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Power Quality Analysis of a Ceramic Manufacturing Unit Using Field Measurements

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Abstract: Power quality plays a significant role in the efficient operation and energy management of industrial facilities. Electrical issues such as voltage waveform distortion, harmonic currents, reactive power consumption, and low power factor can contribute to higher system loading and increased electrical losses. This study investigates the power quality performance of a continuously operating ceramic manufacturing unit located in Thangadh, Surendranagar, Gujarat, India, using actual field measurements. The selected small and medium-sized enterprise (SME) has a sanctioned electrical load of 100 kW and is supplied through the utility grid, with a diesel generator for backup and a 50 kW photovoltaic system.Electrical measurements were recorded using a three-phase power quality analyzer. The assessment included RMS voltage and current, system frequency, voltage and current total harmonic distortion (THD), active and reactive power, apparent power, distortion power, and overall power factor. The recorded phase voltages were 252.4 V, 250.1 V, and 250.0 V, with voltage THD values between 5.8% and 6.0%. In comparison, the current waveform showed considerably greater distortion, with current THD ranging from 15.4% to 17.5%. Under the measured operating condition, the facility consumed 36.78 kW of active power and 19.81 kVAr of reactive power. The corresponding distortion power and apparent power were 7.901 kVAr and 42.52 kVA, respectively, resulting in an overall power factor of 0.865. The relatively small variation among the three phase currents suggests that current imbalance was not a major concern during the measurement period. Instead, harmonic distortion and reactive power demand were identified as the more significant power quality issues. The study further examines the facility's existing 60 kVAr automatic power factor correction system, including the effect of a reported derated capacitor step. The findings indicate that combining on-site power quality measurements with conventional energy auditing provides a useful approach for identifying opportunities to improve power factor, reduce harmonic-related problems, and strengthen demand-side energy management in ceramic SMEs.

Keywords: Energy audit; energy conservation measure; energy efficiency; small and medium enterprise; power quality; techno-economic analysis, power quality analysis

I. INTRODUCTION

Energy is a vital input in industrial manufacturing, with its cost and reliability directly affecting competitiveness. Ceramic manufacturing facilities rely heavily on continuous electrical operation because motors, ball mills, compressors, blowers, drives, and other auxiliary systems run for extended periods. For small and medium enterprises (SMEs), controlling energy costs is especially critical due to limited capital and technical resources. Therefore, an energy audit should go beyond utility bills, incorporating measurements that reveal how electricity is used and where avoidable losses may occur. [1], [4], [5], [12]–[15]

Power quality is closely linked to industrial energy performance. Variations in voltage, harmonic distortion, load unbalance, and poor power factor can lead to increased current, electrical losses, thermal stress, and overloading of distribution equipment. Nonlinear loads like variable-frequency drives, rectifiers, and electronic controllers generate harmonic currents that distort the current waveform and, depending on system impedance, may affect supply voltage. Previous energy audits for SMEs have repeatedly highlighted the importance of assessing power factor and power quality, addressing harmonic issues, load balancing, and improving monitoring as key industrial measures [1]. [2], [6], [9], [10]

This study integrates historical utility-bill data with field measurements from a three-phase power-quality analyzer at a ceramic manufacturing SME. Its goal is to report on the electrical conditions observed and interpret their implications for energy auditing, power quality enhancement, and demand-side management.

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II. OBJECTIVES

The primary objective of this study is to assess the three-phase electrical power quality of a ceramic manufacturing facility using field measurements. The investigation focuses on measuring voltage and current harmonic distortion to identify the major power quality concerns within the electrical system. It also examines phase loading and key electrical parameters, including active power, reactive power, apparent power, and power factor. In addition, the performance of the existing automatic power factor correction (APFC) system is evaluated. Based on the measurement results and analysis, practical opportunities for energy conservation, power factor improvement, and effective demand-side management are identified.

III. DESCRIPTION OF THE CERAMIC MANUFACTURING UNIT

The study was conducted at Champion Ceramic, Thangadh, Surendranagar, Gujarat, India, a small and medium-sized enterprise (SME) engaged in ceramic manufacturing. Ceramic production is an energy-intensive industrial process in which a reliable and continuous electrical supply is essential for maintaining production, operating machinery, and minimizing process interruptions. [12]–[14]

The industrial unit is supplied through a three-phase LTMD (Low Tension Maximum Demand) electrical connection from the PGVCL distribution network, with a sanctioned electrical load of 100 kW. The plant contains several electrical loads associated with the manufacturing process, including motors, pumps, compressors, fans, material-handling equipment, lighting systems, and other auxiliary machinery. The simultaneous and varying operation of these loads results in changes in the electrical demand throughout the production cycle.

To improve the reliability of the electrical supply, the plant also has a diesel-generator (DG) backup system, which provides power during grid interruptions or other supply-related disturbances. In addition, a 50 kW rooftop solar photovoltaic (PV) system is installed at the facility. During daylight hours, the PV system contributes to the plant's electrical energy requirement, thereby reducing the amount of electricity drawn from the utility grid.

TABLE I TECHNICAL AND OPERATIONAL DETAILS OF THE INVESTIGATED CERAMIC MANUFACTURING UNIT

Parameter	**Description**
Industrial unit	Champion Ceramic
Location	Thangadh, Surendranagar, Gujarat
Category	SME
Supply	Three-phase AC
Connection	LTMD
Sanctioned load	100 kW
Grid utility	PGVCL
DG backup	Available
Solar PV	50 kW
Operation	24×7

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The combination of PGVCL grid supply, rooftop solar PV generation, DG backup, and continuously varying industrial loads creates a mixed electrical operating environment. Changes in production demand and solar generation can influence parameters such as voltage, current, active power, reactive power, power factor, maximum demand, and overall energy consumption.

The plant operates on a 24 × 7 continuous production schedules. Therefore, electrical supply reliability, efficient energy utilization, and power quality are particularly important, as interruptions or poor electrical performance may affect production continuity, equipment operation, energy losses, and operating costs. For this reason, Champion Ceramic provides a suitable industrial case study for evaluating the plant's electrical loading pattern, energy consumption, power quality performance, and the contribution of rooftop solar PV generation under actual operating conditions.

IV. MEASUREMENT METHODOLOGY

The electrical distribution system of the investigated ceramic manufacturing unit is supplied primarily by the PGVCL utility grid. The incoming supply is received at 11 kV and stepped down to 440 V through an 11 kV/440 V transformer. The low-voltage supply then passes through the PGVCL metering section, where the electrical energy supplied by the utility is measured.

In addition to the utility supply, the plant is equipped with two supplementary power sources: a diesel generator (DG) for backup supply and a photovoltaic (PV) generation system for renewable energy contribution. These sources are integrated with the plant's electrical network before power is supplied to the downstream distribution system.

An automatic power factor correction (APFC) panel is connected to the electrical system to provide reactive power compensation and improve the operating power factor. From this section, electrical power is supplied to the main distribution panel (MDP), which serves as the central point for distributing electricity to the major plant loads.

The main loads connected to the MDP include the ball mill, air compressor, kiln, glazing room, and lighting load. These loads represent different operating characteristics and can contribute differently to the plant's overall power demand, reactive power requirement, and power-quality performance. The arrangement shown in the figure therefore provides the basis for evaluating power flow and identifying suitable locations for power-quality measurements and energy-efficiency improvements.

The assessment was carried out using an energy-audit-based approach that involved defining the electrical system, collecting baseline information, conducting on-site measurements, identifying power quality issues, prioritizing suitable corrective actions, and verifying the resulting improvements. Historical electricity consumption and billing records covering the period from April 2024 to March 2025 were examined to establish the baseline operating characteristics. In addition, field measurements of the electrical system were obtained using a three-phase power quality analyzer. [4], [5], [15]

The measurement campaign covered RMS voltage and current, frequency, voltage total harmonic distortion (THD), current THD, crest factor, harmonic loss factor, active power, reactive power, distortion power, apparent power, and power factor. Together, these parameters were used to characterize the quality of the voltage waveform, the extent of current distortion, loading across the phases, and the reactive and distortion-related contributions to the overall apparent power. [7], [9]–[11]

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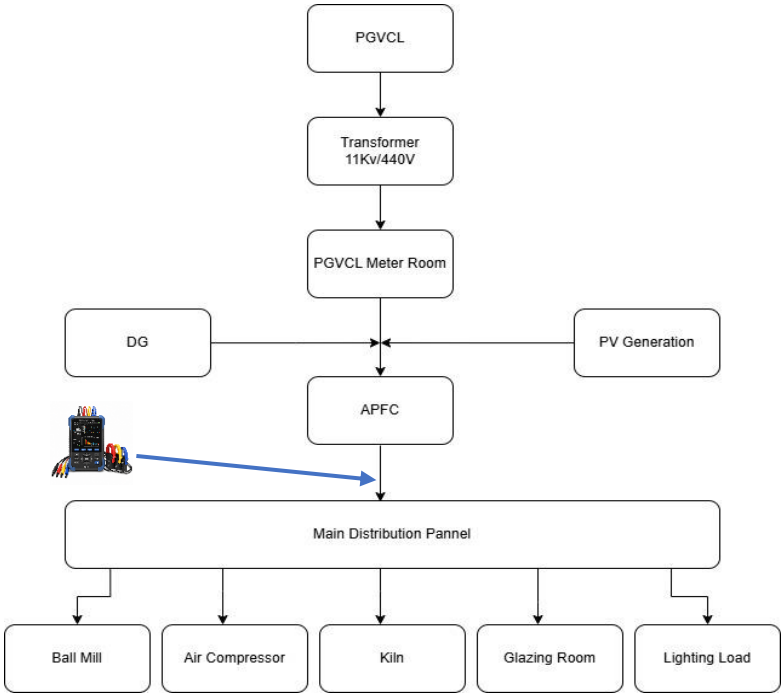


Fig. 1 Electrical Diagram

V. CERAMIC MANUFACTURING PROCESS

The ceramic manufacturing process starts with the preparation of the main raw materials, primarily China clay and Then clay. The required quantities of these materials are introduced into a ball mill along with water, sodium silicate, and sodium carbonate. The milling process produces a uniform slurry with the desired consistency. The prepared slurry is subsequently passed through a de-ironing stage to remove iron particles and other undesirable impurities. After purification, the slurry is converted into mould slip and transferred to the moulding section, where the required product shape is formed. The moulded products are then allowed to dry naturally to reduce their moisture content. Once sufficiently dried, finishing operations are performed to achieve the desired dimensions, shape, and surface condition.

Glaze preparation is carried out separately from the body preparation process. The required glaze raw materials and chemicals are mixed with water and processed in another ball mill to obtain a uniform glaze slurry. This slurry also undergoes de-ironing to minimize iron contamination and other impurities. Carboxymethyl Cellulose (CMC) is subsequently added to improve the viscosity and application characteristics of the glaze. The prepared glaze is applied to the dried and finished ceramic products using a spray-glazing process. The glazed products are then naturally dried and subjected to glaze-finishing operations to obtain a uniform surface suitable for firing.

Following glazing and drying, the products are transferred to the tunnel kiln, where firing is performed under controlled high-temperature conditions. This thermal treatment provides the ceramic body with the required mechanical strength, hardness, dimensional stability, and final surface properties. After completion of the firing cycle, the products are unloaded from the kiln and inspected. Sorting is then carried out on the basis of product quality, dimensions, surface appearance, and observed defects. Products meeting the required quality criteria are finally prepared for dispatch to customers or further distribution.

Overall, the production sequence comprises raw-material preparation, ball milling, de-ironing, moulding, natural drying, finishing, glaze preparation, spray glazing, glaze drying and finishing, tunnel-kiln firing, sorting, and final dispatch.

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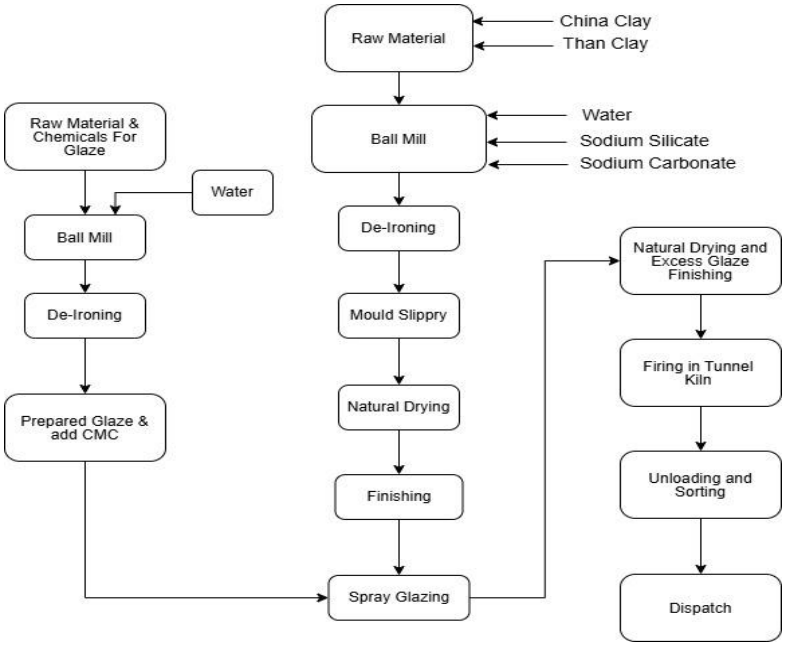


Fig. 2 Ceramic Unit Process Chart

VI. HISTORICAL ENERGY AND POWER-FACTOR ANALYSIS

Monthly utility data for April 2024 to March 2025 show variable maximum demand and power factor. Maximum demand ranged from approximately 57 to 89 kVA, while the recorded monthly power factor ranged from about 0.92 to 0.98. The best monthly PF values occurred during July and August 2024, while lower values were observed in April, June, February and March. These variations indicate that reactive power demand changes with operating conditions and loading.

TABLE II MONTHLY ELECTRICITY INDICATORS USED IN THE STUDY

Month	Max. Demand	Month	Max. Demand
Apr-24	60.7	13,796	0.92
May-24	78.0	11,000	0.92
Jun-24	80.8	12,224	0.92
Jul-24	70.5	12,855	0.96
Aug-24	89.0	27,066	0.98
Sep-24	77.5	7,932	0.95
Oct-24	65.0	9,325	0.94
Nov-24	72.0	15,226	0.95
Dec-24	62.0	14,429	0.93
Jan-25	66.0	16,335	0.94
Feb-25	73.5	11,701	0.92
Mar-25	57.0	14,906	0.92

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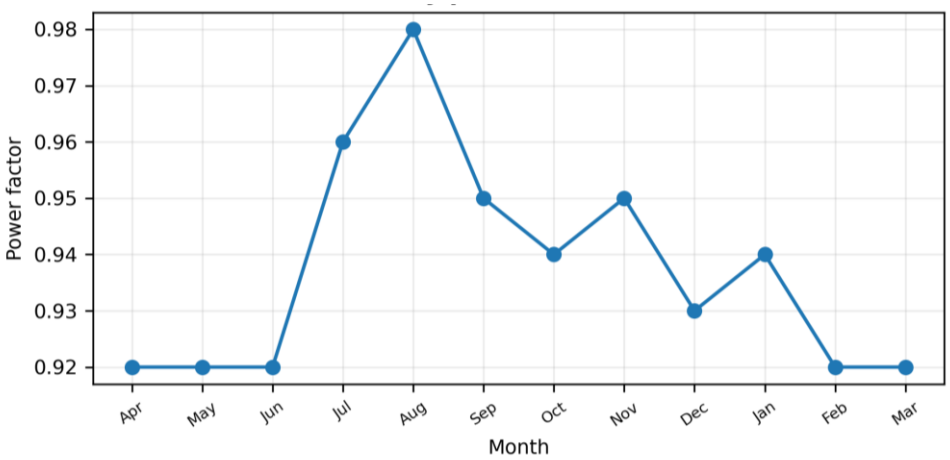


Fig. 3 Monthly power-factor trend

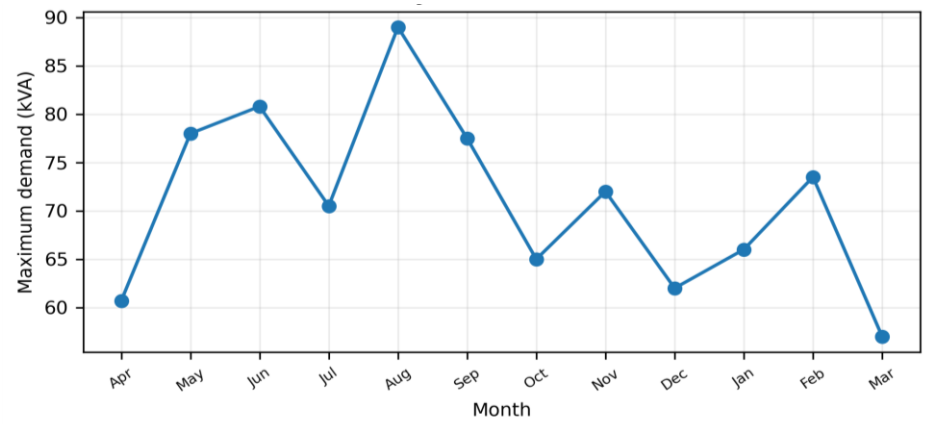


Fig. 4 Monthly maximum demand

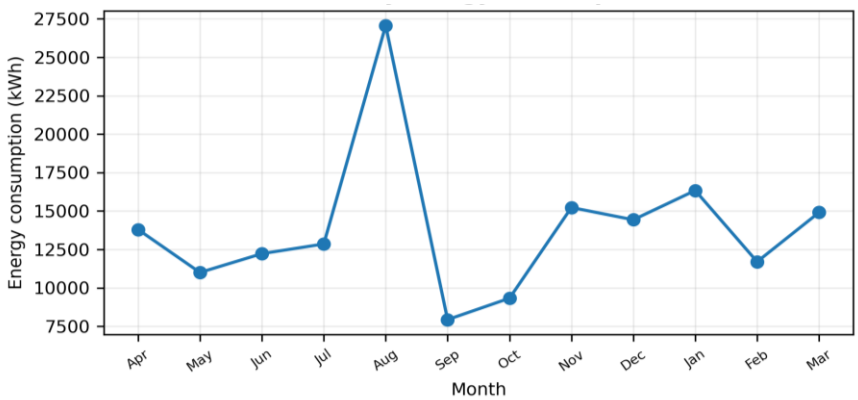


Fig. 5 Monthly electrical energy consumption

The monthly power factor data from April 2024 to March 2025 indicate that the ceramic manufacturing unit operated within a range of 0.92 to 0.98. The highest power factor of 0.98 was recorded in August 2024, followed by 0.96 in July 2024. In contrast, the lowest value of 0.92 occurred during April, May, and June 2024 and again during February and March 2025. The average power factor over the twelve-month period was approximately 0.94.

The variation in power factor reflects changes in the operating conditions and loading of the plant. Ceramic manufacturing equipment such as ball mills, air compressors, pumps, and other motor-driven loads requires reactive power, which can reduce the overall power factor. Although the plant is equipped with an APFC system, the monthly values below unity indicate that reactive power compensation is not fully effective under all operating conditions. This may be associated

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with variations in plant loading, switching of capacitor steps, or reduced capacity of the reported derated capacitor step. [1], [2], [6]

The field measurement further supports this observation. At the measured operating condition, the plant recorded 36.78 kW active power, 19.81 kVAr reactive power, 42.52 kVA apparent power, and an overall power factor of 0.865. The lower instantaneous power factor compared with the monthly billing values suggests that the electrical operating condition can vary considerably during production. Moreover, the measured current THD of 15.4–17.5% indicates that harmonic distortion may also contribute to the difference between displacement power factor and the overall true power factor.

Therefore, regular monitoring of the APFC panel, capacitor-bank condition, reactive power demand, and harmonic levels is recommended. Proper adjustment or replacement of derated capacitor steps, together with suitable harmonic mitigation where required, could improve the overall power factor, reduce apparent power demand and current loading, and improve the electrical efficiency of the plant. [1], [6], [8], [9]

Key result for the paper: The annual billing data show an average PF of approximately 0.94, while the field-measured PF was 0.865, indicating that short-term operating conditions can exhibit significantly poorer power-factor performance than monthly average billing records.

VII. ASSESSMENT OF THE EXISTING APFC SYSTEM

The unit has an automatic power factor correction system with eight capacitor steps and a total installed rating of 60 kVAr. One capacitor step is reported as derated, corresponding to 7.5 kVAr at a rated voltage of 440 V. The condition of the APFC system is therefore relevant to the measured power factor and should be considered together with the harmonic environment before any additional capacitors are installed.

TABLE III EXISTING APFC SYSTEM CHARACTERISTICS

Parameter	**Value**
APFC make	Neptune Ducati
Number of steps	8
Installed capacity	60 kVAr
Reported derated step	1
Derated capacity	7.5 kVAr
Rated voltage	440 V

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Fig. 6 Meter Room at Ceramic Unit

VIII. POWER-QUALITY MEASUREMENT RESULTS

a. Voltage Profile

The measured phase voltages were 252.4 V, 250.1 V and 250.0 V for phases R, Y and B, respectively. The three values are relatively close, indicating a reasonably balanced fundamental voltage condition during the measurement. The measured frequency was approximately 49.97–49.98 Hz

TABLE IV MEASURED PHASE-VOLTAGE AND VOLTAGE-DISTORTION PARAMETERS

Parameter	**R**	**Y**	**B**
RMS voltage (V)	252.4	250.1	250.0
Voltage THD-F (%)	5.8	5.9	6.0
Voltage THD-R (%)	5.8	5.9	6.0
Crest factor	1.47	1.48	1.48

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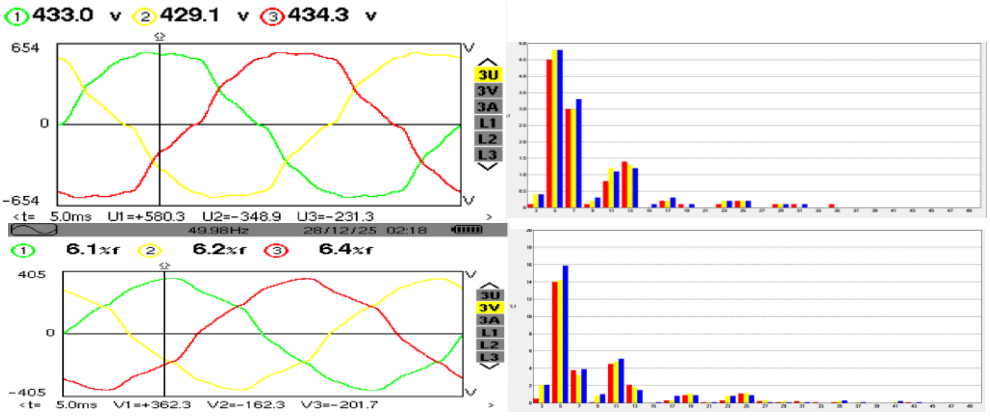


Fig. 7 Voltage Profile

b. **Current and Harmonic Distortion**

The current measurements show more pronounced distortion than the voltage measurements. RMS phase currents were 57.18 A, 55.14 A and 54.96 A. Current THD-F was 15.4%, 15.7% and 17.5% for phases R, Y and B, respectively. The maximum current distortion occurred in phase B. The results indicate the presence of significant nonlinear-current components and justify further equipment-wise investigation of VFDs, rectifiers and other electronic loads. [2], [6], [10], [11]

TABLE V MEASURED PHASE-CURRENT AND CURRENT-DISTORTION PARAMETERS

Parameter	**R**	**Y**	**B**
RMS current (A)	57.18	55.14	54.96
Current THD-F (%)	15.4	15.7	17.5
Current THD-R (%)	15.3	15.5	17.2
Crest factor	1.59	1.54	1.59

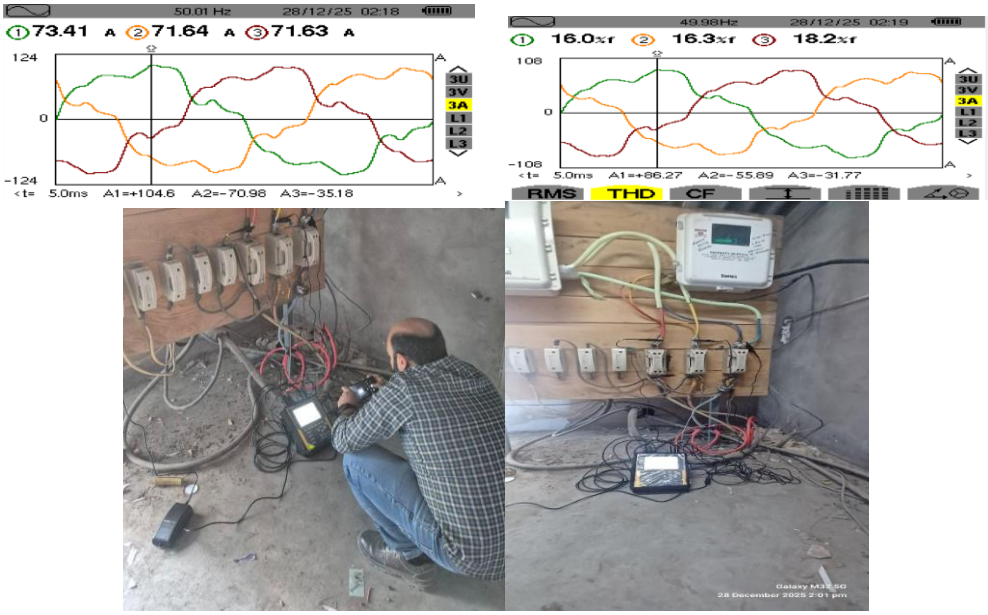


Fig. 8 Current Profile and Power analyser connection

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c. **Load Unbalance**

The phase currents of 57.18 A, 55.14 A and 54.96 A give an average current of approximately 55.76 A. The maximum deviation from the average is approximately 2.55% of the average current. The measured active powers of 12.62, 12.28 and 11.88 kW also show close phase loading. Thus, severe fundamental load imbalance was not observed under the measured operating condition. Harmonic distortion and reactive power are therefore more prominent concerns than fundamental phase-current imbalance.

TABLE VI PHASE-WISE ACTIVE, REACTIVE, DISTORTION AND APPARENT POWER

Parameter	**Line 1**	**Line 2**	**Line 3**	**Total**
Active Power	12.62 kW	12.28 kW	11.88 kW	36.78 kW
Reactive Power	7.062 kvar	5.993 kvar	6.752 kvar	19.81 kvar
Distortion Power	2.565 kvar	2.530 kvar	2.711 kvar	7.901 kvar
Apparent Power	14.69 kVA	13.89 kVA	13.93 kVA	42.52 kVA
Power Factor	0.859	0.884	0.853	0.865
Cos φ / DPF	0.871	0.897	0.868	0.88
Phase Angle, φ	29°	26°	30°	—

d. **Active, Reactive, Apparent Power and Power Factor**

The measured total active power was 36.78 kW, reactive power was 19.81 kVAr, distortion power was 7.901 kVAr and apparent power was 42.52 kVA. The corresponding overall power factor was 0.865. The phase-wise values show the lowest PF in phase B at 0.853 and the highest in phase Y at 0.884.

IX. DISCUSSION

The measured results reveal three principal electrical characteristics. First, the phase voltages are relatively well balanced, so voltage magnitude imbalance is not the dominant issue under the recorded condition. Second, current harmonic distortion is substantially higher than voltage distortion, with current THD reaching 17.5% in phase B. This points toward nonlinear-load behavior and indicates that harmonic sources should be traced to individual drives and electronic equipment rather than addressed only at the incoming point. [2], [6], [10]

Third, the measured power factor of 0.865 is accompanied by 19.81 kVAr of reactive power and 7.901 kVAr of distortion power. Therefore, the apparent-power requirement is influenced by both reactive and distortion components. The existing 60 kVAr APFC panel, including the reported 7.5 kVAr derated step, should be inspected and tested before further compensation is added. [6], [9]

The harmonic results also have implications for capacitor selection. Conventional capacitor addition without considering harmonic spectrum and system impedance can create resonance risks. The next stage should therefore include individual harmonic orders, short-circuit level at the point of common coupling, capacitor current/temperature checks and long-duration logging under representative production conditions. [6], [9], [10]

The historical billing data complement the instantaneous analyzer measurements. Monthly PF values were generally in the 0.92–0.98 range, while maximum demand varied considerably. This confirms that the electrical operating condition changes over time and supports repeated or long-duration measurements rather than reliance on a single instantaneous reading. [7], [9]

Energy-Conservation And Demand-Side-Management Opportunities

- Inspect and restore the reported derated APFC capacitor step and verify controller operation.
- Perform a detailed harmonic-spectrum study before selecting capacitors or harmonic filters. [6], [10]

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- Identify major nonlinear loads by equipment-wise current and THD measurements. [2], [6], [10]
- Evaluate detuned APFC or suitable active/passive harmonic mitigation where technically justified. [6]
- Maintain phase loading and periodically verify phase-current balance under different production conditions.
- Schedule major electrical loads to reduce unnecessary coincident demand where production permits.
- Continue periodic power-quality logging to establish representative operating profiles. [7], [9]
- Integrate power-quality indicators with the wider energy-audit and measurement-and-verification process. [4], [5], [8], [15]

X. LIMITATIONS AND FUTURE WORK

The present study is based on historical utility-bill data and field measurements available for the investigated operating condition. The analyzer dataset reported here does not establish long-duration statistical distributions of power quality, nor does it provide a complete individual-harmonic spectrum at all major loads. Consequently, the study does not claim that the measured values represent every production state.

Future work should include long-duration monitoring, individual harmonic orders, equipment-wise measurements, short-circuit ratio information at the point of common coupling and post-implementation measurement and verification. Integration of power-quality monitoring with data analytics or machine-learning methods may further support anomaly detection and forecasting of electrical energy performance. [3], [7], [9], [10]

XI. CONCLUSION

A measurement-based power-quality assessment was carried out for a continuously operated ceramic manufacturing SME in Thangadh, Gujarat. The measured phase voltages were 252.4, 250.1 and 250.0 V, while voltage THD ranged from 5.8% to 6.0%. Current THD was substantially higher, ranging from 15.4% to 17.5%, with the maximum value occurring in phase B. The measured three-phase active power was 36.78 kW, reactive power was 19.81 kVAr, distortion power was 7.901 kVAr and apparent power was 42.52 kVA. The resulting overall PF was 0.865.

The ceramic unit has a nearly balanced three-phase supply with normal frequency around 50 Hz, but the power quality is affected by moderate voltage harmonics and significant current harmonics. The measured load shows low overall power factor of 0.865, reactive power demand of 19.81 kVAr, and distortion power of 7.901 kVAr, indicating that inductive loads and harmonics are contributing to poor power quality.

The phase currents and active powers were comparatively balanced, indicating that fundamental load unbalance was not the dominant issue during the measurement. Instead, the results identify harmonic distortion, reactive power demand and the condition of the APFC system as the principal areas requiring further investigation. The study demonstrates that integrating power-quality measurements into an energy audit provides a more complete basis for energy conservation and demand-side management in ceramic SMEs.

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