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CUK-SEPIC fused MPPT converter using Inverted Sine PWM Technique for a Grid Connected Hybrid Renewable Energy System

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ABSTRACT

Prominence of Non-conventional energy sources is ever increasing in order to protect our deteriorating planet. This paper presents a standalone hybrid Wind/photovoltaic power generation system. Based on the availability of energy sources, this configuration allows the two sources to supply the load either individually or simultaneously. The proposed design is a fusion of Cuk and Sepic converters which eliminate the need of additional input filters to filter out the high frequency harmonics. Maximum Power Point Tracking (MPPT) technique used is Modified Incremental conductance algorithm due to its high tracking accuracy and precise control under rapidly changing atmospheric conditions. A new parabolic prediction technique is applied for tracking the maximum power and Inverted sine PWM technique is applied for minimizing the harmonic contents in the output power. Simulation results were obtained using MATLAB/Simulink

Keywords : DC-DC converter, Incremental conductance (IncCond), Maximum Power Point Tracking (MPPT), Cuk converter, SEPIC converter, Inverted Sine PWM

I. INTRODUCTION

The conventional energy sources are depleting and relying on the non-conventional energy sources is the only way to meet global energy crisis in order to preserve the earth for the future generations. Solar energy and wind energy has become the least expensive renewable energy technology in existence and has attracted the interest of scientists and educators over the world [1]. Photovoltaic cells convert the energy from sunlight into DC electricity. PVs are advantageous over other renewable energy sources such as they give off no noise and require practically no maintenance [15] and green house emissions are reduced[1]-[3]. The presence of solar and wind is unpredictable since they depend on the weather conditions like insolation (incident solar radiation) levels, shadows by birds, clouds and temperature. Standalone solar photovoltaic and standalone wind systems have been promoted around the globe on a comparatively larger scale. These independent systems cannot provide continuous source of energy, as they are seasonal.

A. Hybridization of Renewable energy sources

Hybrid renewable energy systems (HRES) are becoming popular for remote area power generation applications due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. In order to satisfy the load demand, one or more renewable energy sources can be combined together. A wind and solar hybrid system can supply more stable power than a single wind or PV source [2]. The solar and wind energies are complementing nature. By integrating and optimizing the solar photovoltaic and wind systems, the reliability of the systems can be improved and the unit cost of power can be minimized. Hybridizing solar and wind power sources provide a realistic form of power generation and is able to satisfy the load demand. By hybridizing the solar and wind sources power generation can be improved. The prime aim of this paper is to extract the maximum amount of power from sources such as wind, Solar depending on the availability and by incorporating Maximum Power Point Tracking techniques. A hybrid power system consisting of these renewable energy sources which can be made into operation by proper utilization in a completely controlled manner.

B.MPPT Methods

Maximum Power Point Tracking technologies have been used in photovoltaic systems to deliver the maximum power output to the load under rapidly changing conditions of solar isolation and temperature. All MPPT methods follow the same goal which is maximizing the PV array output power by tracking the maximum power on every operating condition. There are different techniques for MPPT such as Perturb and Observe (hill climbing method),Incremental conductance, Fractional Short Circuit Current, Fractional Open Circuit Voltage, Fuzzy Control, Neural Network Control etc. Among all the methods Perturb and observe (P&O) and Incremental conductance are most commonly used because of their simple implementation, lesser time to track the MPPT and several other economic reasons. The P&O method [15], [18] is perturbation in the operating voltage of the PV array. However, the P&O algorithm cannot compare the array terminal voltage with the actual MPP voltage, since the change in power is only considered to be a result of the array terminal voltage perturbation. Thus, there are some disadvantages with these methods, where they fail under rapidly changing atmospheric conditions [19]. MPPT fuzzy logic controllers have good performance under varying atmospheric conditions and exhibit better performance than the P&O control method [8]; however, the main disadvantage of this method is that its effectiveness is highly dependent on the technical knowledge of the engineer in computing the error and coming up with wrong MPP. Incremental algorithm overcomes the above mentioned disadvantages and is successfully used in tracking the maximum power under uniform isolation where only one maximum power point (MPP) exists in the power against-voltage (P–V) curve. However, in partially shaded condition where there are multiple MPPs in the P-V curve, the conventional algorithms are unsuccessful in identifying the global MPP (GMPP) among the local MPPs (LMPPs), therefore reducing the overall efficiency of the PV system [12]–[14].Concerning the multiple-peak issue during partial shading, several solutions have been proposed by modifying the conventional algorithms. As reported in [15], Inc Cond algorithm is altered to to track the GMPP . P&O algorithm is widely used to track the MPPs and GMPP [22]. However, under rapid-varying solar irradiation, the P&O algorithm may fail to track the MPPs accurately [23]. In this paper, a modified Inc Condi algorithm is proposed which effectively utilizes the periodic P-V characteristics of partially shaded condition described in [22]. This modified algorithm was successfully demonstrated in tracking the GMPP under varying loads and weather conditions and in addition it eliminates the sensor circuitries at the output of dc–dc converter.

C. Fused converter Topology

A simpler multi input structure is proposed [5] that combine the sources from the DC-end while still achieving MPPT for each renewable source and the structure proposed by [5] is a fusion of the buck and buck-boost converter. This requires passive input filters to remove the high frequency current harmonics injected into wind turbine generators [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 [9]. The circuit operating principles will be discussed in this paper. Simulation results are provided to verify with the feasibility of the proposed system.

II. PROPOSED MULTI INPUT CONVERTER TOPOLOGY

DC-DC converters can be used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage. The regulation is normally achieved by Pulse Width Modulation at a fixed frequency using the switching devices like BJT, MOSFET or IGBT. Now-a-days, MOSFETs are used as a switching device in low voltage and high current applications. It may be noted that, as the turn-on and turn-off time of MOSFETs are lower as compared to other switching devices, the frequency used for the dc-dc converters using it (MOSFET) is high, thus, reducing the size of filters as stated earlier. Many consider the basic group to consist of the three: BUCK, BOOST and BUCK-BOOST converters. The CUK, essentially a BOOST-BUCK converter, may not be considered as basic converter along with its variations: the SEPIC and the zeta converters

A. Block Diagram of Proposed system

In this paper, a new converter topology for hybridizing the wind and solar energy sources has been proposed. In this topology, both wind and solar energy sources are incorporated together using a combination of Cuk and

SEPIC converters, so that if one of them is unavailable, then the other source can compensate for it. Solar energy source is the input to the Cuk converter and wind energy source is the input to the SEPIC converter. The average output voltage produced by the system will be the sum of the inputs of these two systems.

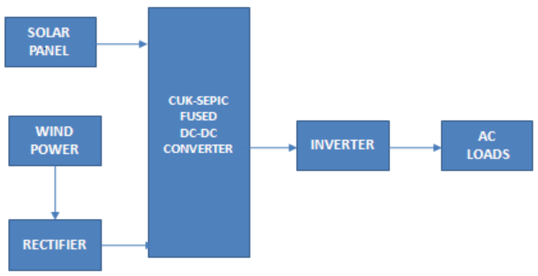


Figure 1. Block Diagram of the proposed Cuk-SEPC fused converter

The Cuk-SEPIC fused converters have the capability to eliminate the HF current harmonics in the wind generator. This eliminates the need of additional passive input filters in the system also step-up or step-down the input voltage during startup and overload conditions, lower input current ripple, and less electromagnetic interference (EMI) associated with the DCM topology[30]. These converters can support step up and step down operations for each renewable energy sources. They can also support individual and simultaneous operations. All these advantages of the proposed hybrid system make it highly efficient and reliable. 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 simultaneous operation is supported. The converter is operating in discontinuous capacitor voltage (DCV) mode where its input current is kept continuous. The Cuk and SEPIC converters operating in discontinuous current mode (DCM) can offer a number of advantages, such as inherent PFC function, very simple control, soft turn-on of the main switch, and reduced diode reversed-recovery losses. The SEPIC and Cuk converters offer several advantages in PFC applications, such as easy implementation of transformer isolation, inherent inrush current limitation. In SEPIC and Cuk converters, the average voltage across each inductor is zero whilst the average voltage across ,V_c , is as follows.

For SEPIC, $V_{c=} V_i$

For Cuk converter $V_{c=} V_o$

The output of DC-DC converters are sent to an external DC-AC inverter to supply AC power to the load. So the new proposed input side converter topology with maximum power point tracking method to meet the load and opt for a grid connected load as well as commercial loads. The implementation of new converter topology will eliminate the lower order harmonics present in the hybrid power system circuit.

B. Circuit Diagram of Multi-input Cuk-SEPIC converter

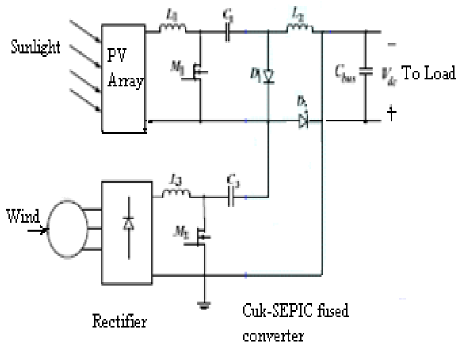
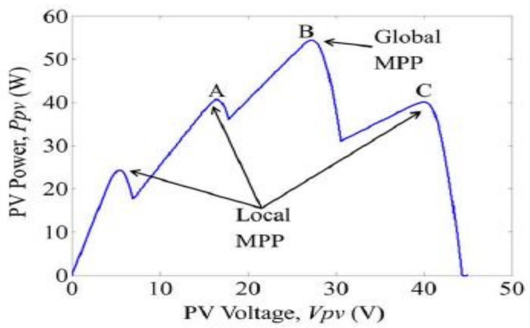


Figure 2. Circuit Diagram of the proposed Multi inputCuk-SEPIC fused converter

When only wind source is available,(i.e) When M2 is on condition, in the hybrid system, Wind energy will meet the load by a sepic converter operation. The wind energy will produce the Ac power, the Ac power further converted to dc power by using the rectifier. 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. Thus, individual and simultaneous operation is supported depending on the availability of sources.

III. MODIFIED INCREMENTAL CONDUCTANCE ALGORITHM FOR THE PROPOSED CIRCUIT

A Maximum Power Point Tracking algorithm is necessary to increase the efficiency of the solar panel. There are different techniques for MPPT such as Perturb and Observe (hill climbing method),Incremental conductance, Fractional Short Circuit Current, Fractional Open Circuit Voltage, Fuzzy Control, Neural Network Control etc. Among all the methods Perturb and observe (P&O) and Incremental conductance are most commonly used because of their simple implementation, lesser time to track the MPPT and several other economic reasons. Under partial shading conditions, multiple peaks are observed in the power–voltage (*P–V*) characteristic curve of a photovoltaic (PV) array, and the conventional maximum power point tracking (MPPT) algorithms may fail to track the global maximum power point (GMPP). Therefore, this paper proposes a modified incremental conductance (Inc Cond) algorithm that is able to track the GMPP under partial shading conditions and load variation. Inc Cond algorithm is implemented instead of P&O algorithm due to its consistent performance under fast-varying weather conditions. The GMPP is located in the middle of three consecutive peaks.



The proposed algorithm finds three consecutive peaks and locates the one which has the highest magnitude. If the GMPP is not in the middle of the three peaks, the algorithm continues to explore until the GMPP is in the middle or until the end of the *P–V* curve where the lowest or highest possible voltage is reached. The flowchart is shown below

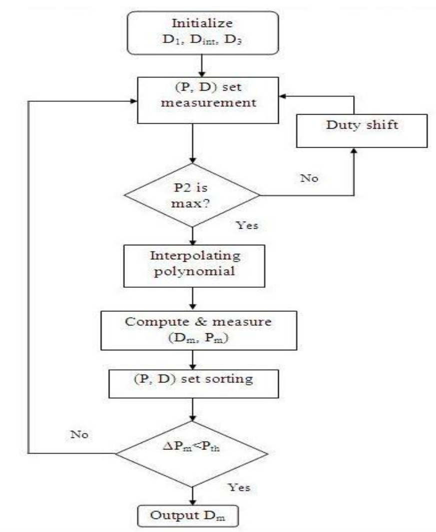


Figure 3. Flow chart for the proposed Incremental conductance algorithm

A parabolic function Q(x) can be represented for estimating the objective function f(x) and is given by

$$Q(x) = Ax^2 + Bx + C \quad (1)$$

$$Q(x) = f(x_0)\frac{(x-x_1)(x-x_2)}{\Delta x_{01}\cdot\Delta x_{02}} + f(x_1)\frac{(x-x_0)(x-x_2)}{\Delta x_{10}\cdot\Delta x_{12}} + f(x_2)\frac{(x-x_0)(x-x_1)}{\Delta x_{20}\cdot\Delta x_{21}} \quad (2)$$

where,

$$\Delta x_{ij} = x_i - x_j \quad i, j = 0,1,2 \quad (3)$$

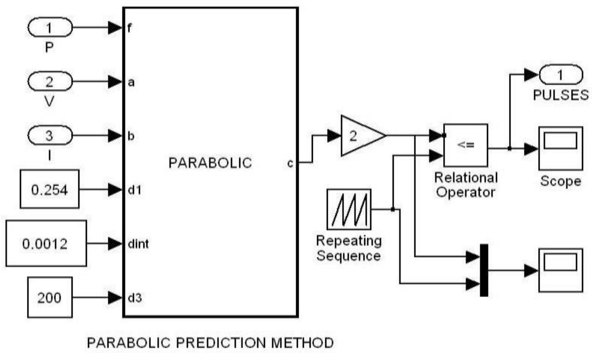


Figure 4. Simulation diagram for proposed MPPT technique

The proposed algorithm is able to track the GMPP accurately and thus reduces the power losses faced by the conventional algorithm

IV. EXRERIMENTAL RESULTS

The MATLAB/Simulink software is used to perform simulation. When Wind source has failed and only the PV source (Cuk converter mode) is supplying power to the load. Figure illustrates the system where only the wind turbine generates power to the load (SEPIC converter mode). Finally, Figure 4 illustrates the simultaneous operation (Cuk-SEPIC fusion mode) of the two sources where M2 has a longer conduction cycle.

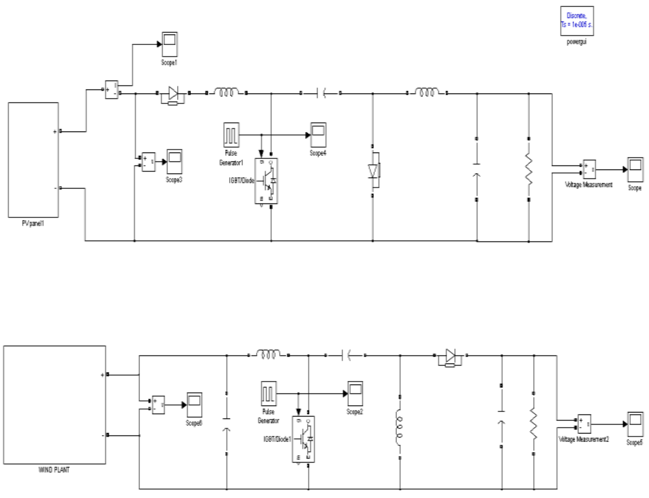


Figure.5. Simulation Model for individual Cuk and Sepic mode operations

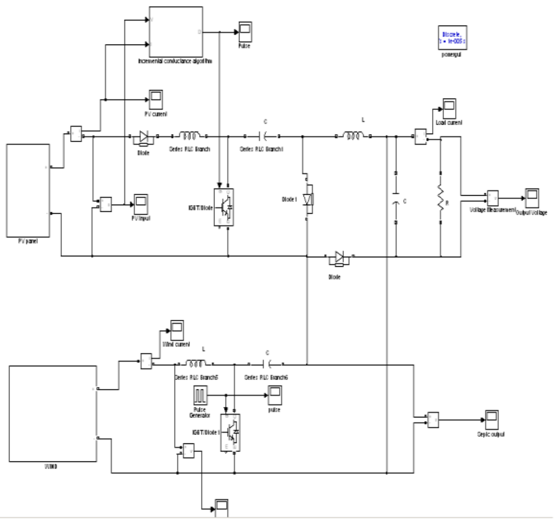


Figure.6 Simulation Model for Closed loop Hybrid Energy System

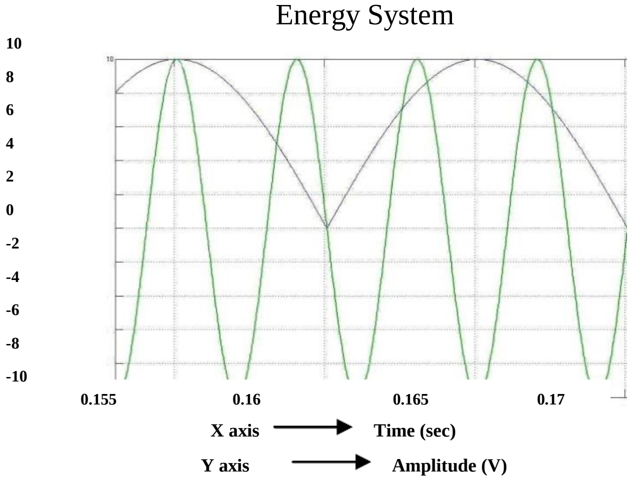


Figure 7Carrier and reference signals

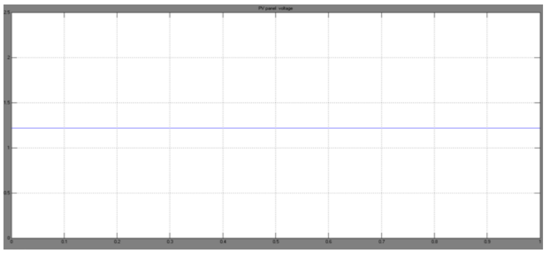


Figure 8 PV Panel Output Voltage

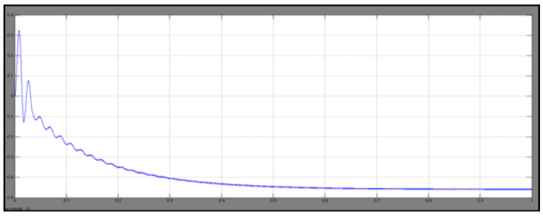


Figure 9 PV Panel Output Voltage After Cuk Converter Operation

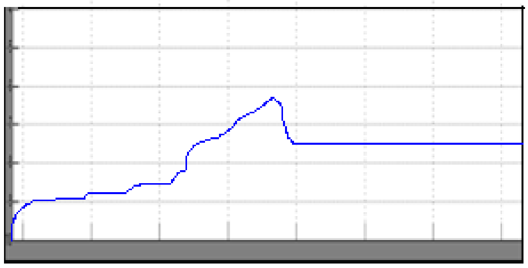


Figure 10 Modified Incremental Conductance Output Voltage To Cuk Converter

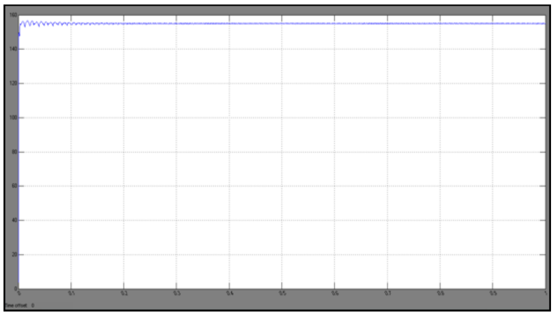


Figure 11 Wind Output To Sepic Converter

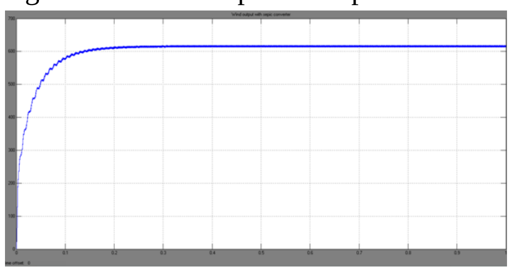


Figure 12 Wind Output After Sepic Converter Operation

A.Closed Loop Model Output With Cuk-Sepic Fused Converter

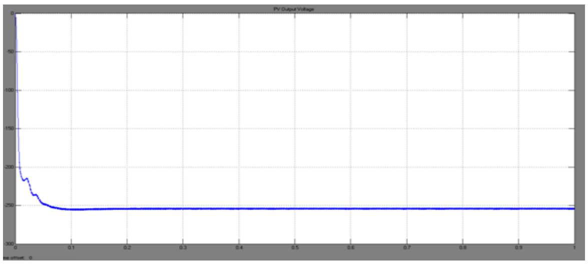
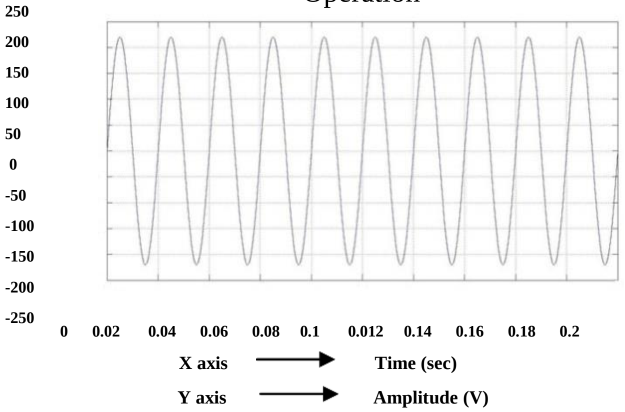


Figure 13 :PV Panel Output Voltage After Cuk –Sepic Operation



PARAMETERS OF WIND & SOLAR MODEL

Wind Turbine	
Generator speed	200 RPM
Pitch angle	1 deg
Wind speed	12 m/s
Solar	
Irradiance	5
I_{SC}	70 Amp
V_{OC}	40 Volt
Temperature	15 deg Celsius

TABLE-II
PARAMETERS OF CUK CONVERTER MODEL

Parameters	Value
Input Voltage, Vd	60V
Output Voltage, Vo	100V
Switching frequency, f_s	20kHz
Duty cycle, D	0.625
Output Current, Io	1 A
L1	3.75 mH
L2	6.25 mH
C1	3.907 µF
C2	1 µF
R	100 Ω

TABLE-II
PARAMETERS OF SEPIC CONVERTER MODEL

Parameters	Value
Input Voltage, Vd	70V
Output Voltage, Vo	100V
Switching frequency, f_s	20kHz
Duty cycle, D	0.5714
Output Current, Io	1 A
L1	5.371 mH
L2	7.1433 mH
C1	3.265
C2	1 µF
R	100 Ω

The experimental setup is shown in Fig.14 The Microcontroller from Microchip Technologies(PIC 16F877A) is used as the MPPT controller to implement the proposed algorithm. We use fixed voltage regulator namely LM7805.The IC LM7805 is a +5v regulator which is used for microcontroller. Full bridge rectifier – rating 5A, filter capacitor – 1000 micro farad, 63V is used for rectification. For many applications, especially with single phase AC where the full-wave bridge serves to convert an AC input into a DC output, the addition of a capacitor may be important because the bridge alone supplies an output voltage of fixed polarity but pulsating magnitude and a filter is used for output smoothing. Driver circuit performs three operations which are amplification, Isolation and Impedance matching. The microcontroller is a sensitive device and MOSFET carries high current, in order to provide isolation between the two, isolation is being provided by the opto coupler. Optp coupler MCT2E – 1 K, 100 Ω resistance. The operation of power supply for microcontroller circuits built using filters, rectifiers, and then voltage regulators.

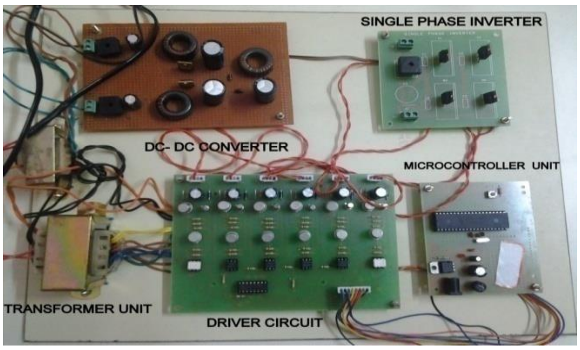


Figure 14 .Proposed converter Topology

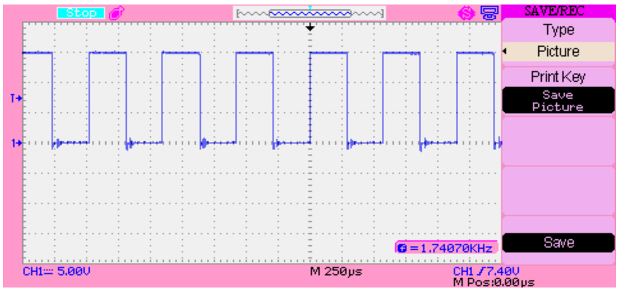


Fig.15.SEPIC Converter SWITCH pulse.

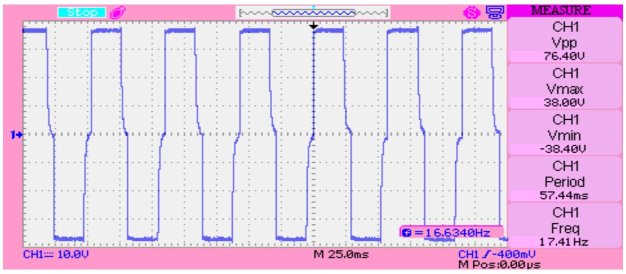


Figure 16 PULSED AC Output From Solar and Wind as Source.

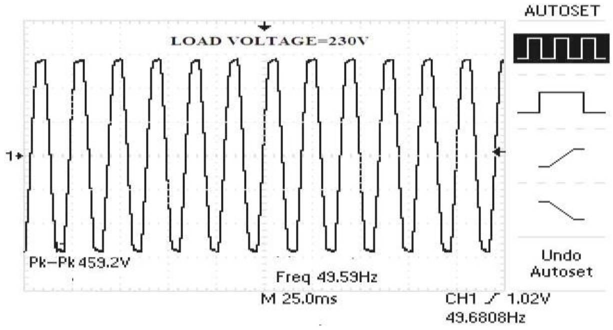


Figure 17. Inverter output

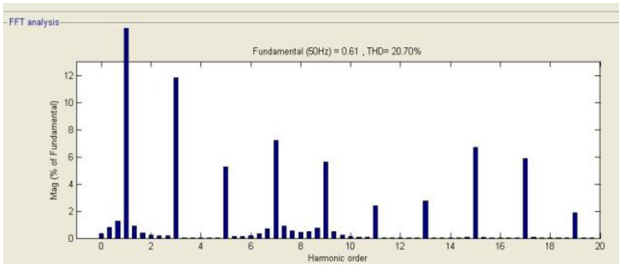


Figure 18 Harmonic spectrum without ISPWM

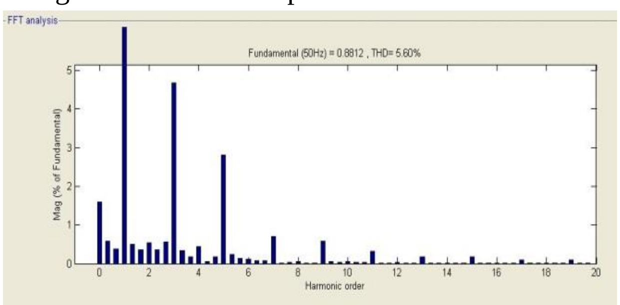


Figure19. Harmonic spectrum with ISPWM

The proposed overall experimental set up is shown. The generated PWM pulses from the controller will be given to the inverter circuit and it controls its ac output with low THD. The experimental results have been observed by a Digital storage Oscilloscope. The simulation and experimental results showed that the proposed algorithm is able to track the GMPP Accurately and thus reduces the power losses faced by the conventional algorithm. The experimental results also showed that the proposed algorithm is able to respond rapidly and accurately to the variation in the load.

V. CONCLUSION

In this paper a fused Cuk-SEPIC converter stage for hybrid wind/solar energy systems has been presented. This topology makes continuous power generation possible in order to meet the load demand by allowing the two sources to supply the load either individually or simultaneously. The advantages of proposed converter are eliminating the need of additional input filters to filter out the high frequency harmonic**s**, supports wide ranges of PV and wind input, low input current distortion, low conduction losses and improving the conversion efficiency using Maximum Power Point Tracking algorithm. Simulation results have been presented using MATLAB/Simulink to verify the features of the proposed topology. This system has lower operating cost and finds applications in remote area power generation, constant speed and variable speed energy conversion systems, aerospace industries, electric vehicles, communication equipment and rural electrification.

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