The Practical Study of Sinewave Inverters And modified Sinewave Inverters

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Abstract

The power industry has been evolving towards cleaner and more abundant sources of energy. Renewable energy is becoming mainstream studies in the power generation. Nowadays we have become more and more reliant on electrical and electronic appliances. Appliances such as TVs, mobile phones, microwave ovens, lights, heaters, fans and more, are built around the AC mains supply from the public grid.

With the advance of the renewable energy sources off grid power has become within affordable reach and many consumers have invested in such technologies, such as Solar panels and wind power generators. Both technologies have peak time and down time thus to allow for continuous power availability throughout the day, batteries are used to store the electrical energy generated by the source and then electronic devices such as inverters are used to generate mains level voltages to allow the appliances to work with the off grid system. This study will cover the two main solutions that are commonly used, the Pure Sinewave Inverter and the Modified Sinewave Inverter covering the advantages and disadvantages for each type from a consumer perspective.

Keywords: Sinewave Inverter, Modified Sinewave Inverter, Harmonics, Renewable Energy.

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1. Introduction

For our practical study we took a sample of the two types of inverters that are available in the market and took these samples from the same manufacturer to minimize the technical variations that one company technology might have versus the other.

Our choice also took into consideration the practical appliance loading that the user might normally look for between 1000W and 1500W load.

The following figures illustrate the mechanical differences between the two types. The modified sine wave version is smaller and lighter due to the simplicity of the drive circuits involved in shaping the output signal; Fig. 1.

The Pure Sine wave unit is much more complex and requires more complicated circuitry to drive the sine wave output at a lower load rating,

Fig. 2 [1].

Fig. (1). Standard modified Sine wave Inverter

Fig. (2). Standard pure sine wave inverter

In this paper we are studying the shape of the wave output and harmonics of the output signal based on various load settings and load types as harmonics are the main difference between the two types of inverters. Harmonics is what effects the different type of loads such as electronic equipment, motors, lighting and heaters etc.

Besides to carry out practical load tests and monitor the effect of the load on the output of each type of inverters, starting with some general information about the two types of inverter technologies and also give some background information on Harmonics and how they affect different types of loads.

2. Inverter Technology

With the introduction of high power switching transistors and power electronics, such as thyristors, triacs and IGBT modules, people have been experimenting with generating AC power from DC power. The idea was based on the fact that you can store DC power in batteries converting the DC power to chemical power during charging and from chemical power to electrical power when discharging. This is not true for AC power as there is no means of storage other than mechanical rotation of a heavy flywheel through kinetic energy that is very short term, not to mention very heavy and not portable. Of course, arguments can be made that petrol and diesel engine generators also convert chemical power to electrical power by burning fuel in the engine and rotating the generator. The latter is still cumbersome expensive and is not as efficient as DC power storage using batteries and inverters to produce AC power [2].

The simplest way to produce AC is to use a simple electronic oscillator at a nominal 50Hz or 60Hz, depending on your country main standard, and use a simple push-pull power circuit with a step-up transformer to acquire the required AC output voltage. Although simple this method produces high excessive RMS power that is reflected in the harmonics of square wave versus a pure sine wave, as in fig. 3.

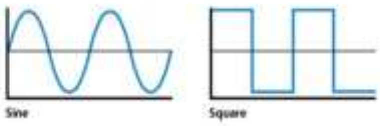

Fig. (3). Sine wave vs simple Square wave

The harmonics delivered in this technique are very high and can generate high noise and in the higher frequencies generate power loss in the transformers and coils within the load that can also generate heat as a result of the losses.

The second technique was to create a modified sine wave that is closer to the sine wave but with less harmonics that the square wave, while keeping the electronics as simple as possible, as illustrated in fig. 4 [3].

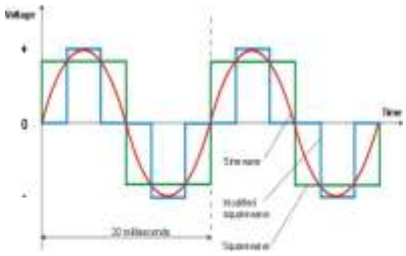

Fig. (4). Comparison between Square wave and Modified Square wave with pure sine wave

Of course, to generate a pure sine wave will require more sophisticated methods of generation not as simple as the two methods above. To understand the differences between these methods better, we cast a brief introduction to Harmonics and their importance [4].

3. Harmonics

Using Fourier expansion with cycle frequency (f) over time (t), we can describe the representation of an ideal square wave with an amplitude of 1 as an infinite series using Fourier expansion with cycle frequency (f) over time (t) in the following formula

$$x_{\text{square}}(t) = \frac{4}{\pi}\sum_{k=1}^{\infty}\frac{\sin\left(2\pi(2k-1)ft\right)}{2k-1}$$
$$= \frac{4}{\pi}\left(\sin(2\pi ft) + \frac{1}{3}\sin(6\pi ft) + \frac{1}{5}\sin(10\pi ft) + \cdots\right)$$

From the above we can define harmonics as voltages or currents at frequencies that are a multiple of the base frequency. In European countries with 50 Hz mains power systems, the harmonic order is 100 Hz, 150 Hz, 200 Hz, etc . For other systems, the base frequency is 60 Hz. Therefore, harmonic order is 120 Hz, 180 Hz, 240 Hz and so on [5].

Usually these orders are specified by their harmonic number or multiple of the fundamental frequency. For example, a harmonic with a frequency of 150 Hz is known as the third harmonic (50 x 3 = 150). In this case, for every cycle of the fundamental waveform, there are three complete cycles of the harmonic waveforms. The even multiples of the fundamental frequency are known as even-order harmonics while the odd multiples are known as the odd-order harmonics.

We notice from the above Fourier expansion that the dominant harmonics are of the odd-order which is the first, third, fifth, seventh and so on for the ideal square wave.

If the signal was a pure Sine wave (in and ideal scenario) we would only see the base frequency or the first and only harmonic, as in fig. 5.

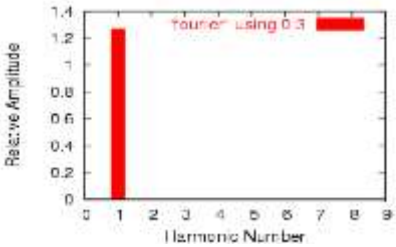

Fig. (5). Harmonics distribution for an ideal sine wave

Practical square waves are mostly composed by the odd-order harmonics as shown in the following FFT representation, fig. 6, of a 50Hz square wave as there is no ideal square wave in practice.

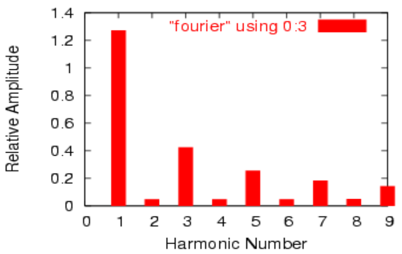

Fig. (6). Harmonics distribution for a given square wave

The Modified sine wave will have a different distribution to that of the square wave which will be illustrated as part of our practical study and compared with that of the pure sine wave inverter [6].

4. Harmonics effect on electric and electronic equipment

The impact of using a modified sine wave solution will affect any device that uses a control circuitry that senses the phase (for voltage / speed control) or instantaneous zero voltage crossing (for timing control) will not work properly from a voltage that has a modified sine waveform [7].

As the modified sine wave is a form of square wave, it is comprised of multiple sine waves of odd harmonics (multiples) of the fundamental frequency of the modified sine wave as detailed above. For example, a 50 Hz. modified sine wave will consist of sine waves with odd harmonic frequencies of 3rd (150 Hz), 5th (250 Hz.), and 7th (350 Hz.) and so on. The high frequency harmonic content in a modified sine wave produces enhanced radio interference, higher heating effect in motors / microwaves and produces overloading due to lowering of the impedance of low frequency filter capacitors / power factor improvement capacitors [8] [9].

Some examples of devices that may not work properly with modified sine wave and may also get damaged are given below:

- Some fluorescent lamps / light fixtures that have power factor correction capacitors that might cause the inverter to shut down indicating overload
- Laser printers, photocopiers,
- The built-in clocks in devices such as clock radios, alarm clocks, coffee makers, bread makers,
- VCR, microwave ovens etc may not keep time correctly
- Output voltage control devices like dimmers, ceiling fan / motor speed control may not work properly (dimming/ speed control may not function)
- Sewing machines with speed / microprocessor control
- Transformer less capacitive input powered devices like electric razors, flashlights, nightlights, smoke detectors
- Rechargers for battery packs used in hand power tools.
- Devices that use radio frequency signals carried by the AC distribution wiring such as automation controllers and internet extenders.
- Some new furnaces with microprocessor control
- High intensity discharge (HID) lamps like Metal Halide lamps. These may get damaged [10].

5. The Lab Bench Setup

In this section we describe our lab setup and the methods that we used to carry out our tests and measurements in addition to the presentation of results illustrating the practical comparison.

The lab setup is illustrated in the following figure, 7.

Fig .(7). The lab bench setup

The setup consists of the following:

1- A fully charged 12v 100Ah battery as the source for the inverter under test
2- Resistive load in the form of incandescent lamps
3- A Multimeter to monitor the Battery DC voltage, (Philips PM2517E)
4- A Multimeter to monitor the DC current by measuring the voltage drop on a 20A/100mv standard current shunt. (Philips PM2517E)
5- A Multimeter to monitor AC voltage generated by the inverter. (Philips PM2517E)
6- An Oscilloscope to monitor the wave shape (Metrix OX710B)
7- A Clamp meter that measures the voltage and amplitude ratio of each harmonic component up till the 25th harmonic which is 25x50 =1250 Hz, in addition to the THD% (Total Harmonic Distortion ratio)(Chauvin Arnoux F27 Harmonic & Power Meter)
8- The Inverter under test
9- A fan with inductor motor (not shown in the picture).

6. The Test Method

To allow us to understand the differences we used three type of loads:

1- Resistive (incandescent Lamps)
2- Inductive (Fan with induction Motor)
3- Mixed resistive and inductive load (using the two above)

This will be close to most of the applications we would look for to use the inverters such as light, heat and motors for pumps or fans.

We carried out the same tests buy only changing the inverter between modified square wave and pure sine wave and registered the results.

We also carried out a DC power consumption test on each of the inverters to see the efficiency in their operation using a fixed resistive load (incandescent lamps).

During the testing we have taken snapshot of the output wave form on the oscilloscope to demonstrate the impact of loading on the shape of the output and the frequency of each type of inverter.

7. The Tests and results

1- Resistive load:

We observed the output wave form showing the two types of outputs, as in fig. 8.

Fig. (8). Measured modified square wave vs pure sinewave

We clearly see the difference between the two signals and the square edges of the modified square wave that will produce harmonics.

For a resistive load we did not notice any deformation of the modified square wave as a result of load change as the same with the sine wave inverter thus we registered the results based on a fixed load as in table. 1.

Table. (1). Test results for harmonics based on resistive load

	Harmonics tests with Resistive load			
	Modified Sinewave		Sinewave	
	Uac= Hz= THD= Idc=	213 55.11 27	Uac= Hz= THD= Idc=	222.2 50 0.4
Harmonics	Amplitude Ratio	Volt	Amplitude Ratio	Volt
H1	100.0%	204.6	100.0%	222.2
H3	13.3%	27.3	0.3%	0.8
H5	8.9%	18.0	0.1%	0.3
H7	14.6%	29.7	0.2%	0.5
H9	10.8%	22.3	0.1%	0.1
H11	3.1%	6.5	0.0%	0.1
H13	3.7%	7.6	0.0%	0.1
H15	6.8%	14.0	0.0%	0.1
H17	5.5%	11.4	0.0%	0.1
H19	1.5%	3.1	0.0%	0.0
H21	2.5%	5.1	0.0%	0.0
H23	4.4%	9.1	0.0%	0.0
H25	3.5%	7.4	0.0%	0.0

Fig. 9. shows samples from the sample measurements taken that clearly illustrates the difference between the modified square wave (left) and the sine wave (right). The frequency is higher and the voltage is lower because of the modified sine wave, which is also clear in the oscilloscope reading as well.

Fig. (9). Measurement differences between the two inverters

We can also see the immediate difference in measured harmonics by just comparing the 3rd harmonic as shown in fig. 10.

Fig. (10). Difference in 3rd harmonic value

We plotted the measured harmonics for each inverter based on the documented test results in the table. 1, as showed in fig. 11.

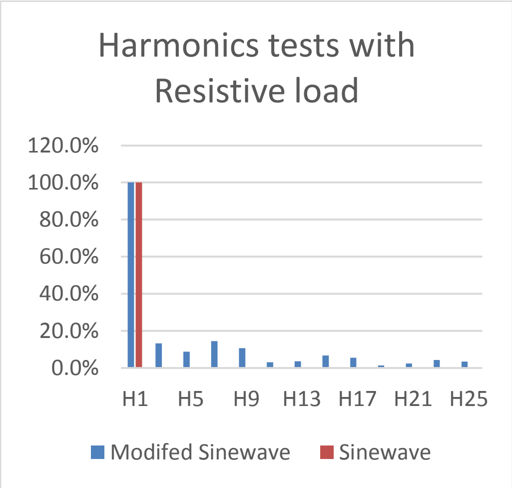

Fig. (11). Harmonics comparison between modified sine wave and pure sinewave

We notice that the power distribution along the harmonics differs from the square wave due to the modification of the wave to bring it closer to the actual sine wave.

2- Inductive Load

In the same way we conducted the resistive load measurements we have carried out the same for the inductive load with the addition of varying the load by varying the speed of the fan.

We also notice the change in the wave form of the modified square wave output due to the interaction with the coils of the motor, while output of the sine wave inverter did not change.as showed in fig. 12, table. 2 and fig. 13, 14, 15.

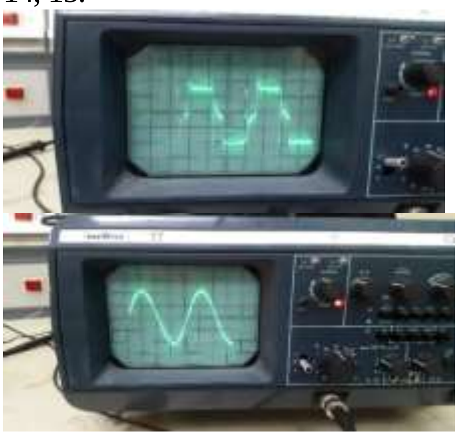

Fig. (12). Effect of the inductive load on the output wave

Table. (2). Test result for inductive load at three fan speeds

	Harmonics tests with Inductive load			
	Fan Speed 1			
	Modified Sinewave		Sinewave	
	Uac=	218	Uac=	223
	Hz=	55	Hz=	50
	THD=	23	THD=	0.4
	Idc=		Idc=	
Harmonics	Amplitude Ratio	Volt	Amplitude Ratio	Volt
H1	100.0%	211	100.0%	223.4
H3	13.0%	27.4	0.2%	0.4
H5	12.7%	26.8	0.3%	0.6
H7	9.4%	19.9	0.1%	0.3
H9	4.2%	8.8	0.1%	0.2
H11	7.3%	15.3	0.1%	0.2
H13	5.1%	10.7	0.0%	0.1
H15	2.1%	4.2	0.0%	0
H17	5.4%	11.3	0.1%	0.2
H19	4.0%	8.5	0.0%	0
H21	0.9%	1.8	0.0%	0.1
H23	4.3%	9.1	0.0%	0
H25	3.7%	7.8	0.0%	0
	Fan Speed 2			
	Modified Sinewave		Sinewave	
	Uac=	216.5	Uac=	223.2
	Hz=	55.22	Hz=	50
	THD=	26.7	THD=	0.4
	Idc=		Idc=	
Harmonics	Amplitude Ratio	Volts	Amplitude Ratio	Volts
H1	100.0%	208.8	100.0%	223.1
H3	12.3%	25.7	0.2%	0.5
H5	13.7%	28.6	0.3%	0.7
H7	10.7%	22.4	0.1%	0.3
H9	2.4%	5.1	0.1%	0.2
H11	7.8%	16.3	0.0%	0.1
H13	7.3%	15.3	0.0%	0
H15	1.0%	2.1	0.0%	0
H17	5.3%	11	0.0%	0
H19	6.6%	13.7	0.1%	0.2

H21	**2.6%**	**5.5**	**0.1%**	**0.1**
H23	**3.6%**	**7.4**	**0.0%**	**0**
H25	**6.0%**	**12.5**	**0.0%**	**0**

	Fan Speed 3			
	Modified Sinewave		**Sinewave**	
	Uac=	**216.9**	**Uac=**	**222.6**
	Hz=	**55.03**	**Hz=**	**50**
	THD=	**31.8**	**THD=**	**0.4**
	Idc=		**Idc=**	
Harmonic	**Amplitude Ratio**	**Volt**	**Amplitude Ratio**	**Volt**
H1	**100.0%**	**206.2**	**100.0%**	**222.5**
H3	**6.4%**	**13.3**	**0.2%**	**0.5**
H5	**16.7%**	**34.3**	**0.2%**	**0.5**
H7	**12.8%**	**26.4**	**0.1%**	**0.2**
H9	**1.5%**	**3**	**0.1%**	**0.2**
H11	**10.0%**	**20.5**	**0.1%**	**0.1**
H13	**10.7%**	**22**	**0.0%**	**0.1**
H15	**4.7%**	**9.8**	**0.0%**	**0.1**
H17	**6.5%**	**13.4**	**0.1%**	**0.1**
H19	**9.6%**	**19.8**	**0.1%**	**0.2**
H21	**6.9%**	**14.2**	**0.0%**	**0**
H23	**4.8%**	**9.8**	**0.0%**	**0**
H25	**8.1%**	**16.5**	**0.0%**	**0**

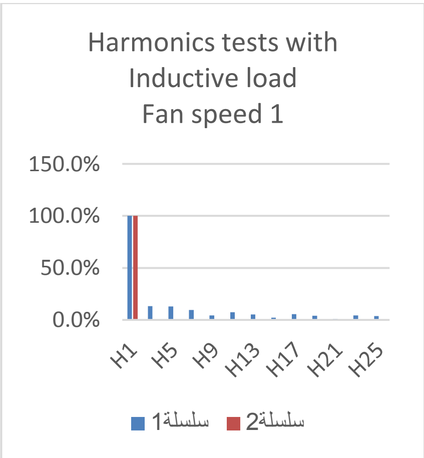

Fig. (13). Harmonics comparison between modified sine wave and pure sinewave Fan speed 1 low

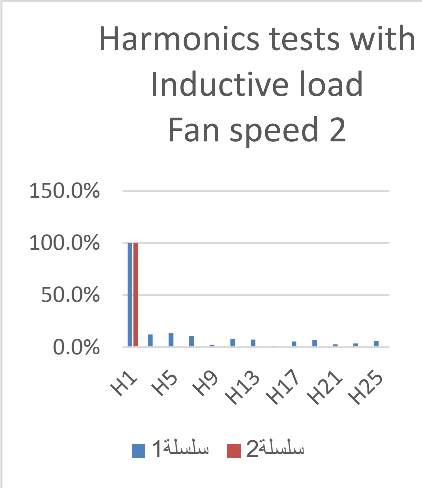

Fig. (14). Harmonics comparison between modified sine wave and pure sinewave Fan Speed 2 medium

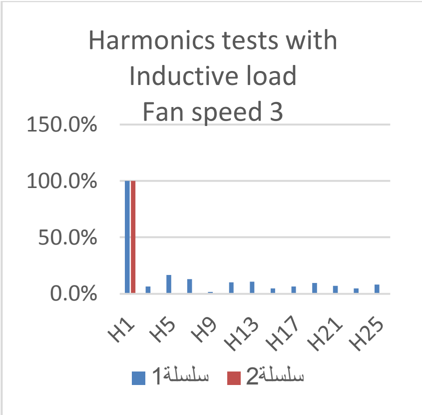

Fig. (15). Harmonics comparison between modified sine wave and pure sinewave Fan Speed 3 High

We notice from the above that the higher the speed the stronger the effect of the harmonics becomes.

3- Mixed Load

For this test we added the resistive load to the inductive load to observe any changes in harmonic behavior. The results are as in table. 3 and fig. 16, 17, 18.

Table. (3). Test result for mixed load at three fan speeds

	Harmonics tests with Mixed load			
	Modified Sinewave		Sinewave	
	Uac=	212.6	Uac=	221,8
	Hz=	55.2	Hz=	50
	THD=	25.3	THD=	0.4
	Idc=		Idc=	
	Fan Speed 1			
Harmonic	Amplitude Ratio	Volt	Amplitude Ratio	Volt
H1	100.0%	206	100.0%	221.7
H3	14.2%	29.3	0.4%	0.9
H5	8.9%	18.3	0.0%	0
H7	12.5%	25.8	0.2%	0.4
H9	7.6%	15.6	0.1%	0.2
H11	1.1%	2.2	0.1%	0.2
H13	6.1%	12.4	0.1%	0.1
H15	7.0%	14.3	0.0%	0.1
H17	3.7%	7.5	0.1%	0.1
H19	1.2%	2.4	0.1%	0.1
H21	4.6%	9.4	0.1%	0.2
H23	4.8%	9.8	0.0%	0
H25	2.1%	4.3	0.0%	0
	Fan Speed 2			
	Modified Sinewave		Sinewave	
	Uac=	212.2	Uac=	221.2
	Hz=	55.23	Hz=	50
	THD=	27.1	THD=	0.4
	Idc=		Idc=	
Harmonic	Amplitude Ratio	Volt	Amplitude Ratio	Volt
H1	100.0%	204.8	100.0%	221.2
H3	13.6%	27.9	0.4%	0.8
H5	9.7%	19.8	0.0%	0.1
H7	14.0%	28.6	0.2%	0.4
H9	9.1%	18.6	0.1%	0.2
H11	0.9%	1.7	0.0%	0.1
H13	5.7%	11.6	0.0%	0
H15	7.7%	15.7	0.0%	0.1
H17	5.1%	10.4	0.1%	0.1
H19	0.4%	0.8	0.1%	0.2
H21	3.9%	8	0.0%	0.1
H23	5.2%	10.6	0.0%	0
H25	3.4%	6.9	0.0%	0
	Fan Speed 3			
	Modified Sinewave		Sinewave	
	Uac=	212.1	Uac=	221.1
	Hz=	55.22	Hz=	50
	THD=	29.2	THD=	0.4
	Idc=		Idc=	
Harmonic	Amplitude Ratio	Volt	Amplitude Ratio	Volt
H1	100.0%	203.6	100.0%	221.1
H3	12.5%	25.5	0.4%	0.8
H5	10.4%	21.2	0.0%	0
H7	15.8%	32.2	0.2%	0.4
H9	11.5%	23.4	0.2%	0.4
H11	3.1%	6.3	0.0%	0.1
H13	4.8%	9.7	0.0%	0
H15	8.1%	16.5	0.0%	0.1
H17	6.6%	13.5	0.0%	0.1
H19	2.2%	4.5	0.0%	0
H21	2.8%	5.7	0.0%	0
H23	5.2%	10.6	0.0%	0
H25	4.5%	9.2	0.0%	0

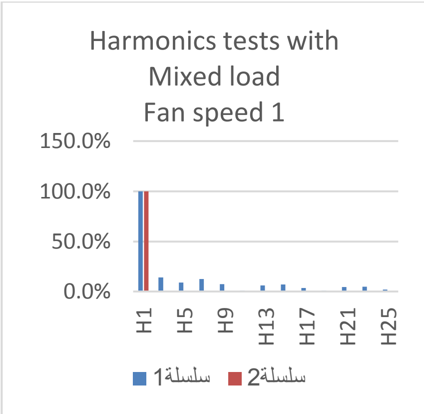

Fig. (16). Harmonics comparison between modified sine wave and pure sinewave Fan Speed 1 low

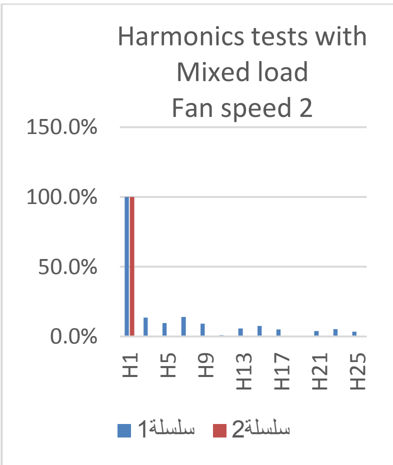

Fig. (17). Harmonics comparison between modified sine wave and pure sinewave Fan Speed 2 medium

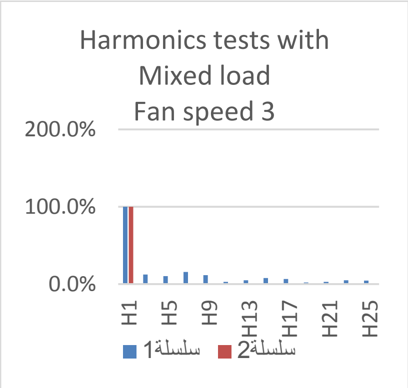

Fig. (18). Harmonics comparison between modified sine wave and pure sinewave Fan Speed 3 High

We have noticed from the above that the resistive load has actually a direct effect on the harmonics and this is due to introducing a change in the overall load characteristics due to a change R-L circuit, that acts as a filter to some frequencies while increasing the effect of others which also impacts better on the THD of the overall output.

4- Inverter power consumption

The two types of inverters have different circuits to achieve the output result. The modified square

wave is the simpler of the two and has less components and a more intolerant approach to the frequency and voltage accuracy, whereas the sinewave inverter is more accurate in means of frequency and voltage and creates less noise which requires more complex circuitry.

We tested the two inverters with the same resistive load over a period of 30 minutes while monitoring the following:

- The Battery DC current based on the voltage drop on the current shunt
- The battery DC voltage
- The Output AC voltage

We then took the average current consumption to compare the two types of inverters. We found that there is an approximate difference of 15% in favor of the modified square wave inverter as it uses less current to operate than the pure sinewave inverter.

The results in table. 4 show the findings.

	Power consumption with resistive load					
	Modified Sinewave			Modified Sinewave		
Time	Adc	Vdc	Vac	Adc	Vdc	Vac
0	44.9	12.3	213.0	50.6	12.4	222.0
5	44.9	12.3	212.8	50.4	12.3	221.0
10	44.8	12.3	212.7	50.6	12.3	221.9
15	44.7	12.3	212.5	51.1	12.3	221.8
20	44.5	12.3	212.3	51.4	12.3	221.7
25	44.4	12.3	212.2	51.5	12.3	221.6
30	44.3	12.3	212.1	51.4	12.3	221.5

Average Shunt voltage	44.6	mV	51.0	mV
Average DC Current based on Shunt Characteristics	8.9	A	10.2	A

Table. (4). The findings

Conclusion

After studying the main two technologies used in inverters we have concluded that the choice between the two types is down to overall load category. If the main requirement is to support day to day essentials that are not frequency sensitive then the modified square wave would be sufficient. It is more cost effective from a commercial point of view as it is cheaper based on price per WATT and has a better efficiency factor which allows for longer battery operations in comparison to the sinewave inverter. In fact the ratio in price between the two units is double, the sinewave being the more expensive one.

But if the application and the equipment is frequency sensitive and can be affected by harmonic noise then the user will have no choice but to use the sinewave inverter.

In a more practical approach for consumers, a hybrid solution can be achieved by separating the mains circuit feeds to the different loads and by means of automatic transfer switches or conductors or relays; the loads can be separated and the user can have a modified square wave inverter for the non-harmonics sensitive loads and a second sinewave inverter for the harmonics sensitive loads running from the same battery bank storage facility in the home or office.

References

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Received	**2017/12/13**	**إيداع البحث**
Accepted for Publ.	**2017/03/30**	**قبول البحث للنشر**