

# A Modified LUO Converter for Hybrid Energy System FED Grid Tied Inverter



K. Vinoth, M. Ramesh Babu

**Abstract:** A novel topology of a hybrid grid connected topology based on photo voltaic system and permanent magnet synchronous generator is proposed in this paper. In this grid connected inverter topology the source are connected to the grid with the help of multi input modified LUO converter followed by a single phase three level inverter. Thus compared to the conventional schemes the proposed topology is modeled with the help of reference frames includes direct axis and quadrature axis elements. The modified LUO converter inherits the advantages compared to other DC-DC to converter topologies. The fuzzy logic based MPPT algorithm shows excellent performance under various testing conditions. The PWM generators are used to trigger the inverter and LUO converter. Steady state and transient response of the controllers are discussed and implement the excellent operation of the hybrid energy system. The grid current synchronization is achieved by using PI controller also it will reduce the THD and satisfies the IEEE harmonics standard.

**Keyword-** LUO Converter, hybrid energy system, photovoltaic, PMSG, grid connected three level inverter, PI controller, Fuzzy logic algorithm.

## I. INTRODUCTION

Distributed energy generators based on renewable energy sources, including photo voltaic system (PV) and wind energy system provides mean energy generation[1]. The distributed generation based on renewable energy sources requires new power electronic DC-DC converters and inverters for increasing the power quality and efficiency of the DG system[2-3]. The energy generation system based on single renewable system like solar as well as wind energy is not suitable, because of the availability due to the seasonal variation. The energy generation system consists more than one renewable energy sources provides good reliability and constant power applications[4]. The DFIG (double Fed Induction Generators requires additional gear box setup with wind turbine so it needs regular maintenance and efficiency also very less[5]. The modern permanent magnet synchronous generator does not require gear box setup only wind turbine is enough. Also the rotor is made up of permanent magnet. It increases the efficiency of the system. At the same time PMSG support for near unity power factor operation and good efficiency than other generators, because of its residual magnetism properly[6].

Earlier PV based transformer less grid connected topology was attempted, in which the PVC array is connected to a boost converter and desired bus voltage has achieved[7].

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Then hybrid system based DGS more formed. In that both PV system and WEGs system needs a separate DC-DC boost converter for maintaining constant voltage to the system. This DC link voltage is given to the voltage source inverter after that AC voltage feeds to the grid

[8]. But in this MPPT algorithm not performed, so that DC voltage gets ripples and will affect the grid current. A PMSG solar PV based multi input hybrid system also proposed<sup>10-11-12</sup>.

In all the [10-11-12] systems with PMSG – solar attempted so far the DC system either had individual DC-DC power converters for each input DC source or a battery backup system. Also each controller requires complex algorithm for tracking the maximum power. But in this case switching and power losses are high due to two DC to DC converters. To reduce such losses we have to reduce the DC-DC converters and power conversion stages. In<sup>13</sup> the hybrid solar and battery source based DC micro grid formed, in this case solar is the only primary source, this produces voltage stability problem. In [14-15] separate wind energy source form the grid, this achieves high power applications with non linear load, but wind is not a primary source also PMSG induces voltage stability issues due to nature of the material.

The hybrid energy with transformer less inverter is proposed [16-17]. Cuk converter has reverse voltage polarity problem also distorted current in input side. Buck-boost converter with three phase inverter topology produces high oscillatory current and harmonics. In hybrid energy system[18-19] based micro grid formed, the MPPT algorithm fails to maintain the maximum power concept. DFIG produces high power losses also. The micro grid formed with sliding mode control achieves steady state operation but not optimized algorithm for achieving higher efficiency when connected in grid [20].

In this paper multi input DC-DC converter topology introduced. in addition it is desirable that power supplies in customer sites employ with minimum number of power electronic devices for increasing the efficiency. Also the proposed scheme is compared with conventional Boost converter.

## II. DC-DC CONVERTERS

### A.Boost Converter

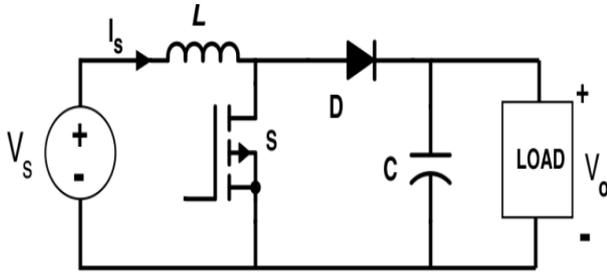
The figure 1. shows the boost converter. The boost converter consists of boost inductance L and output capacitor C, its provides smoothening the output DC voltage. The diode D provides snubbed protection from reversing current.

The output voltage equation of the boost converter is given by,



$$V_o = V_s \left( \frac{1}{1-\alpha} \right)$$

Where  $V_o$  is the output voltage to the load.  
 $V_s$  is the input voltage to the boost converter.  
 $\alpha$  is the duty cycle.

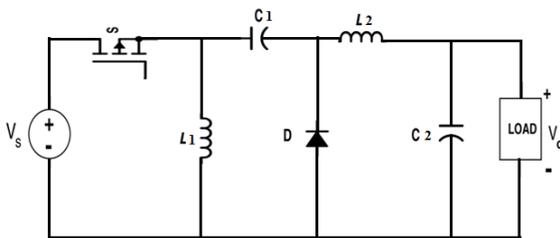


**Fig 1. Boost converter**

The boost converter is single order low pass filter and its voltage boost ratio is very less, to overcome this drawback the proposed LUO converter has been designed.

**B.LUO Converter**

Luo converter is the higher version of boost converter and SEPIC converter. The figure 2 shows proposed DC-DC converter. The inductance  $L_1$  and  $L_2$  stores the energy, inductor  $L_2$  maintains the output current as continuous. Luo converter input current also remains continuous, due to this properties converter efficiency becomes high. The capacitor  $C_1$  and  $C_2$  acts as the filters and furthermore reduce the ripples in the voltage and current. Duty cycles define the modes buck or boost because LUO converter can act as buck boost converter with same polarity output.



**Fig 2. Luo Converter**

The output voltage of the LUO converter is given as,

$$V_o = V_s \left( \frac{2-\alpha}{1-\alpha} \right)$$

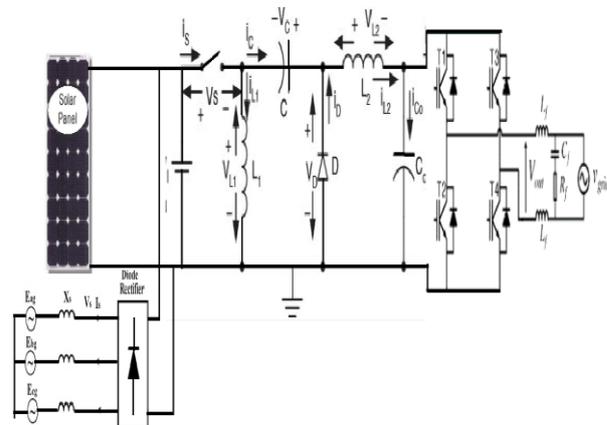
The LUO converter achieves double frequency suppression system for input voltage and current ripples. In this paper multi input modified LUO converter has proposed. This will increase the performance of the system. Such that with lower duty cycle it can support for high output voltage gain. The fuzzy logic algorithm provides optimized solar power point tracking. It will increase the converter efficiency. In grid side reactive power has been increased due to the loads. Due to the nonlinearity characteristics grid current becomes non uniform, so that a power quality issue arises. In this paper PI controller achieves grid current compensation and this will make grid current and voltages are in phase. Finally our proposed system achieves high voltage stability in the grid side. The voltage equalizer reduces the partial shading effect from the PV system. The modified LUO converter works as the voltage equalizer. The proposed scheme is grid connected topology it does not require any battery storage system. Generally the DC-DC converter achieves 95% efficiency, balance 5% has dropped due to the input voltage un stability. But due to the fuzzy logic based MPPT algorithm

the operating efficiency will increase. The proposed system detailed description as follow.

**III. DESCRIPTION OF THE PROPOSED SCHEME**

The proposed distributed generator block diagram is show in figure 1, consists two input voltage source. From the PMSG three phase AC voltage is generated and uncontrolled diode bridge rectifier makes uncontrolled rectified DC voltage with higher order ripple contents, then the DC voltage is given to the LUO converter. Another DC source is PV system. Due to the temperature and irradiation variation the solar output voltage have higher order ripple contents also partial shading effect arises. This variable DC voltage is fed to the LUO converter. Two different options are available for connections, means cascaded and parallel connection. In this work parallel operation is achieved for continuous voltage supply. The DC-DC LUO converter has one inductor and one capacitor in series and another one in parallel. This reduces the voltage and current ripples from the input voltage. The LUO converter series inductor and diode combination achieves solution for partial shading effect. The main advantage of LUO converter is its input current is continuous with good output voltage gain.

The converter output voltage does not having voltage inverting polarity problems compared to buck boost and CUK converter. The series and parallel diode combination provide voltage and current snubber protection. With low duty cycle converter provides increased output voltage from the PV system the reference voltage and currents are measured and from there values we can employ MPPT algorithm. The reference voltage and current are given to the low pass filter, then the voltage and currents are multiplied from this get the reference power. The reference and the active power errors are compared. This error is given to the fuzzy logic algorithm. The mamdani based triangular membership function FLC gets the error. The actual error and the errors are combined and the FLC generates reference signal for PWM generation.



**Fig 3. Proposed System circuit diagram**

The reference signal and the triangular carries signals are compared and give the PWM pulses. These pulses are given to the LUO converter single switch.

The fuzzy logic algorithm achieves constant output voltage with reduced voltage ripples. This voltage is given to the single phase voltage source inverter. For grid voltage and current synchronization, the reference voltage and current current feed backs are taken from the grid. The reference voltage and reference current provides real and reactive power. The reference and actual grid powers are compared and the error is compensated using PI controller. The trial and error approach achieves reference to total current. The actual harmonics current are subtracted with the PI controller output and gives reference sinusoidal signal. This sinusoidal signal is compared with the triangular carrier signal with 10KHz switching frequency. The 180 degree displacement signals are produced and the pulses are given to the voltage source inverter. The dead band operation reduces the shoot through problems So that IGBT switches can work safely. This pulse achieves the grid current synchronization with voltage. This look like a FACTS (Flexible AC Transmission System) devices. The reactive power compensation takes place. Here total harmonics distortion (THD) is the major power quality issues. The THD's are developed from the non linear load and this affect the source current. Also it is the major reason for non linearity between voltage and current of the grid. Furthermore produce voltage sag and swell problems with regular change in transient conditions this affects the voltage stability for the loads. The grid current compensation reduces the THD problems. The PI controller suppresses the total harmonic distortion. The third and fifth harmonics has reduced using the PI controller.

Finally our proposed work satisfies the grid current issues problems. Also our system can work with either stand alone mode or simultaneous mode with input power supplies.

**IV. MODEL OF THE SYSTEM**

The proposed system model is developed as follows here.

**A. Permanent synchronous generator**

The PMSG is described using equivalent circuit analysis.

- VDC- Rectified DC output voltage
- IDC – Rectified DC output current
- Vs(rms) - Stator RMS voltage of the PMSG
- Is(rms) - Stator RMS current of the PMSG

The rectified DC voltage is given as

$$VDC = 3 \frac{\sqrt{6}}{\pi} V_s(rms) \tag{1}$$

$$IDC = \frac{\pi}{\sqrt{6}} I_s(rms) \tag{2}$$

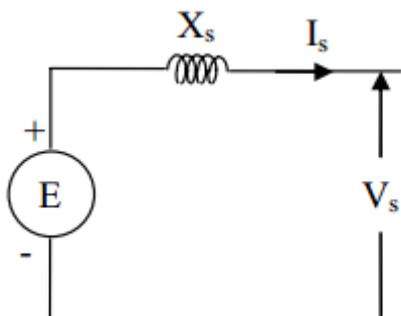


Fig 4. PMSG steady state equivalent circuit

This DC voltage (1) is given to the LUO converter.

**B. Solar panel**

From the PV panel the PV array current is given as,

$$I_{pv} = I_{sc} - I_d \tag{3}$$

$$\text{Where } = 10^{-9} I_{sc} \left( \exp \frac{20.7}{V_{oc}} (V_{pv} + R_{sc} \cdot I_{pv}) \right) \tag{4}$$

Isc – solar short circuit current

**C. LUO converter output voltage**

Now the LUO converter output voltage is,

$$V_{luo} = V_{out} = \left( \frac{2-\alpha}{1-\alpha} \right) VDC \tag{5}$$

Where α- Duty cycle

The DC link current is

$$I_o = I_{luo} + I_{pv} \tag{6}$$

**D.Voltage source inverter**

The direct axis and quadrature axis voltage of the inverter is ,

$$V_d = VDC \ gd \tag{7}$$

$$V_q = VDC \ gq \tag{8}$$

gd – Even harmonic presents in the output voltage

gq – Odd harmonic presents in the output current

$$gd = \left( \sum_{n=1,5,9} \cos(n-1) \omega t - \sum_{n=3,7,11} \cos(n+1) \omega t \right) \tag{9}$$

$$gq = \left( \sum_{n=2,6,10} \sin(n-1) \omega t - \sum_{n=4,8,12} \sin(n+1) \omega t \right) \tag{10}$$

let as consider loss less power in the single phase inverter.

$$I_o = \frac{1}{2} (i_d \ gd + i_q \ gq) \tag{11}$$

Where id ,iq – Direct and quadrature axis current.

$$\begin{aligned} I_o &= I_{luo} + I_{pv} \\ &= \frac{(1-\alpha)}{\alpha} IDC + I_{pv} \\ I_o &= \frac{(1-\alpha)\pi}{\sqrt{6} \alpha} I_s + I_{pv} \end{aligned} \tag{12}$$

In this proposed system duty cycle and the converter reference currents are varied for extracts the maximum output current at any time instants.

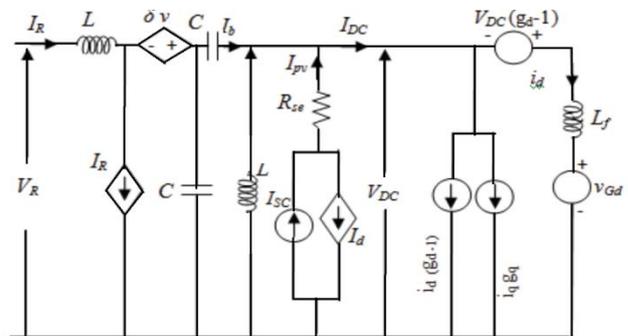


Fig 5. Direct axis equivalent circuit.



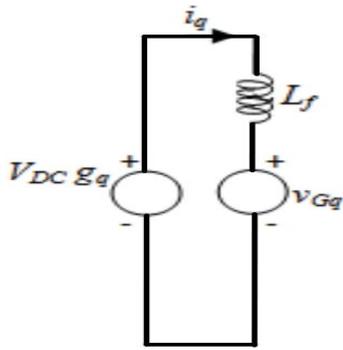


Fig 6 Quadrature axis equivalent circuit.

V. OPERATING MODES

Case 1: (hybrid system wind and solar generations)

In this case both the wind and solar generating the power. In this mode wind system provides maximum voltage(Vdc) and the solar system provide the maximum current (Ipv). So that the LUO converter duty cycle varies related with the output voltage because both input source extracts the power.

Now the MPPT reference current is given as,

$$Iref(new) = Iref(old) + (\Delta(Ipv + Iluo)) \quad (13)$$

where  $(\Delta(Ipv + Iluo))$  - change in current

From this reference current the fuzzy logic controller adjust the duty cycle, so that LUO converter output voltage remains constants this voltage is fed to the inverter. Then for grid reference current it is given as,

$$Iref = \sqrt{2}(Vpv.Ipv + Vdc, Idc)/Vgrid \quad (14)$$

From this change in reference current the PI controller adjusts the pulses to the inverter so that PI controller achieves grid synchronization.

Case 2: (PMSG generating the power)

At night time the PV panel output is zero. At that time wind will supply power to the load through LUO converter.

Now the reference current is,

$$Iref(new) = Iref(old) + \Delta Iluo \quad (15)$$

At this case converter extracts the maximum power from the PMSG.

Case 3: (PV generating power)

It the wind velocity is very less only solar provide voltage to the system.

Now the reference current is,

$$Iref(new) = Iref(old) + \Delta Ipv \quad (16)$$

At that finally, the PV and PMSG system works together the fuzzy logic controller produces the PWM pulses to the LUO converter and the PI controller generates the reference current command from the grid. If only PV panel is works then the algorithm will not produce any duty cycle to the converter, but the PI controller extracts the maximum power from the PV system. In case PMSG works alone the algorithm produce the duty cycle.

VI. VI. ALGORITHMS USED

In this paper, MPPT, P&O algorithm and fuzzy logic algorithms are compared to extract maximum power from PV system. The introduction about these algorithms is discussed in [21].

VII. VII. SIMULATION RESULTS

The proposed work is simulated using the matlab software. Here the device used is IGBT for losses power losses. The FLC algorithm produces the PWM pulses for LUO converter and PI controller produces pulses for single phase inverter. From the grid voltage, harmonic are calculated using FFT analysis. This satisfies allowable IEEE standard.

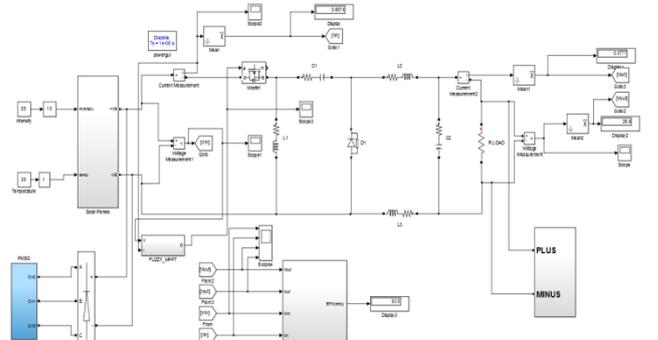


Fig 9. Matlab simulink diagram

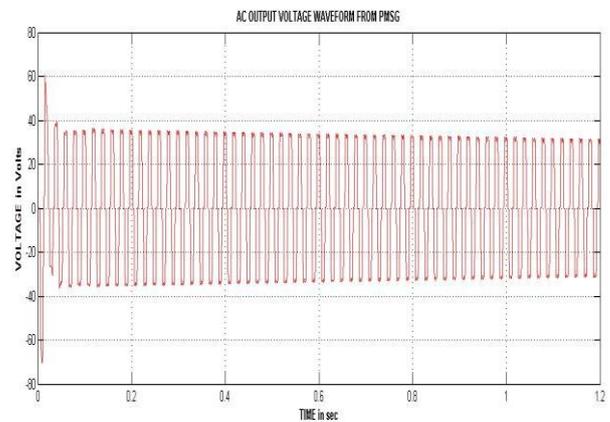


Fig 10. PMSG output voltage waveform

The figure 10 shows the output voltage of the permanent magnet synchronous generator. The PMSG output is converter into DC voltage using uncontrolled diode bridge rectifier. The permanent magnet rotor creates oscillatory nature in the output voltage.

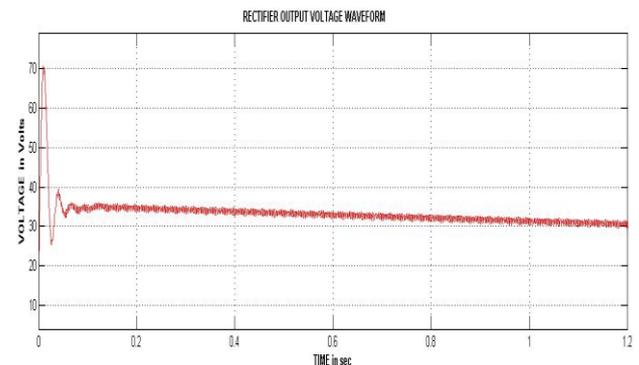
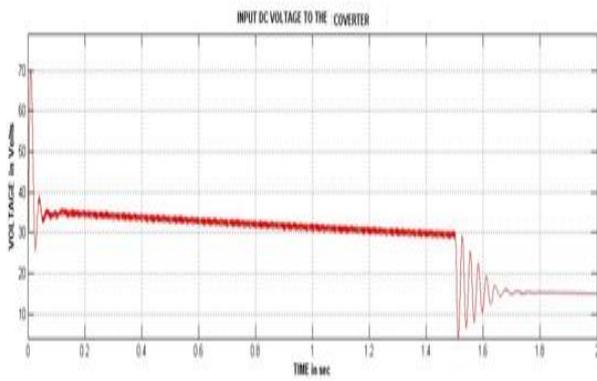


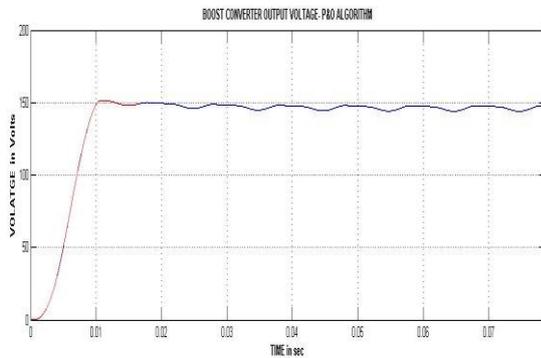
Fig 11. Rectifier output voltage waveform

The PMSG voltage is converted into DC voltage with the help of three phase uncontrolled rectifier, the capacitive filter used for smoothening purpose.



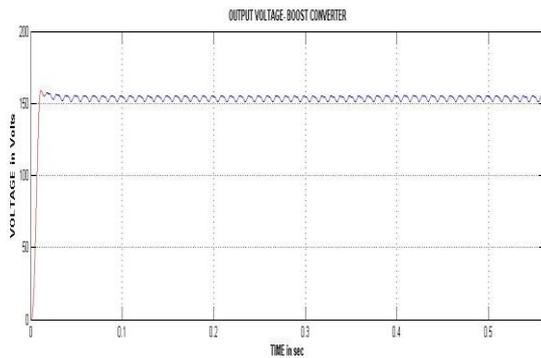
**Fig 12. Input DC voltage waveform to the LUO converter**

The figure 12 shows the hybrid voltage to the LUO converter, due to solar panel input variation, solar output voltage having higher order ripples. This voltage is fed to the LUO converter.



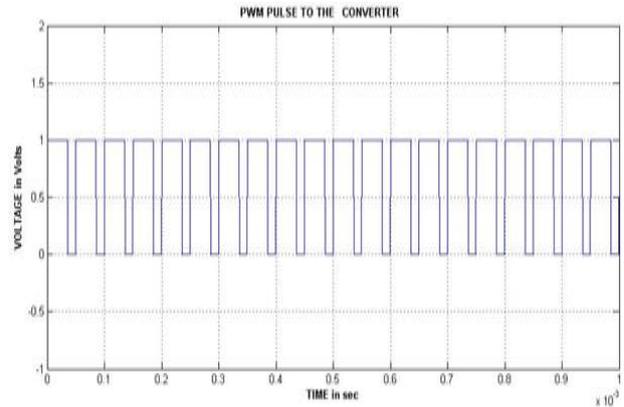
**Fig 13. Boost converter output voltage using fuzzy logic algorithm**

The figure 13 shows the output voltage of the boost converter using P&O algorithm,



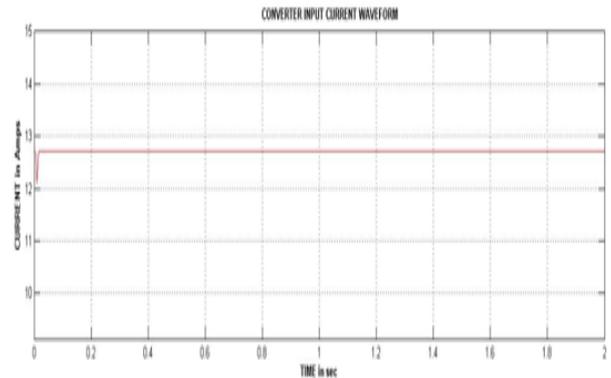
**Fig 14. Boost converter output voltage using fuzzy logic algorithm**

The figure 14 shows the output voltage of the boost converter using fuzzy logic algorithm. Compared to P&O algorithm its provides voltage stability.



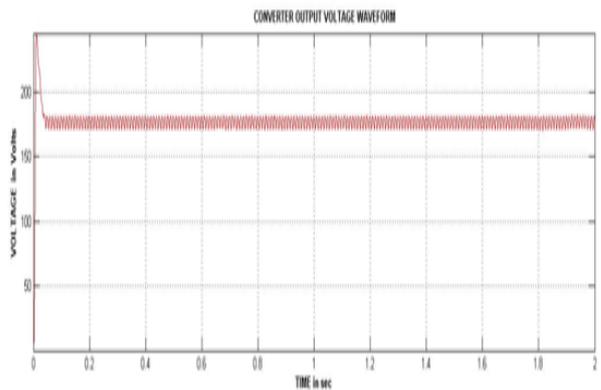
**Fig 15. PWM pulse waveform to the LUO converter**

The figure 15 shows the PWM pulse applied to the LUO converter, the MPPT fuzzy logic algorithm is carried out for producing the PWM pulses with switching frequency 20 KHz. The fuzzy logic algorithm is the self tuning optimized MPPT algorithm.



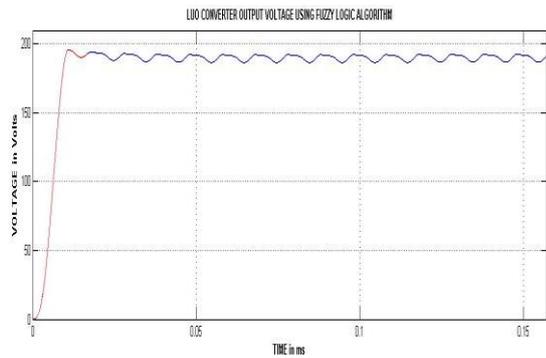
**Fig 16. Input current waveform from the LUO converter**

The figure 16 shows the input inductor current waveform, the inductor L1 present in the LUO converter maintains the input current as continuous. This makes the system efficiency as high.



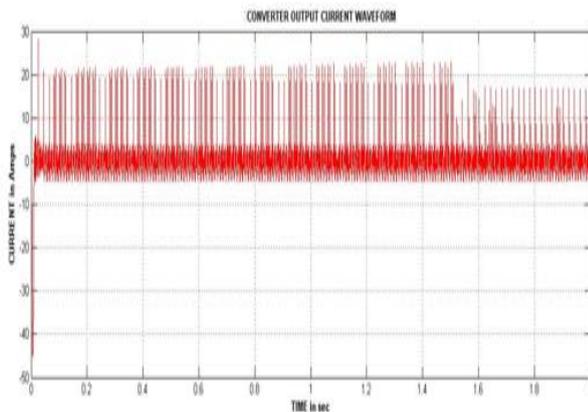
**Fig 17. Output DC voltage waveform of the LUO converter**

The figure 17 shows LUO converter output voltage, LUO converter reduce input voltage ripples and amplify the output voltage. P&O algorithm produce voltage oscillation in the output voltage, this is reduced by fuzzy logic algorithm.



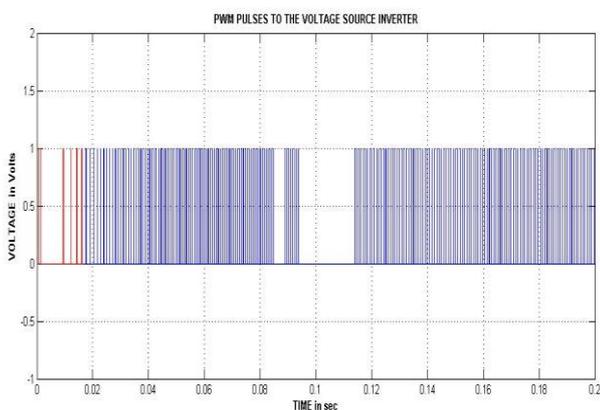
**Fig 18. Output DC voltage waveform of the LUO converter using fuzzy logic algorithm**

The figure 18 shows LUO converter output voltage, LUO converter reduce input voltage ripples and amplify the output voltage. Fuzzy logic algorithm reduces voltage oscillation in the output voltage.



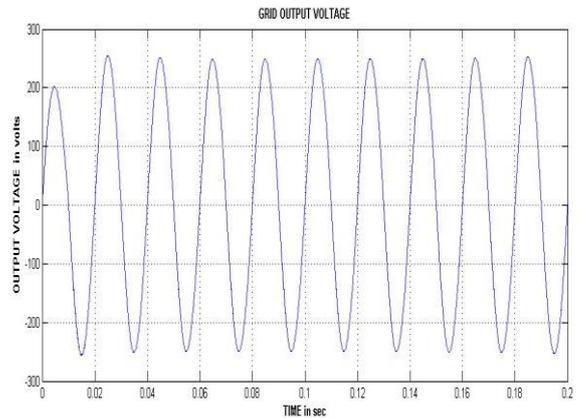
**Fig 19. Output DC current waveform of the LUO converter**

The figure 19 shows output current waveform of LUO converter. Due to non linear loads current having noises.



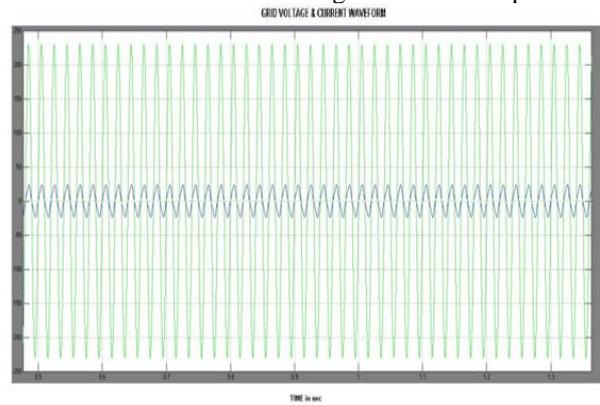
**Fig.20. Gate pulse to VSI**

The figure shows the PWM pulse to voltage source inverter, the PI controller produces reference signal and 10KHz carrier signal is compared to produce PWM pulses. The pulses having 180 degree phase displacements for the single phase inverter. Four micro seconds dead band is provided to avoid the short circuit between switches in voltage source inverter.



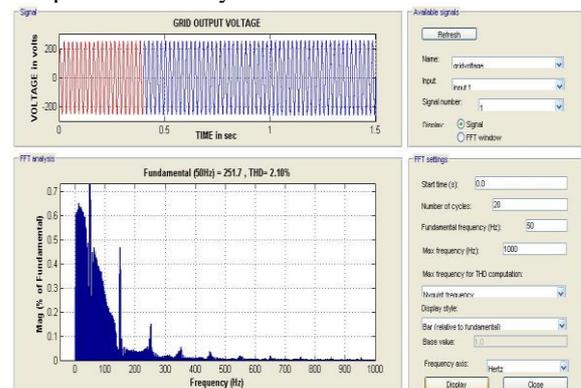
**Fig .21. Inverter output voltage**

The figure shows the inverter output voltage with inductive filter because voltage injected in the grid should be sinusoidal. PI controller achieves grid current compensation.



**Fig .22. Grid voltage and current waveform synchronization**

The figure shows grid voltage and current waveform, its indicates both are in phase. This achieves near unity power factor operation. This system looks like STATCOM device.



**Fig .23 Voltage THD waveform**

The figure shows the THD waveform of grid voltage, its shows only 2.10 percentage. This system satisfies IEEE harmonics standard. LUO converter and fuzzy logic MPPT algorithm maintains constant voltage to the grid with the help of inverter. PI controller achieves steady state operation in grid.

**A. Comparison Boost Converters**

The proposed system is validated through fuzzy logic based MPPT algorithm and P&O algorithm. This chapter deals with comparison between proposed converter with Boost converter.

SINO	PARAMETERS	BOOST CONVERTER	LUO CONVERTER
1	INPUT VOLTAGE	70 V	70 V
2	OUTPUT VOLTAGE (P&O)	148 V	178 V
3	OUTPUT VOLTAGE (FUZZY)	156 V	198 V
4	EFFICIENCY (P&O)	91%	96%
5	EFFICIENCY (FUZZY)	92%	97%

### VIII.CONCLUSION

Hybrid generation system based on PV and wind based LUO converter has been successfully implemented. The performance of the system has analyzed using matlab simulation. From the results the proposed system can work both simultaneously or separately. The fuzzy logic algorithm extracts maximum power from the input sources, compared to other algorithms fuzzy logic algorithm provide less ripple with the help of LUO converter. The PI controller achieves the grid current synchronization. Due to this inverter have very less THD and inverter obeys the power quality harmonics standard. The proposed converter is compared with the conventional boost converter using both fuzzy and P&O algorithm. Comparison shows LUO converter with fuzzy logic MPPT algorithm provides good performance. Finally this application useful for reactive power compensation in smart grids and power grids.

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