Quality Assessment of a Single-phase resonant inverter

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ABSTRACT

The paper presented the quality assessment of a single phase PWM (Pulse width modulated) voltage source inverter with a series–parallel resonant inverter using simulation method. The performance of the inverter with and without filter has been compared in terms of harmonic contents present in output voltage and current. For this a single phase PWM inverter with and without LLCC (series-parallel) filter has been designed and investigated. Later on a RMS value controller is introduced in the inverter to obtained stable output. This work is helpful for the inverter used in application where high quality ac with minimum % THD is prime requirement.

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1. INTRODUCTION

High quality ac power is the prime requirements in many applications such as motor drive; uninterruptable power supplies (UPS), emergency power supply, hospitals, aerospace applications and many more. Most of the time a pulse width modulated PWM inverter is used to perform this task. In order to get high quality less distorted sinusoidal output from a PWM inverter, it has to operate on higher switching frequency. PWM operation in inverter at higher switching frequency involves lots of problem such as high switching stress on semiconductor devices, great power losses in them. Electromagnetic interference (EMI) problem also comes in to picture due to high dv/dt & high di/dt involves in PWM inverter operation [1]-[3].

To overcome these problems resonant-filter techniques are used in inverter. The soft-switching techniques constrain the turning on and off of switching device in a time interval, when the voltage across or current through the switching device is almost zero [4], [5]. The resonant inverter reduces the stress, power losses, EMI losses, reduces filter's size to a large extent by resonating the load. By resonant filter techniques life span of switching devices, overall inverter performance gets increased. Hard switching increases harmonic distortion at the inverter output. Level of Total harmonic distortion (THD) in output current and voltage is measure criteria to improve inverter performance; especially higher order harmonics having less magnitude affects the inverter's performance. These higher order harmonics can easily be eliminated by a resonant filter [6], [7].

For this a 1500VA inverter with and without series–parallel LC filter was considered and its output voltage and current quality was compared in terms of %THD in them. A PWM inverter with series resonant filter provides high efficiency at all load conditions but light load voltage regulation is not possible. It does not provide the voltage-boosting capability [8], [9]. On the other hand parallel resonant filter can provide considerable voltage boosting that is needed near the valleys of the ac line voltage but efficiency decreases with the decrease in load [10]-[12]. The series-parallel resonant filter combines the desirable characteristics of the series and parallel resonant filter and it also maintain the rated voltage level .In this inverter model a conventional PI controller has been used in feedback path.The Matlab-Simulink software was used to analysis the performance of the PWM inverter with series-parallel LC filter and without this resonating filter, as it is necessary to analysis its performance before implementing it in to hardware [13]-[15].

2. RESEARCH METHOD

PWM inverter (bridge type) having four MOSFETs switch. The resonant filter is composed of L_s, C_s (series branch element), L_p, C_p parallel branch elements. Specification of choosen PWM inverter is shown in Table-1.The circuit diagram of the simulated PWM inverter is shown in Figure 1.The PWM operation shifted the harmonics of lower order to higher order.These harmonics eliminated by resonant filter.

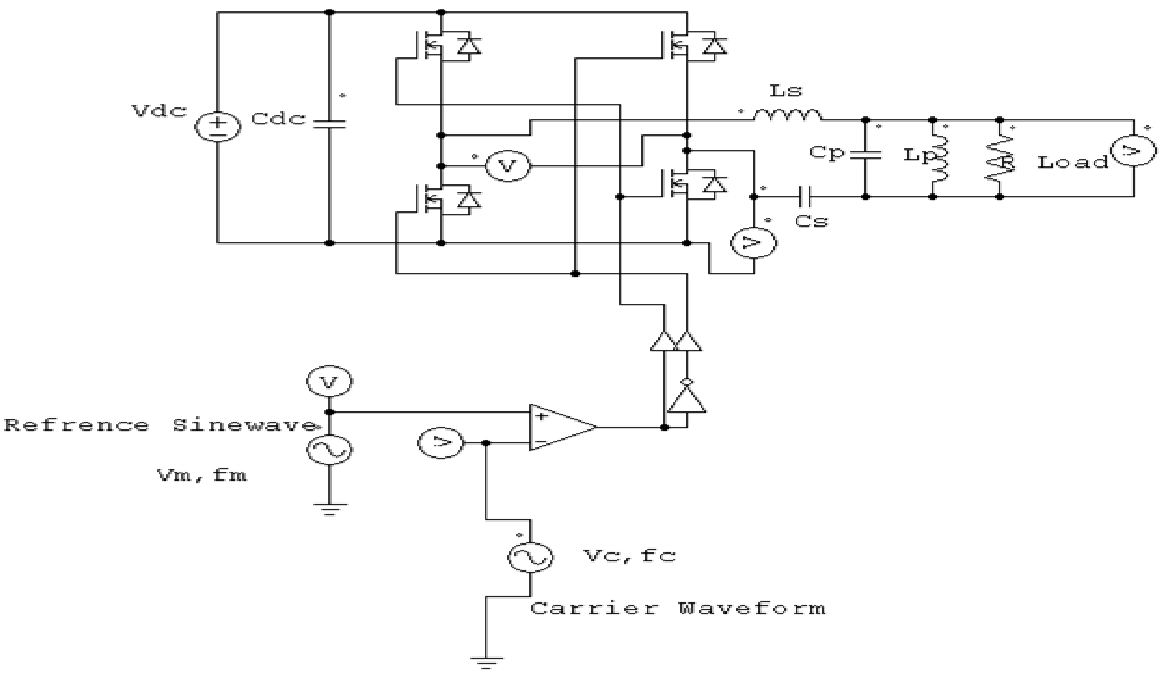

Figure 1. Circuit diagram of designed PWM inverter

2.1. PWM pulse train generators

In this simulation model pulse train was generated by comparing a sine wave signal, having frequency 50Hz, with high frequency carrier signal (f_c=1050Hz). Pulse train generated by interrelation of these two signals produces less distorted output. In this design we have used unipolar switching strategies as it involves less power losses, as compared to bipolar switching techniques. The frequency modulation ratio (m_f) of this signal is ratio of carrier frequency to frequency of reference signal frequency. The amplitude modulation ratio is the ratio of the amplitude of the reference signal to amplitude of carrier signal $m_a = (V_{rms}/V_m)$. The number of pulse use to make half cycle at inverter output decides the harmonic contents in output. If the number of pulses is high, than it increases higher order harmonics whereas lower number of pulses decreases the magnitude of fundamentals. Higher order harmonics can easily be filtered by using a series parallel filter. Figure 2.Shows the Matlab-simulink diagram of proposed inverter. Figure 3.shows the harmonic contents (%THD) in output voltage of the PWM inverter without resonant filter and feedback controller. It observed from the result that %THD has value 0.51%.By using resonant filter these harmonics again reduced.

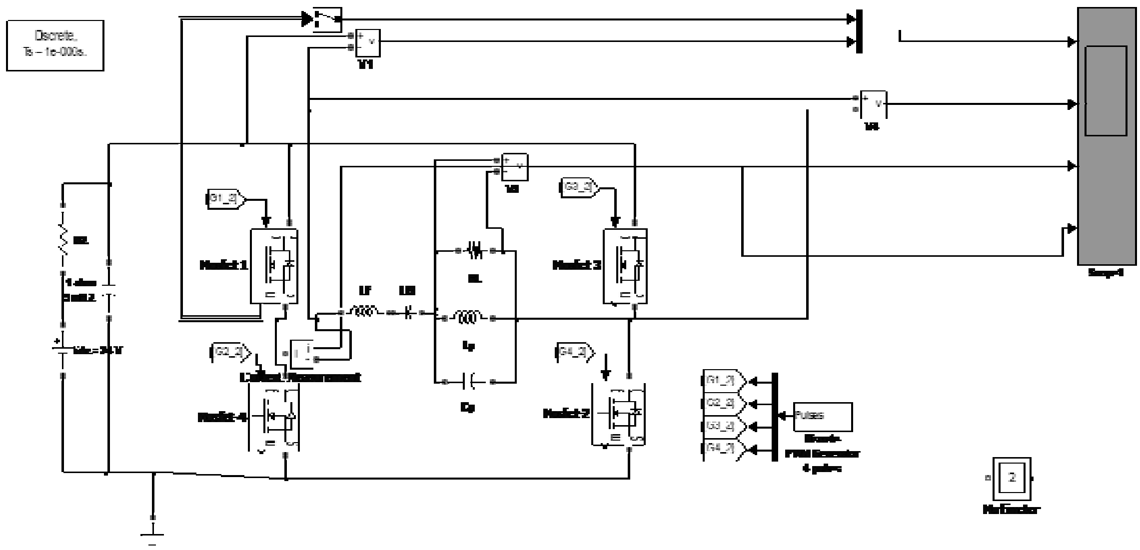

Figure 2. Simulink diagram of output voltage and current of PWM inverter with series -parallel filter

Table 1. Design Specification of proposed inverter

	Symbol	Parameter (eV)	Value
1	V_{dc}	DC Voltage Source	240V
2	f_o	Output /Resonant frequency	50 Hz
3	fc	Carrier frequency	1050 Hz
4	L_f	Filter Inductor	0.10142H
5	Cr	Filter Capacitor	100µF
6	R_{load}	Load Resistor	28.8Ω
7	Cdc	DC blocking Capacitor	10,000µF

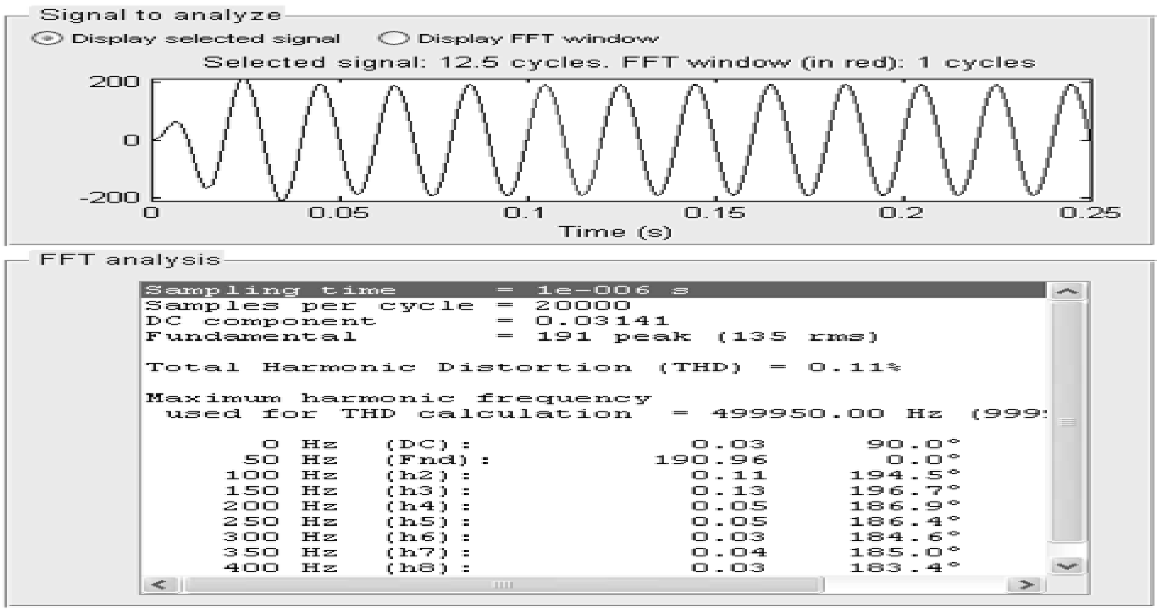

Figure 3. FFT window and harmonics contents (% THD) in output voltage of designed single phase PWM inverter without series –parallel resonant filter and PI controller

2.2 Output Filter Design

Output of the full bridge is filtered using a low pass filter to create an undistorted output sinusoidal voltage. The LLCC low pass filter is a second order filter which eliminates all high order harmonics from PWM sine waveform .The cut off frequency of the low pass filter was selected such that the output total harmonic distortion (THD) was less than 5%.

The output voltage of resonant tank is

$$Vo = Vm\sin(\omega t + \theta)$$

Where Vo and θ represent output voltage and its phase. The input impedance of the LLCC-resonant tank can be represented as

$$Z_{ini} = j\omega sLs + \frac{1}{j\omega sCs} + \frac{1}{Y}$$

where $Y = \frac{1}{R_L} + \frac{1}{j\omega sLs} + j\omega sCs$.

The voltage gain of the LLCC-resonant tank G_{LLCC} is defined as the ratio of the ac output voltage and the fundamental of square input voltage.

$$G_{LLCC} = \frac{1}{Z_{in}}$$

$$[(1+\frac{C_P}{C_S}+\frac{L_S}{L_P}-\frac{1}{\omega_{S2}L_P C_S}-\omega_{S2}L_S C_P)+j(\frac{\omega_S L_S}{R_L}-\frac{1}{\omega_S R_L C_S})$$

When the resonant condition occurs, the real part of the denomination of is equal to zero, that is

$$(1+\frac{C_P}{C_S}+\frac{L_S}{L_P}-\frac{1}{\omega_{S2}L_P C_S}-\omega_{S2}L_S C_P) = 0$$

The filter inductor value (L_f) is calculated such that the voltage drop across the inductor is less than 3% .The chosen resonant capacitor value is 20uF .The filter inductor value (Lr) is then calculated from the resonance relation:

$$L_f = \frac{1}{(2\pi f_r)2C_s} H$$

Where $L_f = L_p = L_S$ And $C_f = C_p = C_S$

2.3 Feedback Controller Design

The magnitude of output voltage and current of the inverter decreases due to the presence of some resistance in inductor and capacitor in resonant filter. To maintain the magnitude of voltage a RMS controller is incorporated in feedback path as shown in Figure 2. The feedback RMS controller works as a PI controller for the PWM inverter. The proportional control minimizes the steady state error. In feedback control process, the voltage across the load was being fed to a comparator along with desired reference output level. The comparator in turns generates error signal. The error signal was compared with a standard modulation index. The resultant signal was then fed to a PWM pulse generator to produces switching pulses in multiplexed form Figure 4.

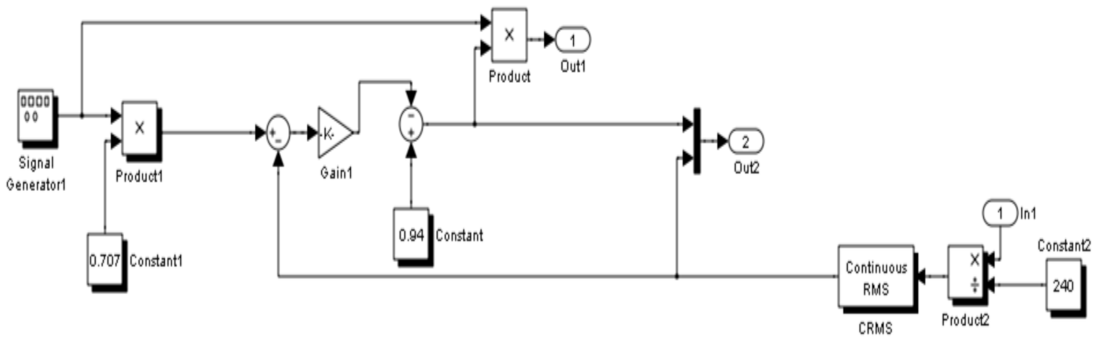

Figure 4. Internal block diagram of feedback controller

Table 2. shows the values of voltage and current with %THD present in them .The value of %THD in output voltage and current was very low with resonant filter and feedback controller. It reduces from 0.51 to 0.06%.

Table 2. Observation summary of output voltage and current

Load	Parameter	Value	%THD
28.8Ω (without resonant filter)	Load Voltage	117.4V	0.11%
	Load Current	6.628 A	1.38A
40Ω (without resonant filter)	Load Voltage	189.8V	.51%
	Load Current	4.75A	1.94%
Load=28.8Ω (with resonant filter)	Load Voltage	191.2V	0.05%
	Load Current	6.639 A	1.37%
28.8Ω (with resonant filter and feedback controller)	Load Voltage	223.6V	0.06%
	Load Current	6.628 A	1.38%

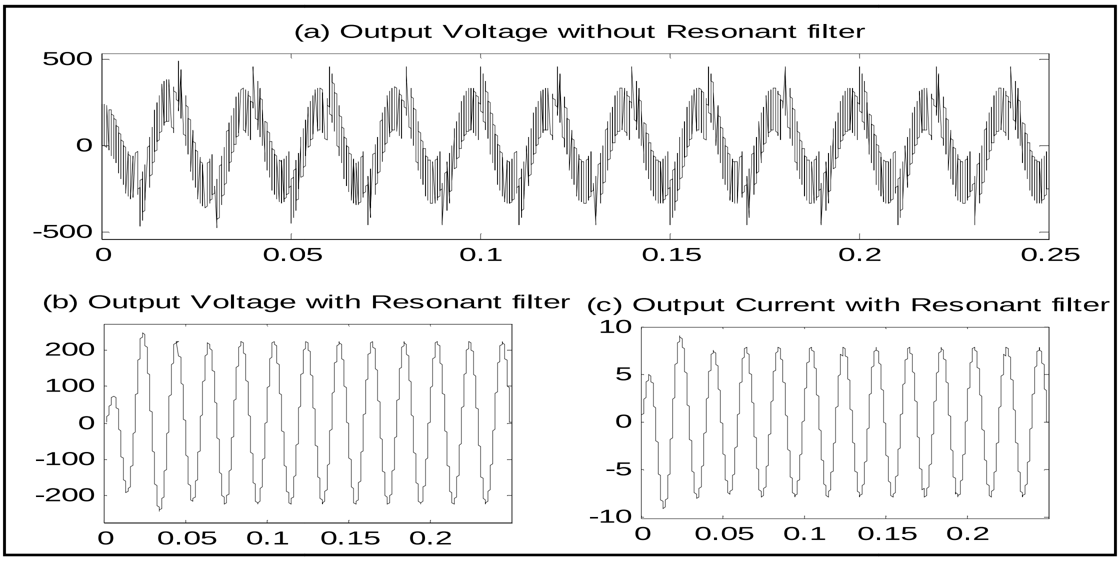

Figure 5. (a) Output voltage without resonant filter (b) Output voltage with resonant filter (c) Output current with resonant filter

3. RESULTS AND ANALYSIS

Harmonic analysis of the output voltage and current of the PWM inverter was performed. The Figure 5 shows the voltage waveforms of PWM inverter with and without LLCC resonant inverter. The results of FFT analysis are shown in figure.6. It was observed from the result that the %THD in voltage and current were 0.06% and 3.22% respectively with resonant filter. It indicates that on applying LLCC-series parallel resonant filter harmonic contents in output voltage and current get reduces to great extant. Although a feedback controller is needed to control the magnitude of output voltage at par with rated voltage. By using RMS feedback controller voltage almost maintains its rated value.

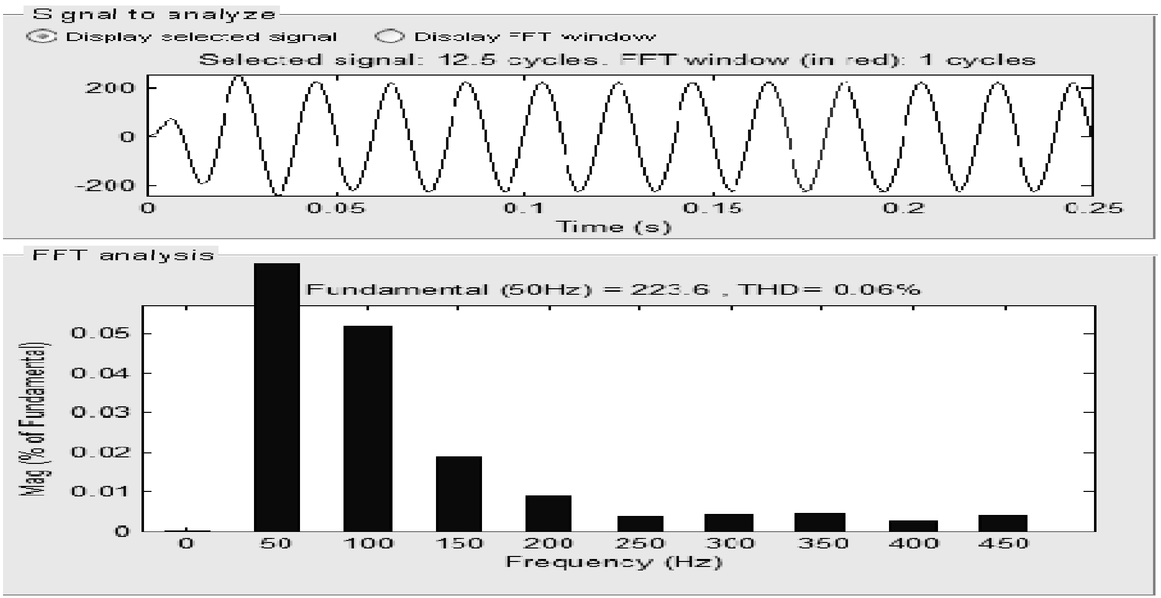

Figure 6. FFT window and harmonics contents % THD in O/P voltage analysis diagram of single phase PWM inverter with series –parallel resonant filter and PI controller

4. CONCLUSION

Harmonic analysis has been performed for a single phase PWM inverter with a series parallel filter. Result obtained with and without seris-parallel filter was compared and it has been found that the proposed resonant filter reduces the percentage (%) THD more than 2% for various values of load change. RMS controller as a feedback controller was sucefull. The result of introduction of feedback controller has given constant and stable output. The switching losses of inverter also reduces by this technique.

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