QUALITATIVE ANALYSIS OF LOW RATING UNINTERRUPTIBLE POWER SUPPLIES

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ABSTRACT— *Uninterruptible Power Supplies (UPS) are used to provide power to sensitive and critical domestic loads when the utility supply has been interrupted. These domestic loads may be non-linear, which often includes fans, compact fluorescent lamps and tube lights. The appliances used at domestic or commercial levels are AC in nature and they are required to operate on pure sinusoidal alternating current waveform. Output of the UPSs available in the local market contains harmonics and inter-harmonics and not give pure sinusoidal output waveform. The appliances operated on such UPSs may overheat and reduce the efficiency. On the basis of the output signal many different uninterruptible power supplies configurations exists that can be used to power the basic domestic load. This research is going to analyse the waveforms of different configurations of UPSs and their harmonics, inter-harmonics on the basis of the characteristic of resultant output. For the purpose mentioned above, a very high range Xilinx electronics explorer board oscilloscope with different capabilities has been used. The measurements are analysed to find out amount of harmonics and inter-harmonics in the voltage output of each UPS.*
This paper discusses the qualitative differences between five existing configurations of low power rating domestic UPS that are mostly used in Pakistan. The text in this paper has been supported through data of the real time power signal analysis to quantify total harmonic distortion (THD), inter harmonics and comparative analysis of frequency spectrum of different UPS.

Keywords— *harmonics, inter-harmonics, UPS, total harmonics distortion (THD), frequency spectrum.*

I. INTRODUCTION

Uninterruptible power supplies (UPSs) are used to provide clean and continuous power to equipment in critical load applications, such as servers and storage systems, computers, biomedical equipment, data centres, industrial and commercial controls, etc.[1]. Now a days in Pakistan uninterruptible power supplies are the back bone for the domestic users to meet their basic load requirements during the load shedding. Pure and safe electrical energy is the basic need of every electrical device for its long life. In the world, now a days, locally made UPS are used for continuous electric supply. The available UPSs at domestic or commercial level are actually contains square wave inverters or quasi square wave inverters. Due to the harmonic contents, electronic equipment operated by these inverters will be damaged [2, 3]. The cost of the pure sine wave inverters is too high and their output at maximum loading condition is non-sinusoidal. Most of the local manufacturers of the UPSs are not considering the quality of electrical signal but they only concentrate on the marketing competition to make them cost effective. The waveform generated by these inverters are non-sinusoidal although all appliances at domestic and industrial levels are of AC nature i.e. they operate on Alternating Current having the shape of pure sinusoidal wave.

It is generally expected that the UPS will perform the following functions [4].

1. Load voltage stabilization (±5% voltage regulation) in both normal and abnormal utility power conditions.
2. Supply of clean and uninterrupted power to the loads.
3. Harmonic mitigation (THD < 5%) in both normal and abnormal utility power condition

The local manufacturers of the UPS does not care the above conditions. The output wave form of real time inverter contains harmonics, inter-harmonics and is non-sinusoidal [5, 6]. Due to the sufficient amount of harmonics and inter-harmonics in UPS output voltage signal may cause malfunctioning of electrical appliances. Due to harmonics contents in UPS output voltage signal it will be distorted and causes the problem of power quality [7]. Harmonics is the main issue with inverters especially with those inverters used in the Uninterrupted Power Supplies (UPS). Though the sinusoidal and space vector types of PWM (SPWM & SVPWM) used in inverters help reduce harmonics they incur high switching losses. In square wave inverters usually with single pulse scheme all the odd harmonics are present [8].Modified sine wave and square wave form voltage are might be acceptable for medium and low power applications, but for high power applications, sinusoidal and less distorted voltage waveform is required [9]. The increased in harmonic distortion causes the extra heating losses, shorter insulation life span, higher insulation stress and temperature, reduced power factor and efficiency of the electrical equipment. The Simulink based harmonic analysis is already published in the world wide. But the frequency spectrum of practical output voltage signal of different UPS with high resolution analyser is not observed. However, the results published by the most of the researchers may still suffer low accuracy, long computational time and measurements limitations in complex signal waveforms.

In this research the real time voltage signal of different UPS is analysed in both time and frequency domain to check its quality. This work starts with the study of output signal types, an experimental setup is arranged to measure the real time signal harmonics and inter-harmonics of different UPS. The performance parameters are defined in section II. Time domain signal of different UPS is shown in section III. Calculations of harmonics and total harmonics is presented in section IV. The frequency spectrum of different UPS is included in section V. Conclusions and future work is discussed in the final section.

II. PERFORMANCE PARAMETERS

The output of the most UPSs contains harmonics, inter-harmonics, sub harmonics and quality of UPS is evaluated in the terms of the subsequent performance parameters.

A. Waveform Distortion

Waveform distortion is a deviation from the steady-state sine wave of power frequency. There exists five primary types of waveform distortions: harmonics, notching, inter harmonics, electric noise and DC offset. [10]. Mathematical definitions of all these are given in table considering f_1 is the fundamental frequency.

Table 1: Definition of waveform in terms of frequency components

Harmonics	$f = h \times f_1$, where h is an integer > 0
Inter-harmonics	$f \neq h \times f_1$, where h is an integer > 0
Sub-harmonics	$f > 0$ Hz and $f < f_1$
DC offset	$f = 0$ Hz ($f = h \times f_1$, where h=0)

B. Harmonic Factor (Distortion Factor) (DF)

Harmonic distortion factor is defined as the ratio of the root-mean square of the harmonic content to amplitude of the fundamental quantity, expressed as a percent of the fundamental. [11]

$$DF = \sqrt{\frac{sum\ of\ square\ of\ amplitude\ of\ all\ harmonics}{square\ of\ amplitude\ of\ fundamental}} \qquad (1)$$

C. Total Harmonic Distortion (THD)

A measure of the harmonic components in a distorted waveform, which is expressed in percentage of the fundamental (e.g. voltage or current) component [11]:

$$THD = \frac{\sqrt{\sum_{h=2}^{\infty}(V^h)}}{V} \qquad (2)$$

D. Individual Harmonic Distortion (IHD)

It is the simplest the ratio of a given harmonic component to the fundamental component. This value is used to check the effect of individual harmonic and its magnitude. IHD is determined by:

$$IHD = \frac{F_i}{F_1} \qquad (3)$$

Where Fi is the amplitude of the ith harmonic and F_1 shows the amplitude of the fundamental component 11].

III. REAL TIME SIGNAL

The real time output voltage signal of different domestic UPS is taken by connecting electronics explorer board oscilloscope (70MHz bandwidth, 4 channel) at the output of each UPS, all the data is shown on laptop through Digilent software. The hardware setup of pure sine wave UPS is shown in figure 1.

Figure 1 shows that the resistive load of 60 to 1000 W is connected at the output because the no load voltage of each UPS exceeds the limitations of the measuring devices. The real time signal obtained through electronics explorer board is directly shown on the display screen of laptop. The data could be in the form of time signal waveform, FFT and it can also be import into excel and pdf file format for further analysis. The observed output voltage wave forms of different UPS are shown in figure 2, 3, 4, and 5. The horizontal axis in the figures shows the time for one period which is 20 ms at 50 Hz and vertical axis shows the magnitude of output voltage for complete cycle which is 125 times scale down for peak voltage .

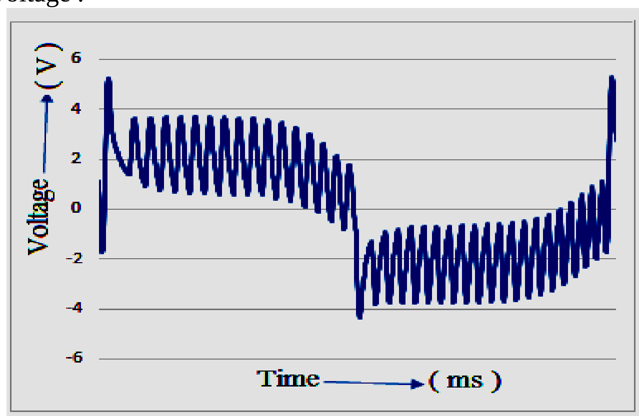

Fig 1: Hardware setup of pure sine wave UPS.

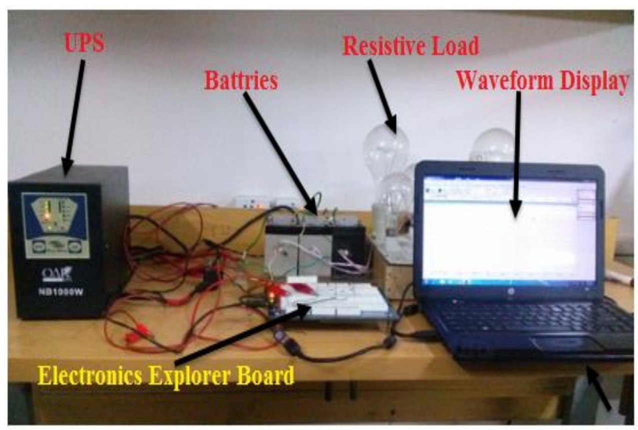

Fig 2: Square wave UPS output.

Figure 2 shows the output voltage wave form of the square wave UPS, which has oscillation and spikes in both the positive and negative half that causes the noise and overheating in the load operated by these UPS. The output voltage wave form of quasi square wave UPS is shown in figure 3, which has notches at zero crossing point and rising edge and roundness at the falling edge of the wave form that causes the losses and overheating in the device operated by these UPS.

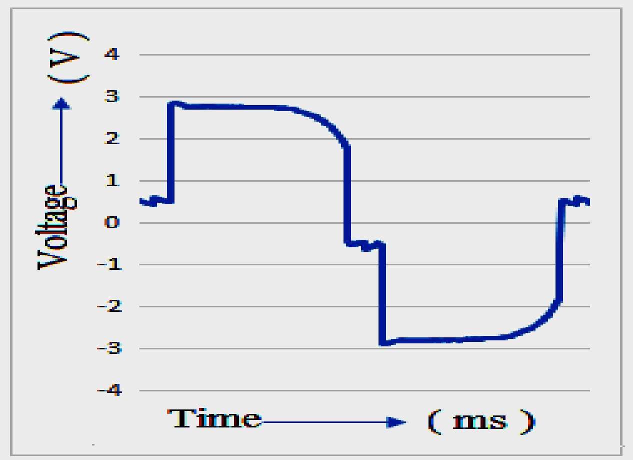

Fig 3: Quasi-square wave UPS output.

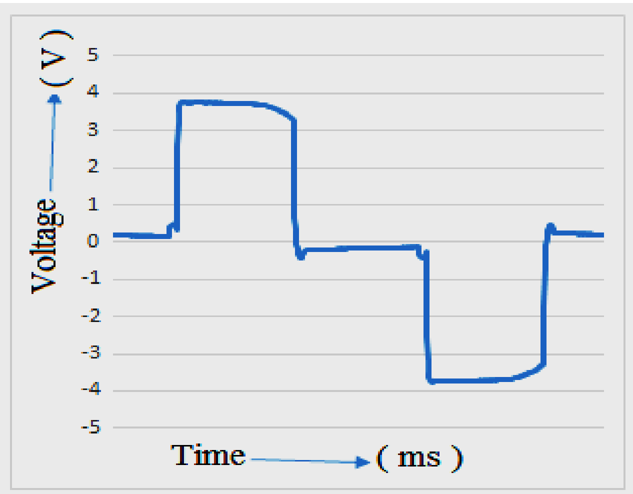

Fig 4: Modified sine wave UPS output.

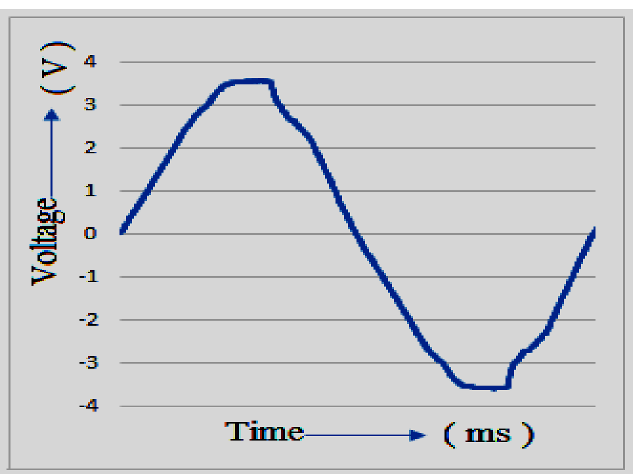

Fig5: Sine wave UPS output.

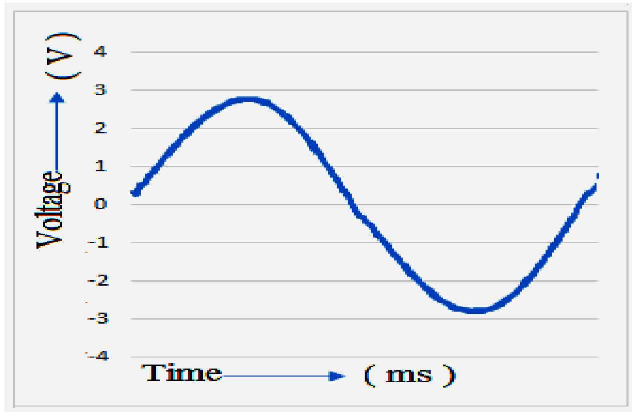

Fig 6: Pure sine wave UPS output.

Modified sine wave UPS output is shown in figure 4, which shows that the distortion in the wave form. Figure 5 shows the sag in the positive and negative half of the wave form peak which is due to third harmonic in the output of the sine wave UPS. The output of the pure sine wave UPS is shown in figure 6, which is free from distortion, notches, noise and harmonics. It is best in quality wise from the remaining UPS and god for the home appliances efficiency and operating life.

IV. HARMONICS AND TOTAL HARMONICS DISTORTION (THD)

As already explained briefly that the paper is the resultant of an experimental work on different types of locally made UPSs. The quantitative results of harmonics and inter-harmonics are taken by using an advance Digillent oscilloscope and measuring devices. The output waveforms of different UPSs have been plotted in the previous section. The pollution in electrical power system is going to increase due to the huge use of low quality UPSs which are major cause of harmonics and inter harmonics. The integer multiple of fundamental frequency is called harmonic which is 50 Hz in our case. The measured results of harmonics magnitude, individual harmonics distortion and total harmonic distortion of different UPSs are shown in table 2, 3, 4, 5 and 6.

The harmonics in the voltage output of the square wave UPS are shown in table 2. The magnitude of the voltage harmonics was scale down to 125 times to remain within limitations of the Digilent oscilloscope. The table results shows that only odd harmonics up to order 19 exists in the locally made square wave UPS, the third harmonic 23.86% and the total harmonics distortion (THD) is 34.176% which is not healthy sign for home appliances.

The magnitude of the quasi square wave UPS output voltage harmonics is taken as 1/105 times of the actual magnitude, the results are shown in table 3. Quasi square wave contains the odd harmonics up to order 9 and %THD 22.81. The percentage of the harmonics decreases from 3^{rd} to 7^{th} and then suddenly jumps at 9^{th} harmonic, which is dangerous for domestic load.

Table 2: Square wave UPS harmonics.

Harmonic Order	Magnitude	%IHD
1	1.8376	100.00
2	0.0000	0.00
3	0.4386	23.86
4	0.0000	0.00
5	0.26818	14.59
6	0.0000	0.00
7	0.1928	10.49
8	0.0000	0.00
9	0.1444	7.86
10	0.0000	0.00
11	0.1421	7.70
12	0.0000	0.00
13	0.1233	6.70
14	0.0000	0.00
15	0.1108	6.03
16	0.0000	0.00
17	0.1157	6.30
18	0.0000	0.00
19	0.1050	5.70
20	0.0000	0.00
%THD=34.176		

Table 3: Quasi-square wave UPS Harmonics

Harmonic Order	Magnitude	%IHD
1	2.2620	100.00
2	0.0000	0.00
3	0.4929	21.79
4	0.0000	0.00
5	0.0686	3.03
6	0.0000	0.00
7	0.0360	1.59
8	0.0000	0.00
9	0.1314	5.80
%age THD=22.81		

Table 4: Modified sine wave UPS harmonics

Harmonic Order	Magnitude	%IHD
1	2.1171	100.00
2	0.0000	0.00
3	0.7802	36.85
4	.0000	0.00
5	0.3557	16.80
6	.0000	0.00
7	0.3269	15.44
8	.0000	0.00
9	0.2096	9.90
10	.0000	0.00
11	0.1934	9.13
12	.0000	0.00
13	0.1503	7.10
14	.0000	0.00
15	0.1157	5.46
16	.0000	0.00
17	0.0583	4.97
18	.0000	0.00
19	0.1000	4.72
20	.0000	0.00
%THD=46.59		

Table 5: Sine wave UPS harmonics.

Harmonic Order	Magnitude	%IHD
1	2.3915	100.00
2	0.0000	0.000
3	0.0285	1.19
4	0.0000	0.00
%THD=1.19		

The %THD of modified sine wave UPS is highest among all the UPS under test as shown in table 4. The reason is the limitation of modified sine wave inverter is that 3rd order harmonics exists to a notable value [12].

Table 6 : Pure sine wave UPS harmonics.

Harmonic Order	Magnitude	%IHD
1	1.87	100
%THD=0		

The measured harmonics of sine and pure sine wave UPS are shown in table 5 and 6, which are within the limit of %THD defined in the IEEE-519 standard. From the results of the all five types of UPS it is clear that the harmonics order of modified sine wave and square wave UPS is the same but the %THD of square wave type is 34.176% and modified sine wave is 46.59%.

V. FREQUENCY SPECTRUM

The frequency spectrum contains the contents of harmonics and inter-harmonics. The integer multiple of fundamental frequency are the harmonics and non-integer multiple of the fundamental frequency are the inter-harmonics of voltages or currents. The order of inter-harmonic is given by the ratio of the inter-harmonic frequency to the fundamental frequency. If its value is less than unity, the frequency is also referred to as a sub-harmonic frequency. The combination of harmonics, Interharmonics and sub-harmonics is called frequency spectrum which is used to check the quality of output signal of UPS. The frequency spectrums of the UPSs under testing are shown in figure 7, 8, 9, 10 and 11. The minimum frequency step is taken as 5 Hz for the spectrum analysis and their corresponding amplitudes are shown in below figures.

From the frequency spectrums of all the UPSs it is clear that outputs of all the uninterruptible power supplies contains subharmonics, harmonics and Interharmonics. The harmonics and Interharmonics amplitudes are higher near fundamental component of frequency and decreases towards the highest frequencies.

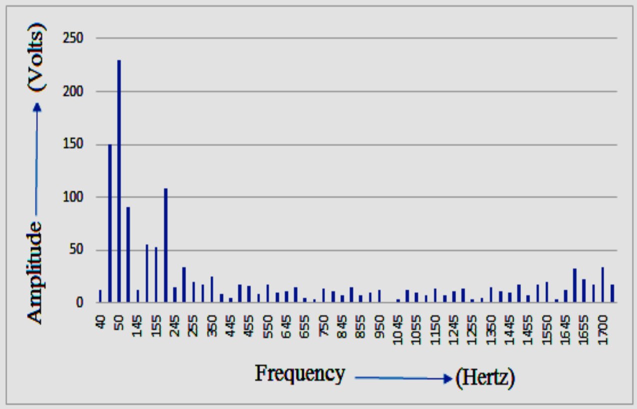

Fig 7: Frequency spectrum of square wave UPS

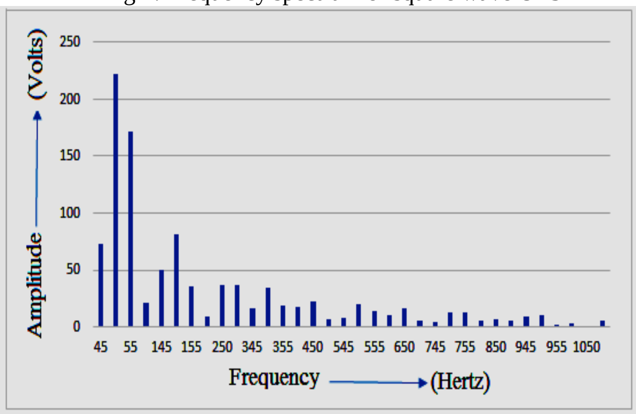

Fig 8: Frequency spectrum of quasi square wave UPS

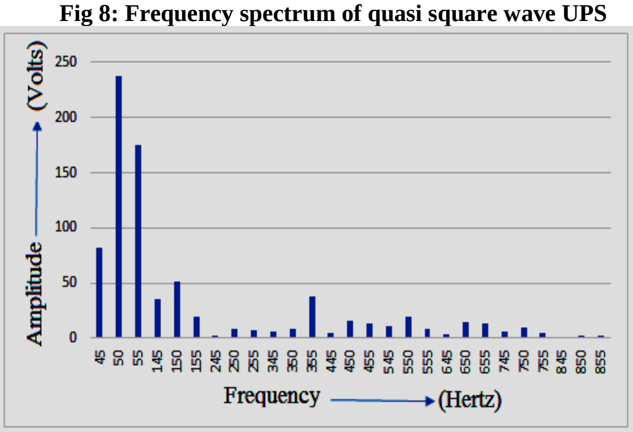

Fig 9: Frequency spectrum of modified sine wave UPS

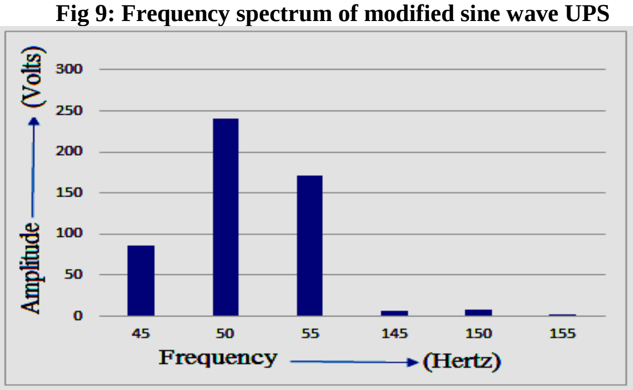

Fig 10: Frequency spectrum of sine wave UPS

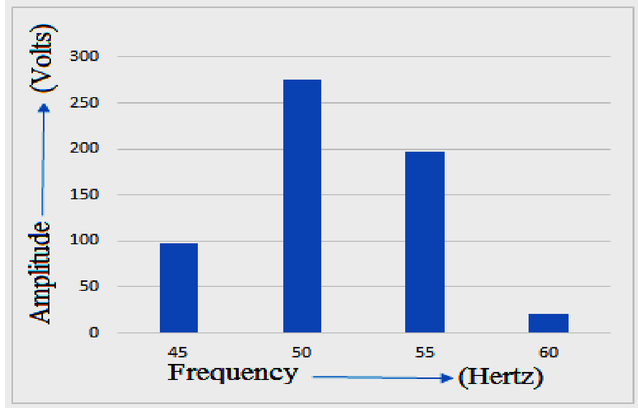

Fig 11: Frequency spectrum of pure sine wave UPS

Pure sine wave UPS has highest amplitude of the subharmonic and square wave UPS has lowest order. The harmonics contents are already discussed in section 4. Most of the inter harmonics are observed near the above and below of the integer multiple of the fundamental frequency. Interharmonic at 55 Hz in the frequency spectrums of different UPSs has significant amplitude, the highest amplitude in pure sine wave UPS is observed but it has only two Interharmonics in its spectrum which shows it provides clean energy to the loads.

Square wave UPS output spectrum has significant amount of Interharmonics which are shown up to 1700 Hz due to limitations of paper. The harmonics and Interharmonics amplitude decrease up to 1450 Hz and then increased to 1650 Hz and remained constant from 1650 Hz to 2200 Hz which can cause the sever problem in the devices operated on such UPS. Unfortunately, most of the domestic users in Pakistan use square wave UPS, which reduces the life span of the ceiling fans, compact fluorescent lamps and tube lights operated on these UPSs.

VI.EFFECTS OF HARMONIC AND INTERHARMONICS

Due to harmonics in a power system, a lot of unwanted effects and problems can occurs. A high level harmonic distortion of a UPS output can become the basis of such effects as increased fans motor heating and noise, misoperation of electronic home appliances specially which relies and operate with respect to the zero crossing detection in voltage signal or the equipment's sensitive to wave form may causes the intervention with telephone circuits etc.

Similarly the common effects of the presence of inter-harmonics are variations in RMS voltage magnitude, flicker, thermal effects, low frequency oscillations in mechanical systems, turbulence in fluorescent lamps and electronic equipment operation. In practice, the operation of any equipment that is synchronised with respect to the supply voltage zero-crossing or crest voltage can be disturbed. Telecommunication interference and acoustic trouble may be the results of inter-harmonics.

VII. CONCLUSION

From above discussion, waveforms, %THD and frequency spectrum of different UPS it is clear that more pure, safe and suitable electrical energy source is pure sine wave UPS, which is too much expensive. Square wave UPSs are mostly used at domestic level and these have distorted harmonics and Inter-harmonics richer output which cause losses and overheating in the home appliances.

Moreover waveforms and their frequencies obtained in this research are also very useful for the designer of harmonic filters to design active and passive filters for different UPS.

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