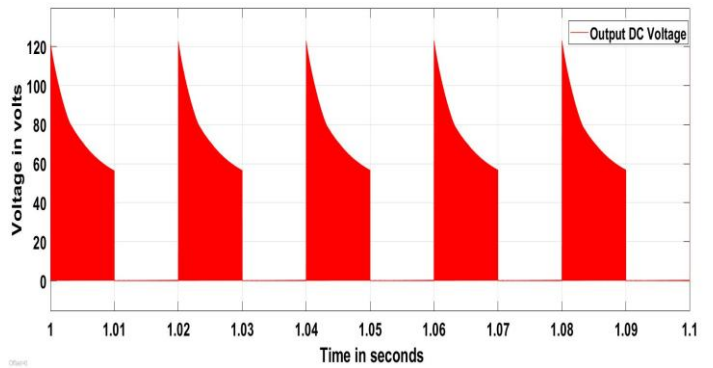


Fig. 20. Simulated converter mode load voltage

The hardware implementation was done for the same simulation parameters. The block diagram and hardware setup are shown in Figure 20.

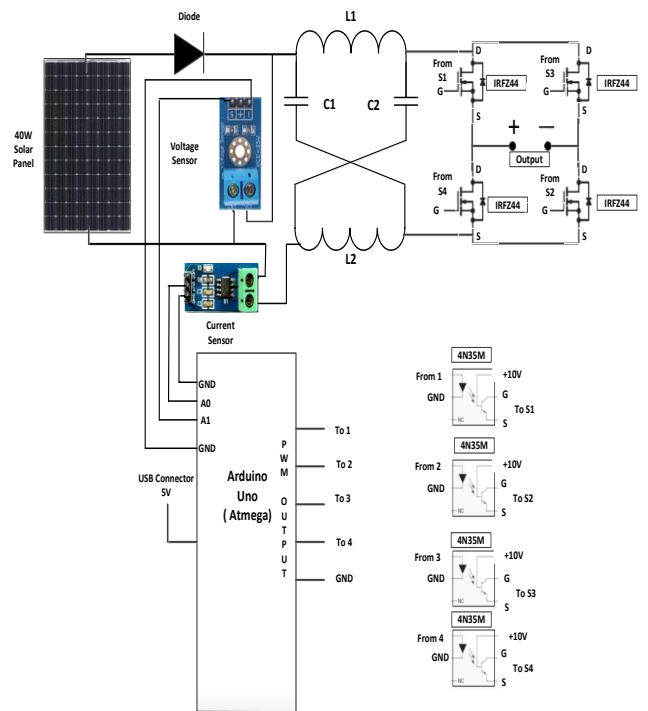


Fig. 21. Hardware Implementation Diagram

The performance of the MPPT integrated Z-Source DAD converter is evaluated with the help of hardware circuitry. The AC as well as DC output power was tracked and plotted in MATLAB, as shown in Figures 21 and 22. The hardware output closely matches the simulated output. This shows the proposed converter ability to track the MPP in both DC-DC converter mode and DC-AC inverter mode.

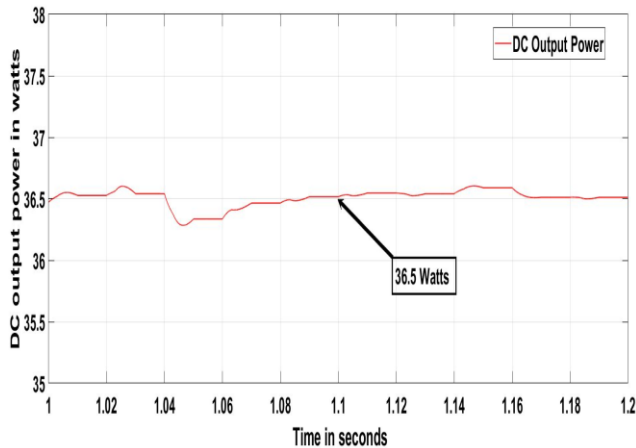


Fig. 22. DC output power

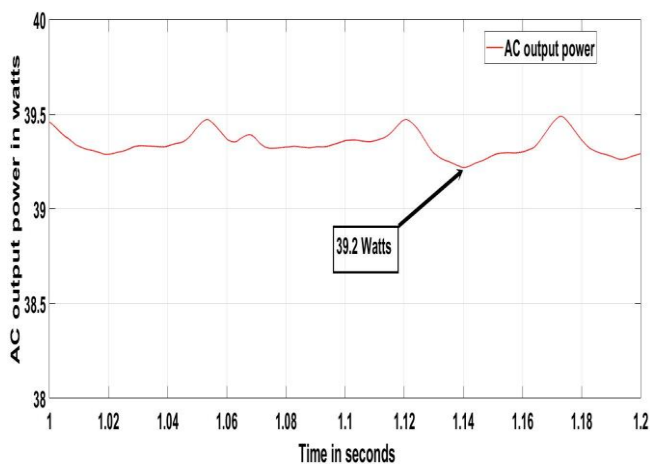


Fig. 23. AC output power

In the DC-DC converter mode the power output will be around 36.5 watts for 1000 W/m² irradiance, which gives approximately 92% efficiency, and in DC-AC inverter mode the power output will be around 39.2 watts for 1000 W/m² irradiance, which gives approximately 98% efficiency.

V. CONCLUSION

The performance of the proposed MPPT integrated Z-source DAD converter was evaluated by MATLAB-Simulink simulation as well as by hardware implementation. Both the simulation and the hardware results show that the MPPT integrated Z-source DAD converter can be used for AC load as well as for the DC load, depending on the need. Also, the MPPT is integrated with the converter circuit; therefore, it reduces the number of power conversion stages compared with the conventional SPV system. As the number of power conversion stages are reduced, the overall dimension and the cost decrease. This type of MPPT integrated power converter is highly suitable for SPV systems. Because it can deliver AC as well as DC, this MPPT

integrated converter can be used to store solar power in the DC battery or we can directly connect with residential appliances which work in AC. Further, this MPPT integrated Z-source DAD converter provides challenges and opportunities for researchers to explore the proper design of Z-source and converter controlling techniques.

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AUTHORS PROFILE



R. Sivapriyan completed his M.Tech in Power Electronics at VIT, Vellore. Presently he is pursuing his Ph.D in VIT, Vellore. He has 15 years teaching experience. His research area is solar photovoltaic systems. He has SCIE and SCOPUS indexed paper in his credit.



Dr. D. Elangovan Associate Professor and HoD of Department of Energy and Power Electronics, VIT, Vellore. He has more than 15 years teaching and research experience. He has published more than 70 research articles indexed by SCIE, SCOPUS. His research area is DC-DC converters and Electric Vehicles.



Dr. G. Arunkumar Associate Professor in Department of Energy and Power Electronics, VIT, Vellore. He has more than 15 years teaching and research experience. He has published more than 50 research articles indexed by SCIE, SCOPUS. His research area is Boost converters and Boost Inverters.