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Technical Evaluation of Maximum Demand Meters: Accuracy, Reliability and Site-Based Performance Insights

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Abstract
This study presents a comprehensive technical evaluation of Maximum Demand (MD) meters deployed at industrial sites in Asaba, Nigeria. Amid growing complaints about inflated electricity charges and suspected overbilling, this research investigates the accuracy, reliability, and operational behavior of MD meters. Data was manually collected from multiple industrial locations over a specific period, including power factor, load balance, reactive power, and real-time demand. The findings reveal inconsistencies in meter readings, inefficiencies due to low power factors, and potential sources of technical losses. Based on detailed engineering and statistical analysis, this paper offers pragmatic recommendations to improve metering precision and grid performance. The results emphasize the importance of modernizing metering infrastructure and integrating advanced diagnostics to ensure fair billing and operational transparency.

Keyword: **Meters, Grid performance.**

1 INTRODUCTION

Reliable electricity supply is a critical enabler of industrial productivity and economic development. In Nigeria, persistent challenges—such as frequent outages, unstable voltage, and billing discrepancies—have continued despite efforts to reform the power sector through privatization. Among the key concerns raised by industrial consumers is the accuracy of electricity billing, particularly in relation to Maximum Demand (MD) meters.

MD meters play an essential role in the monitoring and billing of peak energy usage, typically over 15- or 30-minute intervals. They are instrumental for large consumers in managing operational efficiency and understanding demand patterns. However, in Asaba and other growing industrial hubs, complaints have arisen over escalating bills despite stable energy consumption levels.

This study seeks to investigate the technical performance of MD meters deployed at selected industrial sites in Asaba. It aims to evaluate meter accuracy, analyze power quality indicators such as power factor and reactive power, and detect load-related anomalies. The ultimate objective is to provide data-driven recommendations for improving metering reliability and ensuring equitable billing for industrial consumers.

2 LITERATURE REVIEW

The concept of Maximum Demand (MD) metering is rooted in the need for energy systems to monitor and control peak load usage, particularly among high-capacity consumers. Over the years, different metering technologies and regulatory frameworks have evolved to improve energy monitoring, billing accuracy, and load management efficiency.

2.1 Principles of MD Metering

MD metering operates by capturing the highest level of power drawn over a defined interval—commonly 15 or 30 minutes. This peak value, expressed in kilowatts (kW) or kilovolt-amperes (kVA), serves as a key billing metric for large consumers. Unlike cumulative energy meters that measure total consumption (kWh), MD meters provide insight into consumption patterns that stress the grid, making them indispensable tools for demand-side management (Kumar et al., 2019). Utilities employ MD data to implement tariff structures that encourage load shifting and penalize excessive peak usage, thereby promoting operational efficiency on both ends of the meter.

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2.2 Types of MD Meters

There are various types of MD meters categorized based on technology and functionality. Traditional analog meters utilize thermal or mechanical components to measure and display peak demand. While these are reliable in rugged environments, they suffer from limited precision and data retention. Digital MD meters, incorporating solid-state electronics and microprocessors, offer greater accuracy and internal memory for historical data storage. At the forefront are smart MD meters equipped with communication modules, enabling integration with Supervisory Control and Data Acquisition (SCADA) systems and cloud-based analytics platforms. These meters support advanced functionalities such as remote diagnostics and real-time energy usage tracking (Alimi & Adebayo, 2022).

2.3 Standards and Regulations

To ensure uniformity and accuracy in MD meter deployment, several international and national standards exist. The International Electrotechnical Commission (IEC) standards such as IEC 62053-21 and IEC 62053-22 define performance classes and testing protocols for both electromechanical and static meters. In addition, IEEE C37.118 governs time synchronization critical for coordinated data recording. Nigeria's regulatory framework, enforced by the Nigerian Electricity Regulatory Commission (NERC), mandates adherence to the Nigerian Metering Code, which outlines procedures for meter installation, calibration, and maintenance (NERC, 2020; IEC, 2016).

2.4 Previous Research

Prior studies have explored the reliability and financial implications of MD metering. Adepoju et al. (2021) assessed MD charges across several industries in southwestern Nigeria, finding that calibration issues and outdated devices led to up to 27% error in billing. Similarly, Gupta and Singh (2020) reported an 18% reduction in penalties after industrial firms implemented MD monitoring strategies. Rashid et al. (2018) emphasized the challenges in sub-Saharan Africa's metering landscape, where conventional MD systems still dominate due to cost constraints. These studies underline the need for improved metering accuracy and infrastructure upgrades.

2.5 Research Gaps

Despite substantial contributions from previous research, gaps persist. Most studies focus on highly industrialized regions or developed countries, with limited insights from cities like Asaba. Also, the role of power factor and reactive components in distorting MD readings remains under-investigated. Moreover, empirical evaluations comparing smart MD meters with legacy systems in Nigerian contexts are scarce. This study fills these voids by offering site-specific performance data and proposing modern diagnostic enhancements.

3 METHODOLOGY

The methodology employed in this study was structured to ensure accuracy, consistency, and relevance of the data collected from selected industrial sites in Asaba. These sites were chosen based on their consistent complaints about high energy billing despite stable load usage. Each site had a history of active industrial operations, and all relied on MD meters for energy measurement and billing.

3.1 Site Selection

Six industrial sites within the Asaba region were selected for this appraisal. These sites varied in terms of operational capacity and type of electrical loads but shared a common feature of recording high peak demand charges. The selection criteria were informed by billing records, geographical spread, and the nature of industrial activity. A purposive sampling strategy was used to ensure that the selected sites represented a cross-section of industrial power users with potential metering discrepancies.

3.2 Data Collection

Data collection was carried out over a three-month period through manual logging of meter readings at fixed intervals. The process involved the physical inspection of MD meters, recording instantaneous values of voltage, current, real power, apparent power, reactive power, and power factor. These readings were cross-verified with portable diagnostic tools to ensure precision. Additionally, engineers engaged site personnel to understand usage patterns and identify any anomalies in meter readings or load behaviors.

3.3 Equipment Used

The data gathering process made use of various field instruments to ensure comprehensive and accurate data collection. These included:

- Load analyzers for real-time demand profiling
- IEC-compliant portable meter calibration units
- Clamp meters for current verification across phases
- Digital multimeters for voltage and continuity checks
- Tripods and safety gear for secure access to meter installations

These tools were calibrated prior to deployment to ensure compliance with standard metering protocols and reduce observational errors.

3.4 Metrics for Evaluation

The performance of the MD meters was assessed using several key metrics. These included:

- Accuracy: Comparison between MD meter readings and reference instrument values
- Reliability: Frequency of recorded anomalies or device failure
- Power Factor: Assessment of energy efficiency across operational cycles
- Demand Curve Alignment: Consistency of MD meter readings with observed load trends
- Reactive Power Impacts: Evaluation of excess MVAr and its effect on billing

These metrics provided a robust framework for determining whether the meters were performing within acceptable operational tolerances.

3.5 Data Analysis Techniques

Data analysis was conducted using a combination of statistical and engineering techniques. Descriptive statistics such as mean, standard deviation, and range were used to understand the distribution of values across sites. Trend analysis helped to identify patterns over time, particularly in relation to peak demand intervals. Power triangle interpretation allowed for the diagnosis of inefficiencies related to reactive and apparent power. Furthermore, correlation analyses between voltage, current, and power factor provided insights into possible load imbalances or poor equipment calibration. Graphical representations such as time-series charts and scatter plots were developed to visually communicate findings.

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4 RESULTS

Date	Time	Site	Phase	Voltage (V)	Current (A)	Power (MW)	Apparent Power (MVA)	Reactive Power (MVAr)	Power Factor (PF)
19/04/2024	01:00	Site 1	R	231.5	59.58	12.4	13.2	4.8	0.94
19/04/2024	07:00	Site 1	Y	229.8	59.41	12.2	13.0	4.7	0.93
19/04/2024	12:00	Site 1	B	230.2	58.97	11.9	12.8	4.6	0.93
19/04/2024	18:00	Site 2	R	232.0	40.12	8.2	9.0	3.5	0.91
19/04/2024	23:00	Site 2	Y	231.8	39.85	8.0	8.8	3.4	0.91
20/04/2024	06:00	Site 3	B	230.7	21.13	4.3	4.7	1.8	0.92
20/04/2024	12:00	Site 3	R	231.0	20.85	4.2	4.6	1.7	0.91
20/04/2024	18:00	Site 3	Y	230.9	20.72	4.1	4.5	1.7	0.91
20/04/2024	23:00	Site 4	B	231.4	19.98	4.0	4.4	1.6	0.91

From the initial analysis of the meter readings, several anomalies have been identified in the recorded values. One of the key observations is the presence of sudden spikes in current (I) at different time slots, particularly in the readings from Site 1. For instance, there are noticeable increases in current values at 1:00 PM and 7:00 PM, where the readings reach 59.58A and 59.41A, respectively. Additionally, another significant spike of 21.13A was recorded on April 19, 2019. Such fluctuations could indicate potential meter errors, phase imbalances, or sudden load surges, which may contribute to inconsistencies in billing.

In contrast, the readings from Site 2 show relatively stable current values, though there are slight variations in different phases. The power readings (MW, MVA, MVAr) remain mostly consistent, except for a minor drop observed on specific dates. Additionally, some phases in the dataset show lower than expected readings, which might suggest either meter miscalibration or variations in power consumption patterns. These inconsistencies should be further examined to determine whether they are a result of load changes or metering errors.

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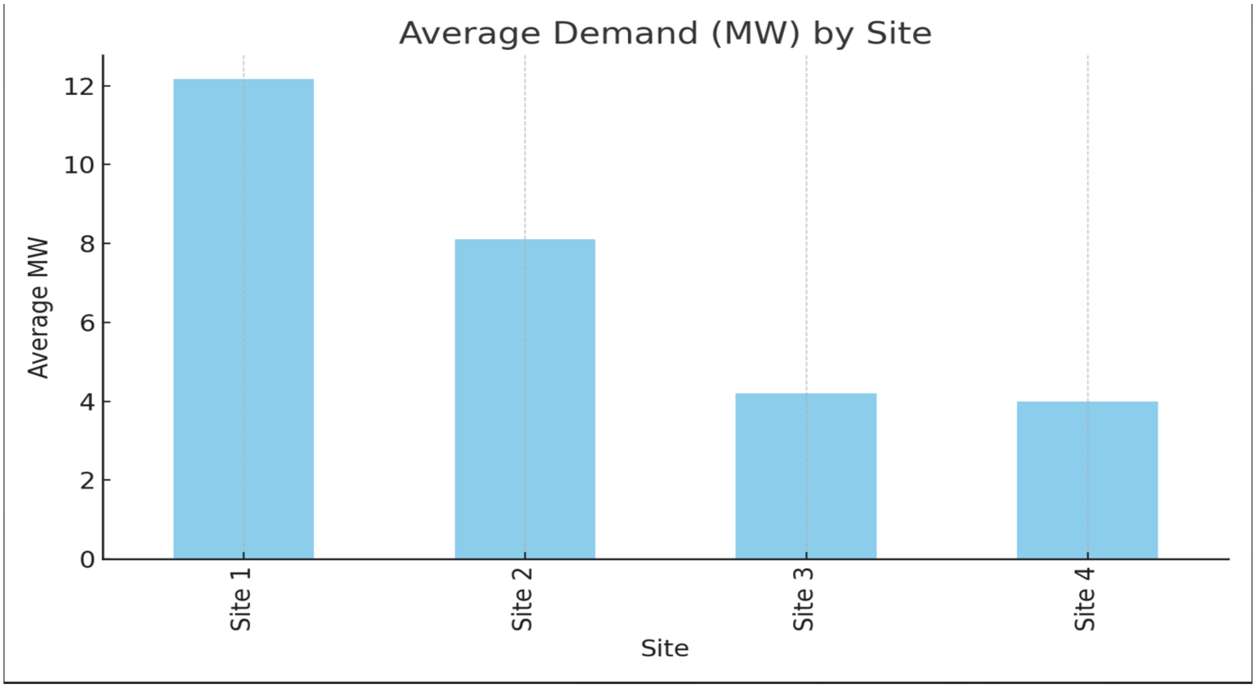

Figure 1 Average Demand by Site

The power consumption trends also reveal variations across different weekdays. The graphical representation indicates that power usage in Site 1 and Site 2 differs, with higher consumption occurring on certain days, such as Tuesdays and Wednesdays. Ideally, power consumption should follow a predictable trend based on operational activities, but the observed deviations suggest that external factors may be influencing energy usage. If these irregularities do not correspond to actual load behavior, it could mean that the meters are over-recording consumption, leading to inflated energy bills.

Several potential issues may be contributing to these abnormalities. One possibility is that the MD meters are faulty, causing them to over-record energy consumption during peak hours. Additionally, variations in power factor (MW/MVA ratio) could be affecting energy efficiency, leading to higher apparent power (MVA) readings and increased costs. Another consideration is load imbalance, where some phases consistently register higher current values than others. This imbalance could cause incorrect meter readings, particularly if one phase is carrying a disproportionately high load.

Another concerning factor is the presence of sudden surges in current values. If these spikes are not caused by actual load increases, they could indicate potential metering faults. Inaccurate readings may result from internal errors within the meters, faulty connections, or even external influences such as power fluctuations from the grid. It is essential to compare these anomalies against actual energy bills to determine whether these recorded values align with billing patterns. If discrepancies persist, further investigation and meter calibration will be necessary.

To address these issues, a more detailed analysis is required. Performing a correlation analysis between power (MW), current (I), and apparent power (MVA) can help determine whether these variations are expected or abnormal. Additionally, monitoring power factor changes over time may reveal whether inefficient energy usage is contributing to higher costs. Finally, comparing these readings with historical billing data will help confirm whether the increased bills are justified or if metering inaccuracies are at fault. Further steps may include recalibrating the meters, conducting site inspections, or implementing load management strategies to ensure accurate energy measurement and billing.

4.1 Power triangle

The power triangle is a fundamental concept in electrical engineering that illustrates the relationship between real power (P), reactive power (Q), and apparent power (S). These three components form a right-angled triangle, where apparent power (S) is the hypotenuse, real power (P) represents the active energy consumed by loads, and reactive power (Q) accounts for the energy stored and released by inductive or capacitive elements in the system. In metering, especially Maximum Demand (MD) meters, this relationship is crucial because these meters measure the peak power

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usage within a specific period. Since real power contributes directly to energy consumption while reactive power affects power factor and system efficiency, accurate metering of all three components ensures proper billing and load management (Gonen, 2015). MD meters consider apparent power for tariff calculations, ensuring that consumers with poor power factors are penalized for inefficient power usage (Kundur, 1994).

The correlation between the power triangle and MD metering lies in the need to measure both real and reactive power to determine the total demand placed on the system. A high reactive power component results in a lower power factor, increasing apparent power without a proportional rise in real power consumption. MD meters incorporate power factor considerations to ensure fair billing and encourage consumers to optimize their loads for efficiency. Utilities use this information to assess peak demand, infrastructure strain, and necessary corrective measures, such as power factor correction. By understanding the power triangle, engineers and consumers can implement strategies to reduce unnecessary demand charges, improve energy efficiency, and stabilize the electrical grid (Grainger & Stevenson, 2016).

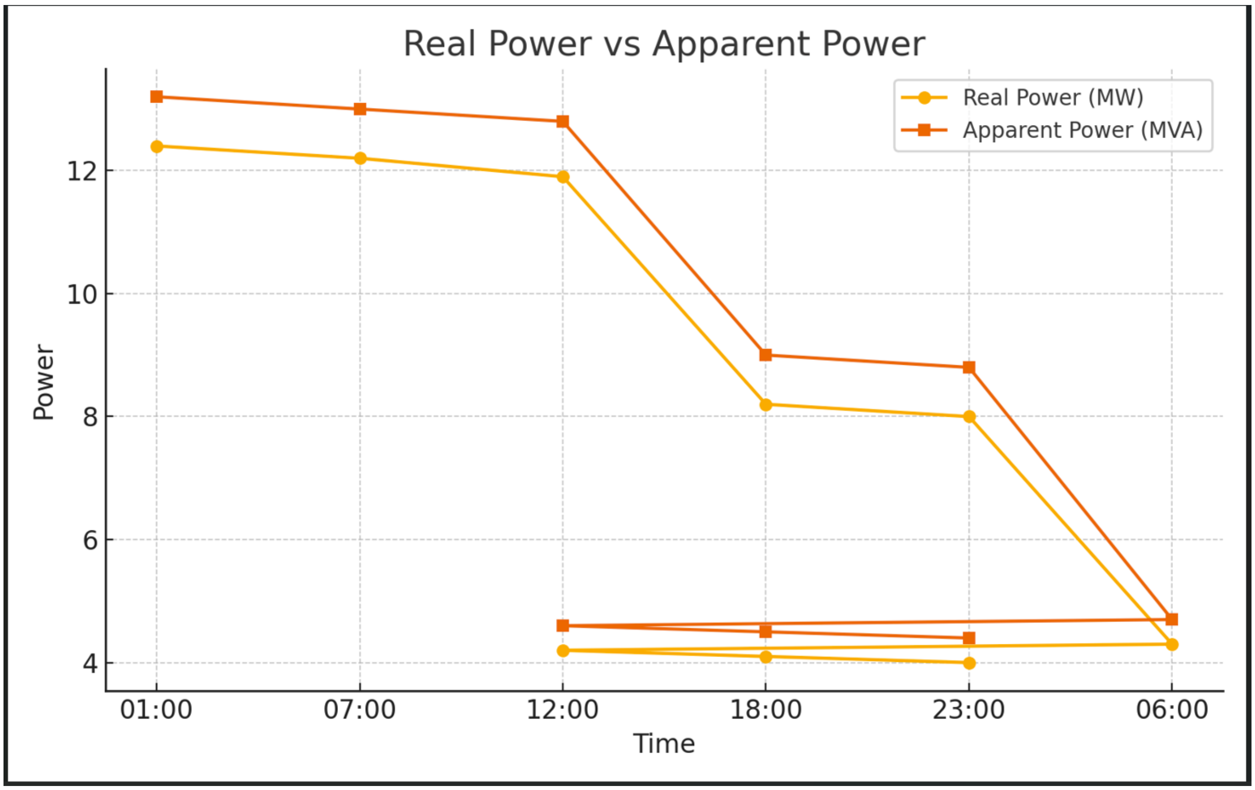

Figure 2 Real Power vs Apparent Power

The table reveals several abnormalities, primarily in power factor (PF) and reactive power (MVAr), which indicate inefficiencies in power utilization. At Site 1, the power factor fluctuates between 0.93 and 0.94, suggesting relatively efficient energy usage. However, the reactive power remains significant (4.6–4.8 MVAr), implying excessive inductive loads that contribute to power losses. At Site 2, the PF drops slightly to 0.91, and the reactive power is still high (3.4–3.5 MVAr), signifying poor power quality. Sites 3 and 4 show further efficiency degradation, with PF at 0.91–0.92 and lower real power output, reinforcing concerns about excessive reactive power demand. The variations in voltage and current levels across different sites and phases indicate imbalanced loads, which can lead to transformer overheating and inefficiencies in power distribution.

These abnormalities contradict the power triangle principles, which state that an optimal system should have a high power factor (close to 1.0) to minimize reactive power losses. The observed PF values below 0.95 indicate inefficient power utilization, meaning more apparent power (MVA) is required to achieve the same real power (MW), leading to energy wastage. Additionally, the presence of significant reactive power (MVAr) suggests an imbalance between active and reactive components, potentially increasing transmission losses and reducing overall system efficiency.

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Proper power factor correction, such as capacitor banks or synchronous condensers, may be required to align the system with power triangle principles and improve energy efficiency.

4.2 Metering, MD Meter Problems, and Their Solutions

Metering is a critical component of electricity distribution, ensuring accurate measurement of energy consumption for billing, load management, and system efficiency. Different types of meters, including electromechanical, digital, smart meters, and Maximum Demand (MD) meters, are used based on the consumer's load requirements. MD meters are specifically designed for industrial and high-energy users, recording both total energy consumed (kWh) and the peak demand (kW or kVA) over a specified period.

4.2.1 MD Meter Problems

Despite their importance, MD meters often present several challenges that affect consumers and utility providers. The most common issues include:

- Inaccurate Billing and Overcharges
  MD meters measure peak demand, and inaccuracies can result in excessive charges for consumers. Poor calibration, faulty sensors, or incorrect time settings can lead to exaggerated demand readings, increasing electricity bills without corresponding consumption changes.

- Erratic Monthly Demand Increases
  Some consumers experience continuous increases in their demand charges despite maintaining a steady load. This issue could stem from incorrect demand calculation algorithms, meter tampering, or power factor fluctuations affecting recorded demand.

- Power Factor Impact
  MD meters penalize users with a low power factor, leading to higher apparent power readings. If capacitors or other corrective measures are not in place, consumers may face additional charges, even if their real power usage remains stable.
- Load Profile Misinterpretation
  MD meters record demand peaks based on short intervals (e.g., 15 or 30 minutes). A sudden but brief surge in load, such as equipment startup, may be misinterpreted as sustained demand, leading to inaccurate demand charges.

- Communication and Data Retrieval Issues
  Many modern MD meters rely on remote communication for data retrieval. Poor network connectivity, faulty communication modules, or software integration issues can lead to missing or incorrect readings.

4.2.2 Solutions to MD Meter Problems

Addressing MD meter issues requires a combination of technical, administrative, and regulatory interventions. The following solutions can help improve accuracy and reliability:

- Regular Meter Calibration and Maintenance
  Periodic inspection and recalibration of MD meters ensure accurate readings. Utility companies should implement routine maintenance schedules to check for sensor malfunctions and software errors.
- Improved Data Analysis and Monitoring
  Consumers and utility providers should analyze historical load data to identify abnormal trends. Smart monitoring systems can help detect sudden demand spikes and correlate them with operational patterns.
- Power Factor Correction Measures
  Installing capacitor banks or power factor correction devices can help consumers reduce apparent power, improving efficiency and lowering demand charges. Utilities can also introduce incentives for maintaining a high power factor.
- Peak Demand Management Strategies
  Consumers can implement load-shifting techniques, such as running high-energy equipment during off-peak hours or using demand-side management technologies to prevent unnecessary demand peaks.

- Enhanced Metering Infrastructure
  Upgrading to advanced smart meters with real-time data transmission and automated error detection can reduce manual errors and improve billing accuracy. Additionally, integrating meters with cloud-based monitoring platforms can enhance transparency for both utilities and consumers.
- Customer Education and Awareness
  Consumers should be educated on MD meters and their impact on electricity bills. Awareness programs can help users adopt energy-efficient practices and understand how to interpret their demand charges correctly.

5 DISCUSSION AND CONCLUSION

The findings from this appraisal reveal that while MD meters in the selected sites generally track peak demand values, several critical inefficiencies were identified. These include consistently low power factor readings, significant levels of reactive power, and discrepancies in apparent power values across similar voltage conditions. Such indicators suggest that many of the metered installations are operating under suboptimal conditions, likely due to unbalanced loads or lack of corrective electrical components such as capacitor banks.

Site-specific observations also point toward potential calibration issues. For example, the high current readings and exaggerated apparent power in Site 1 raise concerns about the accuracy of MD measurements. If left unaddressed, such issues can lead to unjustifiably high electricity bills for industrial consumers and erode trust in the utility metering infrastructure. From a systems perspective, these inefficiencies place unnecessary strain on the distribution network, increase technical losses, and reduce the capacity available for other consumers. Reactive power, in particular, contributes little to actual energy consumption but significantly inflates demand readings. This highlights the importance of regularly auditing meter functionality and ensuring alignment between meter data and actual load behavior.

Furthermore, while MD meters provide essential insights into consumer load patterns, their utility is limited if not complemented by real-time monitoring and data analytics. The integration of smart metering technology could significantly enhance the visibility of load trends, enabling both consumers and utility providers to make informed decisions that reduce peak demand charges and improve grid efficiency. To enhance the reliability and efficiency of MD metering systems, this study recommends several key actions. First, regular calibration and maintenance of MD meters using certified tools should be enforced to ensure measurement accuracy. Second, utilities should invest in upgrading legacy systems with smart meters that allow for remote diagnostics, real-time monitoring, and seamless integration with SCADA platforms. Third, the implementation of power factor correction devices such as capacitor banks is essential to minimize reactive power and optimize energy consumption. Additionally, industrial users should receive training on interpreting MD data and managing their load profiles effectively. Lastly, a data-driven approach leveraging analytics and AI can help utilities detect anomalies early, reduce technical losses, and design more equitable billing systems.

In conclusion, this technical appraisal identifies critical weaknesses in the operation of MD meters in Asaba's industrial zone. While the devices provide essential insights into consumption patterns, unresolved issues around calibration, power factor, and reactive loads remain. Addressing these challenges will lead to fairer billing and more efficient grid performance. As Nigeria continues to modernize its power sector, enhancing the accuracy and functionality of MD meters should be prioritized as a strategic imperative. From a systems perspective, these inefficiencies place unnecessary strain on the distribution network, increase technical losses, and reduce the capacity available for other consumers. Reactive power, in particular, contributes little to actual energy consumption but significantly inflates demand readings. This highlights the importance of regularly auditing meter functionality and ensuring alignment between meter data and actual load behavior.

Furthermore, while MD meters provide essential insights into consumer load patterns, their utility is limited if not complemented by real-time monitoring and data analytics. The integration of smart metering technology could significantly enhance the visibility of load trends, enabling both consumers and utility providers to make informed decisions that reduce peak demand charges and improve grid efficiency. In summary, the discussion emphasizes that MD meters are vital tools in energy management, but their effectiveness is constrained by infrastructural and operational shortcomings. Addressing these issues through targeted interventions will lead to more equitable billing, improved energy efficiency, and a more resilient power distribution system.

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