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A Critical Comparative Analysis of Single Phase Single Stage Boost Inverters

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Abstract

We have considered in this paper two separate topological approach of Single Phase Single Stage Boost inverter and have compared the feature and functional aspects of the two based on minimized Total Harmonic Distortion. A boost converter is generally found to be necessary for photovoltaic applications. This is so because of the lower o/p voltage requirement of the PV applications. The advantage of boost inverter is that it successfully bypasses the requirement of dual stage conversion from DC to AC. In present scope we will analyse two of such Single Stage boost inverter specifically designed for the Photovoltaic applications.

Introduction

In the existing field of Power Engineering, the tag of war always take place between the generation of power and the consumption of the same. Also, the consumption part always biases this picture with its growing rate. In India, even at this stage of the civilization, we primarily (70 percentage of the total generated power) depend on fossil fuel for the generation of Electric Power. Though the rank of India in terms of energy generation is not mentionable, but in terms of energy consumption, India comes third just after United States of America and People's Republic of China. Renewable power source is proven to be the unavoidable option in order to minimize this gap between supply and demand of Electric Power. Though several options are found available under the category of renewable power source, Solar Power was found to be the most viable solution among all the options provided by all renewable power sources. From its inception back in mid nineteenth century, PV cells have undergone many changes in its design and technologies. Still after all these developments, the primary disadvantage of PV cells are that, they can deliver the output voltage in Dc that too found most of the time deficient in meeting up the voltage requirement. In general, before applying the output power of a PV cell, the output is fed to a VSI (for buck action) for a boost and then applied to an inverter for its conversion to AC. The major usage of boost inverter is within the electrically powered vehicles where the fuel emission is economized. Further, a normal single stage conversion comes with the benefit of lesser number of components and thus with better optimization. A diagrammatic representation seems essential at this stage to understand the operation of any renewable energy system, which may be found as follows:

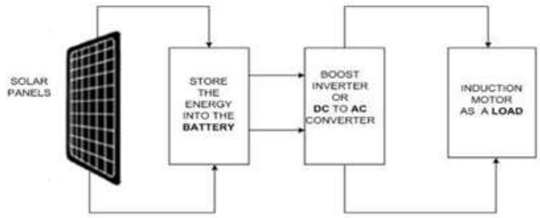

Fig. 1. Diagram of a Typical Renewable Energy System

In this paper, we will discuss two different approaches of single phase boost inverter for single stage conversion with its application at single phase PV cell. Among the two approaches, the first is considered to be the base topology and the second approach is the modification of the first approach and we will see the performance of the two under different parametric conditions.

The base topology assumes a couple of L-C pairs as neutral and phase out of the H0bridge (4 switched). In this, the two switches are provided with complimentary pulses for execution of boost operation with the aim to generate the single phase output of pure sine wave. IEEE STD 519-2014 is used as the standard for estimating the THD of the modified model and the base model.

As per the results of the simulation, the results are compared in terms of the output waveforms and THD values for each of the base model and modified model and thus a quantitative comparative analysis have been undertaken in the consequent subsections.

Base Boost Inverter Model:

The base model will be considered in this sub section for the generation of single phase boost inverter which was proposed for the first time during 1995. The Total Harmonic Displacement is also measured and has been tabulated accordingly

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which has been shown here. The circuit diagram and the results are detailed as follows:

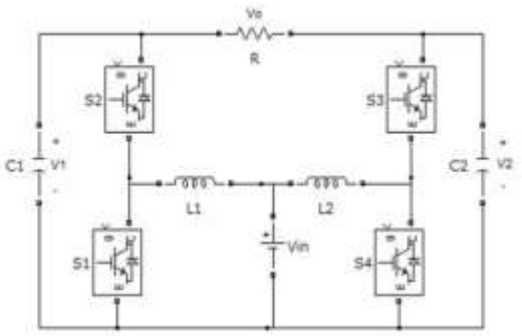

Fig. 2. Base Model Single-Phase Boost Inverter (R load).

The parameters are detailed as:

Parameters	**Values**
Inducting Load, L=L1=L2 (in Mh)	8
Capacitor, C=C1=C2 (in µF)	775
Resistor, R (in Ω)	200
DC Voltage at input, Vin (in V)	105
AC Voltage at Output , Vo (in V)	305
rms value, Vrms (in V)	215
Switching Frequency, fs (in KHz)	10

With such parameters under experimental condition, the simulation provides the simulated model of Single Phase, Single Stage Boost Inverter for Base Model as:

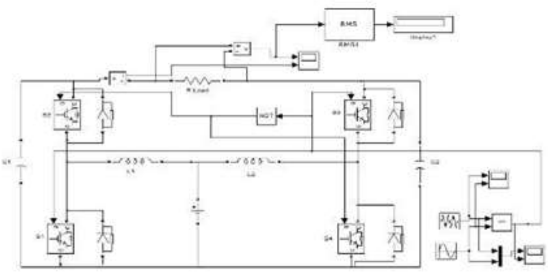

Fig.3. Simulink Model of Boost Inverter with Resistive Load (Base Model)

The output voltage magnitude and waveform pattern of the simulated circuit for the Base Model is found like:

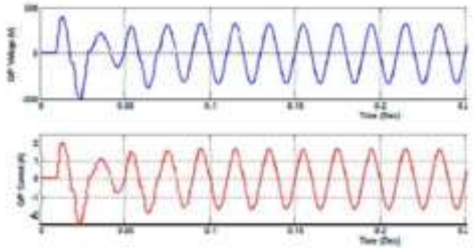

Fig.4. Voltage Magnitude and Waveform Pattern of Boost Inverter (Base Model)

Also, the Total Harmonic Distortion for the base model Single Phase, Single Stage boost inverter is found as the following:

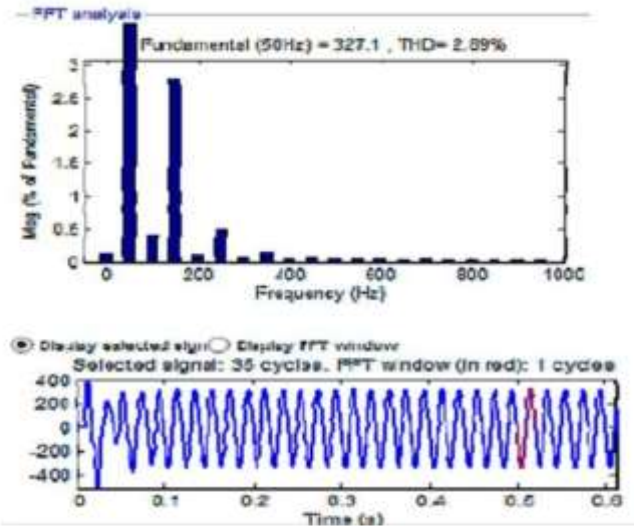

Fig.5. THD analysis of Boost Inverter with ResistiveLoad (Base Model).

While keeping the fundamental frequency to 50 Hz (+/- 00.01 Percentage), the THD found for the above topology is 02.894 %.

Modified Boost Inverter Model:

As stated earlier, this modified topology has its origin in the base boost inverter model. After analyzing the Base model, let us have a look at the modified model:

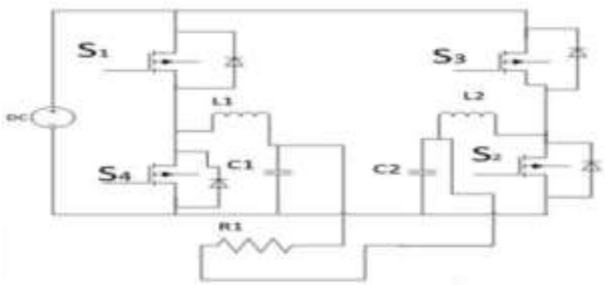

Fig.6. Diagram of Modified Boost Inverter Model

Here, the functioning of the boost inverter is made while operating the switches S3 and S4 in

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complimentary to that of the switches S1 and S2 at the same time in pairs.

Functional Aspect of Modified Boost Inverter Model:

The functioning of the modified model may be described corresponding to its two different mode depending upon the two switching configurations, say when S3 and S4 are kept on (keeping S1 and S2 in off mode) and when S1 and S2 are kept on (while keeping S3 and S4 in off mode). We may call these modes as Mode A and Mode B respectively.

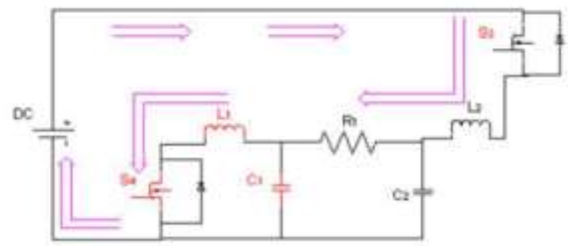


Fig. 7 Flow of Electric Current in Mode A

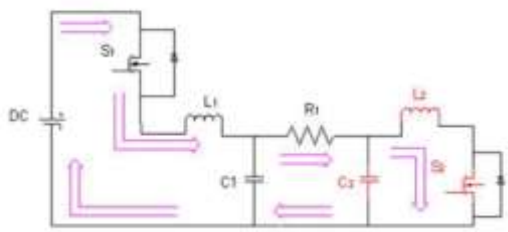


Fig. 8 Flow of Electric Current in Mode B

As it can be easily seen, during mode A, the S3 and S4 are kept on (while putting S1 and S2 off). This results in the magnetization charged state of L2 and C2 are attained in the reverse mode and discharge takes place via the load which results in the desired boost action. We find in Mode A, that L1, C1 and S4 forms a closed loop thereby enabling the magnetization and charging of L1 and C1. This back to back charging-discharging and magnetization-demagnetization on the couple of LC pairs eventuates the LC tank circuital moment which ensures the generation of pure sine wave along with the inversion of DC to AC in single stage mode.

Similarly, in Mode B, we may find that S2, L2 and C2 form a closed loop and thereby enabling the magnetization and charging of L2 and C2 and consequent discharge takes place via the load which results in the desired boost action. Here, we find the current flow direction from S1 to L1 via the load.

Calculation of Parameters:

The Load (L) and Capacitance (C) connected to the two legs form a resonating LC pair with being operational at the frequency of 50 Hartz.
Capacitors in case are found to have equal value, i.e.,

$$C1 = C2\,;$$

Same is true for pair of L,

$$L1 = L2\,;$$

We must have the product of L,C component as constant when operating at a certain fixed frequency.
Here, we have,

$$R1 = 50\,\Omega\,;$$

As we know, the resonating frequency comes to:

$$f = \frac{1}{2\pi\sqrt{L}}\,;$$

Which entails,

$$\sqrt{L} = \frac{1}{2\pi}\,;$$

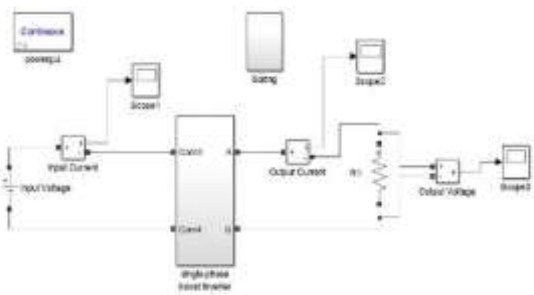
i.e.,

$$L = \frac{1}{(2\pi)^2}$$

As per our assumption, the operating frequency for the boost inverter for both mode is 50 Hartz. The resonating frequency thus comes to 50 Hartz as well for the LC pair. We, in this way, find the mathematical calculation which provides us the proof that the product of L,C is 1.024 e-5.

Simulation in Simulink

At the concerned simulation at Simulink, we will get the DC input as 50 volts. The resistive load connected with the inverter circuit is also 50 Ω. We have detailed the simulation diagram of the said single phase single stage inverter in Figure 9.



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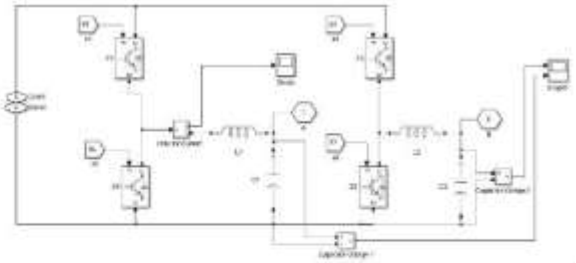

Fig. 9. Diagram of Simulink Circuit for Modified Model.

The pulse sequence can be found in figure 10, where the pulses corresponding to switch S1 and S2 are marked in pink colour whereas the pulses corresponding to switch S3 and S4 are marked in blue colour. Clearly, as expected, the pulses for S1,S2 and S3,S4 are out of phase.

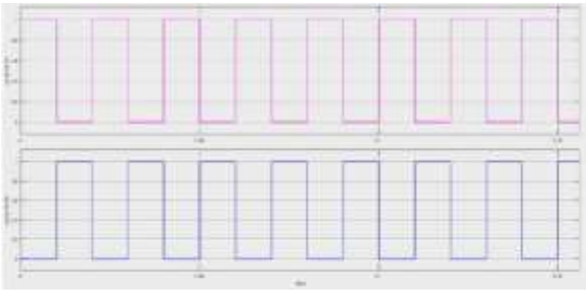

Fig. 10.Output Waveform Pattern for Modified Model

While the input voltage is kept at 50 Volts, with the help of the resonant frequency the corresponding values of the capacitor and inductor are estimated out. Pulse duty cycle was kept 0.5. In figure 11, we will find the raw output voltage waveform without boost from the modified model of single phase, single stage inverter topology. If booster is applied, the output voltage is found to be 100 volts.

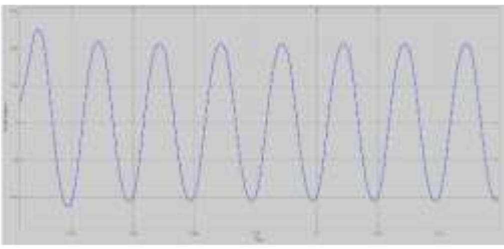

Fig. 11. Output Voltage Waveform of Modified Single Phase Inverter Model Across Load R.

When the output current is measured in simulation across the resistive load of 50 Ω, the following output line of 3.5 Ampere was found.

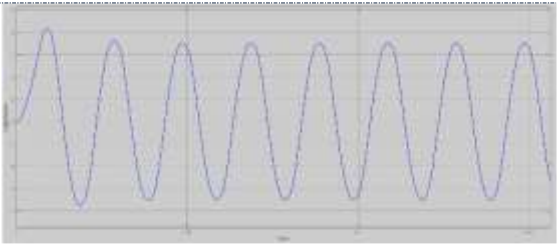

Fig. 12. Output Current Waveform of Modified Single Phase Inverter Model Across Load R.

The current waveform pattern along the inductors (I_{L1}& I_{L2}) can be found as the diagram 12.

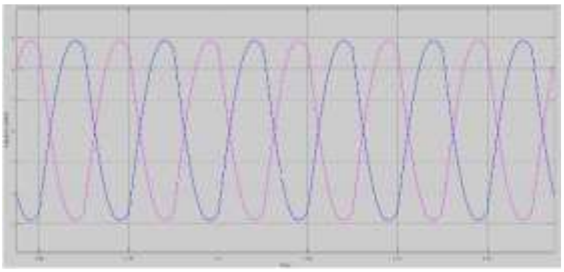

Fig. 13. Output Current Waveform of Modified Single Phase Inverter Model Across I_{L1}& I_{L2}.

180^0 phase shifted nature of the voltage pulses are prominently shown in the capacitor voltage. The respective capacitor voltage viz. V_{C1} and V_{C2} are shown in the following diagram.

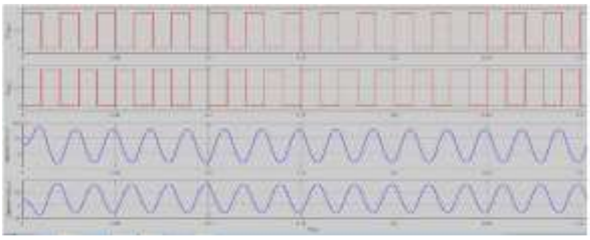

Fig. 14. Output Voltage Waveform of Modified Single Phase Inverter Model Across Capacitors.

Calculation of Total Harmonic Distortion

For the modified model of Single phase single stage boost inverter, we are finding the THD value as 01.79% where the frequency is kept 50 Hz. While employing Fast Fourier Transform Window Analysis, we find the following as the result:

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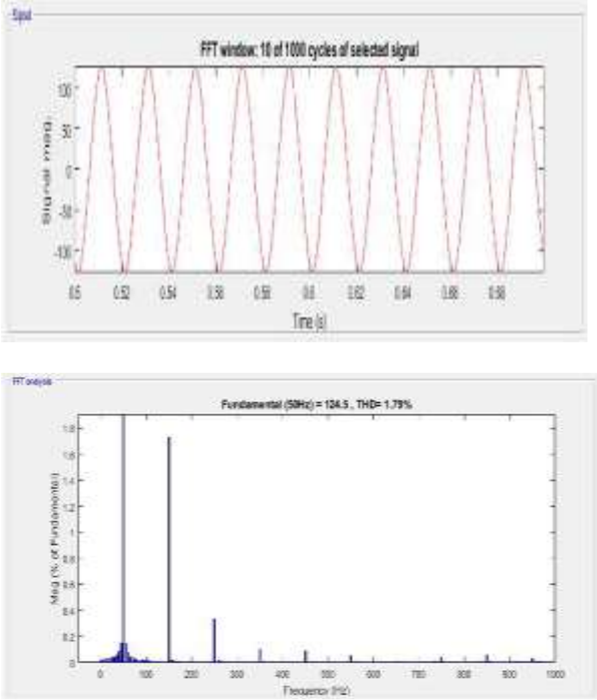

Fig. 15. Total Harmonic Distortion of Modified Single Phase Inverter Model

Conclusion

We found some positive outcome as obvious since the modified Single Phase Single Stage Inverter has a very low THD in comparison to the base model. The percentage values are 1.79% and 2.89% respectively which implies with the modified model, we have successfully achieved some significant improvement. While analysing the Total Harmonic Distortion, we have used the MATLAB Simulink FFT Analysis Tool. For calculating the THD. The method adopted for THD calculation of modified model is based on IEEE standard where 10 cycles of FFT window have been considered whereas for the base model, THD calculation has been based on considering single cycle. The significant improvement of the THD value and Boosted output of the modified model makes it very much suitable for various appliances like submersible water pumping solution, off-grid Photovoltaic setup where we may use the single phase motor in efficient manner.

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