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Analysis of Harmonics on Power Factor in Industrial Loads

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Abstract: This paper investigates the effect of nonlinear load variation on power factor and harmonic distortion using MATLAB/Simulink. A three-phase system with a step-down transformer and a diode bridge rectifier feeding a resistive-inductive load was modelled. The inductance was varied in steps to analyse its impact on Total Harmonic Distortion (THD) and power factor (PF). FFT analysis was used to extract the harmonic spectrum, while scope blocks were used to observe voltage-current waveforms and calculate PF. Results show that increasing the inductive component of the nonlinear load significantly raises THD and reduces power factor. This highlights the importance of harmonic analysis and the role of simulation in designing power-efficient and power-quality-compliant industrial systems.

Keywords: Power Factor, Harmonics, THD, MATLAB Simulation, Nonlinear Loads.

I. INTRODUCTION

Power factor is a critical parameter in electrical power systems that reflects how effectively electrical energy is being utilized. It is defined as the ratio of real power to apparent power and ideally should be close to unity. A low power factor indicates inefficiency, leading to increased transmission losses, voltage drops, and higher electricity bills for industrial consumers. One of the key contributors to poor power factor in modern industrial systems is the presence of harmonics—non-sinusoidal waveforms generated primarily by nonlinear loads such as diode bridge rectifiers (DBRs), variable frequency drives (VFDs), and uninterruptible power supplies (UPS). These loads draw current in abrupt pulses rather than smooth sine waves, causing distortion in the current waveform. As a result, the overall system power factor deteriorates, not only due to phase displacement but also because of waveform distortion, known as the distortion power factor component.

In practical power systems, nonlinear loads introduce harmonic currents that interact with system impedance and create voltage distortion, adversely affecting both equipment performance and energy efficiency. The inductive component of such loads plays a major role in shaping the current waveform and influencing the generation of harmonics. As the inductance increases, it alters the conduction angle of rectifiers, resulting in more severe current distortion and higher Total Harmonic Distortion (THD). To study this phenomenon in a safe, flexible, and cost-effective environment, MATLAB/Simulink offers a powerful simulation platform. This project investigates the relationship between varying inductance in a DBR-based load and its effect on both harmonic content and power factor. By using an FFT analyser and scope blocks, the simulation captures the harmonic spectrum and power factor behaviour under different inductance values, offering insight into power quality challenges and the importance of harmonic mitigation techniques in industrial systems.

II. LITERATURE REVIEW

Harmonic distortion caused by nonlinear loads has been a major area of concern in power systems due to its adverse effects on power factor and overall power quality. According to IEEE 519-2014 standards, controlling harmonics is essential to ensure efficient and safe system operation. Nonlinear devices such as diode bridge rectifiers (DBRs) generate non-sinusoidal currents, which distort the waveform and increase Total Harmonic Distortion (THD), leading to a reduction in power factor. Various researchers have used simulation tools like MATLAB/Simulink to model and analyse these effects under controlled conditions. Prior studies have demonstrated that as the inductive nature of the load increases, harmonic distortion becomes more significant, further degrading the power factor. Moreover, harmonic-rich environments have been linked to increased system losses, overheating, and equipment malfunction.

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These findings highlight the necessity of harmonic analysis and mitigation in industrial systems, especially where large-scale nonlinear loads are present. This research builds on such studies by focusing on how varying inductance in a DBR-based system affects THD and power factor using MATLAB simulation.

III. SYSTEM MODELLING

The MATLAB/Simulink model used in this study consists of several key components designed to simulate the behaviour of a nonlinear load under varying inductance and to analyze its effect on power factor and harmonic distortion.

1. Three-Phase Voltage Source: This block provides a balanced 11 kV, 50 Hz three-phase AC supply, representing a typical industrial power source.

2. Step-Down Transformer (11 kV/400 V): The transformer is used to reduce the high-voltage supply to a usable 400 V level suitable for feeding the nonlinear load. It ensures proper voltage isolation and step-down conversion.

3. Diode Bridge Rectifier (DBR): A three-phase diode bridge rectifier is employed to convert the AC output of the transformer into a pulsating DC voltage. This rectifier introduces nonlinearity into the system, making it a significant source of current harmonics.

4. R-L Load (Resistive-Inductive Load): Connected to the DC side of the rectifier, this load simulates industrial nonlinear characteristics. While the resistance is kept constant, the inductance is varied to analyse its impact on THD and power factor.

5. FFT Analysis Block: This block is used to analyze the harmonic spectrum of the input current. It calculates the Total Harmonic Distortion (THD) by evaluating the magnitude of harmonic components relative to the fundamental frequency.

6. Scope Block: Scope blocks are employed to visualize the voltage and current waveforms. These waveforms are used to observe distortion and phase shift, which help estimate the power factor for each load condition.

7. Measurement Blocks: Voltage and current measurement blocks are added to provide input data for the FFT analyzer and scope. These measurements form the basis for all performance evaluations in the simulation.

IV. METHODOLOGY

1. A simulation model was developed using MATLAB/Simulink to study the impact of nonlinear load variation on power factor and Total Harmonic Distortion (THD).

2. The system includes a three-phase 11 kV, 50 Hz AC source, connected to a step-down transformer rated at 11 kV/400 V.

3. The secondary of the transformer supplies a three-phase diode bridge rectifier (DBR), forming the nonlinear load.

4. A resistive-inductive (R-L) loads are connected to the output of the rectifiers. The resistance remains constant, while the inductance is varied.

5. Total Harmonic distortion (THD) is measured using the FFT Analyzer.

6. Power factor is analysed using Scope blocks by observing the phase shift and waveform distortion between current and voltage waveforms.

7. Voltage and current measurement blocks are used to supply data to the FFT analyser and scopes.

8. The simulation is executed for a duration of 0.2 seconds using a fixed-step discrete solver, ensuring accurate capture of waveform behaviour.

9. The results for each inductance value are recorded, compared, and analysed to determine the relationship between inductance variation, harmonic distortion, and power factor performance.

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V. SIMULATION MODEL

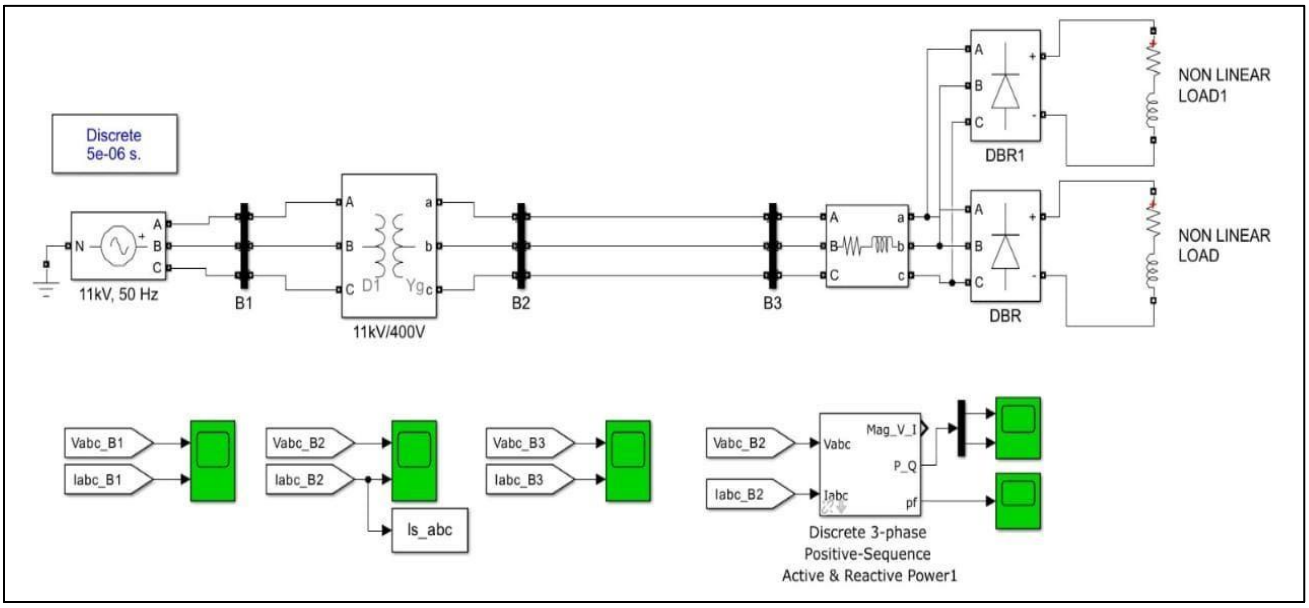

Fig 1. Block Diagram

Table 1. Analysis Of THD (%) On Power Factor in Industrial Loads

Non-Linear Load 1 Inductance	Non-Linear Load 2 Inductance	THD (%)	Power Factor
5mH	10mH	3.29%	0.834
10mH	20mH	3.52%	0.83
30mH	40mH	4.55%	0.82
50mH	60mH	4.79%	0.815
70mH	80mH	5.09%	0.804
100MH	150mH	5.45%	0.801

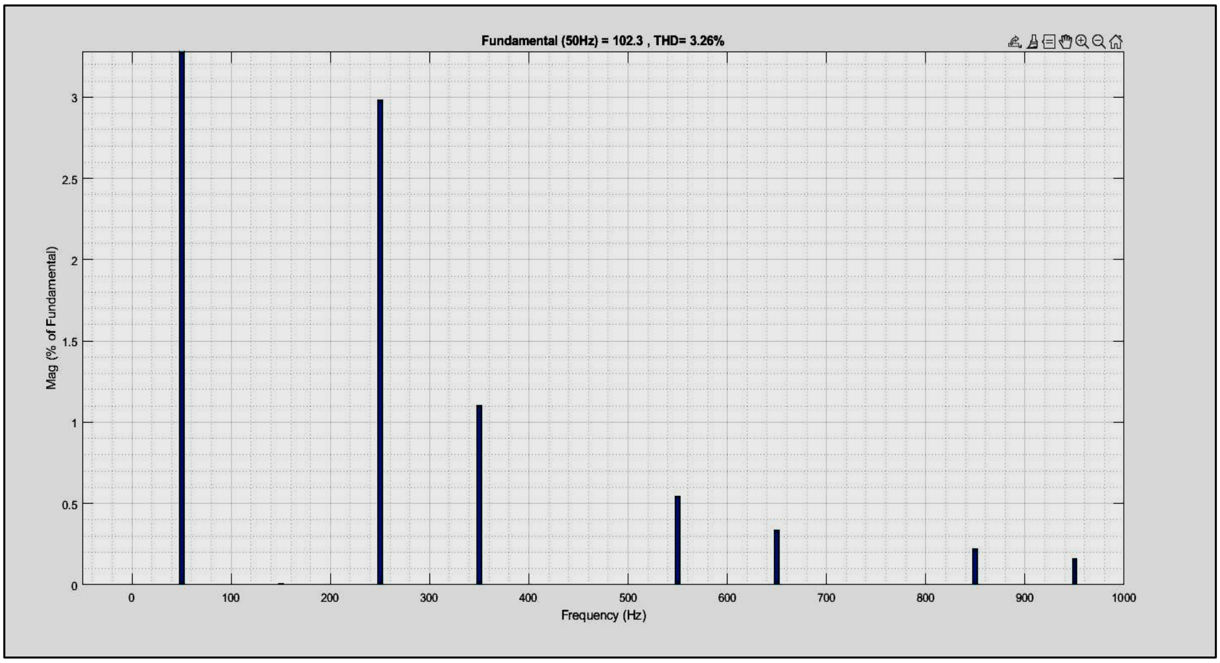

Fig. 1.1(a): Simulated THD (3.29%) waveform

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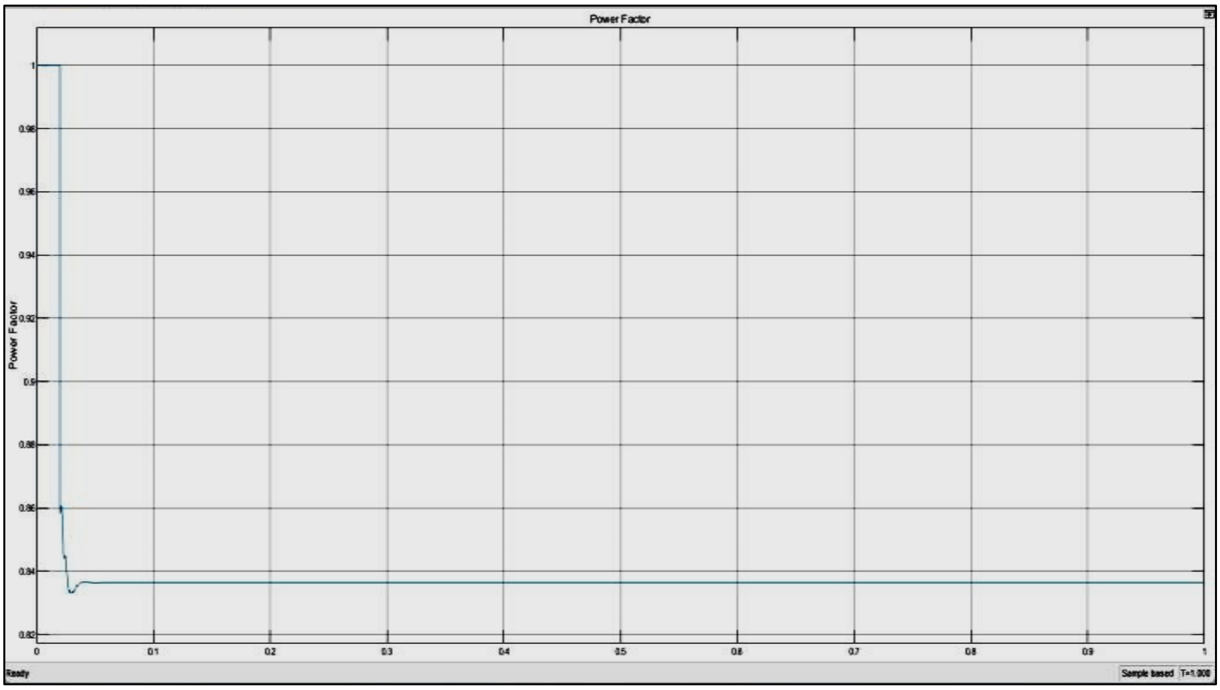

Fig. 1.1(b): Simulated Power Factor (0.834) waveform

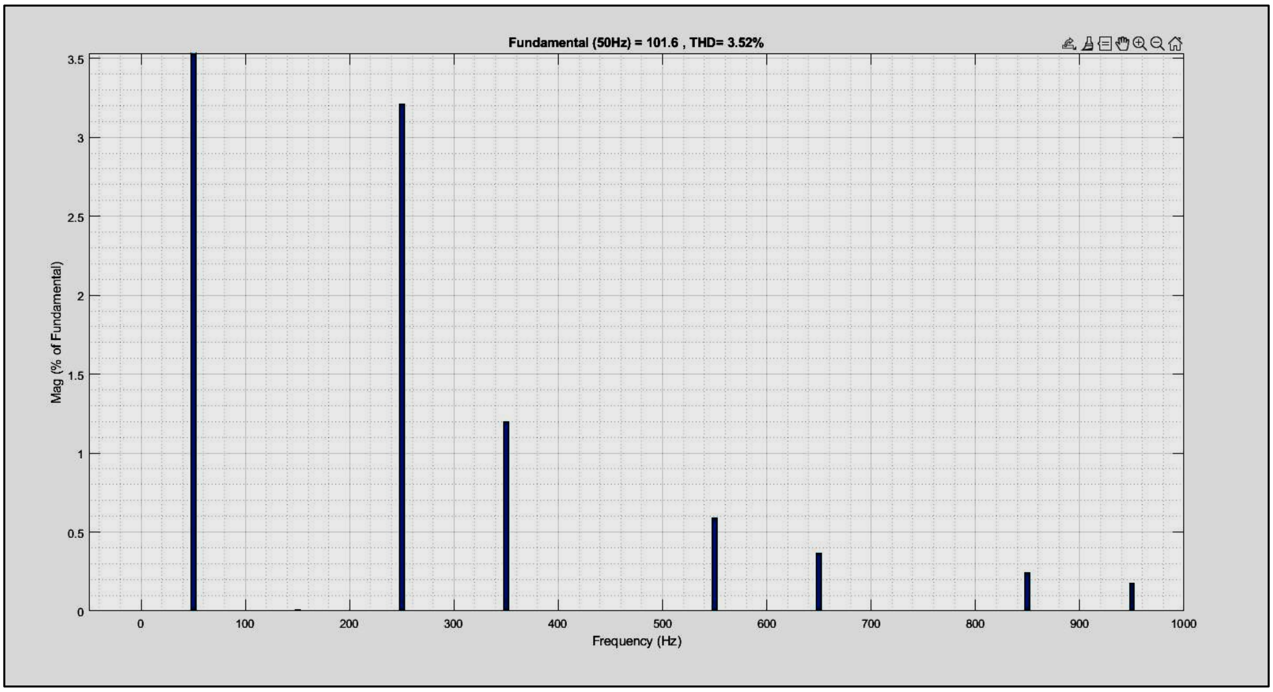

Fig. 1.2 (a): Simulated THD (3.52%) waveform

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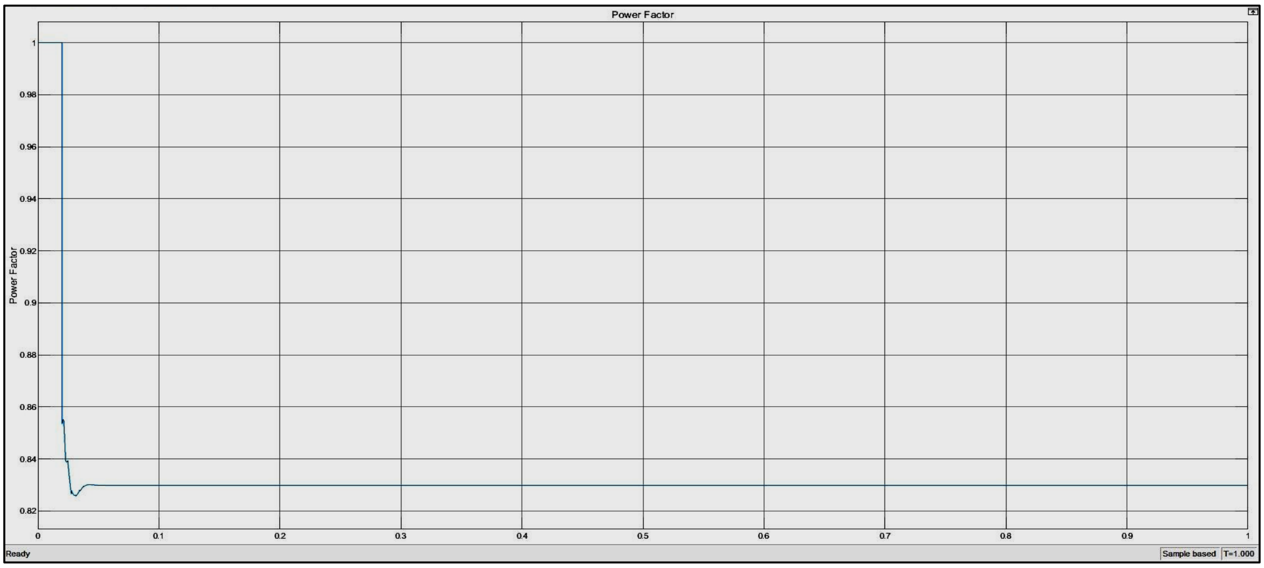

Fig. 1.2 (b): Simulated Power Factor (0.83) waveform

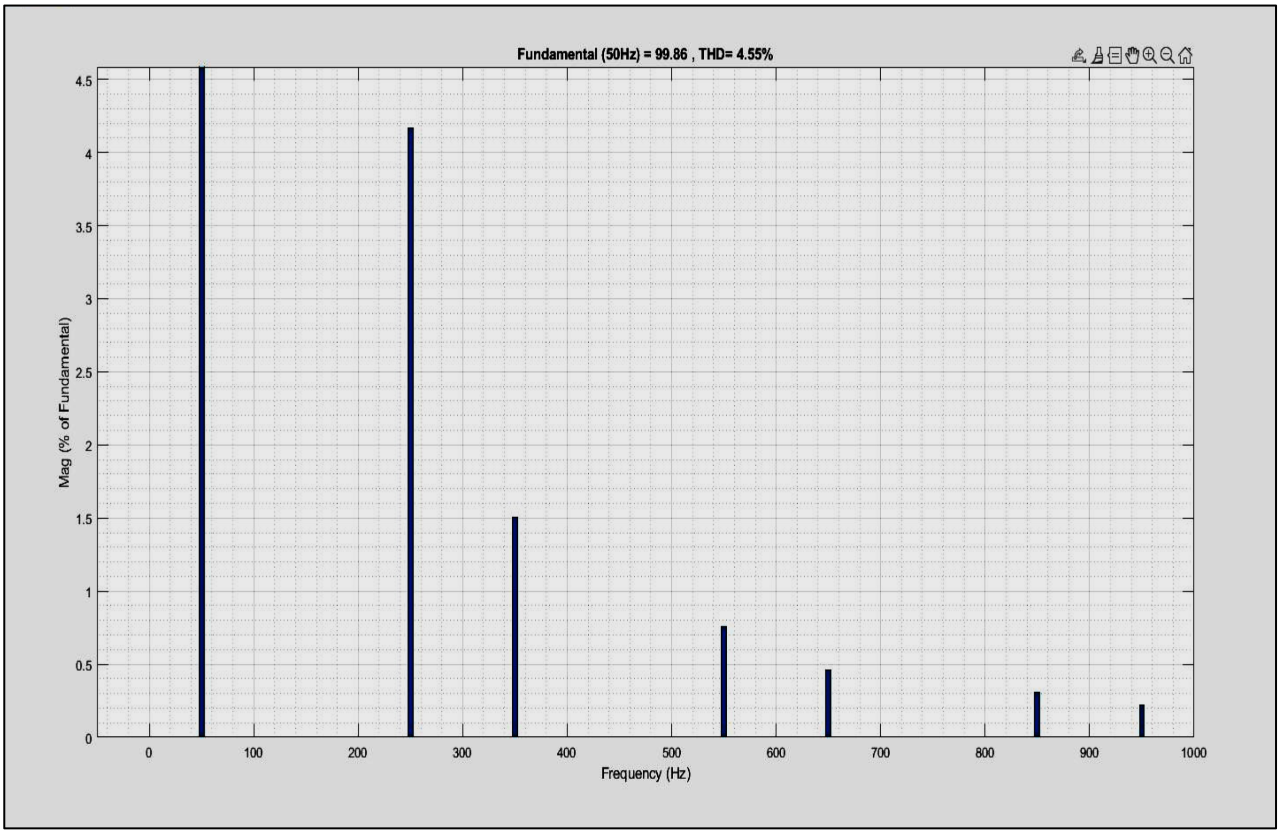

Fig. 1.3(a): Simulated THD (4.55%) waveform

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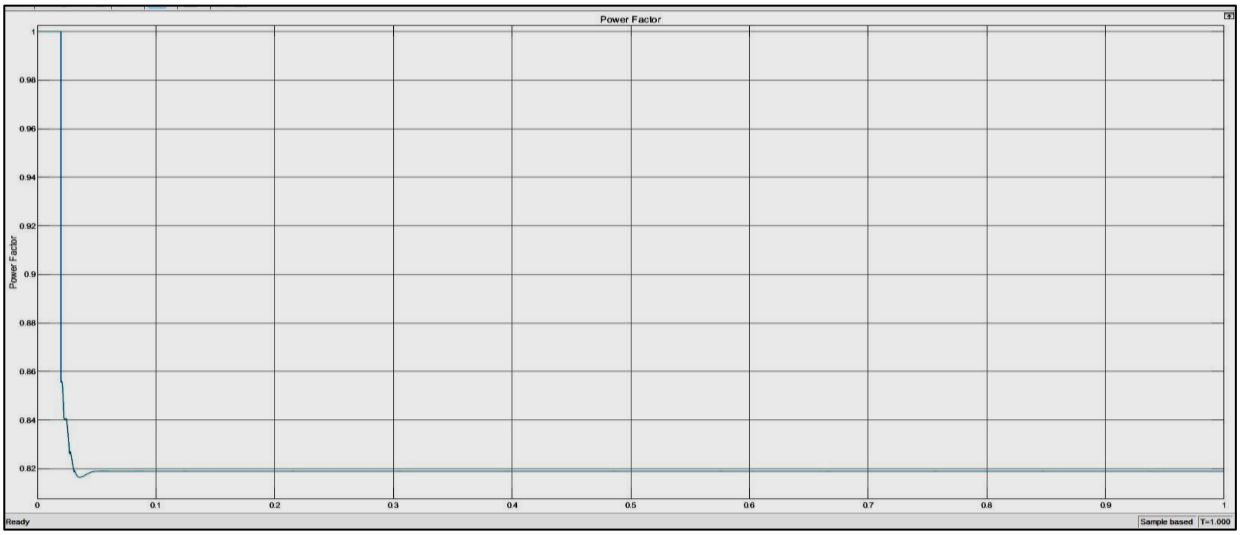

Fig. 1.3 (b): Simulated Power Factor (0.82) waveform

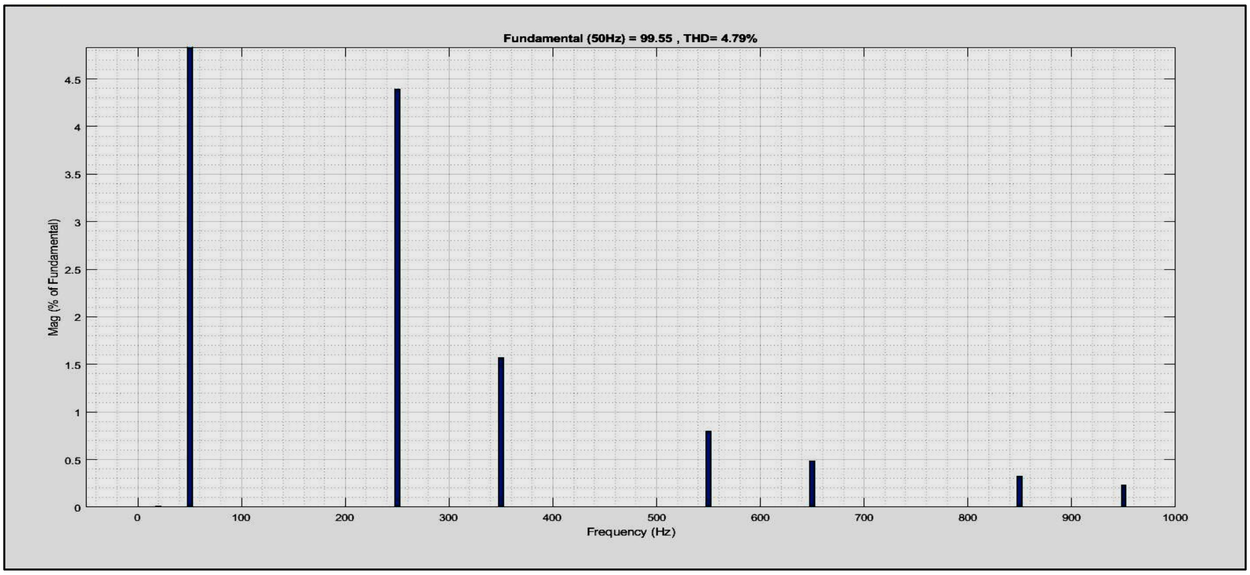

Fig. 1.4(a): Simulated THD (4.79%) waveform

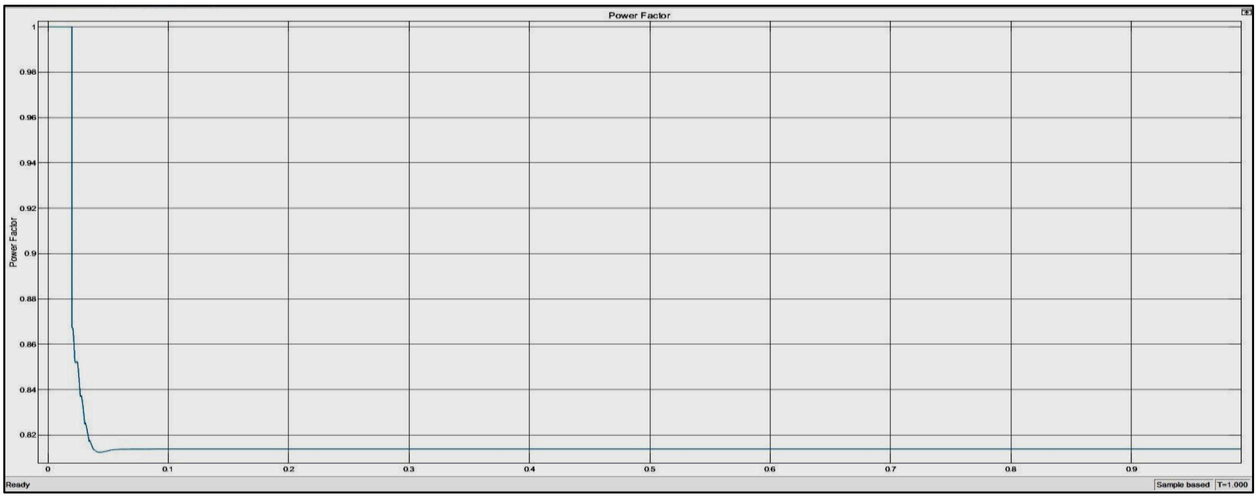

Fig. 1.4(b): Simulated Power Factor (0.815) waveform

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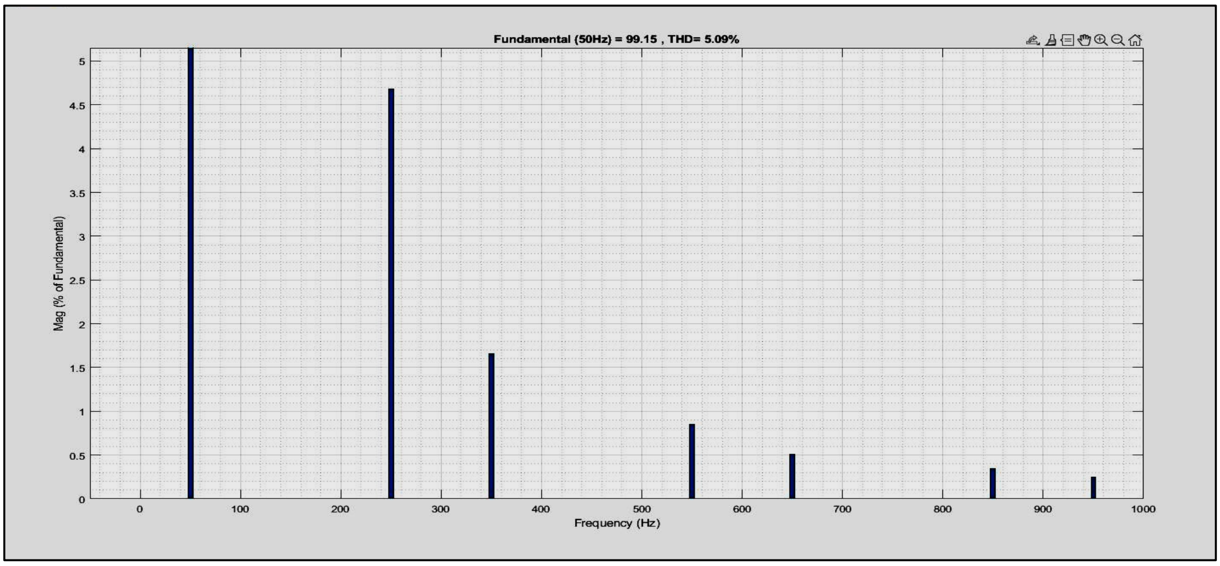

Fig. 1.5(a): Simulated THD (5.09%) waveform

Fig. 1.5(b): Simulated Power Factor (0.804) waveform

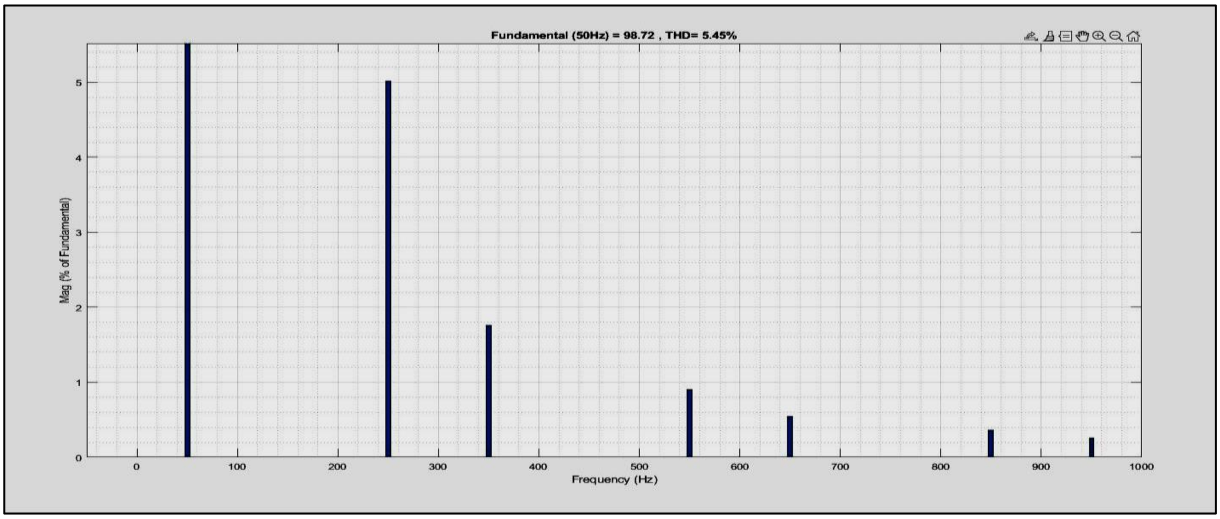

Fig. 1.6(a) : Simulated THD (5.45%) waveform

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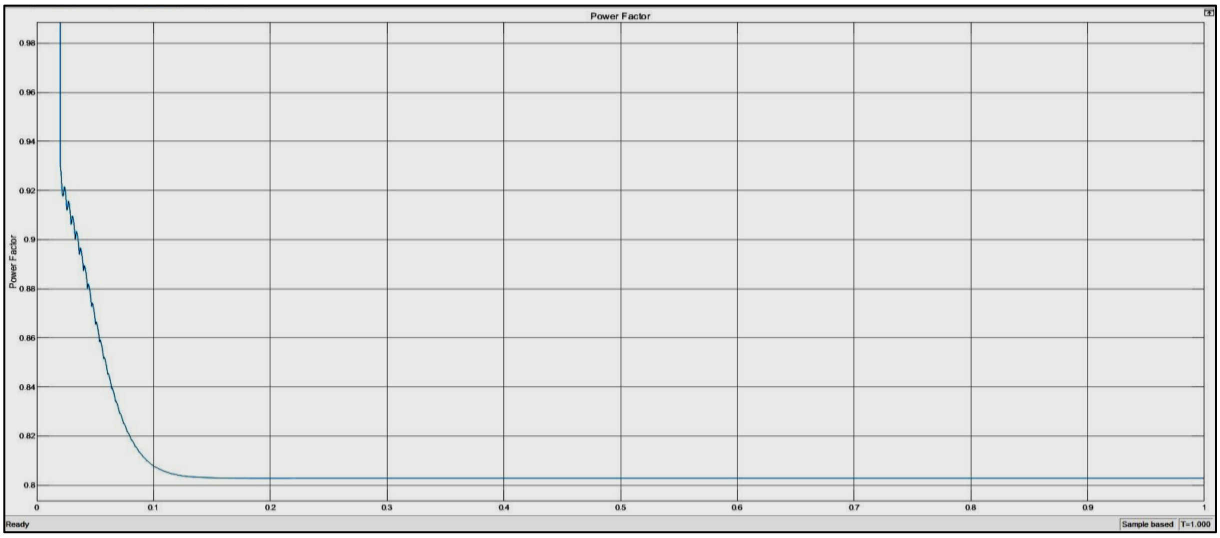

Fig. 1.6(b): Simulated Power Factor (0.801) waveform

VI. CONCLUSION

This study successfully demonstrates the significant impact of nonlinear load variation on power factor and harmonic distortion in electrical systems. Through MATLAB/Simulink simulation, it was observed that as the inductance in a diode bridge rectifier-based R-L load increases, the Total Harmonic Distortion (THD) rises, leading to a noticeable decline in power factor. The FFT analysis confirmed the presence of dominant low-order harmonics, while scope-based waveform observation revealed increased phase displacement and distortion with higher inductance. These findings highlight the critical role of harmonic analysis in power system design and the need for harmonic mitigation techniques in industrial applications. The simulation model proved to be an effective and flexible tool for evaluating power quality issues, enabling engineers to predict system behaviour under varying load conditions and take corrective actions to maintain efficiency and stability.

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