



Simulation of Solar Based High Stepup DC-DC Boost Converter Fed Transformerless Inverter Using Fuzzy Logic Controller and PR controller

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ABSTRACT

This paper presents the simulation of a solar based high stepup DC-DC boost converter fed transformerless inverter using fuzzy logic controller (FLC) and proportional resonant (PR) controller. The proposed topology is a two-stage (DC-DC-AC) power conversion topology. In this proposed topology a non-isolated high stepup DC-DC Boost stage is coupled with a dynamic dc-link single phase inverter. The front-end boost stage is controlled by fuzzy logic controller based Perturb and Observe (P&O) MPPT control technique and the inverter stage is controlled by PR controller based current and voltage control techniques. The performance of the proposed boost converter fed inverter configurations is validated through simulation in Matlab/Simulink platform. The proposed FLC -P&O MPPT control technique have high efficiency, low overshoot and less oscillation time compared to conventional P&O MPPT technique. The proposed boost converter proves good steady state performance, low voltage and current ripple and preserve constant output voltage with help of FLC. The proposed PR controller based current and voltage control techniques are used for control the inverter output voltage and current by changing the modulation and maintain zero steady state error in sinusoidal quantities compared to PI controller. The proposed inverter proves good steady state performance, low THD, and preserve constant output voltage with help of PR controller. The FLC based control technique, PR controller-based control techniques and unipolar sinusoidal PWM technique are increases the efficiency and reduce the THD range within 5% of the proposed model.

KEYWORDS: FLC based P&O MPPT, PR Controller, Boost converter, Transformerless stand-alone Inverter, Unipolar SPWM, Low Harmonic distortion, Matlab/Simulink.

I. INTRODUCTION

In recent years, many research works have been done on the use of solar photovoltaic (PV) energy as an alternative energy resource. PV energy is one of most hopeful renewable energy resources and it is clean and pollution free [1]-[2]-[3].

The conventional P&O MPPT have low MPPT ratio, more oscillation time and high overshoot

There are two different type of power conversion topologies such as isolated and non-isolated configuration [1]-[5]. Due to use of transformer in the isolated inverter structure, there are some drawbacks such as low power density and complicated to control the output [1]-[4]-[5].

voltage [2]-[7]. Due these drawbacks the output power efficiency should be very low and it affect efficiency of the system [1]-[8]-[11].

The Fuzzy logic controller-based P&O MPPT technique have less settling time, low oscillation time and low overshoot, and it sable at change in irradiance [2]-[3]-[10]. Due to these advantages, it improves the MPPT ratio, reduce oscillation and overshoot voltage [2]-[3]-[10]-[12].

The PI controller cannot produce zero steady state error in sinusoidal quantities [4]-[18]. Due this drawback, it makes overshoot voltage and also it reduces the quality of the sine wave [5]-[14].

The PR controller can maintain zero steady state error in sinusoidal quantities. Due this advantage the PR controller produce zero steady state error in sinusoidal quantities [4]-[5]-[19]-[20]. This paper presents work on improving MPPT algorithm which should be able to increase performance of the PV system. This paper introduces combination of features in both conventional P&O MPPT and FLC to form single algorithm for MPPT of PV dc-dc boost converter which is simple and faster. This proposed MPPT method proves better steady state performance with various irradiance conditions. This paper introduces PR controller based Current and Voltage control techniques for stand-alone inverter to control the inverter output voltage. This proposed PR controller-based control technique proves better steady state performance. This control technique achieves zero steady state error in sinusoidal quantities. The Figure:1 shows block diagram of Proposed model

To further explain about this work, Section 2 in this paper covers configuration of Proposed model, and followed by discussion on fuzzy logic controller implementation in Section 3, PR controller implementation discussed in Section 4, simulation and results are discussed in Section 5, Finally, Section 6 concludes findings from this work.

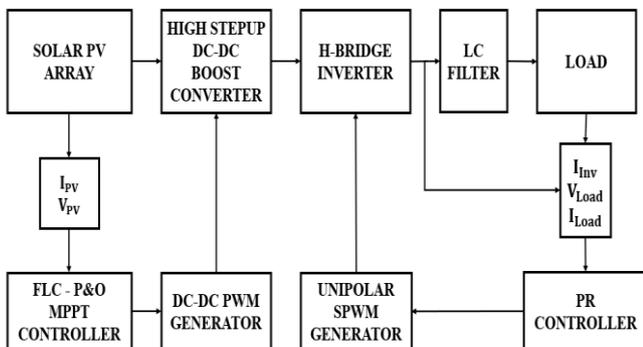


Figure:1 Block diagram of Proposed model

II. CONFIGURATION OF PROPOSED MODEL

The configuration of proposed model consists of Solar PV array PV, High stepup DC-DC Boost converter, Stand-alone inverter. The proposed inverter topology is a two-stage power conversion power conversion topology, as shown in figure:2 Configuration of the proposed high stepup DC-DC boost converter fed Transformerless Inverter.

A. SOLAR PV ARRAY

In this proposed model, 1SOLTECH 1STH-215-P PV panel is used with the following characteristics: Maximal Module Power (Pm) of 213.15W, optimal voltage (V_{mp}) of 29V, optimal current (I_{mp}) of 7.35A, saturation current (I₀) of 2.9259e⁻¹⁰A, photo-current (I_{ph}) of 5.9602A, short circuit current (I_{sc}) of 7.84A, open circuit voltage (V_{oc}) of 36.3V, serial resistance (R_s) of 0.037998Ω, shunt resistance (R_{sh}) of 313.3991Ω and number of cells equal to 60. As regards the PV array, its characteristics are serial modules number of 7 and parallel modules number of 5. Hence, the PV has a power of 7 × 5 × 213.15W = 7500W. Irradiance of 1kW/m² and cell temperature of 25°C are the electrical specifications under test conditions.

B. HIGH STEPUP DC-DC BOOST CONVERTER

In this proposed model, dc-dc converter make use of MPPT. dc-dc converter can be used as switching-mode regulator to convert a dc voltage, normally unregulated, to a regulated dc output voltage. The regulation is normally achieved by pulse-width modulation (PWM) technique and the switching device is normally. Boost dc-dc converter's function is to step up dc voltage. Maximum power is reached when the MPPT algorithm changes and adjusts the PWM's duty cycle of the boost dc-dc converter. The proposed FLC-P&O MPPT technique is control the boost converter. Boost Inductor and DC link capacitor functions of boost converter is instead defined as:

$$\text{Boost Inductor } (L_b) = \frac{(V_{out} - V_{in}) V_{in}}{f_{sw} \times \Delta I \times V_{out}} \quad (1)$$

$$\text{DC link capacitor } (C_{dc}) = \frac{(V_{out} - V_{in}) I_{out}}{f_s \times \Delta V \times V_{out}} \quad (2)$$

where f_s-Switching frequency (f_s = 25 kHz), Vin and Vout are the inputs and outputs voltages, respectively, ΔI and ΔV are the inductor current and voltage ripple. The value of boost inductor is 10.89 mH and dc-link capacitor is about 1000μF.

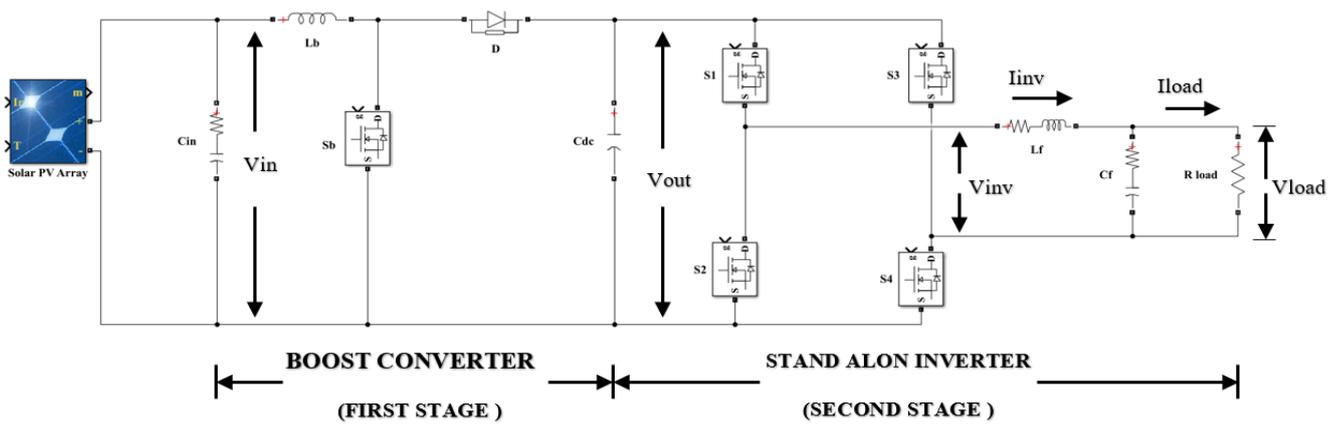


Figure:2 Configuration of the proposed high stepup DC-DC boost converter fed Transformerless Inverter

C. STAND ALONE INVERTER

In this proposed model, closed loop (stand-alone) single phase inverter stage is directly coupled with dc-dc converter. The proposed inverter output voltage and current are controlled by PR controller-based control technique. In this inverter voltage and current control is normally achieved by Unipolar sinusoidal pulse-width modulation (SPWM) technique. This inverter can convert 400V DC voltage into 230V (RMS) AC voltage using PR controller

To design a LC filter by using this formula,

$$\text{Cut off frequency } (f_c) \leq \frac{f_{sw}}{10} \quad (3)$$

$$\text{Filter Inductor } (L_f) < \frac{0.03 V_{out}}{(2\pi f_c) I_{Lmax}} \quad (4)$$

$$\text{Filter Capacitor } (C_f) = \frac{1}{(2\pi f_c)^2 L_f} \quad (5)$$

Here, V_{out} - Inverter DC input voltage, I_{Lmax} - Inductor maximum current, f_{sw} - Switching frequency ($f_{sw} = 10\text{kHz}$). The value of filter inductor is 4.06mH and the filter capacitor is about 6.23 μF .

III. FUZZY LOGIC CONTROLLER IMPLEMENTATION

A fuzzy inference system (FIS) is mathematical means of describing vagueness in linguistic terms instead of exact mathematical description. They are appropriate dealing with uncertainties and approximate reasoning. Membership function ranges from 0-1 in their linguistic from associated with imprecision concept. A FLC-P&O MPPT is more stable and it have low oscillation time compared to conventional P&O MPPT controller. A FLC is divided into four categories, which include fuzzification, fuzzy inference, rule-base and defuzzification.

FLC-P&O MAXIMUM POWER POINT TRACKING

The conventional and popular Maximum Power Point Tracking technique is P&O MPPT algorithm. The voltage is perturbed and the change of the output power is observed so it is called P&O MPPT algorithm. The inputs of the P&O algorithm are PV current and voltage. The proposed FLC-MPPT technique uses inputs of P&O algorithm such as differential power ΔP and differential voltage ΔV . The proposed change in this algorithm is to replace comparing and switching methods with fuzzy logic approach, as shown in Figure:3 shows Comparison between P&O and FLC- P&O MPPT and Figure:4 shows implementation of the algorithm in MATLAB-Simulink.

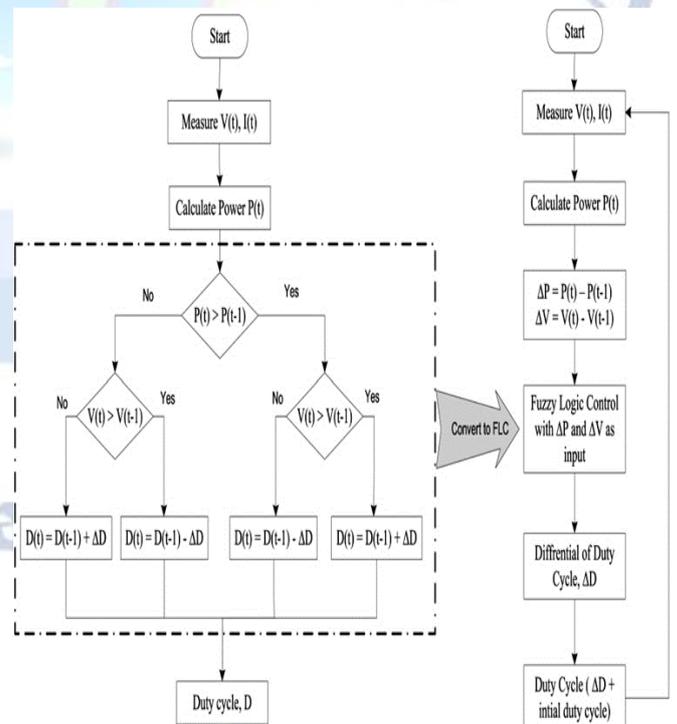


Figure:3 Comparison between P&O and FLC- P&O MPPT

During fuzzification, the numerical input variables are converted into linguistic variables based on the membership functions. Various fuzzy levels could be used for input and output variables. Five proposed fuzzy sets for input and output variables are N (negative), ZE (zero), PS (positive small), P (positive) and PB (positive big). Figure :5 shows membership functions for input of difference between the current power and the previous power ΔP , input of difference between the current voltage and the previous voltage ΔV and output of difference between the current duty cycle and the previous duty cycle ΔD . After ΔP and ΔV are calculated, they are converted into linguistic variables and then the output ΔD is generated by looking up in a rule-base table as shown in Table 1, which consists of 25 rules. This algorithm uses Mamdani fuzzy inference system to determine the output. Usually, weights are added to the rules to improve reasoning accuracy and to reduce undesirable consequent. The fuzzy output is converted back to numerical variable from linguistic variable during defuzzification. In this algorithm uses method the common COA is used for the defuzzification.

In its operation, when ΔP and ΔV are either positive or negative values, the FLC will decide the best and accurate value of ΔD . Therefore, ΔD will be changed according to the condition of ΔP and ΔV at certain time where measurement process is done. It will obey the membership function designed in the proposed FLC.

Table 1 Fuzzy Rules

$\Delta P \backslash \Delta V$	N	ZE	PS	PS	PB
N	NE	PS	P	PB	PB
NE	NE	ZE	PS	P	PB
PS	N	ZE	ZE	PS	P
P	N	N	ZE	ZE	PS
PB	N	N	N	ZE	ZE

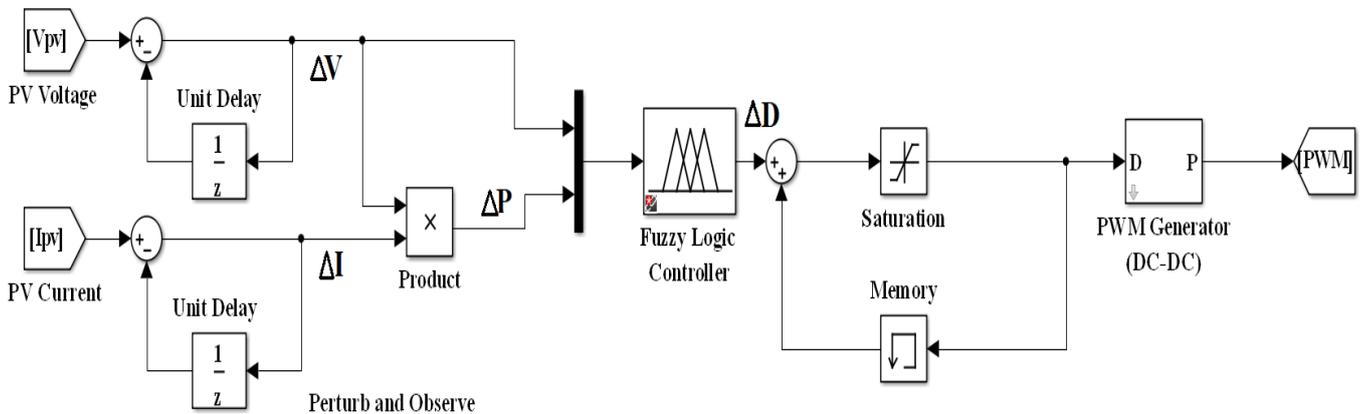


Figure:4 Implementation of the FLC_P&O MPPT algorithm in MATLAB-Simulink

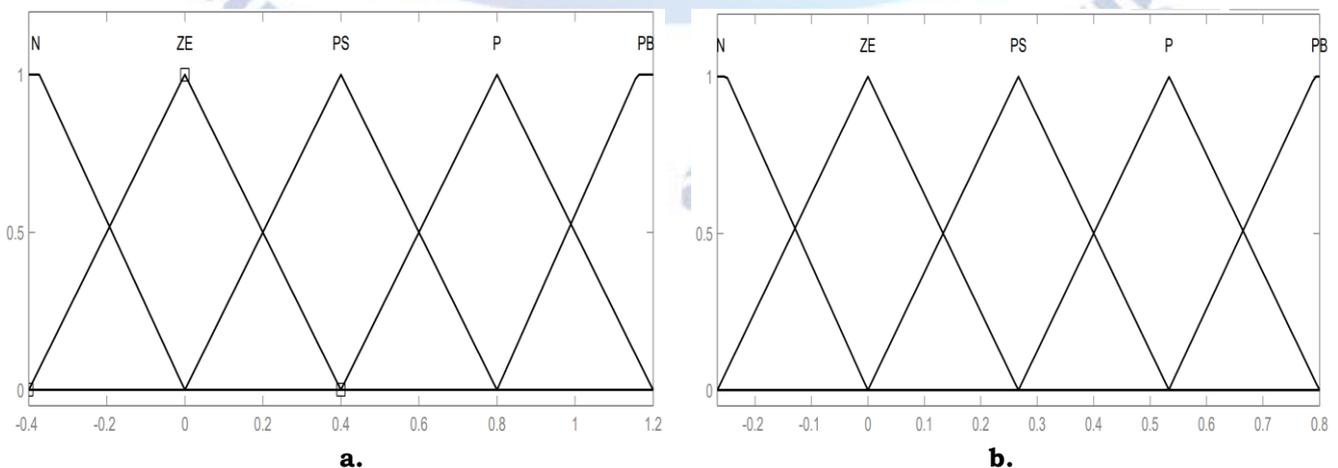


Figure:5 Membership function. a. Input of ΔP and ΔV , b. output of ΔD

IV. PR CONTROLLER IMPLEMENTATION

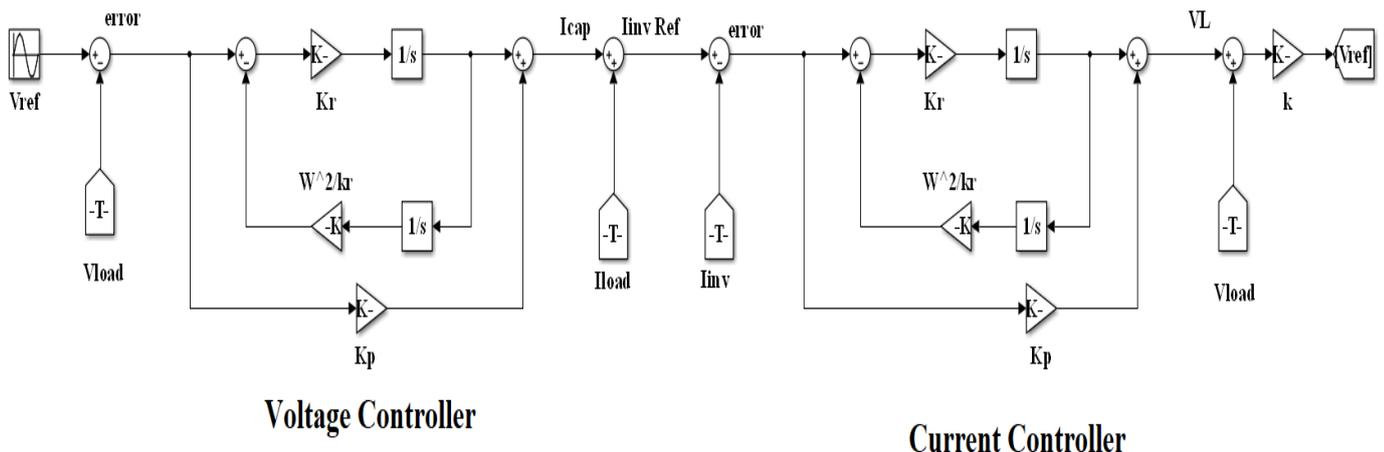


Figure:6 PR Controller block diagram

The Proportional Resonant (PR) Controller is used as out voltage controller and current controller. By comparison with the conventional PI control method, the PR control can introduce an infinite gain at the fundamental frequency and hence can achieve zero steady state error in sinusoidal quantities and this controller has additional negative feedback loop. This feedback loop makes controller performance better when compared to PI controller. For implementation of closed loop control following three voltage and current values are needed 1. output voltage or load voltage (V_{load}), 2. inverter (I_{inv}), 3. load current (I_{load}). In voltage controller side, find the error between the sine wave reference voltage and actual load voltage (V_{load}) now the error is fed to the PR controller. Output of the controller give capacitor current (I_{cap}) now the capacitor current is added to load current according to the Kirchoff's current law (KCL) sum of the capacitor current and load current will give reference inverter current ($I_{inv Ref}$). In In current controller side, the inverter reference current ($I_{inv Ref}$) is compared to actual inverter current (I_{inv}) it gives error signal; the error signal is fed to PR controller. Output of the PR controller is given voltage across inductor (VL) now add the voltage across inductor (VL) to load voltage (V_{load}). According to Kirchoff's Voltage law (KVL) this will give reference inverter voltage (V_{ref}) and this is the voltage to be generated by the inverter and this voltage act as the reference voltage for Unipolar SPWM generation block, as shown in Figure:6 PR controller block diagram

Transfer function

$$Y(s) = E(s) * \left(k_p + \frac{k_r s}{s^2 + \omega^2} \right) \quad (6)$$

Calculation of Proportional gain (k_p) value for Voltage Controller

Controller Time Constants = 200 μ s

Filter Capacitance (C_f) = 6.23 μ F

$$k_p = \frac{\text{Capacitance}}{\text{Time Constant}} = \frac{6.23 \times 10^{-6}}{200 \times 10^{-6}} = 0.03115$$

Calculation of Proportional gain (k_p) value for Current Controller

Controller Time Constants = 150 μ s

Filter Inductor (L_f) = 4.06mH

Inductor series resistance = 0.001

$$k_p = \frac{\text{Inductance}}{\text{Time Constant}} = \frac{4.06 \times 10^{-3}}{150 \times 10^{-6}} = 27.066$$

Calculation of Resonant gain (k_r) value for Current Controller

$$\text{Gain of the PR controller } (G_n) = \frac{k_r \omega_n}{\omega_n^2 - \omega^2} \quad (7)$$

$$\text{Resonant frequency } (\omega_n) = \frac{1}{\sqrt{LC}} \quad (8)$$

$$\text{Natural frequency } (\omega) = 2 \times \pi \times 50 \quad (9)$$

k_r value for current controller = 100

$$\frac{\omega^2}{k_r} = \frac{(2 \times \pi \times 50)^2}{100} = 986.83$$

k_r value for voltage controller = 400

$$\frac{\omega^2}{k_r} = \frac{(2 \times \pi \times 50)^2}{400} = 246.7$$

If $V_{out} = 400v$ set $k = 1/400$

V. SIMULATION RESULTS AND ANALYSIS

The proposed model has been developed and simulated in Matlab/Simulink Platform. The Simulation diagram of proposed high stepup DC-DC boost converter fed transformerless inverter is shown in Figure:7. The circuit components are obtained from Sim Power System library. A fuzzy logic controller is designed by fuzzy logic controller designer application in Matlab/Simulink Platform, refer section 2 for design a FLC. A PR controller is developed by Matlab/Simulink Platform refer section 3 for PR controller implementation. In PR controller, sine wave reference amplitude value is 230 for 230V (RMS) output, frequency value is 314.4(rad/sec). In unipolar SPWM, the repeating sequence time value is (0, 0.00005, 0.0001) and output value is (-1,1, -1). Scope is used for viewing the simulation results. The proposed boost converter is simulated at a switching frequency of 25kHz. The proposed inverter is simulated at a switching frequency of 10kHz. The values of circuit components for the simulation are selected based on the design considerations and are listed in Table:2 shown below. Table:3 lists the specifications of the proposed model. The discrete state variable model of sampling time $T_s = 1e^{-06}$ sec is used for simulation. The various waveforms for the proposed converter and inverter are shown in Figure:8 – Figure:14 respectively. The output DC and AC voltage are compared with that of the conventional MPPT, Voltage and control schemes.

The simulation results demonstrate that the proposed model shows improved voltage gain compared to that of conventional boost converter, improved MPPT ratio and zero steady state error compared to P&O MPPT and PR controller preserve zero steady state error in sinusoidal quantities compared to PI based control technique.

Table:2 Simulation Parameters of proposed model

Circuit components	Values
Input Capacitor (C_{in})	1000 μ F
Inductor (L_b)	10.45mH
DC link Capacitor (C_{dc})	1000 μ F
Filter Inductor (L_f)	4.06mH
Filter Capacitor (C_f)	6.23 μ F
Load Resistor (R_{load})	56 Ω

Table:3 Specifications proposed model

Specifications	Values
Solar Input voltage (V_{in})	(150-260) V (DC)
Boost converter Output voltage (V_{out})	(220-400) V (DC)
Inverter output voltage (V_{inv}), (V_{load})	(220-400) V (AC)
Maximum Power (P_m)	7500W

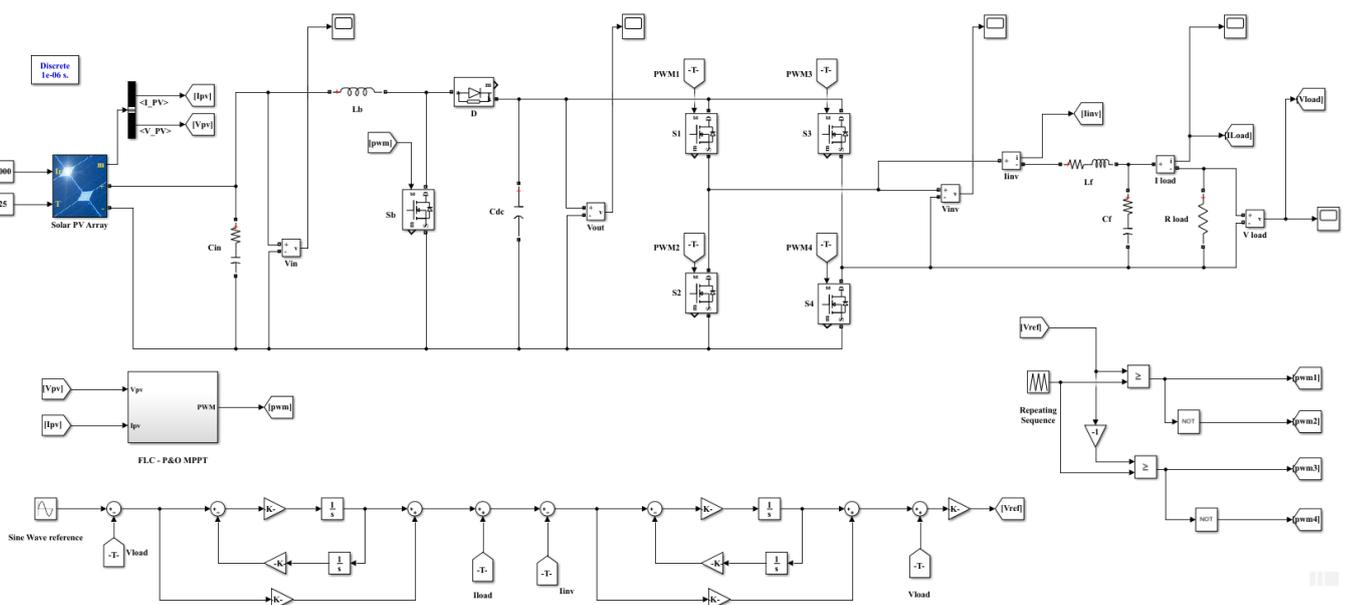


Figure:7 Simulation diagram of proposed high stepup DC-DC boost converter fed Transformerless inverter

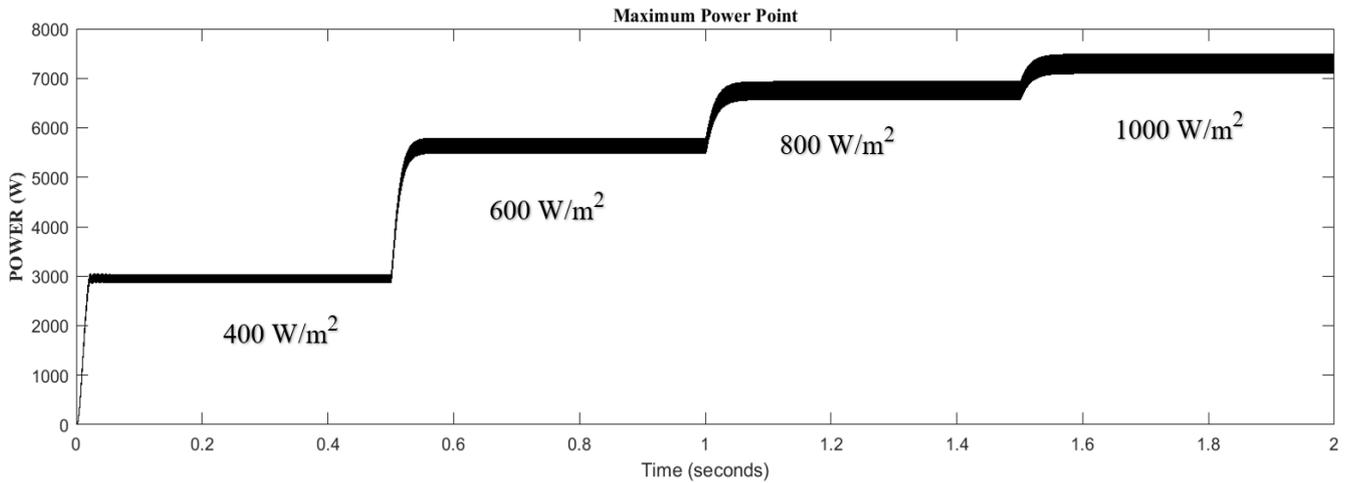


Figure:8 Maximum power point waveform of proposed FLC-P&O MPPT at change in Irradiance with $P_{max} = 7500w$

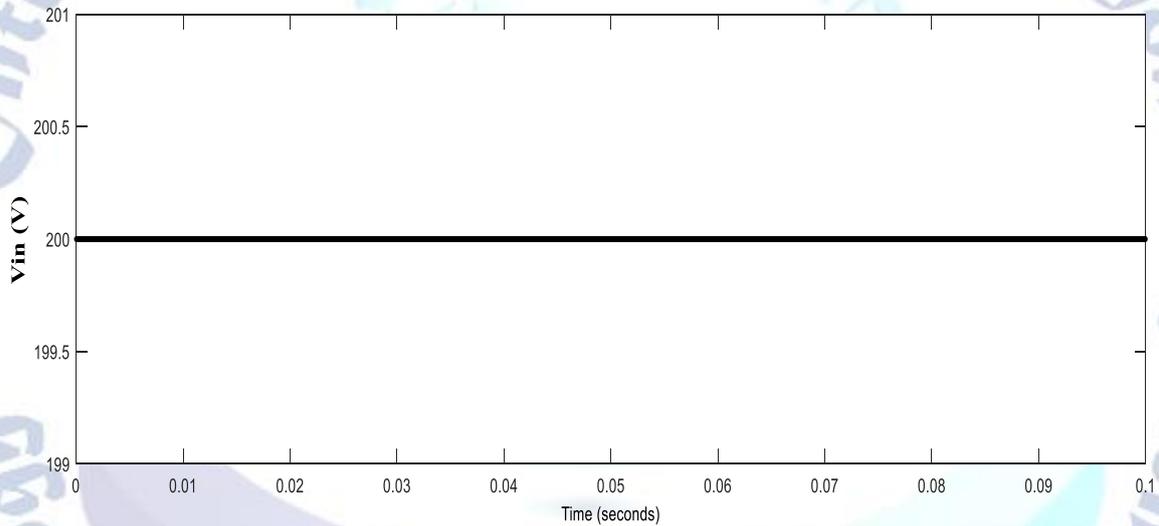


Figure:9 Input DC voltage waveform of proposed Boost converter $V_{in}=200V$, at Irradiance of $1kW/m^2$ and cell temperature of $25^{\circ}C$

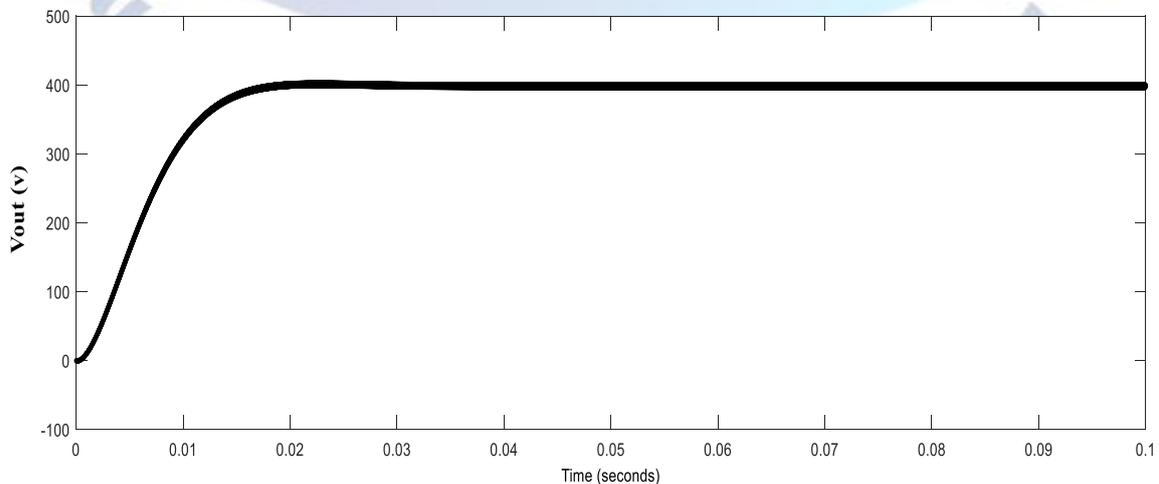


Figure:10 Output Voltage waveform of proposed Boost converter with duty cycle $D=0.5$, $V_{out}=400V$

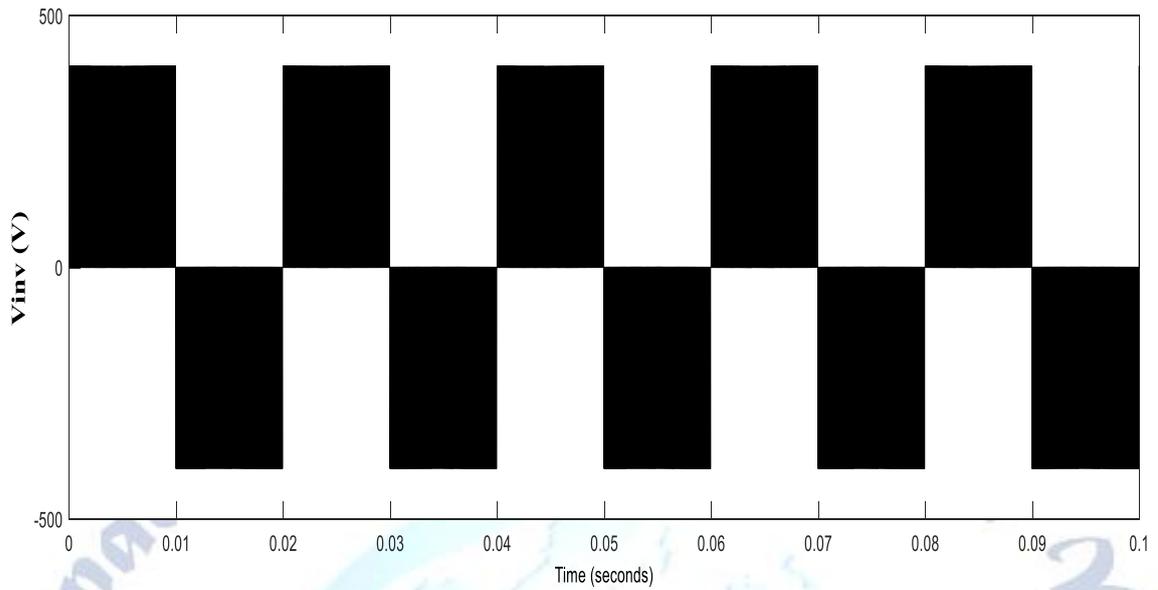


Figure:11 Before filter output voltage waveform of proposed inverter with $V_{inv}=400V$

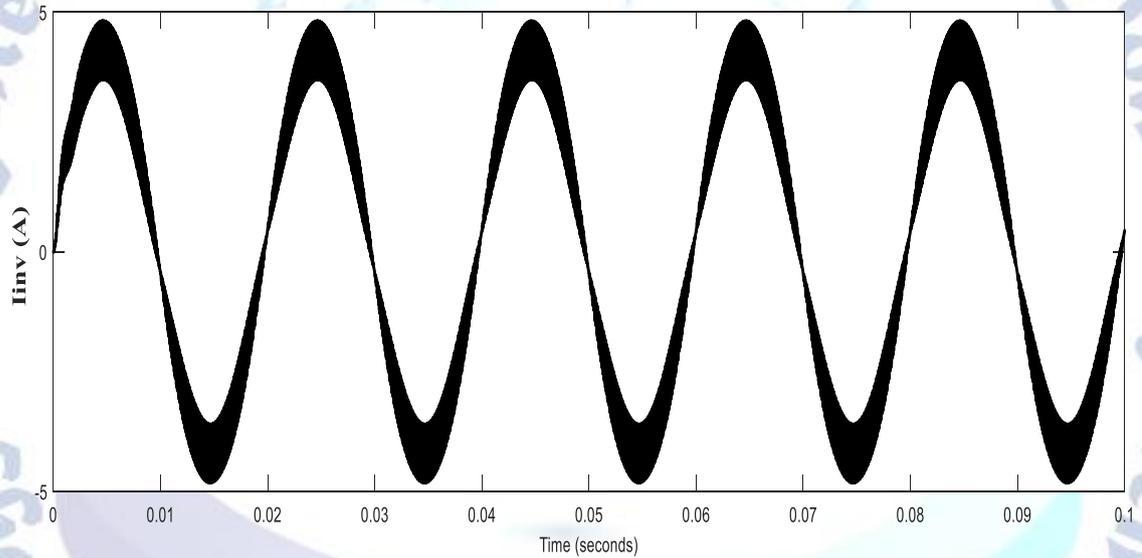


Figure:12 Before filter output current waveform of proposed inverter with $I_{inv}=4.3A$

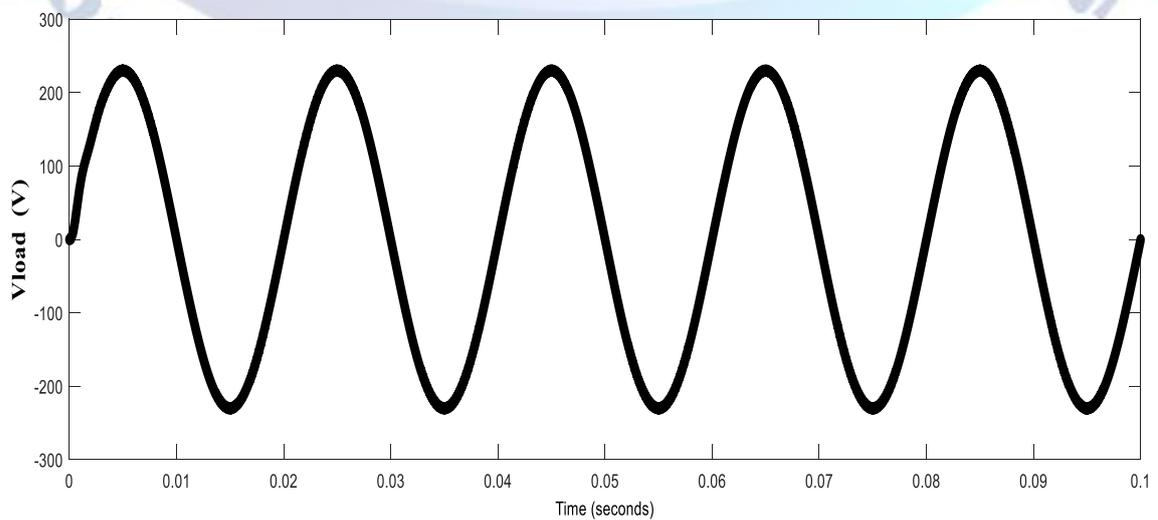


Figure:13 After filter output voltage waveform of proposed inverter with $V_{load}=230V$ (RMS)

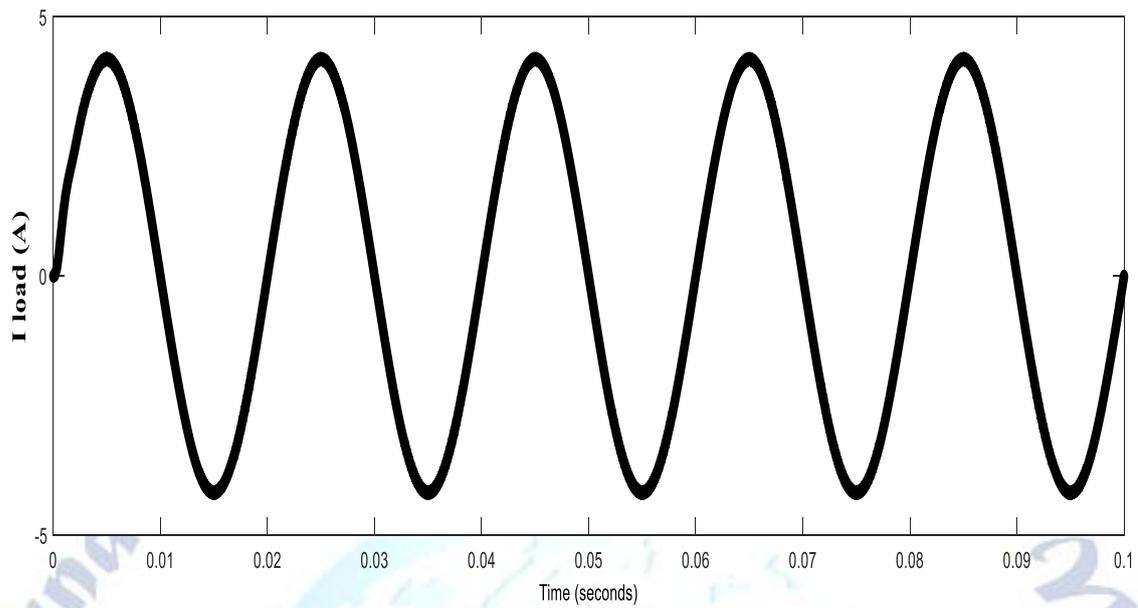


Figure:14 After filter output current waveform of proposed inverter with Iload=4.258 A (RMS)

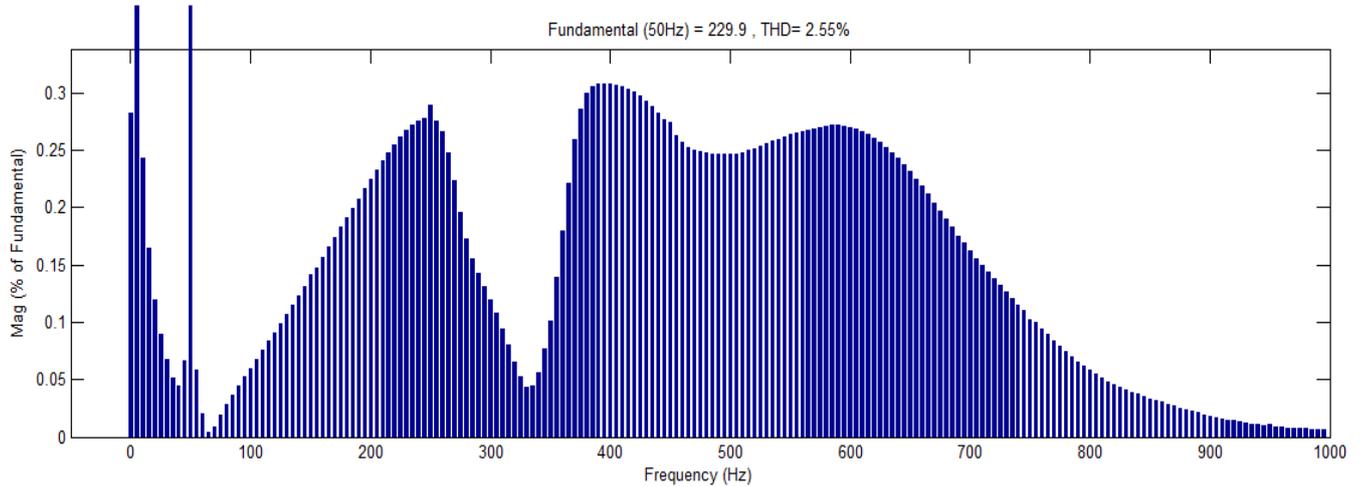


Figure:15 FFT analysis and THD value of proposed inverter output voltage with THD=2.55%

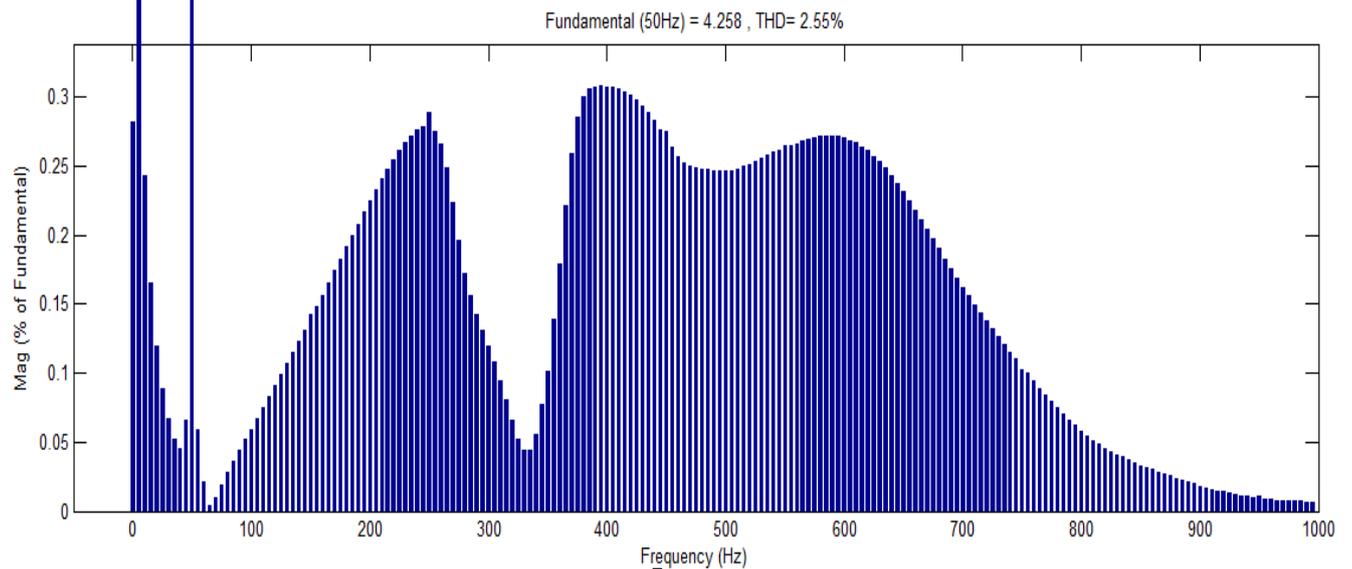


Figure:16 FFT analysis and THD value of proposed inverter output current with THD=2.55%

VI. CONCLUSION

In this paper, fuzzy logic controller based P&O MPPT and voltage control scheme and PR controller based voltage and current control scheme has been presented for high stepup DC-DC boost converter fed single phase transformerless inverter. The MPPT, control strategy and unipolar sinusoidal PWM are simulated in Matlab/Simulink environment. Based on the investigations made from simulation results following important points are concluded. The FLC in boost converter side so the results show low oscillation and settling time, low in over shoot, zero steady state error and P&O MPPT have efficiency of 98% at changes in temperature and irradiance. The PR controller in inverter side so the results show zero steady state error in sinusoidal quantity and low in THDs. In this proposed model a stable DC voltage is supplied to inverter through the Boost converter by FLC and a controlled AC output voltage is obtained by adjusting Sinusoidal Pulse Width Modulation through PR controller. The Unipolar SPWM technique improves quality of output voltage, current power. This proposed inverter produces highly efficient AC output successfully.

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