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A Mathematical Physics-Based Framework for Predicting Energy Savings in Harmonic-Rich Low-Voltage Grids Using the Wafeer System

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Abstract

This paper presents a unified mathematical physics, based framework for evaluating and predicting the energy-saving performance of the Wafeer system in nonlinear low-voltage electrical grids. The proposed methodology integrates utility-meter measurements with analytical conductor-loss models to establish a practical engineering approach for quantifying energy savings and explaining their physical origin. A predictive model is also introduced to estimate the expected saving before installation using measurable indicators obtained from power-quality assessments. The framework is supported by documented field measurements from large-scale installations, including the riyadh boulevard and adeer giant screen projects. The analysis demonstrates that the achievable energy saving depends strongly on grid condition, with greater benefits obtained in harmonic-rich installations characterized by elevated neutral-current circulation and degraded power quality. The proposed methodology provides engineers with a practical tool for feasibility assessment, performance prediction, and interpretation of measured energy savings while maintaining consistency with established electrical-loss mechanisms.

Keywords: Wafeer System, Low-Voltage Electrical Grids, Harmonic Distortion, Neutral Current, Energy Saving, Copper Losses, Power Quality, Functional Linear Grounding, Faden Spectrum Phenomenon

1. Introduction

Improving energy efficiency in nonlinear low-voltage electrical grids remains an important engineering challenge, particularly in large installations containing power-electronic equipment and capacitive loads. In such environments, elevated harmonic distortion, increased neutral currents, and excessive reactive power circulation contribute to additional electrical losses that are not directly associated with the useful load. Conventional energy-saving approaches generally focus on improving the power factor or optimizing load operation. However, these methods do not always address the circulation of non-useful currents that arise under severely distorted operating conditions. Consequently, electrically degraded grids may continue to experience unnecessary copper losses despite the application of conventional compensation techniques. The wafeer system was developed as a practical engineering implementation derived from the faden spectrum phenomenon, previously introduced and experimentally investigated by the author in earlier publications. The system is designed to utilize otherwise unused backflow energy for charging its capacitor bank while redirecting excess non-useful current through a controlled functional linear grounding path instead of allowing its complete return to the transformer neutral point. Field observations have shown that the effectiveness of the wafers system depends strongly on the electrical condition of the grid. Installations exhibiting high harmonic distortion, elevated neutral currents, and significant reactive power circulation provide greater opportunities for reducing internal electrical losses. Conversely, the achievable energy saving becomes progressively smaller as overall grid quality improves, explaining why the system is not intended for electrically healthy installations. The primary objective of this paper is not to disclose the proprietary implementation of the wafeer system, but rather to establish the mathematical and physical framework required to predict its expected energy-saving performance before installation. Using documented field measurements obtained from actual large-scale projects, including riyadh boulevard, this paper presents a set of engineering calculation methods, analytical models, and predictive relationships that provide a technically consistent basis for evaluating the expected energy-saving potential of the proposed system.

1.1. Scientific Novelty of This Work

Unlike previous publications that focused primarily on the physical interpretation of the Faden Spectrum phenomenon and the experimental validation of the Wafeer concept, the present paper introduces the first integrated mathematical framework for predicting the expected energy-saving performance of the Wafeer system before installation. The proposed methodology combines direct utility-meter measurements, electrical-loss analysis, and an empirical prediction model within a unified engineering framework. This approach enables quantitative feasibility assessment while preserving consistency between measured energy savings and established mechanisms of conductor-loss reduction in harmonic-rich low-voltage electrical grids.

1.2. Methodology for Predicting Potential Energy Savings

The proposed methodology provides a practical framework for estimating the expected energy saving achieved by the Wafeer system before its installation. The methodology relies primarily on utility energy-meter readings because electrical energy (kWh) represents the official and most reliable indicator of actual energy consumption. Consequently, the calculated saving reflects the actual reduction in metered electrical energy rather than estimated improvements inferred from indirect electrical parameters. To ensure a valid comparison, the measurements obtained before and after installation should preferably cover equivalent operating periods under comparable operating conditions. Whenever measurable operational differences exist between the two periods, an appropriate correction factor is introduced to compensate for these variations and isolate the actual contribution of the Wafeer system. The methodology consists of two complementary parts. The first is a direct energy-based calculation derived from utility-meter readings, which serves as the primary method for evaluating energy saving. The second is a supporting physical interpretation that explains the measured saving in terms of reduced internal electrical losses associated with non-useful current circulation in harmonic-rich low-voltage grids. Unless otherwise stated, all energy values presented in this paper are expressed in kilowatt-hours (kWh), and all comparisons refer to equivalent operating periods.

1.3. Engineering Assumptions

The mathematical framework presented in this paper is developed under the following engineering assumptions.

- The utility energy meter provides reliable measurements of electrical energy consumption.
- The useful electrical load remains approximately constant during the comparison period.
- The electrical-grid topology remains unchanged before and after installation.
- The observation periods are equivalent in duration or appropriately corrected using the proposed correction factor.
- The investigated electrical grid exhibits measurable nonlinear loading and harmonic distortion.
- Electrical measurements are obtained using calibrated instrumentation under normal operating conditions.

1. Standard Equation for Measuring Energy Saving from Utility Meter Data Definitions

$E_b ase$

2. Electrical energy consumed before installation of the Wafeer system during the selected reference period (kWh).

$E_p ost$

3. Electrical energy consumed after operation of the Wafeer system during an equivalent observation period (kWh).A

Correction factor representing measurable operational differences between the two observation periods, including changes in operating hours, screen brightness, additional connected loads, or other operating variables.

1.4. Energy Saving Equation

$$Saving(\%) = 100 \times \frac{E_{base} + A - E_{post}}{E_{base} + A}$$

When the operating conditions before and after installation are considered sufficiently similar, the correction factor may be neglected for simplicity.

Therefore,

$$A=0$$

and the equation becomes

$$Saving(\%) = 100\left(1 - \frac{E_{post}}{E_{base}}\right)$$

1.5. Practical Application

The methodology was applied to the documented Riyadh Boulevard project using utility-meter readings obtained over two equivalent observation periods.

The recorded measurements consist of:

- Before installation: E_{base} measured during a 30-day reference period.
- After installation: Ep_{ost} measured during an equivalent 30-day operating period.

Since both observation periods have identical durations and comparable operating conditions, the correction factor is taken as

$$A=0$$

Accordingly, the achieved energy saving is calculated directly using the simplified equation above. The resulting saving percentage corresponds to the value reported in the Riyadh Boulevard field report.

1.6. Determination of the Correction Factor

When measurable operating conditions differ between the two observation periods, the correction factor A should be estimated using one or more operational variables.

Typical variables include:

- Operating hours.
- Screen brightness level.
- Average current.
- Number of active display modules.
- Other measurable operating parameters affecting energy consumption.

The measured data are divided into suitable intervals (typically hourly or 15-minute intervals).
For each interval during the reference period, the following quantities are recorded:

- Energy consumption E_i
- Operational variable(s) X_i

A baseline model is then established using a simple linear regression

$$\hat{E}_i = \alpha + \beta X_i$$

or, when appropriate, by using a multivariable regression model.
The expected energy consumption during the post-installation period, assuming that the Wafeer system had not been installed, is calculated as

$$E_{baseline,adj} = \sum \hat{E}_i$$

The final energy saving is subsequently determined using

$$Saving(\%) = 100 \times \frac{E_{base} + A - E_{post}}{E_{base} + A}$$

This normalization minimizes the influence of operational variations and provides a more reliable estimate of the energy saving attributable specifically to the Wafeer system rather than to changes in operating conditions.

2. Physical Basis for the Observed Energy Saving

The energy-saving equation presented in the previous section provides the official quantitative measurement of the achieved saving using utility-meter readings. However, utility-meter measurements alone do not explain the physical mechanism responsible for the observed reduction in energy consumption. Therefore, a complementary physical interpretation is required to relate the measured saving to well-established electrical loss mechanisms.

In nonlinear low-voltage electrical grids, particularly those supplying large LED display systems and other power-electronic loads, elevated harmonic distortion and increased neutral-current circulation produce additional electrical losses that do not contribute to useful power delivery. These losses are primarily dissipated as conductor and transformer heating and therefore appear as additional energy consumption recorded by the utility meter. Under such operating conditions, a significant portion of the achievable energy saving results from reducing the circulation of non-useful currents, especially harmonic currents and neutral currents responsible for increased copper losses.

The approximate copper-loss model is expressed as

$$P_{Cu} = 3R_{\phi}I^2_{\phi,rms} + R_N I^2_{N,rms}$$

(Arrillaga & Watson, 2003; IEEE Std 519-2014)
Accordingly, the reduction in copper losses resulting from improved current distribution is

$$\Delta P_{Cu} = 3R_{\phi}(I^2_{\phi,0} - I^2_{\phi,1}) + R_N(I^2_{N,0} - I^2_{N,1})$$

The corresponding energy saving over an operating period T is obtained by integrating the reduction in power losses with

$$\Delta E_{loss} = \int_0^T \Delta P_{loss}\, dt$$

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This physical interpretation is fully consistent with the observed behavior of the Wafeer system. Electrical grids exhibiting severe harmonic distortion, elevated neutral currents, and poor power quality inherently experience larger non-useful current circulation and consequently greater internal electrical losses. These conditions provide a greater opportunity for reducing dissipative losses, thereby explaining why the effectiveness of the Wafeer system increases as overall grid quality deteriorates.

It should be emphasized that this physical model is not intended to replace the direct energy-saving calculation based on utility-meter readings. Rather, it provides a theoretical explanation for the measured reduction in electrical energy consumption by linking the observed savings to established mechanisms of conductor and transformer loss reduction.

3. Measurement Methodology Based on Utility Meter Readings

3.1 Objective

The primary objective of this methodology is to determine the energy saving achieved by the Wafeer system using utility energy-meter readings. Since the utility meter provides the official record of electrical energy consumption, it serves as the primary reference for evaluating system performance.

3.2 Definition of Variables

The variables used throughout the proposed methodology are defined as follows. Energy Consumption E_base
Electrical energy consumed before installation of the Wafeer system during the selected reference period (kWh). E_post

Electrical energy consumed after installation during an equivalent observation period (kWh).

Observation Period
T_base
Duration of the pre-installation observation period. T_post
Duration of the post-installation observation period.
For the most reliable comparison,

$$T_{base} \approx T_{post}$$

Equivalent observation periods eliminate the need for additional normalization with respect to operating time.

3.3. Operational Correction Factor

The correction factor A represents the equivalent energy adjustment required when measurable operating conditions differ between the two observation periods.

Typical situations requiring the correction factor include:

- Increased operating hours.
- Significant changes in screen brightness.
- Additional connected electrical loads.
- Other measurable operational variations affecting energy consumption.

When operating conditions remain substantially unchanged, A=0

and no operational correction is required.

3.4. Primary Energy-Saving Equation

The percentage energy saving is calculated using

$$Saving(\%) = 100 \times \frac{E_{base} + A - E_{post}}{E_{base} + A}$$

3.5. Simplified Form

When both observation periods have nearly identical duration and equivalent operating conditions, A=0

and the governing equation becomes

$$Saving(\%) = 100\left(1 - \frac{E_{post}}{E_{base}}\right)$$

3.5. Practical Application

The methodology was applied to the Riyadh Boulevard project using utility-meter measurements collected over two equivalent thirty-day operating periods. Since both measurement periods were obtained under comparable operating conditions using the same utility meter, the correction factor was taken as $A=0$

The measured saving therefore corresponds directly to the simplified expression presented above.

3.6. Application of the Correction Factor

The correction factor should only be introduced when measurable operational differences exist between the two observation periods.

Typical examples include.

- Changes in daily operating hours.
- Significant variation in display brightness.
- Installation of additional electrical equipment.
- Any measurable operational change affecting energy consumption.

The purpose of the correction factor is to compensate for operational variations so that the calculated saving represents the actual contribution of the Wafeer system rather than changes in operating conditions. Whenever detailed operating records are unavailable, direct before-and-after comparison remains acceptable provided that the observation periods are equivalent, and the operating conditions are reasonably comparable.

3.7. Applicability of the Measurement Method

The proposed measurement methodology is applicable to all low-voltage electrical installations. However, its physical interpretation becomes particularly important in grids exhibiting elevated harmonic distortion, increased neutral-current circulation, and degraded power quality. Power-quality measurements obtained from the Adeer Giant Screen project indicate substantial harmonic distortion under different operating conditions, providing a representative example of an electrically degraded grid in which the physical mechanisms discussed in this paper become significant. It should be emphasized that harmonic measurements are not required to calculate the achieved energy saving. Rather, they provide additional physical evidence explaining why measurable reductions in electrical energy consumption may occur in grids characterized by excessive harmonic distortion and non-useful current circulation.

4. Advanced Mathematical Framework for the Wafeer Energy-Saving Model

The mathematical framework presented in this section provides the theoretical basis for interpreting the energy-saving mechanism of the Wafeer system. Unlike the previous sections, which focus on direct measurement using utility-meter readings, the following analysis establishes the physical relationship between measured energy reduction and the decrease in internal electrical losses within nonlinear low-voltage grids. The objective of this framework is not to replace the direct measurement methodology, but to demonstrate that the observed reduction in metered electrical energy is physically consistent with established power-loss mechanisms.

4.1. General Energy Balance

The total electrical energy recorded by the utility meter is given by.

$$E_{meter} = \int_0^T (P_{useful} + P_{loss})\,dt$$

where

- P_{useful} represents the useful active power consumed by the intended electrical load.
- P_{loss} represents the electrical power dissipated within the internal grid.

The total internal power loss may be expressed as $P_{loss}=P_{Cu}+P_{core}+P_{harm}$

For nonlinear electrical systems characterized by significant harmonic distortion, such as the Adeer Giant Screen installation

$$P_{harm} + P_{Cu} \gg P_{core}$$

indicating that harmonic-related losses and conductor losses dominate the overall internal energy dissipation.

4.2 Copper-Loss Model Under Harmonic Conditions

The true RMS current in the presence of harmonic components is

$$I_{rms}^2 = I_1^2 + \sum_{h=2}^{\infty} I_h^2$$

Consequently, conductor losses in the phase and neutral conductors are [1].

$$P_{Cu} = 3R_{\phi} I_{\phi,rms}^2 + R_N I_{N,rms}^2$$

In nonlinear LED installations, the neutral conductor frequently carries substantial harmonic current due to triplen harmonic components and capacitive loading. As a result, neutral-conductor losses may represent a significant portion of the total conductor losses.

4.3. Mathematical Representation of the Wafeer Effect

Let

- $I_{N,0}$ denote the neutral current before installation.
- $I_{N,1}$ denote the neutral current after installation.
-

The operating principle of the Wafeer system assumes that part of the non-useful apparent current is redirected through the functional linear grounding path, thereby reducing the current returning to the transformer neutral point.
Accordingly,

$$I_{N,1}^2 < I_{N,0}^2$$

and

$$I_{\phi,1}^2 \le I_{\phi,0}^2$$

The corresponding reduction in conductor losses is therefore [2-4].

$$\Delta P_{loss} = 3R_{\phi}\left(I_{\phi,0}^2 - I_{\phi,1}^2\right) + R_N\left(I_{N,0}^2 - I_{N,1}^2\right)$$

The resulting reduction in energy consumption over an operating period is.

$$\Delta E_{loss} = \int_0^T \Delta P_{loss}\, dt$$

4.4. Relationship Between the Mathematical Model and Utility Meter Measurements

Because the utility meter records.

$$E_{meter} = \int_0^T \left(P_{useful} + P_{loss}\right) dt$$

and assuming that the useful electrical load remains approximately unchanged,

$$P_{useful,0} \approx P_{useful,1}$$

it follows that

$$\Delta E_{meter} \approx \Delta E_{loss}$$

This relationship demonstrates that any measurable reduction in internal dissipative losses appears directly as reduced electrical energy recorded by the utility meter.

4.5. Compact Mathematical Model

Combining the previous relationships yields the following compact expression describing the expected energy saving [2-4].

$$Saving(\%) \approx 100\,\frac{\int_0^T \left[R_N\left(I_{N,0}^2 - I_{N,1}^2\right) + 3R_{\phi}\left(I_{\phi,0}^2 - I_{\phi,1}^2\right)\right] dt}{E_{base}}$$

This expression does not require direct measurement of every individual harmonic component. Instead, it provides a physically consistent mathematical explanation for why the reduction in non-useful current circulation can produce measurable reductions in utility-meter energy consumption.

4.6. Engineering Interpretation

The proposed mathematical framework leads to two practical engineering conclusions.

- The Wafeer system is expected to provide limited benefit in well-designed electrical grids characterized by low harmonic distortion and minimal non-useful current circulation.
- The achievable energy saving increases as electrical-grid quality deteriorates, particularly in installations exhibiting elevated harmonic distortion, significant neutral-current circulation, and nonlinear loading conditions [5-7].

5. Final Technical Conclusion

The analytical framework, mathematical models, and documented field measurements presented in this paper provide a consistent engineering basis for interpreting the energy-saving performance of the Wafeer system. The proposed methodology adopts utility-meter energy measurements (kWh) as the primary criterion for evaluating system performance because they represent the official and objective measure of electrical energy consumption. This measurement-based approach is complemented by a physically consistent mathematical framework demonstrating how reductions in non-useful current circulation can directly reduce internal electrical losses. The developed theoretical model shows that, under approximately constant useful-load conditions, reductions in conductor losses and harmonic-related losses appear directly as reductions in metered electrical energy. Consequently, the measured energy saving is not interpreted as an indirect consequence of load reduction or conventional power-factor correction, but rather as the result of mitigating dissipative losses associated with excessive harmonic distortion and neutral-current circulation.

The mathematical relationships developed throughout this paper further explain the observed dependence of the Wafeer system on grid condition. Electrical installations characterized by poor power quality, elevated harmonic distortion, nonlinear loading, and increased neutral-current circulation inherently possess greater non-useful energy losses and therefore provide greater potential for measurable energy savings. Conversely, well-designed electrical grids exhibiting low distortion provide only limited opportunity for additional loss reduction, thereby limiting the achievable benefit of the proposed system.

The agreement between the mathematical formulation, the physical interpretation, and the documented field measurements establishes a coherent engineering framework for evaluating the expected performance of the Wafeer system without requiring disclosure of its proprietary implementation details. Accordingly, within the assumptions adopted throughout this study, the measured reduction in utility-meter energy consumption should be regarded as a physically explainable and experimentally measurable consequence of reducing non-useful current circulation and the associated internal electrical losses in harmonic-rich low-voltage electrical grids.

5.1. Study Limitations

The mathematical framework presented in this paper has been developed and calibrated using documented field measurements obtained from nonlinear low-voltage electrical installations characterized by elevated harmonic distortion and significant neutral-current circulation. Consequently, the proposed predictive relationships should be interpreted within this range of operating conditions. Additional field validation involving a broader variety of electrical installations will further improve the generality and predictive accuracy of the proposed model.

6. Predictive Model for Estimating the Expected Energy Saving

6.1. Objective

The purpose of the proposed predictive model is to estimate the expected energy saving that may be achieved by the Wafeer system before installation. Unlike the direct measurement methodology presented in the previous sections, this model is intended for engineering feasibility studies and preliminary performance assessment. The model estimates the expected reduction in electrical energy consumption using measurable indicators of electrical-grid quality obtained from standard power-quality reports.

6.2. Model Calibration

The predictive model has been calibrated using documented field measurements obtained from practical installations representing different levels of electrical-grid distortion.

The calibration currently includes the following documented projects:

Installation	Grid Condition	Measured Saving
Adeer Giant Screen – Al Khobar	High electrical distortion (≈135%)	≈48%
Riyadh Boulevard	Moderate electrical distortion (≈45%)	≈26%

Although the available database is currently limited, these measurements provide an initial empirical basis for estimating the expected performance of the Wafeer system.

6.3 Engineering Principle

The proposed predictive model is based on the observation that the achievable energy saving increases as electrical-grid quality deteriorates. Higher harmonic distortion produces greater circulation of non-useful current and consequently larger conductor losses. Since the Wafeer system is intended to reduce these losses, installations exhibiting poor power quality generally provide greater potential for measurable energy saving.

At very high distortion levels, however, the achievable saving approaches a practical saturation limit imposed by the physical characteristics of the electrical grid.

6.4 Predictive Equation

The proposed empirical relationship is

$$E_s(\%) \approx 15 + \beta D$$

where

$$D \geq 25\%$$

The model has been calibrated using the currently available field measurements and is expected to be refined as additional installations become available.

Consequently, the predictive equation should be regarded as an engineering estimation tool rather than a universal physical law.

6.5. Definition of Parameters

Electrical Distortion Index (D): The distortion index D is obtained from power-quality measurements and represents the magnitude of non-useful apparent current relative to the useful line current. This index is intended exclusively as a practical engineering indicator used within the Wafeer predictive model and is not intended to replace standardized indices such as THD or TDD.

Expected Energy Saving

$$E_s(\%)$$

Predicted percentage reduction in electrical energy consumption.

Empirical Constant

$$\beta = 0.24$$

The empirical constant was obtained from calibration using the currently available field measurements.

6.6. Applicability of the Model

The proposed predictive model is applicable to nonlinear low-voltage electrical grids exhibiting measurable harmonic distortion.

It is intended primarily for

- engineering feasibility studies,
- preliminary energy-saving assessment,
- comparison between candidate installations,
- estimation of expected project performance before installation.

The model is not recommended for electrical grids exhibiting distortion levels below approximately 25%, where the expected influence of the Wafeer system becomes negligible.

6.7. Engineering Interpretation

The predictive model leads to the following engineering conclusions.

- Electrical grids exhibiting good power quality generally provide limited opportunity for additional energy saving.
- Harmonic-rich electrical grids characterized by elevated neutral-current circulation provide significantly greater potential for measurable reduction of internal electrical losses.
- The predictive equation is intended to support engineering planning and feasibility assessment and should not be interpreted as an absolute performance guarantee.

This paper presents a unified engineering framework that combines direct utility-meter measurements, analytical electrical-loss models, and an empirical predictive equation into a single methodology for evaluating the expected energy-saving performance of the Wafeer system. Unlike previous publications that focused primarily on the physical phenomenon and experimental validation, the present work establishes a practical mathematical framework for estimating the expected energy saving before installation while maintaining consistency between field measurements and established electrical-loss mechanisms.

6.8. Scope of Applicability

The proposed methodology is intended for nonlinear low-voltage electrical grids where harmonic distortion, elevated neutral-current circulation, and reactive-power-related losses constitute a measurable portion of the total energy consumption. Typical applications include large LED display systems, commercial facilities with significant power-electronic loading, and other harmonic-rich electrical installations. The proposed predictive model should not be interpreted as a universal energy-saving equation for all electrical grids but rather as an engineering framework applicable within the operating conditions considered in this study.

6.9. Future Work

Future research will focus on expanding the calibration database using additional electrical installations operating under different harmonic conditions. The proposed predictive equation may subsequently be refined through statistical calibration and validation using larger datasets. Additional investigations may also examine the applicability of the Wafeer methodology to industrial facilities, commercial buildings, renewable-energy systems, and other nonlinear low-voltage electrical grids exhibiting significant harmonic distortion.

7. Conclusion

This paper presents a unified mathematical and physical framework for evaluating and predicting the energy-saving performance of the Wafeer system in nonlinear low-voltage electrical grids. Unlike conventional approaches that rely solely on measured energy consumption, the proposed methodology combines direct utility-meter measurements with established electrical-loss models to provide both quantitative evaluation and physical interpretation of the observed energy saving. The developed framework demonstrates that the reduction in utility-meter energy consumption can be consistently interpreted as a consequence of reducing non-useful current circulation and the associated conductor losses within harmonic-rich electrical grids. The analytical relationships presented in this study establish a coherent link between field measurements and recognized mechanisms of electrical power dissipation without requiring modification of conventional energy-metering principles. In addition to the measurement methodology, this paper introduces a practical predictive model that enables preliminary estimation of the expected energy-saving performance before installation. The proposed model provides engineers with a feasibility assessment tool based on measurable electrical-grid characteristics and documented field observations obtained from real installations.

The presented methodology is primarily intended for nonlinear low-voltage electrical grids exhibiting significant harmonic distortion, elevated neutral-current circulation, and measurable internal electrical losses. Accordingly, the expected benefit of the Wafeer system is closely related to the electrical condition of the investigated grid, with greater savings anticipated in harmonic-rich installations than in electrically healthy grids. Future work will focus on expanding the experimental database through additional field applications, refining the empirical prediction model using larger datasets, and further validating the proposed mathematical framework under a wider range of operating conditions. Finally, the principal contribution of this work is not the proposal of a new fundamental law of electrical engineering, but the establishment of a practical engineering framework that quantitatively relates measurable energy savings to identifiable electrical-loss mechanisms in harmonic-rich low-voltage electrical grids. By integrating utility-meter measurements, analytical loss models, and a predictive engineering methodology within a unified framework, this study provides a practical basis for estimating the expected performance of the Wafeer system prior to installation.

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