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Assessment Analysis of Neutral to Earth Voltage (NTEV) in the Distribution System at the Government Building Using Statistical and Analytical Methods Analysis

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Abstract

Elevated neutral-to-earth voltage or simply known as Neutral-To-Earth Voltage (NTEV), and the related phenomenon called stray voltage is typically caused by fundamental frequency currents returning to the source via the neutral conductor and earth. The nature of grounded power systems results in the fact that the neutral conductors are not always at zero potential with respect to the earth. This study also aims to investigate the effect of Neutral to Earth voltage on power distribution. Using the appropriate measurement equipment, the data logger was attached to Main Switch Boards to record data for 4 days for monitoring, recording, and analyzing frequency, harmonics, and voltage fluctuation. In addition, the data logger for this measurement tool have been installed on the main switchboard (MSB1) in Agensi Nuklear Malaysia. This study performed a comparison of peak time (8 am-5 pm) and non-peak time (6 pm-6 am) and also the correlation between each parameter. Based on the result of standard deviation and mean, all parameters deviate very closely to the mean value. The skewness value provide evidence that the measured data was distributed close to the nominal specification. Through correlation analysis, at the end of this study it was found that the correlation between NTEV and THDV of each phase in the first location has a very high correlation.

Keywords

Neutral-to-Earth Voltage (NTEV), Power Quality Disturbances, Total Harmonics Distortion (THD), Pearson Correlation, Descriptive Analysis, Statistical Analysis

1. Introduction

Power quality encompasses the key attributes of electrical power, such as voltage, frequency, and waveform integrity, ensuring they meet the necessary standards for optimal device and equipment performance. Power quality disturbances, such as excessive Neutral-to-Earth Voltage (NTEV) and Total Harmonic Distortion (THD), can compromise operational efficiency and lead to equipment failure. Statistical analysis, including Pearson Correlation and Descriptive Analysis, are valuable tools in assessing and quantifying the impact of these disturbances. A detailed understanding of these factors is crucial for maintaining reliable and efficient electrical systems.

The growing emphasis on power quality has led to notable advancements in monitoring technologies capable of characterizing disturbances and fluctuations in power quality. This paper examines the various types of power quality disturbances and explores methods for effectively analyzing and presenting this data in a meaningful way.

1.1. Overview of NTEV

Neutral-to-Earth Voltage (NTEV) in distribution systems is a critical concern affecting safety and reliability. Elevated NTEV often results from unbalanced loads, harmonic distortions, and poor grounding, causing voltage differences between the neutral point and earth. This can lead to stray voltage, compromising both human safety and equipment performance. Harmonic currents from nonlinear loads exacerbate the issue by generating triple harmonics that do not cancel out in the neutral conductor. Key factors contributing to elevated NTEV include unbalanced loading, system asymmetries, earth resistivity, and feeder length. By referring to IEE1159 (IEEE Recommended Practice for Monitoring Electric Power Quality), the acceptable thresholds for NTEV or stray voltage is 10 V [1]. **Table 1** shows the summary table for NTEV level.

Table 1. Summary table for NTEV level.

Condition/Location	Max. NTEV (V)	Comments
Residential Areas	1.0 V	Standard for safety in residential system
Commercial Areas	1.5 V	Slightly higher allowance for commercial equipment
Industrial Areas	2.0 V	Higher due to larger electrical systems and loads
Sensitive Equipment Zones	0.5 V	Critical areas such as hospitals or labs
NTEV with Isolation Transformer	0.5 V	Significant reduction when isolation transformers are used
Acceptable Limits (IEEE 519-2014)	1.0 V	Per IEEE guidelines for maintaining safe power quality

Shafie *et al.* (2010) examine the use of isolation transformers to mitigate harmonic voltages and Neutral-to-Earth Voltage (NTEV) in distribution systems, focusing on their effectiveness at Universiti Teknologi MARA in Penang. NTEV, or common-mode voltage, represents the potential difference between the neutral conductor and safety ground, which can cause operational issues, equipment failure, and higher losses for linear loads [2]. The results show that the isolation transformer significantly reduced both NTEV and Total Harmonic Distortion (THD). For example, Figure 1 and Figure 2 show the maximum NTEV in Computer Lab 1 decreased from 1.464 V to 0.977 V, and the THD for phase voltage dropped from 1.927% to 1.501%. These improvements are in line with IEEE 519-2014 standards on harmonic distortion [3].

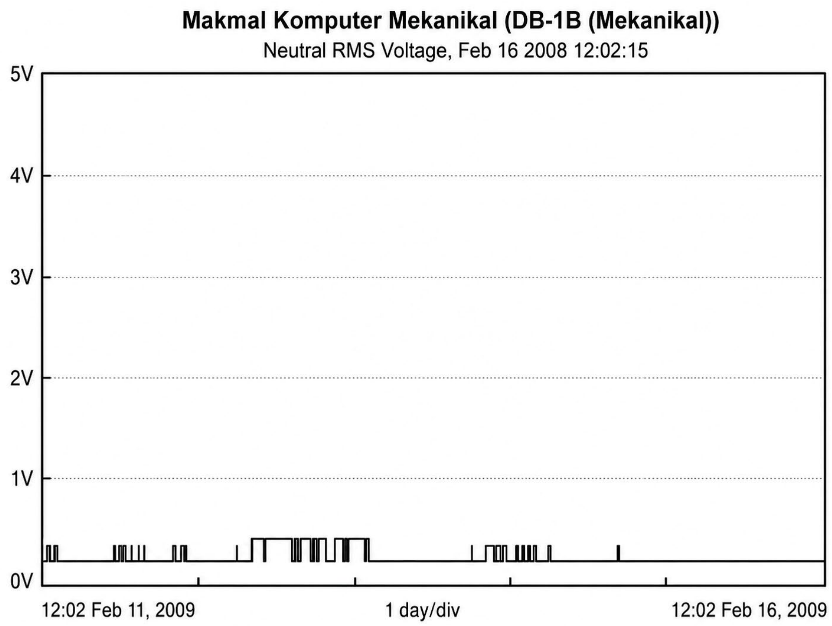

Figure 1. NTEV profile with Isolation Transformer at Lab 1.

1.2. Objective

Research on Neutral-to-Earth Voltage (NTEV) in government buildings is of paramount importance, as these structures are subject to stringent safety regulations, possess intricate electrical systems, and have a significant public impact. Conducting such research enables the identification of potential electrical hazards, interference with communication systems, and issues related to legal compliance. A key objective of this research is to evaluate the relationship between Neutral-to-Earth Voltage and Total Harmonic Distortion (THD) in identifying the cause and effect of Neutral-to-Earth Voltage at government buildings. Thereby it aligns the government's standards with international benchmarks.

1.2.1. Type of System in This Research

Recent studies from M.A Shafie highlight the increase in the use of nonlinear loads (like computers, printers, UPS, and electronic lighting) in distribution systems cause harmonic distortion and elevated neutral-to-ground voltages, which can lead to equipment malfunction, higher losses, and reliability issues. This study focuses on Low Voltage system with varies of load that contribute to the NTEV level which is distribution system at government buildings.

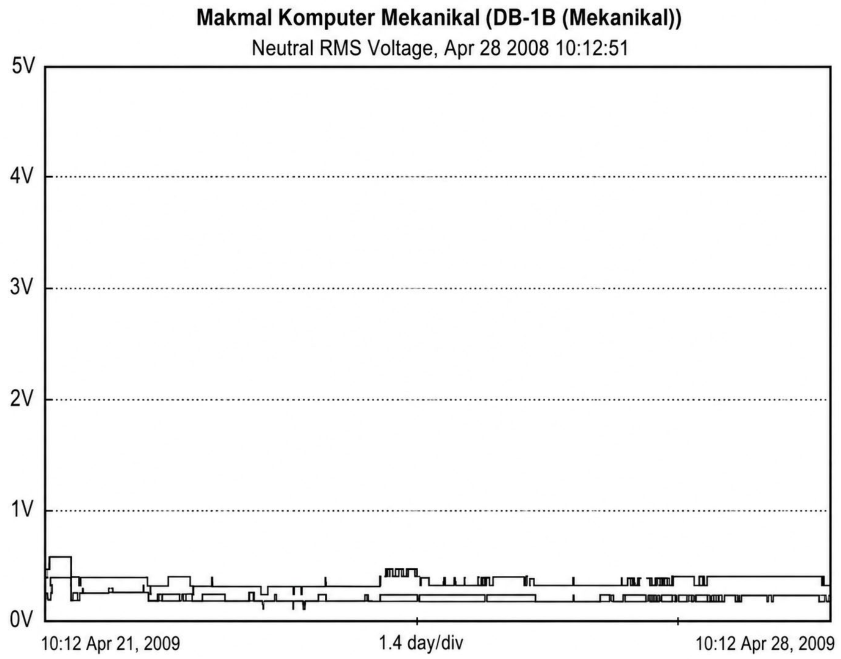

Figure 2. NTEV profile without Isolation Transformer at Lab 1.

1.2.2. Parameter

1) Frequency Stability

Referring to Malaysia Distribution Code, under clause 5.4.3 system frequency are required to be continuously maintained ±1% from 50 Hz within the range 49.5 Hz to 50.5 Hz this is to make sure the active power output does not decrease by more than 5% [4].

2) Harmonic Distortion

Harmonic distortion is defined as departure of a waveform from sinusoidal shape that is caused by the addition of one or more harmonics to the fundamental waveform. In Malaysian Distribution Code, clause 5.4.6.9 it is stated that Total Harmonic Distortion is to be maintained below 5% from the magnitude of the fundamental wave form [4]. In principle total harmonic distortion is equal to I harmonic divide by I fundamental [$THD = I_H/I_1$].

2. Methodology

Figure 3 presented the overall research workflow employed in this study, beginning with site selection and site visits, followed by PQ data logger installation and continuous data measurement and monitoring. The recorded data were then extracted, sorted, processed, and systematically arranged for analysis. Descriptive analysis, correlation analysis, and visual observation were subsequently conducted to evaluate data characteristics and relationships. Finally, the outcomes of these analyses were consolidated and interpreted in the results and discussion stage, marking the completion of the research process.

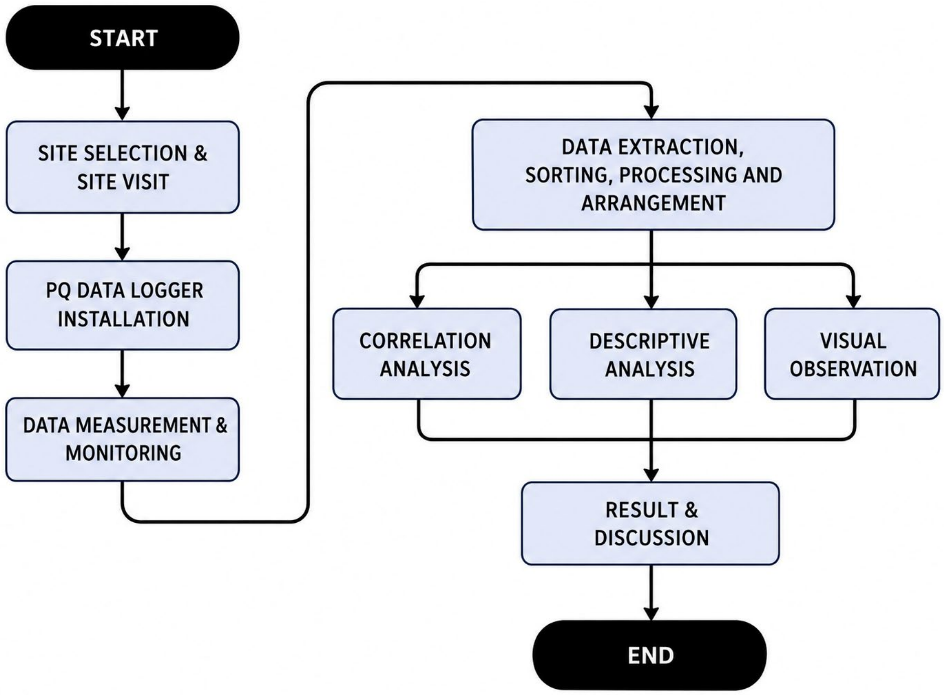

Figure 3. Research methodology flowchart.

2.1. Site Selection & Site Visit

The site selection and site visit, as well as discussions with the building owner regarding the building's function and the categories of loads present, are the initial steps of the process.

Overview of THD

Changes in frequency on each wave whether voltage or current, it can cause the existence of harmonic distortion. This includes neutral voltage and current components [5]. In a power system, the issue of power quality is very important because it can disrupt the entire system. Among the main components in this determination are harmonics. Therefore, all harmonics is very important for any operation or planning studies.

According to David from Okanagan College in Kelowna, BC, Canada states that Total Harmonic Distortion (THD) is the ratio for V_{rms} of all the harmonic frequency starting from the 2nd harmonic on, over the V_{rms} fundamental frequency. He also provided the equation to determine the THD value

$$\text{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} V_{n\_rms}^2}}{V_{fund\_rms}}$$

were,

V_{n_rms} is the RMS voltage of the nth harmonic;

V_{fund_rms} is the RMS voltage of the fundamental frequency.

Scope

Standard and Regulation

In Malaysia, Total Harmonic Distortion (THD) limits are prescribed through national grid codes and utility-specific technical requirements to ensure power quality and the secure operation of electrical infrastructure. These regulations are primarily documented in the Malaysian Grid Code, the Distribution Code for Peninsular Malaysia, and technical publications by Tenaga Nasional Berhad (TNB), the country's principal utility provider.

Voltage THD limits differ based on system voltage levels. According to the Malaysian Grid Code and corroborated by technical analyses, the allowable THD values are as follows:

- High Voltage (HV) Systems (500 kV, 275 kV, 132 kV): Maximum THD is limited to 3.0% [6].
- Medium Voltage (MV) Systems (33 kV, 22 kV, 11 kV, 6.6 kV): THD must not exceed 6.5% [7].
- Low Voltage (LV) Systems (400 V and below): A THD threshold of 5.0% is applied [7].

Maintaining THD within these limits is critical to minimizing harmonic distortion, which can lead to overheating, equipment malfunction, and increased system losses.

Voltage Level	Voltage THD Limit	Current THD Limit (Inverter Output)
500 kV, 275 kV, 132 kV	3.0%	N/A
33 kV, 22 kV, 11 kV, 6.6 kV	6.5%	5.0%
400 V and below	5.0%	5.0%

2.2. Type of Analysist

Two types of analysis are used, which are Descriptive Analysis and Correlation Analysis.

Descriptive statistical analysis was applied to summarize the fundamental characteristics of the measured variables, including central tendency, variability, and data distribution. This preliminary analysis provides an essential basis for understanding the behavior of Neutral-to-Earth Voltage (NTEV) and Total Harmonic Distortion (THD) prior to inferential evaluation. Pearson correlation analysis was selected because both NTEV and THD are continuous variables, and this method is appropriate for examining the strength and direction of their linear relationship. Consequently, Pearson correlation offers a suitable statistical approach for assessing the association between harmonic distortion and variations in neutral-to-earth voltage.

The study conducted by Suziyani from the School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA Dungun, Terengganu, demonstrated that the correlation coefficient method is an effective tool for analyzing the relationships between variables [8].

Referring to the research by Gabrijela Dimić and colleagues demonstrates the effectiveness of descriptive statistical analysis in educational data mining. By providing detailed insights into data distribution, identifying skewness, and applying histogram discretization, the method improved prediction model accuracy, particularly with the Random Forest classifier, which achieved 91.49% accuracy. The analysis also facilitated the transformation of continuous features into discrete intervals, enhancing algorithm efficiency and model performance. Overall, the study underscores the critical role of descriptive statistics in preprocessing, leading to more accurate and efficient data mining outcomes [9]. **Table 2** presents the judgement table for the descriptive analysis.

Table 2. Judgement table for descriptive analysis.

Measure	Description	Purpose	Interpretation
Mean	The average value of the dataset.	To identify the central tendency of the data.	Provides the overall average value of the dataset.
Median	The middle value when the data is arranged in order.	To determine the central point of the data.	Useful for skewed distributions or outliers.
Mode	The value that appears most frequently in the dataset.	To understand the most common value.	Indicates the most frequent observation.
Standard Deviation	The square root of variance, showing data spread in the same units as the data.	To gauge the dispersion or consistency in the data.	Helps in understanding the consistency of data.
Skewness	Measures the asymmetry of the data distribution.	To assess the direction of skew in the data.	Positive skew: right tail longer; Negative: left tail longer.

Table 3. Pearson correlation coefficient guide table.

Correlation Coefficient Value	Interpretation Criteria
−0.800 to −1.000	Perfectly Negative
−0.600 to −0.799	Strongly Negative
−0.400 to −0.599	Moderately Negative
−0.200 to −0.399	Weakly Negative
0 to −0.199	Very Weakly Negative
0.000 to 0.199	Very Weakly Positive
0.200 to 0.399	Weakly Positive
0.400 to 0.599	Moderately Positive
0.600 to 0.799	Strongly Positive
0.800 to 1.000	Perfectly Positive

Table 3 shows a guide to interpreting the Pearson Correlation Coefficient, which measures the strength and direction of the linear relationship between two continuous variables. In practice, the closer the coefficient is to either +1 or −1,

the stronger the linear relationship. Values closer to 0 indicate weaker relationships, and the direction of the relationship (positive or negative) is indicated by the sign of the coefficient [10].

2.3. PQ Data Logger Installation

In this phase, several measurement locations have been identified for the purpose of acquiring raw data prior to analysis. Figure 4 below illustrates the point diagram, where a Fluke 435 PQ as shows in Figure 5 meter will be installed on the distribution network to collect data according to the desired parameters. Each location will be installed within a period of four days.

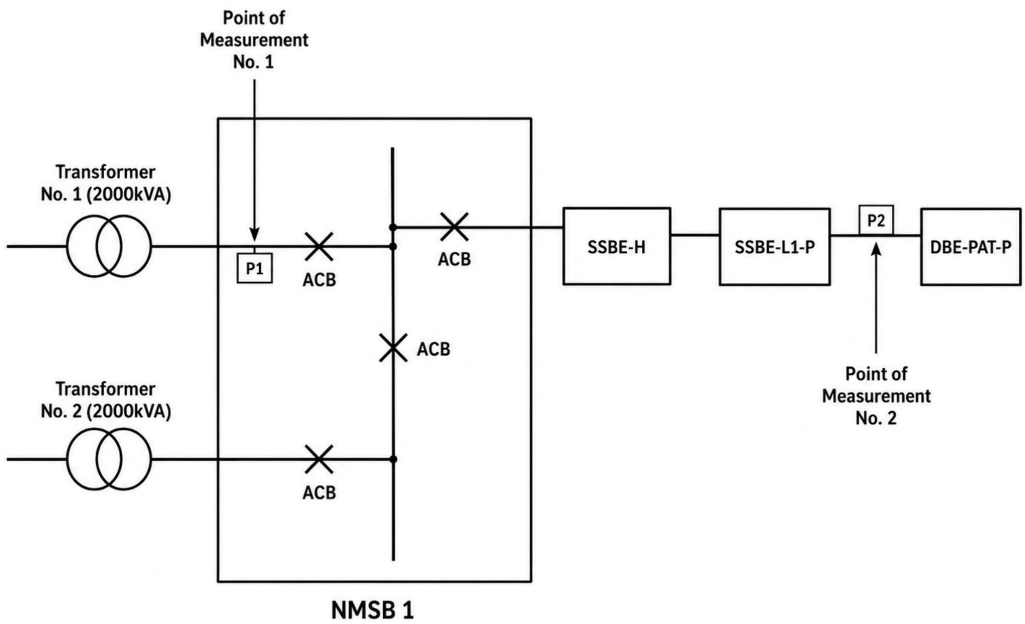

Figure 4. Point of connection.

Figure 5. PQ data logger fluke 435.

2.4. Analytical and Statistical

This research will utilize statistical methods, such as the Pearson correlation coefficient, to analyze the relationship between frequency, THD, and Voltage variation with NTEV levels. These analyses confirm that as frequency changes, especially with harmonic distortion, there is a significant correlation with fluctuations in NTEV levels. Consequently, Minitab software as shown in Figure 6 was selected as the optimal tool due to its user-friendly interface and extensive statistical capabilities. Within Minitab, two distinct types of analytical methods were employed:

1) Descriptive Statistical Analysis
2) Pearson Correlation Analysis

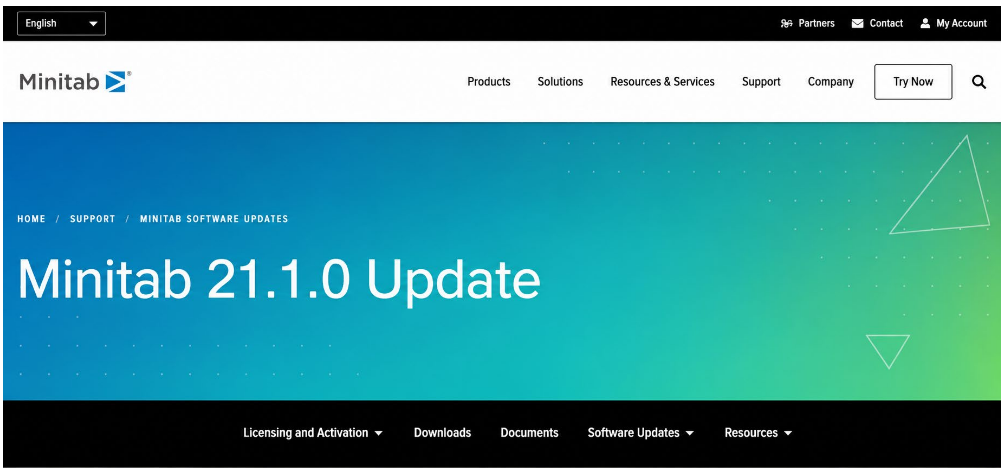

Figure 6. Power log software interface

2.5. Visual Observation

A visual observation for Neutral-to-Earth Voltage (NTEV) graft and Total Harmonic Distortion (THD) graft typically involves comparing two separate graphical representations to assess their respective trends and relationships.

By comparing these graphs, one can observe if there's a correlation between NTEV variations and spikes in THD. For instance, an increase in NTEV may coincide with a rise in THD, suggesting that grounding issues could contribute to higher harmonic distortion in the system.

This type of analysis helps to diagnose power quality problems and take corrective actions to improve the overall stability and performance of the electrical system.

3. Result

3.1. Neutral to Earth Voltage

Observation

From the result obtained in Figure 7, sine wave view, it can be seen that the NTEV pattern is directly proportional to the current value in each phase. High values occur during peak hours while low voltage values occur outside of peak hours.

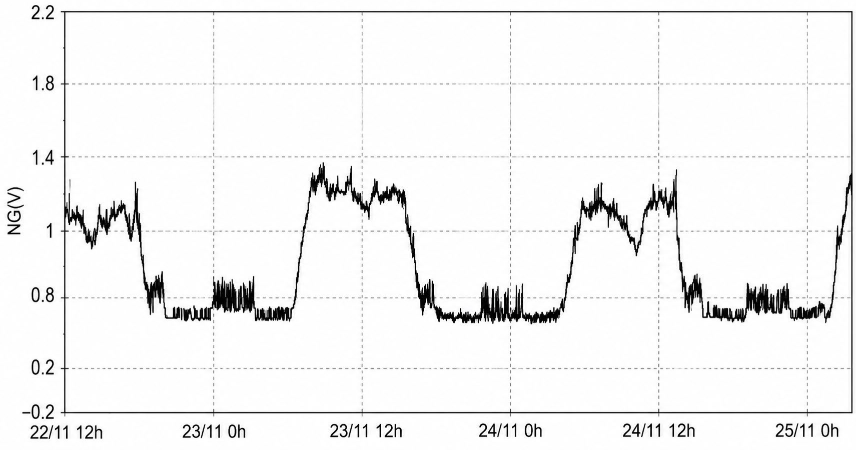

Figure 7. Neutral to earth voltage at MSB1.

Table 4. Minimum and maximum NTEV for MSB1.

Location	Neutral Voltage (V)	Date	Time
MSB1	Min: 0.32	23/11/2022 24/11/2022 25/11/2022	Mostly during off-peak hours from 6.30 pm-7.00 am
	Max: 1.34	23/11/2022	Mostly during peak hours from 7.00 am-6.30 pm

The Neutral to Earth Voltage's minimum and maximum values are displayed in Table 4. During the recorded measurement period November 22nd to 25th 2022 at the first site, the minimal NTEV value of 0.32 V occurred every day during off-peak hours. The maximum value of 1.34 V happened on November 23, 2022, at 10 am, during peak hour.

3.2. Total Harmonic Distortion (THD)

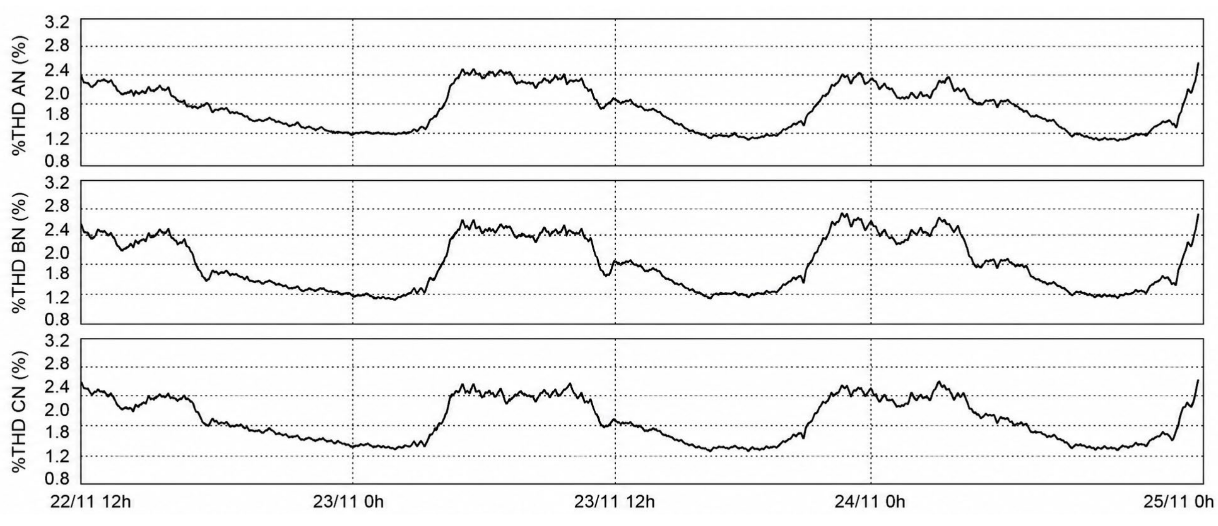

Figure 8. THD for MSB1.

The percentage THD value at the first location is shown in Figure 8. The measurement began on November 22, 2022, at 10.40 a.m. and ended on November 25, 2022, at 9.16 a.m. Throughout the measurement record, the THD value remains within the specification range of less than 5%. When compared to the current in each phase, the pattern is nearly same, with high value at peak time and low value at non-peak. This is because VTHD and total current are depended on each other.

Table 5. THD at MSB1.

Phase	Min (%)	Date	Time	Max (%)	Date	Time
R-N	1.38	24/11/2022	12.51 am	2.58	25/11/2022	9.14 am
Y-N	1.2	24/11/2022	1.10 am	2.95	24/11/2022	10.13 am
B-N	1.19	23/11/2022	7.12 am	2.82	24/11/2022	10.02 am

According to Table 5 above, for the Red phase, the lowest value is 1.38% and occurs on November 24, 2022, at 12.51 am, while the highest value occurs at peak time on November 25, 2022, at 9.15 am. On November 24, 2022, at 1.10 am, the yellow phase recorded a lowest value of 1.2%, and at 10.13 am the same day, a maximum value of 2.95%. One of the lowest VTHD values ever recorded was in the blue phase on November 23, 2022, at 7.12 am, while the highest value was at peak time on November 24, 2022, at 10.02 am.

4. Analysis

4.1. Descriptive Statistics

Table 6. Statistic of MSB1.

Variable	Mean	Std. Dev.	Minimum	Median	Maximum	Skewness
NTEV	0.67	0.31	0.32	0.54	1.34	0.46
VTHD R	1.85	0.28	1.38	1.86	2.58	0.08
VTHD Y	1.96	0.50	1.20	1.82	2.95	0.23
VTHD B	1.82	0.38	1.19	1.76	2.82	0.17

NTEV

Referring to the Table 6 Statistic of MSB1, NTEV std deviation is 0.31, and mean 0.67. By this two information, the value of standard deviation provides evidence that Neutral to Earth voltage across neutral to ground line deviates very closely to the mean value. While skewness with the value of 0.46 and median of 0.54 provide informative evidence on how the measured data was distributed during measurement period and in this case is skewed to the right. As a result, the data might be interpreted as NTEV voltages tend to be greater than the average value.

VTHD RYB

Overall, the VTHD value on each phase is in the range of 1.19% to 2.95%. By this information, the value of standard deviation provides evidence that VTHD each phase deviates very closely to the mean value. While skewness with the value of 0.08, 0.23 and 0.17, provide informative evidence on how the measured data was distributed during measurement period. The data measured in this case is positively skewed. As a result, the data might be interpreted as VTHD each phase tend to be greater than the average value.

4.2. Analysis

Table 7. NTEV and VTHD correlation MSB1.

	NTEV	VTHD Red	VTHD Yellow
VTHD Red	0.845		
VTHD Yellow	0.919	0.956	
VTHD Blue	0.905	0.952	0.974

Interpretation:

NTEV and VTHD correlate to each other. Referring to **Table 7***, the analysis of Pearson correlation coefficient between NTEV to VTHD Red, VTHD Yellow and VTHD Blue are* 0.845, 0.919 *and* 0.905. *According to the Pearson correlation guideline, a coefficient with* 0.7 *to* 0.9 *can be interpreted as highly positive correlation. In this case the NTEV is slightly dependent on VTHD Red compared with VTHD Yellow and Blue.*

While the size of correlation is more than 0.9, the interpretation is very high correlation. Hence the result can be interpreted as NTEV is dependent to VTHD Red, Yellow and Blue, as VTHD value increase the voltage at Neutral increase. This is due to the effects of harmonics in which it changes the base frequency of the voltage hence changes the voltage magnitude. While within spec value of THD impose limited problem to line stability, severe THD beyond the specification imposes potent risk to the system stability.

5. Discussion

Table 8. Summarize value of VTHD and correlation for all location.

Location	Average Max. VTHD (%)	Size of correlation between NTEV & VTHD	
MSB1	2.78	0.8 - 0.9	High positive

The correlation analysis reveals a strong to very strong positive relationship between NTEV and VTHD across all phases at MSB1(see **Table 8**). This finding indicates that harmonic distortion plays a significant role in influencing NTEV levels in low-voltage distribution systems. From a practical perspective, this suggests that effective harmonic mitigation strategies, such as the installation of passive or active harmonic filters, can contribute to the reduction of NTEV and improve overall power quality in government buildings.

It should be noted, however, that harmonics are not the sole contributors to elevated NTEV. Other factors, including load imbalance, grounding resistance, and system configuration, may also influence NTEV levels. These aspects were not explicitly analyzed in this study and should be considered in future investigations to provide a more comprehensive understanding of NTEV behavior.

The study is subject to several limitations, including measurements taken at a single location and over a relatively short monitoring period. Future work should involve multiple measurement points and longer observation durations to capture broader operating conditions.

Acknowledgements

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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