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To Design and Develop Single Phase Grid-Tie PV Inverter and measurement of THD

Ms.Varsha Hanmantrao Patil
Electrical Dept.
TSSM's BSOER,Narhe-41
Pune,India
Varshapatil297@gmail.com

Mrs. Jyoti Sachin Kulkarni
Electrical Dept,
TSSM's BSCOER,Narhe-41
Pune,India
Jyotikulkarni79@gmail.com

***Abstract*— In today's condition, the renewable energy sources are affordable and accessible solution to achieve demand equal to generation under the critical conditions of power grid. Solar energy is environmental friendly, everlasting & freely available which has creates the enormous demand of solar PV system in the market. To satisfy the load demand, Transformerless Grid Tie PV Inverter is widely used. it is because of reduced size, cost, weight and efficiency but it carries leakage current of a significant value compared to other inverters used with transformer. To reduce the leakage current transformer less grid tie inverter NPC technology is proposed in this paper. The system is modeled in SIMULINK/MATLAB then this model is turned into fully functional model to supply the other load.**

Keywords— PV panel, MPPT, DC-DC Boost Converter, DC-AC Inverter, Control Circuit, L-C-L Filter, Grid

I. INTRODUCTION

Energy is one of the most important parts of our life. Any uncertainty about its functioning can threaten the functioning of the entire economy, particularly in developing economies. India's substantial and sustained economic growth is placing enormous demand on its energy resources. Energy requirement in our country is increasing at a very rapid rate. To balance the demand and supply in energy sources, the Government of India is taking serious efforts to expand energy supplies. To achieve energy security is very important not only for India's economic growth but also for the human development objectives that aim at alleviation of poverty, unemployment and meeting the Millennium Development Goals (MDGs). Holistic planning for achieving these objectives is based on the quality energy statistics. This planning is able to address the issues related to energy demand, energy poverty and environmental effects of energy growth. For that the generation of electricity from the renewable energy sources are used, from that sun is efficient, environmental friendly and costless fuel but the installation cost of solar system is too high than other renewable energy sources[2]; thus the grid tie inverter is design with improved efficiency for faster benefits.

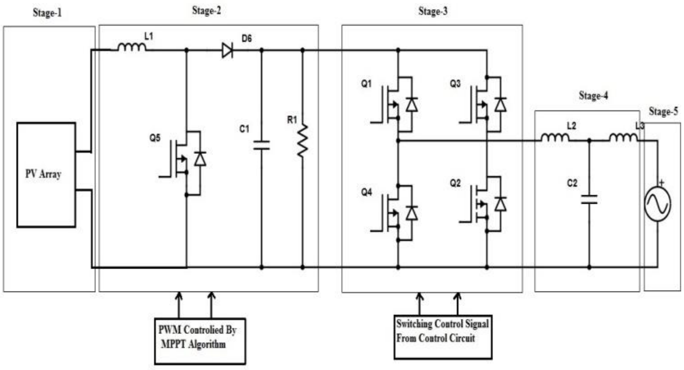

Fig.1.1: Single Phase Transformerless Grid-Tie PV Inverter

The Fig.1.1 shows the Transformerless Grid Tie PV Inverter (GTI) [5], have many advantages like improves efficiency, smaller size &light weight. This leakage current is flowing through the loop of parasitic capacitors, Boost converter, the bridge, filter & utility grid. The leakage current loop is broken by the transformer because of that leakage current is very low, in Transformerless Grid Tie PV Inverter leakage current is too high. To reduce the leakage current the common mode voltage is keep constant during all operating modes of operation & by isolating the AC & DC part at freewheeling mode. For this Purpose various topologies are used from that the neutral point clamped (NPC) topology is used to reduce the leakage current[1 &3].

II. TRANSFORMERLESS GRID TIE PV INVERTER & IT's PARAMETERS

This section discusses the important parameters to design Transformerless Grid Tie PV Inverter. Table 1 gives the parameters of Transformerless Grid Tie PV Inverter. This Transformerless Grid Tie PV Inverter is designed to handle 1kVA power at unity power factor. The most important assumption made is the use of unity power factor.[7 -9]

Table 1: Design Parameters

Parameter	**Value**
Grid Voltage	230V

Output Power of the Inverter	1kVA
Grid frequency	50Hz
Power factor	Unity

A. DC-DC boost converter

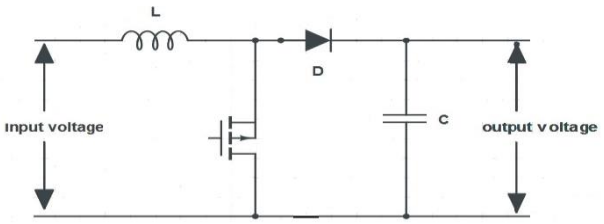

Fig.2.1: DC-DC Boost Converter

In this proposed Transformerless Grid Tie PV Inverter, boost converter is used to boost up the PV output voltage to the required level of Transformerless Grid Tie PV Inverter. As per the rating of Transformerless Grid Tie PV Inverter it's input 325V, 5Ato provide 230VAC, 5A.In this the PV output voltage is 100V.It is collected from 3 series connected panel. The rating of each panel is as shown in table 2.Boost converter is used to boost 100V output of PV panel to 325V.It has given the input terminal of Transformerless Grid Tie PV Inverter trough DC link capacitor. The boost converter switching frequency is 5 KHz which leads smaller inductor size.

Table 2.: PV Panel Specification

Parameters	**Values**
Rated Power	250W
Open Circuit Voltage	45.44V
Short Circuit Current	7.676A
Max. Power Voltage	35.43V
Max. Power Voltage	7.125A
Max Series Fuse Rating	15A

a) Selection of L

The duty cycle of boost converter is given by,

$$D = 1 - \frac{Vin}{Vout} \qquad \dots(1)$$

$$D = 1 - \frac{100}{325.31} = 0.69$$

Let, switching frequency is 5 kHz, so the time period is

$$T = \frac{1}{F} \qquad \dots(2)$$

$$T = \frac{1}{5kHz} = 0.2ms$$

Hence the on time of MOSFET switches is

$$0.2ms \times 0.69 = 0.136\mu s \qquad \dots (3)$$

Let output ripple current of 10 % so,

$$\Delta I = 10\% \frac{\sqrt{2} \times P}{Vgridphase} \qquad \dots(4)$$

$$\Delta I = 10\% \frac{\sqrt{2} \times 1KW}{230} = 0.6428 \text{ A}$$

From (3) & (4)

$$\frac{di}{dt} = \frac{0.6148A}{0.136\mu s} \qquad \dots(5)$$

Under the on time of MOSFET

$$Vin = L\frac{di}{dt} \qquad \dots(6)$$

To calculate the value of inductor from (5) & (6)

$$\frac{Vin}{L} = \frac{di}{dt}$$

$$\frac{100}{L} = \frac{0.6148A}{0.136\mu s}$$

$$L = 22.12mH$$

Hence the value of inductor is= 9.85 mH.

b) Selection of C

The current flowing through the capacitor is,

$$I = C\frac{dv}{dt}$$

Where

I = load current in Amps,

C= output capacitor in Farads and

dv/dt = change in output voltage with time.

From the eq^n (3) the value of dt is 0.136. Let, the voltage ripple is 0.1% of output voltage. So, dv= 0.325V & I=5A, the value of capacitor is,

$$C = 5A \times \frac{0.136ms}{0.3253V}$$

$$C = 2090\mu F$$

Table 3: Calculated Parameters for DC-DC Boost Converter

Parameter	**Value**
Duty ratio	0.69
Switching frequency	5kHz
Boost inductor	22.12mH
Boost capacitance	2090µF

B. Design of T-LCL Flter

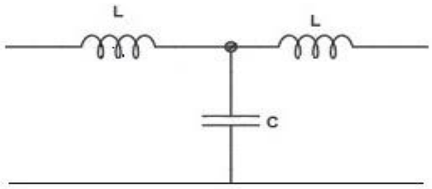

Fig.2.2: L-C-L filter

In this article T-LCL circuit is applied as a filter circuit as it will reduce of harmonic distortion to produce a pure sinusoidal output as well as it helps to obtain the desired constant current output and characteristic impedance Z0 =√L/ C. Therefore, in ideal condition, the filter circuit will provide constant current or constant power. And the output voltage does not depend on the load impedance but depends only on input current and characteristic impedance Z0. Therefore, the ideal circuit will provide constant voltage. At resonant frequency, (taking resonant frequency,($\omega_r = \omega$)); $\omega_L = 1/\omega C$; $\omega^2 = 1/LC$; $Z0 = \sqrt{L/C}$.

These values are for the case; where $\omega_0 = 1$ radian per second and should be frequency scaled by dividing through by $\omega = 2\pi f_c$. Here frequency, f = 50Hz and consider characteristic impedance 20Ω.

$$C = \frac{1}{2 \times \Pi \times f \times R}$$

$$C = \frac{1}{2 \times \Pi \times 50 \times 20}$$

C= 0.159mF

$$L = \frac{R}{2 \times \Pi \times f}$$

$$L = \frac{20}{2 \times \Pi \times 50}$$

63.60mH

$$Z = \sqrt{\frac{63.60mH}{0.159mF}} = 20\Omega$$

$$f = \frac{R}{2 \times \Pi \times \sqrt{LC}} = 50\text{Hz}$$

III. SIMULATION & HARDWARE OF GRID TIE INVERTER

The simulation of NPC grid tie inverter is as shown in Fig.3.1. Stage 1 is PV array, the O/P of PV array is 100V and the boost converter to boost up 100V DC to 325V DC [4] stage 2 is NPC Grid Tie PV Inverter. In this stage switch S,S3c are coolMOSFET, they are operated at switching frequency and other S2,S3,S1c and S2c switches are operated as grid frequency stage 3 is L-C-L filter , which is used to reduce harmonics and used pure sinusoidal wave form at output[5 & 6]. Stage 4 is grid which is 230V, 50Hz supply of electricity.

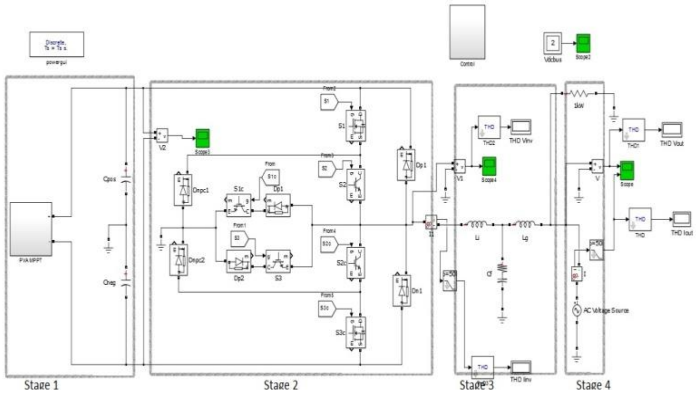

Fig.3.1: Simulation of Single Phase Grid-Tie Inverter

The fig.3.2 shows hardware of single phase grid tie pv inverter

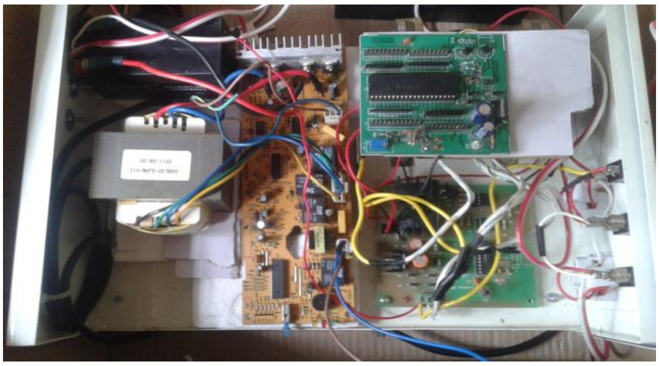

Fig.3.2: Hardware of Single Phase Grid-Tie Inverter

IV. RESULT

The Transformerless NPC Grid Tie PV Inverter for 1 KVA using SIMULINK/MATLAB is shown in Fig.3.1. The waveform of inverter output voltage before & after filter, output current before & after filter is shown in Fig.4.1 to Fig.4.4 for Simulation & hardware.THD of output voltage before & after also THD of the output current for before& after filter is shown in Fig.4.5 to Fig.4.6 for Simulation & hardware.

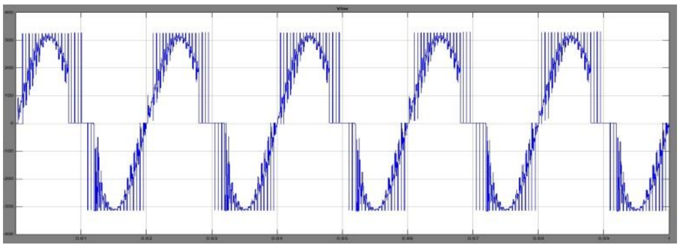

Fig 4.1: Inverter Output Voltage before Filter for Simulation

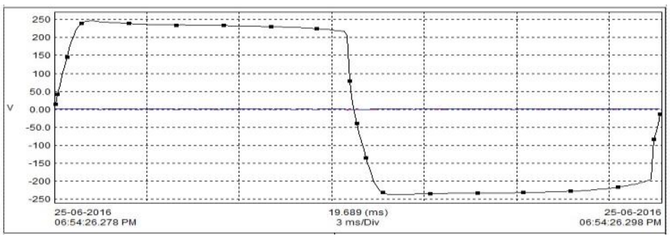

Fig 4.2: Inverter Output Voltage before Filter for Hardware

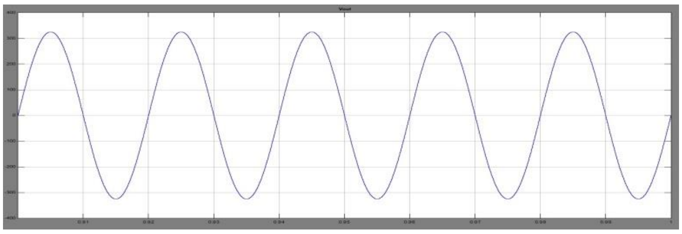

Fig 4.3: Inverter Output Voltage after Filter for Simulation

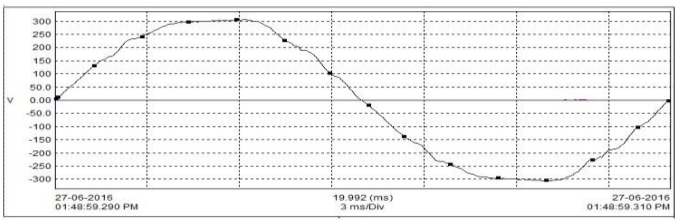

Fig 4.4: Inverter Output Voltage after Filter for Hardware

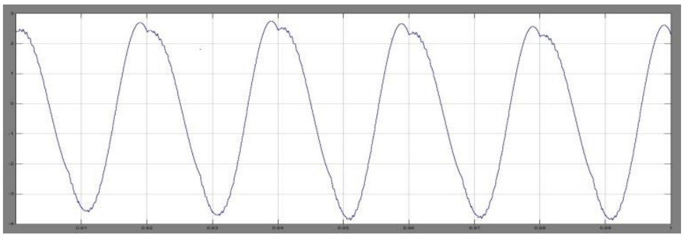

Fig.4.5: Inverter Output Current before Filter for Simulation

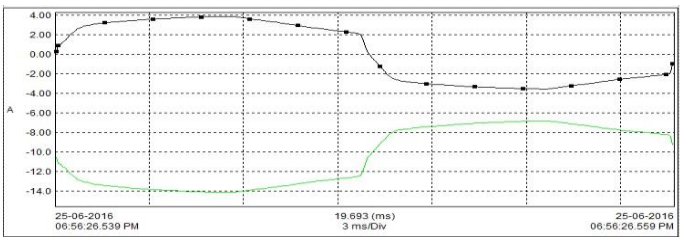

Fig 4.6: Inverter Output Current before Filter for Hardware

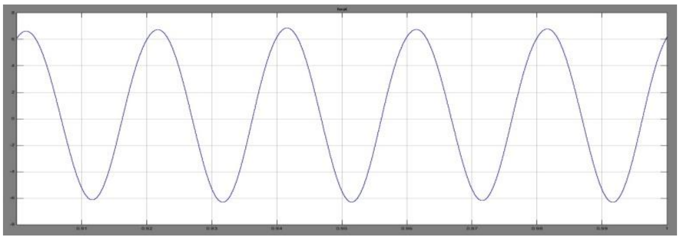

Figure 4.7: Inverter Output Current after Filter for Simulation

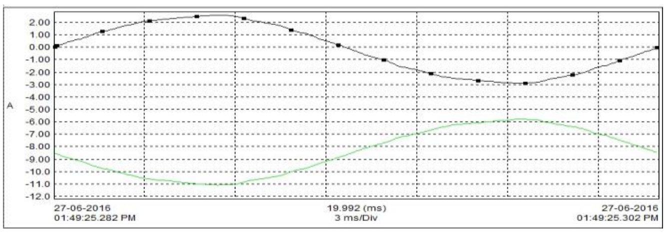

Fig 4.8: Inverter Output Current after Filter for Hardware

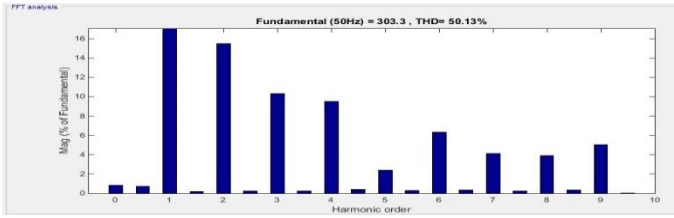

Fig.4.9: THD of Inverter Output Voltage before Filter for Simulation

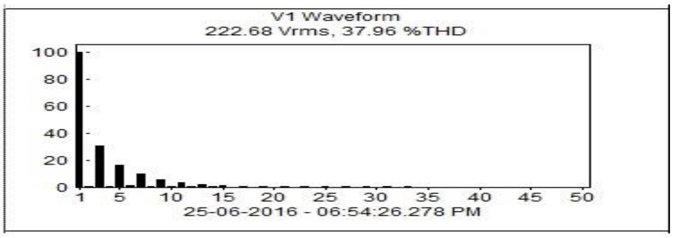

Fig.4.10: THD of Inverter Output Voltage before Filter for Hardware

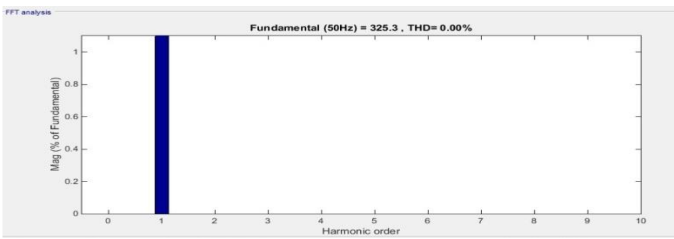

Fig.4.11: THD Inverter Output Voltage after Filter for Simulation

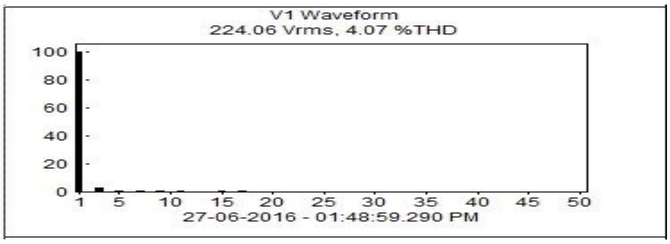

Fig.4.12: THD Inverter Output Voltage after Filter for Hardware

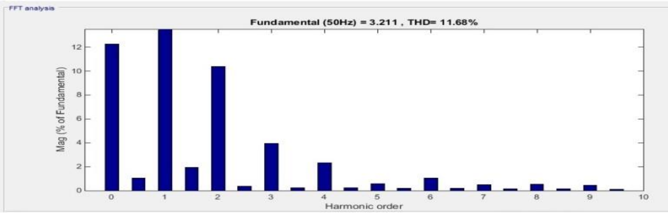

Fig.4.13: THD Inverter Output Current before Filter for Simulation

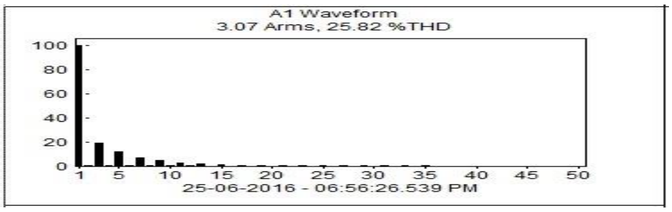

Fig.4.14: THD Inverter Output Current before Filter for Simulation

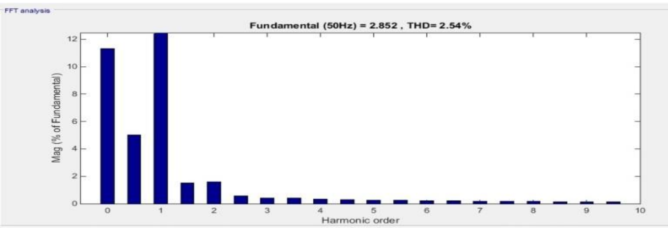

Fig.4.15: THD Inverter Output Current after Filter for Simulation

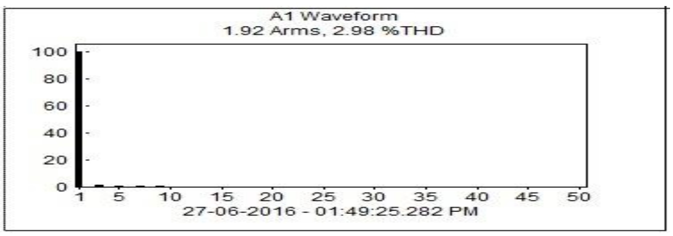

Fig.4.16: THD Inverter Output Current after Filter for Hardware

V. CONCLUSION

In this way Fig.4.1 to Fig.4.16 shows the performance of Transformerless NPC Grid Tie PV Inverter. Fig 4.3, Fig. 4.4 Fig. 4.7 & Fig. 4.8 shows the filtered output voltage and current of inverter for simulation & hardware respectively . The total harmonic distortion (THD) of inverter output voltage before filter is 50.13 % and 36.77% & after filter it becomes 0 % and 4.07% for simulation & hardware respectively as shown in Fig. 4.9 to Fig 4.12. The output current THD of inverter before filter is 11.68 % & 25.62% and after filter it becomes 2.54 % & 2.98% for simulation & hardware respectively as shown in Fig. 4.13 to Fig 4.16.

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