# Performance Improvement of Phase Displacement Modulated Inverter

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***Abstract*—This paper demonstrates an approach to minimize the harmonics contained in the output of a single phase full bridge inverter modulated by phase displacement control so as to improve the Total Harmonic Distortion (THD). With a view to reducing harmonics an LC low pass filter is used which blocks the harmonics and undeniably passes almost sinusoidal output at the output terminal and it is certainly true that THD has been improved to a great extent. An illustration of Fourier Transform has been provided in this paper in order to perceive both the fundamental and harmonics component precisely. It has been found from simulation that the Total Harmonic Distortion (THD) before and after the application of LC low pass filter is 33.34% and 0.003% respectively. That is why this LC low pass filter is quite effective to reduce THD of a 1-phase full bridge inverter.**

***Index Terms*—single phase full bridge inverter, IGBT, Phase displacement control, harmonics analysis, FFT, THD, LC low pass filter, MATLAB simulation.**

## I. Introduction

Inverter can be referred to dc-to-ac converter which changes a dc voltage to a symmetric ac output voltage of desired magnitude and frequency [1].


Figure 1. General block diagram of an inverter.

Inverters can be broadly classified into two types such as single phase inverters and three phase inverters. The output voltage could be fixed or variable at a fixed or variable frequency. A variable output can be obtained by varying the input dc voltage and maintaining the gain of the inverter constant. The output waveforms of an ideal inverter should be sinusoidal. However, the waveforms of practical inverters are non-sinusoidal and contain certain harmonics which can be seen with ease in frequency domain. It is needless to say that harmonics have some detrimental effects on the equipments to be utilized as it causes unbalance and excessive neutral currents, interference in nearby communication networks and disturbance to other consumers, torque pulsations in electric motors and so forth [2].

Due to the availability of high speed power semiconductor devices, the harmonic contents of output voltage can be minimized or reduced significantly by switching technique. BJTs, MOSFETs or IGBTs can be used as ideal switches to explain the power conversion techniques. But IGBT is more popular as it combines the advantages of BJTs and MOSFETs. An IGBT has high input impedance, like MOSFETs, and low on state conduction losses like BJTs. Without a hint of doubt an IGBT is the most common device chosen for new power electronics applications. It has highest capabilities up to 1700KVA, 2000V and 800A [3].

Some typical applications in which inverters may pay a pioneering role are variable speed ac drives, induction heating, standby power supplies, uninterruptible power supplies(UPS), traction, HVDC and so on. [4].

Phase displacement control is used to control the output voltage of the inverter which is often necessary to cope with the variations of dc input voltage, to regulate voltage of inverter and to satisfy the constant voltage and frequency control requirement [5].

Total Harmonic distortion (THD) can be defined as the ratio of the RMS value of all odd number of non-fundamental frequency terms to the RMS value of the fundamental. Mathematically,

$$THD = \sqrt{\frac{\mathrm{Im}^2 - \mathrm{Im}_1^2}{\mathrm{Im}_1^2}} \tag{1}$$

where, $Im_1$ is the rms value of fundamental current component and $Im$ is the rms value of current components.

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It goes without saying that THD measures closeness in shape between an original current waveform and the assumed fundamental current component [6].

Fast Fourier Transform (FFT) is a linear algorithm that can take a time domain signal into the frequency domain and back. Fourier analysis allows a more intuitive look at an unknown signal in frequency domain helping to perceive the fundamental component and the harmonic components without cumbersome [7].

## II. Single Phase Full Bridge Inverter

A single phase full bridge voltage source inverter shown in "Fig. 2," consists of four choppers.

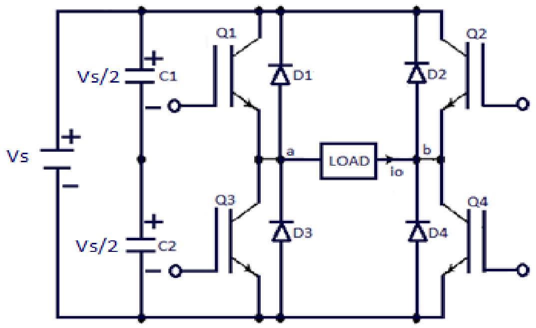


Figure 2. Circuit diagram of a full bridge inverter.

when transistors $Q_1$ and $Q_4$ are turned on simultaneously, the input voltage $V_s$ appears across the load. If $Q_2$ and $Q_3$ are turned on at the same time, the voltage across the load is reversed and is $-V_s$. Again, when $Q_1$ and $Q_2$ are on they give 0 voltage across the load. Moreover, the same result is obtained if $Q_3$ and $Q_4$ are turned on [5]. The operation of the circuit illustrated in "Fig. 2," has been summarized in Table I.

TABLE I. The Summarization for the Operation of the Circuit

| $Q_1$ | $Q_2$ | $Q_3$ | $Q_4$ | $v$ |
|---|---|---|---|---|
| on | off | off | on | $2V_s$ |
| off | on | on | off | $-2V_s$ |
| on | on | off | off | 0 |
| off | off | on | on | 0 |

Undoubtedly, there must a dead time between the switches in order to eschew the shorting out of dc source [8].

## III. Phase Displacement Control

Voltage control can be obtained by using multiple inverters and summing the output voltages of individual inverters. A single phase full bridge inverter in "Fig. 2," can be perceived as the sum of half bridge inverters. A $180^0$ phase displacement produces an output voltage as shown in "Fig. 3c," whereas a displacement angle of $\alpha$ produces an output as shown in "Fig. 3e,"

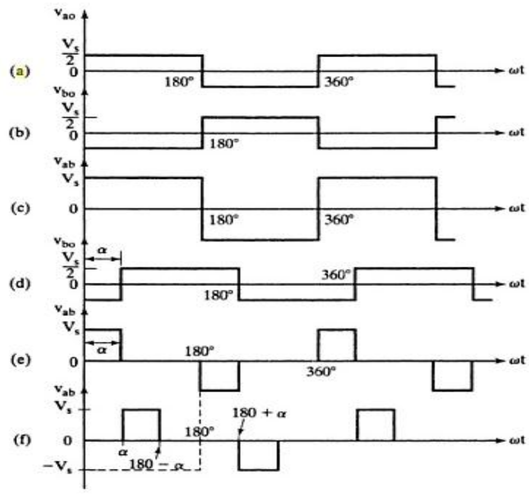

Figure 3. Phase displacement control [5].

The voltage across point a with respect to ground is

$$vao = \sum_{n=1}^{\infty} \frac{2Vs}{n\pi} \sin nwt \tag{2}$$

The voltage across point b with respect to ground is

$$vbo = \sum_{n=1}^{\infty} \frac{2Vs}{n\pi} \sin n(wt-\alpha) \tag{3}$$

$\alpha$ is the delay or displacement angle.

Now, The instantaneous output voltage becomes [5],

$$\begin{aligned} vab &= vao - vbo \\ &= \sum_{n=1}^{\infty} \frac{2Vs}{n\pi}[\sin nwt - \sin n(wt-\alpha)] \\ &= \sum_{n=1}^{\infty} \frac{4Vs}{n\pi} \sin\frac{n\alpha}{2} \cos n(wt - \frac{\alpha}{2}) \end{aligned} \tag{4}$$

The rms value of the fundamental output voltage,

$$V_{01} = \frac{4Vs}{\sqrt{2}} \sin\frac{\alpha}{2} \tag{5}$$

"(5)," indicates that the output voltage can be varied by changing the delay angle.This type of control is especially useful for high power applications,requiring a large number of switching devices in parallel [5].

If the gate signals $g_1$ ana $g_2$ are delayed by angles $\alpha_1 = \alpha \,\&\, \alpha_2 = \pi - \alpha$,

The output voltage $v_{ab}$ has a quarter wave symmetry at $90^0$ as shown in "Fig. 3f,"

In this Circumstances,

$$vao = \sum_{n=1}^{\infty} \frac{2Vs}{n\pi} \sin(n(wt-\alpha)) \tag{6}$$

$$vbo = \sum_{n=1}^{\infty} \frac{2Vs}{n\pi} \sin[n(wt-\pi+\alpha)] \tag{7}$$

$$vab = vao - vbo = \sum_{n=1}^{\infty} \frac{4Vs}{n\pi} \cos(n\alpha)\sin(nwt) \tag{8}$$

"(8)," depicts that the nth harmonic can be eliminated by a proper choice of displacement angle if

$$\cos n\alpha = 0, \alpha = \frac{90^0}{n}$$

And the third harmonic is eliminated if

$$\alpha = \frac{90^0}{3} = 30^0$$

## IV. Simulation and Resluts

It is assumed that input voltage is 230V. Other necessary parameters are considered deliberately like 50Hz frequency with assuming 3rd harmonic prevalent at the output so as to "(1),", "(2)," and "(3)," can be plotted.

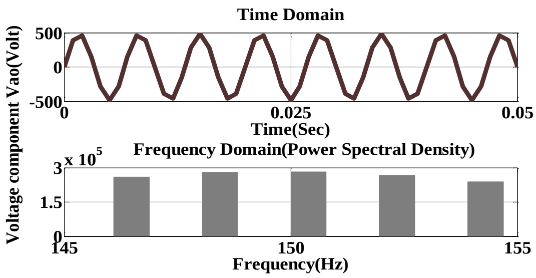


Figure 4. Voltage across point-a.

As is observed, the voltage across a-point with respect to o-point in "Fig. 4," is not sinusoidal at all indicating harmonics exists here.

Now, it is considered that the voltage across point-b is 30 degree delayed version of the voltage across point-a. So, the value of $\alpha$ is $30^0$ and from "Fig. 5," same information is obtained but it is displaced by $30^0$ angle. More importantly, the voltage across the load is calculated using "(4)," and then is plotted to observe the output response.

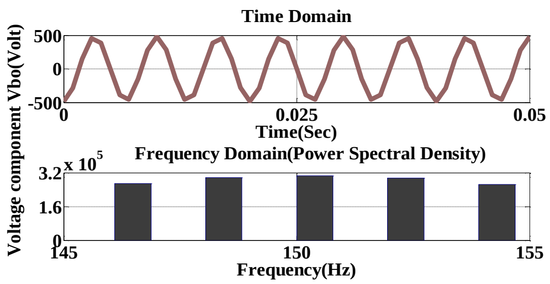


Figure 5. Voltage across point-b.

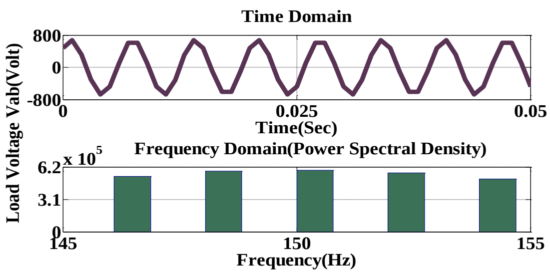


Figure 6. Output voltage response.

According to the illustration, "Fig. 6" deals with the inverter output voltage both in time domain and frequency domain respectively. There is no denial that the output wave shape contains certain harmonics which may be harmful. Moreover, in this case, the calculated THD is 33.34% which is too much and is needed improvement.

## V. LC Low Pass Filter

The implementation of an LC filter at the inverter ac terminals could trigger a parallel resonance which tends to amplify the harmonic voltages and currents in ac network leading, in some cases, to potential harmonic instabilities owing to the fact that the filter capacitance has a profound impact on the harmonic performance [10].An LC low pass filter is used to bring the harmonics into a lower state [11].

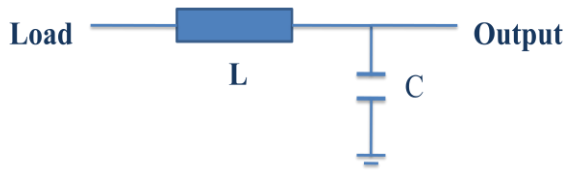


Figure 7. LC low pass filter [12].

## VI. Simulation by Appending a Filter

An LC low pass filter is connected with the load and output is taken across the capacitor having the capacitance of 60F. In order to observe the modified output response it is plotted by MATLAB once again.

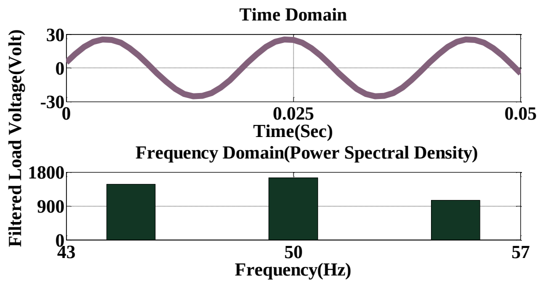


Figure 8. Output response after filtering.

It has been found from "Fig. 8" that due to the profound impact of capacitance on the 3rd harmonic component, a sinusoidal output is obtained. Furthermore, from frequency domain response described in "Fig. 8" it is certainly true that the fundamental component with operating frequency has the highest amplitude. In this circumstance, the evaluated THD is only 0.003%. For this reason, it can be said that a single phase full bridge inverter with phase displacement control shows better performance if an LC low pass filter is connected across the load from which output is measured.

## VII. Conclusion

At normal condition, when 3rd harmonic is considered then there exists 33.34% THD. But as soon as an LC low pass filter is implemented it has been dropped to 0.003%. Therefore, a vast improvement has been noticed.

From [12] it has been found that the THD in case of single phase half bridge inverter undergoing the filtering operation is 0.0183%. But here, it is only 0.003%. Therefore, more convincing output is obtained in full bridge inverter.

A single phase full bridge inverter finds an extensive utilization in variable speed ac drives, induction heating, standby power supplies, uninterruptible power supplies(UPS), traction, HVDC, grid connection of renewable energy sources and so on due to simple design and cost effective aspects. However, unlike single phase half bridge inverter, it does not have the requirement of more components.

In future, using this concept, the output responses of single phase full bridge inverter modulated by different modulation techniques like modified sinusoidal pulse width modulation, trapezoidal modulation, harmonic injection modulation, delta modulation and so forth can be observed as well as the harmonics occurred at the output can be minimized by applying LC low pass filter. An implementation of 2nd order LC low pass filter would be interesting in this case.

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