

# Single Phase Photovoltaic Inverter with Grid Synchronization Using Dual Stage DC-DC Boost Converter

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**Abstract** — Now a days, transformer less inverter for grid connected photovoltaic system getting more attractive because of the benefits like lower cost, smaller in size as well as higher efficiency as compared with the transformer based inverter. However, once a transformer is removed, there is no any kind of galvanic isolation between photovoltaic arrays and grid. There is one another technical problem is the leakage current issue which needs to be escaped carefully. A new H6- type transformer less inverter for grid connected photovoltaic system is proposed that can reduce the problem of galvanic isolation by operating H6 inverter in freewheeling mode. It can also remove the leakage current by maintaining the common mode voltage constant at safe level as per the international standard and also operate with high frequency. In this system, a dual stage DC-DC boost converter is used to reduce the number of series connected PV panel and the effect of partial shading. It can also reduce the cost of full system. Sinusoidal pulse width modulation is used as control strategy to get good quality of voltage at the output of H6 inverter.

**Keywords** — PV Inverter; multistage converter; MPPT; Inverter;

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## I. INTRODUCTION

As per the world energy petition increasing at an exponential rate, the reliant on the fossil fuels is no longer a luxury. Although the fossil fuels gives a temporary solution to this energy crisis, they produce the emission of carbon dioxide and other harmful gases, which affect the environment. This has paved the way for research on renewable energy technology and other studies in the fields of power electronics. Hence, the cost of utilizing the renewable energy is at an ever falling rate [1]. One such source of renewable energy, the Sun, offers unlimited energy. From this solar energy, photovoltaic systems consisting of photovoltaic modules, generates environmental friendly power and it gain more and more recognised with each passing days. The photovoltaic modules comprise of several solar cells, which transform the energy of the sunlight straight into electricity, and it converts into desired levels of DC voltage and current. They produce electricity due to a quantum mechanical process known as the photovoltaic effect. The major drawback with these photovoltaic systems is that their cost is much high as compared to the conventional sources and their efficiency are also quite low. Modern power electronics signify as heart for the semiconductor device which is comprehensively used to turn ON or OFF the switches. To convert AC to AC, DC to DC, DC to AC and AC to DC are basic transformation function among which inverter is one of them which will convert DC to AC [2].

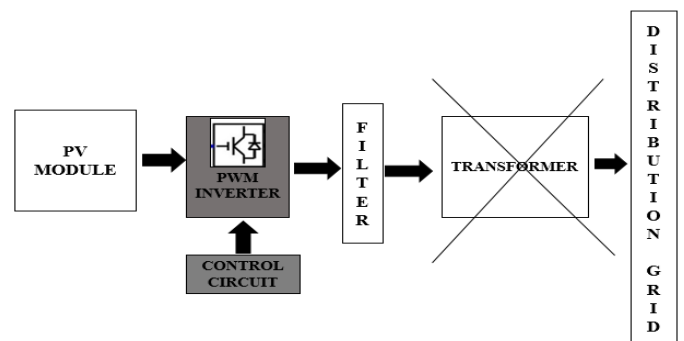


Fig. 1 Transformer Based Inverter System

Whatever the power generated by the photovoltaic system is maintain at maximum level by using the proper control strategy for the DC to DC converter which is used at the output of photovoltaic system. PWM inverter is used to convert the DC voltage generated by the photovoltaic system into AC voltage. This AC voltage is then step-up by using power transformer which is shown in fig. 1 and it is feed to the grid with proper synchronization of frequency, phase and the amplitude of the voltage. The system which used the power transformer to feed the power from photovoltaic system have higher cost and the large space requirement. So to reduce the problems associates with the power transformer, a transformer less grid connected PV inverter topology is proposed based on the conventional full bridge inverter with two supplementary power switches, which ensures the DC decoupling at the freewheeling mode [11].

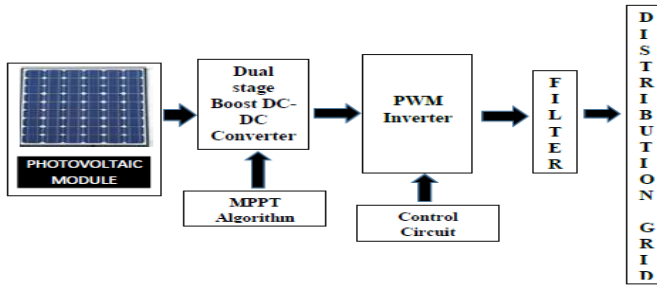


Fig. 2 Transformer less Inverter System

## II. PHOTOVOLTAIC MODULE

A PV module is combination of numerous PV solar cells. A one small PV cell is having a capacity of producing 1 watt or 2 watt of power and it is depends on the type of material used [8]. As per the high demanding of power one or more photovoltaic cells are connecting together and made a high power module. Now as per demand or capacity of the power plant or generating capacity, the number of photovoltaic modules are connecting with each other in the arrangement of an array.

### A. Design of PV module

At first, under Standard Test Condition (STC) sun array S6B2609 panel with 210W maximum output power is being tested. At STC condition of 25-degree temperature and irradiance of 1000 W/m<sup>2</sup> the panel is simulated which output voltage is 52V and is shown in Fig.3 [2]. Table-I shows the system parameters of photovoltaic module.

TABLE-I SYSTEM PARAMETERS OF PHOTOVOLTAIC MODULE

| Parameter               | Value     |
|-------------------------|-----------|
| Manufacturer            | Sun array |
| Solar Panel Model       | S6B2609   |
| $I_{sc}$                | 8.51A     |
| $V_{oc}$                | 33.50V    |
| $I_{mp}$                | 7.84A     |
| $V_{mp}$                | 26.63V    |
| $P_{max}$               | 210W      |
| Characteristic constant | 0.007     |

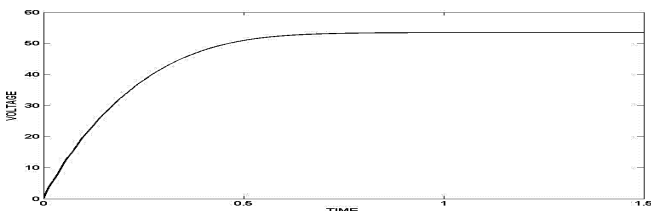


Fig. 3 Output Voltage of PV Array

Fig.3 is indicating the voltage after performing MPPT and connect the PV module in series and parallel as per power and current requirement. Incremental and Conductance MPPT algorithm is used in this system.

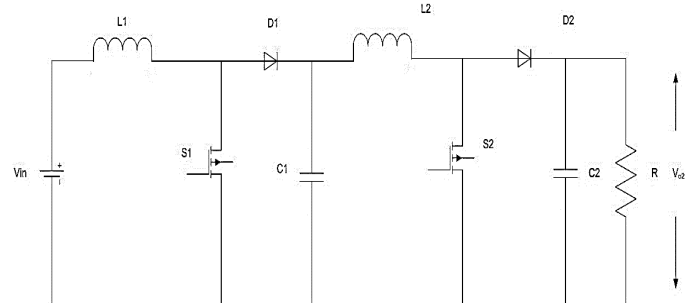
## III. DUAL STAGE BOOST CONVERTER

Dual stage is nothing but converting 52V to 325V in two stage (52V to 130V and 130V to 325V) because of one

limitation of the simple one stage boost converter. Dual stage boost converter is shown in fig.4. This limitation is that single-stage boost converter would be large duty ratio (for 52V to 325V Duty ratio is 0.84 it is above 80%), for this voltage conversion which is not convenient for MOSFET switching (practically) because it lead to increase stress on MOSFET [2]. That is the main reason behind to use dual stage boost converter for this conversion.

Fig.4 Circuit Diagram of Dual Stage Boost Converter

Design parameter of dual stage boost converter is given in table-

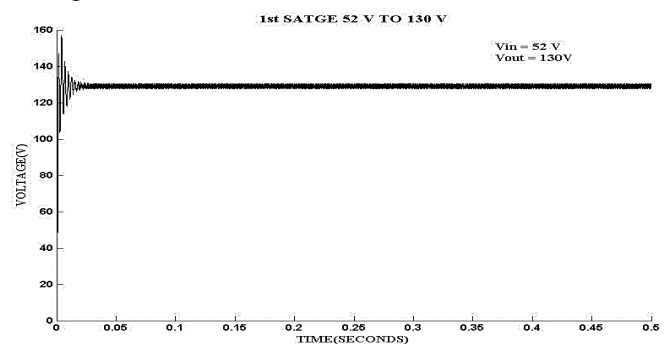


II. Wave form of both stage is shown in fig.5.

TABLE-II DESIGN PARAMETER OF DUAL STAGE BOOST CONVERTER

| Parameter    | Stage 1 | Stage 2 |
|--------------|---------|---------|
| $V_{in}$     | 52 V    | 130 V   |
| $V_{out}$    | 130 V   | 325 V   |
| Frequency    | 20 kHz  | 21 kHz  |
| $\Delta V_o$ | 6.5 V   | 16.25 V |
| $\Delta I_o$ | 2.4 A   | 0.865 A |

### 1<sup>st</sup> Stage of DC-DC Boost Converter



### 2<sup>nd</sup> Stage of DC-DC Boost Converter

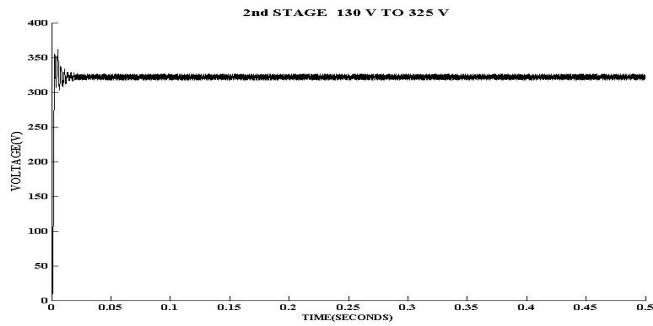


Fig.5 Output Waveform DC-DC Boost Converter

#### IV. SINGLE PHASE H6 INVERTER

Transformer less inverter having a three big issues like galvanic isolation, leakage problem, and common-mode voltage. And H-bridge single phase inverter is fails to solve this three problem and also conventional inverter having more harmonic distortion, so solve these problems uses a new H6 single phase inverter which shown in fig.

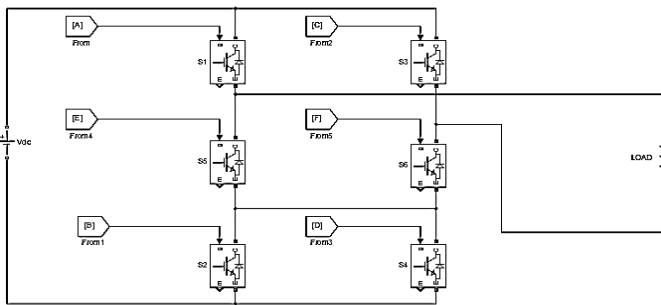


Fig.6 H9 Inverter Topology

A H6 type photovoltaic inverter's gate drive signal and simulink model of are shown in fig.7 and fig.8. Gate drive signal of H6 inverter is indicate that when phase shift is ensued in between the current and voltage, the current of grid  $i_g$  rests in negative, in the beginning of the positive half period and vice versa. So, this H6 inverter enforced to operate in mode 6 and mode 3 which is generally known as freewheeling mode. Output of H6 inverter is shown in fig 9.

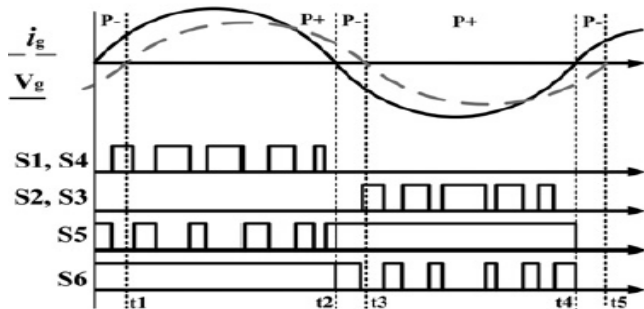


Fig.7 Control signal of H6 inverter

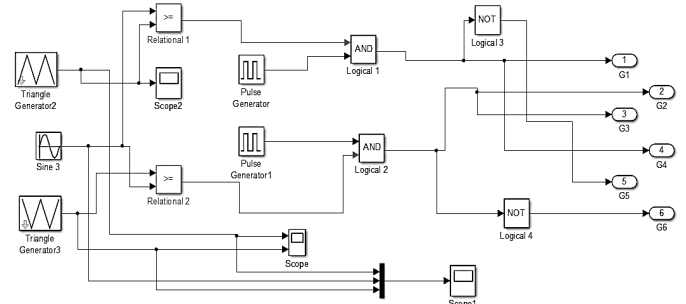


Fig.8. Switching Scheme of H6 Inverter

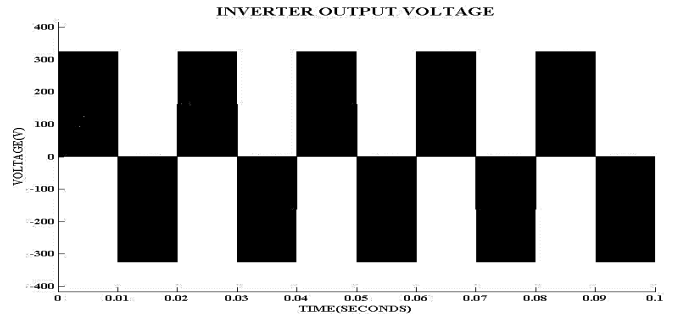


Fig.9. Output Voltage Waveform of H6 Inverter

#### V. GRID SHYNSCHRONIZING & FILTER

##### A. Grid Shynsynchronizing

The control block of inverter is shown in fig.10. First stage is the DC-DC converter with MPPT controller extract maximum power from PV array and second stage is DC-DC converter provide constant DC link voltage. DC side power is transferred to the AC side with the help of inverter. Control circuit of the inverter maintain power balance between DC side and AC side with the help of current control loop. Synchronous PLL is used to synchronise injected voltage with the grid. PI controller ensure proper quality of injected current.

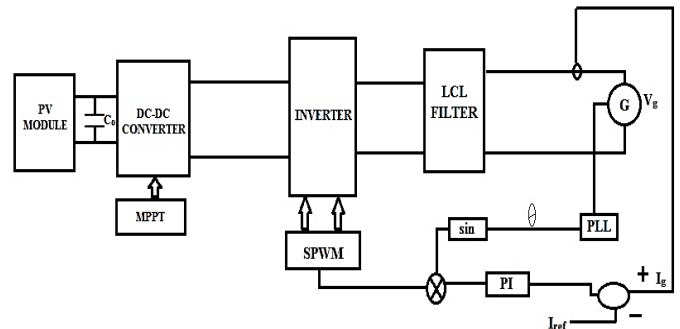


Fig.10 Grid Synchronising Method General Block Diagram

Current is injected in phase with the grid voltage to ensure zero reactive power. Synchronised grid current and reference current will be compared and error will be generate and this error goes into the PI controller to reduce this error. Output of this PI controller multiply with the sine wave which is comes from PLL and generate the reference signal for the SPWM technique. By comparing the reference signal with the triangle carrier waveform, gate pulse is generated for the H6 inverter.

##### B. LCL-Filter

For altering the amplitude of a signal with respect to frequency an electrical network is used, which is defined as

filter [13]. The main function of filter is to remove the unwanted harmonics and will not add further any frequency.

Here in this proposed system LCL filter is used, LCL filters, which are particularly popular in the renewable energy industry today, are an efficient and economical way of ensuring and improving the quality of power fed from the energy source to the grid [13]. Their purpose is to filter the unwanted signal frequencies from the inverter output.

The LCL filter will be very weak to oscillations and it will magnify frequencies nearby its cut-off frequency [14]. The simplest way is to add damping resistor. In general there are four possible places where the resistor can be placed series/parallel to the inverter side inductor or series/parallel to filter capacitor.

a) Calculations of  $L_a$ ,  $L_b$ , &  $C$

$$Z_b = \frac{V^2}{p}$$

Here  $V$  = grid voltage,  $p$  = output power (2)

$$L_a, L_b = \frac{Z_b}{2\pi f}$$

$L_a, L_b$  = Inverter Side Grid Side Inductor,  $f$  = Grid frequency

$$C = \frac{1}{2 * \pi * f * Z_b}$$

$C$  = Filter Capacitance

$$R_{cd} = \frac{1}{3 * 2 * \pi * f * C}$$

$R_{cd}$  = Damping resistor

## VI. RESULTS & DISCUSSION

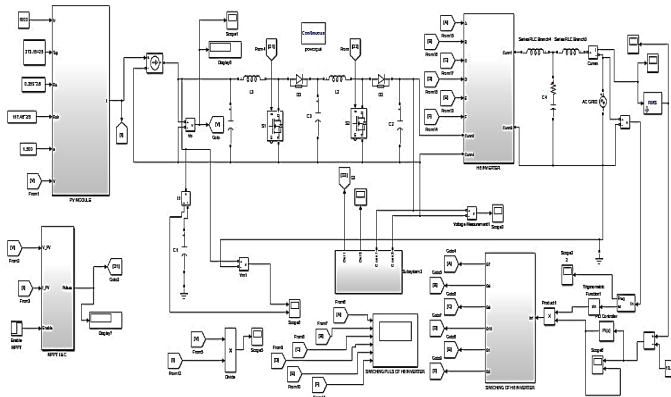


Fig.11 Simulink Model of Proposed System

Fig 11. is indicate the full system simulation circuit diagram of the transformer less PV inverter. In this diagram dual stage boost converter, H6 single phase inverter and filter circuit are connected with the 2.4 kW, 230 V AC Grid. Output grid current, grid voltage, grid power shown in below fig 12 and 13.

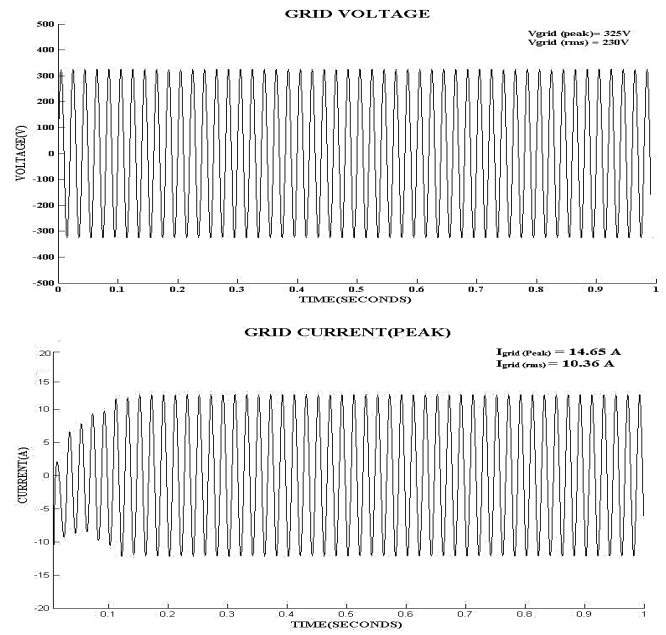


Fig 12 Output Grid Voltage and Grid Current Waveform

In fig 12 indicate the grid voltage, grid current and accordingly power is indicate into the fig 13. As per the grid synchronizing method used in this network is PLL (Phase Locked Loop) voltage and current are in the phase and it is clearly indicating in the above results.

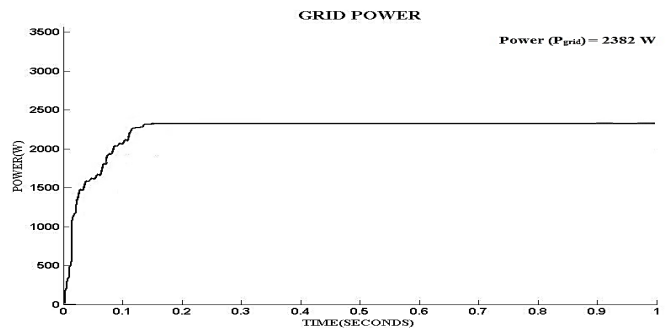


Fig 13 Grid Output Power

Advantage of this proposed system is that common mode voltage is continuously constant in the four working stage of the grid, so from the constant common mode voltage leakage current reduction is possible. Here doing comparison for the H-Bridge inverter and H6 inverter in terms of %THD and leakage current. For both inverter wave form of the leakage current are indicate in the fig.14 and fig.16. Common mode voltage is also indicate for the H6 inverter is in fig.17. Now comes on the %THD analysis in H-Bridge inverter it is coming around 3.93% and for the H6 inverter it is coming 1.43% it is much lower than IEEE519 standard. Analysis of %THD for both is indicate in fig.15and 9.8.

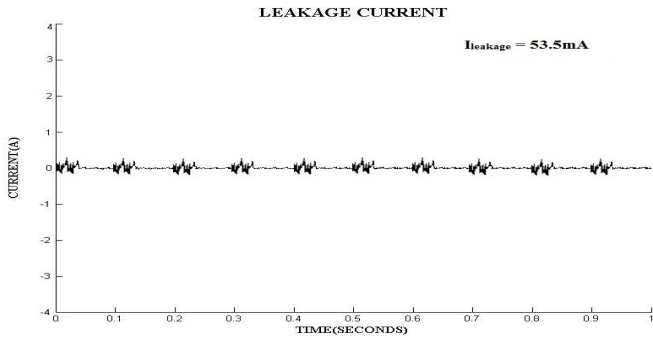


Fig 14. Leakage Current of H-Bridge Inverter

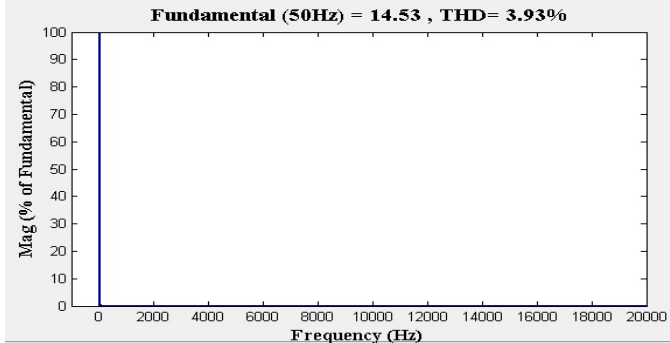


Fig 15. %THD Analysis Output Current of H-Bridge Inverter

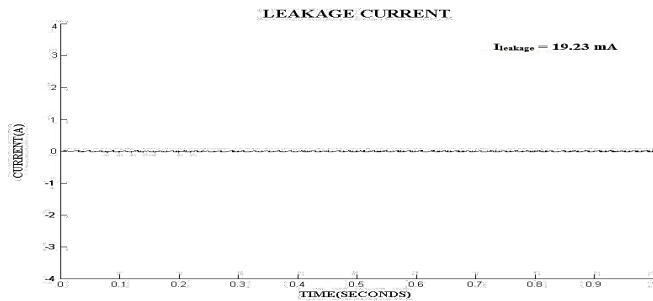


Fig.16 Leakage Current of H6 Inverter

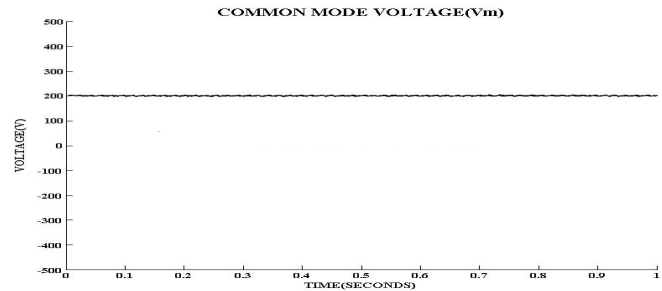


Fig.17 Common Mode Voltage of H6 Inverter

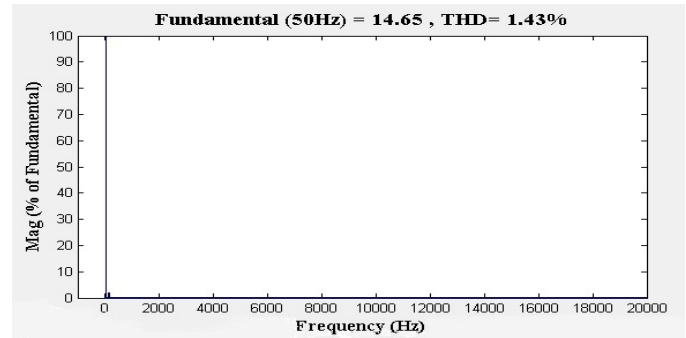


Fig.18 %THD Analysis of Output Current of H6 Inverter

The simulations are carried out to analysis and compare the overall performance of the H-Bridge and H6 topologies using MTLAB software. The parameter used in simulation are same for both the topologies. From the above results of the H-Bridge and H6 inverter it is clearly seen that H6 topology is far better than H-Bridge inverter for transformer less topology. In table III compared the result of both inverter in terms of %THD and leakage current.

TABLE-III RESULT COMPARISON OF H-BRIDGE AND H6 INVERTER

| Parameter | H-Bridge Inverter | H6 - Inverter |
|-----------|-------------------|---------------|
| %THD      | 3.93%             | 1.43%         |
| I leakage | 53.5mA            | 19.23mA       |

## VII. CONCLUSION

The simulation of the transformer less grid connected inverter was performed and compared with the conventional H-Bridge inverter for the same rating system by software and as a result pure sinusoidal waveform was obtained with the reduced of %THD up to the 1.43% in H6 inverter which is less than 1.5% which is much lower than the IEEE519 standard. Also leakage current is analysed for both H6 inverter and H-Bridge inverter so after comparison of the leakage current it is clear that in H6 inverter leakage current is much lower (19.23 mA) than H-Bridge inverter (53.5 mA). The simulation and its results conclude that the H6 inverter topology for transformer less grid connected inverter is more suitable than H-Bridge topology and it is compact in size for being transformer-less, and it is appropriate for supplying constant current with dynamic load with LCL filter.

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