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A New Hybrid Dual Input DC–DC Converter with P&O Algorithm Employing MPPT for Renewable Energy Applications

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ABSTRACT*:* This paper, going to propose a new hybrid dual input DC-DC Converter with P&O algorithm employing MPPT for renewable energy applications. The major disadvantage of conventional single input hybrid DC-DC converters is its inconsistency in nature. Here we are introducing a new DC-DC converter with dual input. The proposed converter is basically a modified version of hybrid Sepic-Cuk converter i.e., a combination of basic Sepic converter and Cuk converter. The new hybrid dual input DC-DC Converter can produce a constant output. Solar photovoltaic panel (SPV) and fuel cell are connected to the two input terminals of the new converter. The outputs of both the converters are integrated to single section. If the availability of the sunlight is decreased due to worst climatic condition or during night time, the fuel cell can compensate the output voltage. The circuit also have an advantage of individual and simultaneous operation. This system finds applications in remote area power generation, constant speed energy conversion systems, variable speed energy conversion systems, rural electrification, water pumping system, etc. MATLAB/SIMULINK R2015a is used for simulation works. The analysis is done based on the simulation results.

KEYWORDS*:* Hybrid DC-DC converter, solar photovoltaic panel, Sepic-Cuk converter, water pumping system.

I.INTRODUCTION

The demand for energy increases day by day. But now, the availability of energy decreases due to the uncontrolled utilisation of conventional energy resources. Fossil fuels are the most prominent conventional energy sources that are used to meet energy demand. Environmental pollution and hence global warming are the major impact made by fossil fuels. Also the limitation of the availability of such sources will raise the importance of renewable energy resources. These resources are environmental friendly and persist abundantly in nature. Solar energy and wind energy are the most important renewable energy resources obtained from nature. The capital cost of systems which uses renewable sources are high but the operating cost is very low. By efficient utilisation of such resources can meet the energy demand. Solar energy is the most efficient and easily available renewable energy resource. One of the major issues with these renewable energy resources are its inconsistent nature, i.e., such systems will generate fluctuating output. Hybridization is the most effective technique to overcome this problem.

Armando Cordeiro, Miguel Chaves, Hiren Canacsinh, Ricardo Luis, Vitor F. Pires, Daniel Foito, A. J. Pires, Joao F. Martins[1] introduced a hybrid Sepic-Cuk DC-DC converter associated to a SRM drive for a solar PV powered water pumping system. The converter proposed in this system is a combination of a Sepic converter and a Cuk converter. Figure: 1 shows the circuit diagram of hybrid Sepic-Cuk DC-DC converter. In mode 1, the switch S is ON. Inductor, L_1 starts charging. The diodes D_1 and D_2 are reverse biased. Capacitors C_1, C_3 and C_4 start discharging the stored energy. Energy stored in the capacitor C_1 discharges through the load. The capacitor C_4 discharges its energy through switch S and then through inductor L_2. Now L_2 starts charging. The inductor L_3 and capacitor C_2 are

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also starts charging by the discharging of the capacitor C_3. In mode 2, the switch S is in OFF position. The diodes D_1 and D_2 are forward biased and starts conducting. Inductor L_1 starts to discharge the energy stored in it. By this energy, the capacitors C_1, C_3 and C_4 become charging condition. The inductors L_2 and L_3 are starts to discharge its energy. The capacitor C_2 is also in discharging mode.

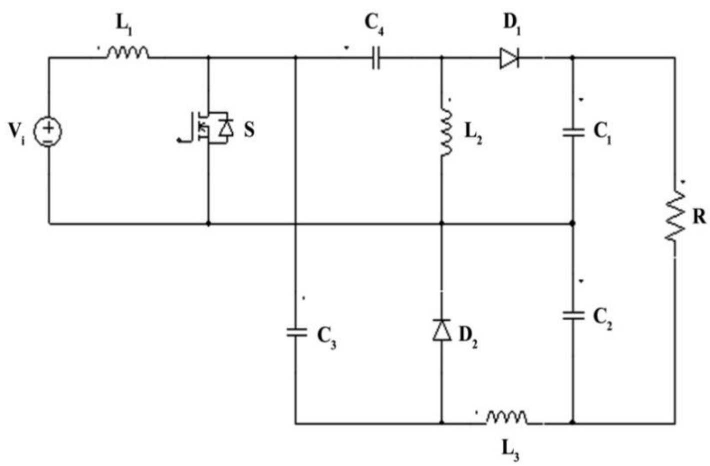

Figure. 1: Hybrid Sepic-Cuk DC-DC converter

The major disadvantage of the above system is the incapability of maintaining a constant output due to the unavailability of solar radiations during night time and due to worst climatic conditions. To overcome this drawback, a solar array - fuel cell hybrid DC-DC converter is presented.

II.PROPOSED CONVERTER

Similar to the hybrid Sepic-Cuk DC-DC converter, the dual input DC-DC converter is also a combination of Sepic converter and Cuk converter. By combining these two converters can be eliminate separate input filters. The proposed converter consists of two input ports and the output sections of both converters are merged to single section to develop the converter topology. Solar radiation and energy stored in a fuel cell are the two inputs of the converter. Solar photovoltaic arrays (SPV) are used to extract energy from solar radiations. Maximum power point tracking (MPPT) is employed to ensure that maximum power should be transferred from source to load. For the proposed converter, perturb and observe (P&O) algorithm is used. For a fuel cell chemical energy stored is converted to electrical energy and that is used as the secondary input of the converter.

The proposed converter is capable of simultaneous or individual operation. Large amount of solar radiations are obtained during sunny days. During these days, the output from the solar photovoltaic array is sufficient to make required output. Individual operation of the converter is enough at this condition. But during rainy days or during night time solar radiations are not sufficient to meet the demand. At this time the fuel cell will act and thereby compensate the output voltage. The fuel cells can supply energy as long as the fuel and oxygen is present. Hydrogen is commonly used in fuel cells to generate chemical energy. Simultaneous operation of the converter is carried out for this situation. Constant output voltage will maintain by using this conditions. The circuit diagram of a new hybrid dual input DC-DC converter is shown in figure 2. V_1 is taken as the solar array voltage and V_2 as the fuel cell voltage. M_1 and M_2 are the switches in the Cuk section and Sepic section of the circuit respectively. L_1 and C_1 are the input inductor and coupling capacitor of the Cuk converter section. Similarly, L_3 and C_3 are the input inductor and coupling capacitor of the Sepic converter section. Diodes D_1 and D_2 of the converters are reconfigured in this circuit. L_2 and C_2 are the output inductor and output capacitor of the converter. R is the load resistor. A constant voltage is obtained across the load resistor.

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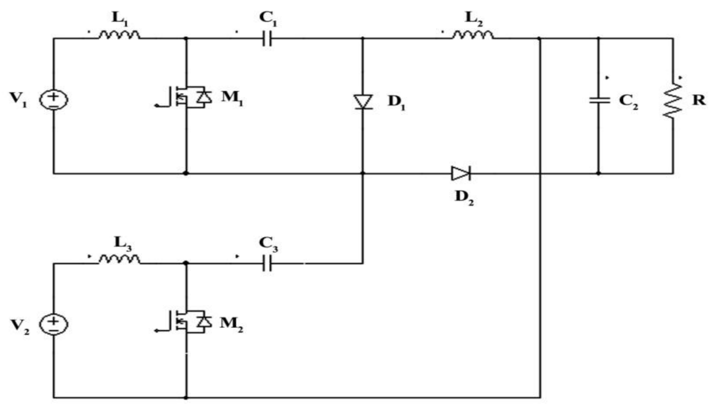
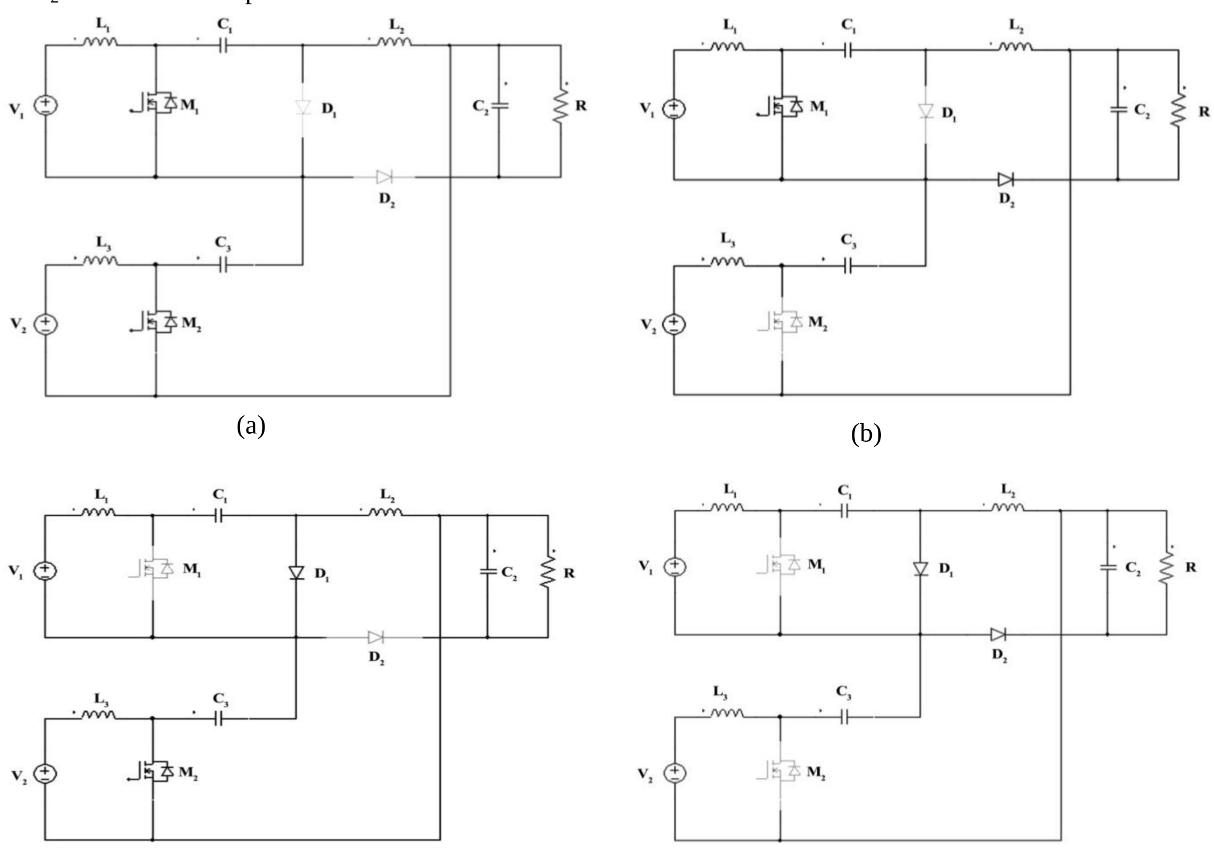


Figure. 2: Circuit diagram of a new hybrid dual input DC-DC converter

III.MODES OF OPERATION

The operation of the proposed converter can be operating in four modes. Depending on the state of the switches M_1 and M_2 the modes are explained as below.



(a) (b) (c) (d)

Figure. 3: Equivalent circuit of the proposed converter (a) Mode 1 (b) Mode 2 (c) Mode 3 (d) Mode 4

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Mode 1: In this mode, the switches M_1 and M_2 are in ON state. By using energy from the sources the inductors L_1 and L_3 becomes charged. The two diodes D_1 and D_2 are not conducting i.e., both diodes are in reverse biased condition. There are three capacitors namely C_1, C_2 and C_3 all are in its discharging state. The energy released during the discharging of load capacitor C_3 will be transferred to the load also the inductor L_2 becomes charged. The equivalent circuit of the proposed converter during mode 1 is shown in figure 3(a).

Mode 2: In mode 2, the switch M_1 is ON and the switch M_2 is in OFF position. The inductor L_1 continues its state of charging during this mode. But now the inductors L_2 and L_3 release the stored energy in it. Diode D_2 becomes forward biased and starts to conduct by the inductor current i_{L3}. Diode D_1 remains in the state of reverse biasing. The inductor current i_{L3} also flows through the load section of the proposed converter. At this time the capacitors C_3 and C_2 becomes charged. Mode 2 equivalent circuit is shown in figure 3 (b).

Mode 3: The switch M_1 is in OFF state. The inductor L_1 starts discharging and the inductor current i_{L1} makes the diode D_1 forward biased and also the capacitor C_1 becomes charged. At the same time the switch M_2 is in ON state and the inductor L_3 becomes charged. Diode D_2 is reverse biased and it will not conduct. As in mode 1, the energy released during the discharging of load capacitor C_3 will be transferred to the load and also the inductor L_2 becomes charged. Figure 3 (c) shows the equivalent circuit of the converter during mode 3.

Mode 4: M_1 and M_2 are OFF in this mode. Inductors L_1 and L_3 start to release the stored energy. The diode D_1 and D_2 becomes forward biased by the flow of inductor currents i_{L1} and i_{L3}. The output section of the proposed converter is also powered by the inductor current i_{L3}. Capacitors C_1 and C_3 becomes charged. Also the inductor L_2 releases its energy through diode D_1, D_2, output capacitor C_2 and the load. The equivalent circuit is shown in figure 3 (d).

IV.DESIGN CONSIDERATIONS

The input voltage to the Cuk converter i.e., PV array voltage V_1 is taken as 120V. The fuel cell voltage used for the proposed converter is 130V. The switching frequencies of both MOSFETs are of 20KHz. D_1 and D_2 are the duty ratio of switches M_1 and M_2 respectively. Here L_1 is the input inductor and C_1 is the coupling capacitor of Cuk converter section; L_3 is the input inductor and C_3 is the coupling capacitor of Sepic converter section; L_2 is the output inductor; C_2 is the output capacitor; R is the load resistor. Output voltage, Vout obtained from the converter is 250V and the output power required (Pout) is 650W.

Duty ratio: The duty ratio of the two switches M_1 and M_2 is,

$$D = \frac{V_{out}}{2V_{in}+V_{out}} \quad (1)$$

$$D_1 = \frac{V_{out}}{2V_1+V_{out}} \quad (2)$$

$$D_2 = \frac{V_{out}}{2V_2+V_{out}} \quad (3)$$

The value of D1 is set at 0.51 and D2 is set at 0.49.

Load resistor: The value of the load resistor can be calculated by using the equation

$$R = \frac{V_{out}^2}{P_{out}} \quad (4)$$

The resistance of the load resistor R is 96.15Ω.

Inductor Selection:

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$$L_1 = V_1 * \left(\frac{D_1}{\Delta I_{L1} * F_{sw}}\right) \tag{5}$$

$$L_2 = (1 - D_1) * \left(\frac{R}{2 * F_{sw}}\right) \tag{6}$$

$$L_3 = V_2 * \left(\frac{D_2}{\Delta I_{L3} * F_{sw}}\right) \tag{7}$$

Where, ΔI_{L1} is 30% of input current of Sepic converter section.

$$I_1 = I_{L1} = \frac{P_{in}}{V_1} \tag{8}$$

Where, ΔI_{L3} is 30% of input current of Cuk converter section.

$$I_2 = I_{L3} = \frac{P_{in}}{V_2} \tag{9}$$

By substituting these values in (5), (6) & (7); the values of inductors L_1, L_2 and L_3 are 1.69 mH, 1.185 mH and 1.91 mH respectively.

Capacitor Selection:

$$C_1 = \frac{D_1}{R * F_{sw}\left(\frac{\Delta V_{c1}}{V_{out}}\right)} \tag{10}$$

$$C_2 = \frac{(1 - D_2)}{8 * L_2 * F_{sw}^2\left(\frac{\Delta V_{c2}}{V_{out}}\right)} \tag{11}$$

$$C_3 = \frac{D_2}{R * F_{sw}\left(\frac{\Delta V_{c3}}{V_{out}}\right)} \tag{12}$$

Where, ΔV_{C1} is 1% of voltage across the coupling capacitor of Cuk converter section.

$$V_{C1} = \frac{V_1}{(1 - D_1)} \tag{13}$$

Where, ΔV_{C2} is 1% of voltage across the output capacitor.

$$V_{C2} = \frac{V_2}{(1 - D_2)} - V_0 \tag{14}$$

Where, ΔV_{C3} is 1% of voltage across the coupling capacitor of Sepic converter section.

$$V_{C3} = \frac{V_2}{(1 - D_2)} \tag{15}$$

By substituting these values in (10), (11) & (12); the values of capacitors C_1, C_2 and C_3 are 0.268µF, 0.068µF and 0.248 µF respectively.

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V.SIMULATION RESULTS

The simulation parameters of the proposed converter are given in Table 1. The input voltages V_1 of 120V and V_2 of 130V give an output voltage V_{out} of 250V for a total output power P_{out} of 650W.

TABLE 1: SIMULATION PARAMETERS

Parameter	**Value**
PV Array Voltage, V_1	120V
Fuel cell Voltage, V_2	130 V
Output Voltage, V_{out}	250V
Switching Frequency, F_{SW}	20 kHz
Output Power, P_{out}	650W
Resistor, R	96.15Ω
Inductor, L1	1.69mH
Inductor, L2	1.185mH
Inductor, L3	1.91mH
Capacitor, C1	0.268µF
Capacitor, C2	0.068µF
Capacitor, C3	0.248µF

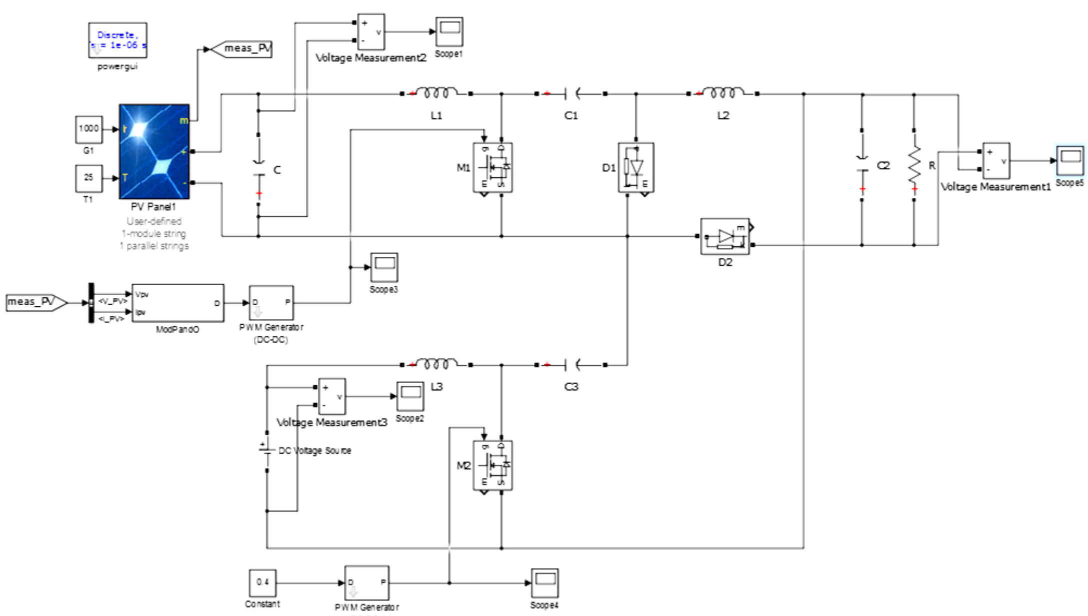

Figure. 4: Simulink model of the proposed converter

The simulink model of the proposed converter is given in figure 4. Simulation results obtained are explained in three sections; simultaneous operation; operation with solar array input only; operation with fuel cell only; as given

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below.

Simultaneous operation: During simultaneous operation of the proposed converter, the power from both inputs is summed up to deliver power to the load. Input terminal 1 and input terminal 2 are connected to 120V DC and 130V DC respectively during simultaneous operation. The PV array voltage V_1 and fuel cell voltage V_2 are shown in figure 5(a) and figure 5(b). By applying these two input voltages simultaneously, the proposed converter will gives an output of voltage 360V and is shown in figure 5(c). Figure 5(d) shows the gate pulses for the MOSFET M_1 and figure 5(e) shows the gate pulses for the MOSFET M_2. The switching frequencies of both the switches are same with 20 KHz. For the simultaneous operation of the proposed converter, pulses have to be given to both switches M_1 and M_2.

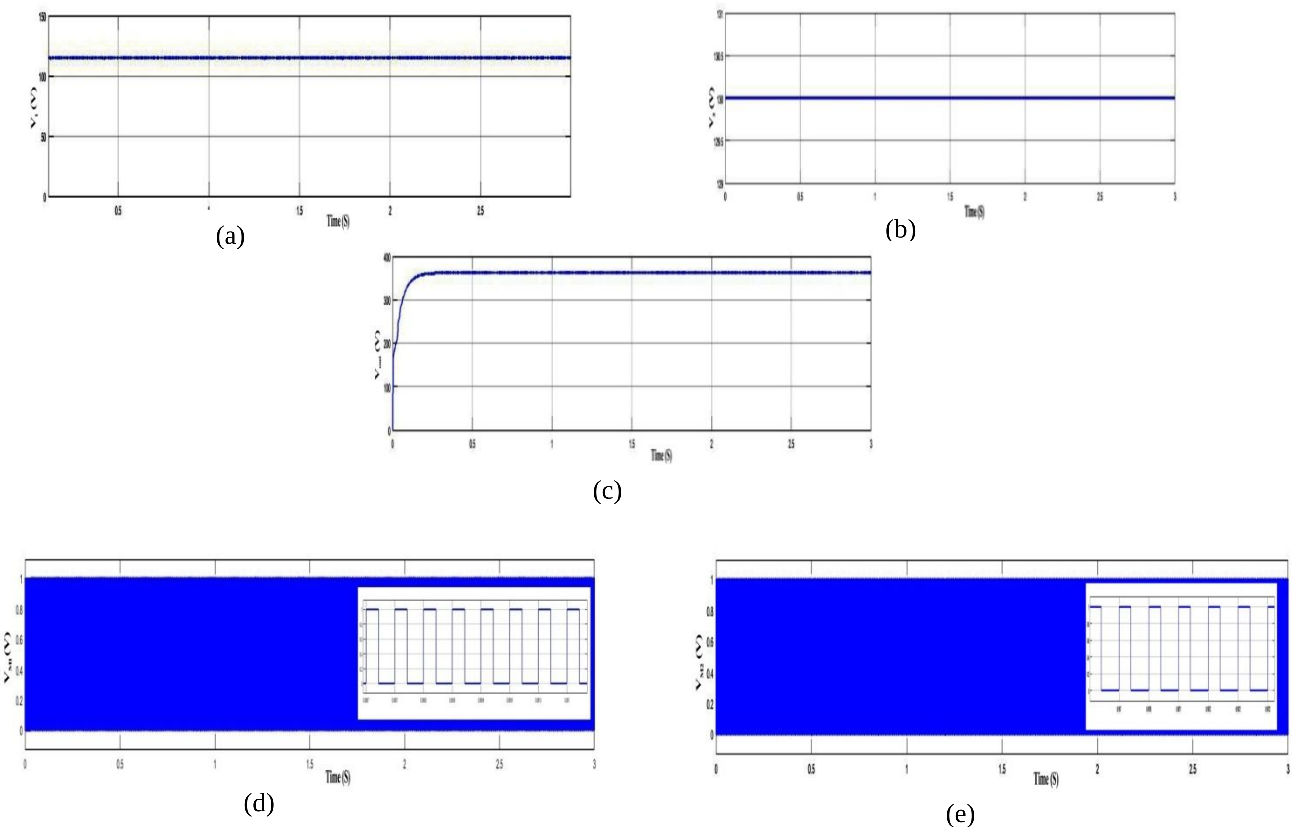

Figure. 5: (a) PV array voltage V_1 (b) Fuel cell voltage V_2 (c) Output Voltage (d) Gate pulses for M_1
(e) Gate pulses for M_2

Operation with solar array input only: During individual operation, one of the input sources to the converter is unavailable and it has to continue its operation with the remaining input source. In this case, there is only solar array input is present. Now the fuel cell voltage V_2 is 0V. Figure 6(a) shows the PV array voltage V_1 and figure 6(b) shows the gating pulses applied to the switch M_1. The output voltage of the proposed converter with solar array input only is shown in figure 6(c).

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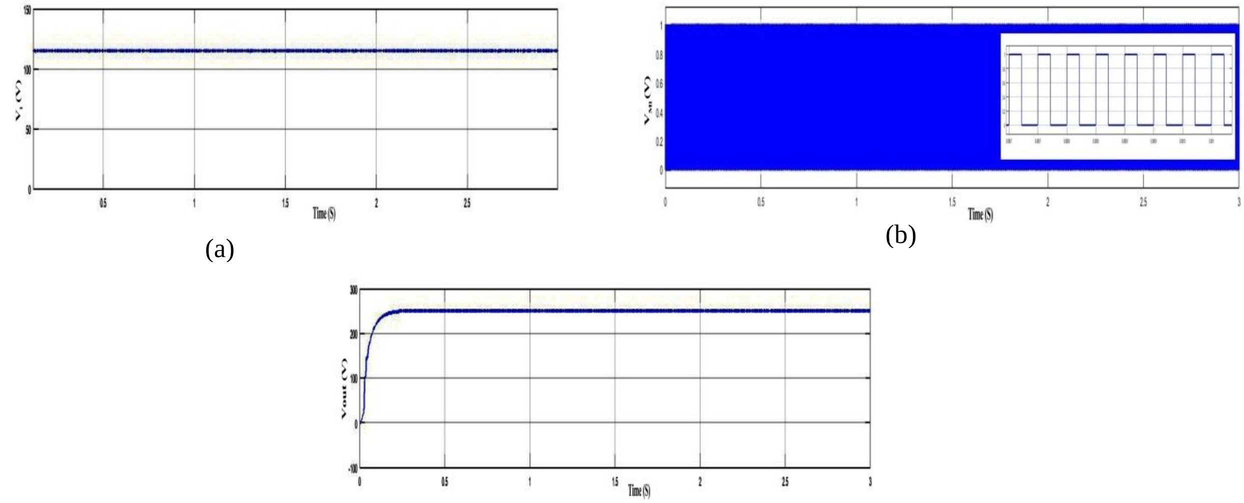
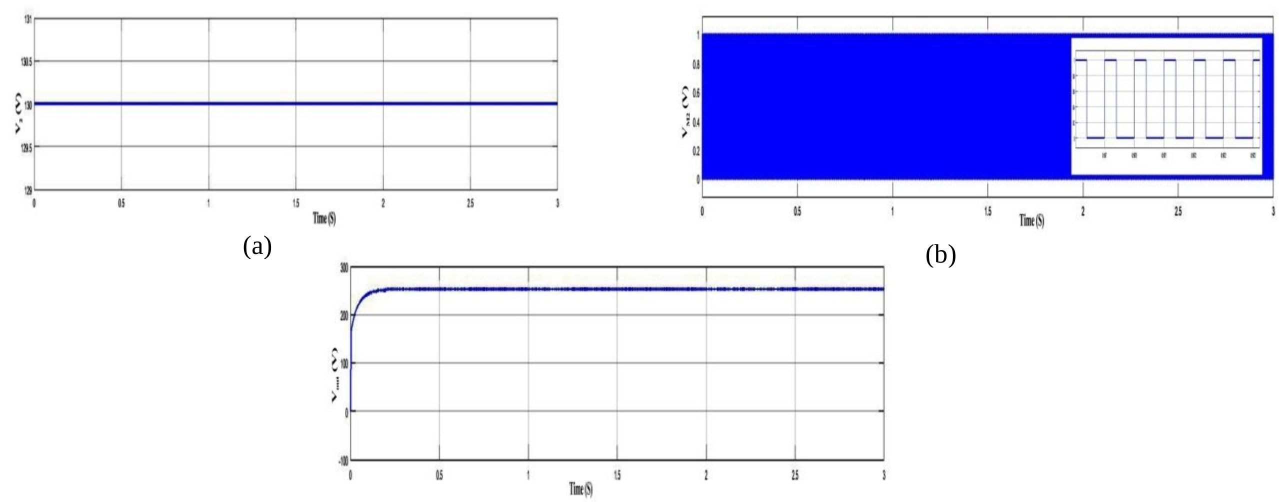


(a) (b) (c)

Figure. 6: (a) PV array voltage V_1 (b) Gate pulses for M_1 (c) Output Voltage

Operation with fuel cell input only: In this case, there is only fuel cell input is present. Now the PV array voltage V_1 is 0V. Figure 7(a) shows the fuel cell voltage V_2 and figure 7(b) shows the gating pulses applied to the switch M_2. The output voltage of the proposed converter with solar array input only is shown in figure 7(c).



(a) (b) (c)

Figure. 7: (a) Fuel cell voltage V_2 (b) Gate pulses for M_2 (c) Output voltage

If the availability of the sunlight is decreased due to worst climatic conditions or during night time, the fuel cell can compensate the output voltage. To explain the proposed converter topology considering that, in the presence of better solar radiation the irradiance is about 1000W/m^2. For example, if the irradiance is low about 500W/m^2 the output of the proposed converter without fuel cell is also low with a value 200V as shown in figure 8(a). But proposed converter is capable of producing the output voltage of 250V with the presence of fuel cell. Figure 8(b) shows the output voltage of proposed converter with fuel cell during low solar radiation.

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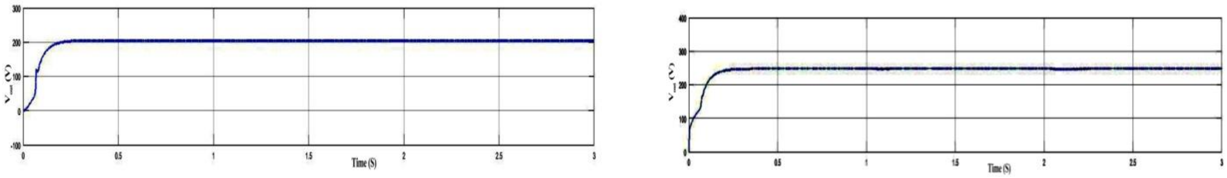
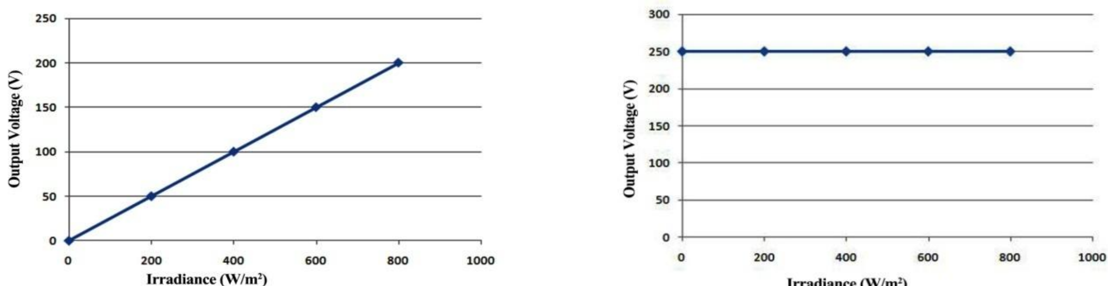


(a) (b)

Figure. 8: (a) Output voltage of the proposed converter without fuel cell at irradiance 500W/m^2 (b) Output voltage of the proposed converter with fuel cell at irradiance 500W/m^2

VI.ANALYSIS

The analysis of a new hybrid dual input DC–DC converter is carried out by considering the parameters output voltage and irradiance. Typical curves for the variation of output voltage as a function of irradiance with fuel cell and without fuel cell are shown in figure 9(a) and figure 9(b). From these figures we can say that the output voltage of the proposed converter is maintained at 250V even when solar irradiance is low due to worst climatic condition or during night time.



(a) (b)

Figure. 9: (a) Output voltage Vs Irradiance (Without fuel cell) (b) Output voltage Vs Irradiance (With fuel cell)

VII.CONCLUSION

This paper proposes a new hybrid dual input DC-DC Converter with P&O algorithm employing MPPT for renewable energy applications. The proposed converter is a combination of Sepic converter and Cuk converter. By combining these two converters can be eliminate separate input filters. If the availability of the sunlight is decreased due to worst climatic condition or during night time, the fuel cell can compensate the output voltage. So a constant output voltage is always maintained to meet the energy demand. The circuit also have an advantage of individual and simultaneous operation. By using a renewable energy as the main input the operating cost can be minimized. This system finds applications in remote area power generation, constant speed energy conversion systems, variable speed energy conversion systems, rural electrification, water pumping system, etc…

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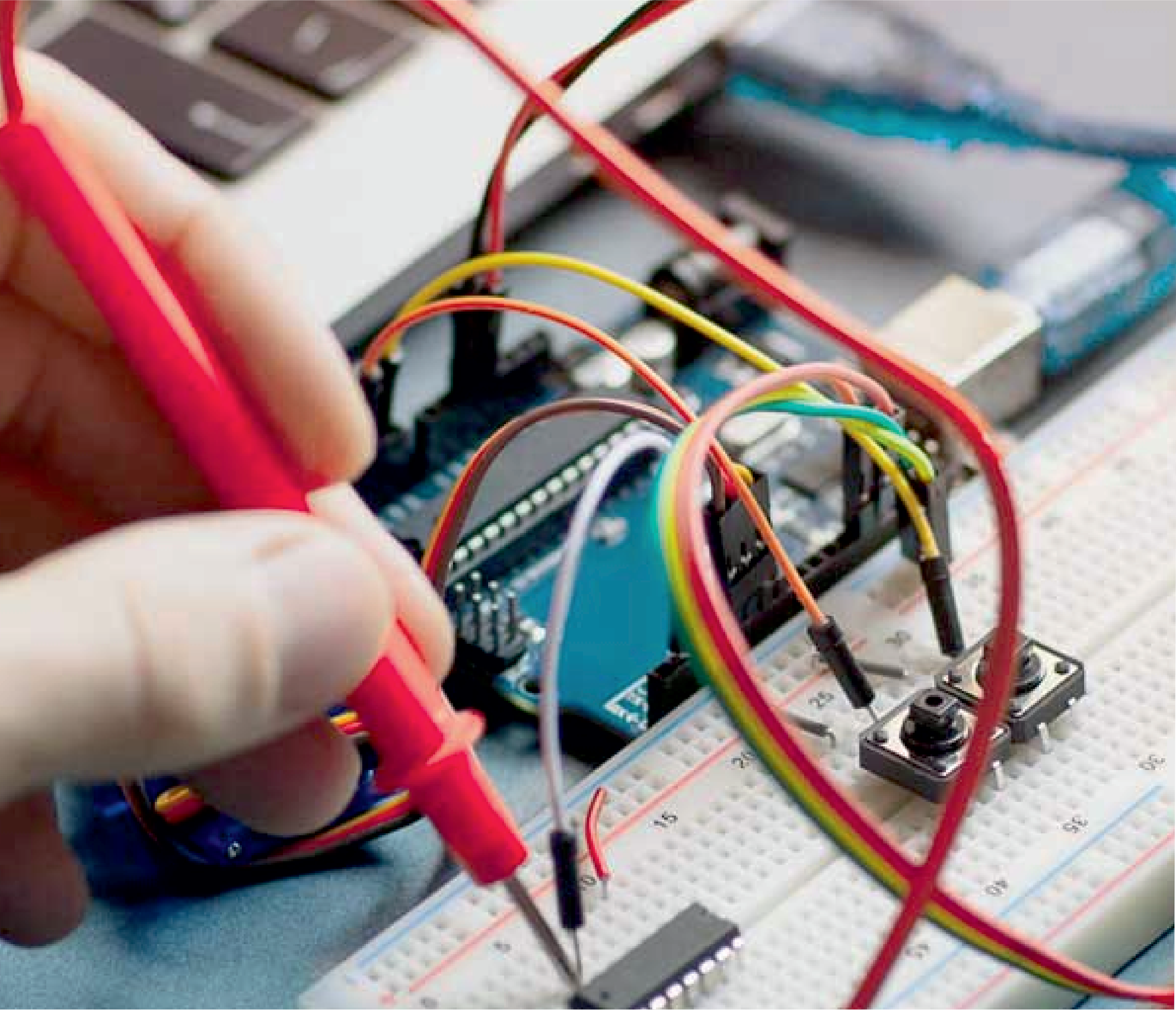

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