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Evaluation of Electrical System Design of a State University in Bacolor, Pampanga, Philippines

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Abstract:

The study was undertaken to evaluate the electrical system design of the Don Honorio Ventura State University (DHVSU). It also looked into the efforts of the university in managing its electrical loads aimed at quality, reliable and efficient electrical systems. Specifically, the study embarked on determining the electrical design of DHVSU along with the areas of: secondary feeder conductor sizes and proper KAIC rating of circuit breakers through short circuit analysis and voltage drop calculations. The evaluation was based on the latest provisions of the Philippine Electrical Code (PEC) 2017 Requirements and Standards for Electrical Loads. Data were obtained through "as-built" plans of the different buildings of the university and were evaluated through intensive calculations based on the prevailing standards of the PEC 2017. Evaluations focused on the status of the existing electrical design of the university: The existing circuit breakers require higher KAIC ratings particularly College Building Extension, College Building E, IT Building, Learning Resource Center, PRINCE Building; and secondary feeder conductors need larger sizes or higher ampacities to cater to the total connected electrical loads specifically 5 Shop Room Building. Generally, the existing electrical design of the university requires immediate attention since some of the aforementioned building electrical design were not conformed with the requirements being set forth by the PEC code, and thus in need of upgrading, rewiring, and re-installation of its electrical system based on standards to prevent the risks of electrical hazards.

Keywords **—Evaluation, feeder, breaker, voltage drop, short circuit, electrical system.**

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I. INTRODUCTION

A country's economic growth and development are highly dependent on the reliability and quality of its electricity supply[1]. Nations including Philippines is a developing country with constant economic growth along with its electricity demand[2]. As the increase in population is high rising, the electricity becomes as critical and essential as yesterday[3]. Moreover, evaluating the electrical design of a building is essential because the safety of property and life depends on it[4].

The factors such environmental, technical and human, are the parameters that the reliability of electrical power system depends considering also the failures that could reduce it[5]. The scheduling of load, problems in connections, aged equipment, are examples that greatly reduces the life span of the system[6]. Moreover, the evaluation of reliability of electric power systems is a critical issue in the planning, design, and operation of power systems. In addition system planning is needed and important to ensuring that the growing demand for energy can be met by improvements to the distribution system that are both technically feasible and economically viable[7]. Also, Electrical safety must be incorporated into the design and installation of all electrical equipment and systems, it also necessitates a thorough knowledge and understanding of all applicable codes, standards, and laws[8].

Due to its increasing size and complexity of loads, modern commercial buildings have become increasingly dependent on adequate and dependable electrical systems. This is exemplified by the Don Honorio Ventura State University (DHVSU), which remains a leading educational institution in Pampanga. By evaluating its electrical design to determine its functional requirements in accordance with the most recent provisions of the Philippine Electrical Code (PEC), one can gain a better understanding of the complex nature of DHVSU.

PEC 2009 and 2017 outline fundamental safety rules for protecting individuals during the installation, operation, and maintenance of electric supply, communication lines, and associated equipment. In most cases, the PEC serves as the basis for legal enforcement when installing electrical system designs in the Philippines (Philippine Electrical Code, 2017)[9]. This study serves as the basis for evaluating DHVSU's electrical design.

Moreover, the National Fire Protection Association (NFPA) contains provisions essential for establishing safety practices and standards. This includes the National Electrical Code (NEC), which addresses protection against electric shock, thermal effects, overcurrent, fault current, and overvoltage. This code is essential to this study; per Section 110.9 of the National Electrical Code, the KAIC rating must be at least equal to the interruptible current (NFPA 70)[10].

Through the years, the university has gone through a lot of changes. The researchers found that there was an incident of burning of wire last 2018 located at the roof of gate 4 of DHVSU. It was caused by short circuit of the service entrance of the Old College Building Extension. For this reason, the researchers have come-up to undertake the study to determine the status of the electrical design of the university.

The general objective of this study is to evaluate the existing electrical system of the Don Honorio Ventura State University. It also aims to determine if the current settings and conditions of the current settings, kilo-ampere interrupting capacity and the conditions of the conductor size focusing on the secondary side. Specifically, it will determine:

1. Proper Feeder conductor size
2. Proper Kilo-Ampere Interrupting Capacity (KAIC) rating

II. STUDY FRAMEWORK

The conceptual framework of this study serves as the guide of the researchers upon completing the paper. Input were the necessary data used to compute values that were needed to evaluate the electrical system. Then follows the process contains the calculation methods that were used to compute the values necessary to obtain the objectives of the paper. In the output, were the results and findings after the process stage, also on this stage of the of the paper, answered and obtained the objectives of the study.

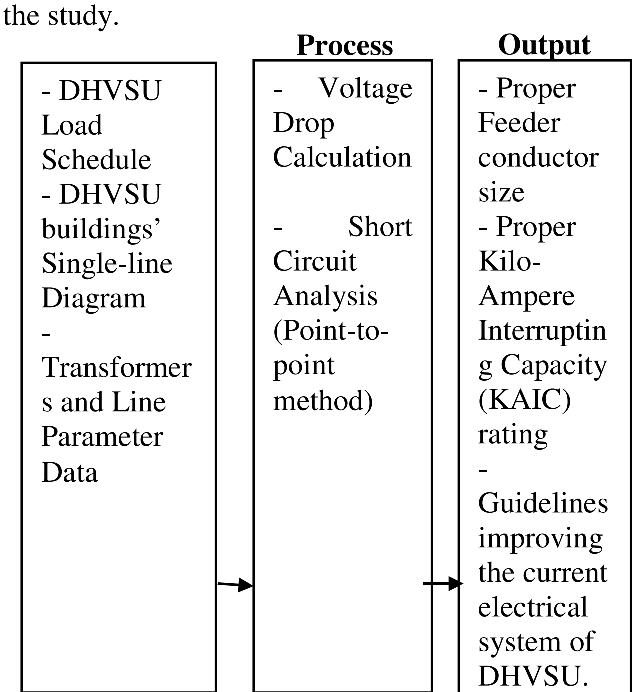

Figure 1: Flow of the Study

III. Methodology

Research Design

This study used descriptive quantitative method of research. Quantitative research falls into two areas: studies that describe events and studies aimed at discovering inferences or causal relationships. Descriptive studies are aimed at finding out "what is," so observational and survey methods are frequently used to collect descriptive data [11]. Studies of this type might describe and evaluate the electrical system of DHVSU. Therefore, descriptive quantitative method is designed for investigation to ascertain facts pertaining to the present status and relate them to existing standards, thus it is the most effective method of research used in this study.

Data Collection

The researchers conducted a site visitation for getting the necessary data such length parameter and available transformers KVA installed in the electrical system. Also, load schedule, single-line diagram, transformer and line parameters of DHVSU was provided by the OPPF after coordinating and requesting process was done.

The proponents also considered market-available equipment for the computed KAIC ratings of circuit breakers and secondary line feeder conductor.

Feeder Conductor Sizing

The researchers used the voltage drop calculation from PEC 2017 edition in order to determine the proper size of the Main Distribution Panel (MDP) feeders and conductors of the system. In order for the researchers to perform the voltage drop calculation following process were performed:

The researchers used the parameters from gathered data such transformers and line parameters, electrical loads, and motor contributions for computation of the values. Also, calculation was easier to perform by making the single-line diagram from the gathered parameters. It was the representation of the electrical parameters on the system. The following formula was used to calculate voltage drop and voltage regulation where, the voltage drop of the branch circuit should not exceed to 3% and maximum total voltage drop from branch circuit to feeder must not exceed 5% as per PEC Section 2.10.2.1(a)(1) FPN No. 4, which is also true for feeder conductors as stated on FPN No. 2 of 2.15.1.2(a)(3) respectively[9]:

$$VD = k\frac{D}{305}I \times \sqrt{R^2 + X^2} \qquad \text{(eq. 1)}$$

The Voltage drop (VD) is the product of the constant k and the distance D which is the distance or length of the conductor expressed in meter divided by 305m, and also multiplied by the I total load and multiplied by the square root of the sum of the squares of the R resistance and X reactance of the load based on the table. 10.1.1.9 Alternating-Current Resistance for 600V cables, 3-Phase, 60Hz, 75 °C – Three Single Conductors in Conduit of PEC 1 2017[9].

Where:

k = Constant (1.732 for 3 phase)

D = Distance of the device from source

R = Line resistance, ohms

X = Line Reactance, ohms

I = load current (amperes)

After calculating the voltage drop, the percentage voltage can be obtained by dividing the voltage drop computed by the operating voltage of the system in DHVSU which is 230V. If the maximum total voltage drop from main feeder to the farthest outlet exceeds 5%, conductor size should be changed to larger size, shortened the length of the conductor or reduce the load. The following formula was used:

$$\%VD = \frac{VD}{V_C} \times 100 \qquad \text{(eq. 2)}$$

Where:

VD = Voltage drop

V_C = circuit voltage

Proper KAIC Rating

Short circuit analysis was performed in order for the researchers to determine the short circuit interrupting ratings of protective devices of the system such as circuit breakers in the secondary of the transformers, specifically point-to-point short circuit calculation from Cooper Busman Selecting Protective Devices Handbook #3002[12]. KAIC rating must be at least equal to the current that it must be interrupted as per Section 110.9 of the National Electrical Code (NFPA 70)[10].

The researchers used the parameters from gathered data such transformers and line parameters, motor contributions and Electrical loads in computing the values for the evaluation. Also, by using single-line diagram, all the parameters are easily presented and for the researchers to easily locate the available faults in the system.

Using the point-to-point short circuit calculation, the kilo-ampere interrupting capacity of the breakers was obtained. In three-phase system the Full load ampere was obtained by the quotient of the product of the available transformer kVA and 1000 and the product of the operating voltage of DHVSU which is 230V and square root of 3.

$$3\emptyset\ Transfromer \quad I_{F.L.A} = \frac{kVA \times 1000}{E_{L-L} \times \sqrt{3}} \qquad \text{(eq.3)}$$

Where:

$1_{F.L.A} =$ is Full load Ampere

kVA = is Kilo Volt Ampere

E_{L-L} = is the line-to-line voltage or the operating voltage.

After the computation of the Full load Ampere, the multiplier $M$was determined by dividing 100 by the %Z of the transformer which was then multiplied by 0.9 because of the 10% impedance tolerance of a transformer at high end worst case. The %Z was obtained using %Z table of Impedance Data for Single-PhaseTransformers (pg. 241) from Cooper Busman Selecting Protective Devices Handbook #3002[12].

$$Multiplier = \frac{100}{\%Z_{transformer} \times 0.9} \qquad \text{(eq. 4)}$$

Where:

%Z = Percentage impedance

The first fault current on the secondary side of the transformer was obtained after multiplying the Full load ampere by the Multiplier computed.

$$I_{S.C.} = Transformer_{F.L.A.} \times Multiplier \qquad \text{(eq. 5)}$$

Where:

$I_{S.C.}$ = Short circuit current

After obtaining the first fault current $I_{S.C.}$, the researchers computed for the $f$factor necessary for computing the succeeding fault Multiplier M. the $F$was computed by dividing the product of Conductor length L, the load I and square root of 3 because the system was three-phase, to the product of constant C, n, and the operating circuit voltage.

$$f = \frac{\sqrt{3} \times L \times I_{3\emptyset}}{C \times n \times E_{L-L}} \qquad \text{(eq.6)}$$

Where:

L = length (feet) of conductor to the fault. For all of the feeder conductor lengths of DHVSU the researchers measured approximately 25 meters.

C = Constant "C" for conductors of Busway. Was obtained using table of Conductors and Bus Ways "C" Values (pg. 241) from Cooper Busman Selecting Protective Devices Handbook #3002[12].

n = Number of conductors per phase (adjusts C value for parallel runs). Which, in DHVSU, according to OPPF there is only single conductor per phase.

I = Available short circuit current in amperes at beginning of circuit.

E = Circuit voltage (230V)

The f was computed and second fault Multiplier M was obtained by dividing 1 over the sum of 1 and the f factor.

$$M = \frac{1}{1+f} \qquad \text{(eq. 8)}$$

After obtaining the multiplier M, the Short circuit RMS $I_{S.C.\ RMS}$ was obtained by Multiplying the short circuit current $I_{S.C.}$ from the transformer to the Multiplier computed in the side of the breaker which was the second fault in the single-line diagram.

$$I_{S.C.sym\ RMS} = I_{S.C.} \times M \qquad \text{(eq. 9)}$$

Economic Analysis

The following formulas were used to compute for the Return of Investment of the suggested changes to size of wire in DHVSU:

For the size of wire, the old and new size of wire *Monthly Loss* was computed. The monthly loss was obtained by the product of load ampere I^2, the resistance R and length and then divided by 1000[13].

$$Monthly\ Loss(kWh) = \frac{I^2 \times R \times L}{1000} \qquad \text{(eq.10)}$$

Where:

I = is the load ampere

R= resistance (obtained from Westinghouse T and D Conductor Table)[14]

L = is the length of the wire

After the monthly losses are obtained, the *Monthly Energy Save* were computed by subtracting the *Monthly Loss Old* by *Monthly Loss New* in order to obtain the *Monthly Savings* using the following formula:

$$Monthly\ energy\ save(kWh) = Monthly\ Loss_{Old} - Monthly\ Loss_{New} \qquad \text{(eq. 11)}$$

Monthly Savings was obtained by multiplying Monthly Energy Saved by the energy rate of P9.64, also the Annual Saving was obtained by multiplying the computed monthly savings by 12.

$$Monthly\ Savings = Monthly\ Energy\ Save \times 9.64 \qquad \text{(eq. 12)}$$

$$Annual\ Savings = Monthly\ Savings \times 12 \qquad \text{(eq.13)}$$

Return of Investment (ROI)[15] was obtained by computing the total investment divided by the annual savings. Total investment was obtained by summing the market prices of suggested wire sizes, including the labor cost, which was 30% of the material cost.

$$ROI = \frac{Total\ Investment}{Annual\ Savings} \qquad \text{(eq.14)}$$

IV. RESULTS AND DISCUSSION

This chapter presents the major findings of the study.

1. Voltage Drop Calculation

Table 1 presents the summary of calculations of voltage drop for the main distribution panel (MDP) feeders and branch circuits' farthest load.

Load Parameter		I(Amp)	Reactance	Resistance	VD	%VD	Total %VD	Remark
$MDP_{\text{5 Shop Room}}$	FEEDER	87.59	0.065	0.78	9.737	4.233	7.156	NOT ACCEPTABLE
	FARTHEST BC	10.96	0.068	2	6.724	2.923		ACCEPTABLE
$MDP_{\text{Business Studies Bldg.}}$	FEEDER	207.22	0.055	0.12	3.885	1.689	2.527	ACCEPTABLE
	FARTHEST BC	14.09	0.064	0.49	1.928	0.838		ACCEPTABLE
$MDP_{\text{CE\&ME Bldg.}}$	FEEDER	158.87	0.057	0.16	3.832	1.666	1.780	ACCEPTABLE
	FARTHEST BC	10	0.057	0.16	0.262	0.114		ACCEPTABLE
$MDP_{\text{CEA Main Bldg.}}$	FEEDER	258.61	0.052	0.079	3.474	1.510	1.954	ACCEPTABLE
	FARTHEST BC	5.48	0.06	0.31	1.022	0.444		ACCEPTABLE
$MDP_{\text{College Bldg. Extension}}$	FEEDER	552	0.049	0.035	4.721	2.053	2.163	ACCEPTABLE
	FARTHEST BC	6.09	0.054	0.16	0.253	0.110		ACCEPTABLE
$MDP_{\text{College Bldg. E4}}$	FEEDER	573.04	0.048	0.029	4.564	1.984	2.063	ACCEPTABLE
	FARTHEST BC	6.52	0.054	0.1	0.181	0.079		ACCEPTABLE
$MDP_{\text{Engineering Lab.}}$	FEEDER	184	0.054	0.1	2.815	1.224	1.305	ACCEPTABLE
	FARTHEST BC	12	0.064	0.1	0.187	0.081		ACCEPTABLE
$MDP_{\text{Food Technology Bldg.}}$	FEEDER	185.92	0.057	0.2	5.491	2.388	2.472	ACCEPTABLE
	FARTHEST BC	7.28	0.064	0.1	0.194	0.084		ACCEPTABLE
$MDP_{\text{General Shop Room}}$	FEEDER	498.06	0.051	0.045	4.811	2.092	3.857	ACCEPTABLE
	FARTHEST BC	17	0.06	0.49	4.060	1.765		ACCEPTABLE
$MDP_{\text{ICT Bldg.}}$	FEEDER	145.13	0.057	0.16	3.501	1.522	1.793	ACCEPTABLE
	FARTHEST BC	12	0.06	0.31	0.623	0.271		ACCEPTABLE
$MDP_{\text{Integrated HRM}}$	FEEDER	223.65	0.055	0.12	4.193	1.823	2.094	ACCEPTABLE
	FARTHEST BC	12	0.064	0.31	0.623	0.271		ACCEPTABLE
$MDP_{\text{Integrated Science Lab.}}$	FEEDER	185.92	0.057	0.2	5.491	2.388	2.554	ACCEPTABLE
	FARTHEST BC	5.65	0.057	0.49	0.382	0.166		ACCEPTABLE
$MDP_{\text{IT Bldg.}}$	FEEDER	326.17	0.049	0.035	2.789	1.213	1.416	ACCEPTABLE
	FARTHEST BC	12	0.064	0.2	0.467	0.203		ACCEPTABLE
$MDP_{\text{Learning Resource Center}}$	FEEDER	790.93	0.048	0.029	6.299	2.740	2.829	ACCEPTABLE
	FARTHEST BC	1.74	0.064	0.49	0.210	0.091		ACCEPTABLE
MDP_{PRINCE}	FEEDER	587.18	0.05	0.039	5.288	2.299	2.521	ACCEPTABLE
	FARTHEST BC	3.57	0.064	0.49	0.510	0.222		ACCEPTABLE
$MDP_{\text{ROTC \& NSTP}}$	FEEDER	87.27	0.064	0.049	6.132	2.666	2.764	ACCEPTABLE
	FARTHEST BC	4.7	0.064	0.49	0.225	0.098		ACCEPTABLE
	FEEDER	484.78	0.051	0.045	4.682	2.036		ACCEPTABLE

Table I: summary of voltage drop calculation

As the result shown, all the feeder conductors meet the requirement of allowable voltage drop not exceeding the maximum total voltage drop of 5% on both the feeder and branch circuit to the farthest outlet, except for the MDP Shop Room with a feeder %VD of 4.23% exceeding 3% and with maximum total voltage drop of 5.63% on both main feeder and branch circuit farthest outlet as per PEC 2017 Section 2.10.2.1(a)(1) FPN No. 4, which is also true for feeder conductors as stated on FPN No. 2 of 2.15.1.2(a)(3).

The results from table 1, shows that the 5 Shop Room building Feeder is not properly sized and requires to be updated. Therefore, MDP Shop Room feeder should be resized. The suggested size would be 2-30 sq.mm THHN + 8.0 sq.mm TW(G), 32 mm dia. IMC, as per PEC 2017 table 3.10.2.6(b)(16) for the feeder wire and PEC 2017 table 2.50.6.13 for the equipment grounding conductor.

2. Short Circuit Analysis

Table 2.1: Summary of the short circuit currents of the MDPs. Highlighted Red are the old KAIC ratings that requires to be updated and Green for the suggested size of new KAIC ratings. Unhighlighted KAIC ratings are still acceptable Circuit breaker sizes.

Fault X_1			
Load Parameter	kVA Transformer	$I_{F.I.}$	$I_{S.C.}$
$MDP_{Shop\ Room}$	150	376.53	27891.31
$MDP_{Business\ Studies\ Bldg.}$	150	376.53	27891.31
$MDP_{CE\&ME\ Bldg.}$	150	376.53	27891.31
$MDP_{CEA\ Main\ Bldg.}$	150	376.53	27891.31
$MDP_{College\ Bldg.\ Extension}$	225	564.80	41836.92
$MDP_{College\ Bldg.\ E4}$	225	564.80	41836.92
$MDP_{Engineering\ Lab.}$	150	376.53	27891.31
$MDP_{Food\ Technology\ Bldg.}$	150	376.53	27891.31
$MDP_{General\ Shop\ Room}$	112.5	282.4	20918.50
$MDP_{ICT\ Bldg.}$	150	376.53	27891.31
$MDP_{Integrated\ HRM}$	150	376.53	27891.31
$MDP_{Integrated\ Science\ Lab.}$	150	376.53	27891.31
$MDP_{IT\ Bldg.}$	150	376.533	27891.31
$MDP_{Learning\ Resource\ Center}$	225	564.80	41836.92
MDP_{PRINCE}	150	376.53	27891.31
$MDP_{ROTC\ \&\ NSTP}$	112.5	282.4	20918.50
$MDP_{Senior\ high\ Bldg.}$	150	376.53	27891.31

Table II.I: summary of short circuit calculation for fault 1

Fault X_2							
kVA Transformer	kcmil Cu	"C" Constant	"F" Factor	Multiplier "M"	$I_{S.C.sysm.RMS}$	Old KAIC	New KAIC
$MDP_{Shop\ Room}$	8	1557	11.062	0.083	2314.98	10	10
$MDP_{Business\ Studies\ Bldg.}$	1/0	8925	1.93	0.341	9510.94	15	15
$MDP_{CE\&ME\ Bldg.}$	1	7293	2.174	0.315	8283.72	15	15
$MDP_{CEA\ Main\ Bldg.}$	3/0	12844	1.341	0.427	11909.59	15	15
$MDP_{College\ Bldg.\ Extension}$	500	22185	1.165	0.462	19328.66	15	22
$MDP_{College\ Bldg.\ E4}$	600	22965	1.125	0.471	19705.19	15	22
$MDP_{Engineering\ Lab.}$	1/0	8925	1.93	0.341	9510.94	15	15
$MDP_{Food\ Technology\ Bldg.}$	2	5907	2.916	0.255	7112.28	15	15
$MDP_{General\ Shop\ Room}$	300	18177	0.711	0.584	12216.40	15	15
$MDP_{ICT\ Bldg.}$	1	7293	2.362	0.297	8283.72	15	15
$MDP_{Integrated\ HRM}$	1/0	8925	1.93	0.341	9510.94	15	15
$MDP_{Integrated\ Science\ Lab.}$	2	5907	2.916	0.255	7112.28	15	15
$MDP_{IT\ Bldg.}$	500	22185	0.776	0.563	15702.81	15	22
$MDP_{Learning\ Resource\ Center}$	600	22965	1.125	0.471	19705.19	15	22
MDP_{PRINCE}	500	22185	0.776	0.563	15702.19	15	22
$MDP_{ROTC\ \&\ NSTP}$	6	2425	5.327	0.158	3305.12	10	10
$MDP_{Senior\ high\ Bldg.}$	300	18177	0.948	0.513	14308.24	15	15

Table II.II: summary of short circuit calculation for fault 2

As observed from the results on table 2, it shows the comparison of the available KAIC ratings of circuit breakers of DHVSU and the new computed KAIC ratings. The old KAIC ratings were still acceptable such with Shop Room Bldg., Business Studies Bldg., CE and ME Bldg., CEA Main Bldg., Engineering Lab Bldg., Food Technology Bldg., General Shop Room Bldg., ICT Bldg., Integrated HRM Bldg., Integrated Science Lab Bldg., ROTC and NSTP Bldg., and Senior High Bldg. and 5 buildings were required to be updated. The new KAIC ratings were the recommended sizes of circuit breaker that must be used by the College Building Extension, College Building E, IT Building, Learning Resource Center and PRINCE building with unacceptable KAIC ratings. The new KAIC ratings computed must be the new proper circuit breaker KAIC ratings that must be used for the safety of the system.

3. Economic Analysis

Table 3: Computation of ROI.

5 SHOP ROOM	Size	Current	Resistance per m	Monthly Loss(kWh)
Old	8.0 squared mm.	87.59	0.002	552.3845832
New	30.0 squared mm.	87.59	0.001	276.1922916

Monthly Energy Save (kWh)	Monthly Savings (Php)	Annual savings	Total Investment	ROI (year)
276.1922916	2662.493691	31949.92429	24466.00	0.765760813

Table III: Summary of Computed ROI

Table 3 presents the comparison of old and new secondary feeder wire for 5 Shop Room Building.

The computed monthly loss in kWH for the new feeder wire of 5 Shop Room amounted to 276.19, which is much lower compared to the old feeder wire since the old size of wire used for the secondary feeder cannot cater the current load of the building, as per PEC 2017 table 3.10.2.6(b)(16), resulting to a much higher power loss. The return of investment of the new secondary feeder wire of 5 Shop Room in years amounted to 0.76576, which is approximately equal to 9 months and 5 days.

V. CONCLUSIONS AND RECOMMENDATIONS

Conclusion

In a nutshell, this report study is believed to improve and integrate new parameters for secondary feeder conductor sizes and proper KAIC ratings of circuit breakers for a quality, reliable and efficient electrical system of the university that can be included in the development plan and priority projects of the institution for the benefit of the administration and employees and student clienteles. The evaluation of the electrical system design of DHVSU found that some of the design is outdated and requires to be updated. Some of the existing electrical system designs of DHVSU satisfied the requirements set by the PEC code, yet correction to: the existing circuit breakers KAIC rating particularly College Building Extension, College Building E, IT Building, Learning Resource Center, and PRINCE Building; and secondary feeder conductors to cater the total connected electrical load of 5 Shop Room Building. Thus, the existing electrical design of DHVSU are inadequately satisfied the requirements set by the PEC code; thus, the existing electrical system needs to be updated to the suggested improvements in the electrical design to prevent the dangers of electrical hazards. There is a need for stricter implementation during the installation of additional electrical loads to prevent unintended overloading of feeder and branch circuit conductors and transformer capacity.

Recommendation

As a result of the findings and conclusions drawn, the following recommendations are offered:

- For a detailed and updated load schedules per buildings of DHVSU, recalculation of loads with the use of load analysis is recommended.

- Future researchers might consider accomplishing coordination study, fire pump electrical supply design, economic analysis, and grounding system considering the computed values in this study.

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