

Research Article

Transformerless Inverter for Low Voltage Grid Connected PV System

Janardhan Gurram^{1*}, N.N.V.Surendra Babu², G.N.Srinivas³

Abstract

Harnessing the energy from renewable sources has gained more significance as the conventional sources will not be lasting for upcoming decades. Besides these alternative energy sources are free, the advanced energy conversion mechanisms raising their demand. Out of all the renewable resources photo voltaic (PV) energy conversion is widely used due to its less maintenance, descent efficiency of conversion. Grid connected PV systems became more popular in the recent years with the advent of sophisticated inverter topologies and conversion techniques. In grid connected PV systems transformer can be eliminated by which space, size of the system can be reduced, and efficiency of the system can be improved. However, by removing transformer, isolation of PV panels and grid is not achieved. If isolation is not achieved, the effect of virtual stary capacitance between PV panels and ground will cause leakage currents due to variation in common mode voltage. A single phase full-bridge/ H-bridge inverter is used and is connected to grid through a LCL filter. Bipolar pulse width modulation is used to eliminate or to suppress leakage current. This paper includes implementation of transformerless inverter for grid connected PV systems using MATLAB/Simulink. It also gives the analysis of various parameters like inverter, grid voltages, currents, and common mode leakage current at various solar irradiance levels.

Keywords: Transformerless inverter, stray capacitance, bipolar pulse width modulation, unipolar pulse width modulation.

I. INTRODUCTION

The increase in the demand of electrical energy across the world has made prominence of alternative energy sources. The most popular and widely used renewable energy resources are Photo voltaic, Wind, Tidal and Biomass etc. due to their abundant availability and less

¹Ph.D Sholar at JNTUH, Asst. Prof, EEE, CVR College of Engineering, Hyderabad, India. Email: g.janardhan@cvr.ac.in

²EEE ,Wollo University, Ethiopia.

³Principal, JNTU, Sultanpur, India.

maintenance. The energy market has a great share of Photo voltaic energy conversion[3]. The contribution of renewable energy sources is 36.2% out of total installed capacity in INDIA. Among all renewable energy sources, solar PV installation has reached 27.2% with 9.8% actual installed capacity of total energy by first quarter of 2020.This indicates the growth rate of PV installation in last few years [1],[18]. INDIA puts a target to raise renewable energy installation capacity to 450GW by 2030. Apart from large standalone or grid connected PV systems, roof top grid connected PV installations has gained importance to export the surplus power to grid is open to the single-phase domestic customers. Single phase grid connected PV systems include a PV array, DC-DC converter and an inverter connected to grid through a Transformer and filter [2]. Transformer will provide galvanic isolation between PV and grid so that no electrical connection is maintained between them. A power or low frequency transformer on grid side to be used. Or a high frequency transformer may be employed on DC side of the grid as shown in Fig.1. However, transformer occupies large space in the circuit and gives reduced efficiency of the system. To counter the problem transformerless inverters are in practice Fig.2.Due to elimination of the transformer, there exists a parasitic capacitance effect on system which will cause leakage currents in the system corresponding to variation of common mode voltage [3]-[5].

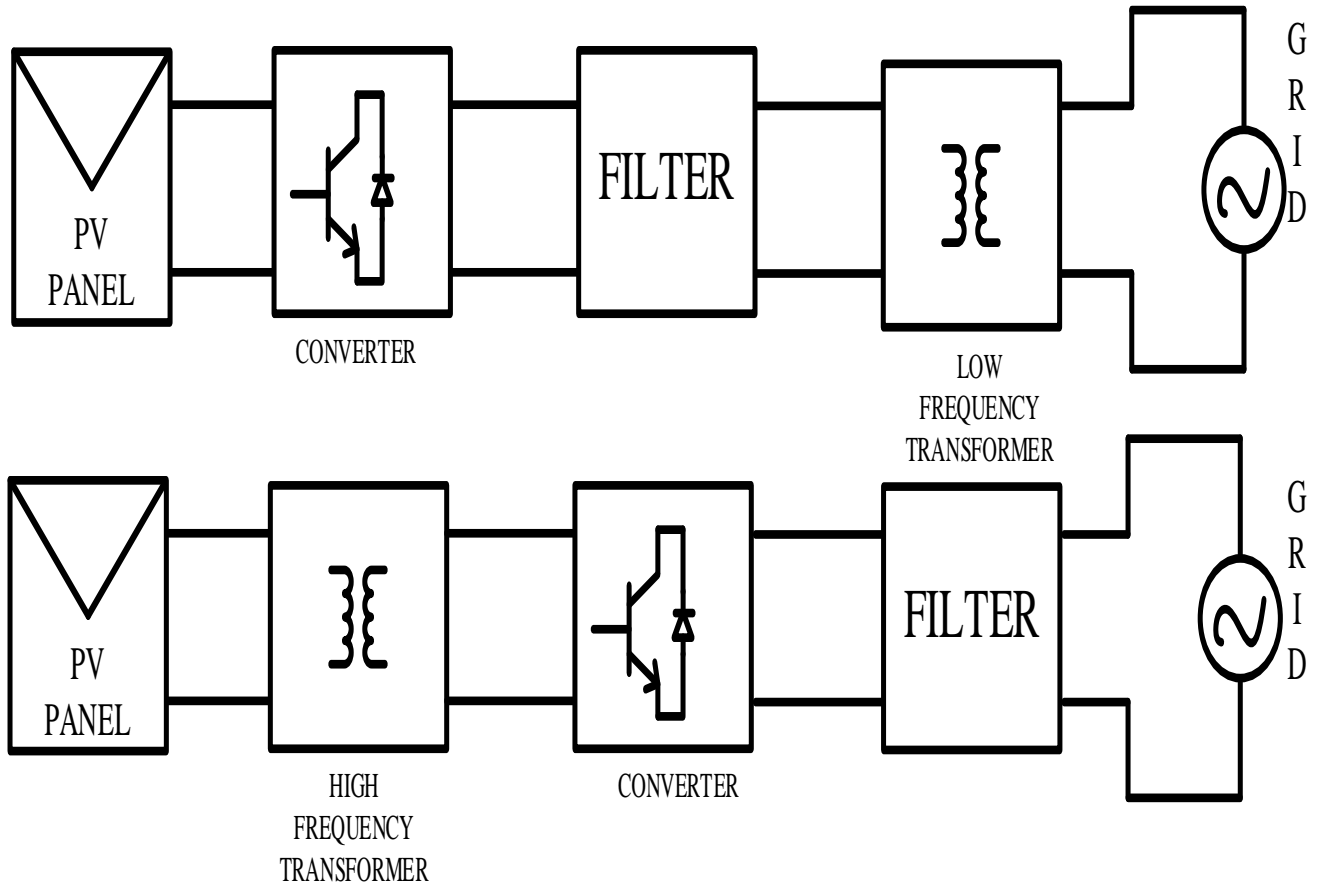


Fig.1.Grid connected PV systems (a)Low frequency transformer of grid connected PV

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system (b) High frequency transformer of grid connected PV system.

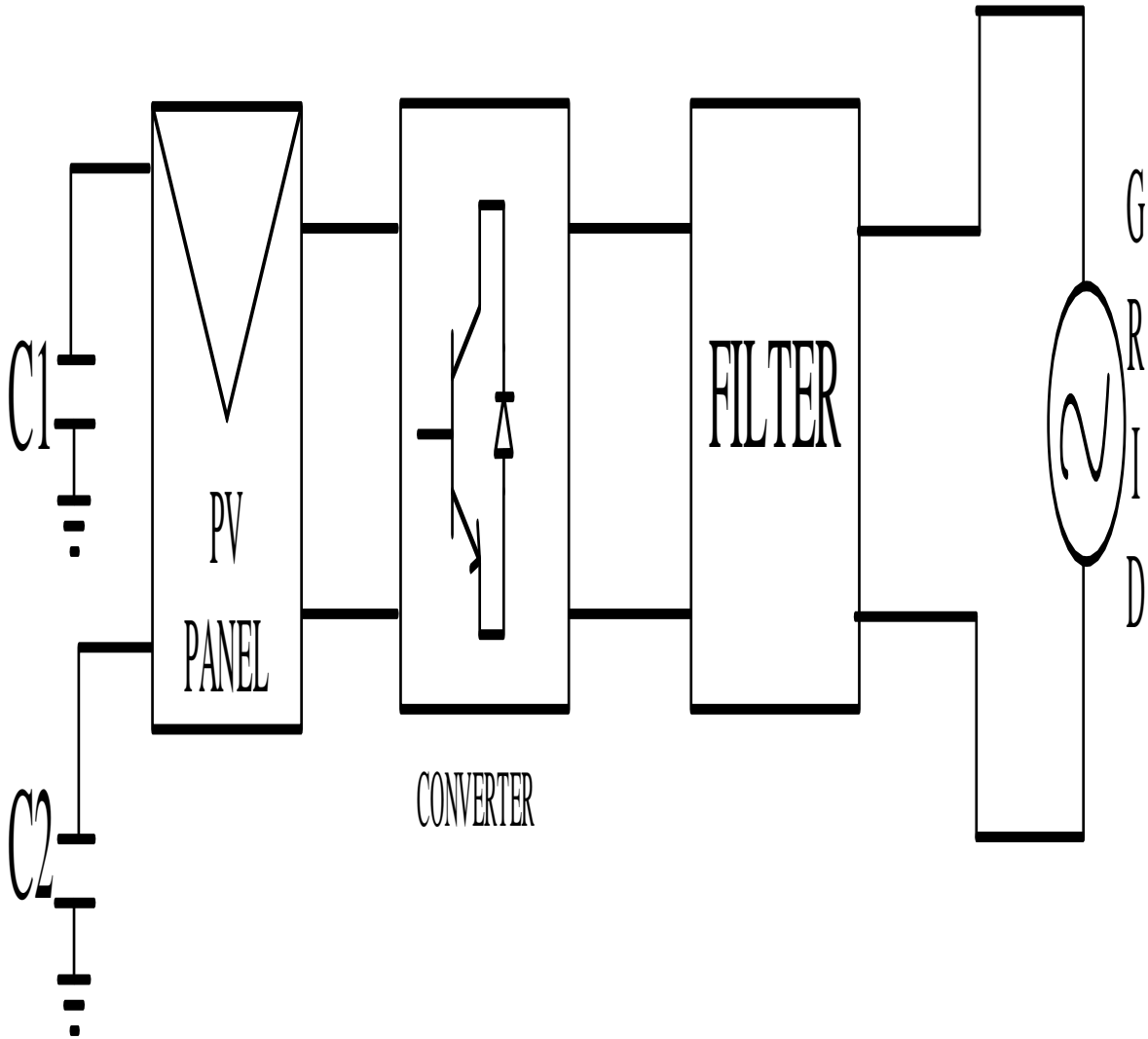


Fig.2 Grid connected transformerless inverters.

Variation of common mode voltage can cause leakage currents which will further inject dc currents into grid. The injection of dc currents will affect the components connected to the system.

II. TRANSFORMERLESS INVERTERS

Grid connected PV system without transformers will cause leakage currents due to variation of common mode voltages, must be limited to the standards of automatic grid disconnection between PV and low voltage grid is listed below in Table. I. This leakage current will affect the efficiency of the system significantly [6].

Table- I: Grid disintegration time for leakage current

Common mode current in (mA)	Disconnection time in sec
30	0.3
60	0.15
150	0.04

A. Common Mode Voltage

Considering the factors weight, space, and conversion efficiency transformerless inverters that do not provide isolation are preferred over inverters that use transformer and provide isolation [8]. Common mode voltage is defined as average of the voltages of respective phases with respect to ground as shown in Fig.3.

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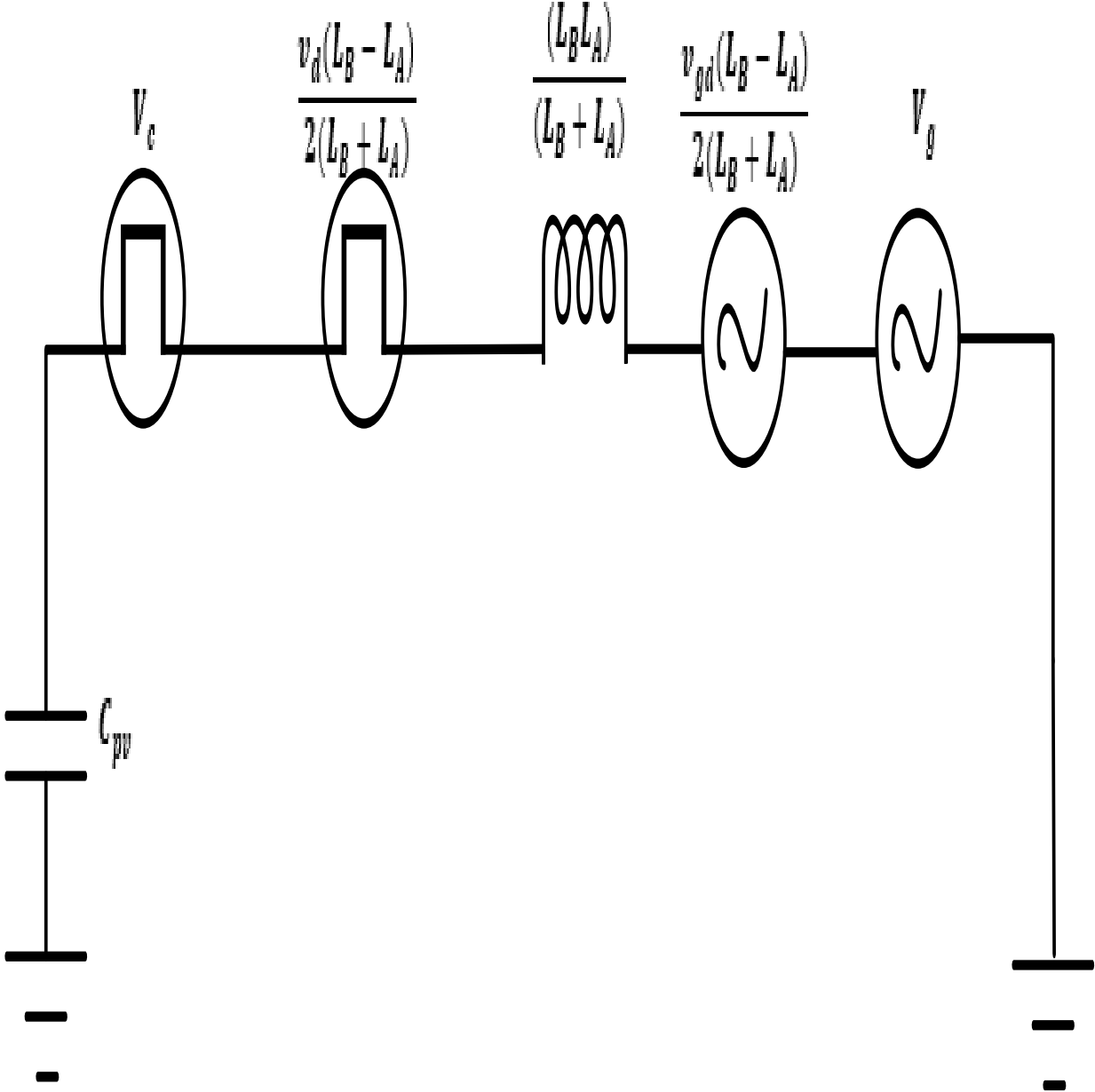


Fig.3.Equivalent circuit of Common mode voltage

$$V_{c\text{-total}} = -V_c - \left[\frac{v_d(L_B - L_A)}{2(L_B + L_A)} \right] + V_{gc} + \left[\frac{v_{gd}(L_B - L_A)}{2(L_B + L_A)} \right] \quad (1)$$

$$V_c = \frac{V_{AN} + V_{BN}}{2} \quad (2)$$

$$V_d = V_{AN} - V_{BN} \quad (3)$$

$$V_{gc} = \frac{V_{gA} + V_{gB}}{2} \quad (4)$$

$$= V_{gA} - V_{gB} \quad (5)$$

V_c : Inverter common mode voltage

V_d : Inverter differential voltage

V_{gc} : Grid common mode voltage

V_{gd} : Grid differential voltage

$V_{c\text{-total}}$: Total common mode voltage

V_{gA} : Phase A voltage with respect to neutral

V_{gB} : Phase B voltage with respect to neutral

L_A, L_B filter inductances

Fig.3 indicates simplified equivalent circuit of the influence of common mode voltage. Variation in voltage across stray capacitance will result leakage currents. To completely remove or reduce the leakage currents various inverter topologies are discussed in literature [9]-[10]. Besides design of different inverter topologies, it is more significant to apply different types of pulse width modulation schemes, by which dc or leakage currents path will be obstructed resulting which efficiency of the system is improved [13].

B. Transformerless Inverter Topologies

Full bridge or H bridge as shown in Fig.4 inverter system with unipolar and bipolar pulse width modulation (PWM) schemes are applied to notice leakage currents. Apart from H bridge inverter, transformerless inverters are mainly classified into the DC side disconnection or ac side disconnection. Most popular inverter topology in DC side isolation is H5 inverter [13]-[14]. An extra switch to a H bridge is used on dc side and would be operated at high frequency, so that it

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will be disconnected at regular intervals obstructing the dc current path into grid. HERIC (Highly efficient reliable concept) is another transformerless inverter isolating PV panel on ac side.

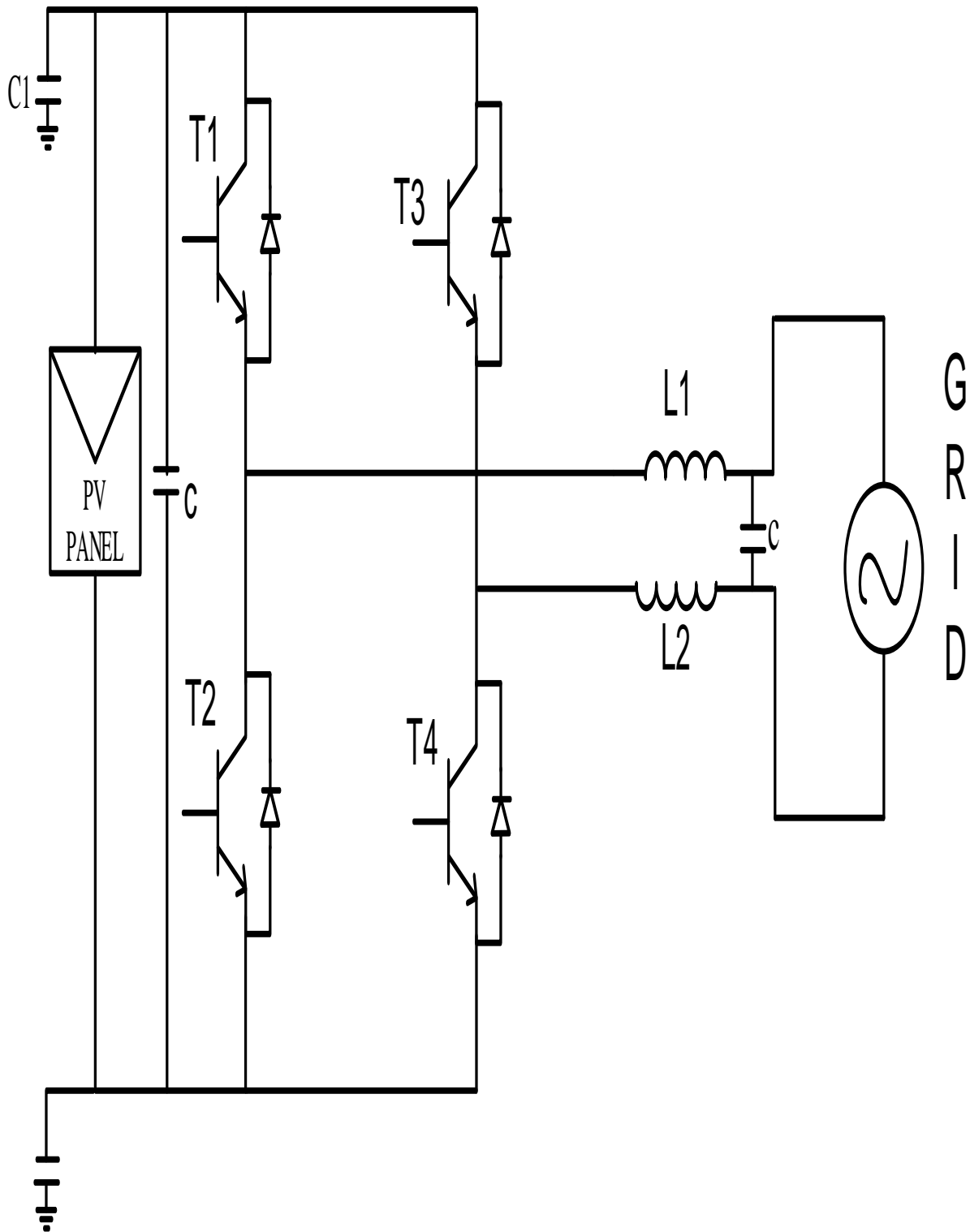


Fig.4. Grid connected H Bridge inverter

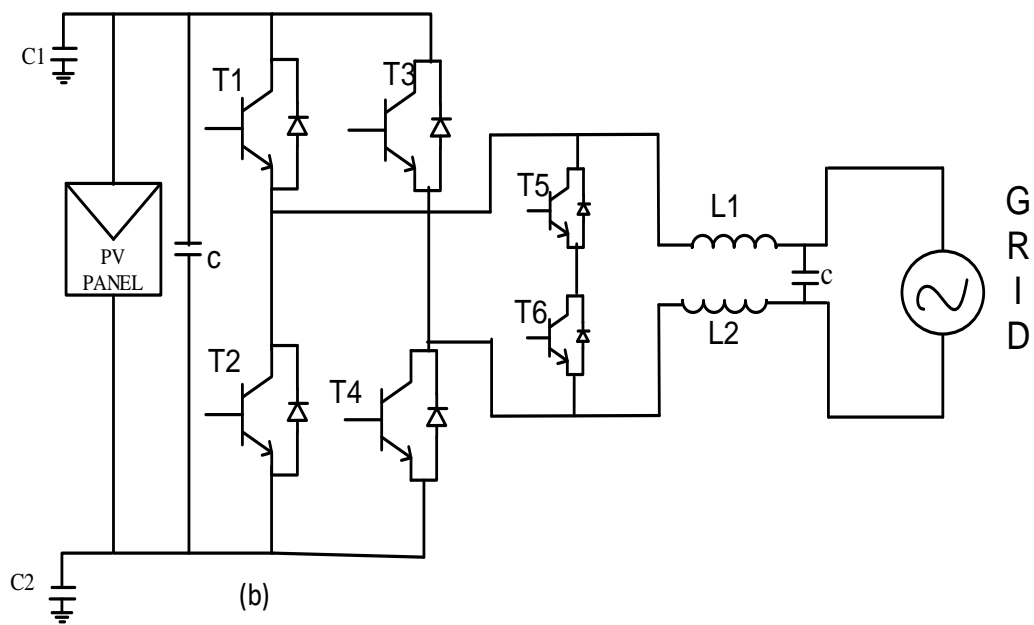
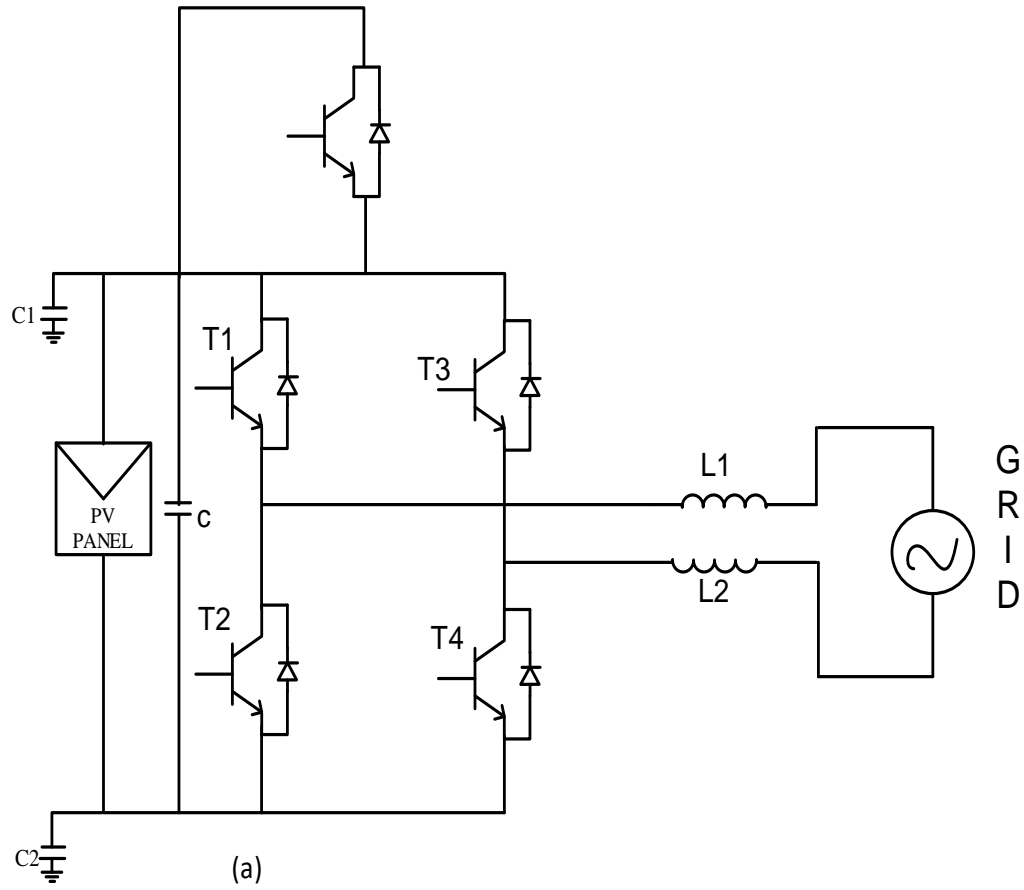
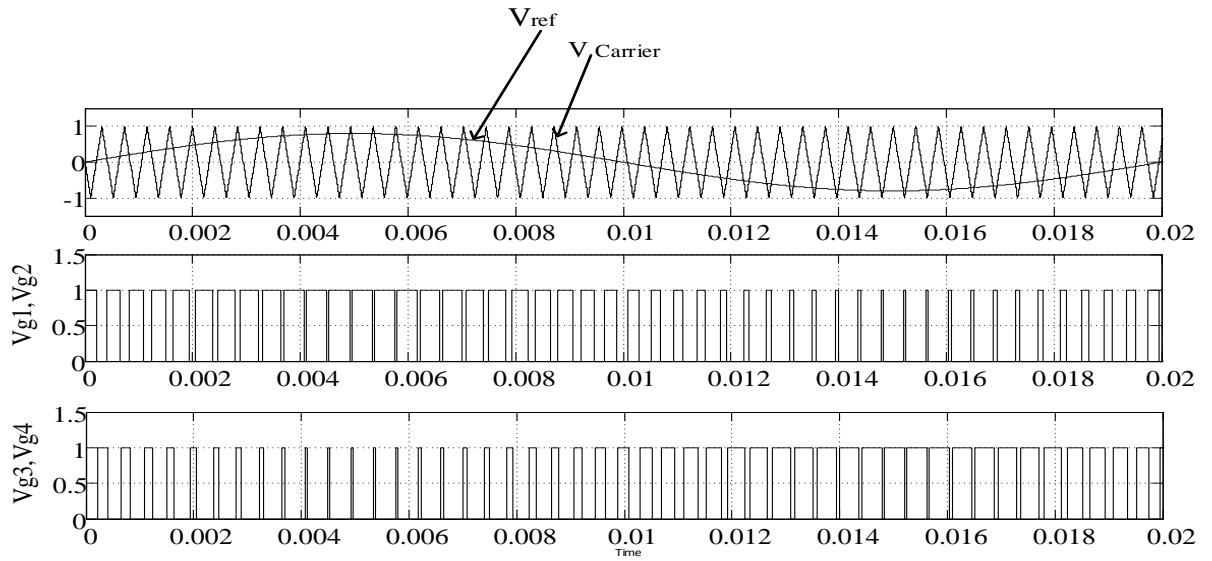


Fig.5(a)H5 grid connected inverter PV system 5(b)HERIC grid connected inverter PV system.

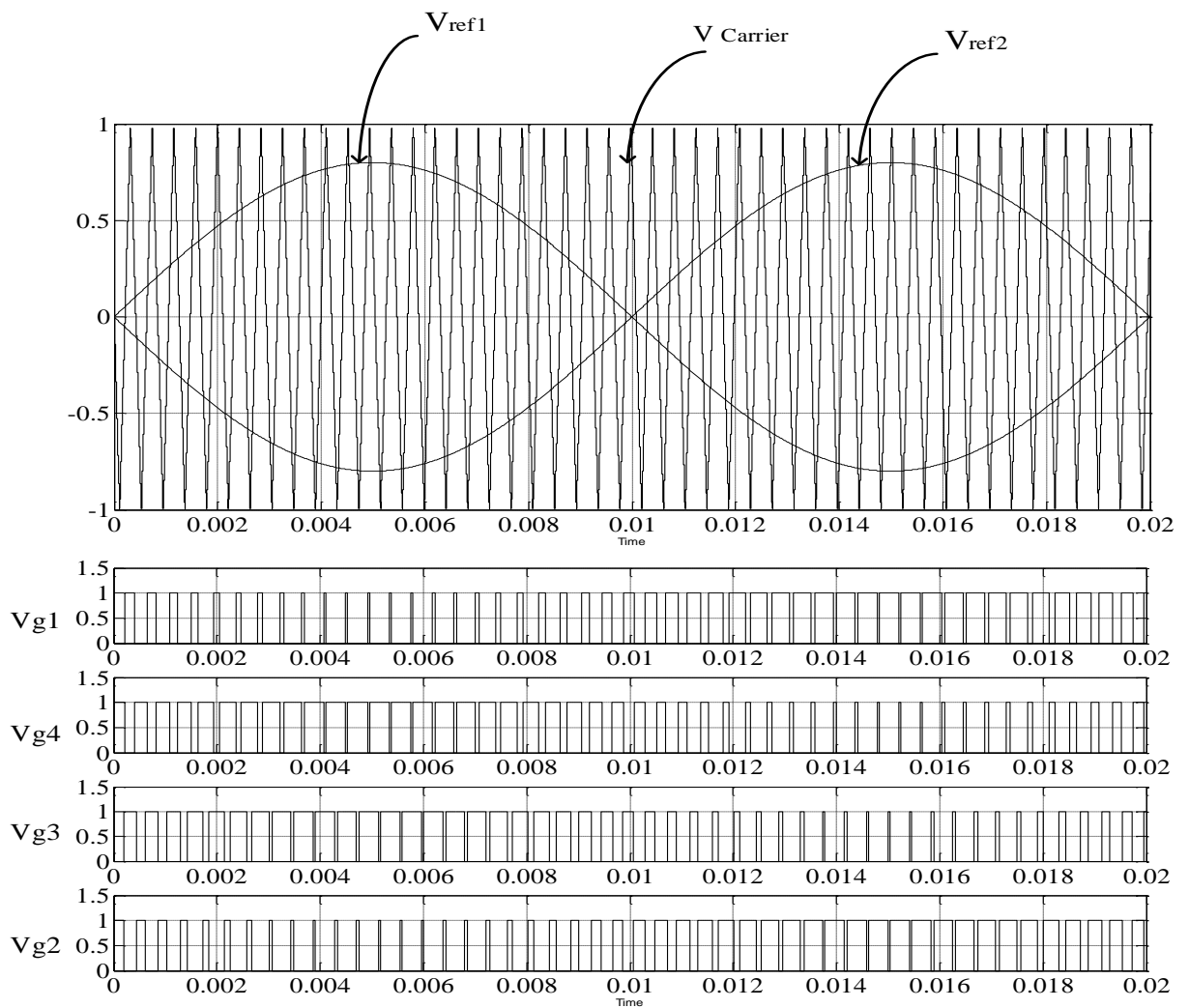
H5 inverter topology is commercially widely used. It uses additional switch T5 which is turned off along with T2, T4 during zero state vector thus isolating PV from grid further avoiding varying voltage across stray capacitance. In counter to H5 topology which uses DC side isolation, HERIC applies ac side decoupling. Two extra switches T5, T6 and D5, D6 are used working as bidirectional switch making the inverter short circuited while zero state vector [15]. Switches T1, T2, T3, T4 are turned off there by isolating PV array from grid resulting constant voltage across stray capacitance. Analysis of leakage currents using single phase full bridge voltage source inverter with different pulse width modulation techniques is done in sub section C.

C. Pulse Width Modulation

A transformerless inverter available in the competitive market of grid connected inverter must have the following features: (i)small or reduced leakage current (ii)reduced distortion in output (iii) Capability to handle reactive power (iv) improved efficiency (v) Reliability (vi) Low Weight (vii) Low Cost (viii) Small volume. All the above features are superior for transformerless inverters when compared to inverters that uses transformers. Leakage currents issue is addressed by employing different pulse width modulation techniques. Bipolar and Unipolar PWM strategies are applied to maintain constant common mode voltage there by achieving reduced or low common mode leakage currents.[12]. Bipolar PWM uses a power frequency sinusoidal signal i.e., reference signal is compared with a high frequency carrier signal i.e., triangular wave from so that the gating signals for T1, T2, T3, T4 are achieved as shown in Fig.6(a). The switches connected to positive and negative bus are not made on simultaneously to avoid dead short circuit of DC bus. The output voltage will be either positive peak or negative peak. The output voltage is bipolar in nature. An LC or LCL filter is used to reduce the ripples in load/output to be injected into grid[14]



6(a)



6(b)

Fig.6 (a) Bipolar Pulse width Modulation (b) Unipolar Pulse width modulation.

Unipolar pulse width modulation is achieved by comparing two sinusoidal signals of equal magnitude positioned at out of phase of i.e., 180^0 with a high frequency triangular wave form to realize gating signals for H bridge inverter. The switches connected to positive bus will not be turned on simultaneously. The inverter output voltage is either zero 0 or positive in positive half of the cycle and zero or negative in the negative half of the cycle. The modulation index is influenced by change in load. Modulation index is defined as ratio of amplitude of reference signal to amplitude of carrier signal.

$$\text{Modulation index} = \frac{V_{\text{reference}}}{V_{\text{carrier}}} \quad (6)$$

As the modulation index is close to unity total harmonic distortion is minimum. Under modulation is when index is less than unity, over modulation is when index is greater than unity [16].

III. SIMULATION

A. Control System

The control flow has mainly the following subsystems. Maximum Power Point Tracker (MPPT) using Perturb and Observe technique to track maximum power from PV under various irradiance conditions. DC voltage regulator determine active current and generates reference current. According to reference currents I_d and I_q controller generates required reference voltages used for PWM signals[10].

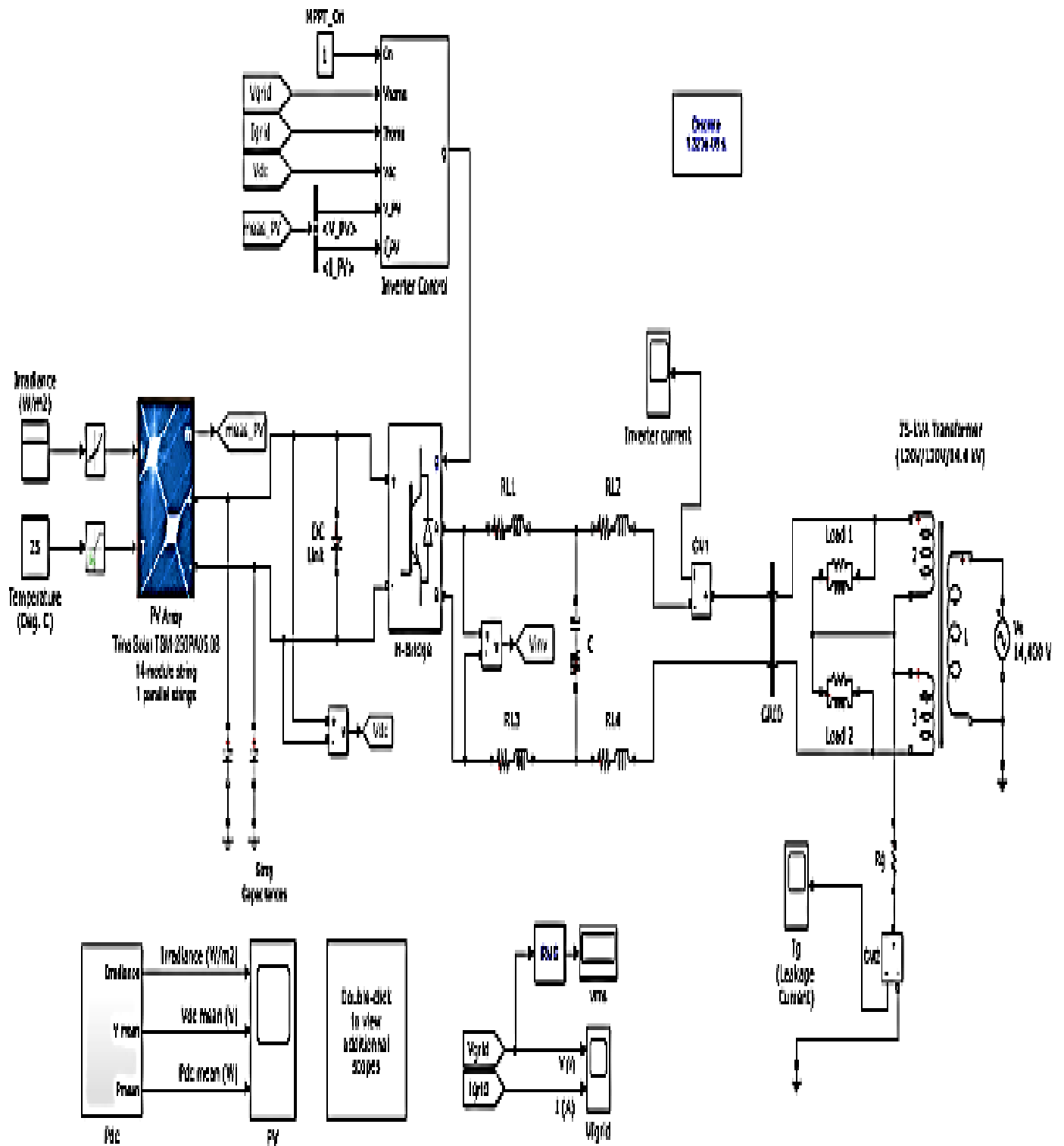


Fig.7.Simulation of grid connected PV system using Transformerless inverter.

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A phase locked loop is utilized for synchronization purpose. Transformerless inverter grid connected PV system for low voltage grid is simulated as shown in Fig.7. The simulation is done for the following parameters as shown in Table. II.

Table- II: Simulation Parameters

Parameter	Value
Irradiance	1000 watts per square meter
Power Raing of Panels	3000 Watts
Grid frequency	50Hz
Swithching Frequency	3150Hz
DC link voltage	450 Volts
Paracitic capacitance	5nF
DC bus capacitor	470uF 450Volts
Grid inductors LA,LB	3.6mH

B. Results

Simulation is done with the parameters mentioned for 1 sec with variation in irradiance at 250 watt per square meter to 1000 watt per square meter and at a normal temperature of 25⁰C. Fig.7. indicates irradiance changed from 250 to 750 and 1000 watt per square meter respectively at 0.1 sec, 0.4 sec and 0.8sec.

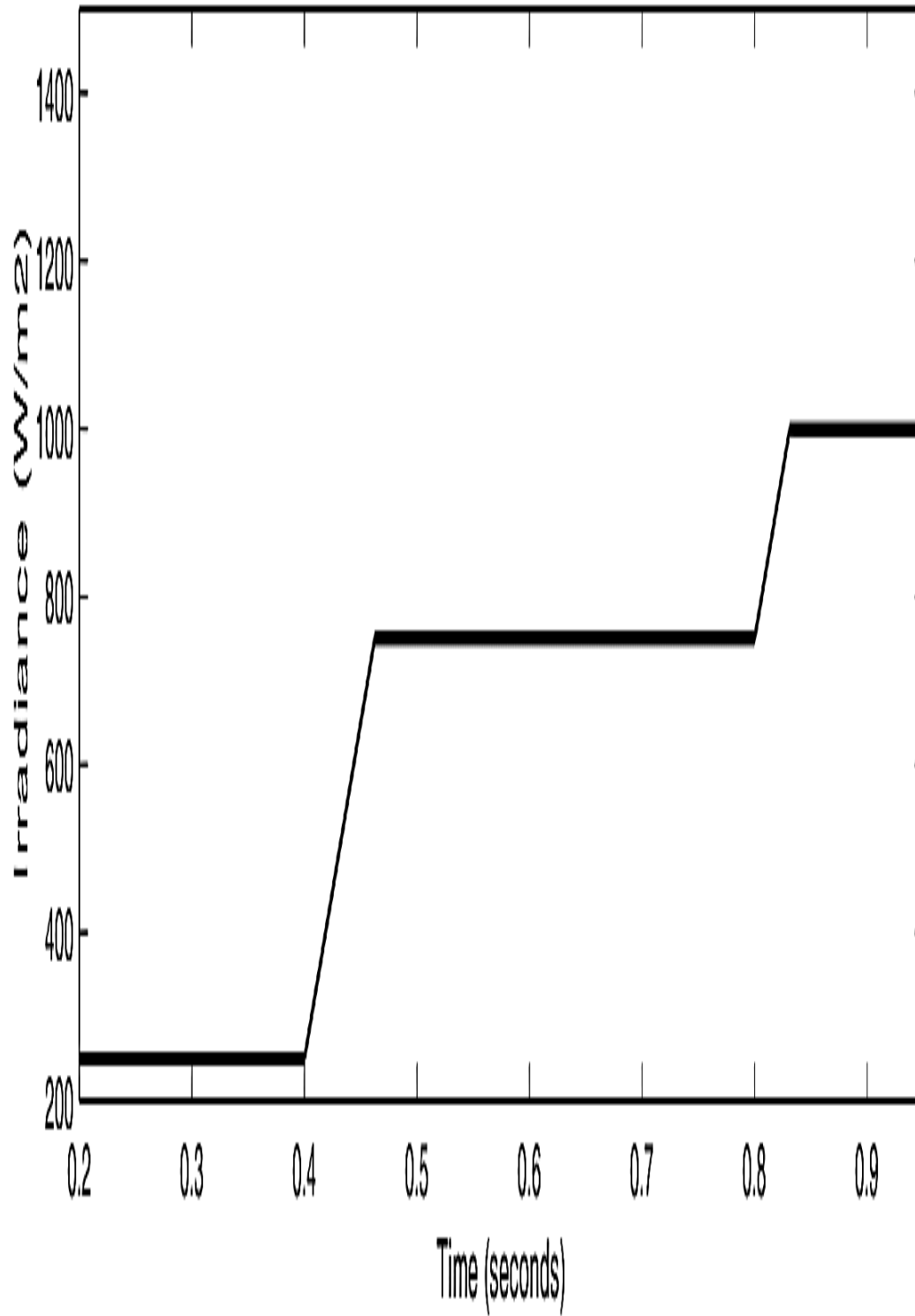


Fig.8.Variation of irradiance

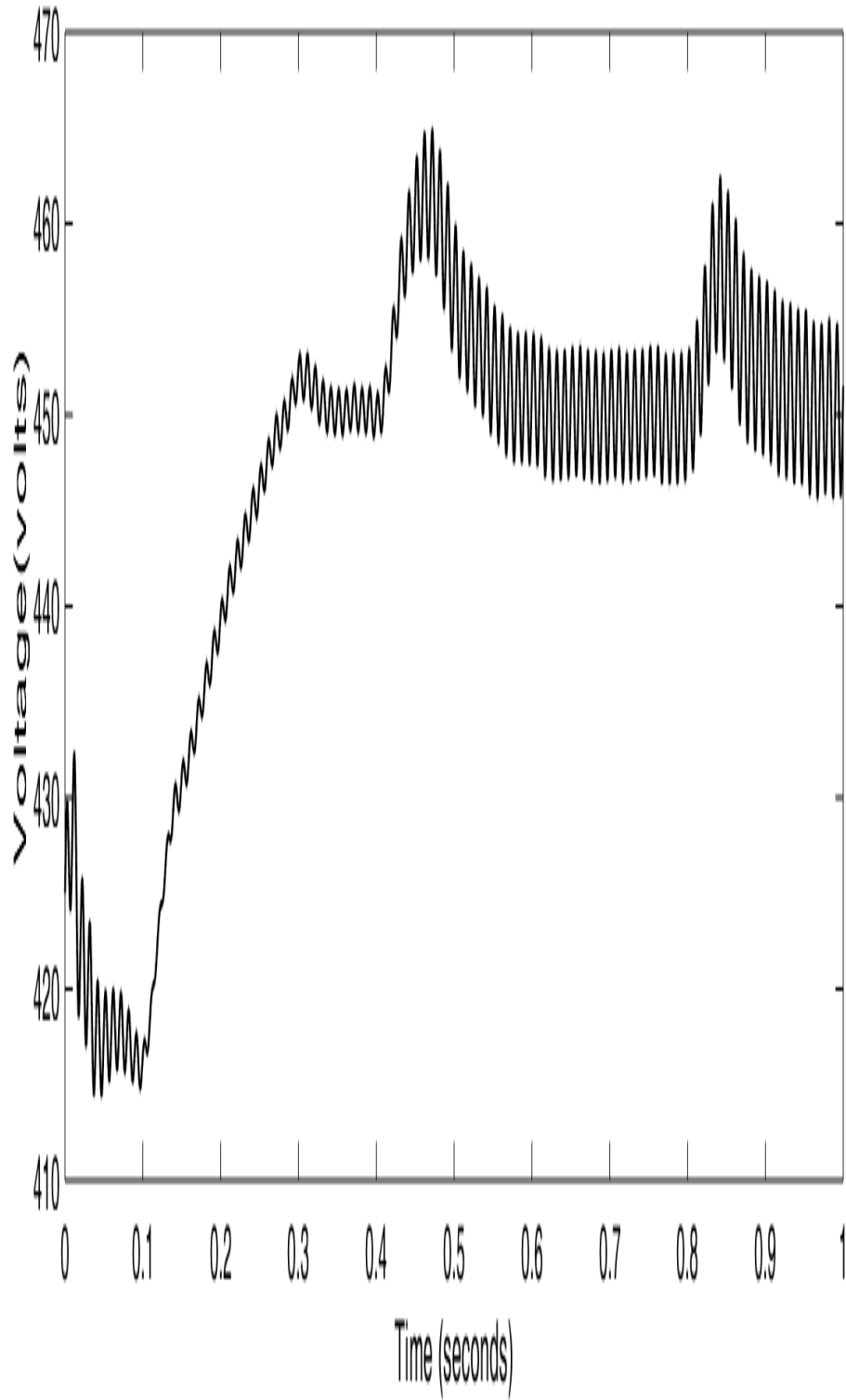


Fig.9.Voltage across PV with respect to Irradiance

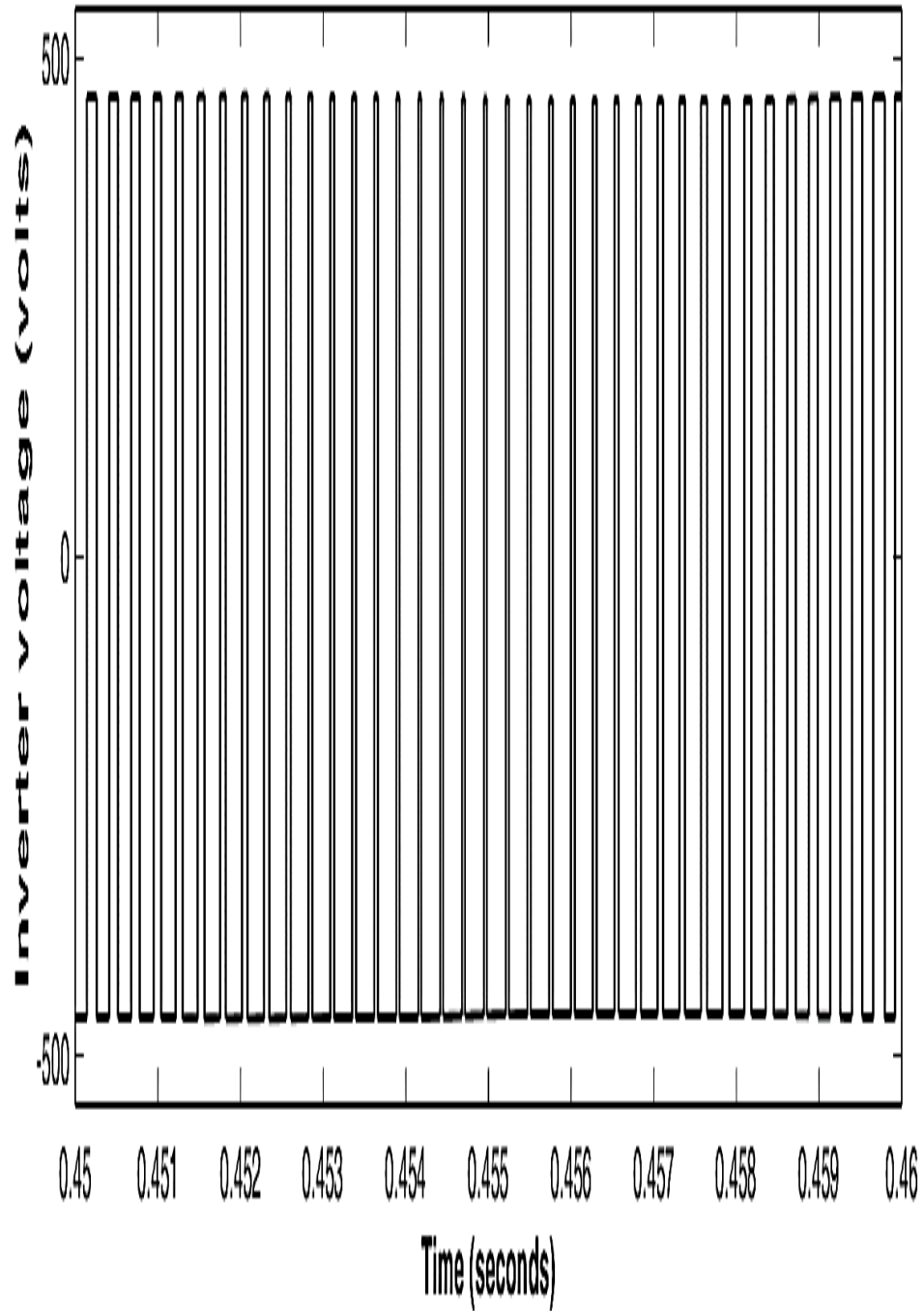


Fig.10.Inverter output voltage with Bipolar PWM

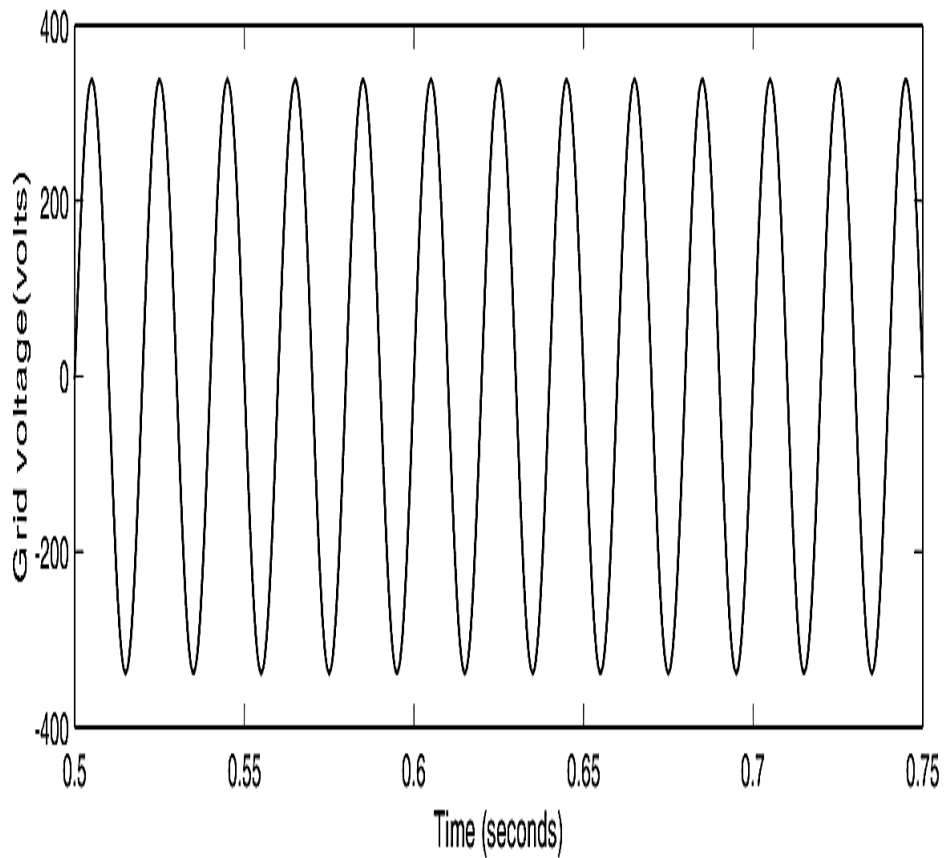


Fig.11. G rid voltage

DC Voltage reference across PV is maintained constant with variation in modulation index depending on active current I_d and reactive current I_q is made zero. Fig.10 indicates inverter output voltage with bipolar nature having 450 volts of maximum value. Grid voltage is shown in Fig.10.

current is measured as zero under steady state condition as shown in Fig.13.Using unipolar PWM the output voltage is seen as positive, zero or negative voltage as shown in Fig.14.Grid voltage and current are shown in Fig.15.,Fig.16. Grid current is varied as per variation in irradiance is shown in Fig.12. Using bipolar pulse width modulation leakage

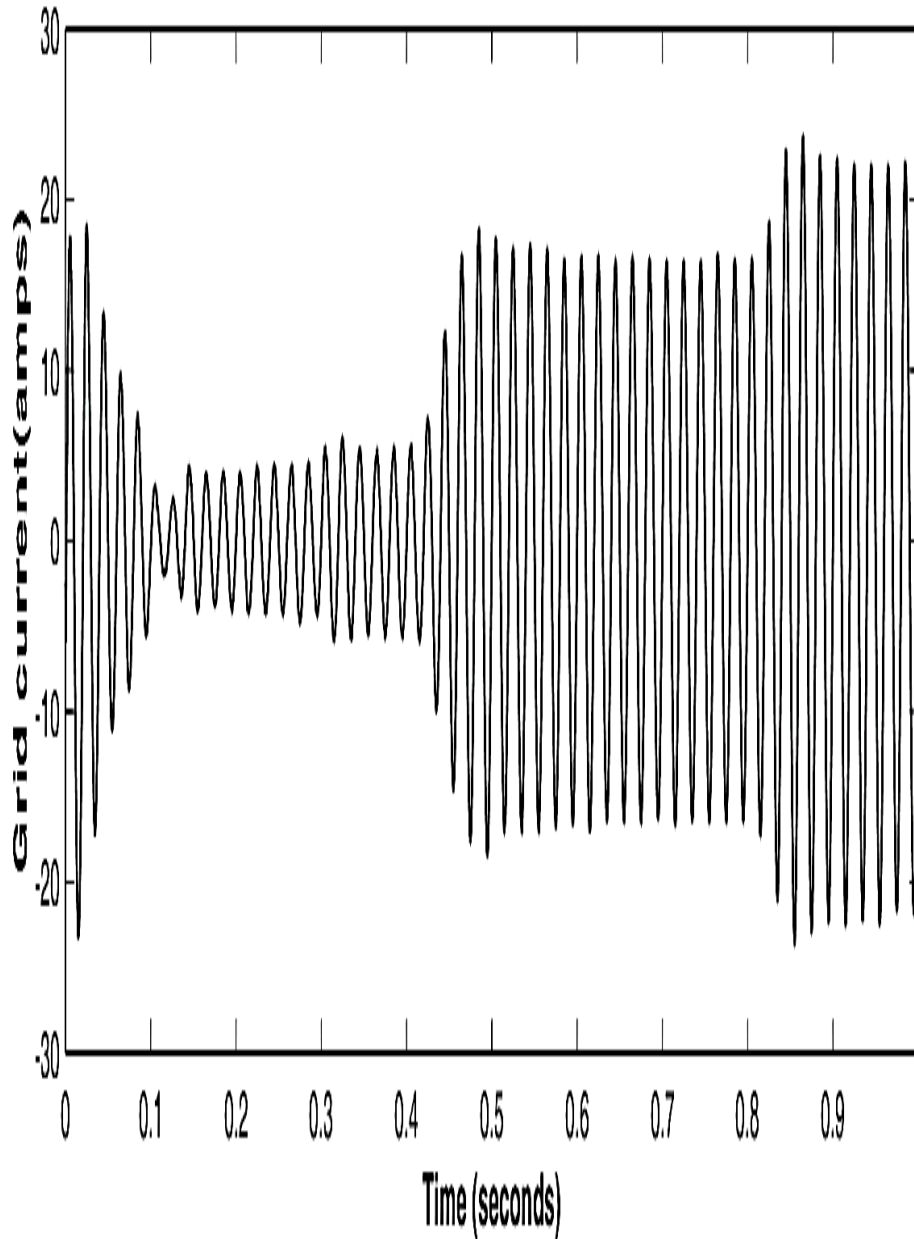


Fig.12.Grid current corresponding to irradiance

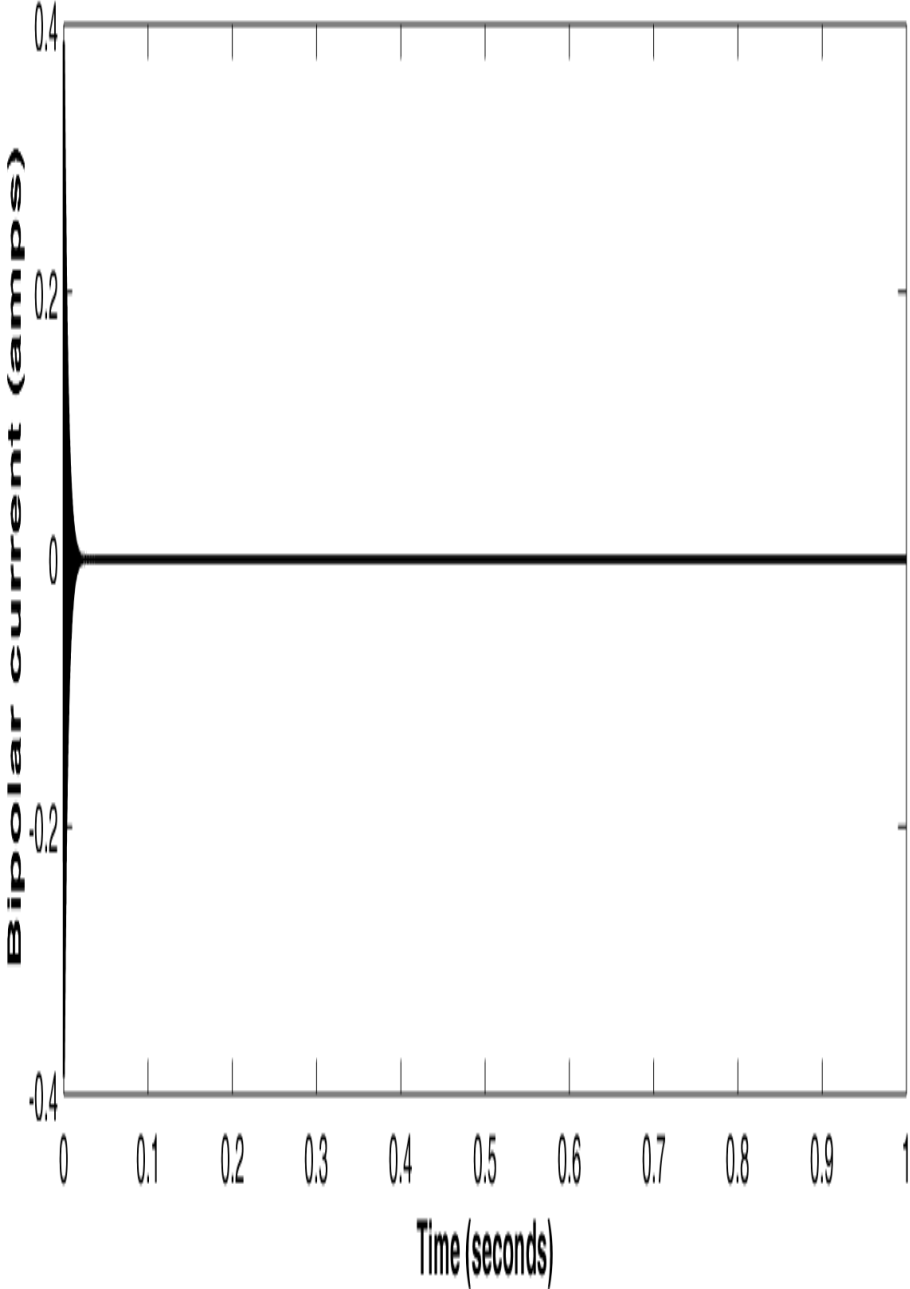


Fig.13.Common mode leakage current using Bipolar PWM

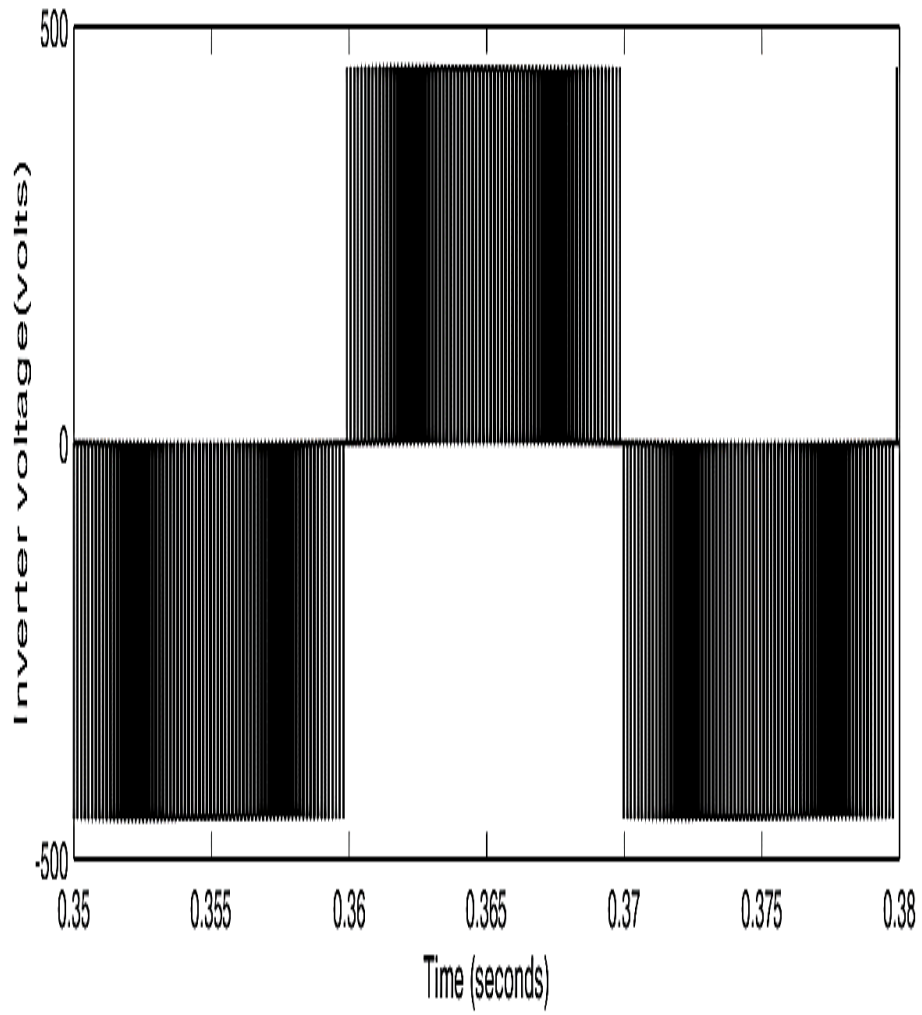


Fig.14.Inverter output voltage using unipolar PWM

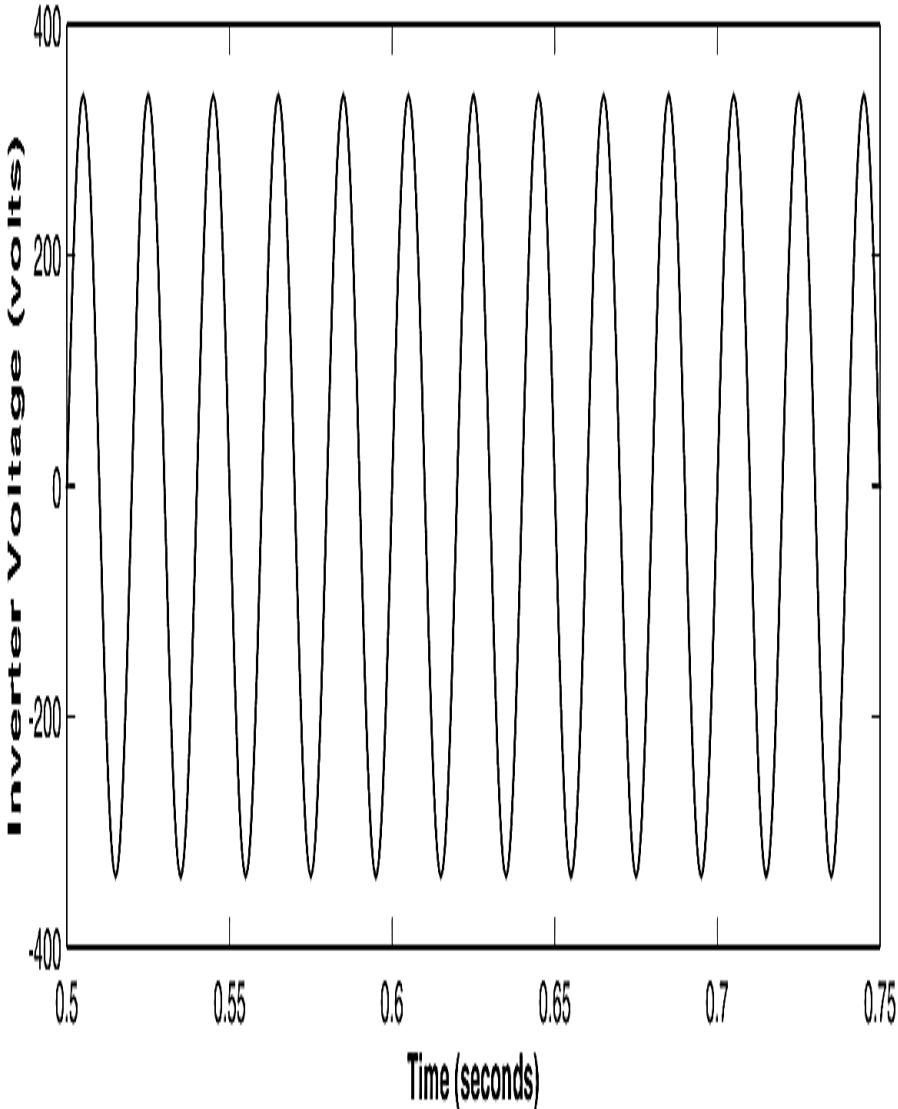


Fig.15.Grid voltage unipolar PWM

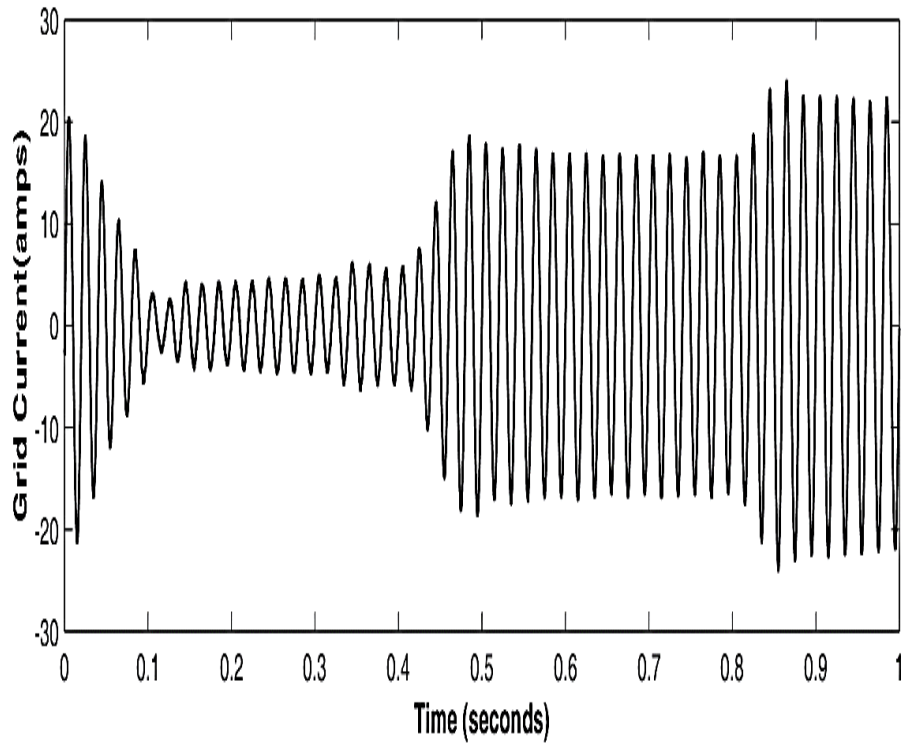


Fig.16.Grid current using unipolar PWM

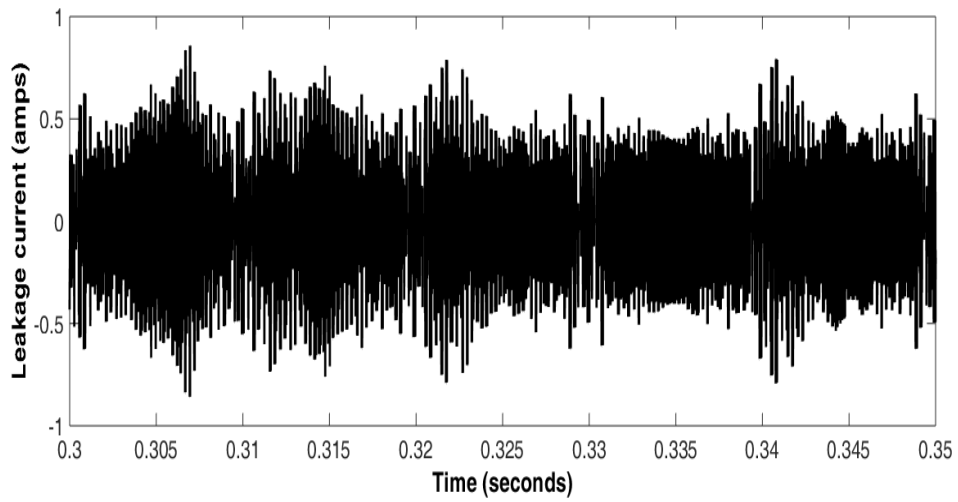


Fig.17. Leakage currents using unipolar PWM

Leakage currents are significantly high when used unipolar PWM as shown in Fig.17.

IV. CONCLUSION

Transformerless inverter for grid connected PV system using full bridge voltage source inverter with the pulse width modulation is carried out with variation in irradiance. The problem of leakage current in the system is addressed by using bipolar pulse width modulation scheme. Though the ripple in the output is more in bipolar when compared to unipolar PWM. However, ripple content in current is reduced by using optimal filter inductance. Leakage currents are found to be zero when used bipolar PWM and considerable value of common mode leakage current is found when used unipolar PWM. As the modulation index is increased close to unity total harmonic distortion can be reduced in both PWM.

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AUTHORS PROFILE



Mr. G. Janardhan is currently working as Asst, professor in EEE department of CVR College of Engineering, Hyderabad. He has completed his B.Tech in EEE in 2008 and completed his M.E in 2011 in Osmania university. He is currently pursuing his Ph.D. in JNTU in Hyderabad. He has published research articles in international conferences and journals. His research interests are grid connected PV systems, Power Electronics and Drives.



Dr. N.N.V. Surendra Babu is currently working as a professor in KIOT , Wollo University, Ethiopia. He has completed his Ph.D in 2013 from IIT Bombay. He has several publications. His research interests are power electronic converters. Cascaded Multilevel inverter and STATCOM



Dr. G. N. Srinivas is currently working as professor, Principal, College of Engineering JNTU, Sultanpur. He completed Ph. D in 2008 in JNTU Hyderabad. He has published 22 national and international journals. His research interests Power Systems Reliability, FACTS. Power System Protection.