

3-Phase, 400 V, 1 KW Inverter Design with Sinusoidal Waveform from A 12 V DC Supply

Gautam Ghosh, Vivek Kumar Sinha, Nishaat Islam

Dept. of Electronics and Communication Engineering, Institute of Engineering & Management, Kolkata

Abstract-The function of an inverter is to convert a dc voltage at its input to ac voltage with a fixed frequency e.g., 50Hz in our country. An inverter can produce different kinds of waveforms at its output, e.g., i) a square wave ii) modified sine wave iii) pulse width modulated wave (PWM), depending on circuit design. The two dominant commercialized waveform types of inverters which are used in the absence of main power supply are modified sine wave and pure sine wave. But as the power consumption by any of the appliances running on sine wave is lesser compared to that of modified sine wave demand of sine wave inverters are increasing day by day.

Index Terms: Amplitude Modulation Index, Frequency Modulation Index, IGBTs, PWM Technique.

I. INTRODUCTION

There are two basic techniques for designing an inverter. First method is to use lower-voltage DC source (battery level) which is converted to a square wave using a PWM inverter. The output of this inverter is applied to the primary of a step up transformer to boost the peak to peak value to a desired level. This is then applied to a full wave bridge rectifier the output of which is used as the supply source of main inverter to convert it to AC. In contrast to it, the second method converts DC to AC (square wave) at battery voltage level. After passing it through a low pass filter (to obtain sine wave) the low level AC is then boosted up using a step-up transformer to the desired level peak to peak value.^[3]

Since we are dealing with a 3-phase inverter with sinusoidal waveform, it is preferable to adopt the first method because using this method; we will require a single step-up transformer. A block diagram along with description is shown in fig. 1.

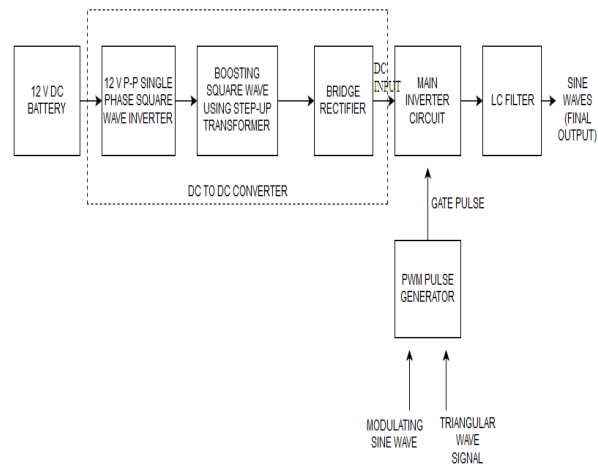


Figure 1: Block diagram of proposed inverter

In the very beginning the 12V DC from battery will be converted to square wave varying from +6V to -6V which will then be boosted up by a step-up transformer and then with the help of rectifier it will again be converted to DC at required voltage level. Accordingly, the step-up transformer ratio will be chosen so that the required higher DC voltage can be obtained after rectification. In our case, we are going to generate final sinusoids having Root mean square (rms) value as 400V that means i.e. Amplitude of sine wave will be $400\sqrt{2}$ i.e. 565.6V. For the generation of sine wave having peak voltage as 565.6V, we need a DC source of 565.6 V. So the transformer ratio should be 6:565.6 to convert the 12V battery source into 565.6 V DC supply. This higher DC voltage source will then be used as power supply source for the switching of the power devices (IGBTs) for the inverter are controlled by the gate pulses produced from PWM pulse generator to generate the PWM waveform at the inverter output which will then be filtered by LC circuit to generate the final sine waves.

On the other hand, choosing the second option will require three line to line step-up transformers to boost

up the output voltages of 3-phase inverter which will un-necessarily add up the cost.

II. OBJECTIVE

To design and simulate 3 phase, 400V, 1kW inverter with sinusoidal output. Our aim is to focus on the proper selection of the parameters like amplitude modulation index, frequency modulation index, values of inductors and capacitors, required for the generation of 3 phase inverter along with finding techniques to design a low pass filter which can give us the required output.

III. DESIGN METHODOLOGY

The aim of the project is to generate 3-phase, 400V rms line to line sinusoidal voltage with 1kW of power output from a 12 V DC supply source. As per calculation, IGBTs with line current 1.804A are required but for the safety reason, we have chosen IGBTs with line current of 5A and 1200V PIV.

The entire project work is divided into three parts namely:

1. DC-DC converter which will convert the 12 V DC source to desired DC level (i.e. 565.6).
2. Design of suitable circuit to generate PWM pulses in proper phase to switch the IGBTs of the main inverter to generate PWM voltage at the inverter output.
3. The third and the most important part is to design 3-phase LC filter section to generate 3-phase, 400V rms value, sinusoidal voltage waveform using the PWM output of the inverter.
4. Simulation of the circuit using PSIM.

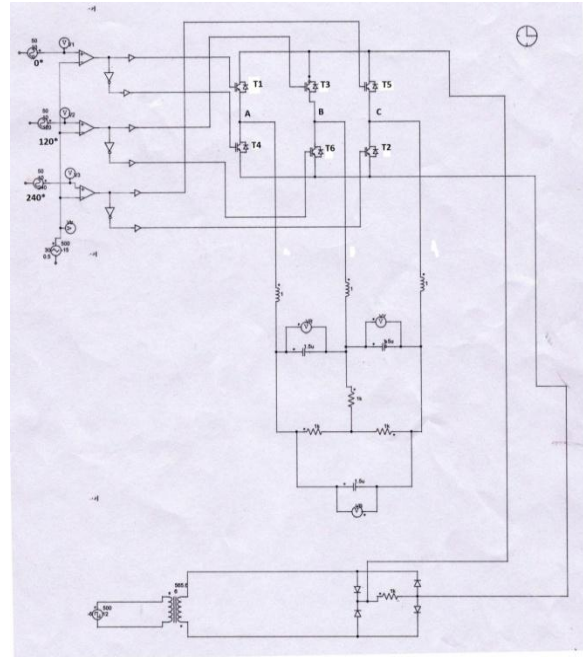


Fig 2: Circuit diagram of PWM inverter section

A. Conversion of 12V DC to 565.6 V DC

In the first part, the 12V DC is first converted to a square wave varying from +6V to -6 V which is then boosted up using a step up transformer having capacity 1000VA approximately with transformer ratio as 6:565.6. Then the boosted square wave, which will vary from +565.6V to -565.6V peak to peak, is rectified using Bridge rectifier to generate the final rectified DC voltage. This boosted DC voltage after filtering will be used as a power supply source for the 3-phase inverter circuit.

B. Generation of pulses for switching IGBTs

In the second part, there are three comparators. In each of these comparators, the triangular waves (which are carrier signals) of same amplitude and frequency are applied at the inverting terminals and the phase shifted sine waves (0°, 120° and 240°) which are also called as modulating signals are applied at the non-inverting terminals of respective comparators as shown in fig 2. However, the amplitude and frequency are same for all the three phase shifted sinusoids. The outputs of these comparators are PWM pulses which are applied to the respective IGBTs with proper sequence. The amplitudes of modulating signal and carrier signal are related as

$$\frac{A_m}{A_c} = \frac{V_{dc}(\text{input})}{V_{rms}(\text{output})}$$

It is very important to control the switching time of the 2 IGBTs present in the same vertical line to avoid short circuiting. So there should be a phase difference of 180 degrees between the switching of the 2 IGBTs present in the same vertical line. For this purpose, NOT gates are used i.e. among the three pulses generated the pulse from first comparator is applied at the gate of IGBT 1 and the output of the NOT gate in which this pulse is applied as the input is applied at the gate of IGBT 4. In this way when the upper IGBT is activated, the lower one is deactivated. Similarly, the pulses from comparators 2 & 3 are applied at the gates of IGBTs 3 & 5 respectively and the inverted logic of these pulses are applied at the gates of IGBTs 6 & 2. In this way at a time 2 IGBTs one from upper half and another one from the lower half are active which complete the circuit. Each IGBT will conduct for 180 degrees but the formation of a specific pair of IGBTs i.e. one from upper half and the another from the lower half will conduct only for 60 degrees which can be easily understood from fig 3. & Table 1.

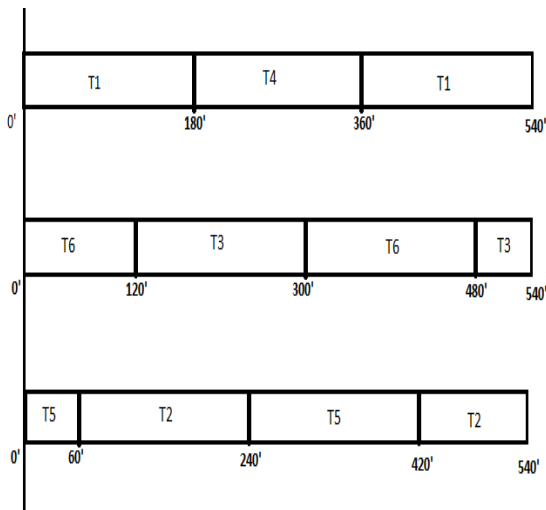


Fig 3: Switching sequence of IGBTs^[2]

S. No.	Incoming IGBT	Conducting pair	Outgoing IGBT
1.	T1	(T6,T1)	T5
2.	T2	(T1,T2)	T6
3.	T3	(T2,T3)	T1

4.	T4	(T3,T4)	T2
5.	T5	(T4,T5)	T3
6.	T6	(T5,T6)	T4

Table 1: Switching sequence of IGBTs

In this way the PWM outputs are generated between AB, BC and CA with 120 degrees phase difference which are further filtered to generate sine waves using low pass LC filter.

Now, the matter of concern in this part is to obtain PWM gate signal with proper selection of amplitude modulation index (M_a) and frequency modulation index (M_f). Amplitude modulation index is the ratio of amplitude of sinusoid wave to the amplitude of triangular wave which are used as the inputs of comparator.

$$M_a = \frac{A_r}{A_c}$$

Here, A_r stands for amplitude of reference signal that is sine wave and A_c stands for amplitude of carrier signal i.e. triangular wave. M_a controls the output voltage.

Formula for frequency modulation index is:

$$M_f = \frac{F_c}{F_r}$$

Here, F_c stands for carrier frequency or frequency of triangular wave and F_r stands for frequency of reference signal or frequency of sinusoid wave. The frequency of modulating signal sets the output frequency. That means if we want the sinusoid waveform at the output with 50 Hz frequency then we will have to set the frequency of modulating sine wave signal at 50Hz. In our design, we have taken the frequency of the reference signals as 50 Hz with three different phase angles.

C. Filter circuit

In the third part, the filtering circuit is included. The filter consists of inductor and capacitor. The final 3 phase sine waves can be obtained from 3 phase PWM output voltage by adding the filter circuit. Finally we will get three line to line phase shifted sine

waves. To get undistorted sine waves, it is important to choose the values of inductor and capacitor properly

IV. SIMULATION RESULTS WITH DIFFERENT VALUES OF M_a , M_f , L (INDUCTOR) & C (CAPACITOR) IN THE OUTPUT WAVEFORM

As mentioned earlier the values of these parameters play an important role in obtaining the final output. Improper selection of values can lead to distorted sine waves. Given below are some of the cases on the basis of which we reach to a conclusion for the selection of a particular value of that parameter. These outcomes of these different cases are supported by the PSIM software simulation. With the help of simulation we can get the trend about how the output waveform is affected on varying the values of these parameters.

In the very beginning for getting an idea that at which range we can get the sine wave, we need apply hit and trial method. At first we need to fix the value of capacitor at some high range and then we will vary the range of value of inductor (say from mH to KH) and then we need to have an observation over the graph. The values of M_a & M_f are considered constant. After this, we will take the values of capacitor in some lower range and will again vary the values of inductor. Similarly, in second stage we will keep M_a & M_f constant and will vary the values C keeping the value of L once in higher range and then in some lower range. In this hit and trial, on proper observation we can get the range in which sinusoids are appearing.

In this way simulation has been done. On the basis of result of simulation, we have chosen the value of inductor as 1H and the value of capacitor as 1.5uF which gives undistorted sine wave.

Keeping the values of the capacitors fixed at 1.5uF, given below are the results of simulation on the variation of the values of M_a , M_f & L.

A. Value of L is fixed to 1H & Value of M_f is fixed to 17, varying only M_a :

In this case we are going to vary M_a . As mentioned earlier, M_a is ratio of amplitude of reference signal to the amplitude of carrier signal; we can vary the values of M_a in 3 ways.

- 1) Variation in the amplitude of reference signal and keeping the amplitude of carrier signal fixed.
- 2) Variation in the amplitude of carrier signal and keeping the amplitude of reference signal fixed.

- 3) Variation in the amplitudes of both the signals i.e. the carrier signal as well as the reference signal.

The amplitude of reference modulating signal is varied keeping the amplitude of carrier signal fixed.

Here, M_f is fixed to 17 with frequency of reference signal as 50 Hz and that of triangular wave as 850Hz ($M_f = \frac{F_c}{F_r}$).

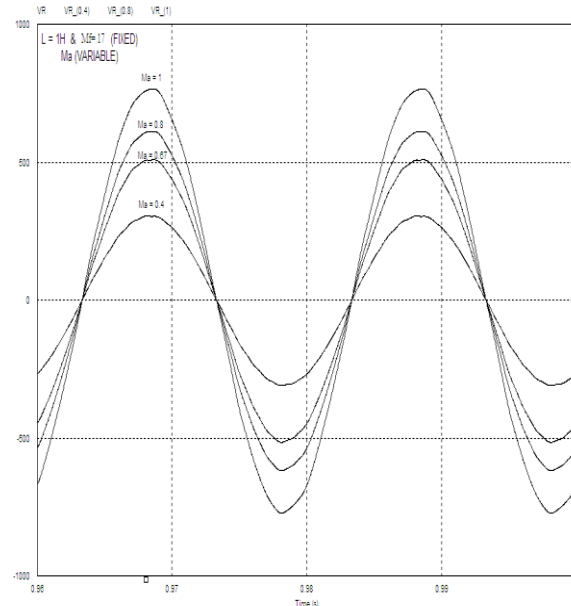


Fig 4: Output waveforms with different values of M_a

As one can see from the result, on the variation of M_a the amplitude of the output sine wave is also varying. Now from the following set of different values of M_a , we need to select such a value at which the output is maximum so that the transformer turns ratio is minimum to reduce the cost. Looking at the graph, it is clear that we will get that peak value when M_a is somewhere in between 0.67 to 0.8. This is shown in fig 4.

In this way, the optimum value of M_a must be decided somewhere in between 0.67 to 0.8.

B. Values of M_a & M_f fixed and variation in L

Here, M_a is fixed to 0.74 and M_f is fixed to 17. Experiment is made for different values of L. The result is shown in fig 5 and fig 6.

Given below are the simulation results.

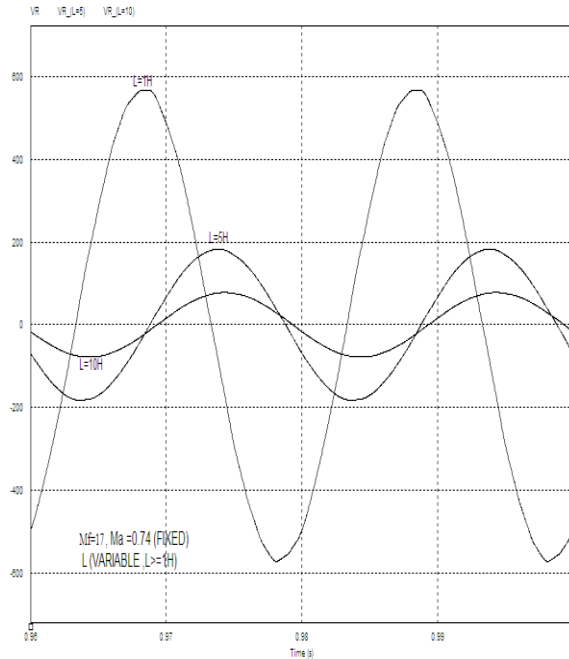


Fig 5: Output waveforms with different values of L

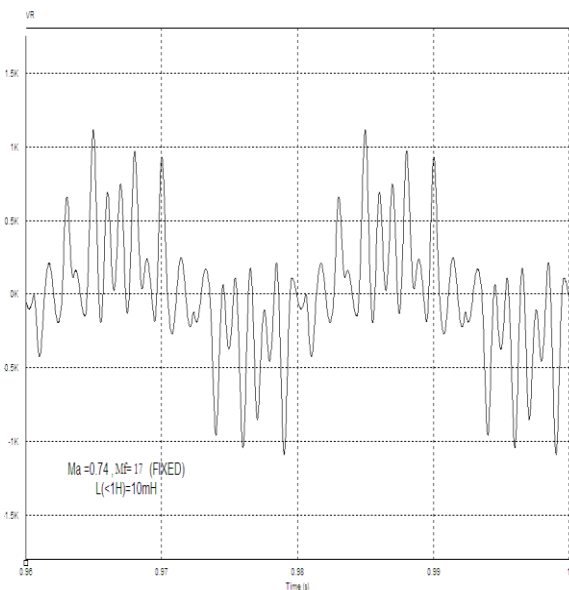


Figure 6: Output waveforms with different values of L

As one can see from the results that a certain trend is followed below and above $L=1H$. At $L=1H$, we are getting the peak value of sinusoid same as the supplied dc source. But when $L>1H$, we observe that the amplitude of sinusoid is decreasing on increasing the value of L. Also the zero crossing of the output wave is getting affected, although the frequency remains the same. On the other hand if we will take value of L much below 1H (say 10mH), a distorted wave is generated.

So we need to keep the value of L fixed around 1H to get an optimum result.

C. Values of M_a & L Fixed, Variation in M_f

Value of M_a is taken as 0.74 and $L=1H$. The simulation of this case is divided into 2 parts.

1) Change in frequency of modulating signal: Here is the result of simulation.

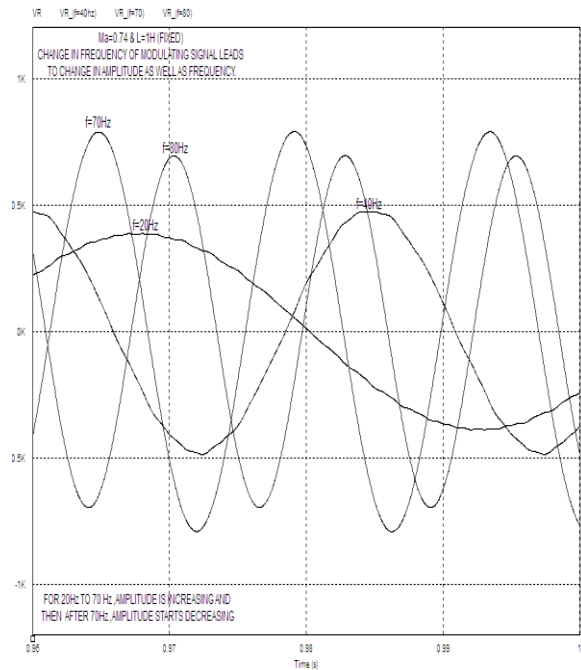


Fig 7: Output waveforms with different values of M_f

As can be seen from fig. 7, change in frequency of modulating signal leads to change in amplitude as well as frequency of the sine wave. Although selection of frequency totally depends upon an individual's requirement. One is free to choose any frequency of the output sine wave. But in our country power supply frequency is 50 Hz; we are going to select 50 Hz only. One important point to be noticed in this case is that amplitude of sine wave with frequency above 50Hz is increasing till 70 Hz and then it is getting reduced after that continuously. However, below 50 Hz amplitude is decreasing continuously.

2) Frequency of modulating signal is fixed and that of carrier signal is varying:

Here is the output of simulation.

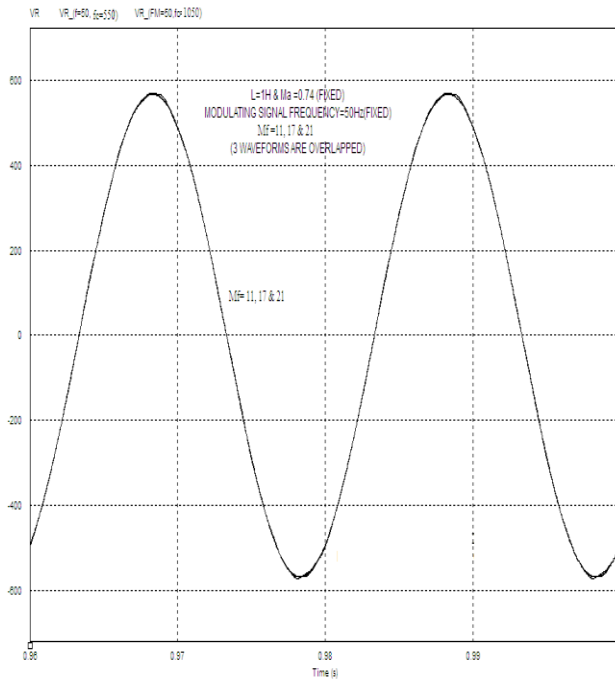


Fig 8: Output waveforms with different values of M_f (<10)

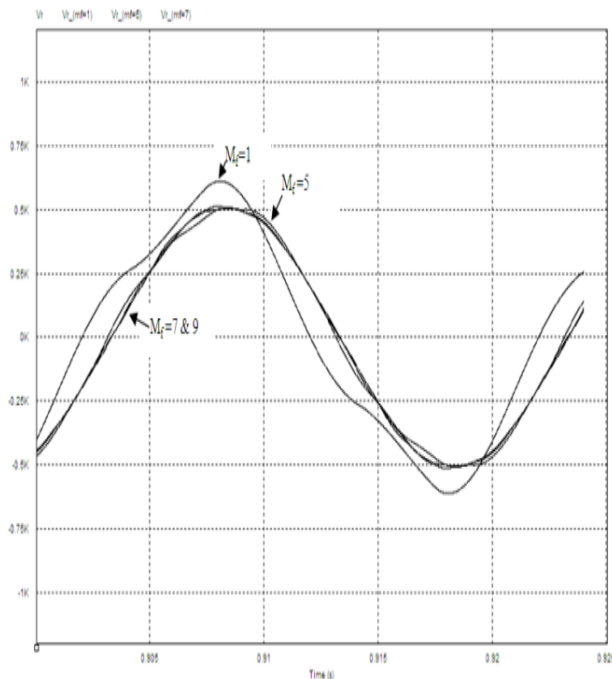


Fig 9: Output waveforms with different values of M_f (>10)

From the figures 8 & 9, it is observed that for lower values of M_f i.e., 1, 5, 7 & 9 the output waveforms are distorted. As we will reduce M_f below 11 and further, distortion will get increased. On the other hand,

increasing value of M_f above 11, the output waveforms will be almost similar. So, we will select M_f as 17. The frequency modulation index i.e., M_f is chosen 17 (an odd number) because the output waveform will then have a quarter wave symmetry and only odd harmonics will be present at the inverter output which is one of the requirements of a PWM signal.^[1]

V. CONCLUSION

The 3-phase inverter with sinusoidal output waveform discussed above helps us to justify the values taken for M_a , M_f , inductor and capacitor. The simulation has been carried out on PSIM software. The proposed system can be modified by using solar panel instead of 12V DC battery supply which can be used in the regions where electricity supply is not available. Agricultural fields can be benefited from the inverter using solar panel as it can run 3 phase motor pump which can enhance productivity. But as per the requirement, the solar panel must supply 1000W power to the main inverter circuit as discussed earlier neglecting losses. This design of 3 phase inverter is cheaper due to the less number of step-up transformers involved in it. If loads are properly balanced across the three lines of 3 phase inverter then a single 3-phase inverter can be used to run three different household appliances just by increasing the power capacity as per the requirement.

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