Bipolar PWM and LCL Filter Configuration to Reduce Leakage Currents in Transformerless PV System Connected to Utility Grid

Shanmuka Naga Raju

***Abstract*—**This paper presents PV system without considering transformer connected to electric grid. This is considered more economic compared to present PV system. The problem that occurs when transformer is not considered appears with a leakage current near capacitor connected to ground. Bipolar Pulse Width Modulation (BPWM) technique along with filter L-C-L configuration in the circuit is modeled to shrink the leakage current in the circuit. The DC/AC inverter is modeled using H-bridge Insulated Gate Bipolar Transistor (IGBT) module which is controlled using proposed Bipolar PWM control technique. To extract maximum power, Maximum Power Point Technique (MPPT) controller is used in this model. Voltage and current regulators are used to determine the reference voltage for the inverter from active and reactive current where reactive current is set to zero. The PLL is modeled to synchronize the measurements. The model is designed with MATLAB Simulation blocks and compared with the methods available in literature survey to show its effectiveness.

***Keywords*—**Photovoltaic, PV, pulse width modulation, PWM, perturb and observe, phase locked loop.

I. Introduction

THE generation of energy, utilizing sustainable power source assets is developing colossally these days. The normal and most elevated asset that is utilized for the most part is sun based power contrasted with different biomasses accessible [1]. Due to the development of PV systems and latest technologies to extract maximum power, it became easy to establish a PV circuit at every place where the generation is required. The installed capacity achieved by PV technology is of 2000 MW in 2006 [2] and significantly increased to 300 GW by the end of 2016. PV systems have the most attention because of their reliability and ease of access [3], [4].

PV systems are designed in such a way that it can be established as micro grid source of the system. A residential grid connected PV circuit consists of PV modules, high frequency transformer and inverter controller to create a medium between grid and PV system. The problem raised with PV circuit is resonance due to transformer and harmonics injected due leakage currents. Reference [1] proposed different topologies schemes to reduce leakage current and make the PV system transformer less. Reference [5] proposed active NPC circuit in PV system to reduce low leakage currents. Reference [6] proposed advanced topology to minimize leakage currents between the capacitor and ground. In [7], the author proposed various filter circuits to minimize leakage current in a transformer less PV system. In [8], the author proposed a single stage procedure to reduce the leakage current in a connected system without transformer. In [9]-[12] authors proposed different topologies to reduce the leakage current in the absence of transformer in connected PV grid.

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It is infeasible and uneconomic to use the high frequency transformer in PV system, so it is considered as disadvantage to use transformer as it occupies huge space and works less efficiently. When transformer is removed from the network, due to isolation, a leakage current can be observed in between capacitance and ground that generate harmonics in the network.

To reduce leakage currents between the capacitor and ground, a topology of Inductor-Capacitor-Inductor (LCL) configuration and bipolar PWM techniques to control inverter are proposed in this paper. The proposed topology proved to suppress common mode current (leakage current). The common leakage current of PV inverter can be computed from voltage obtained between midpoints of the legs of inverter controller. The common leakage voltage is given by

$$V_{CL} = (V_{AN} + V_{BN}) / 2$$

where V_{CL} common mode leakage voltage is considered as average of the sum of the voltages of inverter legs.

II. Problem Formulation

Because of insufficiency of galvanic disengagement between PV circuit and ground, there acquired a typical mode current or spillage current which is delivered because of the capacitance between PV module and ground. Because of spillage current sounds are infused which diminishes the proficiency of the entire framework. To minimize this leakage current, a topology with LCL filter configuration is proposed and inverter is controlled by PWM bipolar modulation to decrease harmonics in the circuit. The topology of the system is designed as follows:

A. PV System Model

The model of PV system consists of series and parallel connected PV modules. The PV module block has two inputs, one is irradiance and other one is temperature. PV array is made of one string of series connected 14TSM-250 modules.

At 25 °C, solar irradiance involved is 1000 W/m^2, each string can create 3500 W of power. Fig. 1 shows a simulation block diagram of irradiance and temperature connected to PV array.

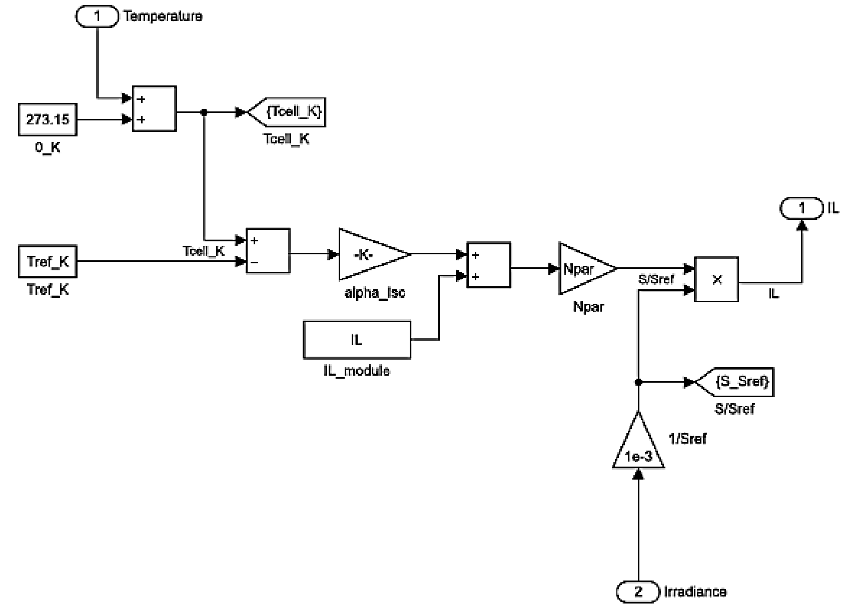

Fig. 1 Irradiance and Temperature of PV array

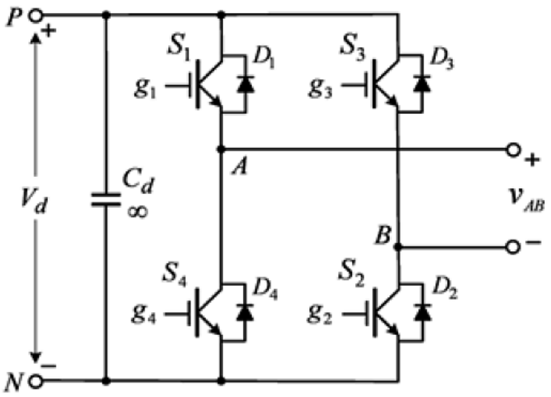

Fig. 2 Single Phase Full Bridge Inverter

Two capacitors, linked to positive and negative terminals of the PV array, are used to model the parasitic capacitance between PV modules and ground.

B. Utility Grid and Load Model

The power grid is modeled utilizing a pole-mounted transformer of 240 V and an AC source of 14.4 kV rms. The secondary winding of the transformer is center-tapped and neutral wire is grounded through small resistance R_g. The residential load having active power 10 kW, reactive power 4 kvar and voltage 240 Vrms is equally spread between two hot terminals of 120V each.

C. Single -Phase DC-AC Converter

The inverter is modeled using a single phase Bipolar PWM-controlled full-bridge IGBT module (H-bridge) and the topology circuit of LCL arrangement with capacitor partitioned with line and neutral branches.

The upper and lower switches of H bridge inverter vary in the complimentary manner when one switch is on another one is off. Fig. 2 shows switching of the single phase full bridge inverter. In this scheme, two gate signals are generated V_{g1} and V_{g3} by comparing V_m (modulated waveform) and carrier wave V_c of triangular form. The terminal voltage of H-bridge inverter is denoted by V_{AN} and V_{BN}, output voltage is $V_{AB} = V_{AN} - V_{BN}$.

The wave form V_{AB} that switches between positive and negative DC voltages is called Bipolar PWM. Fig. 3 illustrates the Bipolar PWM waveforms.

D. Inverter Control

The control circuit system covers five major Simulink-based subsystems:

- MPPT Controller: 'Perturb and Observe' strategy is used in this model to extract maximum power. This controller is varied with respect of V_{dc} reference signal of inverter VDC regulator to obtain certain voltage in DC voltage which can extort maximum power from PV cells.
- V_{dc} Regulator: With PI controller inside the circuit, it determines I_d the active current from reference voltage V_{dc-ref} and $v_{dc-mean}$ as inputs to regulate. Fig. 4 shows the simulated design of voltage regulator.

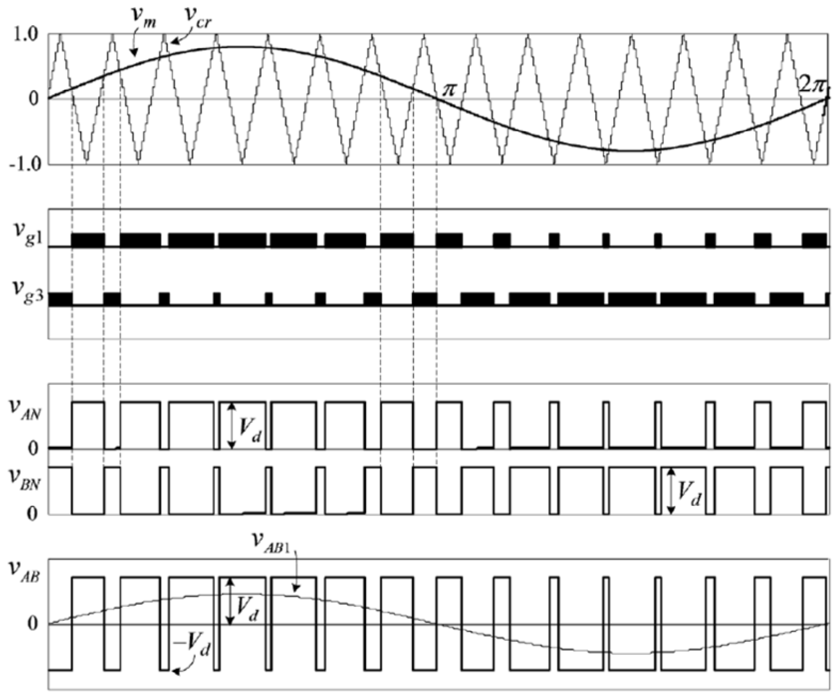

Fig. 3 Bi-polar PWM waveforms

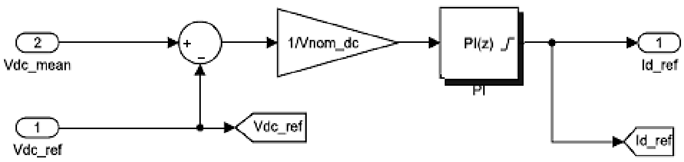

Fig. 4 Voltage (V_{dc}) regulator

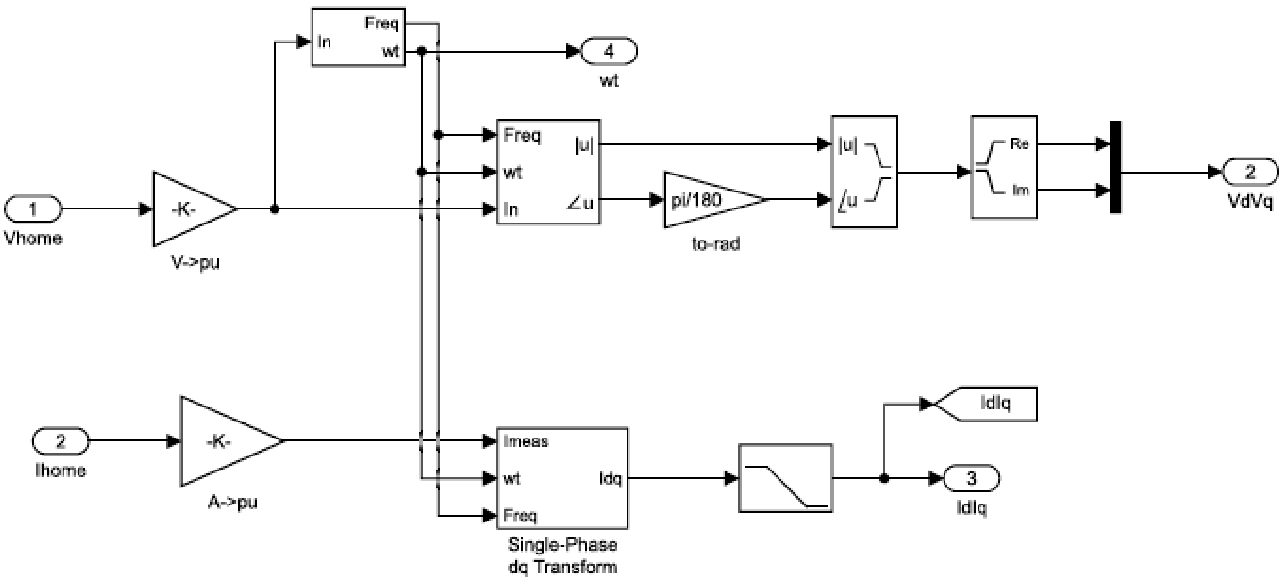

Fig. 5 PLL measurements

- Current Regulator: With current references I_d and I_q (reactive current) as input, the current regulator determines reference voltages for the inverter controller.

The I_q reactive current is set to zero in this paper. Fig. 6 shows the simulated design of current regulator.

Fig. 5 shows the simulated design of PLL block and measurements.

- PLL & Measurements: PLL block measures the frequency, voltage and current magnitudes along with sinusoidal phase angles.
- PWM Generator: It uses a PWM bipolar modulation method as explained in Fig. 1 to generate firing signals to the IGBTs. In this model, the PWM carrier frequency is set to 3780 Hz (63*60). Fig. 7 shows the simulated design of U reference voltage generator to give input to PWM generator.

Fig. 8 shows the schematic model of a transformer less PV system with LCL configuration connected to the utility grid.

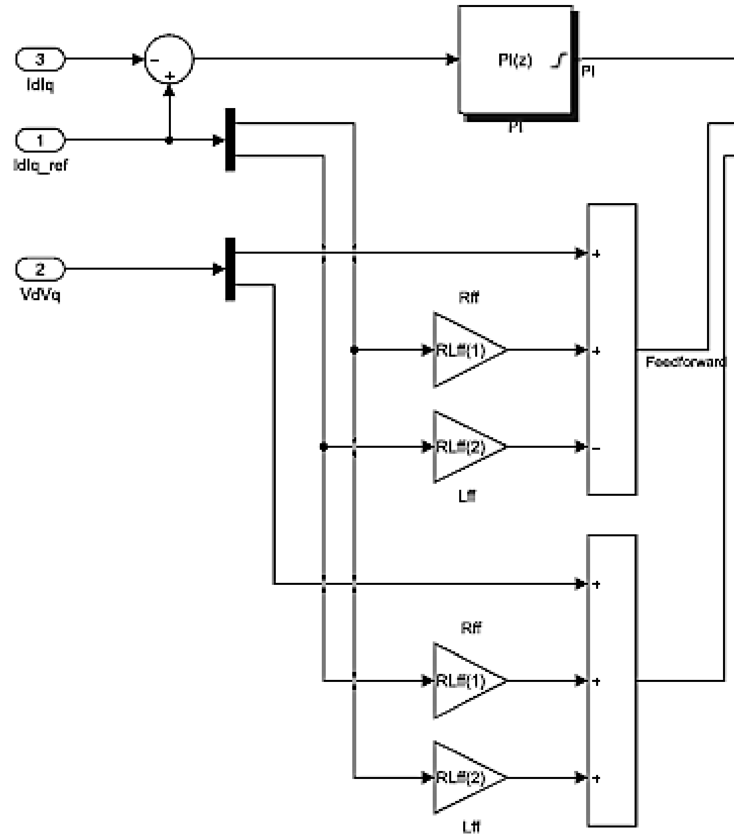

Fig. 6 Current regulator

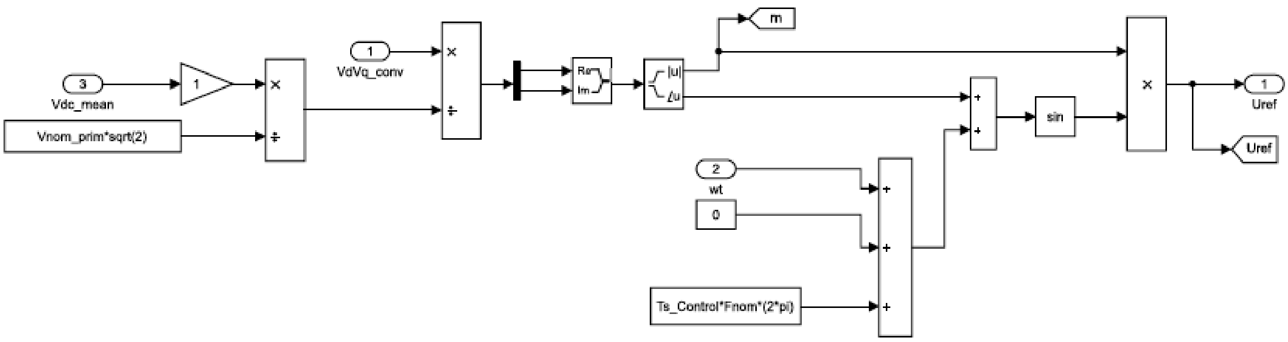

Fig. 7 U ref generator

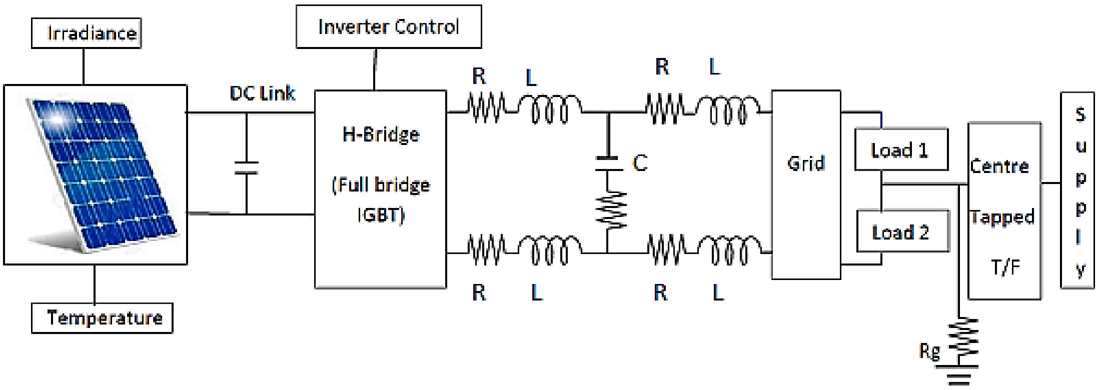

Fig. 8 Schematic model of Transformer less PV system with LCL configuration connected to Utility Grid

III. Results and Analysis

The model designed in this paper is run in MATLAB SIMULINK software to determine the efficiency and reliability of the model. Intel(R) core(TM) i3 processors at 2.20 GHz, 4 GB of RAM are used. Simulation of a model and the resulting signals on the various scopes are shown in Figs. 9-17.

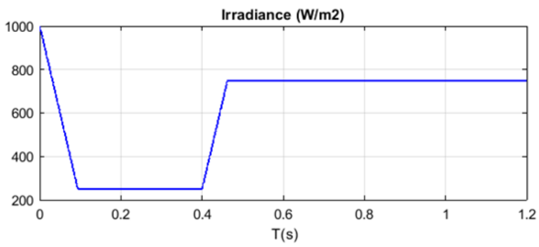

Fig. 9 Irradiance of PV system

Fig. 9 shows the irradiance of PV System. From Fig. 9, it is observed that, at t=0.4 sec, the irradiance is rapidly increased from 250 weber/meter square to 750 weber/meter square.

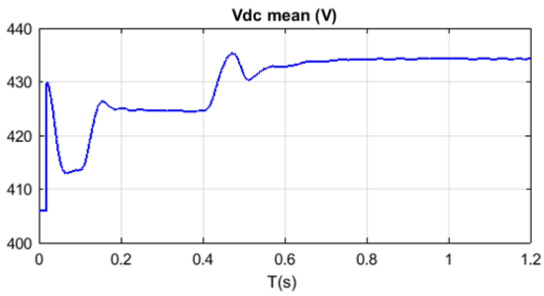

Fig. 10 Mean Voltage of PV system

From Figs. 10 and 11, it is observed that at t=0.25s a V_{dc} mean voltage obtained is 425.5 V and power obtained is 865 W.

The V_{dc} reference voltage is increased to 434.2 V in MPPT operation to extract maximum power.

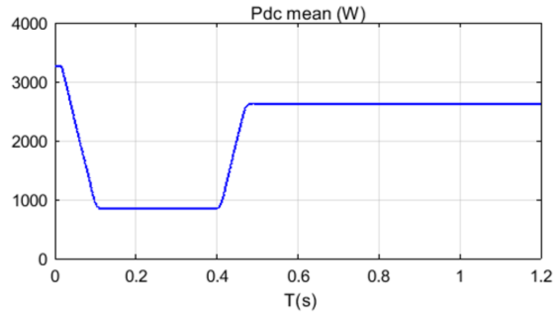

Fig. 11 Mean Power of PV system

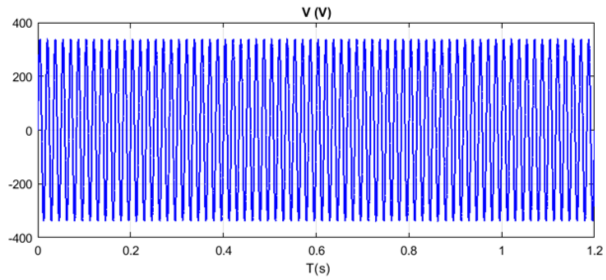

Fig. 12 V grid voltage

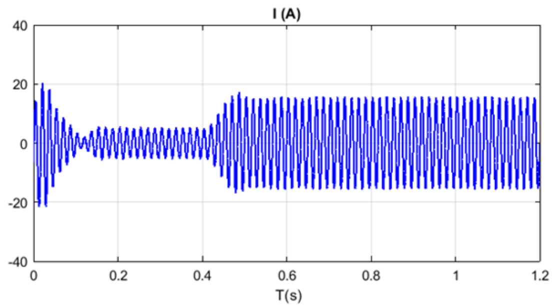

Fig. 13 Grid current

Figs. 12 and 13 show the utility grid voltage and grid current.

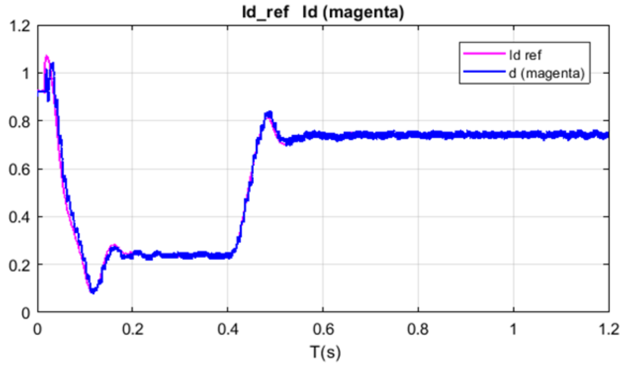

Fig. 14 Active current produced by voltage regulator

Fig. 14 shows the active current produced by voltage regulator and which is used in current regulator to produce reference voltage V_{dc} .

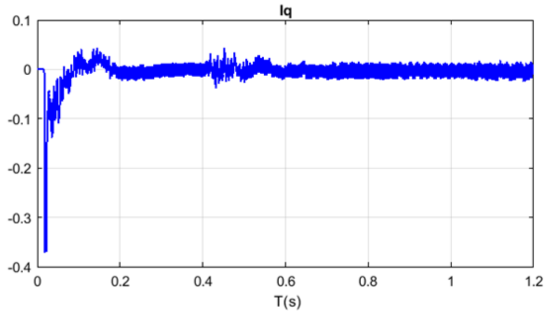

Fig. 15 Input Reactive current to current regulator which is set to zero

Fig. 15 shows input reactive current given to current regulator. This reactive current is produced by voltage regulator.

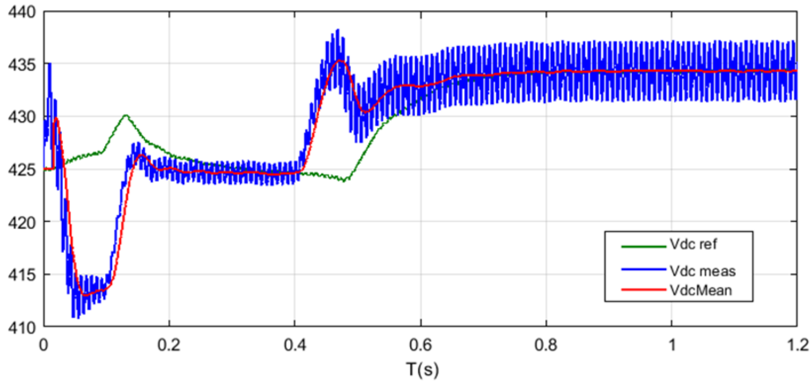

Fig. 16 Vdc reference, mean and measured values voltage inverter controller

Fig. 16 shows the $V_{dc-ref}, V_{mean}, V_{meas}$ voltages of inverter controller that are required to vary to extract maximum power.

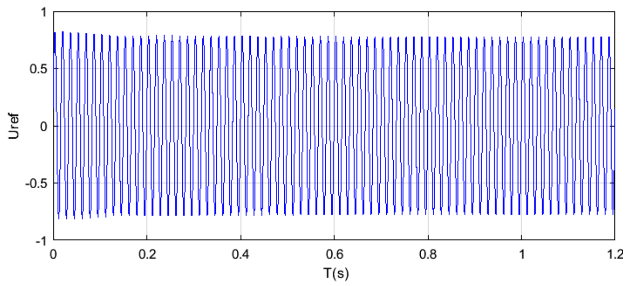

Fig. 17 Reference voltage of Bipolar PWM Generator

Fig. 17 shows the reference voltage of the Bipolar PWM generator. If we observe at leakage current as shown in Fig. 18, we can observe that there is no current flowing through the stray capacitance of PV strings. This is due to Bipolar PWM techniques used and LCL filter topology. Now, if we consider the PWM unipolar modulation method (using the Inverter control menu) and repeat the simulation, we can see a significant leakage current in the system.

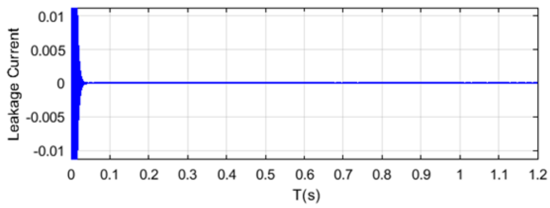

Fig. 18 Leakage current at Rg

From Fig. 18 it can be observed that the leakage current is reduced to minimum compared other methods available in literature [5]-[12].

IV. Conclusion

This paper presented the efficient topology model of transformer less PV system with Bipolar PWM and LCL configuration to reduce leakage currents. The DC/AC inverter is modeled using the H bridge IGBT module and is controlled using a Bipolar PWM controller. Voltage regulators and current regulators are effectively designed to produce a reference voltage that is used to vary in MPPT controller to extract maximum power. The Perturb and Observe technique is effectively used in this PV model to extract maximum power. The leakage current between capacitance and ground is measured which shows the reduced current approximately equal to zero.

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