Single String Interleaved Boost Converter Based PV Eleven Level Inverter System for Rural Application

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ABSTRACT: The most severe problem our society is facing now is limitation of power which we can produce with our limited sources. Non renewable sources of energy are diminishing day by day which has resulted in an increase in cost of these sources. Demand of electricity will worsen present scenario of decreasing non renewable resources. In the present scenario renewable solar energy usage is the most suitable solution. The paper presents insight into most suitable electronic conversion circuit for solar energy usage. Interleaved Boost converter circuit was used because of its parallel current operation using lower rated low cost inductors. Multilevel inverter circuitry is used for converting DC to AC. Structural configuration of PV cells and reflectors for rural are for efficient usage of sunlight is described.

KEYWORDS: PV system Fuzzy, Interleaved Boost Converter, Bi-directional switching, H Bridge Inverter.

I.INTRODUCTION

The most severe problem our society is facing now is limitation of power which we can produce. Non renewable sources of energy are diminishing day by day which has resulted in an increase in cost of these sources. Cost of electrical energy generation based on non renewable energy is affected by this. Demand of electricity will worsen present scenario of decreasing non renewable resources. In these conditions renewable energy usage is the most suitable solution available. Of the renewable energy solar is the best suitable for electricity generation.

The Block diagram of current PV DC/AC system is shown in Fig 1. PV system of single string and multi string are available. Multi string PV has a disadvantage of using multiple boost converters for boosting operation. This will increase conduction losses and switching losses of multi string PV system. So single string PV system is proposed here to be used instead of multi string.
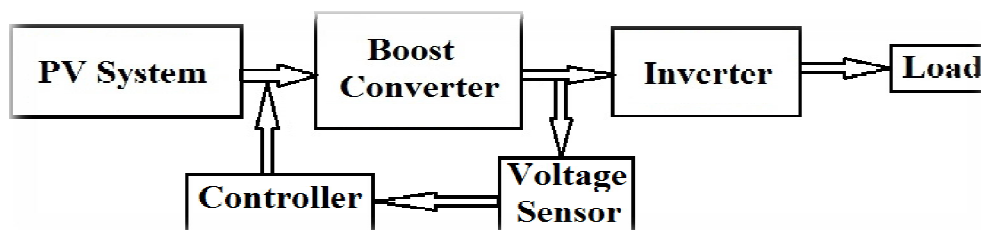

Fig 1   Block diagram of the current system

Normal boost converter is used in current system for boosting. This system when used for high level boosting will have inductors of high rating and cost of such inductors will be high. Interleaved boost converter is proposed to be used instead of normal boost converters. The interleaved boost converter will provide parallel paths for current flow thus the inductor rating of parallel inductors can be lower than the normal inductor and size of such inductor will be smaller.

Basic PI controllers are used for output voltage regulation in current boost converters used in PV systems. Such control systems are complicated, Fuzzy based controllers are considered to be much simpler compared to PI

controller. Fuzzy is a tool used for manipulating imprecise data. Fuzzy based controller is intended to be used in the proposed system replacing PI for better performance.

Eleven levels multilevel inverter is proposed to be used for achieving better AC wave form. At the eleven level inverter circuitry MOSFETs will be replacing IGBT switches since the operation is well under 1000V and 5KW power MOSFET switches can replace IGBT for better conduction properties. The body diode operation of MOSFET can be used here for bidirectional switch representation instead of IGBT with bridge diode configuration. Bidirectional switch representation form of MOSFET is used for capacitor selection and H-bridge inverter is used to achieve eleven levels AC waveform.
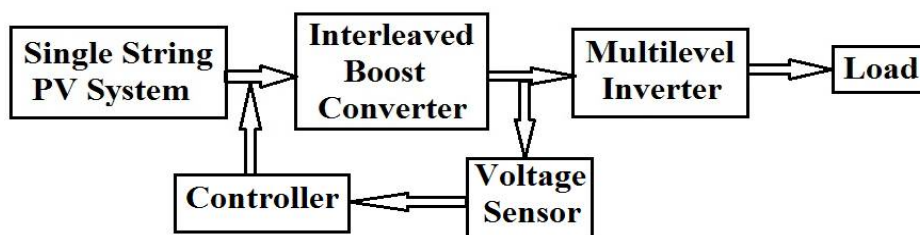

Fig 2   Block diagram of the (proposed system) Single String Interleaved Boost Converter Based PV Eleven Level Inverter System for Rural Application

Fig 2 shows Block diagram of the single string interleaved boost converter based PV eleven level inverter systems for rural application (proposed system). Single string PV system provides a dc input to interleaved boost converter for boosting. Voltage sensors are used for regulating output voltage of interleaved boost converter through controller. The output of interleaved boost converter DC is converted to AC by multilevel inverter and fed to the load.

II. CIRCUIT CONFIGURATION OF INTERLEAVED BOOST CONVERTER

Fig 3 shows the circuit diagram of proposed single string interleaved boost converter based PV eleven level inverter systems for rural application. Here in the circuit PV module is represented by a cell. L1,Sa, D1 and L2 ,Sb,D2 form two parallel paths of interleaved boost converter. Here the switches switch to provide charging and discharging operation of the inductor. When switch Sa (Sb) is turned on then inductor L1 (L2) charges and when turned off the inductors discharges across the capacitors. The capacitor selection capacitors S1, S2, S3, and S4 are used to select intermediate levels between +V max and –V max. Switches S5, S6 , S7 and S8 form H bridge inverter circuit.
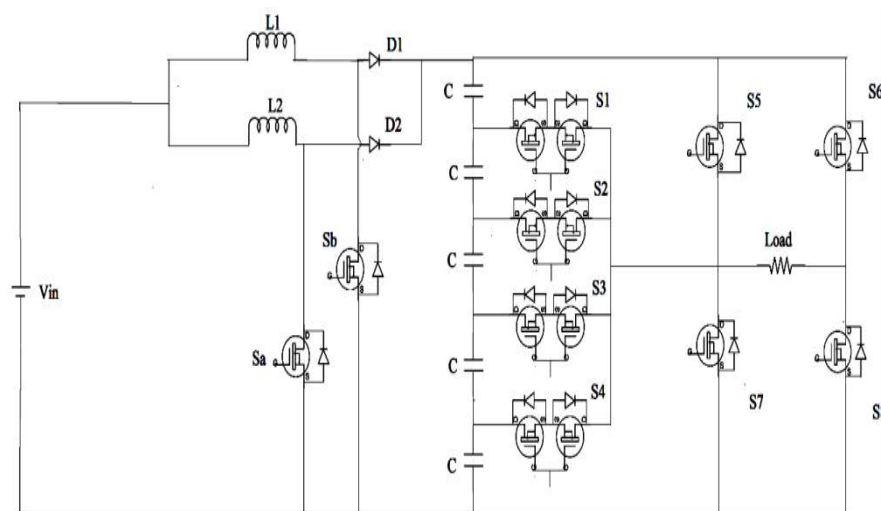

Fig 3   Circuit diagram of the (proposed system) Single String Interleaved Boost Converter Based PV Eleven Level Inverter System for Rural Application

III. CIRCUIT OPERATION OF INTERLEAVED BOOST CONVERTER

For simplifying circuit analysis following assumptions is made:

1) Input voltage is pure sinusoidal
2) Ideal lossless components
3) Switching frequency (fs) is much higher than the ac line frequency (f_L)
4) Output capacitor Ci(i=1,2,3,4,5) is large enough such that the output voltage can be considered constant over the whole line period.

The switches of interleaved boost converter are operated at 50% duty ratio. Here the switches switch to provide charging and discharging operation of the inductor. When switch Sa (Sb) is turned on then inductor L1 (L2) charges and when turned off the inductors discharges across the capacitors. The operation of interleaved boost converter at 50 % duty cycle allows a constant current flow through output capacitor Co thus reducing the output voltage ripple and the inductor size is reduced as the current sharing action is taking place.

At inverter section the bi-direction MOSFET switches are triggered in appropriate intervals to provide eleven level stepped output. The proposed inverter's operation can be divided into eleven switching states. Proper switching of the inverter can produce eleven output voltage levels (Vdc , 4Vdc/5, 3Vdc/5, 2Vdc/5, Vdc/5, 0, -Vdc/5, -2Vdc/5, - 3Vdc/5, -4Vdc/5, - Vdc) from the dc supply voltage. There are eleven level modes of operation based on the switching conditions as shown in the TABLE IV.

Modes of operation of the system:

i. **Maximum positive output (Vdc):**

Switch S5 is ON, connecting the load positive terminal to Vdc, and S8 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF. The voltage applied to the load terminals is Vdc.

ii. **Four Fifth positive output (4 Vdc/5):**

The bidirectional switch 51 is turned ON, connecting the load positive terminal, and 58 is turned ON, connecting the load to negative terminal to ground. All other controlled switches are OFF. The voltage applied to the load terminals is 4 Vdc/5.

iii. **Third-fifth positive output (3Vdc/5):**

The bidirectional switch S2 is turned ON, connecting the load positive terminal, and S8 is turned ON, connecting the load negative terminal to ground. All other controlled switches are OFF. The voltage applied to the load terminals is 3Vde/5.

iv. **Two-fifth positive output (2Vdc/5):**

The bidirectional switch S3 is turned ON, connecting the load positive terminal, and S8 is turned ON, connecting the load negative terminal to ground. All other controlled switches are OFF. The voltage applied to the load terminals is 2Vdc/5.

v. **One Fifth positive output (Vdc/5):**

The bidirectional switch S4 is turned ON, connecting the load positive terminal, and S8 is turned ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is Vdc/5

vi. **Zero output:**

This level can be produced by two switching combinations; switches S5 and S7 are ON, or S6 and S8 are ON, and all other controlled switches are OFF. The terminal a-b is a short circuited. The voltage applied to the load terminals is zero.

vii. **One-fifth negative output (-Vdc/5):**

The bidirectional switch S7 is ON, connecting the load positive terminal, and SI is ON, connecting the load negative terminal to Vdc. All other controlled switches are OFF. The voltage applied to the load terminals is – Vdc/5.

viii. **Two-fifth negative output (-2Vdc/5):**

The bidirectional switch S7 is ON, connecting the load positive terminal, and S2 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF. The voltage applied to the load terminals is -2 Vdc/5.

ix.   Three-fifth negative output (-3Vdc/5):

The bidirectional switch S7 is ON, connecting the load positive terminal, and S3 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is -3 Vdc/5.

x.   Four-fifth negative output (-4Vdc/5):

The bidirectional switch S7 is ON, connecting the load positive terminal, and S4 is ON, connecting the load negative terminal to ground. All other controlled switches are OFF; the voltage applied to the load terminals is -4 Vdc/5.

xi.   Maximum negative output (-Vdc):

Switch S6 is ON, connecting the load negative terminal to Vdc, and S7 is ON, connecting the load positive terminal to ground. All other controlled switches are OFF. The voltage applied to the load terminals is – Vdc.

Out Put Voltages according to switches ON and OFF is shown in TABLE I

TABLE I Out Put Voltages according to switches ON and OFF

MODES	O/P Load Voltage	S1	S2	S3	S4	S5	S6	S7	S8
I	Vdc	OFF	OFF	OFF	OFF	ON	OFF	OFF	ON
II	4Vdc/5	ON	OFF	OFF	OFF	OFF	OFF	OFF	ON
III	3Vdc/5	OFF	ON	OFF	OFF	OFF	OFF	OFF	ON
IV	2Vdc/5	OFF	OFF	ON	OFF	OFF	OFF	OFF	ON
V	Vdc/5	OFF	OFF	OFF	ON	OFF	OFF	OFF	ON
VI	O	OFF	OFF	OFF	OFF	OFF	ON	OFF	ON
VII	-Vdc/5	ON	OFF	OFF	OFF	OFF	OFF	ON	OFF
VIII	-2Vdc/5	OFF	ON	OFF	OFF	OFF	OFF	ON	OFF
IX	-3Vdc/5	OFF	OFF	ON	OFF	OFF	OFF	ON	OFF
X	-4Vdc/5	OFF	OFF	OFF	ON	OFF	OFF	ON	OFF
XI	-Vdc	OFF	OFF	OFF	OFF	OFF	ON	ON	OFF

IV.DESIGN OF INTERLEAVED BOOST CONVERTER USED IN ELEVEN-LEVEL INVERTER

The Interleaved boost Converter is designed based on the following parameters Input voltage (Vdc), Output voltage (Vo), Power (Pin), Switching frequency (fs), Duty ratio (D).The Duty ratio D is given by equation,

$$D = \frac{Vo - Vdc}{Vo}$$

Load resistance is given by equation,

$$R = \frac{Vo^2}{Po}$$

$$Pin = Po$$

Inductor value is given by equation,

$$L = \frac{R \times D \times (1 - D^2)}{2 \times F}$$

Where R = load resistance.
The value of capacitor is given by,

$$C = \frac{V_0 \times D}{F \times \Delta V \times R}$$

Where ΔV is output ripple.

V. CONTROL SYSTEM

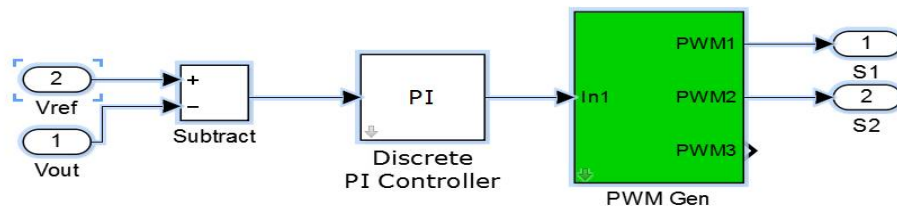### A.   PI CONTROLLER FOR INTERLEAVED BOOST CONVERTER

Fig 4: PI controller for interleaved boost converter

The fig 4 shows the PI controller used in interleaved boost converter. The PI controller is mainly used to eliminate the steady state error resulting from P controller. It has a negative impact on the speed of response and overall stability of the system. The Controller is mostly used in areas where speed of the system is not an issue. It cannot decrease the rise time and eliminate the oscillations.

The error signal is attained by subtracting voltage output value (Vout) from reference voltage value (Vref). The error signal is given to PI controller to produce the duty cycle. The duty cycle value is then provided to the PWM gen Block. PWM Gen Block can produce three PWM signals PWM1, PWM2, PWM3. PWM1 produces PWM pulses at defined duty ratio. PWM2 and PWM3 can be phase shifted comparing to PWM1 output. Here PWM2 will produce PWM pulses at 180^0 phase shift compared to PWM1. PWM1 and PWM2 output pulses are used for gate triggering of switches S1 and S2.

B. FUZZZY CONTROLER FOR INTERLEAVED BOOST CONVERTER

Closed loop control using FUZZY is used in this system so as to provide better and easier control. FUZZY is a tool that can manipulate imprecise data and is much simpler than its predecessors (linear algebraic equation). In earlier system using PI controller in closed loop the output was changed in a steady value. By using triangular membership function in FUZZY mamdani model we are able relate each of the variables, i.e. error and error change in rules to provide an output. FIS editor (Fuzzy inference System editor) is used to enter variables in FUZZY and there triangular membership function (Fig 5).
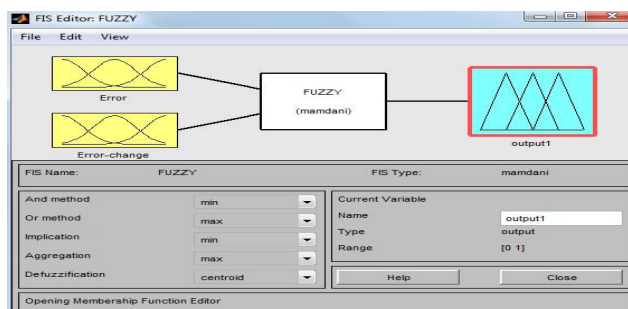

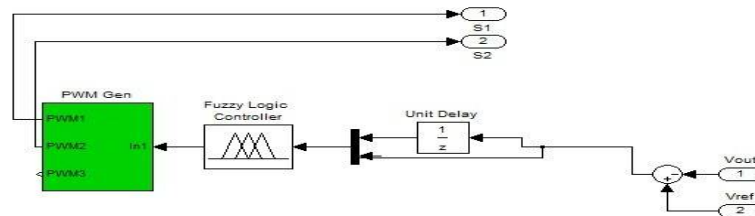Fig 5: FIS editor showing fuzzy variables and FUZZY mamdani model

Fig 6 Closed loop controller using FUZZY

Fig 6 shows the MATLAB model of closed loop controller using FUZZY mamdani model. The error signal is produced by subtracting the voltage output value of the converter with reference value of output voltage. When this error is provided to the unit delay block a change in error signal is occurred. Both this signal is given as input to mux block and the output of mux block is provided as input to FUZZY block. Output of FUZZY block will be the duty ratio. The output of FUZZY is provided as input to the PWM Gen block to produce PWM signals with 180^0 phase difference. These triggering pulses are provided to the switches S1 and S2.

TABLE II FUZZY RULES

e \ ė	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

Table II shows FUZZY rules which shows different output values to be provided according to the error (e) and change in error (ė) signals.
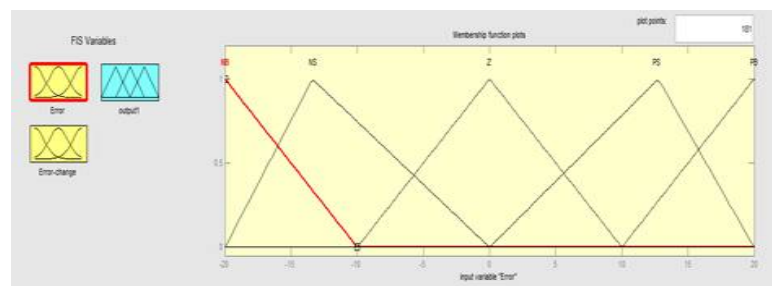

Fig 7a: FUZZY variable Error and its triangular membership functions
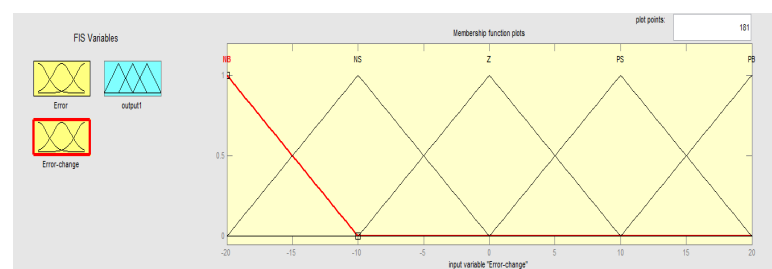

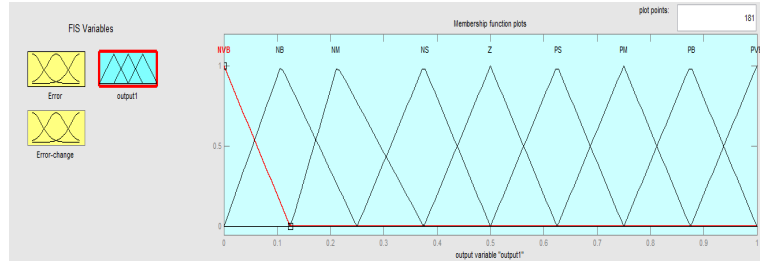Fig 7b: FUZZY variable Error-change and its triangular membership functions

Fig 7c: FUZZY variable output1 and its triangular membership functions

In this system five membership functions NB, NS, Z, PS, PB are used in input variables as shown in Fig 7a, 7b . So a total of twenty five rules can be created relating this to membership function of output variable output1.The membership functions of output variable output1 are NVB, NB, NM, NS, Z, PS, PM, PB, PVB as shown in Fig 7c.

VI.SIMULATION RESULT

For verifying the feasibility and validity of the proposed converter, MATLAB/SIMULINK software is applied for the simulation of the proposed system (Fig 7) with an input voltage of V_{ac} = 24 V at 50 kHz and output voltage of Interleaved boost converter is set as V_o. The duty cycle of the Interleaved boost converter is set as 50%. Switching frequency is taken at 3kHZ and ΔV at 0.01. Simulation parameters used is shown in Table III.

TableIII SIMULATION PARAMETERS

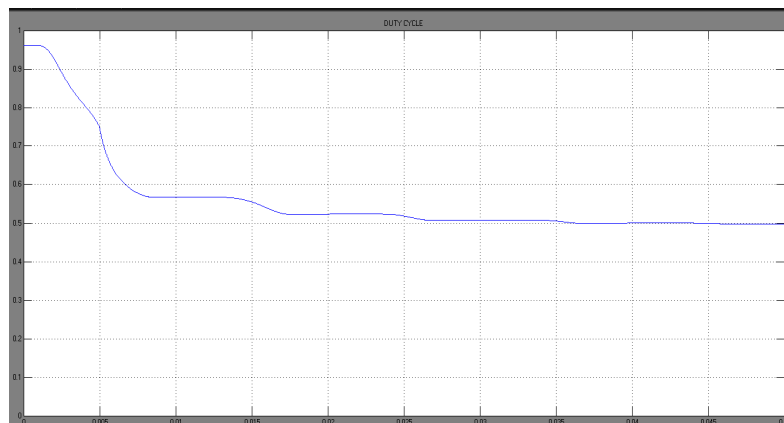| Components	Value
L1	20mH
L2	20mH
Cb	2.5mF
Ci(i=1,2,3,4,5)	10mF
R	320Ω

Fig 8: Output of FUZZY controller (duty cycle)

Fig 8 shows the output of FUZZY Controller i.e. the duty cycle of the converter. This signal is provided to PWM generator for pulse gemeration.
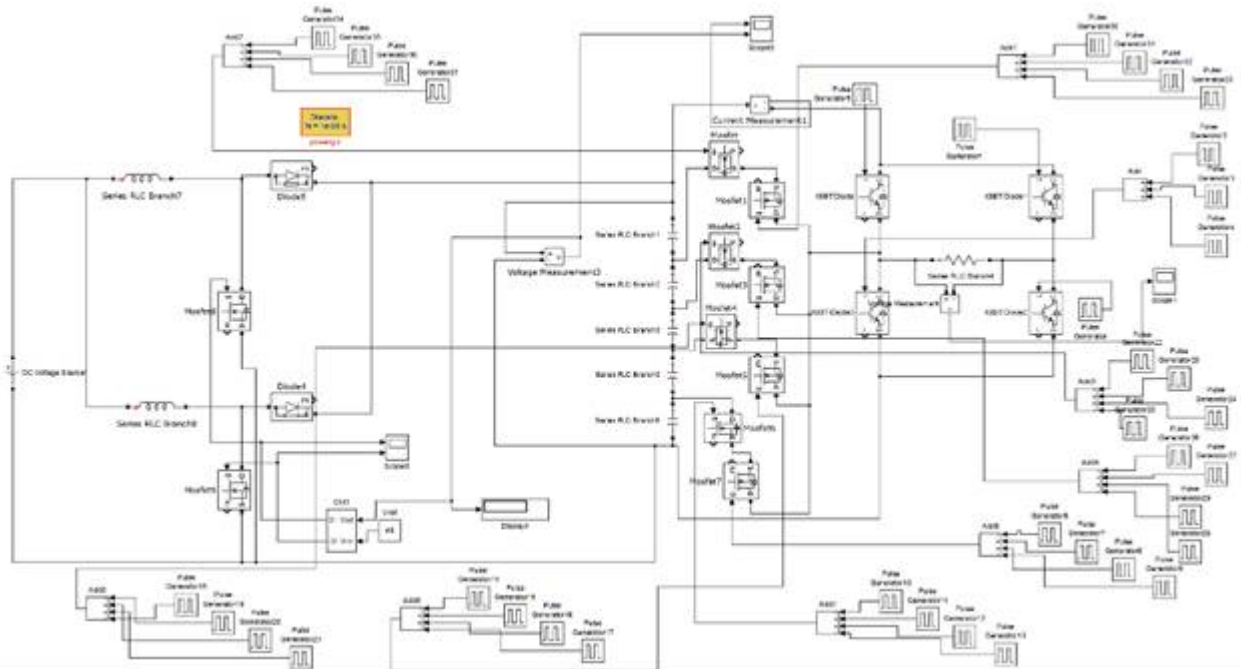
Fig 9: Single String Interleaved Boost Converter Based PV Eleven Level Inverter System For Rural Application

Fig 9 shows the simulation model of Single String Interleaved Boost Converter Based PV Eleven Level Inverter System for Rural Application. A FUZZY controller was used for the closed loop simulation of interleaved boost converter of the above discussed system. The Output Voltage is compared with the reference Output voltage.

The compared Output is fed to FUZZY controller Block. The Output of the FUZZY controller is given as input to PWM Generator module with phase shift 180^0. This Output is fed to the gate of the MOSFET's Sa and Sb for triggering the MOSFETS to ON condition.

Fig 10 and 11 shows the output voltage waveform which is taken across the load resistor. The required out voltage was reached and the overshoots which is seen in PI controller is absent in the FUZZY system and the waveform generated by FUZZY is smoothly increasing to the reference value. Oscillation at the reference value is absent in FUZZY controller output while oscillation of small range was visible at PI controller output.
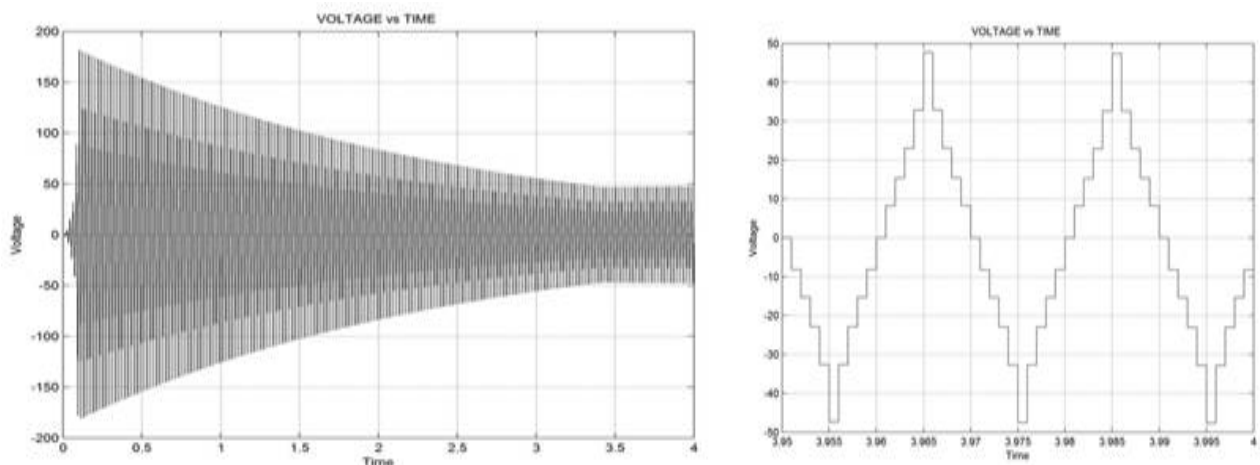

Fig 10: Output voltage of Single String PI controlled Interleaved Boost Converter Based PV Eleven Level Inverter System For Rural Application.
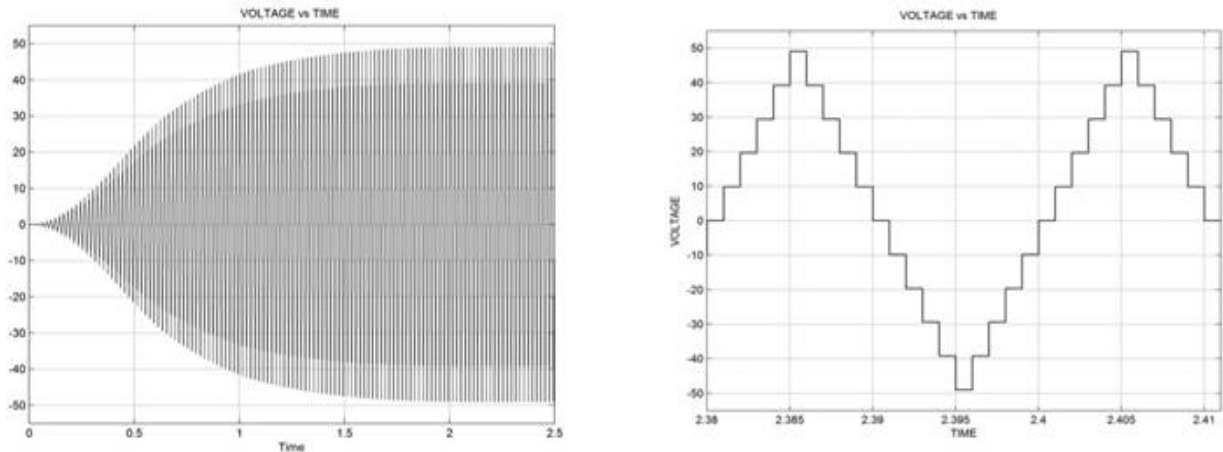
Fig 11: Output voltage of Single String FUZZY controlled Interleaved Boost Converter Based PV Eleven Level Inverter System For Rural Application.
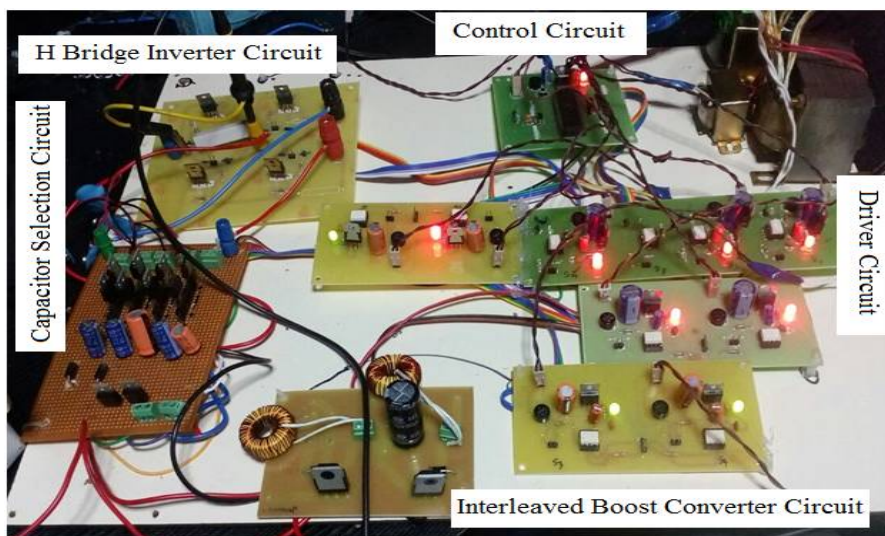
VII. HARDWARE MODEL

Fig 12: Hardware model of Fuzzy controlled single string interleaved boost converter based PV eleven level inverter system for rural application

Fig 12 shows the hardware implementation of the fuzzy controlled single string interleaved boost converter based PV eleven level inverter systems for rural application. The above shown circuit consists of 10 driver circuit to switch 10 MOSFET based switches. Driver circuit is used to provide 15 volts to switch the MOSFET Switches of the inverter. Driver amplifies the voltage from microcontroller which is 5 volts. Also it has an optocoupler for isolating purpose. So damage to MOSFET is prevented. The driver circuit forms the most important part of the hardware unit because it acts as the backbone of the inverter because it gives the triggering pulse to the switches in the proper sequence.

Of these switches four are bidirectional switch (S1, S2, S3, and S4) for capacitor selection. Bidirectional switch is formed here using two MOSFET (IRF840B) and their body diode. Single driver is used here for triggering MOSFETs used in bidirectional switches. Four MOSFETs (IRF840B) switches (S5, S6, S7, and S8) are used to form H Bridge for inverter application. And the two MOSFETs (FGA25S125P) switches (Sa, Sb) are used in interleaved boost converter formation.

The interleaved boost converter boosts the input voltage and the output is provided as input to the capacitor selection circuit. Where according to the switches triggered different voltage levels can be created. The output of the capacitor selection circuit is given across the H bridge inverter. The output of H Bridge inverter results in eleven level inverted output.

The optocoupler steps up PWM voltage level to Vcc (15V). These gating pulses are used to drive or switch MOSFETs. The pulse used for switching Switch Sa and Sb of interleaved boost converter are shown in fig 13. The gating pulses of MOSFETs used in capacitor selection switches are shown in fig 14 (switches S1 and S2), fig 15 (switches S3 and S4),fig 16 (switches S5 and S7), fig 17 (switches S6 and S8).
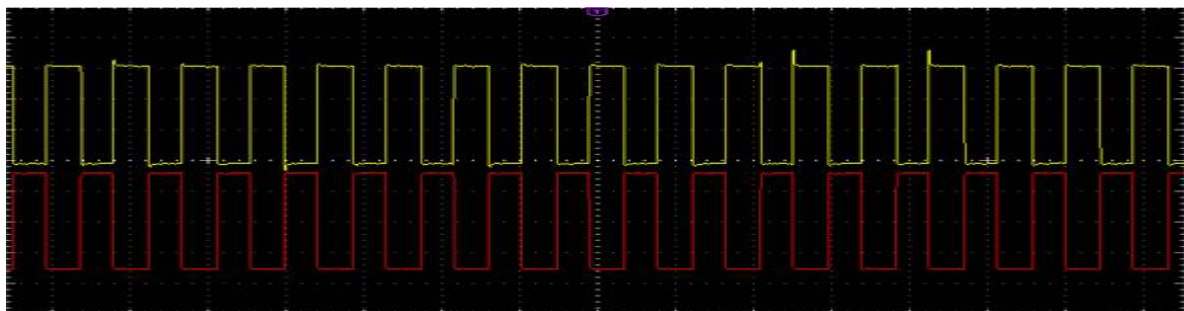

Fig 13: Gate pulses for switch Sa(Yellow) And Sb(Red)

Fig 13 shows the gating pulses provided to switches Sa and Sb. The yellow signal shows the gating pulse to switch Sa and red signal shows the gating pulses to switch Sb.

Fig 14: Gate pulses for switch S1(Yellow) And S2(Red)

Fig 14 shows the gating pulses provided to switches S1 and S2. The yellow signal shows the gating pulse to switch S1 and red signal shows the gating pulses to switch S2.
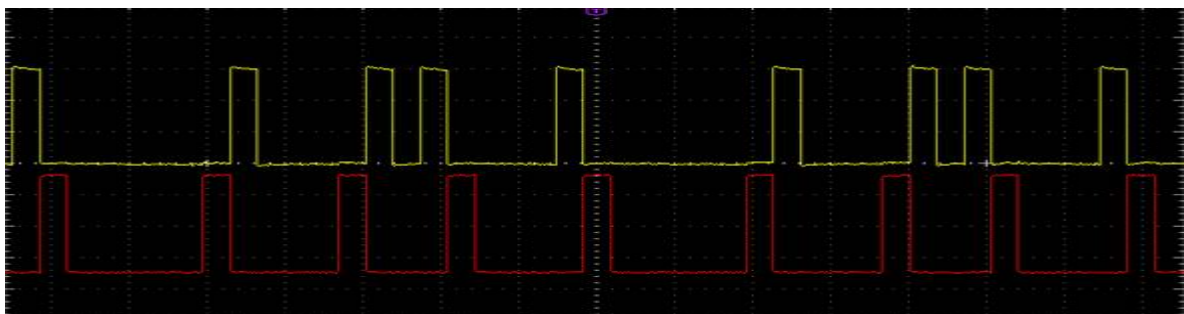

Fig 15: Gate pulses for switch S3(Yellow) And S4(Red)

Fig 15 shows the gating pulses provided to switches S3 and S4. The yellow signal shows the gating pulse to switch S3 and red signal shows the gating pulses to switch S4.

Fig 16: Gate pulses for switch S7(Yellow) And S5(Red)

Fig 16 shows the gating pulses provided to switches S7 and S5. The yellow signal shows the gating pulse to switch S7 and red signal shows the gating pulses to switch S5.
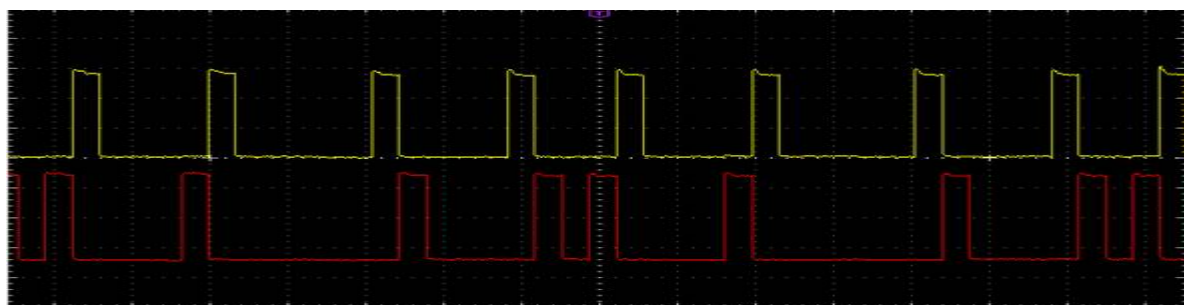

Fig 17: Gate pulses for switch S6(Yellow) And S8(Red)

Fig 17 shows the gating pulses provided to switches S6 and S8. The yellow signal shows the gating pulse to switch S6 and red signal shows the gating pulses to switch S8.
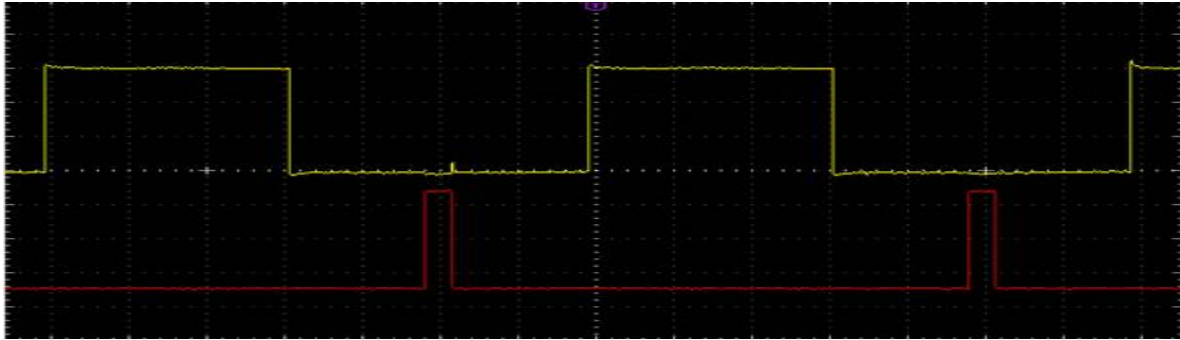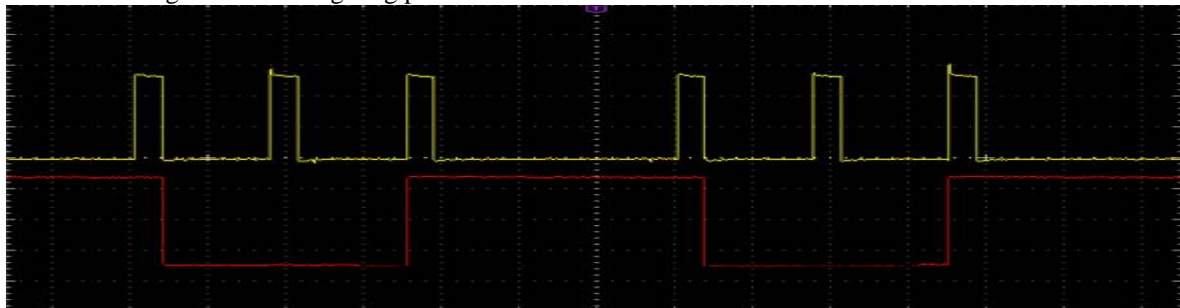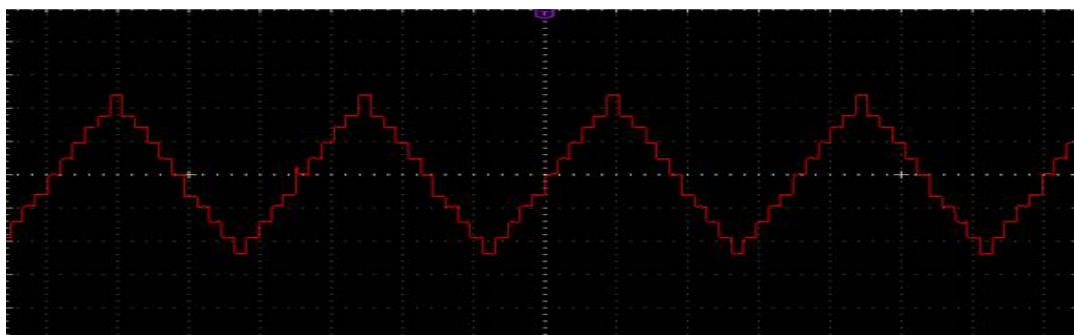

Fig 18: Output voltage waveform

Fig 18 shows the output voltage waveform of of Fuzzy controlled single string interleaved boost converter based PV eleven level inverter system for rural application taken across the load. The switches were successfully triggered and output waveform was achieved.

VIII. CONCLUSION

Single string PV system is selected instead of Multi string PV system. This decreases conduction losses by decreasing number of converters. Highly efficient FUZZY controlled interleaved boost converter with 50% duty ratio is proposed here for AC-DC converters. By using interleaved boost converter the inductor of lover rating can be used

since current is split into two parallel paths. Decrease in rating will lead to lower coast as well as smaller size. The capacitor voltage ripple is also reduced as the current always passes through the capacitor charging the capacitor in case of discharge. So capacitor of lower tolerance to voltage ripple can be used. The overshoots and oscillation seen in PI controller is eliminated in this system by using of FUZZY controller. Fig 19 shows comparison between PI and FUZZY controllers. Fuzzy controller can work when value for object is uncertain.

PARAMETERS	CONTROLLER	
	FUZZY	PI
Time to reach reference value	< 2 sec	3 sec
Overshoot	Absent	Present
Smooth waveform	Present	Absent
Oscillation	Absent	Present

Fig 19: Comparison between PI and FUZZY

By using MOSFET's based bi-directional switch combination replacing IGBT and Diode bridge structure we are reducing the use of non linear structure. MOSFET's are highly suitable for low power operation considering IGBT.

The future research will be focused on reducing no of components so as to decrease the total coast of the system. Advanced controller using neural control can be used for better performance. Research can be done for replacing series capacitor circuit since voltage division is not similar between two capacitors of same rating.

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