A Hybrid Wind-Solar Energy System using Double-port Interface in a Micro grid

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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 multiinput 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. Operational analysis of the proposed system will be discussed in this paper. Simulation results are given to highlight the merits of the proposed circuit.**

*Index Terms***— Renewable sources, Power Electronics Interface, MPPT, Wind generator, PV array**

I. INTRODUCTION

While the global demand of energy is increasing constantly, the use of classic source of energy like oil and coal becomes problematic contributing among other things to climate change. One solution to address climate change is the use of clean renewable energy sources among other solar and wind.

Most areas in South Africa average more than 2500 hours of sunshine per year with an annual 24 hour solar radiation of approx 220 W/m^2, compared with 150 W/m^2 in the USA and averaging 100 W/m^2 for Europe. This makes South Africa's solar radiation resource one of the highest in the world.

The progress in power electronics [1], [2], [3], [4] facilitated integration of these renewable energy sources either grid or as stand-alone for small scale use. Historically, the integration was started with wind farms. When the price for photovoltaic panels became affordable, the penetration of PV became to be used more often but not necessarily at the same level of power as wind. For medium to high power the PV's are modularly used [5], [7], [8].

Many studies propose small power integration (few kW) for both wind and solar PV as hybrid stand-alone systems [6], [9], [11], [12]. Other studies added fuel cells and batteries creating the concept of multi-port system [15]-[20].

Apart from methods of integration a continuous attention was towards controlling the systems in order to maximize solar PV efficiency [7], [8], [9], [10], [11], or wind [21], [22], [23]. Stability of renewable system was also under scrutiny [2], [14].

Double or multi-port integration systems for renewable have been previously proposed [15]-[20]. The communality of all these studies proposed parallel connection of various renewable sources on a single dc bus.

In this study a double-port integration system for renewable energy sources is proposed. Figure 1 shows a small scale system of 1 kW PV array integrated together with a 1.5 kW wind generator (WG).

II. SMALL SCALE MULTI-CONNECTED SYSTEM

The double input interface converts energy delivered by the PV array and wind generator in a comparable DC voltage when operating at nominal conditions. Due to the variable nature of wind and sun irradiation, the system must have a battery back-up. In this proposed solution the corresponding DC output voltage for each renewable source is connected in series and thus increasing the power availability at partial solar irradiation and weak wind.

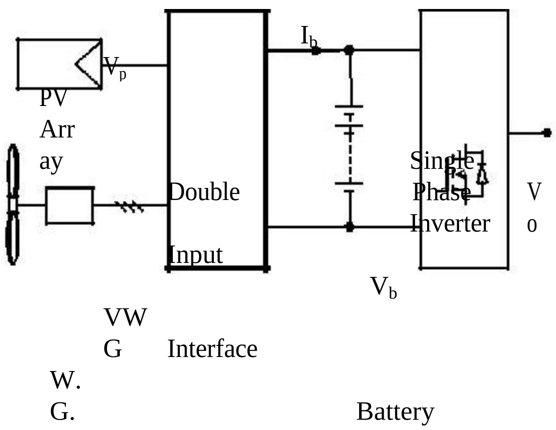

Fig.1 Double Input Renewable System

The third stage of the interface produces a charging current for the battery. During the day light, the consumption is lower than the PV can produce and the greatest part of this energy is stored into the battery. When the wind blows, the energy produced by the wind generator is also stored into battery.

Energy stored is then released for the period when there is no sun or wind.

The output of the system is a single-phase standard voltage 50 Hz PWM inverter capable of delivering 3 kW at peak demand.

The equivalent model of a photovoltaic cell is shown in figure 2. The current-voltage characteristic of the cell is:

$$I=I_{ph}-I_0\left\{exp\left[\frac{q(V+IRs)}{nKT}\right]-1\right\}-\frac{V+IRs}{Rsh} \quad (1)$$

Where: I = output current; I_{ph} = photo current; I_o = saturation current of the diode; V = output voltage; q = the charge of electron; n = [1 2] is the diode constant; K = Boltzmann constant; T = cell's temperature in Kelvin degrees; R_s = series resistance; R_{sh} = shunt resistance.

In this study, four panels rated at approximate 250 W with V_{oc} of 37 V and I_{sc} – 8.9 A. Figure 3 and 4 shows the I-V and power characteristic of one panel at standard conditions rerspectively.

For an efficient energy conversion, the panel should be operated in the MPP point.

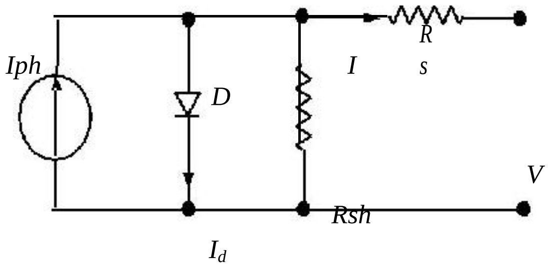

Fig.2 PV Cell's equivalent model

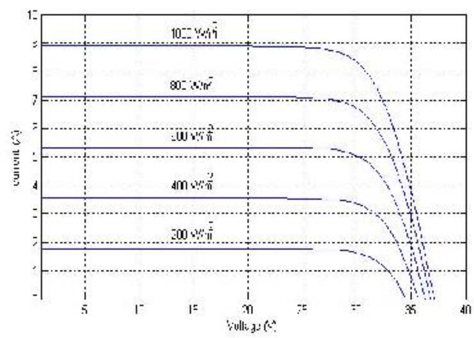

Fig.3 I/V characteristics for the panel used

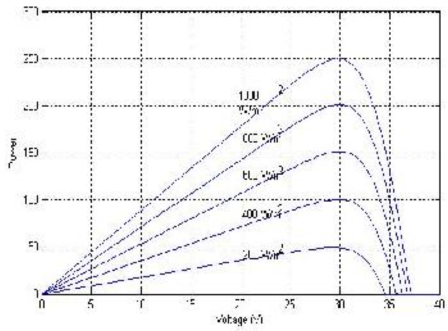

Fig.4 Power characteristics for the panel used

B. Wind generation model

The mechanic power produced by the wind blowing the blades is given as:

$$P_{m-W} \quad 0.5\rho \quad A \quad C_p \quad \lambda,\beta \quad v_W^3 \quad (2)$$

Where ρ is the air density (kg/m^3), A is the turbine swept area (m^2) and v_W is the wind speed (m/s). Coefficient C_p is a dimensionless power coefficient which depends on λ and the blade pitch angle (β) [13]:

$$C_p=0.5176\left[\frac{116}{\lambda_i}-0.4\beta-21\right]exp\left[-\frac{21}{\lambda_i}\right]+0.0068\,\lambda \quad (3)$$

With

$$\frac{1}{\lambda_i}=\frac{1}{\lambda+0.08\beta}-\frac{0.035}{\beta^3+1}$$

$$\lambda=\omega_m R/v_W \quad (4)$$

Where ω_m is the angular speed of the turbine and R is the radius of the turbine/blades.

Then, the electromagnetic torque (T_{em}) of the generator can be written as:

$$T_{m\text{-}W}-T_{em}=J\frac{dw_m}{dt}+Bw_m$$

$$T_{em}=\frac{3EI}{2\omega_m}=\frac{3p\Psi}{4}I \quad (5)$$

Where J is total inertia, B is the effective friction coefficient, p is the number of poles, Ψ is the flux linkage, E is the amplitude of the emf and I is the amplitude of the generator output current.

Then the wind turbine maximum power for different wind speeds (see figure 5) is going to be matched by electric load connected to the generator

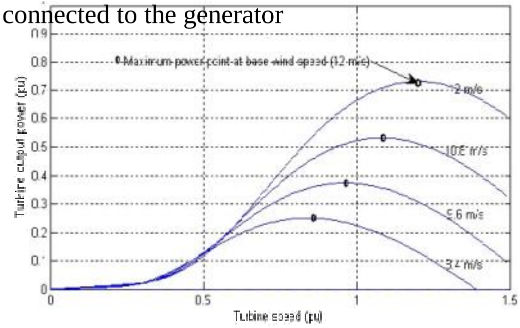

Fig.4 Turbine's power characteristics

III. DOUBLE-PORT INTERFACE

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 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 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].

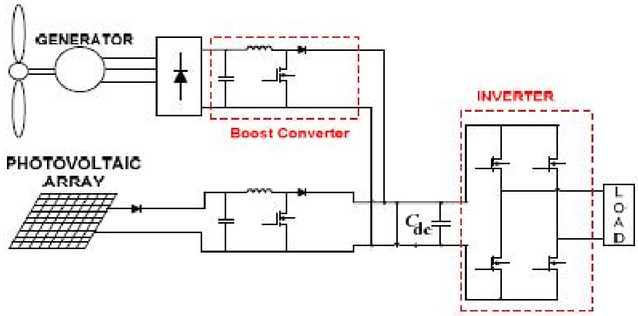

Fig.6 Hybrid system with multi-connected boost converter

IV. CONTROL STRATEGY

The main purpose of the proposed system is to harvest energy from renewable sources in an efficient way. Hence the control strategy is towards each input converter to match the maximum power point for the corresponding source.

A. PV Input Control

For this application a simple PI regulator (figure 7) has been used for controlling the input current $I_{pv} = I_{L1}$.

The initial set point (δ_1) for switch S_1 and value for L_1 are chosen to satisfy the maximum power point corresponding with standard solar irradiation of 1000 W/m^2. One other parameter considered is panel temperature (T_{pv}); because the performances of photovoltaic cells depend on temperature.

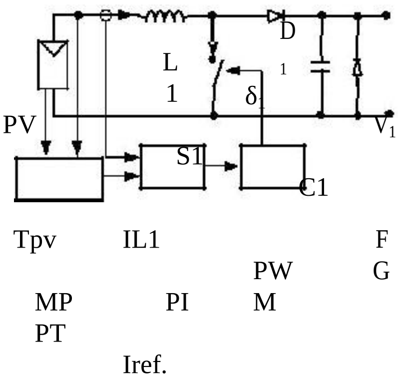

Fig.7 Control for solar PV MPPT

B. Wind Input Control

Figure 8 shows the schematic for the control strategy. In order the turbine to operate efficiently, the electrical load of the generator should match mechanic power at MPP. Usually, the generator is a permanent magnet synchronous type and frequency of the three-phase output voltage is directly proportional with the wind turbine speed. Hence, the information needed to determine the maximum power point is taken from the output of the wind generator. One easy method to find the optimal load (and turbine speed) corresponding to that wind speed (v_W), for maximum power point is using a look-up table which has been previously determined and stored [22].

Same as before, the choice of inductor L_2 and initial duty cycle δ_2 are taken to match the standard output at base wind speed.

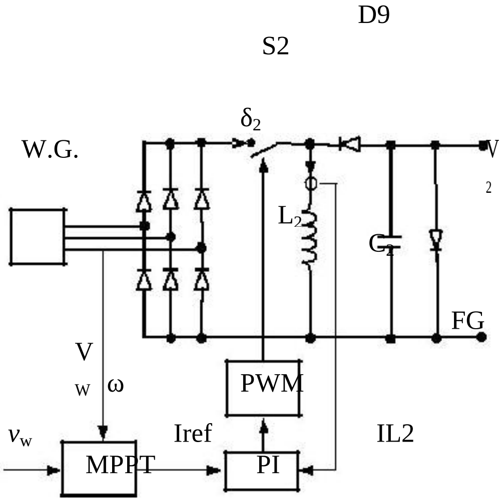

Fig.8 Control for wind generator MPPT

C. Output Regulation

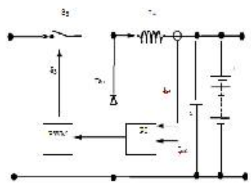

Fig.9 Control for output/charging current

The regulation of the output/charging current for the battery is done using the same type of PI controller. The reference current depends on choice of battery and its capacity in Ah.

The value of L_3 and the range of duty cycle δ_3 for S_3 depend on the range of variation of input voltage V_3. The switching should stop when the input conditions for solar PV and wind generation combined do not produce a voltage V_3 higher than battery voltage (V_b).

V. SIMULATION VALIDATION

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. The specifications for the design example are given in TABLE I. Figure 10 illustrates the system under the condition where the wind source has failed and only the PV source (Cuk converter mode) is supplying power to the load. Figure 11 illustrates the system where only the wind turbine generates power to the load (SEPIC converter mode). Finally, Figure 12 illustrates the simultaneous operation (Cuk-SEPIC fusion mode) of the two sources where M2 has a longer conduction cycle.

Table I. Design specifications

Output Power (W)	3kW
Output Voltage	500V
Switching frequency	20kHz

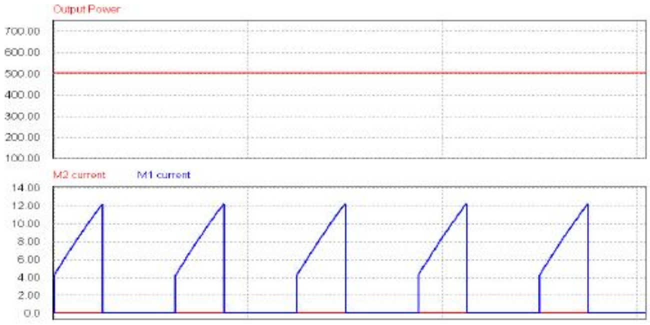

Figure 10 : Individual operation with only PV source (Cuk operation)
Top: Output power, Bottom: Switch currents (M1 and M2)

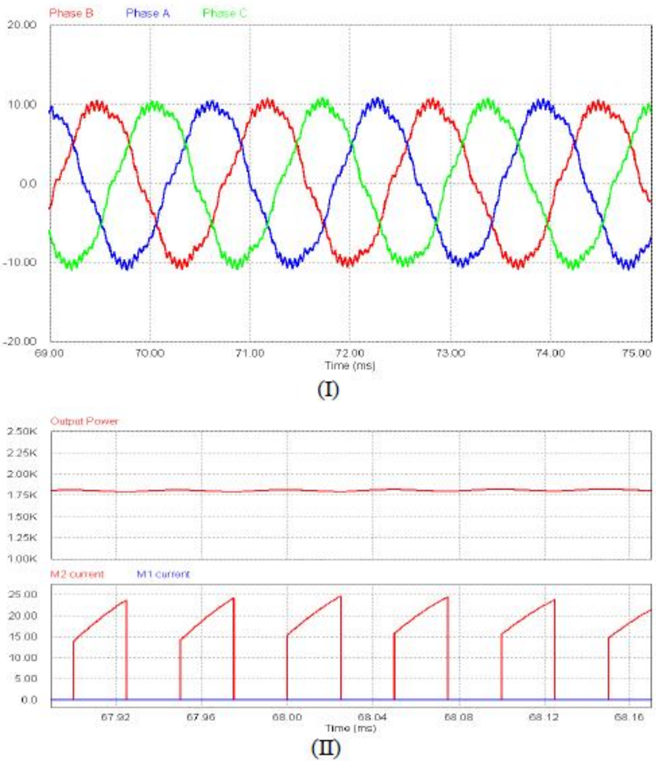

Figure 11 : Individual operation with only wind source (SEPIC operation)
(I) The injected three phase generator current; (II) Top: Output power,
Bottom: Switch currents (M1 and M2)

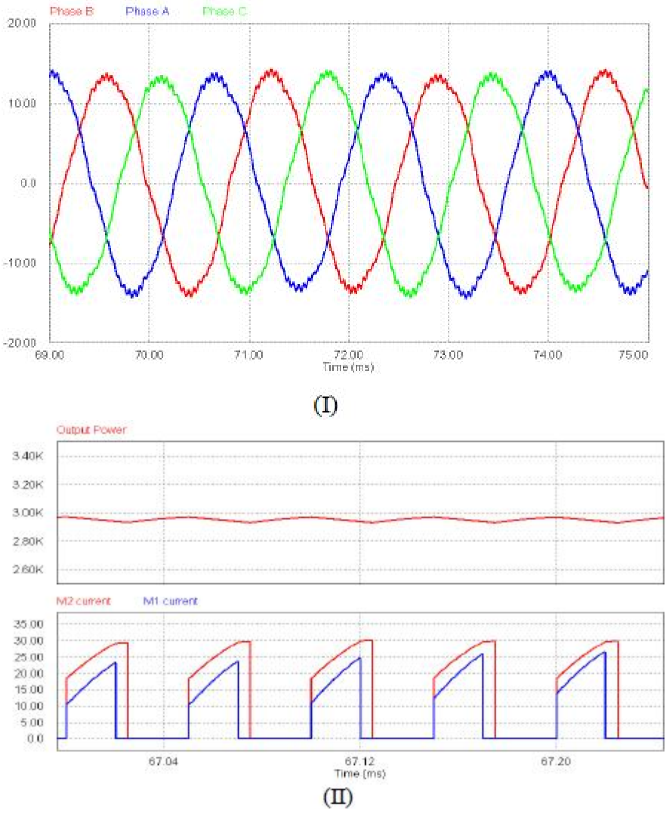

Figure 12 : Simultaneous operation with both wind and PV source (Fusion
mode with Cuk and SEPIC)
(I) The injected three phase generator current; (II) Top: Output power,
Bottom: Switch currents (M1 and M2)

Figure 13 and 14 illustrates the MPPT operation of the PV component of the system (Cuk operation) and the Wind component of the system (SEPIC operation) respectively.

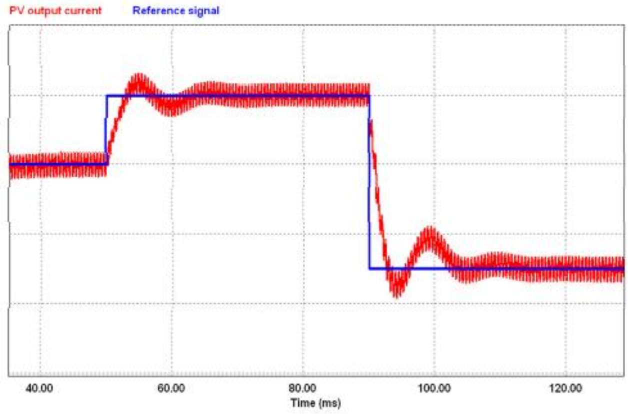

Figure 13 : Solar MPPT – PV output current and reference current signal
(Cuk operation)

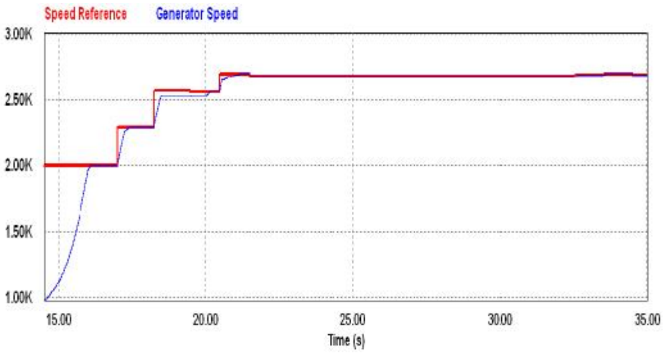

Figure 14 : Wind MPPT – Generator speed and reference speed signal
(SEPIC operation)

VI. CONCLUSION

In this paper a new multi-input Cuk-SEPIC rectifier stage for hybrid wind/solar energy systems has been presented. The specific of this interface consist on naturally series connection of the outputs of the two different dc/dc converter. The system is stable and there is no interference between the two input converters.

Using the data for a 1 kW PV system and 1.5 kW wind generator, the simulation results shown and extended power capability even for partial operating conditions and thus greater energy stored. Hence, this system is recommended for small scale stand-alone renewable energy system 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 presented to verify the features of the proposed topology.

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