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An Innovative Approach for Transform Less GTI Topology Based on Boost Converters

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Abstract: This paper proposes the transformer less grid tie inverter (GTI) based on boost converter. An inverter is design by cascading of two boost converters. Power MOSFETs are used for the switching of boost converters. Transform less GTI provides best efficiency as compare to other inverters due to small size, and maximum power processing. The proposed topology includes H bridge circuit for MOSFETs; voltage divider circuit, rectifier, dual stage boost converters, and filter circuit which is use for removing harmonic distortion(HD) and swells inverter verified efficiency about to 98% within 0.9KW power. Simulation results for output of boost converters, voltage divider circuit voltage waveforms and inverter output waveforms are shown using MATLAB Simulink software.

Keywords: Transform less, Harmonic Distortion (HD), Grid Tie Inverter (GTI).

1. INTRODUCTION

Renewable energy sources play an important role in generation of electric power. Emission of fuel, gases from vehicles and carbon dioxide are badly affecting the climate and temperature of environment. Later on solar energy was produce for the solution of this pollution .It is one of the renewable energy sources that reduce the emission of carbon dioxide (CO_2) (Blackstone, *et. al,* 2012). For the presented topology power electronics interface technique is uses that convert the direct current (DC) voltage into alternating current (AC) voltage. So this technique interfaces the DC-DC boost converters (Ortiz-Rivera, *et. al,* 2008), (Agarwal, *et. al,* 2007), (Liao, *et. al.,* 2008), (coruh, *et. al.,* 2010), (Gonzalez, *et. al,* 2011) and inverters (Gonzalez, *et. al.,* 2011), (Frejedo, *et. al.,* 2009), (Kwang, *et. al.,* 2010). Dual stage boost converter hierarchy not only boosts up the voltage it also increases the power and then distributes that power to inverter and after that fed to the grid. We know that maximum power can be delivering in such a way if the impedance of source matches with load impedance.

Now a days more attention is towards photovoltaic (PV), which supplies power to grid (Benner, *et. al.,* 1999), (Billinton, *et. al.,* 2001), (Bialasiewicz, *et. al.,* 2008), (Guan, *et. al.,* 2010), (Koran, *et. al.,* 2010), (Chen, *et. al.,* 2010). Collaborative inverters are used for residential photovoltaic (PV) generating systems. Maximum power require for such type of inverters is lesser than 4.9KW (Shinjo, *et. al.,* 2007), (Ali, *et. al.,* 2016), (Rossi, *et. al.,* 2006), (Huang, *et. al.,* 2006), (Kjaer, *et. al.,* 2005), (Calais, *et. al.,* 2002), (Salas, *et. al.,* 2009) and dc input voltage is 400V/401V is required that depends upon the features of Photovoltaic section. For residential photovoltaic panels input voltage can be varying i.e. from 199V to 500V it will be changed from the required range 400V.

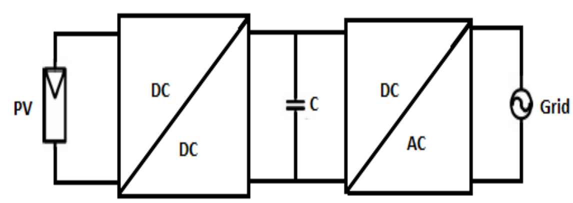

Fig.1. Dual stage conventional photovoltaic (PV)

Above **(Fig 1).** presents the block diagram of dual stage photovoltaic, having maximum frequency dual stage power transformation in cascading of converters and dc link capacitor is connected in the middle part (Kwon, *et. al,* 2006), (Barbosa, *et. al.,* 2006), (Armstrong, *et. al,* 2006), (Ali, *et. al.,* 2018), (Asiminoaei, *et. al,* 2005), (Yang, *et. al,* 2010),(Faiz, *et al.* 2018). In this diagram voltage of dc bus must be rise up from photovoltaic array and dc to ac phase must be a high frequency voltage source inverter or second option is use of isolated line commutated inverter (Bose, *et. al,* 1985), (Saha, *et. al.,* 1996), (Saha, *et. al,* 1996), (Martins, *et. al,* 2000) some of the non-isolated buck boost converters technologies has established (Caceres, *et. al,* 1999), (Va´zquez, *et. al.,* 1999), (Kasa, *et. al.,* 1999), (Chien-Ming, *et. al.,* 2004). Main disadvantage is requirement of dual input sources and limitation of input voltage (Jain, *et. al,* 2007), (Xue, *et. al,* 2004) comparison of the several converter topologies is discussed with effective rate and reliability (Chan, *et. al,* 2006), (Faiz,*et al,*2014), (Ali, *et al.*2018).

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This paper investigates the dc to dc dual stage boost converter with inductor current and frequency is 50Hz to 60 Hz for inverter. Power MOSFETs are used for the boost converters. These converters are operating in the continuous conduction (CCM) mode. The proposed single phase grid tie inverter includes following five parts:

(1) Photovoltaic array, (2) dual stage DC to DC boost converter, (3) filter circuit, (4) voltage divider and (5) DC to AC converter.

Voltage divider circuit is basically used for synchronization of output frequency with grid circuit

The basic block diagram of the proposed inverter is shown in the **(Fig 2).**

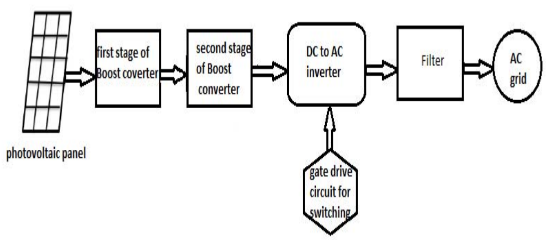

Fig.2. Block diagram of GTI inverter topology based on Dual stage boost converter

2. BACKGROUND

Under the test conditions sanyo HIP210HKHA6 having maximum output power 2.2KW that is tested in the temperature of 25 degree centigrade. Parameters for PV are shown in **(Table 1).**

Table 1: Parameters for PV

Parameter	Value
Manufacturer	Sanyo
Solar panel model	HIP210HKHA6
Short circuit current(I_x)	5.57A
Short circuit voltage(V_x)	50.9V
Maximum power(P_{max})	210W
Characteristic constant(b)	0.0773

Fig.3. Output Waveform

3. MATERIAL AND METHODS

3.1 Analysis of First Stage of Boost Converter

When the voltage of grid is higher than the solar panel voltage then it works in boost mode .when switch is close the diode will be in reverse biased condition. Applying Kirchhoff voltage law:

$$V_L = V_s L\frac{di}{dt}$$

$$\frac{\Delta i}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_s}{L}$$

Duty cycle can be calculated as:

$$D_{boost\_1} = 1 - \frac{V_{in}}{V_{out}}$$

$$D_{boost\_1} = 1 - \frac{24}{86} \approx 0.72$$

3.1.1 Selection of Inductor

In the boost circuit inductor is connected in series within the input voltage to bound the current ripple of the converter. In predictable process, value of inductor is choosing and 24V is converted to 86V.

$$L_{1\_boost1} = \frac{V_{in}(V_{out} - V_{in})}{\Delta i_L \times f_s \times V_{out}}$$

$$L1_{boost1} = \frac{24(86-24)}{4.55 \times 20000 \times 86} \approx 190uH$$

Following table shows the design constraints for the first stage of boost converter

Table2: Design constraints for first stage of boost converter

Symbol	Actual meaning	Value
V_{in}	Input voltage	86V
V_{out}	Output voltage	312V
f_s	Switching frequency	21kHz
I_{Lmax}	Maximum inductor current	230A
ΔI_L	Estimated inductor ripple current	60A
ΔV_{out}	Output voltage ripple	0.35V
I_{out}	Output current	10.4A

3.1.2 Selection of Capacitor

Capacitor value can be estimated as:

$$C_{1\_boost} = \frac{I_{out} \times D}{f_s \times \Delta V_{out}}$$

$$C_{1_{boost}} = \frac{4.3 \times 0.72}{2000 \times .044} \approx 3.5mF$$

Simulation results for stage 1 are shown below:

Output waveform:

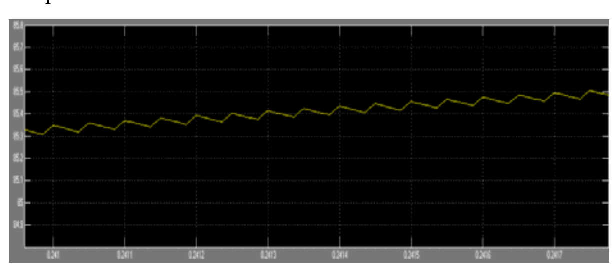

Fig.4. Output voltage (Vout) for stage 1 of boost converter

Current waveform of inductor L1:

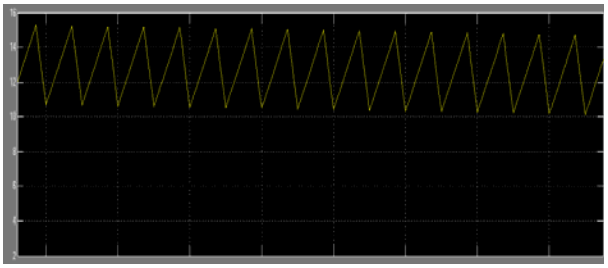

Fig.5. Inductor current wave form for stage 1 of boost converter

3.2. Design Analysis of Second Stage of Boost Converter

This subsection describes the second stage of boost converter within the cascading of first stage .duty cycle for the MOSFETS should be 90% which is not possible for MOSFETs so same duty cycle 72% is applied for MOSFETs.

Duty cycle for second stage of boost converter is calculated as:

$$D_{2\_boost}=1-\frac{V_{in}}{V_{out}}$$

$$D_{2oost}=1-\frac{86}{312}\approx 0.72$$

3.2.1) Selection of Inductor

Inductor is designed using following equation:

$$L_{2\_boost}=\frac{V_{Iin}(V_{out}-V_{in})}{\Delta I_L\times f_s\times V_{out}}$$

$$L_{2\_OOST}=\frac{86(312-86)}{60\times 2100\times 312}\approx 50uH$$

Following table shows the design parameters for second stage of converter:

Table 3: Design constraints for second stage of boost converter

Symbol	Actual meaning	Value
V_{in}	Input voltage	86V
V_{out}	Output voltage	312V
f_s	Switching frequency	21KHz
I_{L_max}	Maximum inductor current	230A
ΔI_L	Inductor ripple current	60A
ΔV_{out}	Inductor ripple voltage	0.35V
I_{out}	Output current	10.4A

3.2.2) Selection of Capacitor

Estimated value of capacitor is:

$$C_{2\_boost}=\frac{I_{out}\times D}{f_s\times \Delta V_{out}}$$

$$C_{2\_boost}=\frac{10.4\times 0.72}{21000\times 0.35}\approx 1mF$$

Following figure shows the dual stage boost converter:

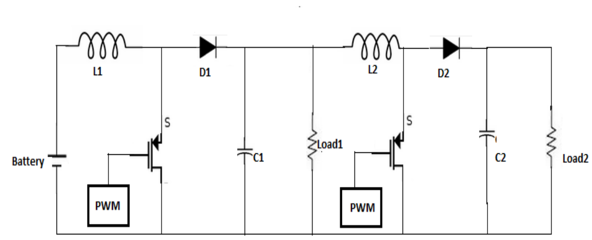

Fig.6. Dual stage boost converter

3.3 Design of AC to DC Circuit

This circuit is basically known as rectifier circuit using thyristor .which is a fast switching active device and current can be control. This dc output is given to inverter then frequency of inverter will be match with grid frequency.

Diagram of rectifier is shown in MATLAB:

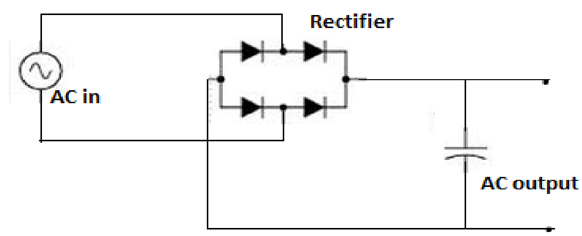

Fig.7. AC to DC rectifier

Output waveform:

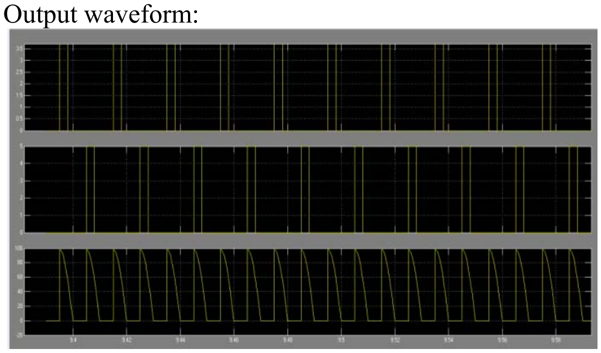

Fig.8. Switching and output waveform of rectifier

3.4 Design of Grid Tie Inverter

3.4.1 Grid Synchronization

For grid synchronization following conditions must be ful fill.

1. Amplitude of output voltage must be equal to grid's amplitude.
2. Inverter's frequency should be coinciding to frequency of grid.
3. Phase of inverter must be equal to grid phase.

The reactive and real power is assumed as (Kang, *et. al*, 2010), (Meksarik, *et. al*, 2003).

$$\text{Real power, P} = \frac{|V_{in}||V_{grid}|}{Z_t}\sin\theta$$

$$\text{Reactive power, Q} = \frac{{V_{in}}^2}{z_t} - \frac{|V_{in}||V_{grid}|}{z_t}\cos\theta$$

z_t = linking line impedance

V_{in} = output voltage of inverter

V_{grid} = grid power voltage

θ = angle between V_{in} and V_{grid}

Maximum real power will be deliver if angle between $V_{in}$and V_{grid} is 90 degree .For stability it will be less than 90 degree and this angle can be positive or negative .when angle is negative it means that power will be flow in reverse direction.

This circuit basically consists of two parts.

1. Power circuit.
2. Control circuit of switches.

3.5 Power Circuit

The basic schematic diagram of proposed inverter includes DC to DC boost converters and DC to AC inverter. Boost converter is use to step up the voltage of photovoltaic PV and the inverter circuit consists of parallel IGBTs gates. Control circuit syndicates the analogue circuit and these analogue circuits produce switching signals for inverters.

3.6 Control Circuit of Switches

Most of the conventional inverters one type of switching technique is use. The proposed scheme includes SPWM technique to reducing switching losses. The sampled sine wave is use to produce SPWM signal which guarantees that the output voltage and grid tie inverter have same frequency (Kwang, *et. al*, 2010). Switching frequency for the first boost converter is 20KHz and frequency for the second boost converter is 21KHz.Square wave is passed through NOT gate and produces a signal of 180 out of phase. The proposed inverter consists of two SPWM signals and two AND gates having 2 groups of switches. A first group consists of two IGBT switches S1, S2 and second group is also consists of two switches S3 and S4.

3.7 LCI Filter Circuit

Filter is applied in this topology for removing harmonics that consists of two inductors and one capacitor in T shape .Equations for the output current are as (Afzal, *et. al*, 2013), (Liserre, *et. al*, 2005).

$$I_2 = \frac{V_1}{z_o}\left[1 - \frac{1}{Q}\frac{z_2}{z_o}\right]$$

V_1 = input voltage

z_2 = load impedance

Q = quality factor

In which

$$Q = \frac{\omega L}{r}$$

$$\omega = 2\pi f$$

r = internal resistance

$$z_o = \sqrt{\frac{L}{C}}$$

If we neglect the internal resistance of inductor then quality factor goes to infinity.

Using the ideal settings;

$$I_2 = \frac{V_1}{Z_o}$$

We can see that output of filter is not depending upon load so values of C and L for filter (Butterworth filter) can be calculated as:

$$z_0 = X_c = \frac{1}{2\pi fC}$$

In this circuit frequency is 59 Hz

So

$$C = \frac{1}{2\pi f z_0} = \frac{1}{2 \times \pi \times 50 \times 20} = 0.159\text{mF}$$

$$L = Cz_0^2 = (0.159 \times 10^{-3})(20^2)$$

$$= 63.60\text{mH}$$

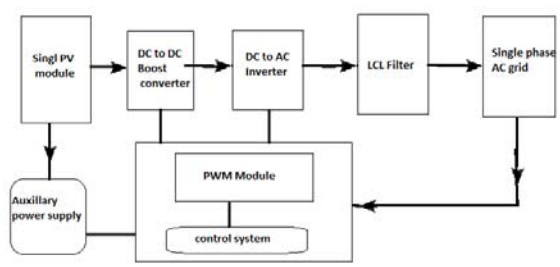

Fig-.9. LCL Filter Circuit

4. RESULTS AND DISCUSSION

The suggested grid tie inverter simulation in on MATLAB Simulink with operation and 10KHz switching frequency is applied .First stage of boost converter boost up the voltage of 24 V to 86V.then convert in about 300DC voltage. After that inverter convert this DC voltage into sinusoidal AC voltage. We did not use transformer because circuit can be too much bulky.

Fig.shows the output of the circuit without using filter.

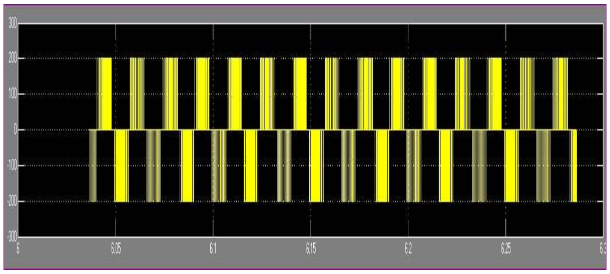

Fig.10. Output voltage of the inverter without using filter

From above figure as we see that output voltage is distorted and consists of harmonics.

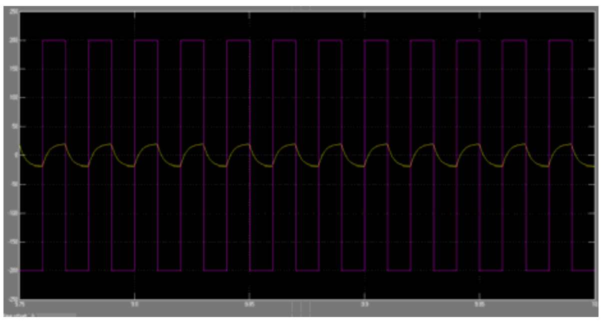

Fig.11. Current waveform

LCL low pass filter is use for removing harmonics. **(Fig. 12).** shows the output after filtering, in which no distortion is produces and harmonics are reduce almost less than 0.12%. **(Fig. 15).** shows the fast Fourier transform before applying the filter. At 50Hz fundamental components and some supplementary harmonics lies but after filtering we see that fundamental components lies at 50Hz but remaining harmonics are negligible

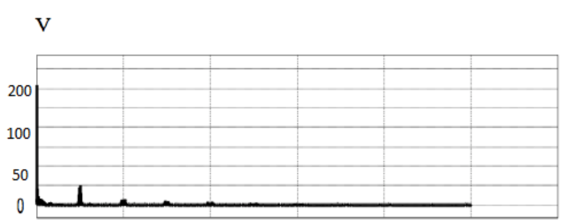

Fig.12. Fast Fourier transform before filtering

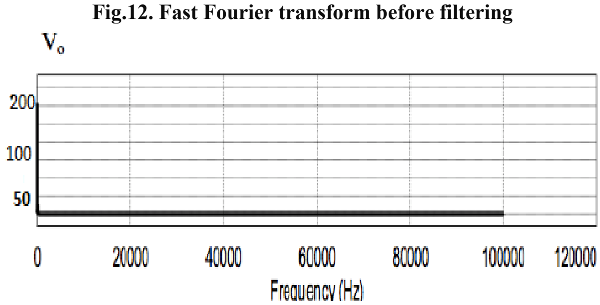

Fig.13. FFT after filtering

5. CONCLUSION

This paper basically presents the photovoltaic scheme applications for the single phase GTI. Overall system consists of dual stage boost converter .These converters will boost up the voltages at certain level within controller. Harmonic distortion which is produce in output has reduced and maximum efficiency is achieved.

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