Minimization of Total Harmonic Distortion of A Single Phase Inverter

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Abstract. An approach of reducing the harmonics contained in the output of a single phase half bridge inverter has been depicted in this paper. The reason behind it is to improve the Total Harmonic Distortion (THD). RLC load is used instead of RL load so that capacitor has an impact on the output response 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 with a view to perceiving both the fundamental and harmonics component precisely. It has been found from simulation that the Total Harmonic Distortion (THD) with RL load is 44.052% that can be mitigated to only 4.12% by changing the prevalent load to RLC in which capacitor is connected in series with resistor and inductor.

Keywords: Single phase half bridge inverter, IGBT, Harmonics Analysis, FFT, THD, Capacitor, MATLAB Simulation.

1 INTRODUCTION

Inverter converts dc power into ac power. Dc voltage is changed to a symmetric ac output voltage of desired magnitude and frequency by the inverters [1]. Some typical applications are variable speed ac drives, induction heating, standby power supplies, uninterruptible power supplies (UPS), traction, HVDC and so forth [4].

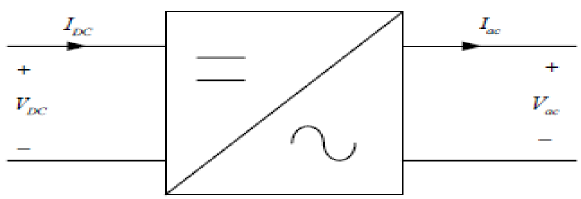

Figure 1.General Block Diagram of Inverter [4].

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. 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 [2].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 [12].

Total Harmonic distortion (THD) is a measure of closeness in shape between a waveform and its fundamental component. For improvement purpose, a LC Low pass filter is appended at the output terminal that provides low harmonic impedance to ground [9].

2 SINGLE PHASE HALF BRIDGE INVERTER

A half bridge inverter consists of a three wire dc source in which $V_s/2$ voltage is obtained across the load as seen in Figure 2. When Q_1 is turned on and Q_2 is turned off, the instantaneous voltage across the load is $V_s/2$ as observed in Figure 2. On the other contrary, if Q_2 is turned on and Q_1 is turned off then according to figure 2. $-V_s/2$ voltage appears across the load. The logic circuit is designed in a way that Q_1 and Q_2 are not turned on at the same. Otherwise, dc source may be shorted out. So, there must a dead time between the switches [3].

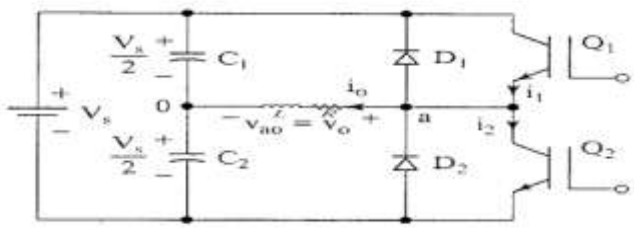

Figure 2. Circuit Diagram of Single Phase Half Bridge Inverter with RL Load [2].

Instantaneous inverter output current,

$$io = \sum_{n=1}^{\infty} \frac{2Vs}{n\pi\sqrt{R^2 + (nwL)^2}} \sin(nwt - \theta n) \ldots\ldots\ldots(1)$$

Where, $\theta n = a\tan(\frac{nwL}{R})$

3 HARMONICS ANALYSIS

A harmonic is a signal or wave whose frequency is an integral multiple of the frequency of some reference signal or wave. The term can also refer to the ratio of the frequency of such a signal or wave to the frequency of the reference signal or wave. Let f represent the main, or fundamental, frequency of an alternating current signal, electromagnetic field , or sound wave. This frequency, usually expressed in hertz , is the frequency at which most of the energy is contained, or at which the signal is defined to occur. If the signal is displayed on an oscilloscope, the waveform will appear to repeat at a rate corresponding to f Hz.

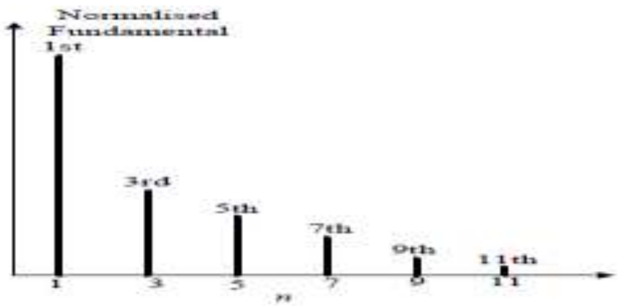

Figure 3. Harmonic Spectra of an Inverter [4].

As is observed, Harmonic decreases as increases. It decreases with a factor of (1/n). Even harmonics are absent–Nearest harmonics is the 3rd. If fundamental is 50Hz, then nearest harmonic is 150Hz. Due to the small separation between the fundamental an harmonics, output low-pass filter design can be quite difficult [4].

The effects of harmonics are unpleasant due to the fact that these cause unbalance and excessive neutral currents. Harmonics give rise to interference in nearby communication networks and disturbance together consumers. In electric motor drives, they cause torque pulsations and cogging [11].

4 FFT ANALYSIS

It 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 [5].As is presented in Figure 3, the fundamental component and the harmonic components can be understood without cumbersome.

5 TOTAL HERMONIC DISTORTION ANALYSIS

Total Harmonic Distortion is a measure of distortion of a waveform. It is given by the expression [9].

$$THD = \sqrt{\frac{\mathrm{Im}^2 - \mathrm{Im}_1^{\,2}}{\mathrm{Im}^2{}_1}} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

Therefore, it is needless to say that 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 [7].

6 APPENDING RLC LOAD

The implementation of an RLC load 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 series capacitor has a profound impact on the harmonic performance [8].

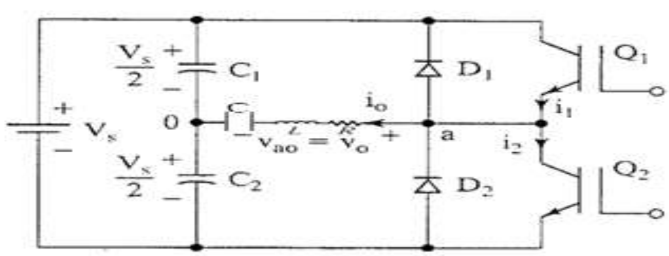

Figure 4. Circuit Diagram of Single Phase Half Bridge Inverter With RLC Load.

Instantaneous inverter output current becomes,

$$ic = \sum_{n=1}^{\infty} \frac{2Vs}{n\pi\sqrt{R^2 + (nwL - \frac{1}{nwC})^2}} \sin(nwt - \theta c) \ldots\ldots\ldots(3)$$

Where, $\theta c = a\tan(\frac{nwL - \frac{1}{nwC}}{R})$

7 SIMULATION AND RESULT

It is assumed that input voltage is Vs=220V. Other necessary parameters are considered deliberately like frequency f=60Hz, Resistor R=40 Ohm, Inductor L=0.009 H. and Capacitor C=100F. Moreover, up to 13th harmonics are considered prevalent at the output so as to [Equation 1] can be plotted.

According to the illustration, Figure 5.and Figure 6.deal with the inverter output current response not only in time domain but also in frequency domain respectively.

Figure 5. Time domain Output Response Under RL Load.

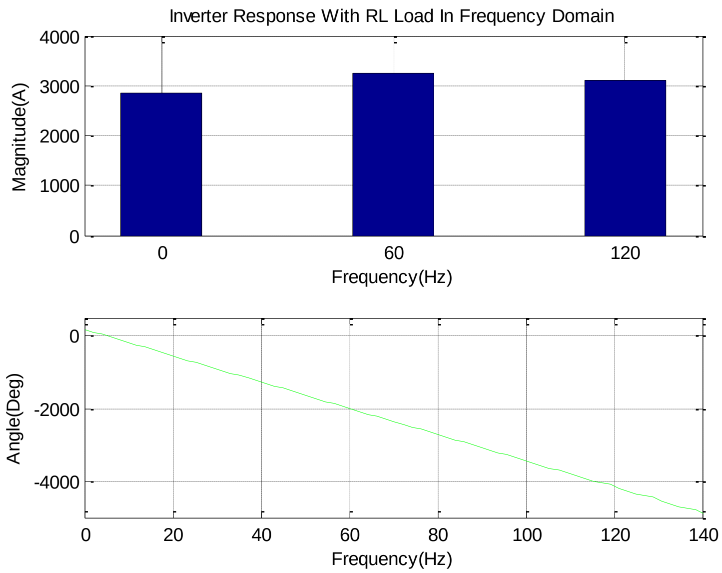

Figure 6. Frequency domain Output Response Under RL Load.

There is no denial that too much harmonics exist at the output even though fundamental frequency is 60Hz. In this case applying [Equation 2] obtained THD is 44.052% which is unquestionably excessive and is needed to be mitigated for better performance. For this reason, RLC load has been recruited in place of RL load in order to visualize the effect of capacitance.

Finally, the output current [Equation 3] is plotted using [again and nearly a sinusoidal response is observed which has been demonstrated in Figure 7. Furthermore, from frequency domain response described in Figure 8, it is found that the fundamental component has the highest amplitude.

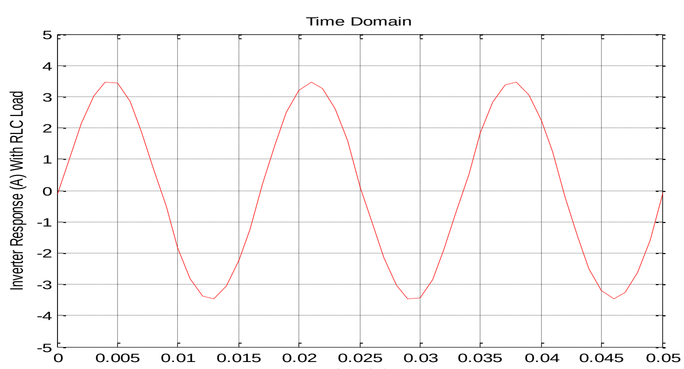

Figure 7. Time domain Output Response Under RLC Load.

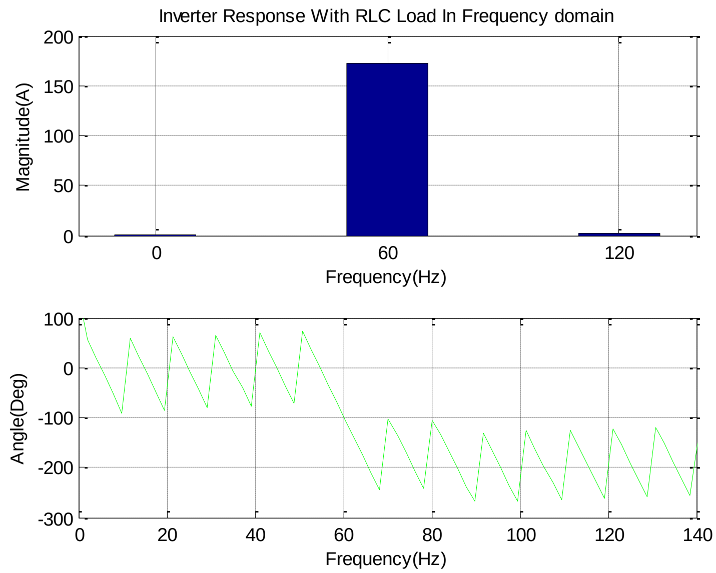

Figure 8. Frequency domain Output Respone UnderRLC Load.

Now, it is required to realize Total Harmonic Distortion under the impact of capacitance. [Equation 2] becomes

$$THDc = \sqrt{\frac{\operatorname{Im} c^2 - \operatorname{Im} c_1{}^2}{\operatorname{Im} c_1{}^2}} \text{.........}(4)$$

Where Imc_1= Fundamental component with 100F Capacitor when n=1.
$Imc_h=Imc^2-Imc_1{}^2$=Harmonic components with 100F Capacitor when n=3,5,7,9,11 and 13.
Here, calculted THD from [Equation 5] is 4.12%.

8 CONCLUSION AND DISCUSSION

It is certainly the case that when up to 13th harmonics are considered then there exists 44.052% THD. But as soon as an RLC load is connected removing RL load, it has been dropped to 4.12%. Therefore, a vast improvement has been noticed and RLC load is preferable to RL load.

A single phase half 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 full bridge inverter the maximum ac voltage is limited half the value of full dc voltage source. Again it may need a center tapped source. Now, if it is intended to get higher ac voltage then a step up transformer can be used.

In coming days, using this concept, the output responses of single phase full bridge inverter can be observed as well as the harmonics occurred at the output can be kept into lower level varying loads. An implementation of LC low pass filter would be interesting in this case.

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