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Electric Power Distribution and Management System Audit of a 4-storey School Building in Davao City

Abstract: - This study evaluated the electric power distribution of a 4-storey School Building in Davao City. The researcher aimed to determine the present electrical load distribution, voltage drop calculations, and connection of the building, identify the maximum current per conductor at the main and sub-feeder circuits, determine the short circuit interrupting capacity, and conduct a coordination study. Moreover, to know if the building complies with the Philippine Electrical Code or PEC standards for its electrical system's main and sub-feeder circuits in terms of the type and size of wire used. The study used the electrical installation audit per the standard of the PEC and identified the PEC Table's set of standards for the allowable ampacity of insulated copper conductors, and it suggested that any circuit branch must have 80 percent of the maximum ampacity and 20 percent spare current capacity for future load increases. The study's findings indicated that the PEC's referenced standard needs to be met by any main and sub-feeder circuit lines of the electric power distribution system of a 4-storey School Building as it surpassed its maximum current capacity. These findings emphasized the necessity of adhering to PEC standards and regulations in electrical system design, installation, and maintenance. Nonconformance could seriously compromise buildings' electrical safety, reliability, and energy efficiency. Overall, this study contributes to quality practices and corrective actions in electrical installations and is a good resource for decision-making in the building's power system and energy management.

Keywords: institution electrical installation audit, building electric power distribution system, voltage drop calculation, short-circuit current calculation, PEC standards.

I. INTRODUCTION

Electricity is an essential part of our human life; it plays a vital role in the economic development of a country [1], and sectors such as Higher Education Institutions are experiencing an increase in electricity demand due to the fact that School buildings are occupied by different facilities and have installed high-power-rated electrical loads [2]. These electrical loads must be managed well and must have a good electric power distribution system to avoid unreliability and instability in the electrical power system of the building [3], which was truly experienced by the 4-storey school building in Davao City last October, 2022, which ran four days of power outages and system failure and made most of the facilities nonoperational. There is a clear need for an electrical installation audit to manage the electric power distribution system of the building in order to maintain power system reliability and stability.

The Philippine Electrical Code or PEC and the National Electrical Code or NEC are standards used for practical safeguarding of persons and property from hazards arising from the use of electricity and contain provisions that are considered minimum requirements necessary for safety. The PEC standard includes the building's electrical one-line diagram, electrical installation requirements, voltage drop on any branch circuit, and table sets of standards for voltage drop impedance and for allowable ampacity of insulated copper conductors [4]–[6]. The Short-Circuit Current or SCC calculation is also used to get the maximum and minimum short circuit currents and short-circuit interrupting capacity [7]–[10]. The Per-Unit in power system is also needed to easily locate electrical faults and provide certain power system protection [11]–[13]. A fluke logger is very useful to easily collect real-time data acquisition and analysis of electrical parameters of the building's electrical power distribution system [14]–[16].

An electrical installation audit creates awareness about electrical safety and provides technical guidance for wiring installations in buildings. This will help electrical engineers and technicians understand the basic needs and procedures for safe and reliable electrical installations and systems [17] [18]–[20] using an up-to-date electrical power distribution system design parallel to the Philippine Electrical Code to increase the system's reliability and the consistency of the supply of electricity to the institution [21].

The main objective of the study is to have an evaluation of the present condition of the electric power distribution of a 4-storey school building. The particular objectives are as follows: (1) to determine the present electricity consumption and electrical load distribution of a 4-storey school building; (2) to identify the voltage stability and

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short-circuit interrupting capacity at the main and sub-feeder circuits; and (3) to evaluate if a 4-storey school building electric power distribution system is in compliance with the Philippine Electrical Code or PEC standards. This research study will greatly contribute to the provision of clear and practical information on the safe and appropriate usage of electricity in the institution, institution administration, building administrators, building electrical inspectors, electrical education, students, the community, and future researchers.

This research study will only focus on the electrical installation audit of a 4-storey school building, including the identification of electrical loads or load mapping, their voltage drop and short circuit current calculation, and the type and size of wire used. The study also applied the Philippine Electrical Code Table's set of standards for the allowable ampacity of insulated copper conductors, with 80 percent of the maximum ampacity for any circuit branch and 20 percent spare current capacity for future load increases.

II. Materials And Methods

2.1 Conceptual Framework

Fig. 1 shows the concept paradigm of the study, in which the input of the study is to consider the factors in the electrical system, specifically the actual electrical loads, current flowing in the conductors, type, and size of the conductors, and ambient temperature at the main and sub-feeder circuit lines. The study process provides a single line diagram, load calculation, voltage drop calculation, PEC standards application, short-circuit current calculation, and selective coordination of the electrical system of the building. Then, the output of the study is to have an evaluation and provide recommendations regarding the present or actual state of the electric power distribution system of a 4-storey school building.

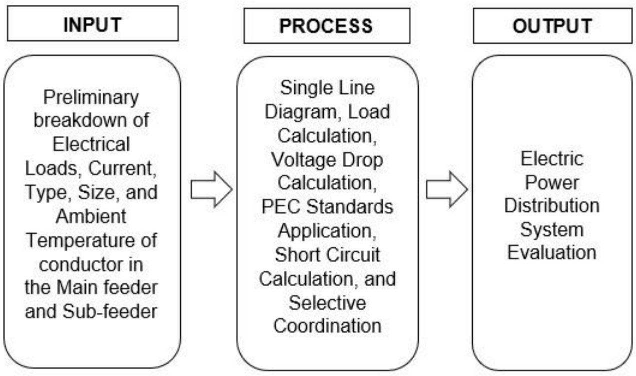

Fig. 1. The conceptual framework of the study.

2.2 Materials and Resources

1. *Sources of data:* The data is collected or obtained through the following sources which are:

a) Manufacturer's data: The building's electrical system's main feeder and sub-feeder circuit lines' existing conductors, as well as a computer simulation analysis using power tool software.

b) *Load mapping:* Obtaining information from the building's panel board regarding the actual current flowing through the main feeder and sub-feeder circuit lines as well as load mapping for the electrical loads currently connected to the building's power source.

2. *Data gathering instrument:* The data is gathered for analysis by using the following tools:

a) *Clamp-on meter:* The device is an ammeter that can measure electrical current without cutting the wiring through which the current is flowing.

b) *Fluke 1736 three-phase power quality loggers:* The tool is for electrical analysis of the three-phase system. It serves as a logger to record electrical data parameters, such as voltage, current, power, and power factor, throughout the day in real-time.

c) *Power tools software:* The power tools software will be employed after precisely collecting the required data to execute the short circuit analysis and coordination study.

2.3 Methods and Procedures

a) *Method used:* A descriptive-evaluated research method will be used to evaluate the electric power distribution and management system of the 4-storey school building based on the electrical installation audit in accordance to the standard of the Philippine Electrical Code.

b) *Procedure of the study:* Fig. 2 shows the organized procedure as a guide when carrying out the study.

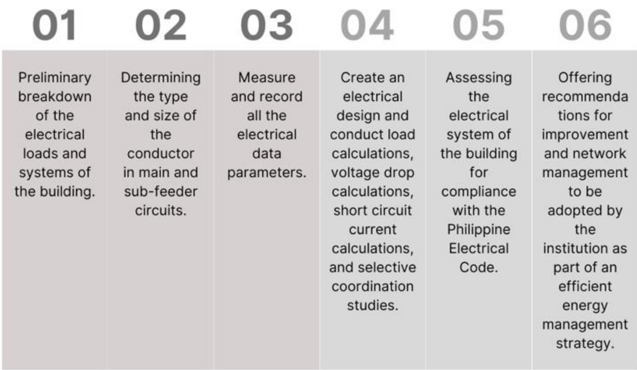

Fig. 2. Procedure in carrying out the study.

3. *Voltage drop calculation:* Equation (1) shows the complete formula to be used for getting the voltage drop or VD of the feeder and branch circuit lines. I is the available maximum current, L is the length in meters, R is the resistance per 305 m, X is the reactance per 305 m, n is the number of conductors in a set, and θ is the angle of the power factor.

$$VD\% = \{1.732 \times I \times L\,[R\cos\theta + X\sin\theta]\} / (305 \times n) \quad (1)$$

4. *Short-circuit current calculation:* Equation (2) shows the short-circuit current formula to be used for getting the fault current or $I_{SC\text{-}F}$ in the three-phase system. $MVA_{SC\text{-}F}$ is the Mega Volt-Ampere fault, and $kV_{B\text{-}F}$ is the kiloVolt base fault value in the three-phase system.

$$I_{SC\text{-}F} = MVA_{SC\text{-}F} / (kV_{B\text{-}F} \times \sqrt{3}) \quad (2)$$

5. *Percentage of total kiloWatt-hour:* Equation (3) shows the formula to get the percentage rise or drop of total killoWatt-hour or kWh of energy consumption of the building within 5 consecutive years.

$$kWh\% = [(\alpha / \beta) \times 100\%] - 100 \quad (3)$$

Where α is the present electric consumption, and β is the previous electric consumption.

2.4 Data Analysis

The study only applied the computed ratio of the conductor's actual current flow to the 80 percent recommended maximum conductor current. As a result, it generates a 20 percent spare capacity for increasing demand in the future. Additionally, the voltage drop calculation analysis provides an evaluation of the electrical system's voltage stability conditions, and the short circuit calculation will manage the appropriate selection of protective devices and equipment to handle the level of current under the worst-case scenario for the building's electrical system, which is a short circuit.

III. RESULTS AND DISCUSSIONS

3.1 Electricity consumption

Fig. 3 shows the 4-storey school building’s kWh electricity consumption, and Fig. 4 indicates the 4-storey school building’s cost electricity consumption in Philippine pesos per school year tabular data within five consecutive school years from 2018-2019 up to 2022-2023. It was found that the highest electricity consumption was in the school year 2022-2023, with a 766 500 kWh in energy consumption and had 165.39 percent rise from the previous school year, with a 9 365 455 Philippine Pesos in cost, and the lowest electricity consumption was in the school year 2020-2021 with a 184 996 kWh in energy consumption and had 74.65 percent drop from the previous school year, with a 1 816 066 Philippine Pesos in cost.

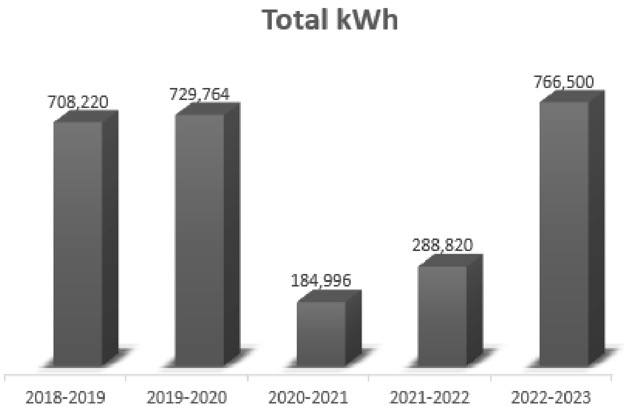

Fig. 3. 4-storey school building's electricity consumption per school year in kWh.

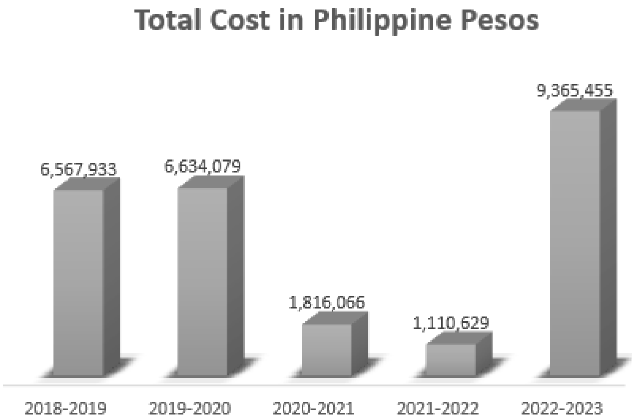

Fig. 4. 4-storey school building's electricity consumption per school year in cost in Philippine Pesos.

3.2 Electrical load distribution

TABLE I shows the connected loads with the total ratings of all electrical equipment connected at the supply point, including lighting units, convenience outlets, air-conditioning and fan units, and all electrical elements regardless of the operation's status. The load capacity in kiloVolt-Ampere or kVA was cumulatively determined by load mapping for both previous existing and new loads. The maximum load current is measured based on the actual current measured by a fluke logger during data collection.

Table I: Connected Load Summary of 4-storey School Building.

Loading Nomenclature	**Capacity in kVA**	**Voltage Level**	**Maximum Load Current**
Load DPBG[a]	158.405	230 Volts	330.8 A
Load DPB2	200.365	230 Volts	156.2A
Load DPB3	173.54	230 Volts	375.9 A
Load DPB4	169.93	230 Volts	272.2 A
Load PBG-ACU[b]	90.16	230 Volts	172.7 A
Load PB2-ACU	51.52	230 Volts	154.3 A
Load PB3-ACU	96.6	230 Volts	259.3 A
Load PB4-ACU	96.6	230 Volts	265.4 A

Load Distribution Panel Board Ground Floor.

Load Panel Board Ground Floor – Air Conditioning Unit.

3.3 Voltage stability

TABLE II summarizes the overall voltage drop from the transformer to the remotest service equipment. As followed in the PEC 1 2017, Article 2.10, Section 2.20.2.2(A), FPN No. 4, page 42, where the percentage value of voltage drop obtained by each feeder is less than 3%, and the percentage value of overall voltage drop obtained by both feeders and branch circuits are less than 5 percent. It was found that the Philippine Electrical Code's referenced standard needs to be met by the feeder and branch circuit from the Transformer to DPB3 or Distribution Panel Board Third Floor circuit line for the previous existing loads.

Table II: Summary of Overall Voltage Drop from Transformer to Remotest Service Equipment.

Feeder Description	Transformer to Bus 1	Remotest Service Equipment	Overall Voltage Drop	Actual %VD	Recommended Provision
Trans to DPBG[c]	1.599	6.36	7.959	3.5	**Less than 5%**
Trans to DPB2	1.599	3.66	5.259	2.3	**Less than 5%**
Trans to DPB3	1.599	10.163	11.76	5.1	**Greater than 5%**
Trans to DPB4	1.599	6.038	7.637	3.3	**Less than 5%**
Trans to PBG-ACU[d]	1.058	2.337	3.395	1.5	**Less than 5%**
Trans to PB2-ACU	1.058	4.183	5.241	2.3	**Less than 5%**
Trans to PB3-ACU	1.058	4.387	5.445	2.4	**Less than 5%**
Trans to PB4-ACU	1.058	4.49	5.548	2.4	**Less than 5%**

Transformer to Distribution Panel Board Ground Floor.

Transformer to Panel Board Ground Floor – Air Conditioning Unit.

3.4 *Short-circuit interrupting capacity*

TABLE III shows the summary of the short-circuit current calculation results utilizing the ETAP *(Electrical Transient Analyzer Program*), a power tool, and the manual computation, which was performed to produce accurate findings because technological advancements can still result in software faults that could produce ambiguous results or inaccurate data. The 4-storey school building will use the results of the short circuit calculations to determine the proper rating of the circuit breakers used in the electric power distribution. Of course, to prevent damage to the circuit breaker and fire accidents, the circuit breaker rating must be equal to or higher than the interrupting capacity, which is shown in TABLE IV, and it was found that the calculated interrupting capacity does not exceed the actual interrupting capacity set in all actual circuit breakers. It means it can withstand short-circuit currents.

Table III: Summary of Fault Calculation

Fault Location	Bus Fault Description	Short Circuit Current 3P	Breaking Capacity (Ics)	Interrupting Capacity (Icu)	Breaking Time
F1	Transformer	43, 975 A	49 kA	71 kA	1 sec
F2	Bus Previous Existing Load/MDPB	33, 871 A	37 kA	54 kA	1 sec
F3	Bus Additional ACU Load/MPB-ACU	35, 507 A	39 kA	57 kA	1 sec
F4	Bus DPBG	10, 513 A	12 kA	17 kA	1 sec
F5	Bus DPB2	9, 430 A	11 kA	15 kA	1 sec
F6	Bus DPB3	8, 348 A	9 kA	14 kA	1 sec
F7	Bus DPB4	9, 695 A	11 kA	16 kA	1 sec
F8	Bus PBG-ACU	12, 918 A	14 kA	21 kA	1 sec
F9	Bus PB2-ACU	7, 746 A	9 kA	13 kA	1 sec
F10	Bus PB3-ACU	11, 186 A	13 kA	18 kA	1 sec
F11	Bus PB4-ACU	11, 186 A	13 kA	18 kA	1 sec

Table IV: Summary of Protection Requirement of Short Circuit Protection Device (Circuit Breaker).

Fault Location	Calculated		Actual		
	Short Circuit Current 3P	**Interrupting Capacity (Icu)**	**Interrupting Capacity (Icu)**	**Location**	**Ampere Trip (AT)**
F2	33, 871 A	54 kA	85 kA	MDPB CBe	800 A
F3	35, 507 A	17 kA	25 kA	DPBG CB	200 A
F4	10, 513 A	15 kA	25 kA	DPB2 CB	200 A
F5	9, 430 A	14 kA	25 kA	DPB3 CB	200 A
F6	8, 348 A	16 kA	25 kA	DPB4 CB	250 A
F7	9, 695 A	57 kA	85 kA	MPB-ACU CBf	1250 A
F8	12, 918 A	21 kA	25 kA	PBG-ACU CB	250 A
F9	7, 746 A	13 kA	25 kA	PB2-ACU CB	150 A
F10	11, 186 A	18 kA	40 kA	PB3-ACU CB	320 A
F11	11, 186 A	18 kA	40 kA	PB4-ACU CB	320 A

Main Distribution Panel Board Circuit Breaker.

Main Panel Board – Air Conditioning Unit Circuit Breaker.

3.5 Fault location

Fig. 5 shows the reactance diagram and the indicated fault location of the 4-storey school building's electrical power distribution system.

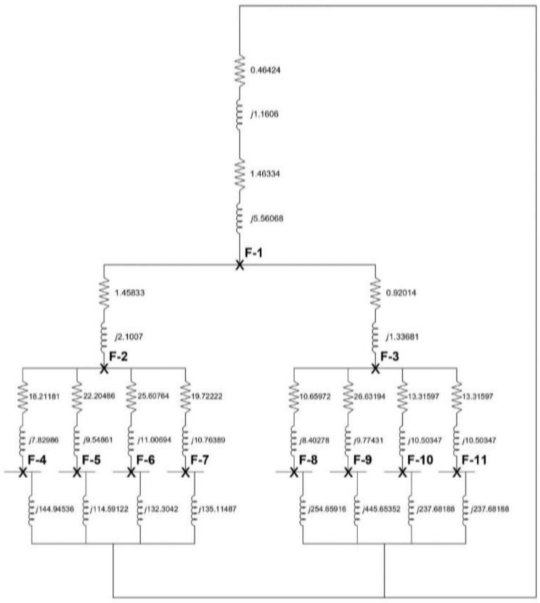

Fig. 5. Reactance diagram and fault location of 4-storey school building's electrical power distribution system.

3.6 4-storey School Building Electric Power Distribution System

Based on the investigation's findings that most of the sub-feeder lines, including the main feeder line circuit line conductors for both previous existing loads and additional ACU loads of the electric power distribution of a 4-storey School Building, needs to comply with the Philippine Electrical Code standard, particularly in PEC 1 2017, Article 3.10, Section 3.10.2.6., Table 3.10.2.6(B)(16), page 174. It is 80 percent maximum load or ampacity to be served for any branch conductors and 20 percent spare ampacity for future load growth. The following are the said main and sub-feeder circuit line conductors:

- Line 3 of the sub-feeder 2 circuit line, for the previous existing loads.
- Line 1.B, 2.B, and 3.B of the main feeder circuit lines, for the previous existing loads. It surpassed its maximum current capacity.
- Line 1, 2, and 3 of the sub-feeders 1, 3, and 4 circuit lines, for the previous existing loads. It surpassed its maximum current capacity.
- Line 1, and 2 of the sub-feeder 2 circuit lines, for the previous existing loads. It surpassed its maximum current capacity.
- Line 3 of the sub-feeder 2 circuit line, for the additional ACU loads.
- Line 1 of the sub-feeder 3, and lines 1 and 3 of the sub-feeder 4 circuit lines, for the additional ACU loads.
- Line 1, and 2 of the sub-feeder 2 circuit lines, for the additional ACU loads. It surpassed its maximum current capacity.
- Line 2 of the sub-feeder 3, and 4 circuit lines, for the additional ACU loads. It surpassed its maximum current capacity.

IV. Conclusion And Future Works

This research shows that the PEC's referenced standard is an important code and guideline that needs to be considered in having an electrical installation of the main and sub-feeder's circuit lines of the electric power distribution system of a 4-storey School Building, particularly the voltage drop percentage of the feeder and branch circuit line for existing loads, and in terms of the type and size of wire used, especially when it surpassed its maximum current capacity in most of its main and sub-feeder circuit lines of the electric power distribution system due to the increasing electrical loads installed in the building. These scenarios emphasized the need to make sure that electrical systems are designed, installed, and maintained to prevent unfavorable outcomes, equipment damage, system failure, electrical system unreliability, and instability, and keep the electrical safety, reliability, and energy efficiency of buildings.

For future works, regular or periodic system monitoring and evaluation should be constantly carried out, and minimize the unbalanced currents by redistribution of load at the main feeder circuit lines. Proper maintenance of the wiring installation is essential to ensure longevity and prevent electrical hazards. Do Energy Audit and Forecasting on the electrical system of the building every 5 years. All of these are highly recommended under RA 7920, often known as the New Electrical Engineering Law. You should always consult an electrical practitioner when performing any electrical work on a building.

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