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Right Selection of Inverter Systems and Harmonics Reduction: A Means of Enhancing Power Infrastructure in Nigeria

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ABSTRACT

The paper examines various types of inverter systems available in the markets in terms of their waveforms, harmonics and quality by taking the ideal Sinusoidal waveform as a reference. It illuminates some vital information on various types of inverters and their technologies. It identifies harmonics distortion has an important criterion for selecting a power inverter. It shows in lucid manner how to mathematically determine Total Harmonic Distortion THD of a waveform. It calculates the harmonics content of a Square wave inverter and proffer solution on how to reduce them. The resultant is an empowerment of power electronics engineers to distinguish which of the types to purchase in order to optimally improve national infrastructure and to enhance values of their scarce resources.

KEYWORDS: *Distortion, Fourier-Series, Harmonics, Power, Waveforms*

INTRODUCTION

Harmonics are multiples of fundamental frequency of a waveform. There are even and odd harmonics. In other words, if the frequency of the fundamental is f, then even harmonics will be 2f, 4f, 6f and so on. In the same vein odd harmonics are 3f, 5f and 7f. In electric power system, the menace of harmonics cannot be overemphasized, they cause system malfunctions and increase the temperature of conductors, imagine a waveform with fundamental frequency, f producing its own I^2R losses in form of heat, so also all the harmonics frequencies will produce theirs thus resulting to excessive heat and fire outbreaks. Maule Derek in its treatise in IEE review magazine of March, 2001 opined that the long term effects of harmonic distortions on a network's conductors and components are self evident. He explained that heating and resonant conductors will cause early components failure and the premature breakdown of insulation. He stressed that costs will rise and level of downtime will increase. Going by this, one should be conscious of which type of inverter unit to acquire; however, there have been debates and questions on the best choice for inverters installations. The buyers always ask a question - which types should we purchase; is it Sine wave, Modified Sine wave or Square wave inverters? Anyway, the choice depends on the loads to be powered by them. Majority of the buyers are either indifferent to this or they are not well informed about harmonics content of each type and how the phenomenon will affect their equipment and installation. In spite of this ignorance, there is an upsurge in the procurement of inverters. Especially in third world countries where there are crisis of low energy per capital, a smart business owner or successful house owner would want to generate his or her own power. Attachment to the technology is also borne out of the benefits accruable from it. An inverter power system does not pollute the environment with carbon monoxide poisoning – a factor that has contributed to avoidable death cases in the third world countries, which Nigeria is among. Also, the system does not generate noise. Inverters are DC powered devices that convert DC (Direct Current) to AC (Alternating Current) power by switching the DC input voltage in a predetermined sequence so as to generate AC voltage output,[9]. In a nutshell, they convert battery voltage which is DC to an alternating quantity which is usually 220V, 50Hz as we have in Nigeria. Figure 1 shows a simple block diagram of a power inverter system. As a result of crave to have alternative power sources, that is, renewable energy from the sun and wind, the desire to have static inverters to convert generated Direct Current DC from these sources to Alternating

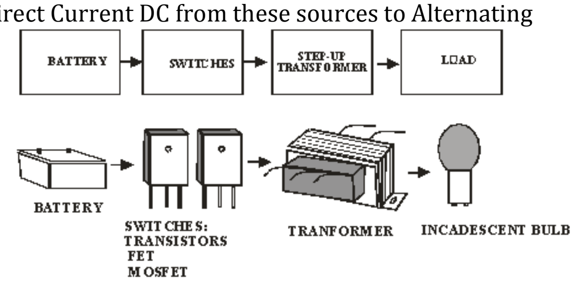

Figure 1: A Representation of a Simple Power Inverter System.

Current AC quantity has increased tremendously, [2]. In olden days, there were rotary inverters that comprise DC motors that have AC generators connected to their shafts. Due to the presence of moving parts, they deliver lower efficiencies of about 60% and they have high idle power consumption, [7]. They are also classified to electric quantity at their sources, that is, Voltage Source Inverters (VSI) and Current Source Inverters (CSI). Current source types are less popular compared to Voltage Source types, [9].

Square Wave Inverters

They have square wave as their output waveforms. The output waveforms rise straight up, level off for a time at peak voltage and then drop straight down. It levels off for a time in the negative direction as shown in figure 2. They were the pioneer static inverters.

The Total Harmonic Distortion THD is about 45%, [2]. They are not efficient, parade poor regulation and are not conducive for some electronic devices, [3]. Electric motors could be powered by them but with excessive heat dissipation. [7].Other devices that may not work properly are laser printers, photocopiers, digital clocks, sewing machines with speed/microprocessor controls and other systems incorporating microprocessors.

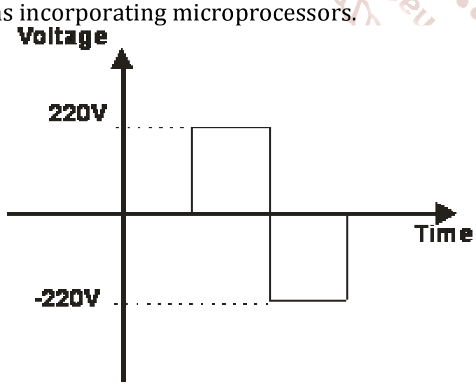

Figure 2: Square Wave.

Modified Sine Wave Inverters

A modified Sine wave inverter, also being referred to as quasi-Sine wave resembles square wave type except that it rests at zero for a short time, thus, has one additional step. [7]. This is the most common inverter output in the market, it has Total Harmonic Distortion THD of 23.8% which is lesser than that of a square wave type of about half of that of square wave, hence more electronics devices will work well with these types. This type has an improved efficiency and better regulation but its high number of harmonics still affects sensitive equipment such as medical monitors. It can also cause hum in a radio or sound system or snowy video picture. [8].

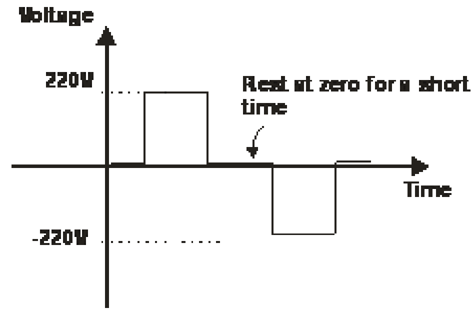

Figure 3 : A Modified Sine Wave

Sine Wave Inverters

They are also referred to as True Sine Wave or Pure Sine Wave Inverters. A Sine wave inverter waveform smoothly increases to its peak and smoothly decreases. They are

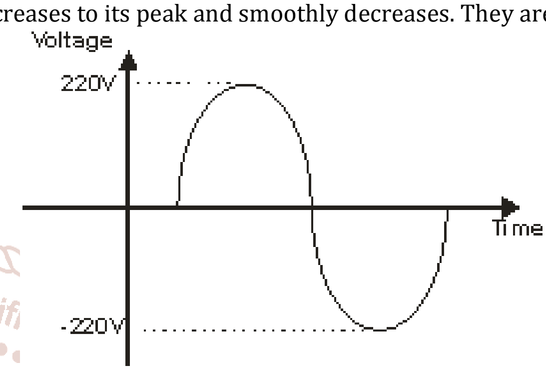

Figure 4: A Sine Wave.

very costly and are not common in the markets. A sine wave inverter has about 3% Total Harmonic Distortion (THD). [2].These types are reliable, harmless, devoid of interference and similar to the power obtainable from the power outlet. [3]. They allow motors to run faster, quieter and cooler. [8]. Pure Sine Wave inverters can safely run more sensitive devices like laser printers, laptop computers, power tools, digital clocks and medical equipment [1].

Inverters Output Waveforms and Timing Circuits of Devices

Timing circuits often work in accordance with zero crossing point. They tend to work for a period where voltages cross zero volts, at this point, they start their clocks. For example, a drill works by pressing its trigger. The trigger allows the electricity to pass depending on the time. A true Sine wave product has a zero crossing slope thus enabling the timing system to commence work. When a load is a simple type, maybe a bulb or resistive element or an induction load, Modified Sine wave performs optimally. But this is not the case with sensitive electronics products – here, a Sine wave inverter will perform better. Some digital clocks are synchronised with ac source voltages, the squaring circuits use the zero crossing points to generate square waves which are afterwards divided by counters for timing purposes.

Waveforms Generation

In electrical engineering, waveforms generations by an engineer can never be waved aside. Everything has to do with either manipulation or synthesizing signals or waveforms. The ideas of waveforms shaping for gating circuitries always highlight the ingenuity of engineers. A function is said to be periodic of its function value repeat it regular intervals of the independent variable. The regular interval between repetitions is the period of the oscillations, [6].

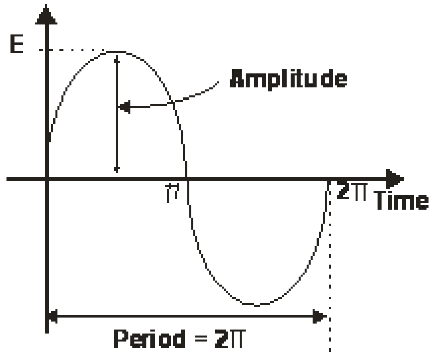

Figure 5: A Representation of a Sine Wave.

Fourier series indicates that a function is made up of sine components. The fundamental frequency consists the largest period and is also called first harmonics. To generate waveforms similar to that of the electricity supply authority, it has to be done in such a way that harmonics distortions are reduced. In some applications, harmonics cause degradation of equipment; hence it has to be de-rated. THD is measured [2] thus

$$THD = \frac{[\Sigma(Distortion\ Products)^2]^{\frac{1}{2}}}{Fundamental} \quad (1)$$

In order to study harmonics, wave shapes understanding is priceless. And this can be done by employing Fourier series which is the tool for analysing wave shapes.

Fourier Series of A Square wave Inverter

If f(x) is defined on the interval $-\pi \leq x \leq \pi$ and $f(x) = f(x + \pi)$, that is, the waveform is periodic,[6].

$$f(x) = a_0 + \sum_{n=1}^{\infty}(a_n Cosnx + b_n Sinnx) \quad (2)$$

$$\text{also } f(t) = a_0 + \sum_{n=1}^{\infty}(a_n Cosn\omega t + b_n Sinn\omega t) \quad (3)$$

it means that

$f(t) = a_0 + a_1 Cos\omega t + a_2 Cos2\omega t + a_3 Cos3\omega t + ... + b_1 Sin\omega t + b_2 Sin2\omega t + b_3 Sin3\omega t + ...$ (4)

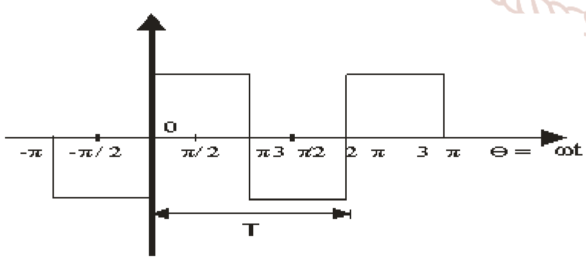

Figure 6: A Representation of a Square Wave.

The square waveform is an odd function since

$$f(t) = -f(-t) \text{ or } f\left(\frac{\pi}{2}\right) = -f\left(-\frac{\pi}{2}\right) \quad (5)$$

$$a_0 = \frac{1}{T}\int_0^{2\pi} f(t)dt \quad (6)$$

$$a_n = \frac{2}{T}\int_0^{2\pi} f(t)Cosn\omega t dt \quad (7)$$

$$b_n = \frac{2}{T}\int_0^{2\pi} f(t)Sinn\omega t dt$$

A waveform that exhibit odd symmetry, only Sine terms are present, $a_0 = 0$. [6].

So equation 4 becomes

$$f(t) = b_1 Sin\omega t + b_2 Sin2\omega t + b_3 Sin3\omega t + ... \quad (8)$$

$$\text{Also, } f(t) = -f\left(t + \frac{T}{2}\right) \quad (9)$$

It repeats itself in magnitude but reverses in phase after every half period. The same thing is applicable over a quarter wave. In this case, $a_n = b_n = 0$ for even n, that is, all even harmonics are absent.

Hence, $f(t) = b_1 Sin\omega t + b_3 Sin3\omega t + b_5 Sin5\omega t + b_7 Sin7\omega t$ (10)

Computing b_n over a quarter wave:

$$b_n = \frac{4}{\pi}\int_0^{\pi/2} f(t)Sinn\omega t dt \quad (11)$$

$$\text{But } f(t) = E_v \text{ dc} \quad (12)$$

By substituting for f (t),

$$b_n = \frac{4}{\pi}\int_0^{\pi/2} ESinn\omega t dt$$

$$b_n = \frac{4E}{\pi n}\left[-Cosn\omega t\right]_0^{\pi/2}$$

$$b_n = \frac{4E}{\pi n}\left[-Cosn\frac{\pi}{2} + Cosn\,0\right] \quad (\Theta = \omega t)$$

$$b_n = \frac{4E}{\pi n}[0 + 1] = \frac{4E}{\pi n} \text{ (n = odd number)}$$

The fundamental coefficient i.e. n=1

$$b_1 = \frac{4E}{\pi}$$

$$f(t) = \frac{4E}{\pi}Sin\omega t + \frac{4E}{3\pi}Sin3\omega t + \frac{4E}{5\pi}Sin5\omega t + \frac{4E}{7\pi}Sin7\omega t \quad (13)$$

From the series, 3rd, 5th and 7th harmonics decreases with a factor of $\frac{1}{n}$, the nearest harmonics having biggest magnitudes, that is, one-third the magnitude of the fundamental, has its frequency equal to 150Hz, [9]. Fundamental frequency is 50Hz as we have in Nigeria. The measure of distortion brought about by harmonics is computed as Total Harmonic Distortion THD thus

$$THD = \frac{[\Sigma(Distortion Products)^2]^{\frac{1}{2}}}{Fundamental}$$

$$= \frac{\left[\sum_{n=3}^{\infty}(b_n)^2\right]^{\frac{1}{2}}}{b_1}$$

Taking E = 1V

$$\text{THD becomes} = \frac{\left[\left(\frac{4}{3\pi} + \frac{4}{5\pi} + \frac{4}{7\pi}\right)^2\right]^{\frac{1}{2}}}{\frac{4}{\pi}}, \pi = 3.142$$

THD = 0.453 × 100% = 45% (Square Wave Inverter)

Using similar methods it can be shown that a Modified Sine Wave and True Sine wave inverters have their THDs equal to 20% and 3% respectively.

Reduction of Harmonics

It has been established that harmonic distortion is the deviation of the generated waveform of the inverter voltage from the ideal sinusoidal waveform. Harmonics presence does affect the load powered by the device hence they have to be mitigated. This can be achieved by connecting harmonics trap filters across the output terminals of the inverter thereby filtering out the harmonics. An LC low pass filter is normally connected to the output terminals of the inverter to roll-off high frequency harmonics. The knowledge of the harmonics frequencies enables tuning of the cut-off frequency of the filter, [9]. The 3rd harmonic is the hardest to filter out and is equal to $\frac{1}{3}$ of the magnitude of the fundamental, [2].

Specifications of Power Inverters

To procure or design and construct an inverter unit, a power electronics engineer is expected to understand the devices to be powered by them in relation to their peculiarities. One should be interested in its protection features, he needs to ask questions like: does it have overload and over temperature shutdown mechanisms, low voltage alarm and shut down protections, short circuit protection, high battery voltage shut down and polarity or reverse connection protection. According to Ningbo, Other desirable specification of note are:

1. Maximum Continuous Power in Watts.
2. Peak Power in Watts.
3. AC output voltage.
4. AC output frequency.
5. AC output waveform.
6. DC input voltage.
7. DC Voltage Range.
8. No load current.
9. Efficiency
10. Charger current
11. Method of cooling
12. Dimensions and Weight.

CONCLUSION AND RECOMMENDATIONS

The paper has succeeded to shed lights on various inverter types; they have been juxtaposed with their harmonic contents. It shows that True Sine wave types have lesser harmonic distortions hence parade superior circuitries with attendant high cost; Square wave types are the cheapest while Modified Sine wave ones are the most common types with quality factor in between the former two. The method for computation of THD for Square wave inverters can as well be employed for others. Reduction of harmonic distortions will undoubtedly mitigate the negatives obtainable from them. All information provided are the types that will aid the capacity of any buyer to choose the right unit for a specific application. Nevertheless, students and designers alike will find the contents provided useful for their scholarly treatise.

Due to the high cost of a pure sine wave inverter, an engineer can obtain an improved Modified Sine Wave Inverter. In addition to the above, the following recommendations are proffered:

1. Modified Sine Wave Inverter can be improved further by adding another step in its waveform, [2].
2. The complexity of the driving stage can be reduced by using MOSFET power stage.
3. The use of IGBT in power stage will bring about excellent high voltage operation and high current handling capacity. [7].

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