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Comparative Study of H-Bridge Inverters Based on Total Harmonic Distortion

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ABSTRACT
Analysis of Total Harmonic Distortion (THD) is important in the field of power electronics in order to maintain desired operation of devices. In this paper, two cases of power electronic inverters are taken into consideration to analyze their performance in terms of total harmonic distortion in their output voltage and current. Finally, a comparative fast Fourier Transform (FFT) analysis is performed between the two types of H-bridge inverters to understand the total harmonic distortion of output current and output voltage of the two cases using FFT tool for POWERGUI in MATLAB/SIMULINK environment to display the frequency spectrum of voltage and current waveforms. Results indicate that the Full-bridge type has a lower THD than the Half-bridge type.
Keywords: Total Harmonic Distortion, H-bridge, Optimization, Matlab, Inverter, Fast Fourier Transform

INTRODUCTION
In recent years, variety of power electronic equipment with voltage fed pulse width modulation inverters used widely in industrial applications and power network systems have caused significant inherent problems, such as generation of reactive current and power, as well as higher harmonic distortion in the utility power sources (Muhammad, 2013).
Total harmonic distortion (THD) is a measurement of the harmonic distortion present in a signal and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency (Reinert et al. 2014).
In power systems, lower THD means reduction in peak currents, heating emission, and core loss in motors. Undesired harmonics cause eddy current losses in transformers, which create a serious problem in the operating temperature of the transformer. They also affect the capacitors by heating the dielectric medium (Khoucha et al. 2015). Due to increase in harmonics in the current, the conductor will be overheated owing to skin effect. They also cause failure of circuit breaker, fuses and generator. Meters used in the utility purpose will show improper measurements due to harmonics present in the supply (Rech et al. 2016). Harmonics multiplies the losses in the core of the motor resulting in the temperature increase of the motor windings. Undesired harmonics do not cause immediate problems in the equipment. However, they slowly overheat the equipment and reduce the overall life span of them (Roshankumar et al. 2012).
In most applications, only the fundamental component in load voltage is of practical use and the other higher order harmonics are undesirable distortions. Many of the practical loads are inductive with inherent low pass filter type characteristics. The current waveforms in such loads have less higher order harmonic distortion than the corresponding distortion in the square-wave voltage waveform (Govindraju and Baskaran, 2015).
In this paper, Fast Fourier Transform (FFT) analysis is done in the waveforms of output voltage and current of H-bridge inverters in order to know about the Total Harmonic Distortion of the generated waveforms and to compare performances.

METHODOLOGY

The first step in the THD analysis involves understanding frequency components of load voltage and load current output waveforms of the H-bridge inverters under study. The load voltage waveform shown in Fig. 34.2(a) can be mathematically described in terms of its Fourier's components as:

$$V_{A0} = \sum_{n=1,3,5,7...\infty} \frac{2E_{dc}}{n\pi} \sin(n\omega t) \qquad (1)$$

where 'n' is the harmonic order and $\frac{\omega}{2\pi}$ is the frequency ('f') of the square wave. 'f' also happens to be the switching frequency of the inverter switches. As can be seen from the expression of Eqn.1, the square wave load voltage consists of all the odd harmonics and their magnitudes are inversely proportional to their harmonic order (Sepahvand et al. 2013). Accordingly, the fundamental frequency component has a peak magnitude of:

$$\frac{2}{\pi}E_{dc} \qquad (2)$$

and the nth harmonic voltage (n being odd integer) has a peak magnitude of:

$$\frac{2}{n\pi}E_{dc} \qquad (3)$$

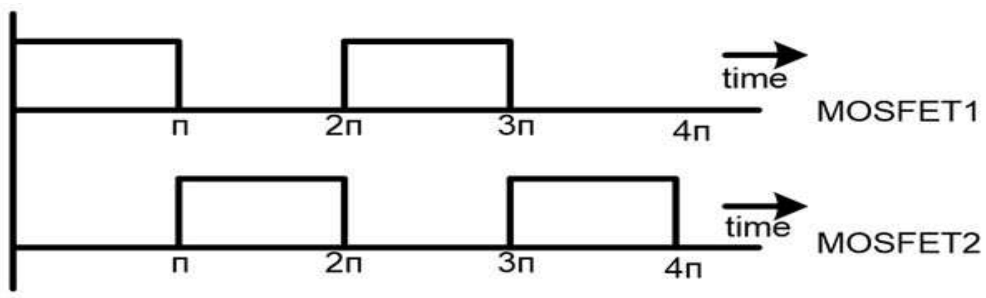

Fig. 1: Voltage output waveforms of Half-bridge inverter

The magnitudes of very high order harmonic voltages become negligibly small. In most applications, only the fundamental component in load voltage is of practical use and the other higher order harmonics are undesirable distortions.

HARMONIC ANALYSIS OF THE FULL-BRIDGE INVERTER

The single-phase full bridge inverter can be thought of as two half bridge circuits sharing the same dc bus. The full bridge circuit will have two pole-voltages (VAO and VBO), which are similar to the pole voltage VAO of the half bridge circuit. Both VAO and VBO of the full bridge circuit are square waves but they will, in general, have some phase difference. Fig. 34.3 shows these pole voltages staggered in time by't' seconds. It may be more convenient to talk in terms of the phase displacement angle 'Φ' defined as below:

$$\emptyset = (2\pi)\frac{t}{T} radians \qquad (4)$$

where 't' is the time by which the two pole voltages are staggered and 'T' is the time period of the square wave pole voltages. The pole voltage VAO of the full bridge inverter may again be written as in Eqn.1, used earlier for the half bridge inverter. Taking the phase shift angle 'Φ' into account, the pole-B voltage may be written as:

$$V_{B0} = \sum_{n=1,3,5,7...\infty} \frac{2E_{dc}}{n\pi} \sin n\,(\omega t - \emptyset) \qquad (5)$$

Difference of VAO and VBO gives the line voltage VAB. In full bridge inverter the single phase load is connected between points 'A' and 'B' and the voltage of interest is the load voltage VAB. Taking difference of the voltage expressions given by Eqns1 and 5, one gets:

$$V_{B0} = \sum_{n=1,3,5,7\ldots\infty} \frac{2E_{dc}}{n\pi} \sin n\,\omega t - \sin(\omega t - \emptyset) \tag{6}$$

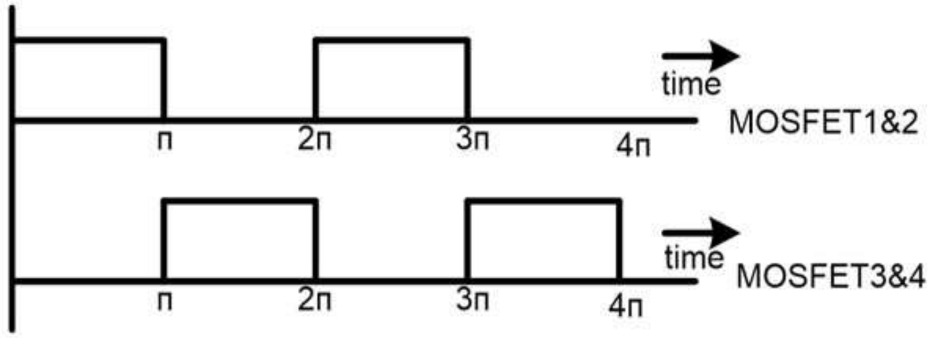

Fig. 2: Voltage output waveforms of Full-bridge inverter

The fundamental component of VAB may be written as:

$$V_{B0} = \frac{2E_{dc}}{\pi}[\sin n\,\omega t - \sin(\omega t - \emptyset)] = \frac{4E_{dc}}{\pi}\cos\left(\omega t - \frac{\emptyset}{2}\right) sin\,\frac{\emptyset}{2} \tag{7}$$

The nth harmonic component in VAB may similarly be written as:

$$V_{ABn} = \frac{2E_{dc}}{n\pi}[\sin n\,\omega t - \sin(\omega t - \emptyset)] = \frac{4E_{dc}}{n\pi}\cos\left(\omega t - \frac{\emptyset}{2}\right) sin\,\frac{n\emptyset}{2} \tag{8}$$

From Eqn.7, the rms magnitude of the fundamental component of load voltage may be written as:

$$(V_{AB,1})_{rms} = 0.9E_{dc} sin\,\frac{\emptyset}{2} \tag{9}$$

The rms magnitude of load voltage can be changed from zero to a peak magnitude of $0.9E_{dc}$. The peak load voltage magnitude corresponds to Φ = 180 degrees and the load voltage will be zero for Φ = $09E_{dc}$. For Φ = 180 degrees, the load voltage waveform is once again square wave of time period T and instantaneous magnitude E.

As the phase shift angle changes from zero to 1800 the width of voltage pulse in the load voltage waveform increases. Thus the fundamental voltage magnitude is controlled by pulse-width modulation.

Also, from Eqns.8 and 1 it may be seen that the line voltage distortion due to higher order harmonics for pulse width modulated waveform (except for Φ = 1800) is less than the corresponding distortion in the square wave pole voltage. In fact, for some values of phase shift angle (Φ) many of the harmonic voltage magnitudes will drastically reduce or may even get eliminated from the load voltage. For example, for Φ = 600 the load voltage will be free from 3rd and multiples of third harmonic.

SIMULATION USING MATLAB AND SIMULINK

Representation of the H-bridge inverter is completed first using simulink blocks showing the bonds between components (Beaman & Paynter, 2016). SIMULINK is software which allows modeling, simulation and analysis of dynamic systems. Simulink has a graphical interface that facilitates the analysis of systems in the time and frequency domain. The two Discrete Fourier blocks allow computation of the fundamental component of voltage and current while simulation is running. Simulink systems are more described by Matlab code lines but simply defined by block diagrams. Figure 3 shows the simulink model describing the two types of H-bridge inverters.

This simulation employs blocks from the Simulink library browser. The blocks in the simulation can be broken up into the following main six subsystems: MOSFETS, DC source, Resistive load, Voltage measurement, Pulse generator, and the Scope.

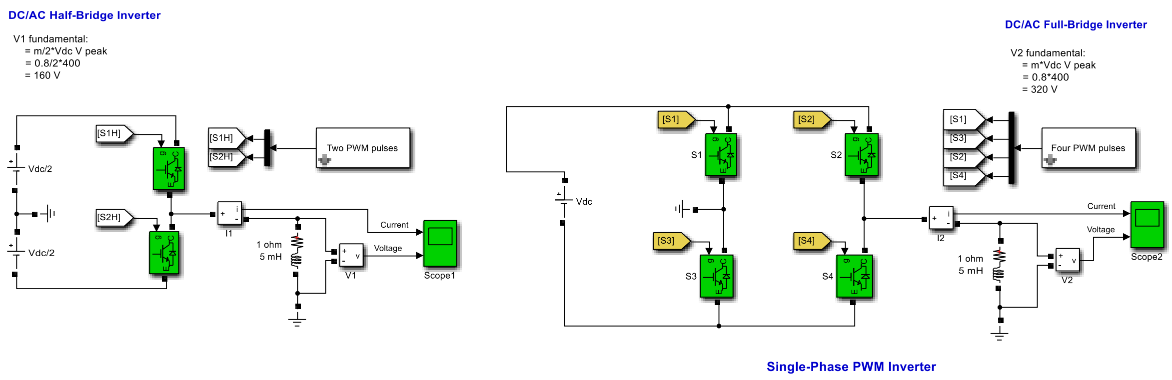

Fig. 3: Simulink model of the single phase H-bridge inverters

To simulate the H-bridge inverter models shown in fig. 3, the SIMULINK default integration algorithm solver (ode45) was used. Next POWERGUI was used to perform FFT analysis of the voltage and current output waveforms to get the THD.

RESULTS AND DISCUSSION

Fast Fourier Transform (FFT) analysis is done in the waveforms of output voltage and current of the inverter in order to know about the Total Harmonic Distortion of the respective waveforms. The results show that THD of the output voltage of the half bridge inverter is 45.51% and for the output current of the same inverter the THD is 6.25%. These results are shown in the Fig. 4 and Fig.5 respectively.

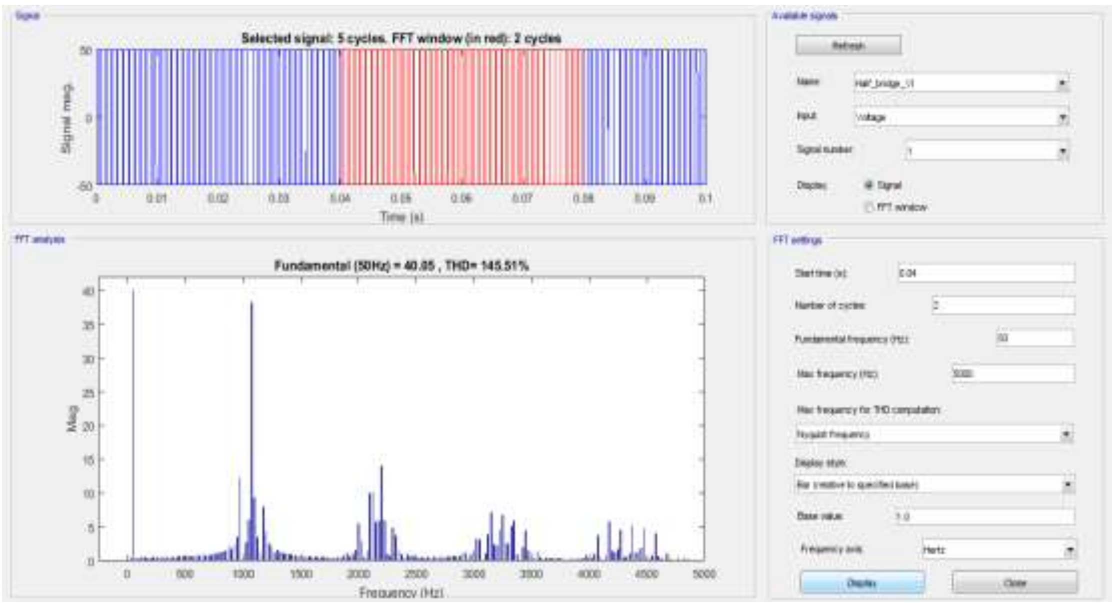

Fig. 4: FFT Analysis of output voltage of Half-bridge inverter

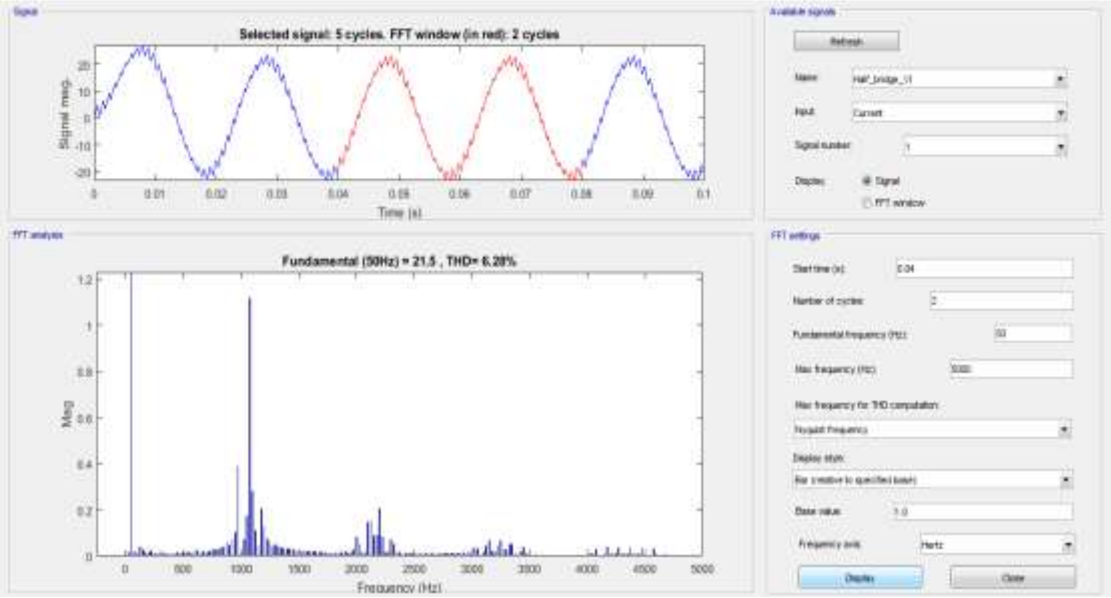

Fig. 5: FFT Analysis of output current of Half-bridge inverter

Fast Fourier Transform (FFT) analysis is done in the waveforms of output voltage and current of the full-bridge inverter in order to know about the Total Harmonic Distortion of the respective waveforms. The results show that THD of the output voltage of the inverter is 77.09% and for the output current of the inverter the THD is 1.78%. These results are shown in the Fig. 6 and Fig. 7 respectively. The analyzed signal is displayed in the upper window while the frequency spectrum is displayed in the bottom window. The fundamental component and *total harmonic distortion* (THD) of the V_{ab} voltage are displayed above the spectrum window.

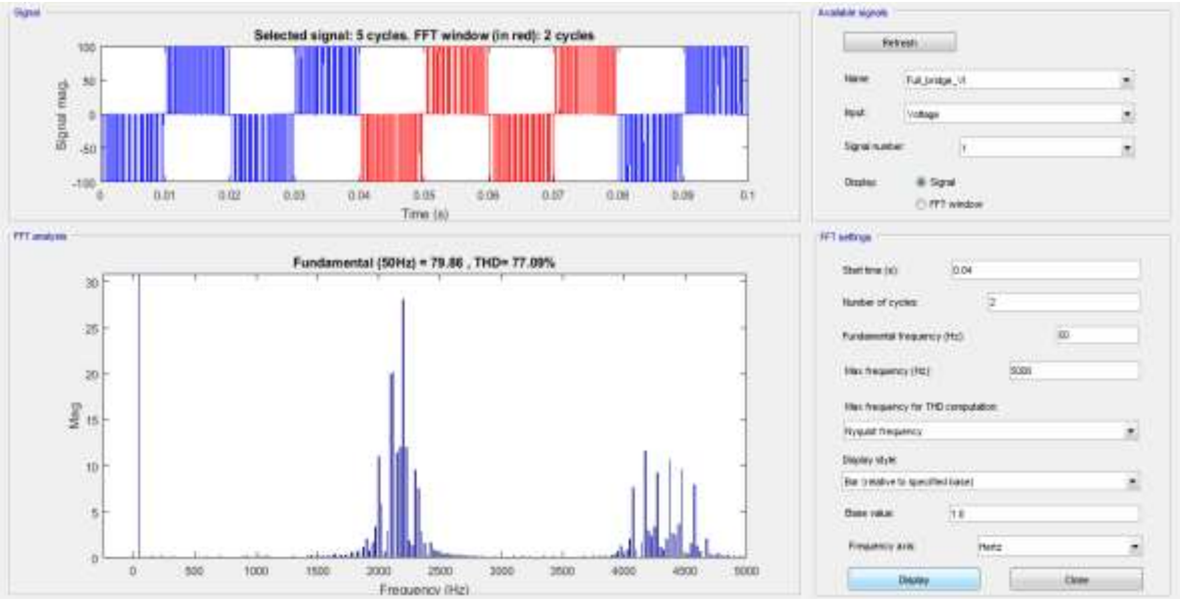

Fig. 6: FFT Analysis of output voltage of Full-bridge inverter

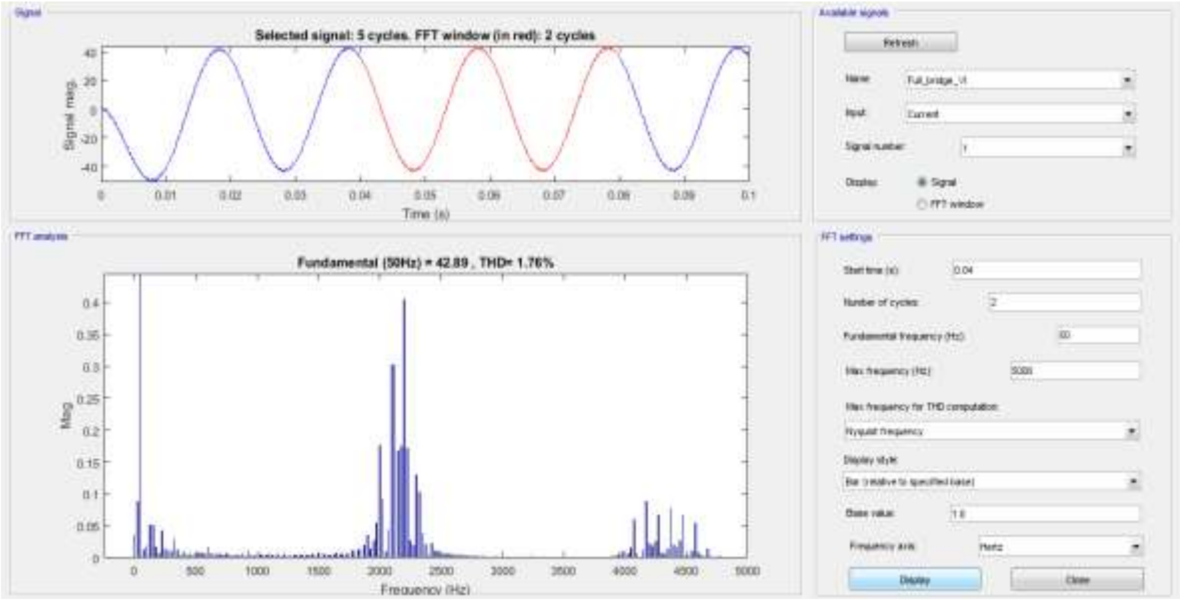

Fig. 6: FFT Analysis of output current of Full-bridge inverter

CONCLUSION

The FFT Analysis is performed to calculate the Total Harmonic Distortion (THD) of the inverters' output voltage and current. While analyzing the performance of the two inverters, Full-bridge inverter shows better performance in terms of THD. Frequency spectrum of the output voltage and current waveforms indicates that the Full-bridge type has a lower THD than the Half-bridge type.

It is recommended that harmonic filters be incorporated at the output of the H-bridge inverters in order to mitigate the harmonics.

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