

Analysis of Single Switch, CUK/SEPIC based Multi-Port Converters

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Abstract— Multi-port converters are used to combine two or more energy sources to give it to the load so as to meet the peak load demand. It achieves high conversion ratio and high efficiency, thus the voltage inputs are boosted to give higher output voltages due to its high voltage gain and the voltage step up capability. The objective is to achieve the voltage step up capability by using the Renewable Energy Sources such as the Wind Energy Systems and Photovoltaic Systems. Here the comparison between the three different PFC converters have been made and thus the SEPIC based PFC is found to be less harmonic and efficient. The Single Switch and the SEPIC/CUK based Multi-Port converters have been simulated and the voltage and Harmonic values have been compared using MATLAB/SIMULINK Software.

Keywords— Multi-Port Converter, FSTPI, SEPIC, SSTPI.

I. INTRODUCTION

Multiport converters interfacing with several power sources and storage devices are widely used in recent years, independent power converters used for each of the energy sources, common high-voltage or low-voltage DC bus is used to interconnect multiple sources. Existing multiport structure is inherently complex also overpriced due to the multiple conversion stages and communication devices between individual converters [1]. Based on power electronics technique, the diversely developed power conditioners including dc–dc converters are essential components for clean-energy applications. Generally, one power source needs a dc–dc converter either for raising the input voltage to a certain band or for regulating the input voltage to a constant dc-bus voltage [2].

However, conventional converter structures have the following disadvantages: 1) large size; 2) complex topology; and 3) expensive cost. In order to simplify circuit topology, improve system performance and reduce manufacturing cost, multi-input converters have received more attention in recent years. The isolated dc–dc converter has multiple input ports for connecting different sources, such as Battery, photovoltaic (PV) panels, wind turbine generators (WTGs), fuel cells, and so on[3]. The multiport dc–dc converter not only regulates the low-level dc voltages of the sources to a constant high level required by the inverter, but also can provide other important control functions, such as maximum power point tracking (MPPT), for the renewable energy sources. [7]

A High step-up multi-port dc-dc converter has the following advantages:

1. High voltage conversion ratio is achieved by using coupled inductors.
2. Simple converter topology which has reduced number of the switches and associate circuits.
3. Simple control strategy which does not need change the operation mode after a charging/discharging transition occurs unless the charging voltage is too high.
4. Output voltage is always regulated at 380 V under all operation modes.

The multiport AC/ DC-DC converter can be used to interface multiple power sources and storage devices. It regulates the system voltages and manages the power flows between the sources and the storage elements [4]. For small hybrid power systems, the multiport concept can provide a reduced parts-count solution compared with the conventional structure that uses multiple converters [5], [13]. A multiport converter may best satisfy integrated power conversion, efficient thermal management, compact packaging, and centralized control requirements.

II. WIND ENERGY CONVERSION SYSTEM USING PMSG

From all the generators that are used in wind turbines the PMSG's have the highest advantages because they are stable and secure during normal operation and they do not need an additional DC supply for the excitation circuit

(winding). Initially used only for small and medium powers the PMSG's are now used also for higher powers. With the developments in permanent magnetic materials, the efficiency and the performance of PMSG based wind turbine systems have been improved and widely used. These systems require neither slip rings nor an additional power supply for magnetic field excitation.

They can also operate in a relatively wide range of wind speeds. Therefore, their efficiency is known to be higher than that of any of the aforementioned wind turbine systems. The power converter with wind turbine is shown below in figure 1. However, a PMSG based wind turbine system requires a full-scale power converter which directly connects the generator to the grid. The rating of the power converter is usually limited by available semiconductor technology.[5]

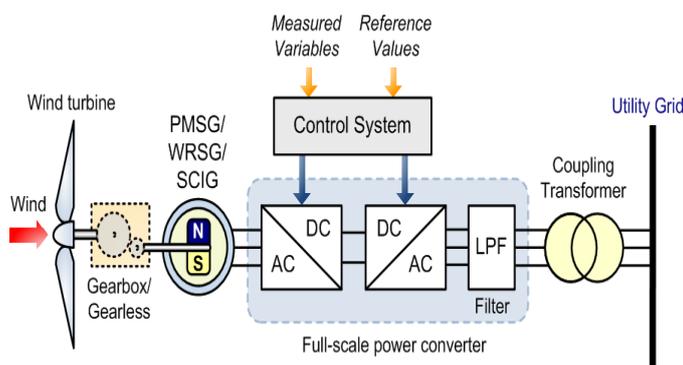


Fig.1. Wind Turbine using PMSG

One effective way of reducing the power converter's rating requirement is to connect multiple power converters in parallel. If three power converters are connected in parallel, then the capacity of each power converter can be reduced to one third of the total capacity of the wind turbine system [6]. The Wind Energy System consists of the Horizontal Axis Wind turbine connected to the PMSG via the gear box which controls the speed ratio. Power converter part consists of the AC – DC converter coupled with DC – AC inverter through a link capacitor. The control system uses the difference between the measured and the reference values for the pulse generation. The LC Low Pass Filter is used to remove the harmonic content and is connected to the utility grid through a Coupling Transformer.

III. PROPOSED INVERTER SYSTEM WITH SINGLE SWITCH CIRCUIT

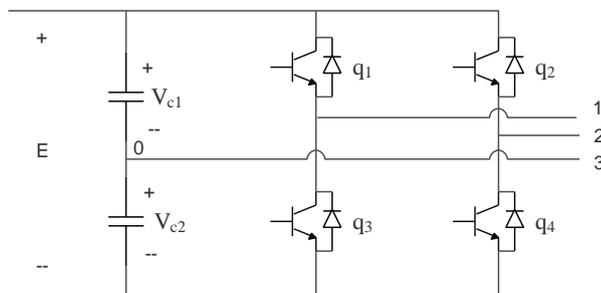


Fig.2. Four Switch Inverter Circuit

A three-phase VSI uses three legs i.e. six-switch three-phase voltage source inverter (SSTPI) with two pair of power switches per phase. The Four Switch Three Phase Inverter Circuit (FSTPI) topology generates four vectors in plane instead of six, as generated by the SSTPI topology. Reduced switch count VSI uses only two legs, with four switches also known as Four Switch Three Phase Inverter (FSTPI).The topology circuit of the Four Switch Inverter circuit is given in the figure 2. Thus the third leg is derived from the centre of the two capacitors V_{c1} and V_{c2} . Thus the output of the FSTPI is given to the load. Thus the dc input is given to the Proposed Four Switch Inverter Circuit which uses the neutral between the V_{c1} and V_{c2} . Thus the output terminal 1 and 2 are taken from the two legs of the inverter and the third terminal is from the neutral point.

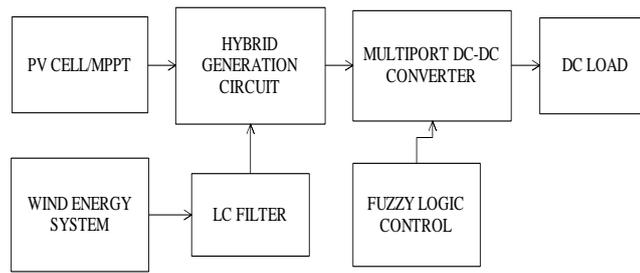


Fig.3. Block Diagram of Multi Port Full Bridge Rectifier

Thus the Fig: 3 shows the block diagram of the Multi Port Full Bridge Rectifier, where the Hybrid Generation Circuit is used to couple the inputs from the PV Cell and the Wind Energy System respectively. Thus the DC output from the Hybrid Generation Circuit is fed to the Multi-Port DC-DC converter, which regulates the DC power supply to the LOAD.

A. PARAMETERS OF WIND TURBINE

TABLE I: INDUCTION MACHINE PARAMETERS

Parameter	Value
Power	0.37 kW
Voltage	230/400V
Speed	1000 RPM
Torque	2.56 Nm
Current	0.15 A
Frequency	50 Hz
Stator Resistance (r_s)	24.6 Ω
Rotor Resistance (r_r)	17.9 Ω
Stator Inductance (L_s)	984 mH
Rotor Inductance (L_r)	984 mH
M	914 mH
J	2.15 g.m ²

TABLE II: PARAMETERS OF WIND TURBINE

Types	Variable Speed Type
Air density	2.065
Turbine radius (m)	0.74
Rated power (MW)	2
Cut –in wind speed, m/s	3
Optimum coefficient Nm(rad/s) ²	1.6*10 ⁻⁴

Thus the table II shows the wind parameters of the wind energy system. Where the output of the coupling transformer is stepped up to the 33kV for an input voltage of 700V.

TABLE III: PARAMETERS OF THE SIMULATION CIRCUIT

Parameters	Values
L	200uH
C	2.2uF
C_r	37uF
L_m	1.7mH
L_{lk}	145uH
C_1, C_2	270uF

The Table III shows the parameter values of the simulation circuit. The Table I shows the parameters including Stator and Rotor Resistances and Inductance values and current density J.

B. SIMULATION RESULT

The Simulation of fuzzy logic based DTC FSTPI fed AC motor with the Solar and the Wind energy generation has been shown in the figure 4.

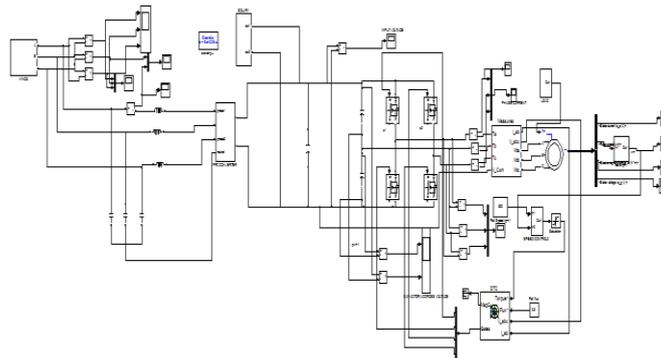


Fig.4. Simulation Circuit

In the Proposed method, two input ports (wind, PV) are deal with single high voltage AC drive application. Unity PFC, THD values have been achieved. FSTPI and the control strategy of novel Direct Torque Control with fuzzy logic scheme is used to eliminating two switches of the conventional six - switch three-phase inverter (SSTPI) and achieve dynamic speed.

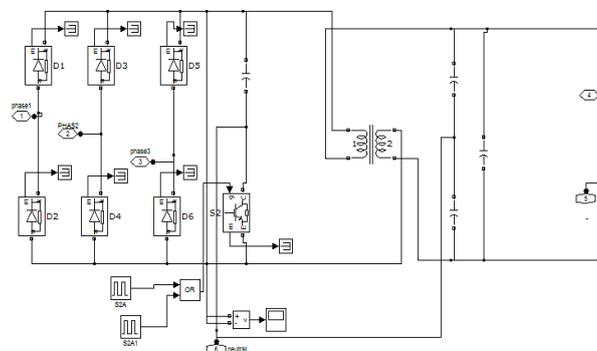


Fig.5. Single Switch Boost Circuit

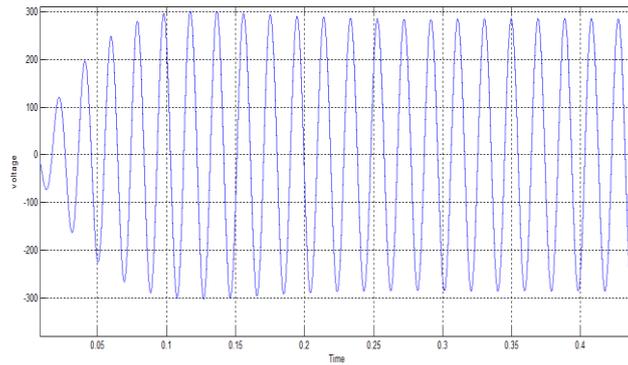


Fig.6. Wind Output Voltage

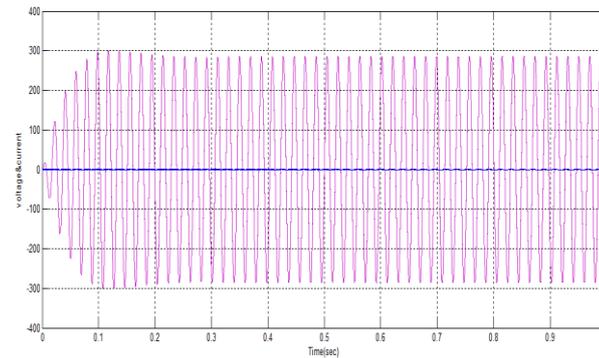


Fig.7. PFC result

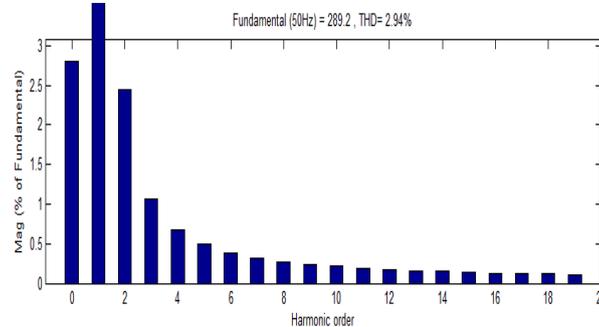


Fig.8. THD Result

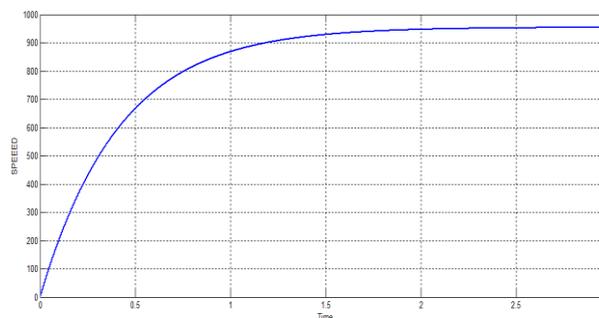


Fig.9. Generator speed

The measured input voltage at 290 and 380VL-L, RMS were 2.9 % and 3.48 % respectively. The Harmonic Content (THD) reached up 2.94% is shown in Fig 8. Thus the Fig. 5 represents the single switch boost circuit which uses the Linear Transformer and the Fig.6 represents the wind output voltage is 280 V.

Thus the constant voltage value is reached within 0.25 ms. As the result of the application of the Power Factor Correction the voltage value becomes constant by 0.2 ms, which is shown in the Fig. 7. The Fig. 9 shows the generator speed of 950 rpm.

IV. PROPOSED INVERTER SYSTEM WITH CUK/SEPIC CIRCUIT

Full bridge converter has the integrated circuit of Cuk /SEPIC converter for PV and wind power generation and isolated full bridge DC-DC converter circuit shown in fig.10 Isolated full bridge converter consists of buck – boost converter circuit and fly back circuit. The SEPIC/CIK converter helps to boost the input voltage levels to the converter. The interleaved double dual boost (IDDB) is a non-isolated step-up dc-dc converter capable of high voltage gain and suitable to high-power applications [11]. The analyses of CUK converter involves the use of steady-state and dynamic small signal models of the converter to determine the responses of the converter when operating in the operational continuous current mode (CCM). In the subsequent, parasitic resistances are negligibly small, and all elements are assumed ideal [12].

The Single Ended Primary Inductor Converter consists of the output which is either greater or less than the input voltage thus the output value is controlled by the duty cycle “D” During the operation, the switch S switches on and off by an externally applied control signal at a switching frequency ‘fs’ and duty ratio “D” within the period T. CCM operation implies that inductor currents do not fall to zero at any instant within the period. The operation of the converter within the period T can be divided into two states for CCM operation where duty cycle of the converter is $D = T_{on} / T$ and $D' = 1 - D$. Multiport converter is the one of the converter which is containing more than one port either input or output side [8]. The different types of converter perform in recent trends. In this chapter we have discussion about CUK and SEPIC converter. The CUK converter performs better over than buck, boost and buck-boost [9]. These converter mainly used for power factor correction and which is located after the WIND/PV [10]. It has the capability of either getting the output voltage greater than or less than the input voltage. Thus the SEPIC/CIK converter not only boost the input voltage but also acts as the voltage regulator. The L-C combination used in the end of the converter eliminates the higher order harmonics.

A. SIMULINK PARAMETERS

A 2 kW simulation module is used for a system with a range of 10-140V. Switching frequency of proposed converter is fixed at 100 kHz, wind source voltage $V_w=150V$, PV source voltage $V_{pv}= 10-15V$. Hybrid converter output voltage $V_{out}=230V$. The output voltage waveform is shown in the fig. 11. Thus here the simulation circuit for the proposed system with CUK/SEPIC converter has been proposed. The fig.10 shows the Simulation circuit for the CUK/SEPIC converter has been presented. The output voltage of the PMSG is shown in the Fig.12. Fig.13 shows the load voltage and the load current of the multi-port system. Fig.14 shows the harmonic content of the entire system. Thus hybrid system consists of the PV and the Wind energy System combined using the single switch inverter topology, where the voltage regulation is done by using the SEPIC/CIK converter. This type of system is used for the high power applications where the reduction in harmonic content plays a major role. The proposed SEPIC based rectifier circuit integrated to wind source and achieved better PFC correction and THD reduction. High step-up continuous voltage regulation is achieved via isolated DC-DC converter. SEPIC and CUK converter circuit improves the Maximum Power generation of wind/PV.

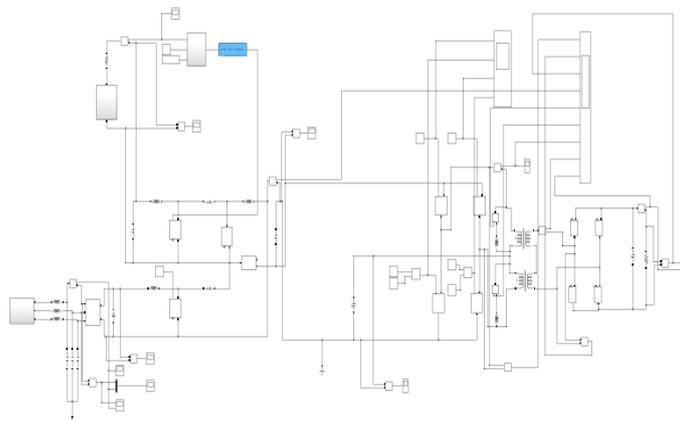


Fig.10. Simulation Circuit

Thus the Fig.10 shows the simulation circuit of the inverter with CUK/SEPIC converter and thus the PV input is given to the SEPIC converter circuit.

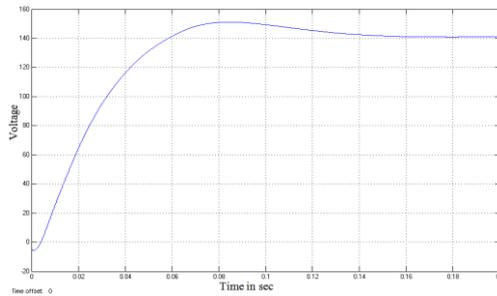


Fig.11. Output Voltage of Multi-port full bridge dc-dc converter

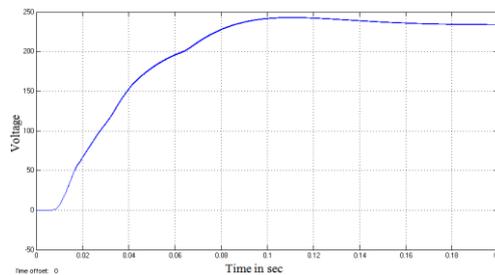


Fig.12. PMSG Voltage waveform

Full bridge converter power flow is controlled by Battery port and used for the voltage regulation as well as to give smooth and continues power output to the Load.

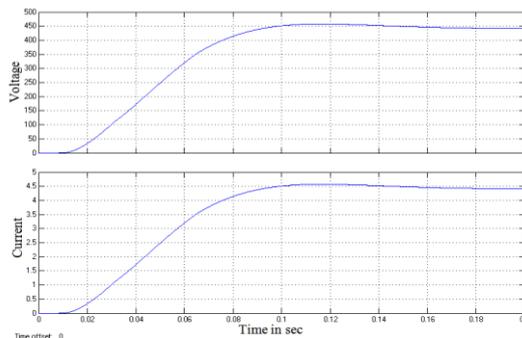


Fig.13. Multi-port full bridge dc-dc converter load voltage and current waveform

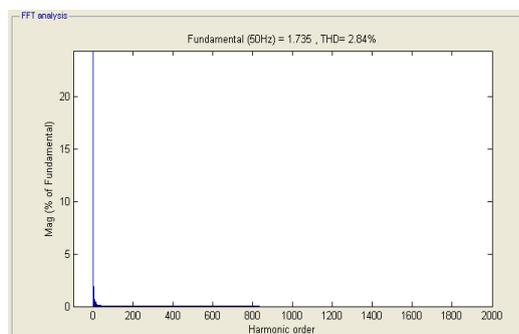


Fig.14. Total Harmonic Distortion

Thus the Fig. 11 shows the output voltage of the Multi-Port Full Bridge DC-DC converter, where the net output dc voltage of 140 V is obtained. The Fig. 12 consists of the Voltage waveform of the PMSG section of 230 V. The Fig. 13 shows the Load Voltage and Current Waveforms of 440 V and 4.45 A respectively. The Harmonic content is shown by the fig.14. In the above figure it is proved the harmonic is reduced to 2.84 percent.

V. HARDWARE RESULTS

In order to verify the proposed converters performance, a low power Four-Port Full bridge prototype converter was built as shown in Fig.15-20. The proposed control scheme is implemented by TMS320F2812 DSP. Two renewable dc voltage sources of PV=24 V and Wind side DC is 10-15 V, with the maximum deliverable currents of 2 A, are utilized as the converter input sources. Moreover, a 24 V battery consisting of two-series 12 V lead-acid batteries is employed in this prototype. In order to validate practical performances of the proposed converter, the different inputs are scheduled for the system by temperature variations of solar currents of the input sources and the load resistance. All the experimental Figures have been captured with the scale of seconds. Fig. 15 represents the Experimental setup of the proposed inverter with the CUK/SEPIC Converter using PMSG at the wind Side.

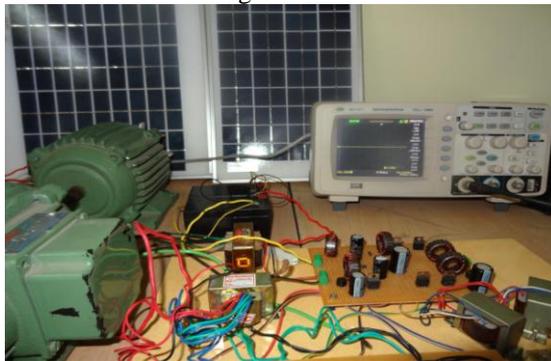


Fig.15. Experimental implementation circuit

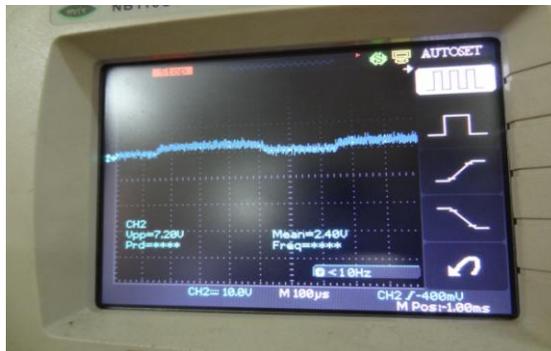


Fig.16. Experimental Waveform for Photovoltaic voltage, CH2=10V/div



Fig.17. Experimental Waveform for Generator side voltage, CH2=10V/div

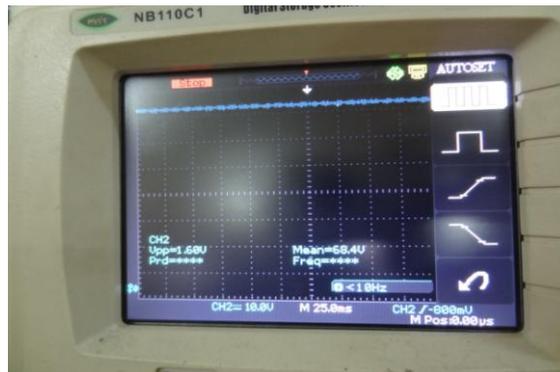


Fig.18. Load Voltage Waveform for proposed Full bridge Converter, CH2=10V/div

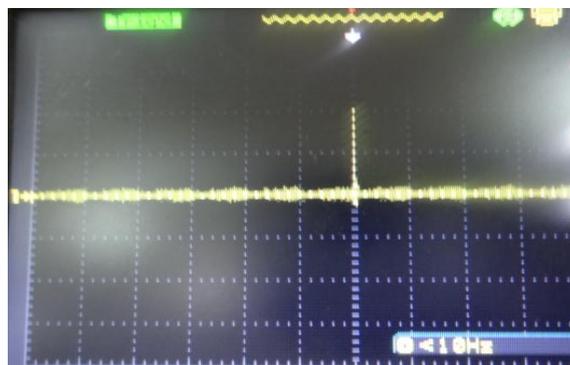


Fig.19. Load Current waveform for proposed Full bridge Converter, CH2=10A

The Integrated Hybrid four port isolated DC-DC converter has a prominent solution for renewable power generation and PFC is obtained in proposed Rectifier circuit. SEPIC based rectifier circuit integrated to wind source and achieved better PFC correction and THD reduction. High step-up continuous voltage regulation is achieved via isolated DC-DC converter. Thus the Fig. 16 represents the Voltage waveform for the photovoltaic voltage. The Fig. 17 shows the Generator side voltage. The Load Voltage waveform is shown in the Fig.18.

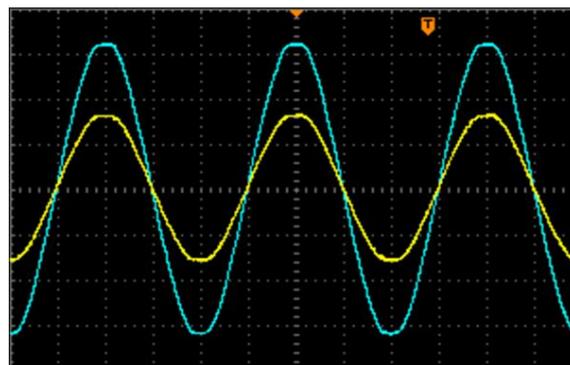


Fig.20. Power factor correction waveform in Generator Phase line, CH2=5V/div

SEPIC and Cuk converter circuit presented to improve the Maximum generation of wind/PV. Full bridge converter power flow is controlled by Battery port. Proposed Multi-port converter provided high step-up voltage conversion with low turns ratio. The performance is analysed and improved than conventional Topology in power quality. Thus the Fig. 20 represents the voltage and the current waveforms obtained by the implementation of the Power factor Correction in the proposed inverter System with CUK/SEPIC converter. Thus the harmonic content is reduced to 2.84 percent and the distortion is reduced considerably.

VI. COMPARISON OF THE SINGLE SWITCH AND SEPIC/CIK CONVERTER TOPOLOGIES

Thus the Four Switch Three Phase Inverter (FSTPI) has been implemented using single switch and the SEPIC/CIK converter topologies. Table IV show the comparison of the three different converter topologies and the voltage and Harmonic contents are compared in the table shown below.

TABLE IV
 COMPARISON OF DIFFERENT PFC CONVERTER TOPOLOGIES

S. No	Methods	Load voltage (v)	TH D (%)
1	Conventional Two switch PFC Converter	290	4.01
2	Single switch PFC Converter	300	2.94
3	SEPIC PFC converter	450	2.84

Thus from the above table it is proved that the SEPIC or the CIK converter based PFC rectifier is getting high voltage output along with the reduced harmonic content which shows the system is suitable for efficient power conversion systems.

VII. CONCLUSION

Thus from the above results it is proved that the SEPIC/ CIK based rectifier has the maximum power generation capability with reduced harmonic content. Thus it also achieved the better power factor compared to the conventional two switch rectifier and the Single switch topologies. Thus the performance of the entire system has been verified under loaded conditions where the Induction machine is used. The proposed system is used for the high power generation applications using Hybrid Systems. The hardware results verifies the feasibility of the proposed inverter system.

VIII. ACKNOWLEDGEMENTS

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