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Hybrid Wind Solar Energy System: New converter design

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ABSTRACT: The aim of this project is to design and simulate a hybrid wind-solar energy system: a new rectifier stage topology. Renewable sources are becoming more important than ever as a result of concern. This project 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 depending on the availability of the wind and solar energy sources. By the inherent nature of this CUK-SEPIC fused converter, additional input filters are not necessary to filter out high frequency harmonics. The fused design of CUK and SEPIC in the rectifier stage also allows Maximum Power Point Tracking (MPPT) to be used to extract maximum power from the wind and sun when it is available. The obtained dc voltage sources depending on the availability are boosted to obtain maximum voltage and inverted by a three phase inverter to supply a three phase load. In case any excess voltage obtained can be stored using an electrostatic capacitor and may be also given to the grid. The simulation results show the efficiency of the CUK and SEPIC integration than the other dc boosters.

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. Alone, 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. 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 and by incorporating maximum power point tracking (MPPT) algorithms, 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 . 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 . A simpler multi input structure has been suggested that combine the sources from the DC-end while still achieving MPPT for each renewable source. The structure proposed by 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 . The harmonic content in the generator current decreases its lifespan and increases the power loss due to heating . 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 input filters for PFC [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

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simultaneous operation is supported. The circuit operating principles will be discussed in this paper. Simulation results are provided to verify with the feasibility of the proposed system.

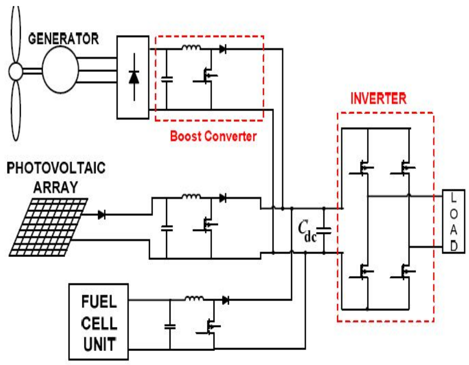

Figure 1: Hybrid system with multi-connected boost converter

II. PROPOSED MULTI-INPUT RECTIFIER STAGE

A system diagram of the proposed rectifier stage of a hybrid 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 diodes 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 D2 turns off and D1 will always be on and the circuit becomes a Cuk converter as shown in Figure 4.

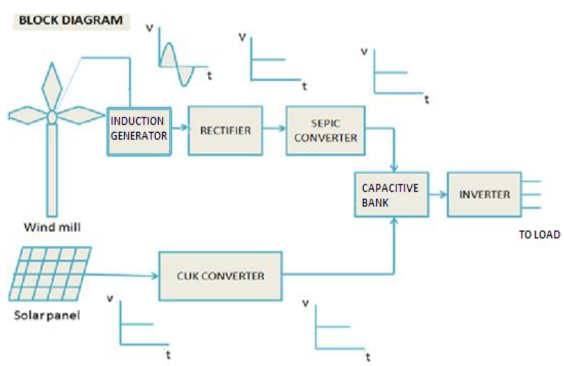

Fig 2: complete block diagram

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 perform MPPT control. Figure 5 illustrates the various switching states of the proposed converter. If the turn on duration of M1 is longer than M2, 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

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better explanation, the inductor current waveforms of each switching state are given as follows 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. The key waveforms that illustrate the switching states in this example are shown in Figure 6.

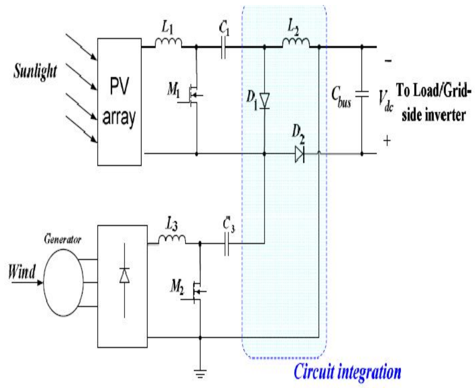

Figure 2: Proposed rectifier stage for a Hybrid wind/PV system

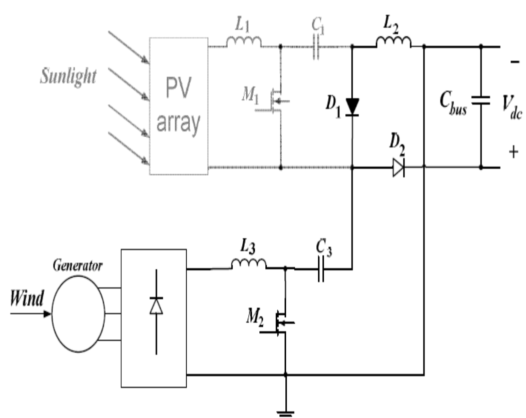

Figure 4: Only wind source is operational (SEPIC)

Figure 4 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

$$\frac{V}{V(w)} = \frac{D2}{1-D2}$$

Here D1 and D2 are diodes of CUK converter.

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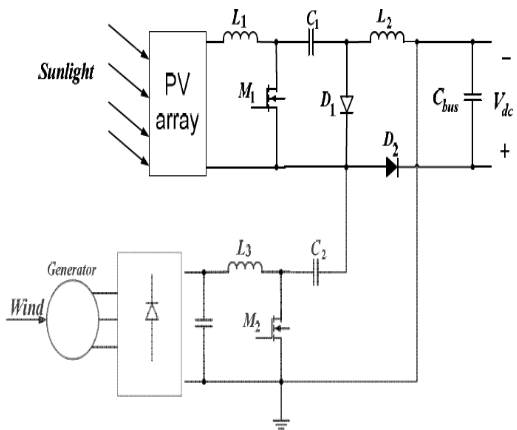
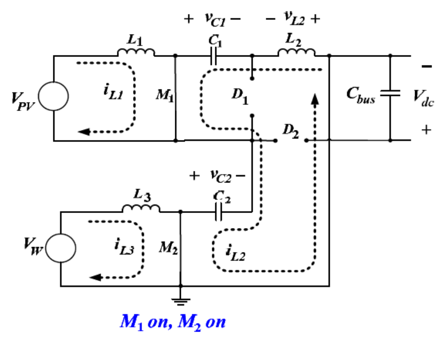


Figure 5: Only PV source is operation (Cuk)

On the other hand, if only the PV source is available, then D2 turns off and D1 will always be on and the circuit becomes a Cuk converter as shown in Figure 5.

The input to output voltage relationship is given by

$$\frac{V}{V(pv)} = \frac{D1}{1- D1}$$



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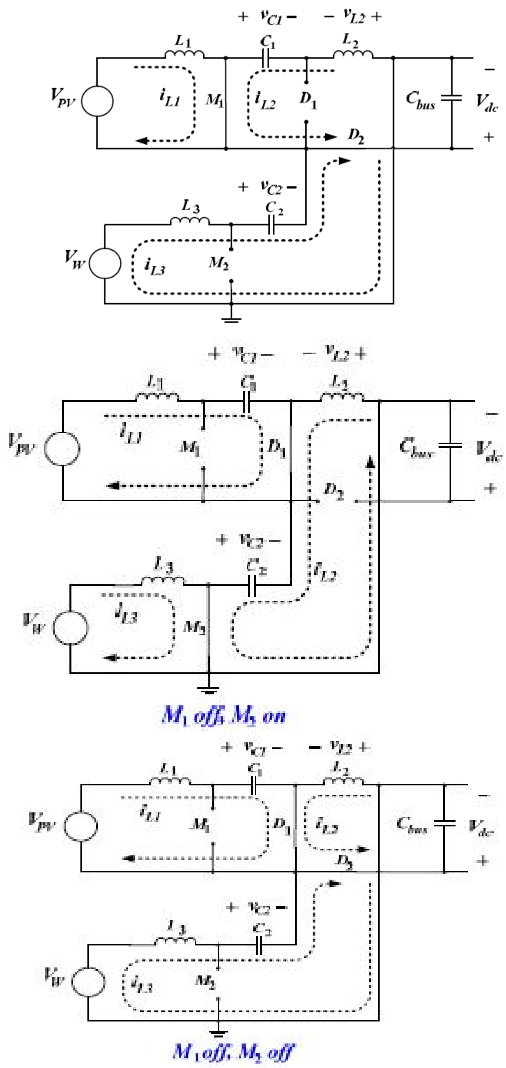

Figure 6 (I-IV): switching states within a switching cycle

III. MODES OF OPERATION

Both converters have step-up/down capability, which provide more design flexibility in the system if duty ratio control is utilized to perform MPPT control. Figure 5 illustrates the various switching states of the proposed converter. If the turn on duration of M1 is longer than M2, 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 given as follows 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. The key waveforms that illustrate the switching states in this example are shown in Fig 6.

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IV. ANALYSIS OF PROPOSED CIRCUIT

To find an expression for the output DC bus voltage, Vdc,the volt-balance of the output inductor, L2, is examined according to Figure 6 with d2 > d1. Since the net change in thevoltage of L2 is zero, applying volt-balance to L2 results in (3).

The expression that relates the average output DC voltage (Vdc) to the capacitor voltages (vc1 and vc2) is then obtained as shown in (4), where vc1 and vc2 can then be obtained by applying volt-balance to L1 and L3 [9]. The final expression that relates the average output voltage and the two input

sources (VW and VPV) is then given by (5). It is observed that Vdc is simply the sum of the two output voltages of the Cuk and SEPIC converter. This further implies that Vdc can becontrolled by d1 and d2 individually or simultaneously

The switches voltage and current characteristics are also provided in this section. As for the current stress, it is observed from Figure 6 that the peak current always occurs at the end of the on-time of the MOSFET. Both the Cuk and SEPIC MOSFETcurrent consists of both the input current and the capacitors (C1 or C2) current.

The PV output current, which is also equal to the average input current of the Cuk converter is given in (12). It can be observed that the average inductor current is a function of its respective duty cycle (d1). Therefore by adjusting the respective duty cycles for each energy source, maximumpower point tracking can be achieved.

$$v_{ds1} = V_{pv}\left(1+\frac{d_1}{1-d_1}\right)$$

$$v_{ds2} = V_{W}\left(1+\frac{d_2}{1-d_2}\right)$$

$$i_{ds1,pk} = I_{i,PV} + I_{dc,avg} + \frac{V_{PV} d_1 T_s}{2L_{eq1}}$$

$$L_{eq1} = \frac{L_1 L_2}{L_1 + L_2}$$

$$i_{ds2,pk} = I_{i,W} + I_{dc,avg} + \frac{V_W d_2 T_s}{2L_{eq2}}$$

$$L_{eq2} = \frac{L_3 L_2}{L_3 + L_2}$$

$$I_{i,PV} = \frac{P_o}{V_{dc}}\frac{d_1}{1-d_1}$$

V. CONVERTER WORKING

When M1 is turned on, current flows from the input source through L1 and M1, storing energy in L1 magnetic field. Then when M1 is turned off, the voltage across L1 reverses to maintain current flow. As in the boost converter current then flows from the input source, through L1 and D1, charging up C1 to a voltage somewhat higher than Vin and transferring to it some of the energy that was stored in L1.Then when M1 is turned on again, C1 discharges through via L2 into the load, with L2 and C2 acting as a smoothing filter. Meanwhile energy is being stored again in L1, ready for the next cycle.

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VI. SOURCE CHARACTERISTICS

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) algorithms, the systems' power transfer efficiency can be improved significantly. To describe a wind turbine's power characteristic, equation (13) describes the mechanical power that is generated by the wind [6].

0.5 (,) 3m p w p □□□AC □□□□v

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. Figure 7 and 8 are illustrations of a power coefficient curve and power curve for a typical fixed pitch (β =0) horizontal axis wind turbine. It can be seen from figure 7 and 8 that the power curves for each wind speed has a shape similar to that of the power coefficient curve. Because the TSR is a ratio between the turbine rotational speed and the wind speed, it follows that each wind speed would have a different corresponding optimal rotational speed that gives the optimal TSR. For each turbine there is an optimal TSR value that corresponds to a maximum value of the power coefficient(Cp,max) and therefore the maximum power. Therefore by controlling rotational speed, (by means of adjusting the electrical loading of the turbine generator) maximum power can be obtained for different wind speeds.

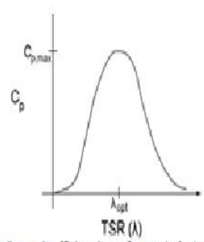

Figure 8 Power Coefficient Curve for a typical wind turbine

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 photovoltage. 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 typical output power characteristics of a PV array under various degrees of

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irradiation is illustrated by Figure 11. It can be observed in Figure 11 that there is a particular optimal voltage for each irradiation level that corresponds to maximum output power. Therefore by adjusting the output current (or voltage) of the PV array, maximum power from the array can be drawn.

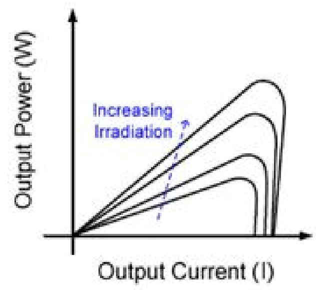

Figure 9: PV cell power characteristics

Due to the similarities of the shape of the wind and PV array power curves, a similar maximum power point tracking scheme known as the hill climb search (HCS) strategy is often applied to these energy sources to extract maximum power. The HCS strategy perturbs the operating point of the system and observes the output. If the direction of the perturbation (e.g an increase or decrease in the output voltage of a PV array) results in a positive change in the output power, then the control algorithm will continue in the direction of the previous perturbation. Conversely, if a negative change in the output power is observed, then the control algorithm will reverse the direction of the pervious perturbation step. In the case that the change in power is close to zero (within a specified range) then the algorithm will invoke no changes to the system operating point since it corresponds to the maximum power point (the peak of the power curves).

V. INVERTER ANALYSIS

Inverters take DC power and invert it to AC power so it can be fed into the electric utility company grid. The inverter must synchronize its frequency with that of the grid (e.g. 50 or 60 Hz) using a local oscillator and limit the voltage to no higher than the grid voltage. A high-quality modern GTI has a fixed unity power factor, which means its output voltage and current are perfectly lined up, and its phase angle is within 1 degree of the AC power grid. The inverter has an on-board computer which will sense the current AC grid waveform, and output a voltage to correspond with the grid. Grid-tie inverters are also designed to quickly disconnect from the grid if the utility grid goes down.

VI. SIMULATION RESULTS

The simulation results for cuk-sepic integrated circuit is shown in figure 10. The output voltages are shown to boost up to a level greater than buck-boost converter and the efficiency is also found to be higher.

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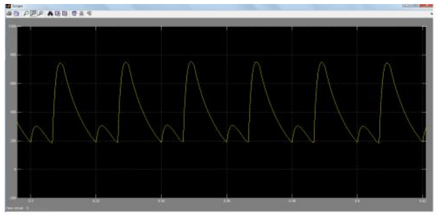

Fig 10: cuk-sepic converter simulation

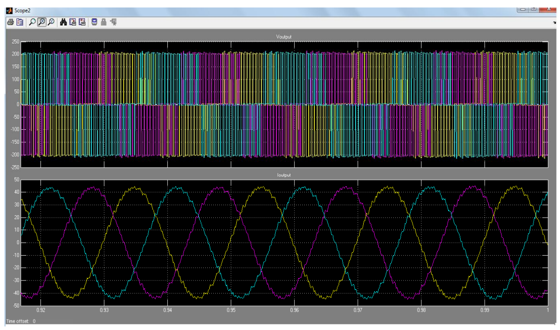

Fig 11: simulation output of the proposed system

TABLE 1
THE OBTAINED VOLTAGE LEVEL

INPUT VOLTAGE	OUTPUT VOLTAGE
200 V	230 V

The simulation results of proposed system indicate that it yields a output of 9.2kw

VII. CONCLUSION

In this paper a new multi-input Cuk-SEPIC rectifier stage for hybrid wind/solar energy systems has been presented.

The features of this circuit are: 1) additional input filters are not necessary to filter out high frequency harmonics; 2) both renewable sources can be stepped up/down (supports wide ranges of PV and wind input); 3) MPPT can be realized for each source; 4) individual and simultaneous operation is supported. Simulation results have been

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presented to verify the features of the proposed topology. This hybrid energy source will surely empower the future world!!!!!

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