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A Single Phase AC Grid Tied Solar Power Generation using Boost DC – AC Inverter with Modified Non-Linear State Variable Structure Control

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Abstract: This paper proposes a single stage solar power generation with boost dc-ac inverter by simple control technique. The boost dc-ac inverter converts and boosts a low output dc voltage of the solar pv array into a $220V_{rms}$ ac voltage at a fundamental frequency of 50Hz in single stage. A simple Modified Non-Linear State Variable Structure (MNLSVS) closed loop control technique is proposed to keep the output voltage constant barring various load conditions. Generally the double-loop control technique and voltage feedback closed loop control were used for control the output of the boost dc-ac inverter but it involves more complex control theory and not control capacitor voltages respectively. Hence it cannot give instant response under inconsistent loads. Hence the proposed control scheme maintains constant output voltage and adopts with inconsistent load conditions. Therefore the proposed MNLSVS control scheme has more desirable features such as low cost and minimum number of switches. The Total Harmonic Distortion (THD) generated by the proposed configuration is quite reasonable. The complete system is modeled using MATLAB/SIMULINK.

Key words: DC–AC power conversion, solar power generation, Single stage boost dc-ac inverter, Total Harmonic Distortion.

INTRODUCTION

The fast diminishing of conventional energy sources, increasing of different pollutions and the ever increasing demand of the electrical energy are driving the engineering society towards the investigation and the developing of alternate energy sources which are less or zero pollution and eco-friendly (Stanley R. Bull, 2001). Among the various renewable energy sources, solar energy has more advantages because of its less pollution and free in nature. Beside this, solar energy is easy to adopt with existing power converters (Arun Kumar Vrema,, 2010; Rong-Jong Wai, 2008; Rafia Akhter, 2007). Hence a power electronic interface is likely to be developed between solar system and the single phase utility grid or ac load, which mainly consists of MPPT Solar Charge controller; dc energy storage device and single stage boost dc-ac inverter, modeled by two current bidirectional buck boost converter (Vazquez, N., 2000). Primarily the maximum energy from the solar photovoltaic array is extracted and stored in a dc energy storage device by MPPT solar charger, which was designed by boost converter and its output controlled by Maximum Power Point Tracking(MPPT) Technique (Weidong Xiao, 2007). The Perturbation and Observation (PO) algorithm is used in MPPT controller because P&O algorithm is most efficient than the other technique algorithms and it is more suitable for regulating the output voltage of the solar charger irrespective of solar radiation. The proposed topology shown in Fig.1 used in this paper, maintains constant voltage under various loads. The double-loop control technique is used for control the output of the boost dc-ac inverter but it involves more complex control theory. Hence it cannot give instant response in abrupt load changes. Also the voltage feedback closed loop control scheme is another method control technique which cannot control the load voltage under inconsistent loads. Hence the proposed control scheme maintains constant output voltage and adopts with inconsistent load conditions than the double-loop control strategy and voltage feedback closed loop control technique.

Modeling of MPPT Solar Charger:

The MPPT solar charge controller is designed by boost converter in which the output voltage is controlled by P&O algorithm based MPPT technique as in the Fig. 2. A MOSFET is selected as a switch for Boost converter in which the average output current is less than the inductor current and also a high rms current is flowing through the capacitor. The output voltage of this boost converter is always greater than the input voltage and it is designed by the assumption of the following parameters.

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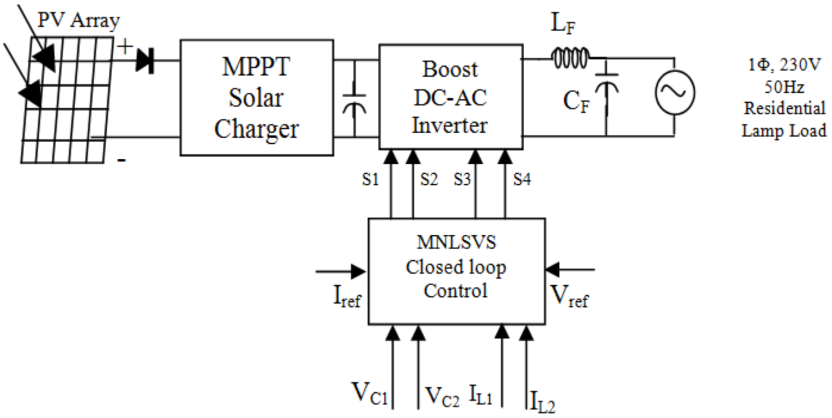


Fig. 1: The proposed solar energy conversion scheme.

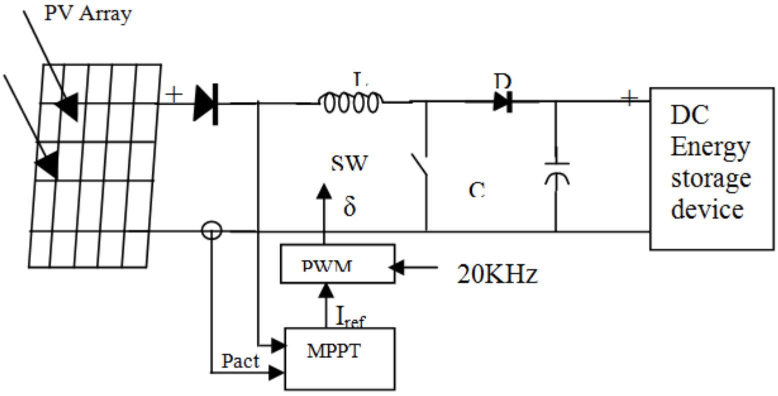


Fig. 2: Modeling of MPPT Solar Charger.

1. Duty cycle (δ) of a boost Converter can be given as

$$\delta = 1 - \frac{V_{in}}{V_o} \tag{1}$$

Where, V_{in} = input voltage of the Boost Converter which is equal to output of the PV array; V_o = output voltage of the Boost Converter

2. The value of the inductor(L) can be given as

$$L = \frac{V_{PV}\delta}{2\Delta i_1 Fsw} \tag{2}$$

Where, V_{PV} = output voltage from the PV array; Δi_1 = output ripple current;

Fsw = switching frequency

3. The value of the output capacitor(C) can be formulated as

$$C = \frac{I_o\delta}{\Delta V Fsw} \tag{3}$$

Where, I_o = output current; ΔV = output ripple voltage

This Boost dc – dc converter is mainly responsible for the regulation of the output voltage and providing a constant voltage for charging the battery. PWM technique is adopted to regulate the output voltage of the Boost converter. Following parameters were calculated from above formulas, assumed for simulation work V_{in}= 21V, V_O = 100V, F_{SW} = 20 KHz, Vripple = 10%, Duty Cycle = 80.34%, Ipk = 0.75A, Irms = 0.20 A, L = 2238 uH and C = 3.2 uF

Single Stage Boost DC-AC Inverter:

The proposed boost dc-ac inverter consists of two separate bidirectional buck-boost dc – dc converters (Brad Bryant, 2005; Pablo Sanchis, 2005) shown in Fig.3, which produces a dc- biased sine wave output so that each source only produces a unipolar voltage as in the Fig.4. The modulation on each converter is 180^0 out of phase with the other, which maximizes the voltage excursion across the load. The load is connected differentially across the two converters. DC bias voltage of each converter is appears at each end of the load and differential dc voltage across the load is zero with respect to ground. The main advantage of this single stage boost dc-ac converter is the reduced number of switches and smooth sine wave of the output voltage. The proposed boost dc-ac inverter is shown in Fig.5

The output voltage of each converter is

$$V_1 = V_{dc} + V_m \sin\omega t \quad (4)$$

$$V_2 = V_{dc} - V_m \sin\omega t \quad (5)$$

Voltage across the load is $V_o = V_1 - V_2$

$$= 2V_m \sin\omega t \quad (6)$$

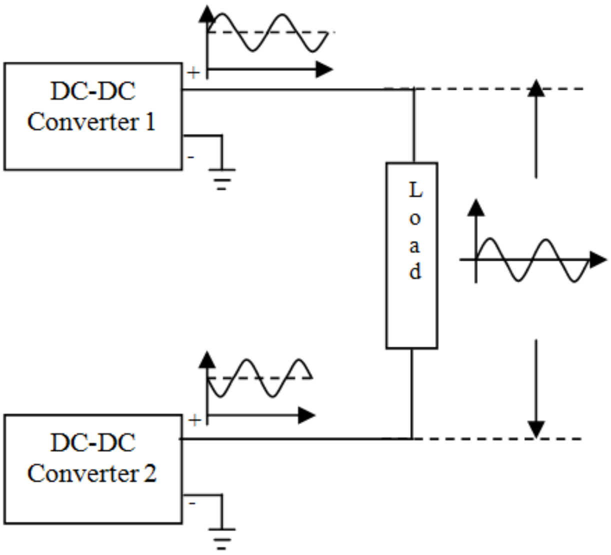


Fig. 3: Basic arrangement of two bidirectional dc-dc buck boost converters.

The operation of boost dc-ac inverter can be explained by modes of operation and each converter operates under two modes such as:

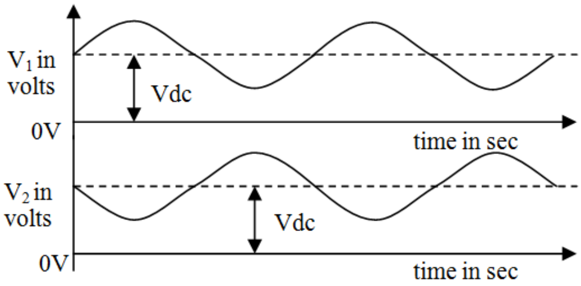


Fig. 4: Output voltages of each dc-dc buck boost converters.

Mode1:

When the power switch S_1 is closed and S_2 is open as in the Fig.5, the current i_{L1} rises quite linearly, diode D_2 is reverse polarized, capacitor C_1 supplies energy to the output stage and voltage V_{C1} decreases.

Mode2:

When the power switch S_1 is open and S_2 is closed as in the Fig.5, supply voltage V_{in} and inductor current i_{L1} flows through capacitor C_1 and the load, the current i_{L1} decreases while capacitor C_1 recharged.

The conduction mode of the converter 1 is given by $\frac{V_{C1}}{Vs} = \frac{1}{1-\delta}$ and the conduction mode of the converter 2 is given by $\frac{V_{C2}}{Vs} = \frac{1}{\delta}$

Where D is the duty cycle, V_{C1} is the voltage across the capacitor of the converter-1 and V_{C2} is the voltage across the capacitor of the converter-2, V_s is the input voltage to the single stage boost dc-ac inverter. Since the two converters are 180^0 out of phase, the output voltage is given by

$$V_0 = V_{C1} - V_{C2}\,; \quad = \frac{Vs}{1-D} - \frac{Vs}{D} \qquad ; \qquad \frac{V_0}{Vs} = \frac{2D-1}{(1-D)D} \tag{7}$$

The state space modeling of the equivalent circuit with state variables i_{L1} and V_{C1} is by applying KVL and KCL

$$\begin{bmatrix} \frac{di_{L1}}{dt} \\ \frac{dV_{C1}}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-R_a}{L_1} & \frac{-1}{L_1} \\ \frac{1}{C_1} & \frac{-1}{C_1 R_1} \end{bmatrix} \begin{bmatrix} i_{L1} \\ V_{C1} \end{bmatrix} + \begin{bmatrix} \frac{V_{C1}}{L_1} \\ \frac{-i_{L1}}{C_1} \end{bmatrix} \lambda + \begin{bmatrix} \frac{V_S}{L_1} \\ \frac{V_{C2}}{C_1 R_1} \end{bmatrix}$$

$$\dot{x} = Ax + B\lambda + C$$

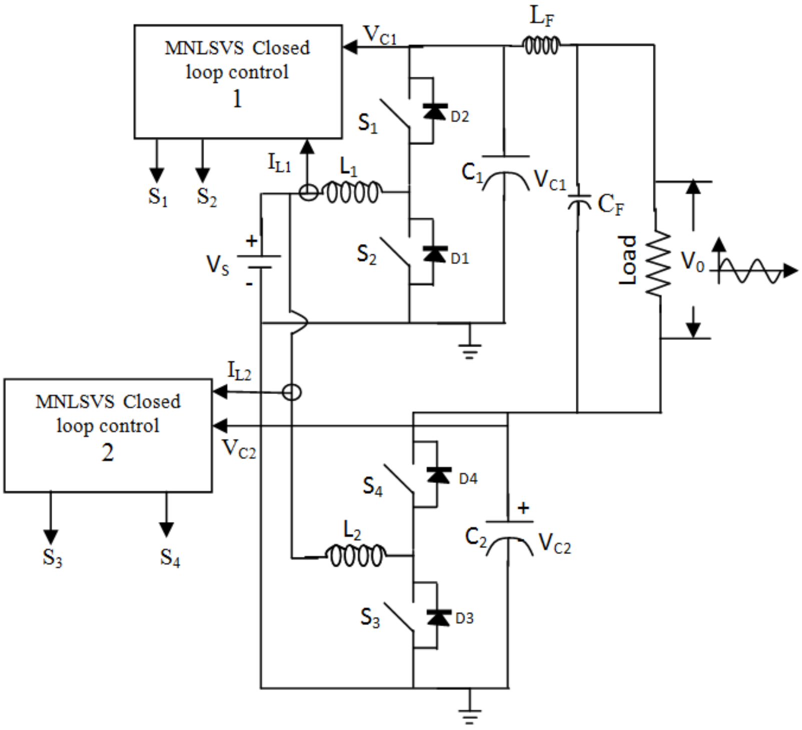


Fig. 5: Proposed boost dc-ac inverter.

Where λ is the status of the switches, $\dot{x}$ and x are the vectors of the state variables (i_{L1}, V_{C1})

$$\lambda = \begin{Bmatrix} 1 \rightarrow S1ON, S2OFF \\ 0 \rightarrow S1OFF, S2ON \end{Bmatrix}$$

MNLSVS Closed Loop Control Technique:

The variable structure control equation in the state space expressed by a linear combination of state variable errors ε_1 and ε_2 are gives a good transient response for the output voltage.

$$\lambda(i_{L1}, V_{C1}) = k_1\varepsilon_1 + k_2\varepsilon_2 = 0 \tag{8}$$

Where coefficients K_1 and K_2 are proper gains

$$\varepsilon_1 = i_{L1} - i_{Lref} \tag{9}$$

$$\varepsilon_2 = V_{C1} - V_{Lref} \tag{10}$$

By substituting equations (9) and (10) in (8),

$$\lambda(i_{L1}, V_{C1}) = k_1(i_{L1} - i_{Lref}) + k_2(V_{C1} - V_{Lref}) \tag{11}$$

The system response is determined by the circuit parameters and coefficients K_1 and K_2. With proper selection of these coefficients in any operating condition, high robustness, stability and fast response can be achieved.

Proposed Control Scheme for Single Stage Boost DC-AC Inverter:

A Non-Linear Sate Variable Structure Control strategy can be modified for boost inverter to maintain the constant output voltage in sudden load changes as in Fig.6. In this method, the capacitor voltage (V_{C1}) and the inductor current (I_{L1}) of the boost dc-ac inverter are considered for control the output voltage of the inverter by relay with proper gains. A continuous pulse produced by the relay and it was logically AND with fundamental frequency with the proper phase shift of fundamental frequency as 50Hz. The main advantage of this closed loop control method is to keep the output voltage constant barring various transient conditions like abrupt load changes. The voltage across the capacitor (V_{C1}) and inductor current (I_{L1}) of the converter 1 is adjusted separately with the proper gain values of K_1 and K_2 to get the proper duty cycle of the converter-1 and hence as a result we can get a continuous pulse signal with unequal width. This signal controls the switches S_1 and S_2 of the converters-1. The same technique is also used to control switches S_3 and S_4 of the converters-2.

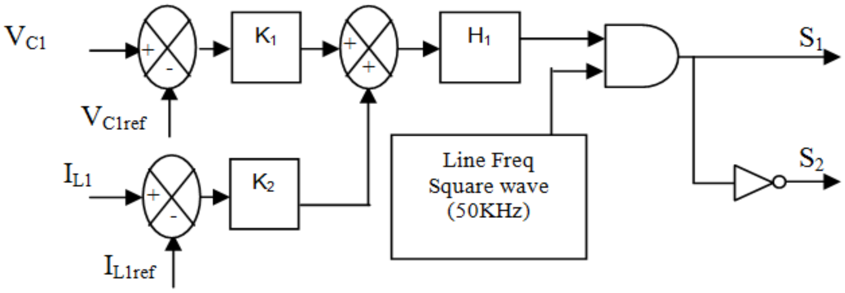


Fig. 6: Proposed MNLSVS closed loop control strategy for single stage boost dc-ac inverter.

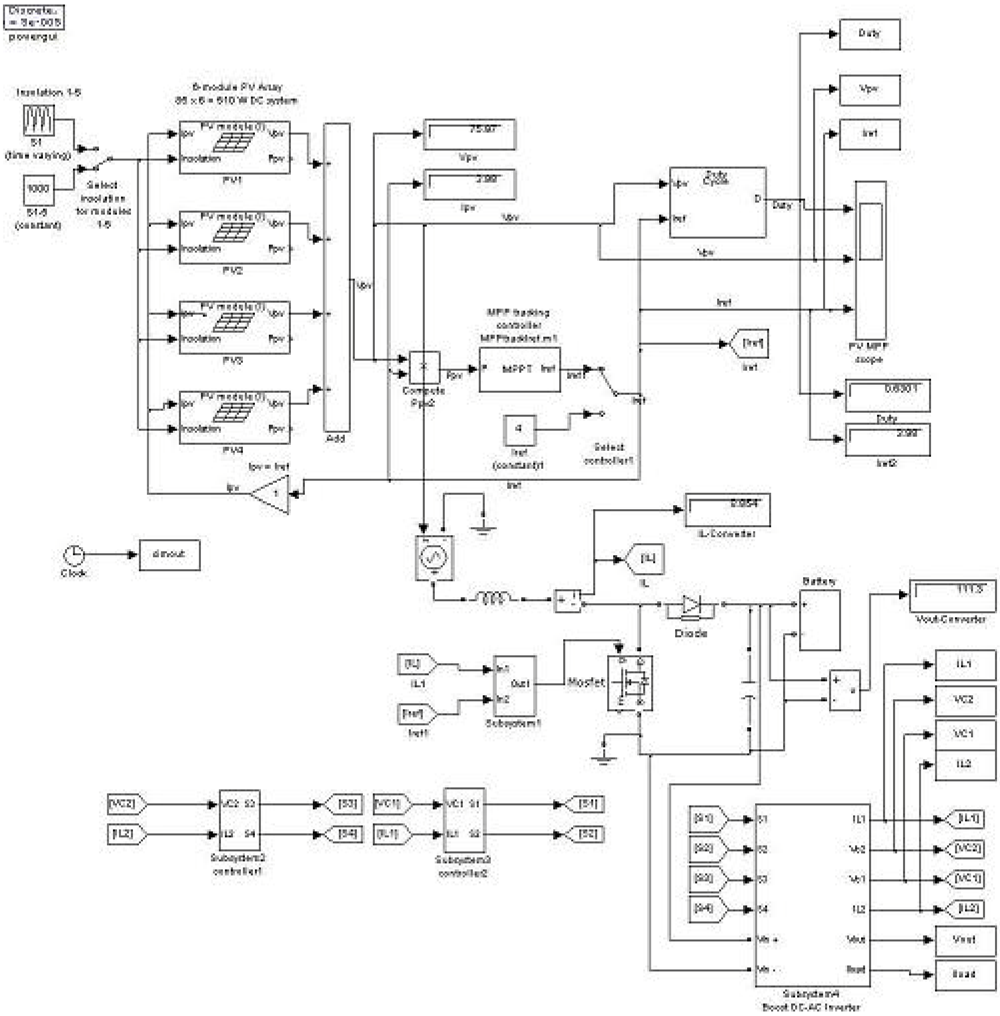


Fig. 7: MATLAB SIMULINK Model of Proposed single stage Solar Power Generation.

Simulation Model of Proposed System:

The Proposed single stage solar power generation with boost dc-ac inverter, in Fig. 7, was developed by MATLAB SIMULINK by assuming the power switches, capacitor voltage and inductors current with internal resistance Ra are ideal. The parameters are:

Vin = 100 V, Vo = 325 sin(2n 50 Hz)t, Po = 100 W, L1, L2 = 750 µH each, C 1, C2 = 20 µF each, f_{SW} = 20 kHz at the duty ratio (D) of 0.67.

Simulation Results:

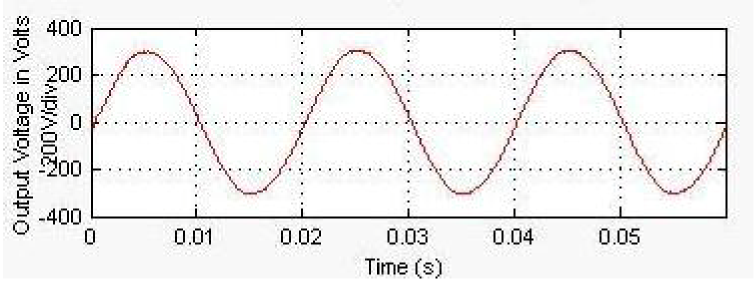
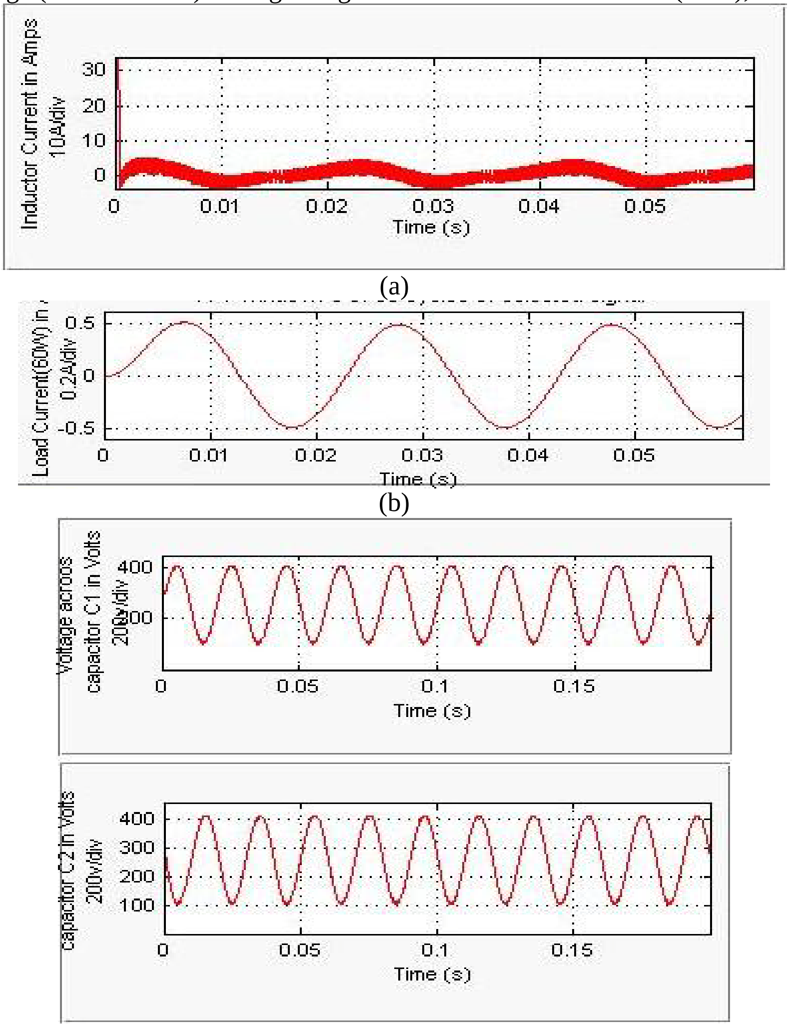
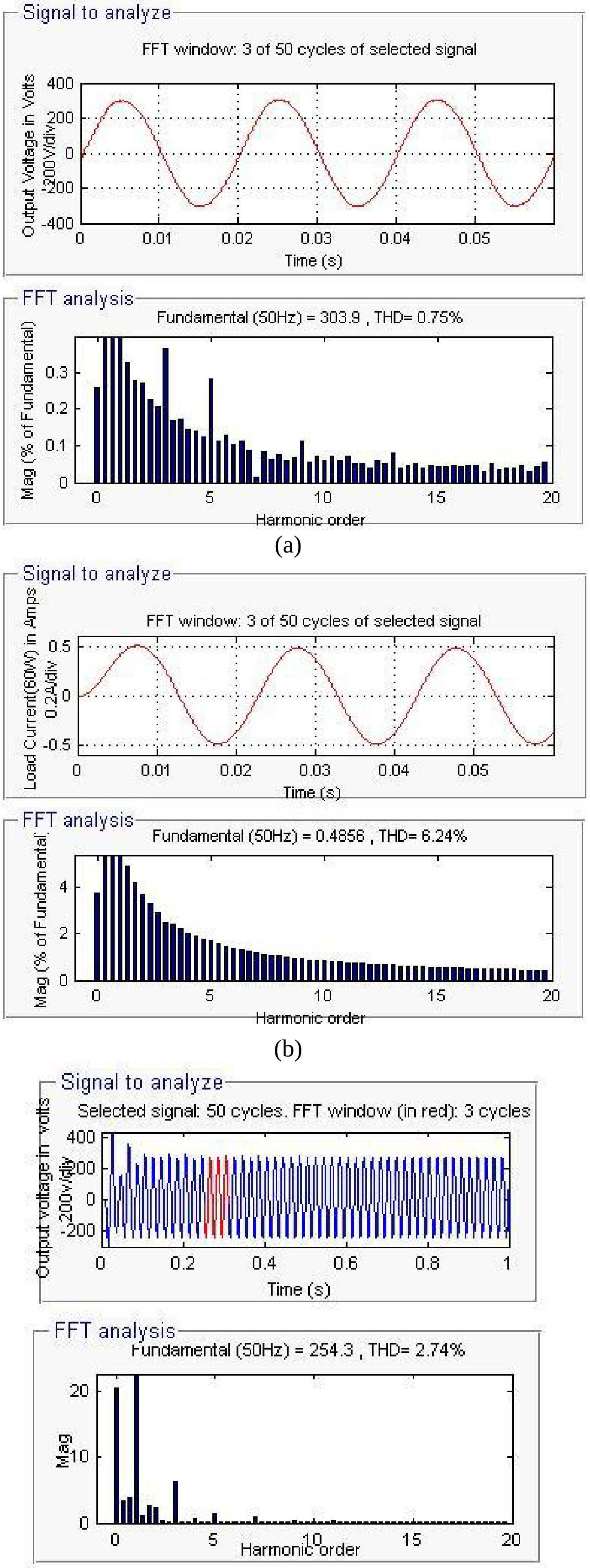


Fig. 8: Output voltage (Vo=215Vrms) of single stage boost dc-ac inverter in volts (60W), 200V/div, 0.01s/div.



(c)

Fig. 9: (a). Inductor current of the boost dc-ac inverter (I_{L1}) 10A/div, 0.01s/div; (b) Load Current for 40watts lamp in Amps 0.5A/div, 0.01s/div; (c) Capacitors Voltage (V_{C1}&V_{C2}) in Volts 400Vm each.



(a)

(b)

(c)

Fig.10: (a). Total Harmonic Distortion for V_o in 0.75% (b) Total Harmonic Distortion in Percentage of load current in 6.24% for fundamental frequency. (c) Total Harmonic Distortion of boost inverter controlled by the voltage feed back closed loop control method for V_o is 2.74%.

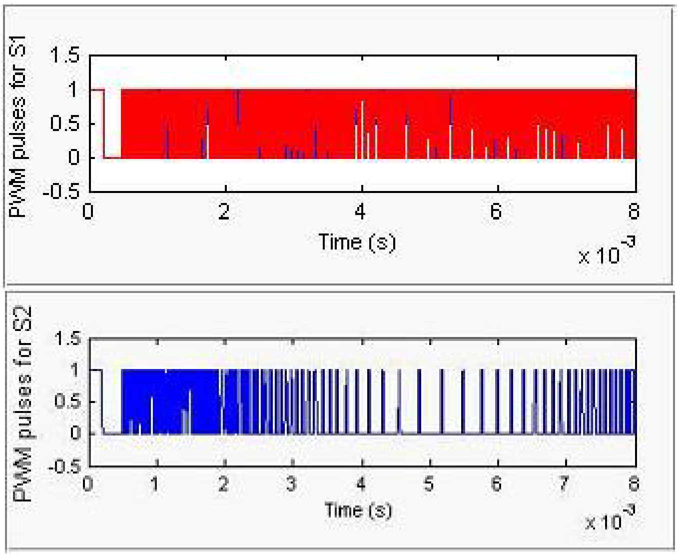


Fig. 11: Pulse for Switch 1,2,of the for single stage boost dc-ac inverter, generated by proposed simple NLVS closed loop control strategy.

Table 1: Output voltage under various load conditions by applied voltage feedback closed loop control method.

Sl.No.	Load in watts	V_o in volts (Vm) (Sliding mode control)	THD %
1	40	147	2.18
2	60	171.7	2.37
3	100	179	2.74

Table 2: Output voltage under various load conditions by applied NLVS closed loop control method and corresponding Total Harmonic Distortion.

Sl. No.	Load in watts	Output voltage(V_o) in volts (V_{rms}) (Proposed)	THD %
1	40	219	0.88
2	60	215	0.75
3	100	209	0.85

RESULTS AND DISCUSSION

Fig. 8 shows the simulated results for the buck boost operation of the single stage boost dc-ac inverter for a Non-linear load of 60 W. The instantaneous AC voltage is 305 V, which means a r.m.s value equal to 215 V. The Total Harmonic Distortion (THD) of V_O is lower than 0.75 % is show in Fig. 10(a). In Fig. 9(a) showed the inductor current i_{L1} of less than 5A and the initial peak current is 30A**,** the maximum current ripple is 4 A. Fig. 9 (c) and (d) shows the capacitors voltage V_{C1} and V_{C2}, the maximum instantaneous voltage of capacitor voltage is 400 V and the minimum voltage is 100 V with the voltage ripple of 7 V.

Fig. 10(a),(b) and (c) shows the total harmonic distortion of output voltage as 0.75% against the simulation result of 60watts Non-linear load and total harmonic distortion in Percentage of load current in 6.24% for fundamental frequency instead of THD=2.74% which was inverter controlled by voltage feedback control technique. Table 2 shows the boost dc-ac inverter was maintained very close to constant voltage at load side under various load conditions and corresponding Total Harmonic Distortion were noted. Table 1 shows Output voltage under various load conditions by applied voltage feedback closed loop control method.

Conclusion:

The proposed single phase topology of solar power generation for transferring the solar power to the utility grid is economical and efficient. This topology is a simple NLVS closed loop scheme which ensures the validity of the system since it compensates the load harmonics and the reactive power with the help of suitable series LC filter between the inverter and grid. Doing such kind of solar power generation scheme shows feasibility, effectiveness and operational simplicity. The low cost due to the minimum number of power devices used to execute the above scheme is an additional merit and also it satisfies the single phase grid parameters when it is synchronized.

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