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Non-Conventional Energy System using Cuk-Sepic Converter

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ABSTRACT: Environmentally friendly solutions are becoming more prominent than ever as a result of concern regarding 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 depending on the availability of the energy sources. The inherent nature of this Cuk-SEPIC fused converter, additional input filters are not necessary to filter out high frequency harmonics. Harmonic content is detrimental for the generator lifespan, heating issues, and efficiency. The fused multi input 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. An adaptive MPPT algorithm will be used for the wind system and a standard perturb and observe method will be used for the PV system.

KEYWORDS: Fusion of the Cuk and SEPIC converters, Hybrid wind/PV system,

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.

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. 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 combine 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.

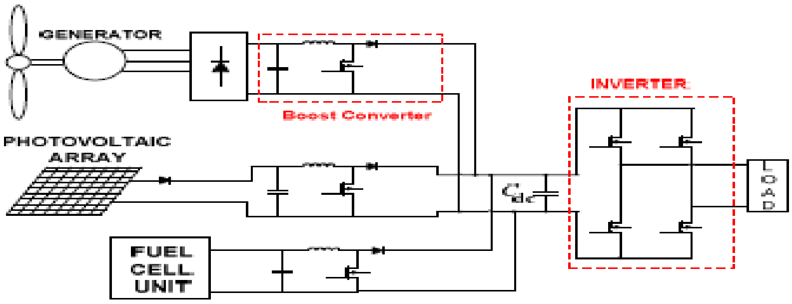

Fig.1. Hybrid system with multi-connected boost converter

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.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, *D*1 turns off and *D*2 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 perform MPPT control.

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

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

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.

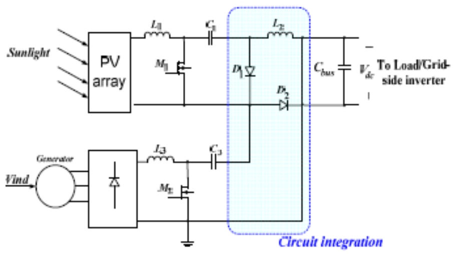

Fig.2 Proposed rectifier stage for a Hybrid wind/PV system

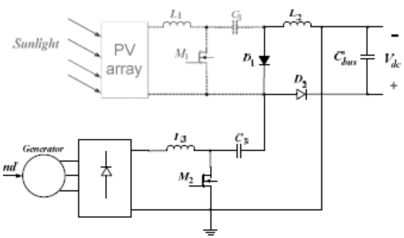

Fig.3 Only wind source is operational (SEPIC)

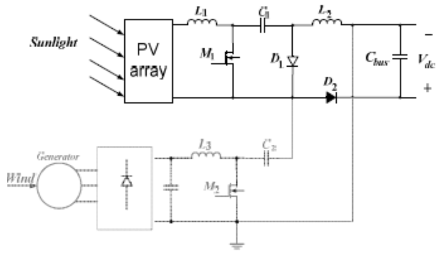

Fig.4 Only PV source is operation (Cuk)

III.ANALYSIS OF PROPOSED CIRCUIT

The expression that relates the average output DC voltage (*Vdc*) to the capacitor voltages (*vc*1 and *vc*2) is then obtained as shown in (4), where *vc*1 and *vc*2 can then be obtained by applying volt-balance to *L*1 and *L*3 [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 be controlled by *d*1 and *d*2 individually or simultaneously.

$$\begin{aligned}&(v_{c1}+v_{c2})d_1T_s+(v_{c2})(d_2-d_1)T_s\\&+(1-d_2)(-v_{dc})T_s=0\end{aligned} \quad (3)$$

$$V_{dc}=\left(\frac{d_1}{1-d_2}\right)v_{c1}+\left(\frac{d_2}{1-d_2}\right)v_{c2} \quad (4)$$

$$V_{dc}=\left(\frac{d_1}{1-d_1}\right)v_{PV}+\left(\frac{d_2}{1-d_2}\right)v_w \quad (5)$$

Both the Cuk and SEPIC MOSFET current consists of both the input current and the capacitors (*C*1 or *C*2) current. The peak current stress of *M*1 and *M*2 are given by (8) and (10) respectively. *Leq*1 and *Leq*2, given by (9) and (11), represent the equivalent inductance of Cuk and SEPIC converter respectively

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 (*d*1). Therefore by adjusting the respective duty cycles for each energy source, maximum power point tracking can be achieved.

$$v_{ds1}=V_{pv}\left(1+\frac{d_1}{1-d_1}\right) \quad (6)$$

$$v_{ds2}=V_w\left(1+\frac{d_2}{1-d_2}\right) \quad (7)$$

$$i_{ds1,pk}=I_{i,pv}+I_{dc,avg}+\frac{V_{Pv}d_1T_s}{2L_{eq1}} \quad (8)$$

$$L_{eq1}=\frac{L_1L_2}{L_1+L_2} \quad (9)$$

$$i_{ds2,pk}=I_{i,w}+I_{dc,avg}+\frac{V_wd_2T_s}{2L_{eq2}} \quad (10)$$

$$L_{eq2} = \frac{L_3 L_2}{L_3 + L_2} \quad (11)$$

$$I_{i,PV} = \frac{p_0}{V_{dc}} \frac{d_1}{1 - d_1} \quad (12)$$

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) 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.

$$p_m = 0.5 \rho A C_p(\lambda, \beta) v_w^3 \quad (13)$$

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.

$$\lambda = \frac{R\omega_b}{v_w} \quad (14)$$

Figure 6 and 7 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 6 and 7 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.

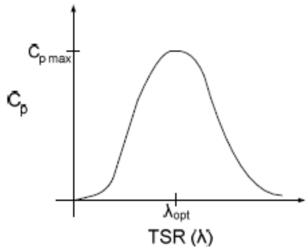

Fig.6 Power Coefficient Curve for a typical wind turbine

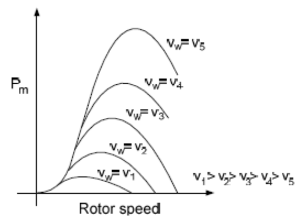

Fig.7 Power Curves for a typical wind turbine

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 photo voltage and the equivalent circuit is shown by Figure8 [11]. The current-voltage characteristic of a solar cell is derived in [12] and [13] as follows:

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$$I = I_{ph} - I_D \tag{15}$$

$$I = I_{ph} - I_0[\exp(\frac{q(V + R_s I)}{Ak_B T}) - 1] - \frac{V + R_s I}{R_{sh}} \tag{16}$$

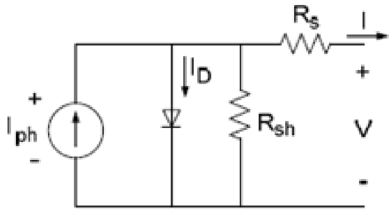

Fig.8 PV cell equivalent circuit

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.

$$I = I_{ph} - I_0(\exp(\frac{qV}{kT}) - 1) \tag{17}$$

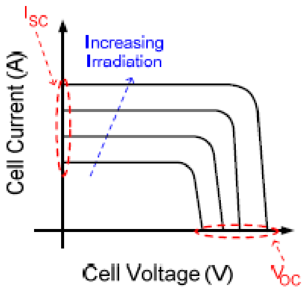

Fig.9 PV cell voltage-current characteristic

The typical output power characteristics of a PV array under various degrees of irradiation is shown in figure 10. It can be observed in Figure 10 that there is a particular optimal voltage for each irradiation level that corresponds to maximum output power.

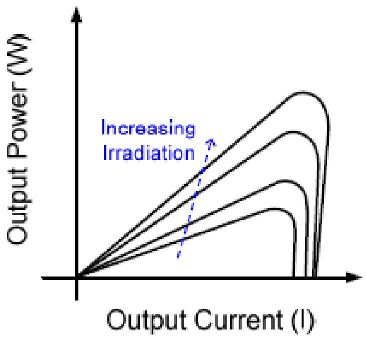

Fig.10 PV cell power characteristics

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

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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.RESULT AND CONCLUSION

In this section, simulation results from PSIM 8.0.7 is given to verify that the proposed multi-input rectifier stage can support individual as well as simultaneous operation. Figure 11 illustrates the simultaneous operation (Cuk SEPIC fusion mode) of the two sources where M2 has a longer conduction Cycle.

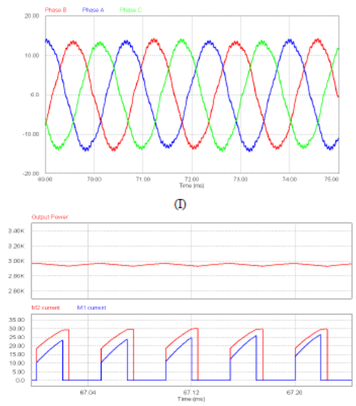

Fig.11 Simultaneous operation with both wind and PV source

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