A CUK-SEPIC FUSED CONVERTER TOPOLOGY
FOR WIND-SOLAR HYBRID SYSTEMS FOR
STAND-ALONE SYSTEMS

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Abstract: 3G means distributed generation, micro grid, and smart grid has become a popular topic and is developing rapidly due to energy storage. Renewable energies are derived from natural processes that are replenished constantly and have various forms. Electricity and heat produced from solar, wind, ocean, hydropower, biomass, and geothermal resources are derived from renewable resources. The common inherent drawbacks of renewable energy are unpredictable and intermittent in nature. Hybridizing renewable energy system utilizes two or more energy sources, usually solar and wind power. This paper presents a new system configuration of the front-end converter stage for a hybrid wind and photovoltaic systems with maximum power point tracking (MPPT) technique. This configuration allows the two sources to supply the load separately or simultaneously depending on availability. The converter is a combination of CUK and SEPIC converter. The inherent nature of CUK-SEPIC fused converter consists of input inductor to filter out high frequency harmonics, thus additional filter is not required and energy transfer depends on capacitor.

Key words: Hybrid system, CUK-SEPIC converter, renewable energy, photovoltaic system, wind power, Maximum power point tracking (MPPT).

I. INTRODUCTION

With the increasing threat 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 hold the potential to meet our energy demands. Wind energy, by itself is capable of supplying large amounts of power, but its presence is highly unpredictable, as it can be here one moment and gone the next. Similarly, solar energy is present throughout the day, but the solar irradiation levels vary, due to the sun’s intensity and unpredictable shadows cast by clouds, birds, trees, etc. The common inherent drawback of wind and photovoltaic system, are their intermittent natures that make them unreliable. Hybrids renewable energy system utilizes two or more energy sources, usually solar and wind power. The major advantage of a solar and wind hybrid system is that, when solar and wind power production is used together, the reliability of the system is enhanced. An additionally, the size of the battery storage can be reduced slightly as there is less reliance on one method of power production. Often, there is no sun, there is plenty of wind. However, by combining these two intermittent sources and 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 the deficit. Several hybrid wind and PV power systems with MPPT technique are discussed in [1]-[4]. Most of the hybrid systems require separate DC/DC converters and passive filter at the input side which increase the cost and makes circuit as bulky [5]-[6]. The proposed circuit operates in 4 modes. The circuit operates as CUK converter when only PV source is available. It acts as a SEPIC converter when only wind source is available. When both the sources are available the switches will turn ON. When both sources are unavailable the switches will turn OFF. The CUK-SEPIC fused converters have the capability to eliminate the high frequency current harmonics in the wind generator. This eliminates the need of passive input filters in the system. This design produces power at all times by efficiently using freely available renewable resources. They can also support individual and simultaneous operations by providing constant output at the load.
II. PV panel and wind turbine characteristics

A. I-V and P-V characteristics of PV panel

Solar energy is one of the most important renewable energy sources has been gaining increased attention in recent years. Solar energy is abundant in compared to other energy sources. The radiation of sun falling on earth in one day is sufficient to power the total energy needs of the earth for one year. Solar energy is clean and free of emissions, since it does not produce pollutants or by-products harmful to nature. The conversion of solar energy into electrical energy has many application fields. Residential, vehicular, space and air craft, and naval applications are the main fields of solar energy.

A photovoltaic cell converts sunlight into electricity, which is the physical process known as photoelectric effect. Light, which shines on a PV cell, may be reflected, absorbed, or passed through; however, only absorbed light generates electricity. The energy of absorbed light is transferred to electrons in the atoms of the PV cell. With their newfound energy, these electrons escape from their normal positions in the atoms of semiconductor PV material and become part of the electrical flow, or current, in an electrical circuit. A special electrical property of the PV cell, called “built-in electric field,” provides the force or voltage required to drive the current through an external “load” such as a light bulb.

B. Power characteristics of wind turbine

There are two aspects of wind resource assessment: (1) determination of the general wind power potential and (2) determination of wind power potential and predicted energy production for wind farms.

The general wind power potential was determined from the wind speed data available, and then wind maps were developed. In general, the wind speed data that were available were at heights of 6 to 20 m; however, some anemometers were on top of buildings or control towers at airports, which influences the accuracy of the data. In many parts of the world the amount of wind speed data was limited to daily or even monthly averages.

Wind is a sustainable energy source since it is renewable, widely distributed, and plentiful. In addition, it contributes to reducing the greenhouse gas emissions since it can be used as an alternative to fossil-fuel-based power generation. Wind turbines capture the kinetic energy of wind and convert it into a usable form of energy. The kinetic energy of winds rotates the blades of a wind turbine. The blades are connected to a shaft. The shaft is coupled to an electric generator. The generator is used to convert the mechanical energy into electrical energy.
III. PROPOSED SYSTEM

An alternative multi-input rectifier structure is proposed for hybrid wind and solar energy systems as shown in fig 7. The proposed design is a fusion of CUK and SEPIC converters which eliminate the need for separate passive filter and support step up/down operations for renewable energy sources.

A hybrid wind-solar energy system is shown in fig 8, where one of the inputs is connected to the output of the PV array and the other input connected to the output of a wind 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.

The various switching states of the proposed converter are shown in fig 9-12. If the turn on duration of M1 is longer than M2, then the switching modes will be mode I, II, IV. Similarly, the switching states will be mode I, III, IV if the switch conduction periods are vice versa.

Mode I (M1-ON, M2-OFF)

In this mode both solar energy and wind energy is available, the switches M1 and M2 are turn ON. The capacitors C1 and C2 connected across diode D1 and D2 respectively then diodes D1 and D2 experience reverse biased. The equivalent circuit is as shown below.
In this mode only solar energy is available and wind energy is not available. The switch M1 turns ON and switch M2 turns OFF. The diode D1 experiences reverse bias. The inductor current in L3 forces diode D2 to conduct. The equivalent circuit is as shown in the figure.

Analysis of proposed circuit

The DC output voltage can be calculated as follows:

\[ V_{pv} - PV \text{ array voltage} \]
\[ V_w - \text{Voltage occurs when wind source is available} \]
\[ D_1 - \text{Duty ratio of switch M1} \]
\[ D_2 - \text{Duty ratio of switch M2} \]
\[ F_s - \text{Switching frequency} \]
\[ T_s - \text{Switching period} \]

The net change in the inductor current L1 is zero

\[(\Delta i_{L1})_{\text{closed}} = \left(\frac{V_{pv}}{L_1}\right) * D_1 * T_s \] (1)
\[
(\Delta i_{L1})_{\text{open}} = \left(\frac{V_{pv}}{L_1}\right) \ast (1 - D_1) \ast T_s \\
(\Delta i_{L1})_{\text{closed}} + (\Delta i_{L1})_{\text{open}} = 0 \\
V_{c1} = \frac{V_{pv}}{1 - D_1} \\
\]

The net change in the inductor current \(L_3\) is zero

\[
(\Delta i_{L3})_{\text{closed}} = \left(\frac{V_w}{L_3}\right) \ast D_2 \ast T_s \\
(\Delta i_{L3})_{\text{open}} = \left(\frac{V_w - V_{c2} - V_{dc}}{L_3}\right) \ast D_2 \ast T_s \\
(\Delta i_{L3})_{\text{closed}} + (\Delta i_{L3})_{\text{open}} = 0 \\
V_{c2} = \left(\frac{V_w}{1 - D_2}\right) - V_{dc} \\
\]

The average voltage across inductor \(L_2\) is zero

\[
(V_{c1} + V_{c2}) \ast D_1 \ast T_s + (V_{c2}) \ast (D_2 - D_1) \ast T_s + (1 - D_2)(-V_{dc}) = 0 \\
\]

Substituting equation (4) and (8) in (9)

Then \(V_{dc}\) is given by

\[
V_{dc} = \left(\frac{D_1}{1 - D_1}\right) \ast V_{pv} + \left(\frac{D_2}{1 - D_2}\right) \ast V_w \\
\]

Thus from the above equation it is observed that the DC link voltage \(V_{dc}\) is controlled by controlling duty cycles \(D_1\) and \(D_2\) simultaneously or individually.

Design of \(L\) and \(C\) components

The inductor values \(L_1, L_2,\) and \(L_3\) are given by:

\[
L_1 = \frac{V_{pv}}{\Delta i_{L1} \ast F_s} \\
L_2 = \left(1 - D_1\right) \ast \frac{R}{2 \ast F_s} \\
L_3 = \frac{V_w}{\Delta i_{L3} \ast F_s} \\
\]

The capacitors \(C_1, C_2,\) and \(C_3\) are given by:

\[
C_1 = \frac{D_1}{\left(R \ast F_s \ast \frac{\Delta V_{c1}}{V_0}\right)} \\
C_2 = \frac{(1 - D_2)}{Bl_2 \left(\frac{\Delta V_{c1}}{V_0}\right) F_s^2} \\
\]

V. MAXIMUM POWER POINT TRACKING (MPPT)

The I-V and P-V characteristics of solar cells are affected by conditions of radiation and temperature. The voltage and current should be controlled to track the maximum power of PV systems. MPPT techniques are used to extract the maximum available power from solar cells. Systems composed of various PV modules located at different positions should have individual power conditioning systems to ensure the MPPT for each module. In this paper perturb and
observe (P&O) method is used for maximum power point tracking.[8]

The voltage from PV array is perturbed in a given direction and if the power drawn from PV array increases, the operating point closer to maximum power pint of P-V curve. If the voltage is perturbed and results in decrease in the power then the point of operation is away from maximum power point. The flow chart is as shown in fig 15.

Fig15: Flow chart of perturb and observe method

VI. INVERTER

DC-to-AC converters are known as Inverters. The function of an Inverter is to change a DC input voltage to a symmetric AC output voltage of a desired magnitude and frequency [9]. The output voltage waveforms of ideal Inverters should be sinusoidal while the practical Inverters are non-sinusoidal and contain certain harmonics. For low and medium power applications, square-wave or quasi-square-wave voltages may be acceptable and for high power applications, low distorted sinusoidal waveforms are required.

VII. SIMULATION RESULTS

The hybrid wind and solar energy systems using conventional boost converter is studied. The hybrid wind and solar energy systems using CUK-SEPIC fused converter is studied and simulated. The simulation tool used is PSIM. The simulation for constant weather conditions is considered as open loop and results are shown in fig 16. For the variations of temperature and radiation of sun falling on earth the I-V and P-V characteristics gets affected and to overcome the drawback the MPPT technique called perturb and observe method is employed for PV panel and for variation wind speed the closed loop PI controller with suitable $K_p$ and $K_i$ values to adjust the duty cycle of SEPIC converter by using Ziegler-Nichols method. The results are shown in fig 17. The results of CUK-SEPIC converter includes PV array voltage, Wind turbine rectified voltage, DC link voltage and load voltage.

Fig16: Waveforms of PV array voltage, wind turbine output (rectified), DC link voltage, Load Voltage (open loop)

Fig17: Waveforms of PV array voltage, wind turbine output (rectified), DC link voltage, Load voltage (closed loop)

VIII. CONCLUSION
In this paper the CUK-SEPIC converter has been proposed for hybrid wind and solar energy system instead of conventional multiple boost converters. The system has following advantages compared to traditional approach:

1) Two boost converters are replaced by single CUK-SEPIC fused converter.
2) Additional input filters are not required to filter out high frequency harmonics because of inherent input filter.
3) Energy storage and transfer depends on capacitors of converter.
4) Both renewable energy sources can be stepped up/down by using converter and which supports wide range of PV and wind input variation.
5) It supports both individual and simultaneous operation of sources.

REFERENCES