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EVALUATION OF THE IMPACTS OF LOAD VARIATION ON VIBRATION AND QUALITY OF POWER GENERATED IN STANDALONE GENERATOR

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Abstract
Standalone generators are vital for supplying electricity in remote areas and serving as backup systems where national grid power is unavailable. Their performance and longevity, however, are often compromised by load variations during operation. This study investigates the impacts of load fluctuations on vibration behaviour and power quality in two standalone generators of different ratings: Generator 1 (TG950, 0.650 kVA) and Generator 2 (SENWEI, 1.5 kVA). Experiments were conducted using resistive loads to simulate real-world operating conditions. The methodology encompassed three stages: analyzing vibration levels under varying load types, assessing voltage and current stability, and developing a predictive model to estimate the effects of load variation. Results showed that load variations influence both vibration intensity and electrical output, with measurable deviations in power parameters of voltage and current under different load conditions. It is concluded that varying loads significantly increase vibrations due to added mechanical stress; and fluctuating loads disrupt voltage and frequency stability. In order to enhance generator performance and reduce vibration issues, implementing effective load management strategies is essential.

Keywords:. Evaluation, load variation, vibration, power generated, standalone generator

Introduction

The assessment of the effects of load change on vibration and quality of the power produced in standalone generator is critical towards the understanding of the behavior of standalone generators under different conditions of load. Standalone generators are very popular in remote locations, micro grids and backup power, where they frequently run under dynamically loaded conditions (IEEE, 2019). The reliability and efficiency of power generation systems are crucial in meeting the increasing demand for electricity. However, power quality issues can significantly impact the performance and longevity of equipment. Load variation is a key factor affecting power quality, particularly in generators, power quality issues can arise from various sources, including load variation, generator design, and operating conditions (El-Sharkawy et. al., 2022). Load variation can cause changes in electromagnetic forces and mechanical stresses within generators, leading to increased vibration (Li *et. al.,* 2021). Vibration can cause mechanical stress, fatigue, and premature failure of generator components, while power quality issues can affect the reliability and efficiency of connected loads by (Ahmed, 2020). Studying the impacts of load variation on generator performance is essential to; improve generator design and operation (by understanding the effects of load variation, generator designers and operators can optimize generator design and operation to minimize vibration and power quality issues) and enhance reliability and efficiency (by mitigating the impacts of load variation, generator reliability and efficiency can be improved, reducing downtime and increasing overall system performance. The variation of load on a generator impacts its performance in several ways, including changes in voltage, frequency, and efficiency. When the load

increases, the generator must work harder, potentially causing a drop in voltage and frequency if it cannot supply the additional power. Conversely, reducing the load may lead to overvoltage or reduced efficiency. According to Pietro (2020), evaluating the impacts of load variation on vibration and power quality involves analyzing how fluctuating electrical loads affect the generator's mechanical stability and electrical output. A study on standalone power generators in Nigeria found that synchronizing seven generators serving different buildings achieved a maximum voltage drop of 2.32%, meeting permissible voltage conditions and indicating potential for increased load efficiency (Dare-Adeniran et al., 2024). The environmental effects of standalone generators are also significant, with gasoline-fired generators producing higher carbon monoxide emissions (up to 733ppm) compared to gas-fired generators (up to 204ppm), exceeding WHO standards, vibration levels can be excessive, with sound levels reaching up to 90dB, posing health risks to operators and nearby residents, (Lawal et al., 2020). Excessive variations can also lead to mechanical stress and overheating, potentially damaging the generator over time. It is important to monitor and regulate the load to maintain optimal generator performance.

Theoretical Review

Load Variation on Generator. Load variation on a generator refers to changes in the electrical load connected to the generator, which can impact its performance, efficiency, and reliability (Kundur and Paserba, 2020).

Effects of Load Variation. Changes in load can cause voltage fluctuations, which can affect the generator's output and connected equipment, and can also cause frequency deviations, which can impact the generator's stability and reliability (IEEE, 2022a). Repeated load variations can lead to increased wear and tear on the generator's components, reducing its lifespan (IEEE, 2018). Current Increase: The current flowing through the coils increases to meet the higher power demand. Temperature rise: The increased current leads to higher copper losses (I2R) and temperature rise in the coils. Also, increased stress: The coils experience increased electromagnetic forces and thermal stresses.

The Effect of Load Variation on Vibration. As the load changes, the generator experiences fluctuations in torque and speed, leading to mechanical stress and variations in vibration levels **(**Bloxsom, 2019). Sudden load increases or decreases can cause resonance conditions, amplifying vibrations that may result in mechanical fatigue or damage (Kastawan, 2018**).** Rotor Imbalance: Uneven load distribution affects rotor stability, increasing vibrations, which, if excessive, can lead to premature wear on components (Albarakati, 2021).

Causes of Generator Vibration. Vibration on generator can be cause by the following: Unbalance rotor or shaft, Misalignment of shafts or bearings, worn or damaged bearings, loose or worn-out components, such as bolts or couplings, operational factors such as Overloading, under loading, or operating at critical speeds, and poor maintenance, such as dirty or worn-out components, can cause vibration.

Effects of Vibration on Generators

Reduced Component Life: Vibration can cause mechanical stress on generator components, leading to premature wear and tear, and ultimately reducing their lifespan (Rao, 2019).

Noise and Dynamic Loading: Vibration can generate noise and dynamic loading on the generator's foundation and surrounding structures, potentially causing damage or disturbance (Zhang. et. al., 2020).

Power Quality Issues: Vibration can affect the generator's output, leading to power quality problems such as voltage fluctuations, frequency variations, and waveform distortion (Power Tech, 2018).

Material and Methods

The practical experiment was setup by designing a load bank, where controlled and incremental load variations can be applied so that the vibration level can be determined.

The Figures 1 and 2 showed section by section of the construction of the load box, using 2.5mm2 cables, single way 10A switch and lamp holder and Figure 3 shows the complete load bank

Assessing the impact of load fluctuations on the power quality generated by standalone generator

Generator 1, in Figure 4 (TG 950) and Generator 2, in Figure 5 (SENWEI) have different specification as shown in Table 1. Both are used for assessing the effects of load variation on vibration and the power quality. In a standalone generator system, the governor and the automatic voltage regulator (AVR) work hand in hand to ensure stable operation. Generator 1, operating under governor race, manages the mechanical side by regulating fuel input to maintain rotor speed and thus frequency stability during load changes. Generator 2, operating with an AVR, manages the electrical side by adjusting the excitation current to stabilize terminal voltage and reactive power flow. Together, these controls complement each other: the governor keeps the system frequency within acceptable limits, while the AVR ensures voltage quality, minimizing sags, swells, and distortion. Effective coordination between the two is essential for reliable power generation, especially in standalone setups where there is no external grid support.



Figure 1: Drilling hole on the socket



Figure 2: Wiring the load box

Table 1: Generator Specifications

Specification	Generator 1	Generator 2
Frequency	50 Hz	50 Hz
Rated Output	0.650kVA	1.5 kVA
Max Output	0.800kVA	1.8 kVA
Phase	Single	Single
Poles	2	2
No-load Voltage	238 V	238.24 V
No-load Current	0.43 A	0.00 A
No-load vibration	3.42 m/s²	1.26 m/s²



Figure 3: Complete load bank



Figure 4: Generator 1

Experiment: voltmeter meter and clamp meter were connected to the load, as shown in Figure 6. Voltage and current were measured during each vibration at variable loads to determine the power quality. Measurement of vibration under various conditions of load was carried out by connecting the generators to the load bank; and vibration sensors from the Vibrometer also connected to the generator metallic part.



Figure 5: Generator 2

Result and Analysis

The load variation and the vibration of generator 1 (0.650kVA).

From the Table 2, the graph of vibration against load, and the chart of voltage, current and load was plotted and presented as shown in Figures 7, 8 and 9.

Vibration (m/s²) grows sharply, showing a nonlinear increase with higher load. The rapid increase of this nature implies that the mechanical load increases the stress of the body without proportional increase. Uncontrolled vibration may increase the rate of bearing wear, lateral misalignment of the shaft, and structural fatigue, and eventually decrease the reliability of the generator.

Load increases gradually decreasing voltage (V). Voltage gradually falls as high as 218 V at 25% loading to 195 V at 100% loading. This deterioration

shows a low voltage regulation ability of the generator at increased load. Such instability can negatively affect sensitive equipment, leading to malfunctions or reduced lifespan.

Table 2 Generator 1 data

Load (W) and its %	Voltage (V)	Current (A)	Vibration (m/s²)
200W (25%)	**218**	**1.04**	**14.00**
400W (50%)	**214**	**1.91**	**20.72**
600W (75%)	**205**	**2.98**	**30.80**
800W (100%)	**195**	**4.21**	**45.74**



Figure 6: Measurement of vibration level, current and voltage

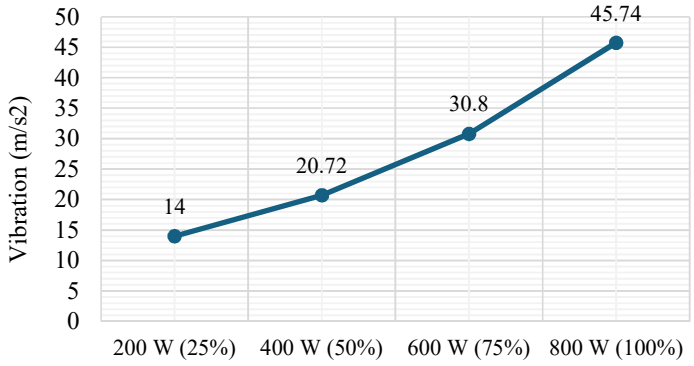


Figure 7: Vibration against Load

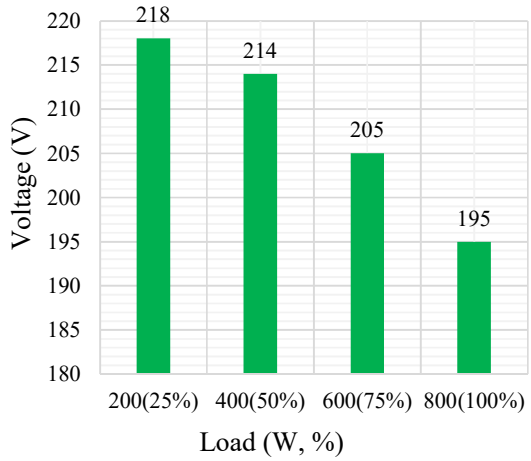


Figure 8: Voltage against Load

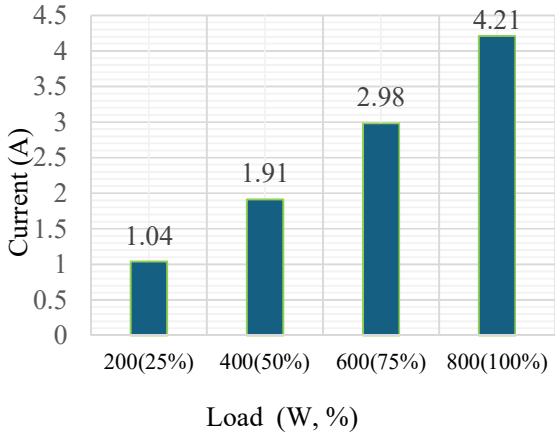


Figure 9: Current against Load

The current (A) increases nearly linearly, increasing by 1.04 A when the load is 25 percent to 4.21 This is due to the fact that the current generated in the generator is proportional to the load and this is in line with the expected behavior of electrical demand. The linear increase in current is however contributing to heating effects in windings and higher copper losses as well. Generally, the chart makes it clear that while electrical parameters follow expected trends, vibration escalates disproportionately, highlighting mechanical stress at full load.

Summary: The curve indicates that, although the current increases in a predictable fashion with load, the voltage stability declines and vibration increases exponentially thus load control is the key factor in both mechanical and power quality. This highlights the importance of balancing load levels to protect both mechanical integrity and power quality in standalone generators

The load variation and the vibration of generator 2, (1.5 kVA).

From the Table 3, the graph of vibration against load, and the chart of voltage, current and load was plotted and presented as shown in Figures 10, 11 and 12.

Voltage (V): Voltage drops from 230 V at 200W (14%) to 187 V at 1400W (100%). Such a gradual degradation implies low level of voltage regulation at high loads that may play out on sensitive electric devices

Vibration (m/s2): grows disproportionately, from 8.12 m/s² at 200W to 26.99 m/s² at full load. Mechanical stress escalates faster than electrical demand, showing that vibration is a critical limiting factor for generator reliability

Current (A)**:** Current is nearly in a straight line, 0.89 A/200W all the way to 7.56 A/1400W. This is no surprise since increased loads require increased current. Nevertheless, increased current is the cause of heating and efficiency loss.

Table 3 generator 2 data

Load (W) and its %	Voltage (V)	Current (A)	Vibration (m/s²)
200W (14%)	230	0.89	8.12
400W (29%)	223	1.84	9.39
600W (43%)	218	2.82	12.18
800W (57%)	208	3.87	15.12
1000W (71%)	203	5.05	19.43
1200W (86%)	193	6.37	23.73
1400W (100%)	187	7.56	26.99

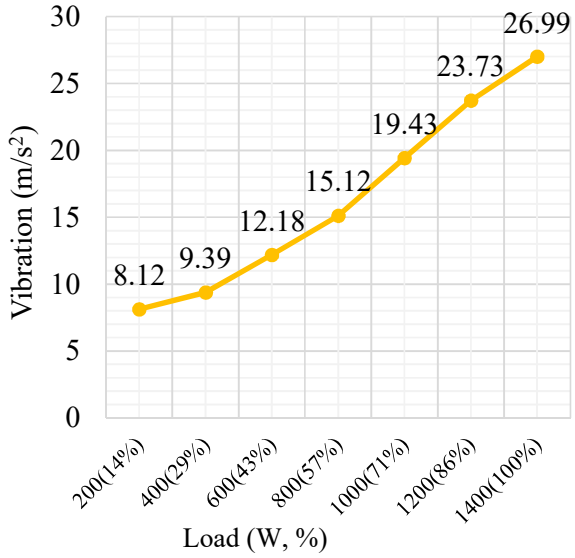


Figure 10: Vibration against Load

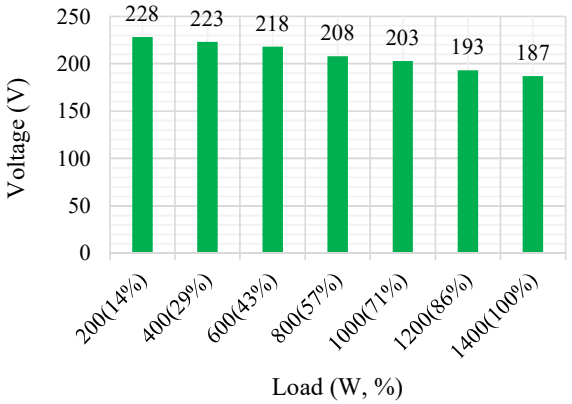


Figure 11: Voltage against Load

Conclusion and Recommendation. This paper reviewed the effects of the load variation in the vibration levels and power quality in standalone generators. The results reveal that different loads cause a considerable amount of vibrations because of additional mechanical stress. This is what reflects the necessity of regular maintenance. Also, changing loads cause a destabilization of voltages and

frequencies, which influences the quality of power negatively. To improve the work of generators and decrease the problem of vibrations, it is necessary to introduce successful load management practices. Further studies on the development of superior monitoring and control procedures to alert vibration exceeding tolerable limit on time to ensure stability and efficiency of generators should be carried out in the future. Finally, the relation between the load change, vibration, and power quality is a more important concept that can be better understood to improve the performance and reliability of a generators.

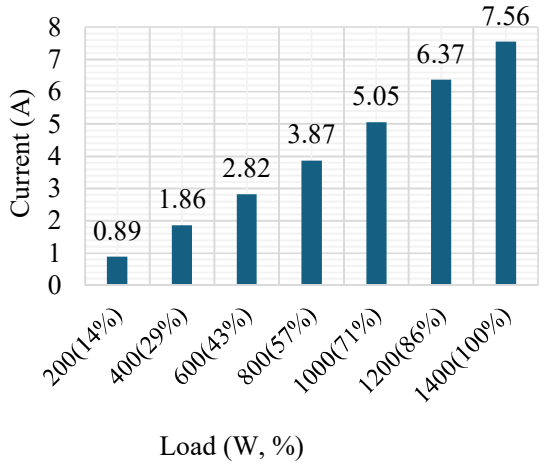


Figure 12: Current against Load

There should be acceptable vibration limit on the generator to be able to trip off the equipment and the loads connected and therefore eliminate malfunctioning and destruction. In addition, should not work at 100 percent capacity, but 70-80 percent to balance efficiency versus stability hence unnecessary vibration

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