Reduction of leakage current of a CSI based grid connected PV system without Transformer

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Abstract—The main aim of renewable energy generation is to improve the power quality and to deliver maximum power into the grid with less total harmonic distortion, high efficiency, and small size, low cost. The grid connected PV system with transformer provides isolation and grounding for PV array. But the transformer increases cost and size of the system. Single and two-stage grid connected systems are commonly used topologies in single and three phase PV application. But two-stage technique suffers from higher cost, and larger size, reduced efficiency. Therefore, the single-stage inverter has gained attention. Hence, single-stage single phase grid-connected PV system based on CSI is considered. A double-tuned parallel resonant circuit is considered to eliminate the second and fourth order harmonics on Dc side. A modified carrier based modulation technique provides a continuous path for the DC side current after each active switching cycle. The control structure consists of maximum power point tracking (MPPT) which is implemented by fuzzy controlling technique, a PI controller for AC side current and voltage loop controller. The leakage current due to parasitic capacitance existing in-between ground and PV array is eliminated by using H6 topology technique. Simulation results confirm the dynamic behavior of the proposed system using Matlab/Simulink.

Keywords— carrier based pulse width modulation, fuzzy logic, grid-connection, leakage current elimination

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I. INTRODUCTION

Due to the modernization of the world day by day power consumption is increasing the usage of renewable energy sources severe environmental effects like ozone layer depletion, radiation health issues etc. so researchers around the world introduces power generation with eco-friendly. One of such eco-friendly energy sources is photo voltaic system. So it can be used several applications like distribution [1] etc. In general PV system Operated in distributed application two Ways Island and grid connected mode [2]-[6].Islanding mode is used for independent power generation. With the increasing research in PV system to increase the efficiency, researchers introduced different MPPT techniques as a result grid connection mode came into existence. The main aim of maximum power point tracking is to gain the maximum power from the source. Grid connected mode again divided based on stage of conversion
(A) Single stage conversion
(B) Double stage conversion
The name itself indicates that in single stage conversion system only DC/AC will be present. In two stage conversion system DC/DC, DC/AC
A) Usually, a grid connected system must have the following requirements.it has high efficiency, small size, low cost, etc… For PV system. To achieve this grid requirement for a PV system single stage converter system there is a primary requirement of a step up transformer. Which will indirectly affect the system efficiency and cost of the system. Etc...
B) This system overcomes the difficulties of single stage conversion that i.e. PV array of high voltage is not required because it has its own boosting capability. But, it still has some disadvantages.
Following are the disadvantages:-
Low efficiency, and increased cost, and large in size. By this we can complete the single stage conversion system is effective than the double stage conversion system. So we are using single stage conversion is proposed this paper.
Many researchers developed different topologies [8] for single stage system one among such system which is frequently used is voltage source inverter (VSI) due to its simplicity and its availability [9]. But it faces the difficulty of the bulky transformer, electrolytic capacitance etc...
Hence it needs to switch another technology. CSI (current source inverter) is not a highly investigate tool for non-conventional energy sources [14], but it is an alternative method. So the proposed system is used CSI based PV system connected to the grid in this paper. Because of it is suitable for the following grid requirements.

1) In grid requirement input current must be continuous it is necessary for PV operating system

2) It improves the system efficiency with the replacement of series inductor instead of shunt capacitor

3) It has an own capability to boost, the obtained low voltage from PV system to be connected to the grid without need of transformer or booster circuit

So that in this paper we consider current source inverter [CSI] based technology for the grid connected PV system. One of the researchers connected PV system to grid with 3-Ø CSI [15] succeeded in delivering power to grid from PV system but it fails regarding the improvement of total harmonic distortion from 4.5%.
So to overcome the above disadvantage a current control loop is necessary to limit the current and quickly recover the variation of the current In the grid with the changes of weather condition.A dynamic model and control structure for a single stage and three phase grid connected PV systems using a CSI is proposed [16]. If current fed into the grid with the changed atmospheric condition has got low THD and unity power factor. Even if, the controllers having only current loops, this will affect the system reliability.

The main difference between three phase CSI connected to grid and single phase system connected to the grid is even harmonic on the DC side, this has affected the system performance i.e. MPPT, reduced life of PV system .these are correlated with the odd harmonics in the ac side i.e. grid side of the system [8].

Therefore necessary to reduce the even harmonics on the dc side for PV application. Hence several techniques have been proposed to quenches the even harmonics in PV system CSI application. In general frequently used method is large inductor to limit the even harmonics. But current source inverter produces large dc current [16].Hence to quench these large harmonic content it requires very large inductor. It increases system size and cost, with the reduced efficiency .therefore it cannot implement in practical application. Without using large inductance to eliminate these harmonic another techniques has been studied in the literature. The suggested method is feedback current control loop. An uncommonly designed feedback controller need to suppress the odd harmonics on the ac side of the PV system connected to the grid without using large inductance in dc side. The main reason of producing dc side harmonic is due to cause of instantaneous power from the grid.
This is minimized by using a proportional integral controller at the third harmonic.A nonlinear pulse width modulation had proposed [18] to mitigate the generated harmonics. Nonlinear pulse width modulation requires several computational calculations require. These are a low pass filter, a band pass filter, a phase shift block, and various mathematical calculations for removal of second order harmonics on the dc side, and its effects in grid current.

Therefore these all are not suitable [17] for single phase single stage operation because of dc current oscillation is large .which causes system losses and reduce its life time. Normally 2nd order harmonic on the dc side which impotently effects the ac side current. Moreover, fourth order harmonics also affect the grid side. But this system has one drawback existed due to the cause of leakage current through ground and PV panel.

From the above snags exclude in this paper, a single stage single phase current source inverter based PV system connected to the grid is proposed. A CPWM (carrier based pulse width modulation) providing the continuous path to dc side inductor in every switching cycle is proposed. And a double tuned resonant filter for removal of the generated 2nd and 4th order harmonics on the dc side is proposed. A controlling loop having current control, voltage control in the grid side and MPPT controller for tracking the maximum power from the photo voltaic panels. To eliminate leakage current with the help of H6 topology is proposed. To determine the usefulness toughness of the proposed system, computer helped model is used to validate the system. Hence it can prove that the proposed system is validated through computer aided simulation.

II.CIRCUIT DESCRIPTION

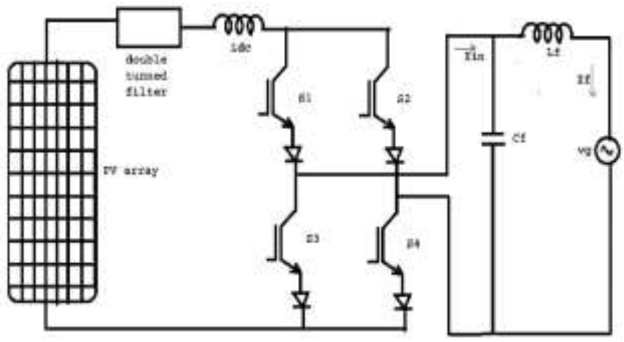


Fig.1 single phase grid connected current source inverter

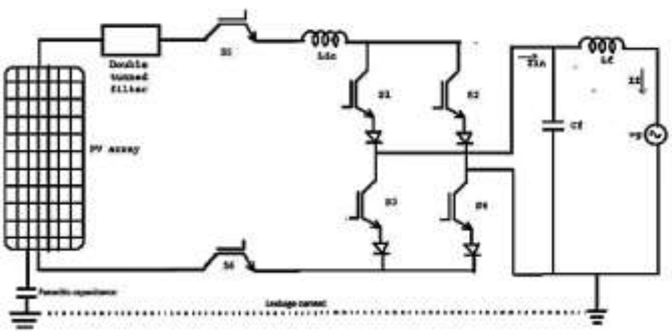


Fig 2. H6 topology for mitigation of leakage current

Photo voltaic system connected to grid based on CSI is shown in fig.1. PV array connected across CSI it is in series with the inductor and double tuned the resonant filter. This double tuned resonant filter and Ldc for smoothing the DC side current. To eradicate the AC side harmonics employ C-L filter. The CSI (current source inverter) consisting of two legged configurations i.e. each leg having two IGBTs (S1-S4). These are connected in series with the four diodes (D1-D4) for reverse blocking capability shown in Fig.2. It's having six IGBT configuration and four diodes to eliminate the leakage current existing in between ground and PV panel.

1) ***DOUBLE TUNNED RESONANT FILTER***

In the proposed system, the pulsating power on the ac side having double frequency it generates even harmonics in the dc side current. Which appears as a lower order harmonics on the ac side in current and voltage waveforms. Undesirably these affect the MPPT and life time of the PV system. It can be moderate the dc side harmonics on the AC side and on the PV. Practically, a large inductor needed to eliminate these harmonics effect. But practically it is not accepted because it increases the cost, weight, size of the system. Hence to reduce the required of the large inductor with the replacement of double tuned resonate filter. It can eliminate DC side harmonics effect in series with the dc link inductor for tuning the 2nd and 4th order. The filter can capable to eliminate these generated harmonics i.e. smoothening the dc side current with the use of small inductance. Even though 2nd ord er harmonics important in dc link current, the fourth order harmonics also affect the dc-link current. To quench these harmonics this paper proposed the double tuned filter for 2nd and 4th order, as shown in Fig 3.

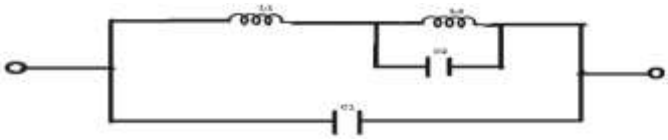


Fig .3 Double tuned resonant filter

In order to tune the resonant filter to the desired harmonics frequencies, the impedance of the C1 must be equal to the L1, L2, and C2 with the opposite sign. For the simplicity, the effect of the resistance is very small, and neglect it.

Zc1+Zt (1)

From (1) the capacitance values can get by using the following equations

$$C_1 = \frac{L_2C_2-(1/\omega^2)}{\omega^2L_1L_2C_2-L_1-L_2} \quad (2)$$

$$c_2 = \frac{-L_2}{\frac{L_2}{C_1}-\omega^2L_1L_2} + \frac{1}{\omega^2L_2} \quad (3)$$

Here C_1 and C_2 are the resonant filter capacitances, andL_1, L_2 are the resonant filter inductors Zc1 is the C1 impedance, Zt is the total impedance of the L1,L2 and C2. And ω is the angular frequency of the 2nd and 4th order harmonics. The required capacitance value can be find out by solving equations (2), (3), when select inductance value, these are able to allowing the extreme di/dt at rated current, angular frequency of 2nd harmonics in(2) and 4th harmonics in (3) are used. In order to get correlation between (L1 and L2), (1) and (2) solved for C1, equation (4) sown in below.

$$C_1 = \frac{\sqrt{L_1(L_1\omega_1^4+L_1\omega_1^2-2L_1\omega_1^2\omega_2^2-4L_2\omega_1^2\omega_2^2)}+L_1\omega_1^2+L_1\omega_2^2}{2L_1^2\omega_1^2\omega_2^2+2L_1L_2\omega_1^2\omega_2^2} \quad (4)$$

From (4), to avoid the difficult solution the relation between (L1 and L2) must be

$$L_2 \leq 1.778L_1$$

The proposed double tuned resonant filter can be extended to any number of harmonics by cascading the circuit shown in fig.4. In order to get the numerical values of the capacitances to eliminate the 1 to n-harmonics in below equations

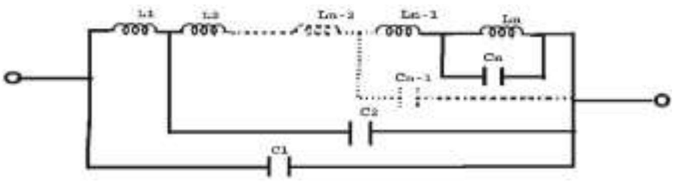


Fig .4 Double tuned resonant filter to eliminate n harmonics

$$L_1\omega_1 + \frac{1}{\omega_1C_1} + Z_t = 0$$

$$L_1\omega_2 + \frac{1}{\omega_2C_1} + Z_t = 0$$

.
.
.

$$L_1\omega_n + \frac{1}{\omega_n C_n} + Z_t = 0 \quad (6)$$

Where Zt is the total impedance of the series and parallel combination of the circuit passive elements L2 to Ln and C2 to Cn, where n is the harmonic order. For example to eliminate 2nd, 4th and 6th order harmonics value. Numerically solved capacitance equations [20] for the elimination of harmonic can be computed.

2) MODIFIED CARRIER BASED PULSE WIDTH MODULATION

It is proposed for controlling the switching patron of single phase single stage system connected to the grid. The use of CPWM is to be responsible for the continuous path of the dc-side current. During operating period switches of the CSI must ON either arm, one of the top switch and bottom of the switch. A commonly used method for generating the pulse signals for the inverter is sinusoidal pulse width modulation (SPWM), the allowed continuous pathway for the dc current is due to the existence of the overlap time as the power devices change its state. Hence this overlap time cannot sufficient to charge DC-link inductor. Moreover, it increases THD. Therefore, in this paper proposed CPWM provides a continuous path for the dc-link current, and it's existed overlap time sufficient for charge the inductor. CPWM is comprising two carrier wave signals with the sinusoidal signal as a reference is used to generating the required pulse signals. From Fig .5 shows carrier and reference signals, the carrier wave with a solid line is responsible for the generation of upper switches. And the another carrier signal with dotted line 180 degrees phase shift of solid line carrier signal, which is responsible the generation of pulses for lower switches. To recognize the switching pattern of the proposed paper fig. divided into ten sections $(t_1 - t_{10})$.These switching combination TABLE I shown below

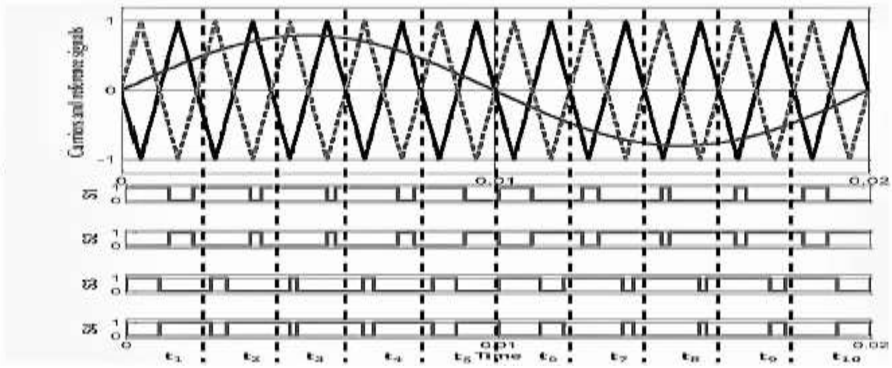


Fig .5 Generated pulse signals

TABLE I

Region	Combination sequence
t_1	$(s_1 - s_3)\,(s_1 - s_4)\,(s_2 - s_4)\,(s_1 - s_4)$
t_2	$(s_1 - s_3)\,(s_1 - s_4)\,(s_2 - s_4)\,(s_1 - s_4)$
t_3	$(s_1 - s_3)\,(s_1 - s_4)\,(s_2 - s_4)\,(s_1 - s_4)$
t_4	$(s_1 - s_3)\,(s_1 - s_4)\,(s_2 - s_4)\,(s_1 - s_4)$
t_5	$(s_1 - s_3)\,(s_2 - s_3)\,(s_2 - s_4)$
t_6	$(s_1 - s_3)\,(s_2 - s_3)\,(s_2 - s_4)\,(s_2 - s_3)$
t_7	$(s_1 - s_3)\,(s_2 - s_3)\,(s_2 - s_4)\,(s_2 - s_3)$
t_8	$(s_1 - s_3)\,(s_2 - s_3)\,(s_2 - s_4)\,(s_2 - s_3)$
t_9	$(s_1 - s_3)\,(s_2 - s_3)\,(s_2 - s_4)\,(s_2 - s_3)$
t_{10}	$(s_1 - s_3)\,(s_2 - s_3)\,(s_2 - s_4)$

III.CONTROLLING TECHNIC FOR PROPOSED SYSTEM

By using current source inverter to design a grid connected PV system. The relation between the PV output voltage and grid voltage is derived follows. By ignoring inverter losses grid power can be considered equal to PV output power

$$V_{pv}I_{pv} = \frac{1}{2} I_{g,peak}V_{g,peak}cos\theta \quad (10)$$

Where $V_{g,peak}$ and $I_{g,peak}$ are the grid voltage, grid current. And θ is the phase angle, Ipv&Vpv are the photovoltaic panel voltage, current.

$$I_{g,peak} = MI_{pv} \quad (11)$$

The grid current is equal to modulation index multiplied with Ipv, from the equation (10), (11) with assuming unity power factor to get the relationship between grid voltage and PV voltage

$$V_{pv} = \frac{1}{2} MV_{g,peak} \tag{12}$$

Therefore the above relation, the photovoltaic voltage must not exceed half of the grid peak voltage. When PV array interfaces to the grid connection based on the CSI. The CSI is employed to track the PV maximum power point and it is interface PV system to grid. In order to achieve these necessities, three control loops are essential, namely MPPT, an ac current loop and voltage loop.

To work the PV at the MPP, MPPT is used to identify the finest grid current peak value. Any conventional MPPT method can be used. However, to diminish the losses in power, the tracking system must be fast enough to handle any dissimilarity in the weather condition. Therefore, the proposed fuzzy logic technique is best suitable to quickly locate the maximum power point and fast in action. The inputs of fuzzy logic are

$$\Delta P = P(k) - P(k-1) \tag{13}$$

$$\Delta I_{PV} = I_{PV}(k) - I_{PV}(k-1) \tag{14}$$

And output equation is

$$\Delta I_{g,ref} = I_{g,ref}(k) - I_{g,ref}(k-1) \tag{15}$$

Where ΔP is output power and ΔI_{PV} output current changes, $\Delta I_{g,ref}$ is current amplitude variation reference of the grid, $I_{g,ref}$ is the ref of the grid, k is the sample instant. The adjustable inputs and output are allocated into four sets: positive big (PB), negative big (NB), and positive small (PS), negative small (NS). Hence it requires 16 fuzzy logic rules, these are based on the hill climbing algorithm, where fuzzy logic rules shown in [20]. The method to operate fuzzy combination is mamdani's with min-max rules. A center of area is used to in the defuzzyfication step to translate the fuzzy subset duty cycle deviations into real numbers.

$$\Delta I_{g,ref} = \frac{\sum_i^n \mu(I_{g,ref},i) I_{g,ref},i}{\sum_i^n \mu(I_{g,ref},i)} \tag{16}$$

To ensure synchronization between the grid current and voltage, a sinusoidal signal generated by a phase-locked-loop (PLL) is multiplied by the MPPT output.fig.6 shows a block diagram of the MPPT structure.

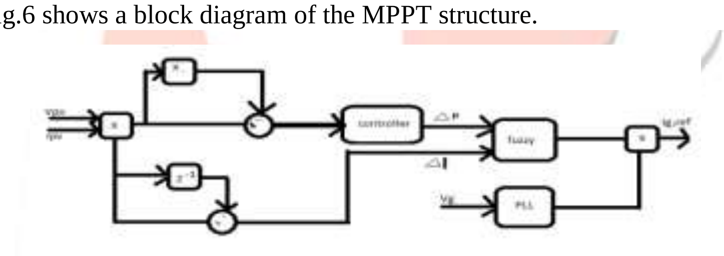


Fig .6 Block diagram of the fuzzy logic based MPPT

To employed in the voltage and current loop controller with the help of a proportional resonant controller. The controller basic principle is to familiarize an unbounded gain at a selected resonant frequency in order to eradicate steady state error at that frequency. The expressed transfer function controller as

$$y = k_p e + k_i \frac{es}{s^2+\omega_0^2} \tag{17}$$

Where Kp is the proportional gain, Ki is the integral gain, e is the signal error, ω_0 is the angular frequency of fundamental. The transfer function of proportional resonant is digitized using follows

$$z(s) = k_i \frac{s}{s^2+\omega_0^2} e(s) \tag{18}$$

Total State space representation of the controller [18]

$$\frac{d}{dt}\begin{pmatrix} V_c(t) \\ z_v(t) \\ \omega_v(t) \\ I_g(t) \\ z_i(t) \\ \omega_i(t) \end{pmatrix} = \begin{pmatrix} \frac{-(K_{pv})}{C} & \frac{1}{C} & 0 & \frac{-(K_{pv}K_{pi})}{C} & \frac{K_{pv}}{C} & 0 \\ -k_{iv} & 0 & -1 & k_{iv}K_{pi} & k_{iv} & 0 \\ 0 & \omega_0^2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{-(K_{pi})}{L} & \frac{1}{L} & 0 \\ 0 & 0 & 0 & -k_{ii} & 0 & -1 \\ 0 & 0 & 0 & 0 & \omega_0^2 & 0 \end{pmatrix} \times \begin{pmatrix} V_c(t) \\ z_v(t) \\ \omega_v(t) \\ I_g(t) \\ z_i(t) \\ \omega_i(t) \end{pmatrix} + \begin{pmatrix} \frac{-(K_{pv}K_{pi})}{C} & \frac{K_{pv}}{C} \\ k_{iv}K_{pi} & k_{iv} \\ 0 & 0 \\ \frac{-(K_{pi})}{L} & \frac{1}{L} \\ -k_{ii} & 0 \\ 0 & \omega_0^2 \end{pmatrix} \begin{pmatrix} I_{g,ref}(t) \\ V_g(t) \end{pmatrix} \tag{19}$$

Equation (49) written in short form

$$\frac{dx(t)}{dt} = Ax(t) + Bu(t) \tag{20}$$

The discrete representation of the above equation is

$$x(k+1) = (1 + T_s A)x(k) + T_s Bu(k) \quad (21)$$

IV.DESIGN PARAMETERS OF THE PROPOSED SYSTEM

TABLE II

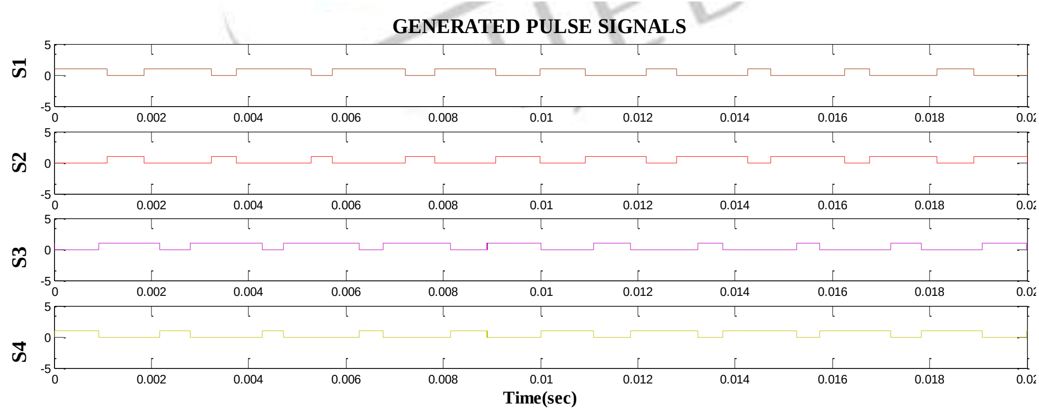
Item	value
PV open circuit voltage, Voc (V)	80
PV short circuit current, Isc (A)	15
PV array rated power, Pr(W)	500
Resonant filter inductor,L1 (mH)	10
Resonant filter inductor,L2 (mH)	5
Resonant filter capacitor, C1 (μH)	125
Resonant filter capacitor, C2 (μH)	250
dc link inductor,Ldc(mH)	5
Switching frequency,Fs(kHz)	4
AC line inductor,L (mH)	1
AC line capacitor, C(μF)	20
Grid voltage,Vg,rms(V)	110

V.SIMULATION RESULTS AND DISCUSSIONS

The proposed system tested with ten series connected PV modules and power rating of this is 500W. The design specification of which is mentioned in Table II. The filter capacitor of AC side decided based on attenuate the harmonics that are supplementary with the switching frequency and also consider the ac & dc side currents. so, the converter capable to supply active and reactive power demand of the ac side at rated power of PV system. The selection of the dc side filter is discussed in above section II (1).

The proposed system validate through Mat lab/Simulink. The obtained results under normal atmospheric condition are shown in below figures. To the track the maximum power from PV panel with reduced oscillations at final state condition, as shown in Fig 7 (a), Moreover, fig.7 (b) represents the MPPT effectively locks the dc current to the optimal value.

The converter maximum power successfully injected to the grid with low total harmonics distortion, high efficiency, and unity power factor. The grid current and voltage waveforms are shown in Fig 7(c). Fig 7(d) shows CSI output current which is not violated by allowing one switching level at the same time. However, the grid active and reactive power shown in Fig 7(e).and the power factor is nearly unity.



Generated pulse signals

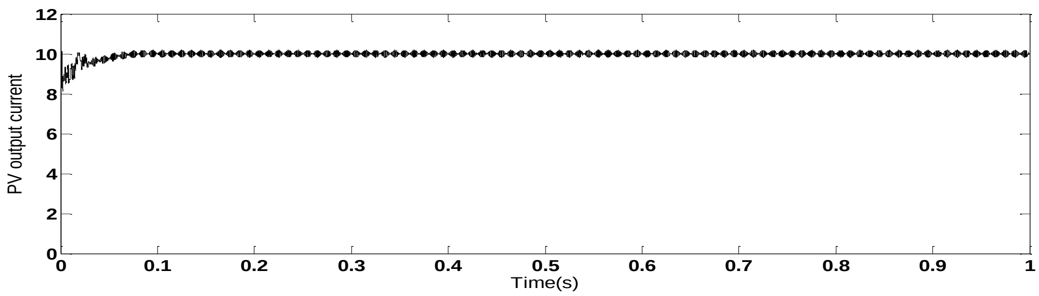


Fig.7 (a) PV output power

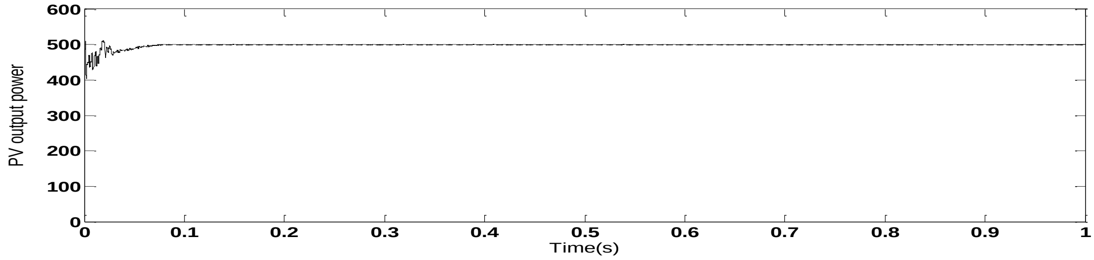


Fig.7(b) PV output current

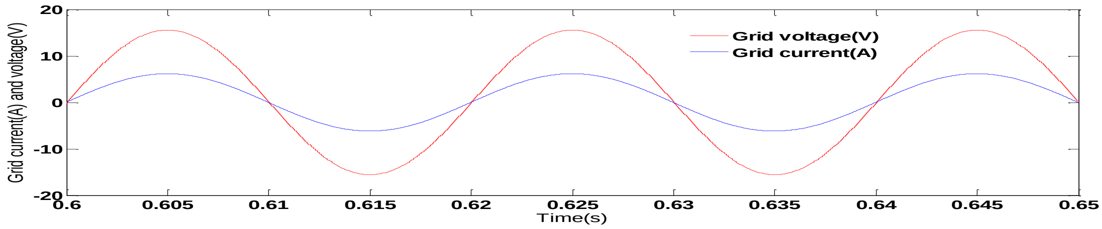


Fig .7 (c) Grid voltage and current

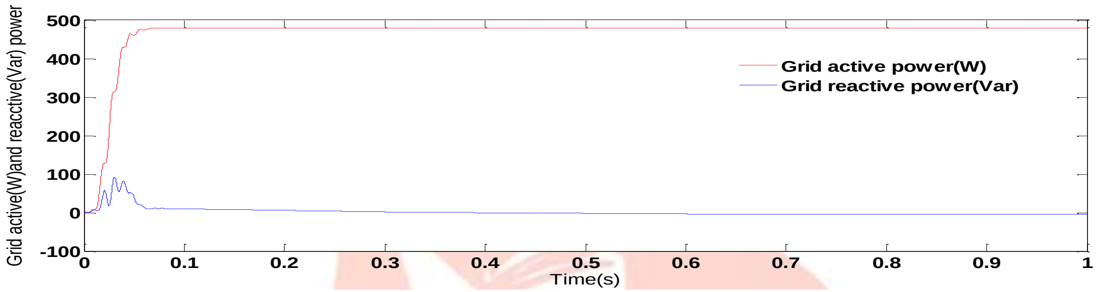


Fig .7 (d) CSI output current

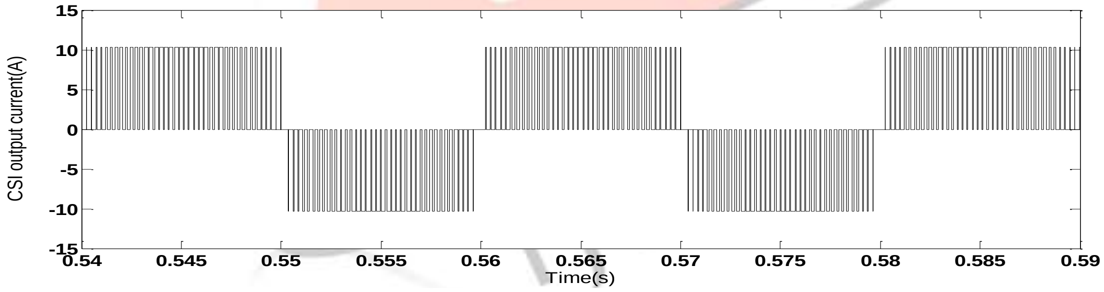


Fig.7 (e) grid active and reactive power

To demonstrate the effectiveness of the proposed system under varying atmospheric condition, a simulation carried out using two radiation levels, 500W/m2 and 1000W/m2 as shown in Fig 8 (a) the PV MPP extracted in a relatively short time, has a small oscillations around the MPP during steady state, and the new MPP is correctly extracted during both weather conditions, fig 8 (b) shows current on the dc side. Fig .8 (c) Shows that the grid current has a small THD and unity power factor under both climate condition. Fig 8 (d) shows the CSI output it is not violated by allowing switching of one current level at the same time on the both radiation level, moreover, fig .8 (e) Shows active and reactive power under the both the climatic condition.

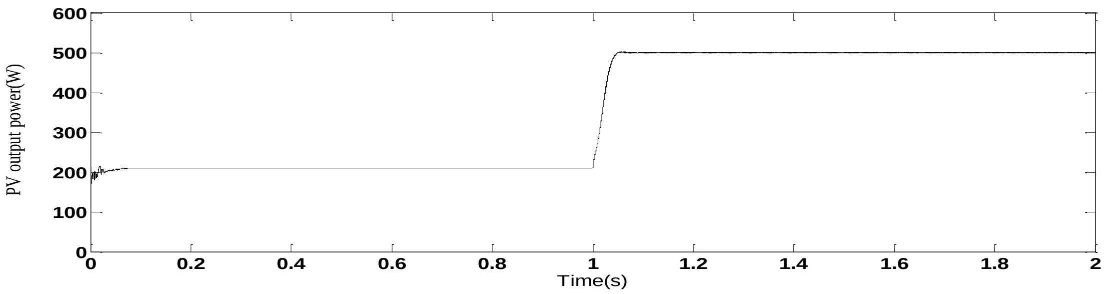


Fig.8 (a) PV output power

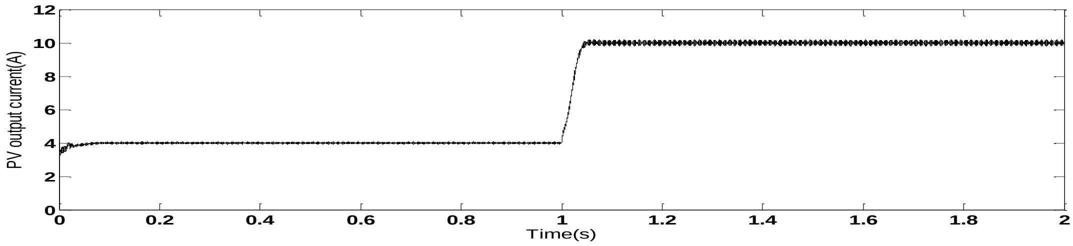


Fig .8 (b) PV output current

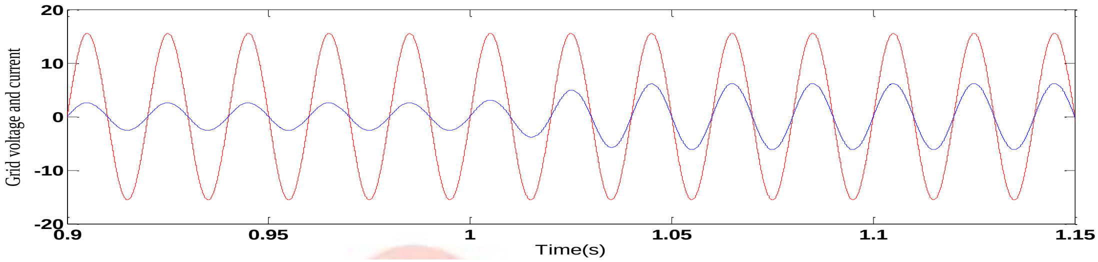


Fig .8 (c) Grid voltage and current

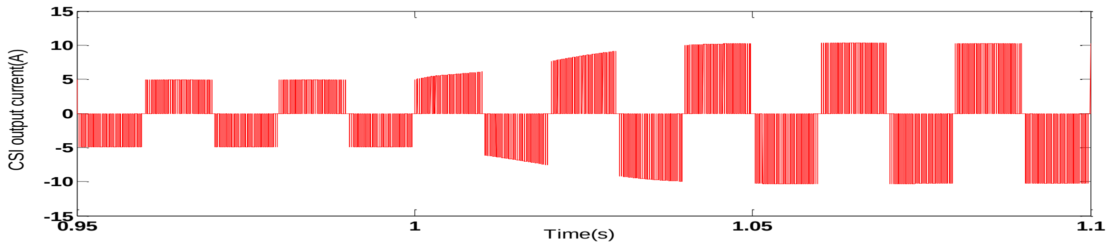


Fig .8 (d) Current source inverter output current

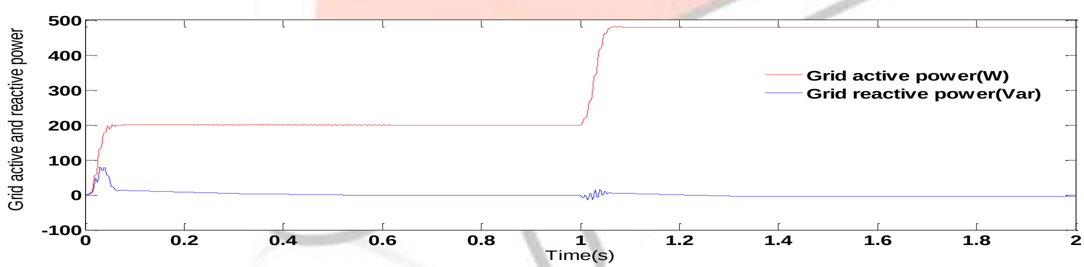


Fig .8 (e) Grid active and reactive power

Leakage Current Suppression:-

In general for a normal human can be felt one mille ampere current,5 mille ampere current can be pain full,10-15 mille ampere a person loses muscle control if it is more than 50 mille ampere it may be death. The proposed system has connected without electrically isolation connection it causes leakage current through ground (40 mille ampere) and PV panel the obtained wave form shown in Fig 9 (a).

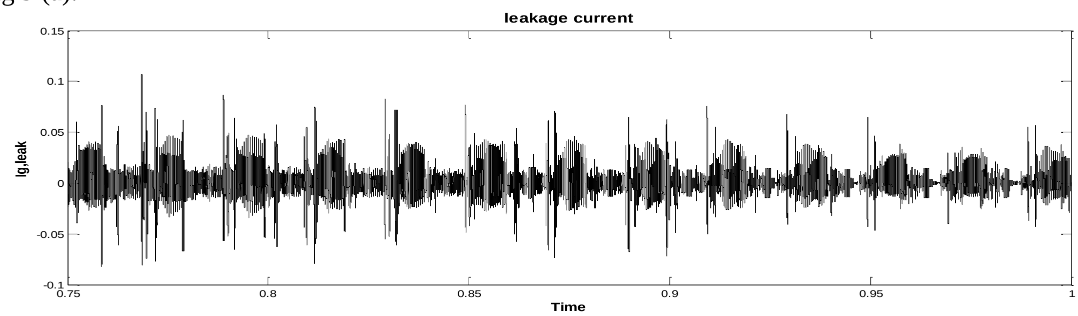
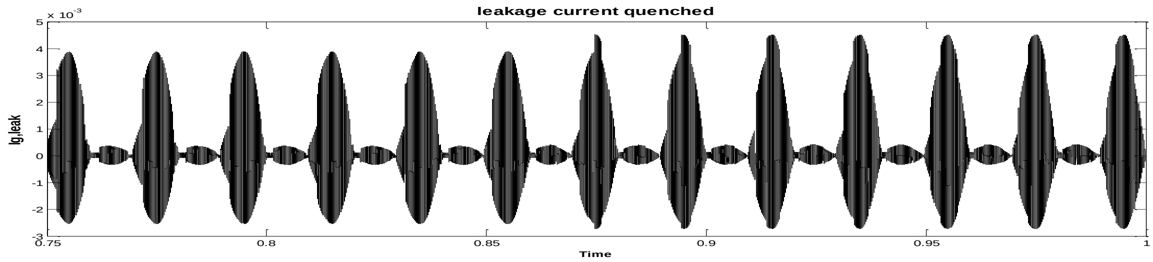


Fig. 9 (a) leakage current

From the above draw back can be eliminated by using H6 topology simulate the same circuit with small changes in inverter that is two more additional switches are used. This switching sequence can eliminate common mode voltage existed in current



source inverter. With this topology leakage current reduced below the dangerous value (4 mille ampere), simulation results are shown in fig.9 (b)

Fig.9 (b) leakage current quenched

VI.CONCLUSION

A single phase single stage grid connected PV system using a CSI has been introduced that meet the grid requirements without using a high dc voltage are or a bulky transformer. The control structure of the system having MPPT, a current loop, a voltage loop to improve the system performance during normal and varying climatic conditions. Hence the system consists of a single stage, the maximum power delivery to the load with high efficiency, low cost, and small. A CPWM to providing the continuous path for dc link current and energize the dc link inductor in every conduction period. A DTRF (double tuned resonant filter) for smoothening the dc link current and to eliminate the 2^{nd} and 4^{th} order harmonics. But it has the drawback of leakage current. Therefore proposed H6 topology reduced the leakage current drawback of the existing system

VII.REFERENCES

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