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# A Hybrid Wind-Solar Energy System Using Cuk-Sepic Fused Converter

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**Abstract**
In recent years, environmental friendly technological solutions are becoming more prominent as a result of concern over the state of our deteriorating planet. This paper presents a new system configuration of the front-end rectifier stage for a hybrid wind-photovoltaic energy system. This configuration allows the two sources to supply the load separately or simultaneously together depending on the availability of the energy sources. The main purpose of this hybrid wind-solar energy system is to meet our daily demand effectively and to get an uninterrupted power supply from any one of the natural source either wind or solar or both .This is off line grid method to supply the street light etc. Hybrid energy system needs the boost converter to be designed to connect with wind and solar energy systems separately. The hybrid model is also designed using Cuk-SEPIC fused converter and the performances are analyzed. Due to the inherent nature of this Cuk-SEPIC fused converter, additional filters are not necessary to filter out high frequency harmonics. Harmonic content is detrimental for the generator lifespan and efficiency. Simulation results are given to highlight the merits of the proposed circuit.
**Keywords**—Wind model, Photovoltaic model, Inverter, Boost Converter, Cuk-Sepic fused Converter, Hybrid Control system, Simulation.

## I. INTRODUCTION

With increasing concern of global warming and the depletion of fossil fuel reserves, many are looking at sustainable energy solutions to preserve the earth for the future generations. Other than hydro power, wind and photovoltaic energy holds the most potential to meet our energy demands. Wind energy is capable of supplying large amounts of power but its presence is highly unpredictable. Similarly, solar energy is present throughout the day but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc. The common inherent drawback of wind and photovoltaic systems are their intermittent natures that make them unreliable. However, by combining these two intermittent sources the system‟s power transfer efficiency and reliability can be improved significantly.

When a source is unavailable or insufficient in meeting the load demands, the other energy source can compensate for the difference. Several hybrid wind-PV power systems with MPPT control have been proposed and discussed in works [1]-[5]. Most of the systems in literature use a separate DC-DC boost converter connected in parallel in the rectifier stage as shown in Figure 1 to perform the MPPT control for each of the renewable energy power sources [1]-[4]. A simpler multi input structure has been suggested by [5] that combines the sources from the DC-end while still achieving MPPT for each renewable source. The structure proposed by [5] is a fusion of the buck and buck-boost converter. The systems in literature require passive input filters to remove the high frequency current harmonics injected into wind turbine generators [6]. The harmonic content in the generator current decreases its lifespan and increases the power loss due to heating [6].

In this paper, an alternative multi-input rectifier structure is proposed for hybrid wind-solar energy systems. The proposed design is a fusion of the Cuk and SEPIC converters. The features of the proposed topology are:

1) The inherent nature of these two converters eliminates the need for separate filters [7]-[8];
2) It can support step up/down operations for each renewable source (can support wide ranges of PV and wind input);
3) MPPT can be realized for each source;
4) Individual and simultaneous operation is supported.

The circuit operating principle of the boost converter and Cuk-Sepic converter will be discussed in this paper. Simulation results are provided to verify with the feasibility of the proposed system.

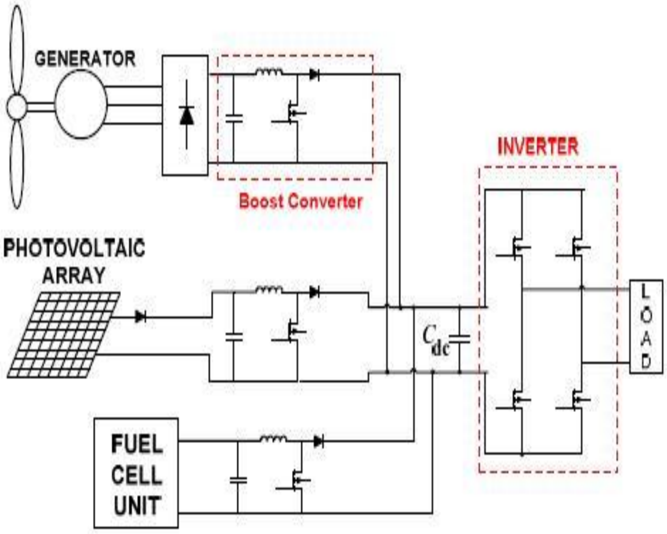



**Figure 1: Hybrid system with multi-connected boost converter**

## II. PROPOSED MULTI-INPUT RECTIFIER STAGE

A proposed hybrid wind-solar energy system is shown in Figure 2, where one of the inputs is connected to the output of the PV array and the other input connected to the output of a generator. The fusion of the two converters is achieved by reconfiguring the two existing diode from each converter and the shared utilization of the Cuk output inductor by the SEPIC converter.

This configuration allows each converter to operate normally individually in the event that one source is unavailable. Figure 3 illustrates the case when only the wind source is available. In this case, D1 turns off and D2 turns on; the proposed circuit becomes a SEPIC converter and the input to output voltage relationship is given by (1). On the other hand, if only the PV source is available, then *D*2 turns off and *D*1 will always be on and the circuit becomes a Cuk converter as shown in Figure 4. The input to output voltage relationship is given by (2). In both cases, both converters have step-up/down capability, which provide more design flexibility in the system if duty ratio control is utilized to improve reliability.

$$\frac{V_{dc}}{V_W} = \frac{d_2}{1-d_2} \qquad (1)$$

$$\frac{V_{dc}}{V_{PV}} = \frac{d_1}{1-d_1} \qquad (2)$$

The various switching states of the proposed converter are shown in fig 5. If the turn on duration of *M*1 is longer than *M*2, then the switching states will be state I, II, IV. Similarly, the switching states will be state I, III, IV if the switch conduction periods are vice versa. To provide a better explanation, the inductor current waveforms of each switching state are assuming that $d2 > d1$; hence only states I, III, IV are discussed in this example. In the following, *Ii,PV* is the average input current from the PV source; *Ii,W* is the RMS input current after the rectifier (wind case) and *Idc* is the average system output current..

*State I (M1 on, M2 on):*

$$i_{L1} = I_{i,PV} + \frac{V_{PV}}{L_1}t \quad 0<t<d_1T_s \qquad (3)$$

$$i_{L2} = I_{dc} + \left(\frac{v_{c1}+v_{c2}}{L_2}\right)t \quad 0<t<d_1T_s \qquad (4)$$

$$i_{L3} = I_{i,W} + \frac{V_W}{L_3}t \quad 0<t<d_1T_s \qquad (5)$$

*State III (M1 off, M2 on):*

$$i_{L1} = I_{i,PV} + \left(\frac{V_{PV}-v_{c1}}{L_1}\right)t \quad d_1T_s<t<d_2T_s \qquad (6)$$

$$i_{L2} = I_{dc} + \frac{v_{c2}}{L_2}t \quad d_1T_s<t<d_2T_s \qquad (7)$$

$$i_{L3} = I_{i,W} + \frac{V_W}{L_3}t \quad d_1T_s<t<d_2T_s \qquad (8)$$

*State IV (M1 off, M2 off):*

$$i_{L1} = I_{i,PV} + \left(\frac{V_{PV}-v_{c1}}{L_1}\right)t \quad d_2T_s<t<T_s \qquad (9)$$

$$i_{L2} = I_{dc} - \frac{V_{dc}}{L_2}t \quad d_2T_s<t<T_s \qquad (10)$$

$$i_{L3} = I_{i,W} + \left(\frac{V_W-v_{c2}-V_{dc}}{L_3}\right)t \quad d_2T_s<t<T_s \qquad (11)$$

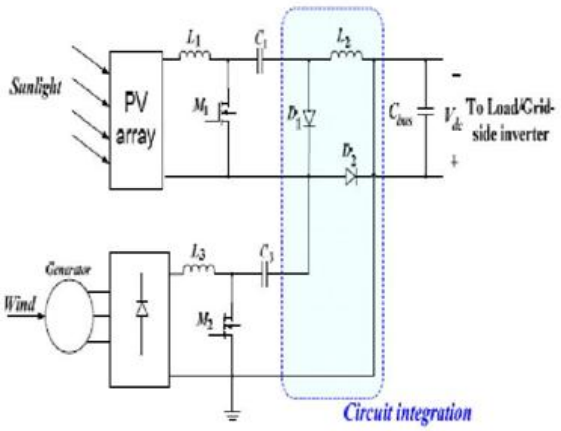



Figure 2: Proposed rectifier stage for a Hybrid wind/PV system

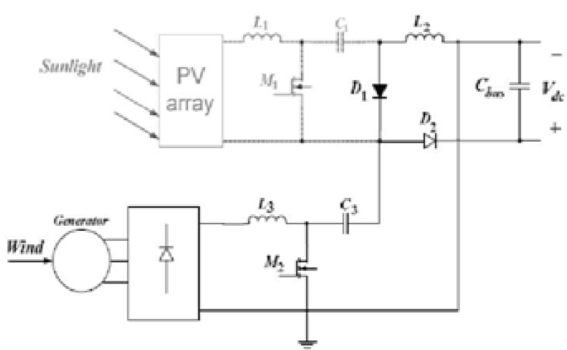



Figure 3: Only wind source is operational (SEPIC)

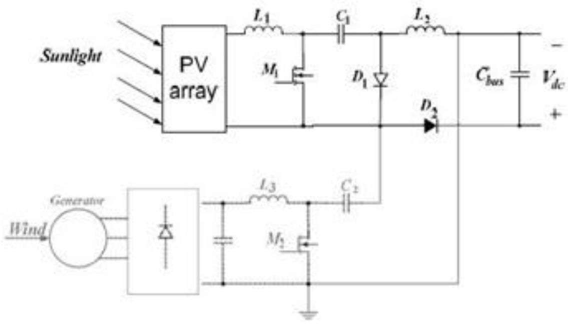



Figure 4: Only PV source is operation (Cuk)

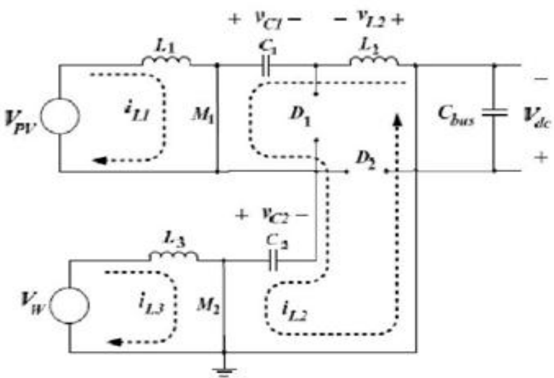


Figure 5 (I): *M1 & M2 on*

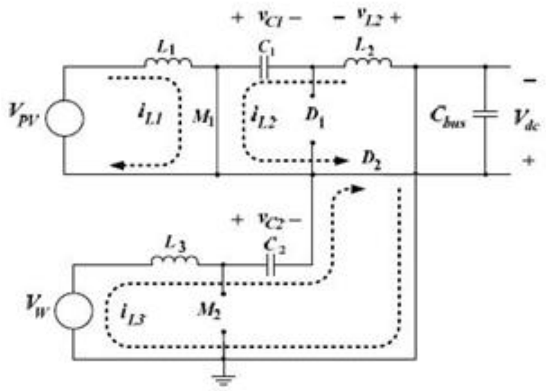


Figure 5 (II): M1 on, M2 off

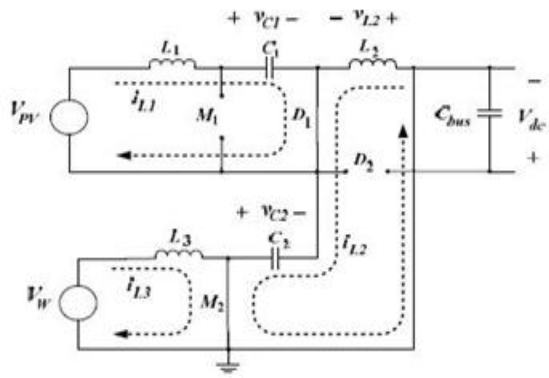


Figure 5 (III): M1 off, M2 off

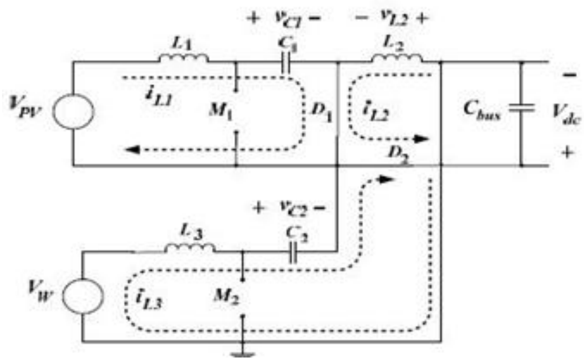


Figure 5 (IV): M1, M2 off
Figure 5 (I-IV): switching states of the hybrid wind solar system

## III. BOOST CONVERTER

The boost converter is a high efficiency step-up DC/DC switching converter; it steps up the input voltage. When the MOSFET is turned on, the source voltage appears across the inductor, and the inductor current builds up. The diode D becomes reverse biased and it remains off. When the MOSFET is turned off, the inductor releases its energy to the capacitor and the load via diode D and the inductor current decreases. The configuration of the boost converter is shown in figure6.

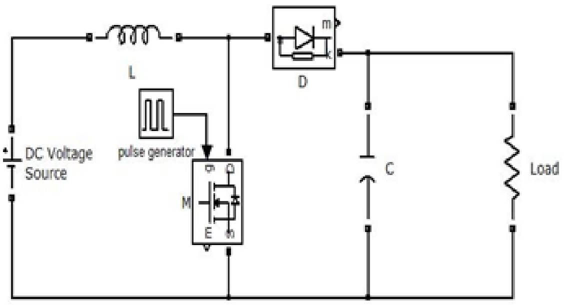



Figure 6: boost converter model

The relationship of voltage and current for an inductor is

$$i = \frac{1}{L}\int_o^t V dt + i_o \qquad (12)$$

For a constant rectangular pulse

$$i = \frac{Vt}{L} + i_o \qquad (13)$$

From this we can see that the current is a linear ramp, when the voltage is a constant pulse

$$\Delta i = \frac{(V_{in} - V_{Trans})T_{on}}{L} \qquad (14)$$

and when the MOSFET switches off the current is

$$\Delta i = \frac{(V_{out} - V_{in} + V_D)T_{off}}{L} \qquad (15)$$

By equating (14) and (15),

$$V_{out} = \frac{V_{in} - V_{Trans} D}{(1 - D)} - V_D \qquad (16)$$

If we neglect the voltage drops across the transistor and diode

$$V_{out} = \frac{V_{in}}{1 - D} \qquad (17)$$

The inductor is designed by

$$L = \frac{(V_{out} - V_{in} + V_D)(1 - D)}{\min(i_{load}) f} \qquad (18)$$

The following design parameters are considered to design the boost converter for solar cell and wind model.

*Boost Converter Design for Photovoltaic Model*

Design parameters: $V_I$ =12V; $V_O$=230V; $R_S$ =10 Ω ; $\Delta_I$=0.5A; F= 3KHZ

$V_O = V_I$ /(1- ಠ )

ಠ = 0.948

L = ($V_I$. ಠ ) /(F. $\Delta_I$)

L = 7.5 µ H

C= ಠ /(F . $R_S$ )

C= 15µ F

*Boost Converter Design for Wind Model*

Design parameters: $V_I$ =50V; $V_O$=230V; $R_S$ =50 Ω ; $\Delta_I$=0.5A; F= 3KHZ

$V_O$= $V_I$/(1- ಠ )

ಠ = 0.791

L = ($V_I$. ಠ ) /(F. $\Delta_I$ )

L = 25.3 µ H

C= ಠ /(F . $R_S$)

C= 2.63 µ F

## IV. MPPT CONTROL OF PROPOSED CIRCUIT

A common inherent drawback of wind and PV systems is the intermittent nature of their energy sources. Wind energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Solar energy is present throughout the day, but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc. These drawbacks tend to make these renewable systems inefficient. However, by incorporating maximum power point tracking MPPT, the systems‟ power transfer efficiency can be improved significantly.

To describe a wind turbines power characteristic, equation describes the mechanical power that is generated by the wind [6].

$$p_m = 0.5\rho A C_p(\lambda, \beta) v_w^3 \qquad (19)$$

*Where*

*ρ = air density,*

*A = rotor swept area,*

*Cp(λ, β) = power coefficient function λ =tip speed ratio,*

*β = pitch angle, vw = wind speed*

The power coefficient (Cp) is a nonlinear function that represents the efficiency of the wind turbine to convert wind energy into mechanical energy. It is dependent on two variables, the tip speed ratio (TSR) and the pitch angle. The TSR, λ, refers to a ratio of the turbine angular speed over the wind speed. The mathematical representation of the TSR is given by [10]. The pitch angle, β, refers to the angle in which the turbine blades are aligned with respect to its longitudinal axis.

A solar cell is comprised of a P-N junction semiconductor that produces currents via the photovoltaic effect. PV arrays are constructed by placing numerous solar cells connected in series and in parallel [5]. A PV cell is a diode of a large-area forward bias with a photo voltage and the equivalent circuits are shown in fig7. The current-voltage characteristic of a solar cell is derived as follows

$$I = I_{ph} - I_D \tag{20}$$

$$I = I_{ph} - I_0\left[\exp\left(\frac{q(V+R_sI)}{Ak_BT}\right)-1\right]-\frac{V+R_sI}{R_{sh}} \tag{21}$$

*Where*

*Iph = photocurrent, ID = diode current,*

*I0 = saturation current, A = ideality factor,*

*q = electronic charge 1.6x10-9,*

*kB = Boltzmann's gas constant (1.38x10-23), T = cell temperature,*

*Rs = series resistance, Rsh = shunt resistance, I = cell current,*
*V = cell voltage*

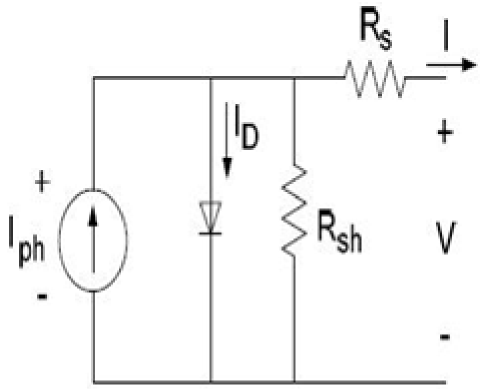



Figure 7: equivalent circuit of PV cell

Typically, the shunt resistance (Rsh) is very large and the series resistance (Rs) is very small [5]. Therefore, it is common to neglect these resistances in order to simplify the solar cell model. The resultant ideal voltage-current characteristic of a photovoltaic cell is given by

$$I = I_{ph} - I_0\left(\exp\left(\frac{qV}{kT}\right)-1\right) \tag{22}$$

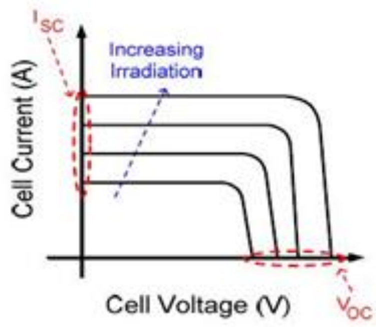



Figure 8: MPPT of solar cell

## V. SIMULATION RESULTS

To start with, hybrid wind-solar energy system using the conventional boost converter is studied. Simulation results are obtained using MATLAB/SIMULINK. The hybrid system with boost converter is shown in fig 9. The output voltage obtained after inversion is shown in fig 10.

Next, the hybrid wind-solar energy system with Cuk-SEPIC fused converter replacing the two boost converter is simulated and studied. The Cuk-SEPIC fused converter model for the hybrid wind solar energy system is shown in fig 11. The simulation results for various operating modes are shown in fig 12-14. The operating modes considered are

1.Cuk Converter mode operation (solar alone)
2.SEPIC Converter mode operation( wind alone)
3.Cuk-SEPIC fused converter mode operation

(both solar and wind)

The maximum power point tracking in solar system is shown in fig 15& 16.

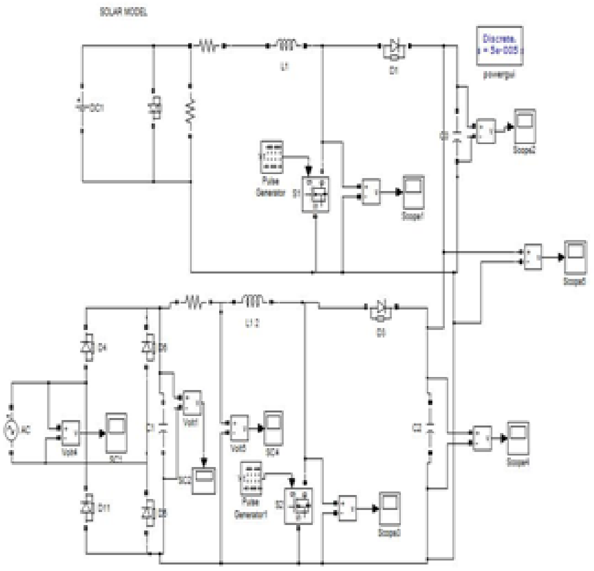
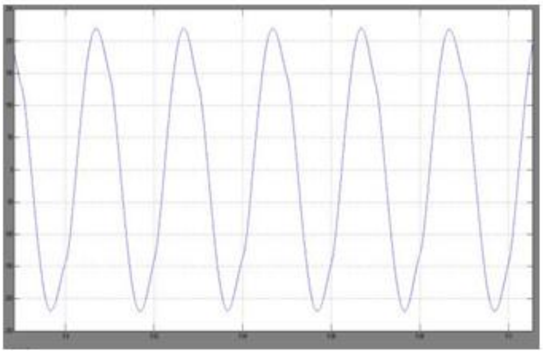


Figure 9: Hybrid wind solar model with boost converter



Figuree 10 : Output voltage of hybrid wind solar energy system with inverter

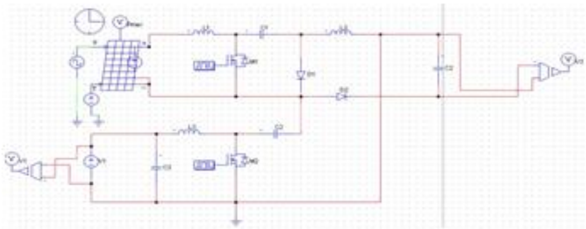


Figure 11: Cuk SEPIC fused converter model (Both wind and solar)

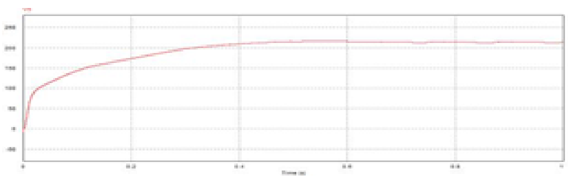


Figure 12: Output voltage of both wind and solar (Cuk-Sepic fusion mode)

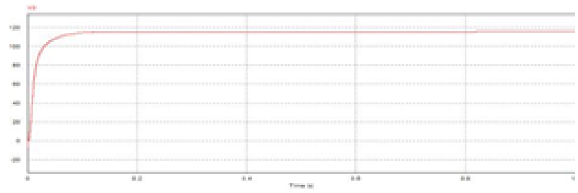


Figure 13: output voltage from solar alone (Cuk operation mode)

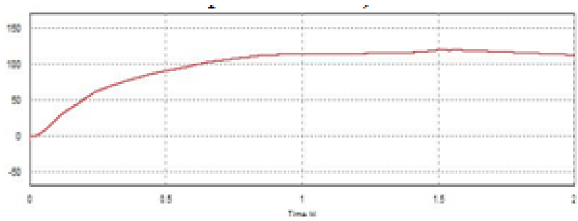



Figure 14: Output voltage from wind source alone

**(SEPIC operation mode)**

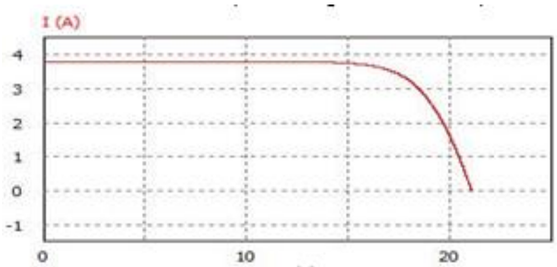



Figure 15: MPPT of solar model (Voltage Vs Current)

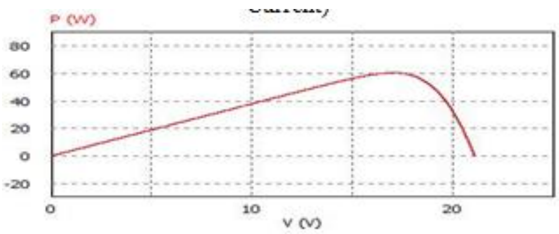



Figure 16: MPPT of solar model (Voltage Vs Power)

## VI. CONCLUSION

In this paper a new multi-input Cuk-SEPIC fused converter for hybrid wind-solar energy system has been discussed in comparison with the conventional boost converter system. For both boost converter system as well as Cuk-SEPIC converter system, simulation results of hybrid system are presented. The following features of the system have been demonstrated in the simulation study.

1) Two boost converters are replaced by one Cuk-SEPIC fused converter in the proposed model.
2) Additional input filters are not necessary to filter out high frequency harmonics
3) Both renewable sources can be stepped up/down (supports wide ranges of PV and wind input)
4) MPPT can be realized for each source

5) Individual and simultaneous operation is supported.

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