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Performance Analysis of Constant-K Low-Pass and Band-Pass Filters in a Uni-Polar SPWM Single Phase Inverter for Resistive Load

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Abstract: **Power system is designed to operate at a frequency of 50 or 60 Hz. However, certain types of non-linear loads produce current and voltages with frequency that are integer multiple of fundamental frequency. These frequency components known as harmonic pollution and is having adverse effect on the power system network. Harmonics generates serious problem to the quality of power supply of transmission and distribution network.. In today's scenario, power system has not only to become reliable one, but also has to ensure about the quality of power. Due to few of the load side equipment only, the quality of power supply worsens. It affects not only the whole power system as well as many consumer side appliances and some sensitive equipment which cannot be afforded to be malfunctioned leading to even loss of life.**

The output voltage waveform of ideal inverter should be sinusoidal. However, the waveforms of practical inverters are non sinusoidal and contain certain harmonics. For low and medium power applications, square-wave or quasi-square wave voltages may be acceptable; and for high-power applications, low distorted sinusoidal waveforms are required. With the availability of high-speed power semiconductor devices, the harmonic content of output voltage can be minimised or reduced significantly by switching techniques.

Keywords: **SPWM inverter. low-pass, band-pass, carrier frequency, cut-off frequency, characteristic impedance, THD.**

I. INTRODUCTION

Output voltage from an inverter can also be adjusted by exercising a control within the inverter itself. The most efficient method of doing this is by pulse-width modulation control used within the inverter.In this method, a fixed DC input voltage is given to the inverter and a controlled AC output voltage is obtained by adjusting the on and off periods of the inverter components. This is the most popular method of controlling the output voltage and this method is termed as Pulse-Width-Modulation (PWM) Control.

PWM inverters are quite popular in industrial applications. PWM techniques are characterized by constant amplitude pulses. The width of these pulses is however modulated to obtain inverter output voltage control and to reduce its harmonic content. The different PWM techniques are as under:

- Single-pulse width modulation (Single PWM)
- Multiple pulse width modulation (MPWM)
- Sinusoidal pulse width modulation (SPWM)

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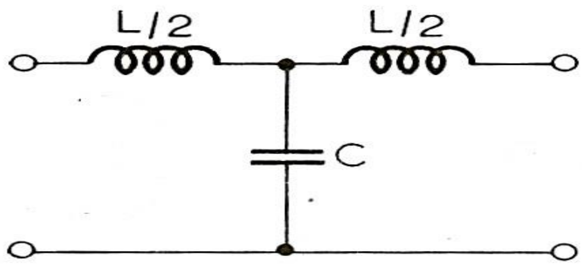
The PWM techniques listed above differ from each other in the harmonic content in their respective output voltages. Thus, choice of a particular PWM technique depends upon the permissible harmonic content in the inverter output voltage. In PWM technique, the devices are switched on and off several times within each half cycle to control the output voltage which has low harmonic content.

II. DESIGN OF CONST-K FILTERS

Design of constant k low-pass filter:



$R = \sqrt{\frac{L}{C}}$; $f_c = {}^{1}/_{\pi\sqrt{LC}}$; $L = {}^{R}/_{\pi f_c}$; $C = \frac{1}{\pi f_c R}$

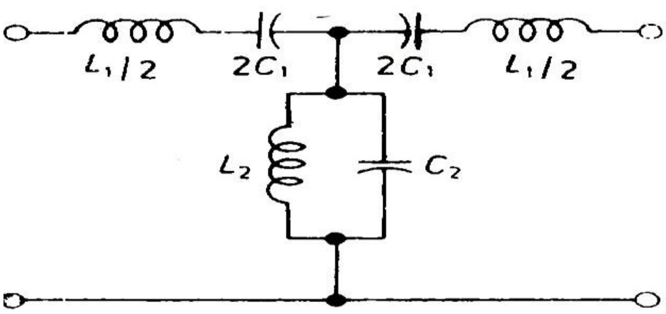
Where R is the characteristic impedance of the filter, which is equivalent to the load impedance connected across the output terminals of filter

If the load impedance is purely resistive R = 10 Ω then for cut-off frequency $f_{cut-off} = 150\ Hz$ and $f_{cut-off} = 300\ Hz$ filter components are different.

$\boldsymbol{f_{cut-off} = 150\ Hz}$ **:-** $L = .021\ henery$ $C = 212\ \mu\ farad$

$\boldsymbol{f_{cut-off} = 300\ Hz}$ **:-** $L = .0106\ henery$ $C = 106\ \mu\ farad$

Design of constant k Band-pass filter:



$R = \sqrt{\frac{L_1}{C_2}} = \sqrt{\frac{L_2}{C_1}}$; $L_1 = \frac{R}{\pi\,(f_2 - f_1)}$; $C_1 = \frac{(f_2 - f_1)}{4\pi f_1 f_2}$

$L_2 = \frac{R(f_2 - f_1)}{4\pi f_1 f_2}$; $C_2 = \frac{1}{R\pi\,(f_2 - f_1)}$

Performance analysis of band-pass filter in un-polar inverter for resistive load is done by selecting two different frequency bands of filter:

(i) $f_1 = 50\ Hz$ to $f_2 = 150\ Hz$

(ii) $f_1 = 50\ Hz$ to $f_2 = 450\ Hz$

(iii) $f_1 = 50\ Hz$ to $f_2 = 850\ Hz$

Filter circuit is terminated by a resistive load R = 10 Ω.

For band $\boldsymbol{f_1 = 50\ Hz}$ to $\boldsymbol{f_2 = 150\ Hz}$:

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$L_1 = .0318\ henery\ ;\ C_1 = .00106\ farad$

$L_2 = .0106\ henery\ ;\ C_2 = .000318\ farad$

For band $f_1 = 50\ Hz$ to $f_2 = 450\ Hz$:

$L_1 = .00795\ henery\ ;\ C_1 = .00141\ farad$

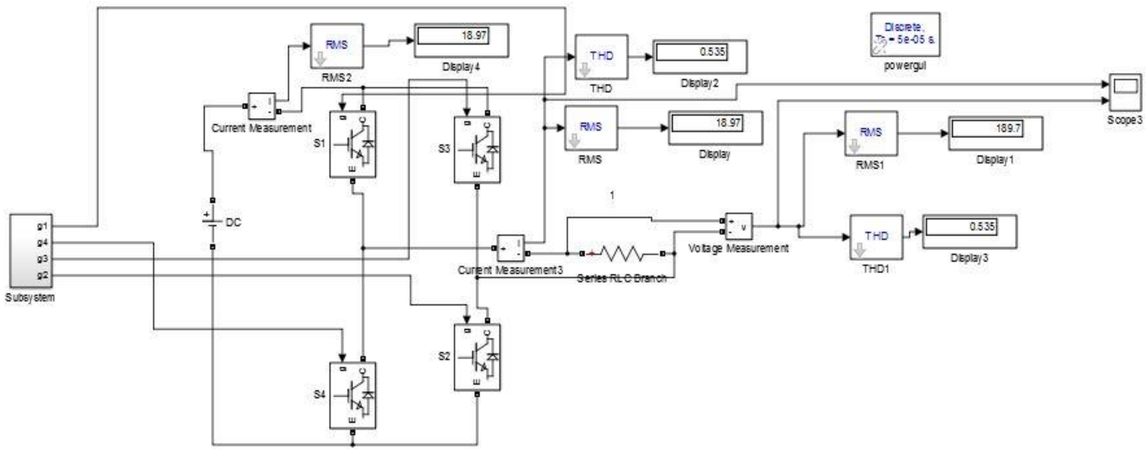
$L_2 = .0141\ henery\ ;\ C_2 = .0000795\ farad$

For band $f_1 = 50\ Hz$ to $f_2 = 850\ Hz$:

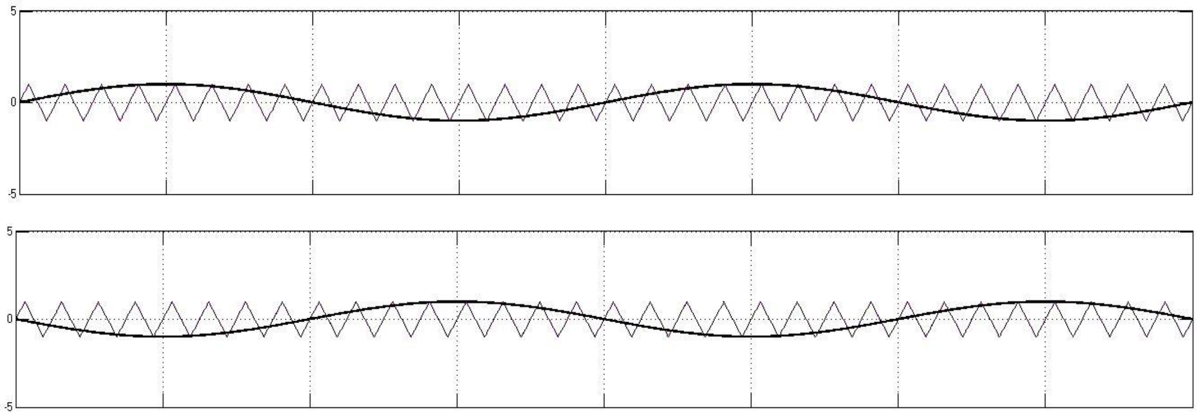
$L_1 = .0039\ henery\ ;\ C_1 = .00149\ farad$

$L_2 = .0149\ henery\ ;\ C_2 = .000039\ farad$

III. SIMULINK MODEL



(a)



(b)

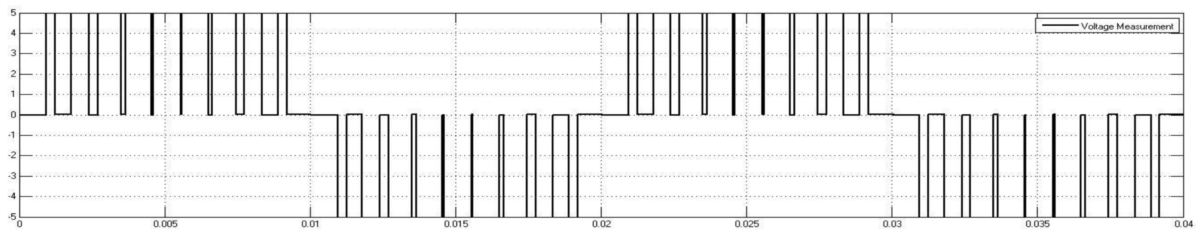


Fig.1 (a) Simulink model of Unipolar inverter, (b) Triggering pulse generation (c) Out put voltage of unipolar inverter

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IV. RESULTS

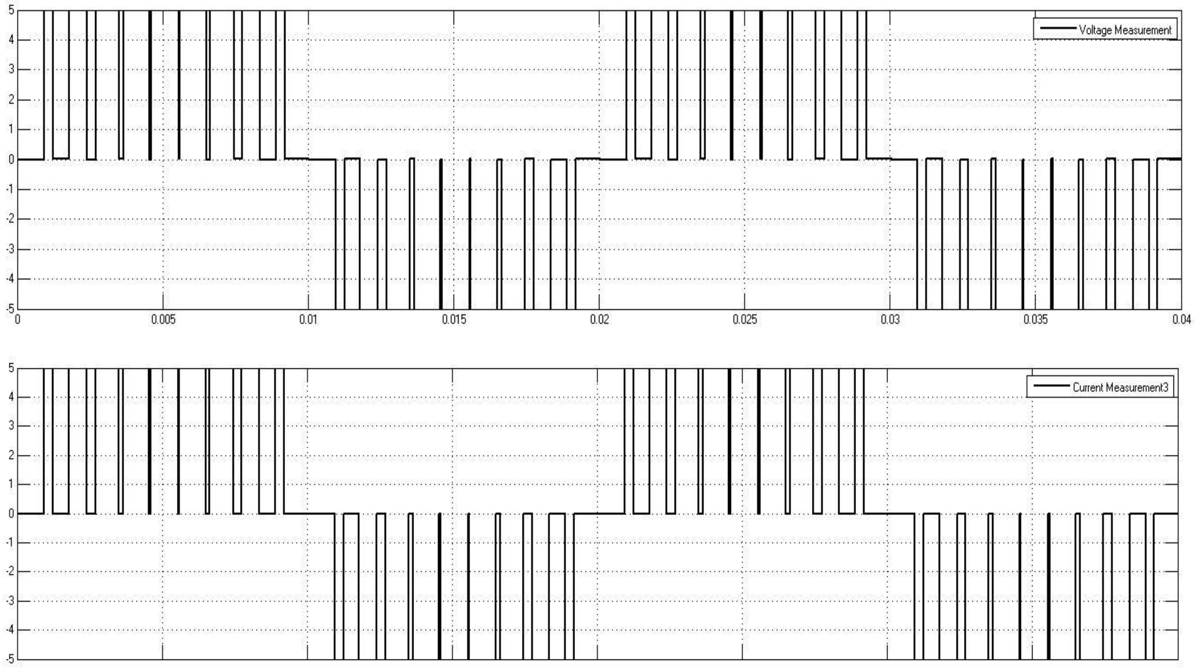
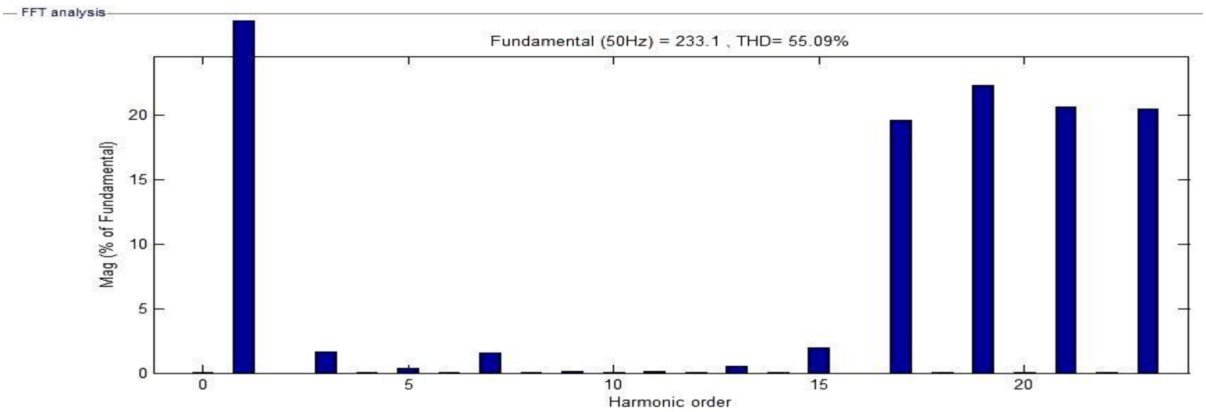
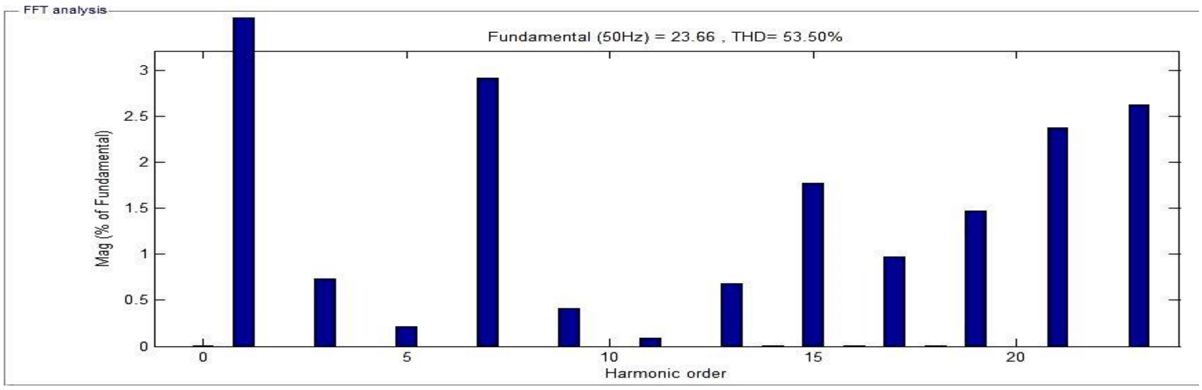


Fig.1. Inverter Output voltage and current waveform for resistive load



(a)



(b)

Fig. 2 Load current harmonic spectra for resistive load R = 10 Ω for MI = 1 for different carrier frequency (a) 500 Hz (b) 800 Hz

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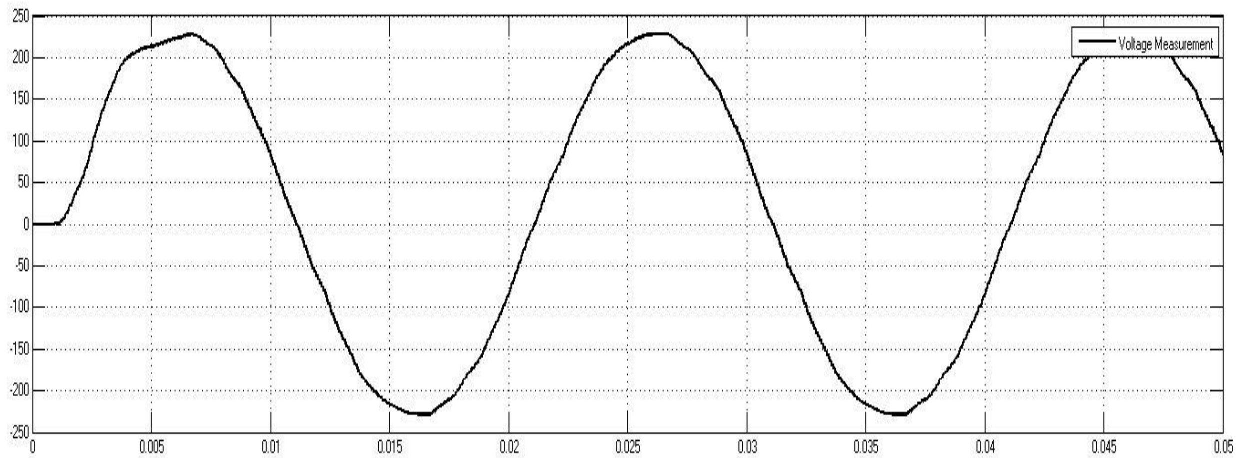
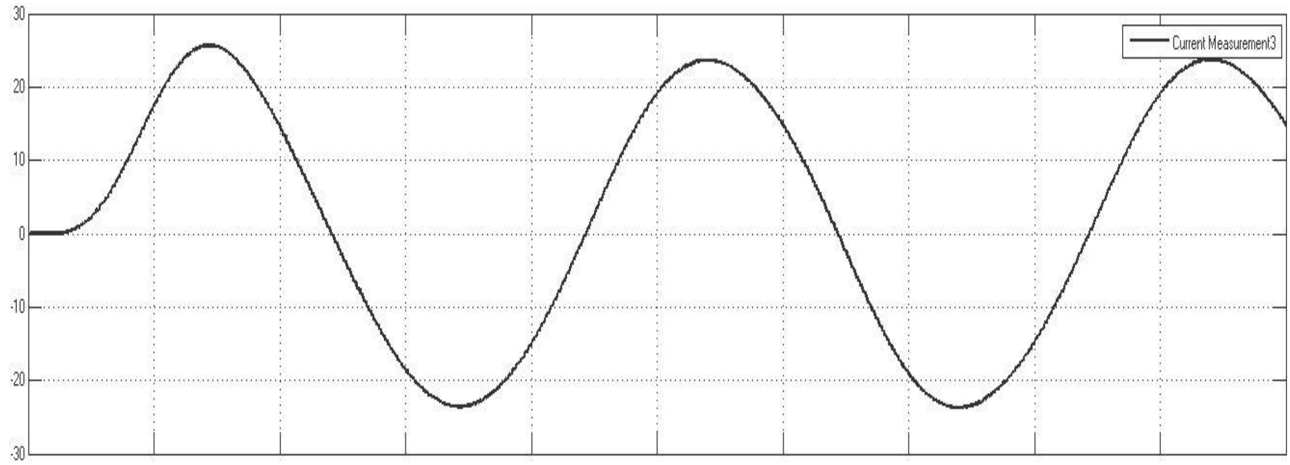
Table 1. Total harmonic distortion of output voltage and load current for resistive load R = 10 Ω and modulation index MI = 1 at two different carrier frequency 500 Hz and 800 Hz.

Harmonic order	$f_c = 500\ Hz$		$f_c = 800\ Hz$	
	$V_{THD} = 55.09\ \%$	$I_{THD} = 55.09\ \%$	$V_{THD} = 53.5\ \%$	$I_{THD} = 53.5\ \%$
DC	0	0	0	0
3	1.62	1.62	0.74	0.74
5	0.37	0.37	0.22	0.22
7	1.58	1.58	2.92	2.92
9	0.11	0.11	0.42	0.42
11	0.11	0.11	0.09	0.09
13	0.48	0.48	0.68	0.68
15	1.91	1.91	1.77	1.77
17	19.56	19.56	0.97	0.97
19	22.3	22.3	1.47	1.47
21	20.62	20.62	2.38	2.38
23	20.41	20.41	2.63	2.63



(a)



(b)

Fig.3 Load current waveform for load R = 10 Ω for MI = 1 , carrier frequency 500 Hz and at different cut-off frequency of low-pass filter for (a)300 Hz (b) 150 Hz

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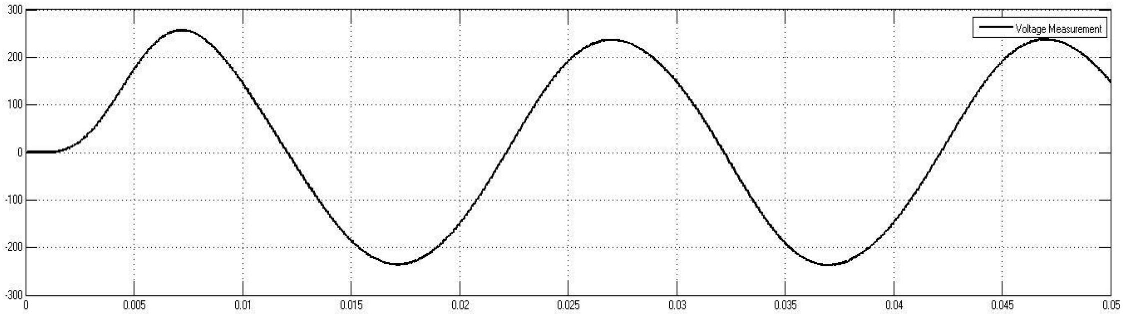
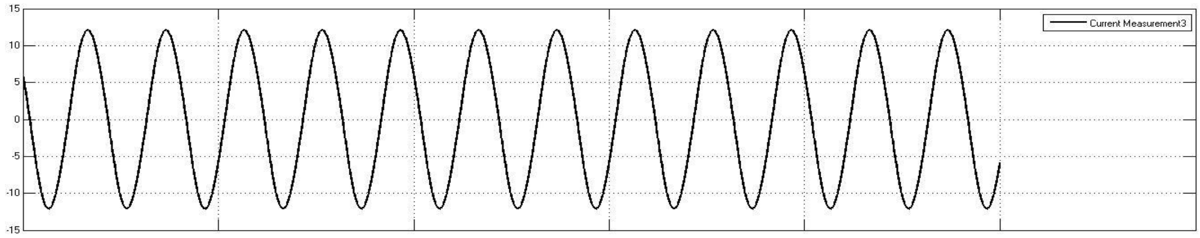


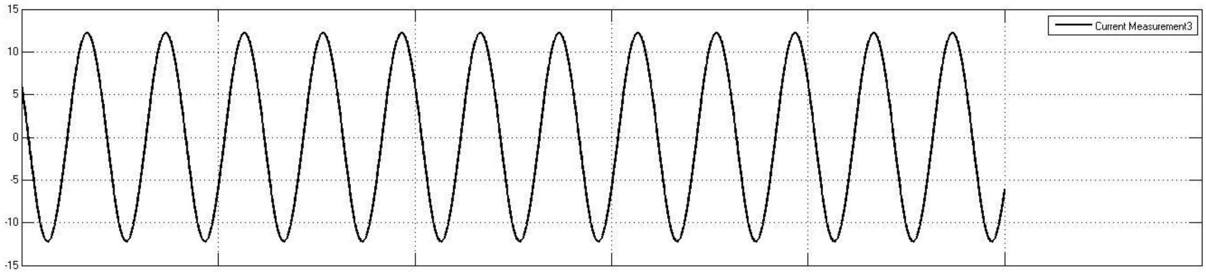
Fig. 4 0utput voltage waveform of unipolar inverter at cut-off frequency 150 Hz of low-pass filter

Table 2. Total harmonic distortion of output voltage and load current in uni-polar inverter for load R = 10 Ω , MI = 1 , carrier frequency 500 Hz and two different cut-off frequency 150 Hz and 300 Hz of low-pass filter

Harmonic order	$f_{cut-off} = 150\ Hz$		$f_{cut-off} = 300\ Hz$	
	$V_{THD} = 1.7$ %	$I_{THD} = 1.7$ %	$V_{THD} = 2.16$ %	$I_{THD} = 2.16$ %
DC	0	0	0	0
3	1.67	1.67	1.79	1.79
5	0.09	0.09	0.57	0.57
7	0.09	0.09	0.82	0.82
9	0.04	0.04	0.02	0.02
11	0.03	0.03	0.01	0.01
13	0.03	0.03	0.03	0.03
15	0.03	0.03	0.07	0.07
17	0.06	0.06	0.45	0.45
19	0.05	0.05	0.36	0.36
21	0.03	0.03	0.24	0.24
23	0.02	0.02	0.18	0.18



(a)



(b)

Fig. 5 Load current waveform of Uni-polar inverter through constant k band-pass filter for frequency band $f_1 = 50\ Hz$ to $f_2 = 150\ Hz$ at two different carrier frequency (a) 500 Hz (b) 800 Hz

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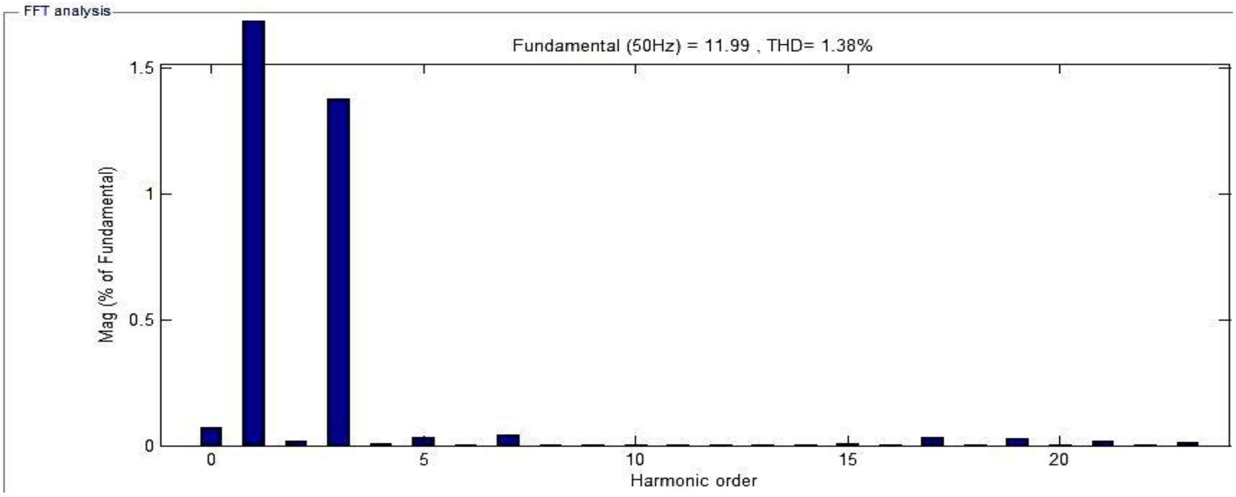
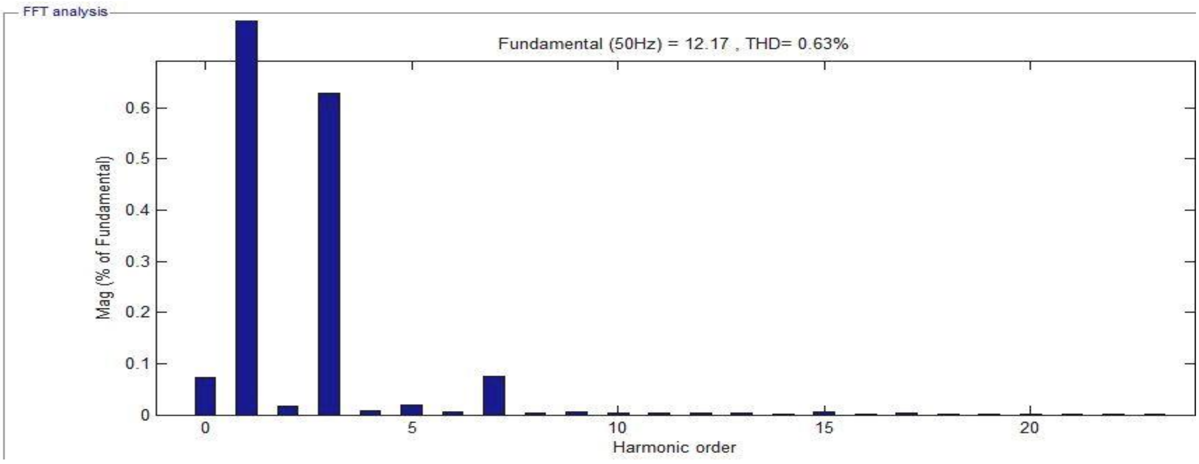


(a)



(b)

Fig.6 Load current harmonic spectra of Uni-polar inverter through constant k band-pass filter for frequency band $f_1 = 50\ Hz$ to $f_2 = 150\ Hz$at two different carrier frequency (a) 500 Hz (b) 800 Hz

Table 3. Total harmonic distortion of output voltage and load current for resistive load R = 10 Ω and modulation index MI = 1 at two different carrier frequency 500 Hz and 800 Hz through a band-pass filter for frequency band $f_1 = 50\ Hz$ to $f_2 = 150\ Hz$

Harmonic order	$f_c = 500\ Hz$		$f_c = 800\ Hz$	
	$V_{THD} = 1.38\ \%$	$I_{THD} = 1.38\ \%$	$V_{THD} = 0.63\ \%$	$I_{THD} = 0.63\ \%$
DC	0.07	0.07	0.07	0.07
3	1.38	1.38	0.63	0.63
5	0.03	0.03	0.02	0.02
7	0.04	0.04	0.08	0.08
9	0	0	0.01	0.01
11	0	0	0	0
13	0	0	0	0
15	0.01	0.01	0.01	0.01
17	0.03	0.03	0	0
19	0.03	0.03	0	0
21	0.02	0.02	0	0
23	0.01	0.01	0	0

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V. CONCLUSION

From the results it can be concluded that:

- In a SPWM Uni-polar inverter the output voltage and load current waveform are non sinusoidal for resistive load.Total harmonic distortion of the load current at carrier frequency 500 Hz is 55.09% and at higher carrier frequency 800 Hz it is 53.5%.
- From fig. 3 and 4, and table 2, it is clear that low pass filter at cut-off frequency 150 Hz makes non-sinusoidal output voltage and current waveform , almost sinusoidal with very less total harmonic distrortion 1.7%. In this improved waveform only 3rd order harmonic is present and remaining components are almost negligible.
- From table 3 it is also clear that in case of band pass filter, output voltage and current is also improved with lower harmonic distortion.

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