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Analysis Of Harmonics On Household Generators

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ABSTRACT
The primary objective of this research is to investigate the impact of harmonics on household generators. To achieve this, harmonic tests were conducted using resistive, capacitive, and inductive loads on an alternating current source connected in series. The methodology involves designing an interface circuit, commonly referred to as a soundcard, to capture the generator output, which was connected to the software scope via a laptop. Additionally, a filter circuit was designed to reduce the harmonic content of the generator output.
The research includes an analysis of data from tests using resistive, inductive, and capacitive loads to determine the impacts of harmonics on a household generator set. Furthermore, the study investigates techniques for eliminating harmonics in a household generator's power supply.
KEYWORDS: *Harmonics, Generator, Loads, Total Harmonic Distortion (THD)*

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I. INTRODUCTION

In today's world, the demand for reliable and high-quality power is at an all-time high due to the widespread use of electronic devices and equipment. The importance of power quality in energy generation is of utmost importance, and managing and minimizing harmonics is a pivotal aspect in ensuring optimal performance and efficiency of the power system. With the development, management, and reduction of harmonics being a significant factor in this context, it is essential to implement effective techniques and technologies for harmonics reduction to ensure a stable and efficient power system [1].

Power quality is crucial in ensuring electrical equipment operates as intended, without significant performance loss [1].

However, harmonic distortions of voltage and current waveforms pose significant challenges to power quality. These distortions have harmful impacts on electrical equipment, resulting in increased power system currents, and affecting the temperature of neutral conductors and distribution transformers. The excessive core heating of motors due to higher frequency harmonics shortens the lifespan of electronic devices and disrupts power systems if left unchecked. Harmonics can also interfere with communication transmission lines [2].

Since the mid-1800s, the development of electrical power generation and distribution has shifted from viewing harmonic content improvement and reduction as a localized generator design issue to an internationally regulated supply characteristic that must be addressed at all points of the power distribution network.

Therefore, this research aims to reduce the effects of current and voltage harmonic distortions on household generators. The study aims to improve the power quality of generators by reducing losses, overheating of equipment, and improving their lifespan, thereby saving consumer spending on generator maintenance, repair, and replacement. This research will explore effective techniques and technologies for harmonics reduction, which will help in ensuring a stable and efficient power system.

II. THEORETICAL FRAMEWORK

Non-linear loads are characterized by a lack of steady impedance in the circuit, unlike linear loads which have constant impedance and current waveform that mirrors the applied voltage. Electronic power loads are a type of non-linear load that can cause harmonic currents and frequency distortion, which can negatively affect communication systems. The issue of harmonic distortions of voltage and current waveforms is currently a major concern for power quality. Ideally, voltage and current waveforms should be perfectly sinusoidal to describe the ideal power supply. Even when serving linear loads, generators may not always produce a completely sinusoidal voltage waveform. If the voltage waveform is not sinusoidal, the voltage distortion caused by the harmonic load currents crossing the generator's sub-transient reactance will be the main cause of voltage distortion [2].

The harmonic distortion is the main measure of power quality, which represents the discrepancy between the actual network voltage or load current and the expected sinusoidal waveform. Harmonics in electrical power engineering can be defined as a sinusoidal waveform of voltage or current that is a perfect multiple of a system's fundamental frequency. Modern electronic gadgets like personal computers (PCs), laser printers, televisions, battery chargers, uninterruptible power supplies (UPS), etc. are known to produce harmonics as by-products. Nonlinear loads powered by SMPS (switched-mode power supplies) units draw current in sharp, brief pulses to produce harmonics [3].

Voltage harmonics can be produced directly from an AC generator due to a non-sinusoidal air gap, flux distribution, or tooth ripple caused by the movement of the slots that house the windings. When an electric generator powers an unbalanced three-phase load, the rotor may experience the flow of a negative sequence current for the frequency conversion effect, which could then induce a third-order harmonic current on the stator winding.

Harmonics can be categorized into two types: odd and even. In supply voltage and load current, odd harmonic distortion predominates [4]. The third harmonic component is responsible for changing the crest factor. Even harmonics are typically modest and are produced by some large converters that are energizing (temporarily increasing) transformers. However, current guidelines on harmonic distortion suggest that equipment should not produce any even harmonics.

In reality, even harmonic distortion is quite modest in supply voltage measurements. Even harmonic distortion causes the signal's positive and negative half cycles to become asymmetrical, but this only occurs when a DC component is present. If there are many even-order harmonics, the signal is not symmetric about the zero axis. Unsymmetrical waves have both even and odd harmonics, while symmetrical waves only have odd harmonics [5]. The asymmetrical waveform is one in which the positive and negative halves of the wave are the same. The positive and negative parts of an asymmetrical wave are different from each other due to a DC component, offsets, or the design of the load. Most modern power system components are symmetrical, but even harmonics can still be produced by ordinarily symmetrical loads due to component mismatches or malfunctions.

III. MATERIALS AND METHOD

Harmonic Measurement Method on Household Generator

The analysis of the harmonics of household generators involves designing an interface circuit to capture the generator output on both load and no-load conditions, and a filter circuit to reduce the harmonic content. To carry out this analysis properly and accurately, essential equipment and materials are required to produce accurate results. These materials include power sources, which are generators, and loads such as resistive, inductive, and mixed loads. The software scope and soundcard interface are also included

The soundcard interface circuit is shown in Figure 1. It consists of a step-down transformer and a variable resistor.

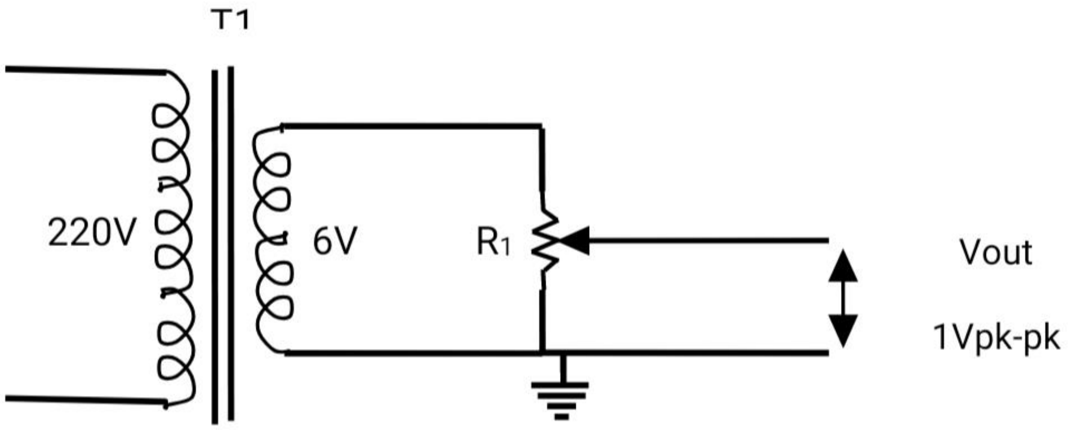


Figure 1: Interface Circuit

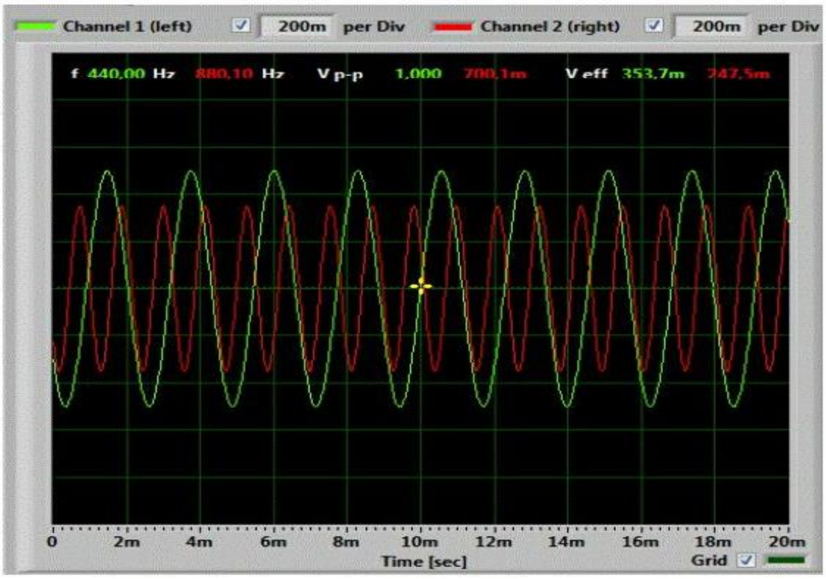
The specification of 1V requires the transformer used to be greater than 1V. Therefore, a step-down transformer of 220V to 6V was chosen. The function of resistor R1 is to adjust the 6V to 1V for the input of the soundcard.

Soundcard Oscilloscope Software

The PC-based soundcard oscilloscope used is by Christian Zeitnitz. It receives data with a 44.1kHz and 16-bit resolution from the soundcard. The frequency range depends on the soundcard model used but typically falls between 20 and 20,000 Hz. The data source can be selected in the Windows mixer as either a microphone, line-in, or wave input. The low-frequency endpoint is limited by the AC coupling of the input signal. It can perform frequency analysis, which is one of the reasons for using it.

Figure 2 illustrates the display of the Fourier analysis results for the selected channel signal in the "frequency analysis" window. The channel can be selected using the button located above the grid. The default settings of the graph display an amplitude range of 0–10,000 Hz. A logarithmic scale, or DB as shown in Figure 3, can be used to depict both the amplitude and frequency.

Figure 2: Signal amplitude and frequency measurement using Zeitniz



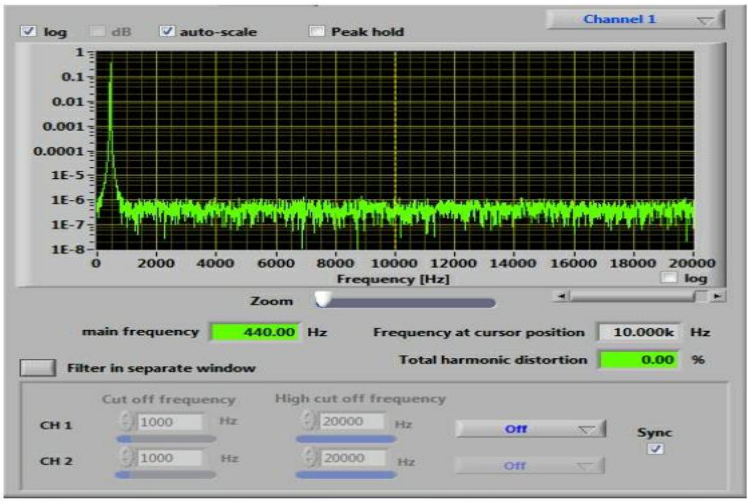


Figure 3: Frequency analysis of a 440Hz signal using Zeitniz

This study involves investigating and analyzing the harmonic content of different generator power sources under no-load and load conditions, which include resistive, inductive, and mixed loads. The analysis setup consists of software, an adapter, an interface, a laptop, a generator, and the load. The adapter is connected to the generator's supply, and the interface and loads are connected to the adapter. The interface is connected to the laptop, and the harmonic distortion waveform is observed through the software. The analysis is performed with three different household generators (750VA, 5KVA, and 7.5KVA), and the results are shown in Tables 1, 2, and 3.

Harmonic Reduction Method

Basics of filter design

Harmonic filters are installed on the AC side of converters to decrease the flow of harmonics that could otherwise interfere with communication circuits and have other negative effects [12].

A harmonic reduction method was introduced to the system by designing and connecting a harmonic filter to the adaptor in the above-mentioned setup connections. The harmonic filter was designed using Series Resonance. Equations 1 and 2 demonstrate that, during series resonance, the inductive reactance of system components (such as transformers) is equivalent to the capacitive reactance of system components (such as cables or capacitor banks), resulting in an extremely low circuit impedance.

$$\omega L = \frac{1}{\omega C} \quad (1)$$

The natural resonant frequency will be

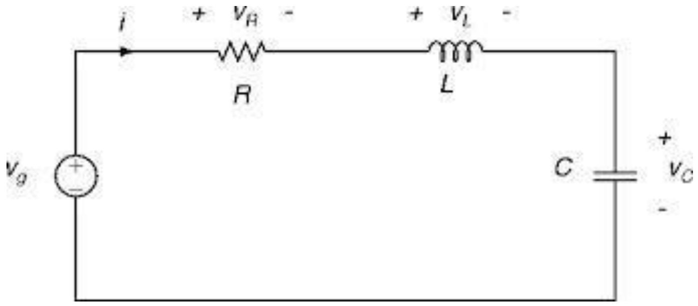
$$f = \frac{1}{2\pi\sqrt{LC}} \quad (2)$$

The resonant frequency is the frequency at which the total impedance of a series RLC circuit becomes purely "real" (i.e., no imaginary impedances exist). This occurs because at resonance, the imaginary impedances are cancelled out, meaning that the value of XL - XC should be equal to zero.

Rating and Design of Inductor

Once the capacitor value has been fixed, it is easy to determine the reactor value needed to achieve series resonance at that specific harmonic frequency. Assuming that R is negligible, the value of L or C can be determined when the value of one of the storage elements is known. For the 150Hz harmonic,

Figure 4: RLC Circuit Diagram



$$L = \frac{1}{4\pi^2 f^2 C} \quad (3)$$

For a value of C as 5µF, the L is

$$L = \frac{1}{4\pi^2\, 150^2\, 5x10^{-6}} = 0.22\text{H}$$

The interface was connected to the laptop, and the harmonic distortion waveform was observed through the software with an LC filter. Using this setup, the analysis was performed on three different household generators (750VA, 5KVA, and 7.5KVA), and the results are presented in Tables 4, 5, and 6.

IV. RESULTS AND DISCUSSION

The harmonic content, as measured and verified using the soundcard oscilloscope, is presented in Tables 1, 2, and 3, as well as Charts 5, 6, and 7 in this section, under various generator sources and load conditions.

Table 1: Test Results from 750VA Tiger Generator

S/No	Load description	Fundamental frequency	Voltage (V)	Total harmonic distortion THD (%)
1	No load	50.8	234	28
2	750W Electric Fan (Inductive)	50.5	226	24
3	100W Incandescent bulb	50.2	221	22
4	20W energy saving bulb	50.4	227	28
5	Mixed loads 75W fan, 100W bulb, 10W LED bulb	49.3	215	21

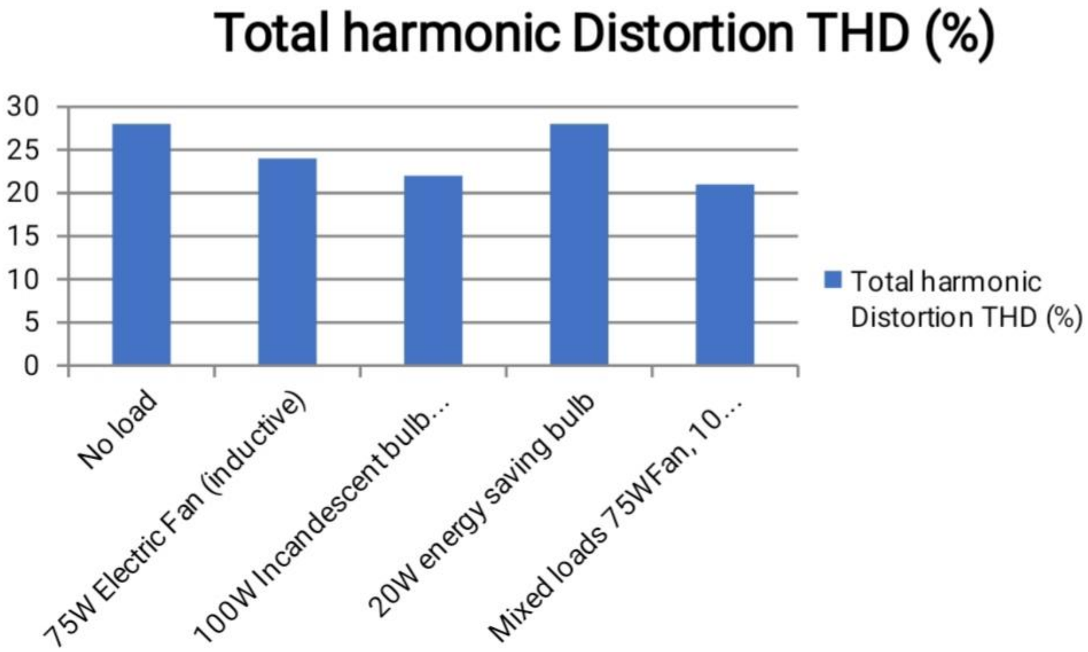


Figure 5: Chart of THD 750VA Generator under varied load conditions

Table 2: Test Results from 5KVA Fireman Generator

S/No	Load description	Fundamental frequency (Hz)	Voltage (V)	Total harmonic Distortion THD (%)
1	No load	50.6	230	13
2	750W Electric Fan (Inductive)	50.5	228	23
3	100W Incandescent bulb	50.2	224	12
4	20W energy saving bulb	50.3	228	14
5	Mixed loads 75W fan, 100W bulb, 10W LED bulb	50.3	222	24

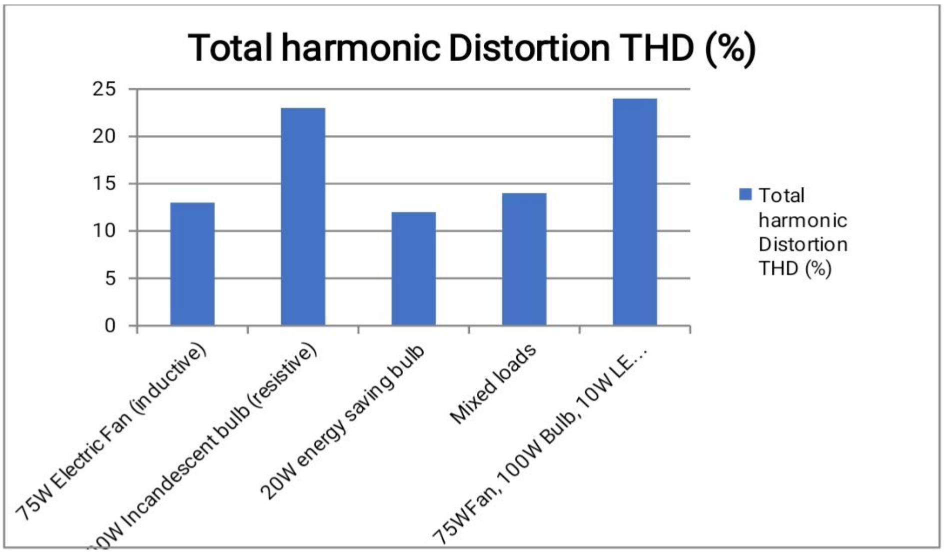


Figure 6: Chart of THD 5kVA Generator under varied load conditions

Table 3: Test Results from 7.5KVA Fireman Generator

S/No	Load description	Fundamental frequency (Hz)	Voltage (V)	Total harmonic Distortion THD (%)
1	No load	50.4	235	10
2	750W Electric Fan (Inductive)	50.3	232	15
3	100W Incandescent bulb	50.4	230	9
4	20W energy saving bulb	50.3	231	13
5	Mixed loads 75W fan, 100W bulb, 10W LED bulb	50.1	229	23

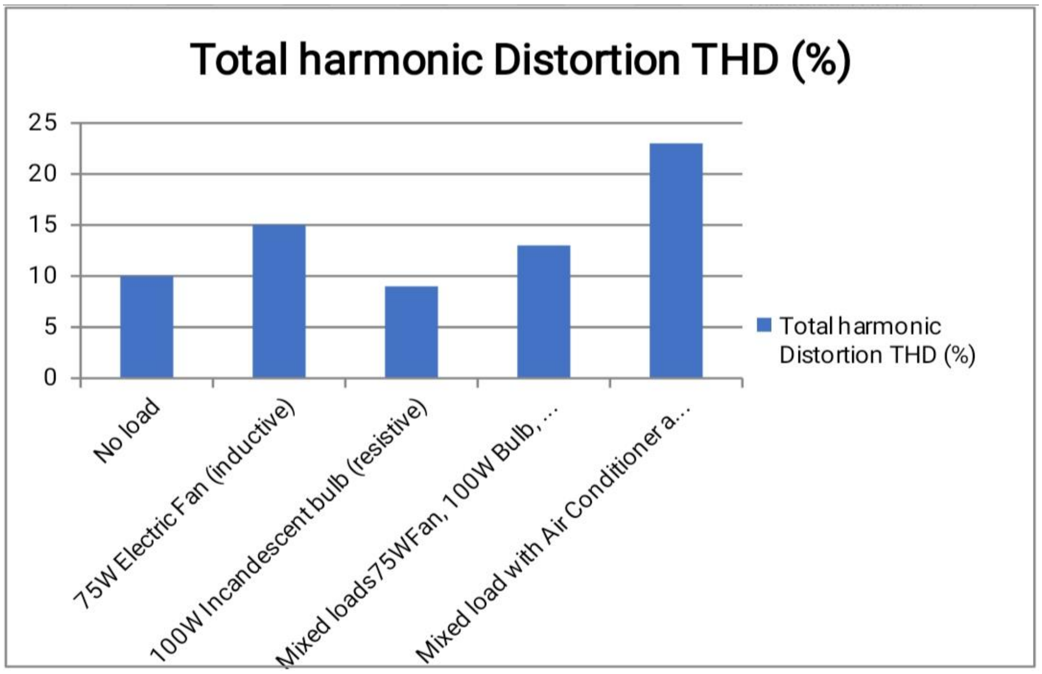


Figure 7: hart of THD 7.5kVA Generator under varied load conditions

Test Results of the Effect of Filter Application to mitigate harmonic Content

Harmonics are unwanted signals that can cause problems with the normal operation of loads, especially inductive and digital loads. Because of the high voltage levels involved (220Vac), a passive LC filter was designed and applied to the output, and all the previous tests were repeated. The test results are presented in Tables 4, 5, and 6.

Table 4: Test results from 750VA Tiger Generator with LC filter

S/No	Load description	Fundamental frequency (Hz)	Voltage (V)	Total harmonic Distortion THD (%)
1	No load	50.8	234	25
2	750W Electric Fan (Inductive)	50.5	226	21
3	100W Incandescent bulb	50.4	221	19
4	20W energy saving bulb	50.2	227	24
5	Mixed loads 75W fan, 100W bulb, 10W LED bulb	49.3	215	18

Table 5: Test results from 5KVA Fireman Generator with LC filter

S/No	Load description	Fundamental frequency (Hz)	Voltage (V)	Total harmonic Distortion THD (%)
1	No load	50.5	230	10
2	750W Electric Fan (Inductive)	50.5	228	21
3	100W Incandescent bulb	50.2	224	10
4	20W energy saving bulb	50.3	228	11
5	Mixed loads 75W fan, 100W bulb, 10W LED bulb	50.3	222	19

Table 6: Test results from 7.5KVA Fireman Generator with LC filter

S/No	Load description	Fundamental frequency (Hz)	Voltage (V)	Total harmonic Distortion THD (%)
1	No load	50.4	235	10
2	750W Electric Fan (Inductive)	50.3	232	13
3	100W Incandescent bulb	50.4	230	8
4	20W energy saving bulb	50.3	231	12
5	Mixed loads 75W fan, 100W bulb, 10W LED bulb	50.1	229	21

The test results show that the total harmonic distortion (THD) varies based on the type of load, load capacity, and generator rating. The higher-rated generators were observed to have better THD values than the popular 650/750VA household generators, and their frequency stability was also better, as shown in the test results (comparing Table 3 and 6). In all three generator models tested, it was observed that inductive loads (e.g. 75W electric fan) have higher THD than resistive loads. This is because inductive loads generate more harmonics than resistive loads.

Comparing tables 1, 2, and 3 with tables 4, 5, and 6, it was observed that the total harmonic distortion was reduced after the introduction of a passive LC filter to mitigate the harmonics in the system. The results show that the use of filters is promising in reducing harmonics if the inductors are properly designed.

V. CONCLUSION

In conclusion, harmonics are a natural occurrence in electrical systems and their study is crucial, especially for generators that power non-linear loads, as excessive harmonic content can lead to a reduced lifespan of the generator. The experiments conducted on 7.5KVA, 5KVA and 750VA generators revealed that the THD values were within acceptable limits of 6% for electrical electronic systems for the 7.5KVA and 5KVA generators, while the 750VA generator produced harmonics which resulted in a THD of over 6%. It was observed that higher rated generators exhibited better THD values, which can be attributed to good automatic voltage regulators (AVR) and output impedance matching between source to load. This research proposes a method for selecting the most appropriate generator output power rating to safely operate non-linear loads, which relies on studying the THD generated by non-linear loads coupled to the system. Overall, this research on harmonics in household generators has provided valuable insights into the causes and effects of power quality in household generators.

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