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Assessment and Forecasting of Transformer Percent Loading of a Private Educational Institution

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ABSTRACT: Transformer percent loading is vital in sustaining the needed energy demand. In this study, assessment and forecasting of transformer requirement for Private Educational Institution (PEI) in Sta. Ana, Pampanga was conducted. Percent loading was assessed from January 2005 to June 2019 and forecasted per quarter in five years ahead of four transformers. Four forecasted models were verified using QM for Windows and selection was made through criterion of least value of MAE, MSE and MAPE. PEI-DTSU 1 and 2 used polynomial model because of lower MAE, MSE and MAPE of 12.16, 243.08, 22.065% and 4.568, 37.2, 728.829% respectively. PEI-DTSU 3 was applied linear model for least MAE, MSE and MAPE of 9.427, 107.466 and 18.887% respectively. PEI-DTSU 4 used exponential model for lower MAE and MAPE of 2.547 and 17.795% respectively. PEI-DTSU 1 and 3 were identified as overloaded, which can damage the transformer. PEI-DTSU 2 and 4 are underloaded, capacities were not fully utilized. Increase of 1.13%, 1.44%, 4.84% and 4.2% in percent loading and maximum loading of 113.49%, 40.64%, 127.21% and 39.63% respective to PEI-DTSU 1 to 4 were forecasted. The researchers find the need for relocating of electrical loads which may call the attention of the administration.

KEYWORDS: *Sole Used Distribution Transformer; KVA Rating; Kilowatt-hour(kWh); Percent Loading, Forecasting.*

1.0 INTRODUCTION

Transformers function is to transform the input current, voltage or power to an output utilization level that can be used by the consumer.
Proper transformer percent loading is vital to achieving the appropriate utilization; the average level is 40%– 70% of the rated capacity. But to perform optimum efficiency loading is suggested to nearly 50% of the nominal rating [1]. With this, transformer loading should be monitored to prevent transformers from becoming extremely overloaded for a significant period which could lead to burning out or worse, catastrophic failure [2]. The overloaded transformer can affect its useful life at approximately 50% [3], while on the other hand, underloaded transformers do not maximize its rated capacity [4]. An effective transformer load monitoring system takes into account the transformer-costumer connectivity and transformer data such as rating, connection, and location to identify the situation of the distribution transformer [5].

Energy management calls for the calculation of energy consumption of consumers accurately, to provide awareness of the details of actual energy usage. All consumers are taking initiatives to improve energy loading management; some were educational institutions. Applying alternative source like solar power was considered by Bohol Island State University-Main Campus [6]. Don Honorio Ventura State University projected the available electric source it can provide for the increase of students due to free tuition [7]. Pamantasan ng Lunsod ng Maynila conducted computer simulated-audit and analyzed the kWh consumption of each room of the school [8].

The electrical energy demand is undeniably increasing and can affect the percent loading of the transformer. Also, there is a rapidly escalating of cost in electric consumption being experienced by all consumer. As important as it is, forecasting energy consumption has been given an effort in Brazil to adequately supply electricity to all its consumers by employing a deep-learning approach [9]. Likewise, to cater to consumers' future energy demands was also studied in Turkey by using least square support vector machines (LS-SVM) [10]. Furthermore, in Iran, they used three (3) sub-models to generate residential power places [13] adequately.

For a Government Educational Institution electrical energy cost is covered by government funds. While in Private Educational Institutions, the maintenance and operation cost for the electrical is shouldered by the students. The amount of the budget allotted is limited due to the number of enrollees. Assessing the present loading conditions is vital to give awareness of the needs of the consumers. Also, forecasting the demand for electrical energy can help to determine if the allowable capacity can

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cater to the energy demand needed and the service span of the transformers that are deployed [11]. Planning additional sources and to the prediction of the phase of electric power can also be done to reduce uncertainties [12]. The objective of the study is to assess the present and future percent loadings of the transformer of the Private Education Institution in Sta. Ana, Pampanga. Specifically, the study aimed to determine the percent loading of each transformer per quarter per year and to analyze the historical percent loading trends. The results are intended to be applied to forecast the percent loading per quarter for the next five years.

2.0 METHODOLOGY

2.1 Locale of the Study

Holy Cross College (HCC) is the selected PEI of this study. It is a private educational institution founded in 1945 and considered as the first private Catholic school in Sta. Ana, Pampanga. The school was built to provide educational opportunities to individuals with limited financial capabilities. Some of its clientele were from towns of Arayat, Sta Ana and Candaba. The private educational institution offers different programs such as graduate studies, college, junior high school, senior high school and elementary.

2. 1.1 Load Demand of the Private Educational Institution

From 2005 to 2015 the total student enrolled in the institution were less than 2000 until the year 2016, when the institution starts to offer a senior high school program, the number of enrolled students increased as shown in Figure 1. In the academic year 2016-2017, an increase of 44.67% of enrolled student had experienced.

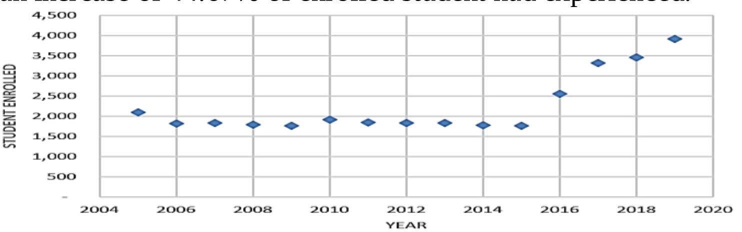

Figure 1: Number of Enrolled Student (2005 – 2019)

The institution has four (4) distribution transformers installed around the campus with kVA ratings of 15kVA (PEI-DTSU 1), three (3) units of 25kVA (PEI-DTSU 2), another 15 kVA (PEI-DTSU 3) and three (3) units of 50kVA (PEI-DTSU4). PEI-DTSU 1 and 2 are being used since 2005, while PEI-DTSU 3 was installed in 2014 to cater the energy demand for the offering of the senior high school program. In 2018 the institution installed an addition transformer which is PEI-DTSU 4 to accommodate additional courses. The annual kWh demand of the institution is shown in Figure 2. In 2016 of kWh demand of PEI started to increase due to the addition of students enrolled. An increase of 14.19% in academic 2015 – 2016 has experienced, and the energy consumption was amounting to ₱1,258,679.84. In 2017 – 2018, 22.93%

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increase for compare in the last academic year and the demand increased.

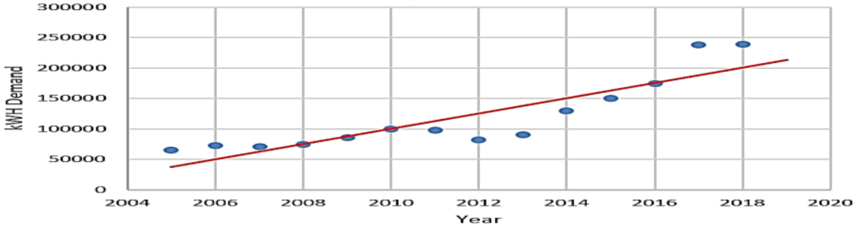

Figure 2: Yearly kWh Demand

Forecasting will be performed in the study using the historical energy consumption of the present system to assess the percent loading. Buildings connected to each meter were not considered in the study since it requires legal coordination with the utility. Hence, the researchers focused on the condition of percent loading of the transformer installed in the PEI. This action aims to give awareness and information that could call the attention of the administration.

2.2 Data Collection and Instrument

Data needed in the study, such as the kWh consumption per meter and kVA rating of transformers installed in the PEI were gathered from the electric utility. January 2005 - June 2019 kWh consumption and kVA ratings of transformers were the input parameters of the study, and these data will be used to evaluate percent loading of the transformer, as shown in Figure 3. The researcher will use QM for Windows for the statistical treatment and Microsoft Excel 2016 for percent loading forecast.

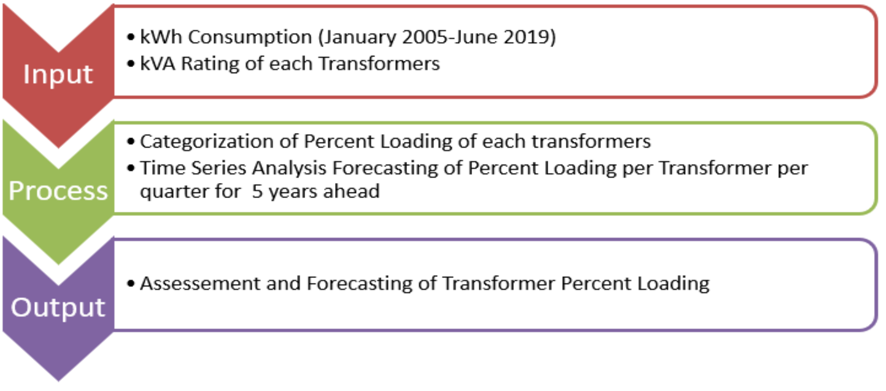

Figure 3: Conceptual Framework of the Study

2.3 Assessment of Transformer

From the data gathered from PELCO I, the four (4) distribution transformer and kWh consumption (January 2005 – Jun 2019) were used to determine the percent loading per quarter of the transformer by using Microsoft Excel 2016 applying the formula as the standard set in the National Electrification Administration (NEA) System Loss Reduction Manual [13].

$$\% \, Loading = \frac{kWhrDemand(3\,months)}{(KVA_{TR})\,(PF)\,(2160H)} \qquad (1)$$

After the percent loading was determined, the transformer will be assessed depending on the loading conditions [1]:

a. Over Loaded = 71 % and up

b. Normal Loaded = 40% to 70%

c. Under Loaded = below 40%

2.4 Forecasting

Percent loading will be used to forecast the per quarter for five years ahead. The study is classified as long-term electrical forecasting [14]. Forecasted data will be gathered using the mathematical forecasted model. QM (for Windows Version 5) will used for the statistical treatment to identify the Mean Absolute Error (MAE), Mean Squared Error (MSE) and Mean Absolute Percent Error (MAPE). The result will be a criterion to test the accuracy of the forecasted model. With this criterion, the forecasted model to be used must be the least value of MAE, MSE and MAPE.

1. Mean Absolute Error (MAE) - It is a measure of how close the forecasted value to the actual value [8], [14].

$$MAE = \frac{\left(\sum_{t=1}^{t=t} |A_t - F_t|\right)}{t} \qquad (2)$$

Where: A_t = Actual Value

F_t = Forecasted Value

t = time

2. Mean Square Error (MSE). It is always a positive value, and it is closer to the value of zero the better [8], [14].

$$MSE = \frac{\left(\sum_{t=1}^{t=t} (A_t - F_t)^2\right)}{t} \qquad (3)$$

Where: A_t = Actual Value

F_t = Forecasted Value

t = time

3. Mean absolute Percent Error (MAPE). Measure of accuracy expressed in percentage of the average of the absolute value of error [14].

$$MAPE = \frac{\left(\sum_{t=1}^{t=t} |A_t - F_t|\right)}{t} \, X \, 100\% \qquad (4)$$

Where: A_t = Actual Value

F_t = Forecasted Value

t = time

3.0 RESULT AND DISCUSSION

3.1 Assessment of Transformer

The graphical representation of the percent loading of the transformers installed is shown in Figures 4-7. These data were taken to account to assess the percent loading condition of the four (4) transformers. PEI-DTSU 1 in Figure 4 shows the percent loading exceeds the maximum normal loading in the 3rd quarter of 2007 and 2015. In the academic year 2016-2017, the percent loading of PEI-DTSU 1 continuously operates higher than the normal loading. 3rd quarter of 2017 the transformer experienced a loading condition higher than 100 percent loading.

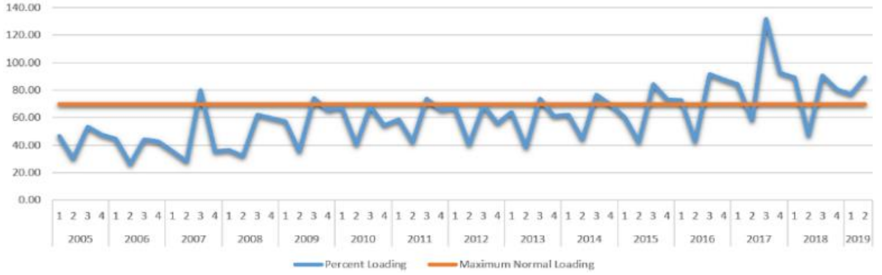

Figure 4: Percent Loading of PEI-DTSU 1

Figure 5 shows that PEI-DTSU 2's percent loading is in underloaded condition; it did not reach the normal loading. Although it reached to 42.43 percent loading for the 3rd quarter of 2017, it can be observed that the loading condition of the transformer decrease for the next quarter. The gap between the maximum normal loading and the present percent loading poses some concerns.

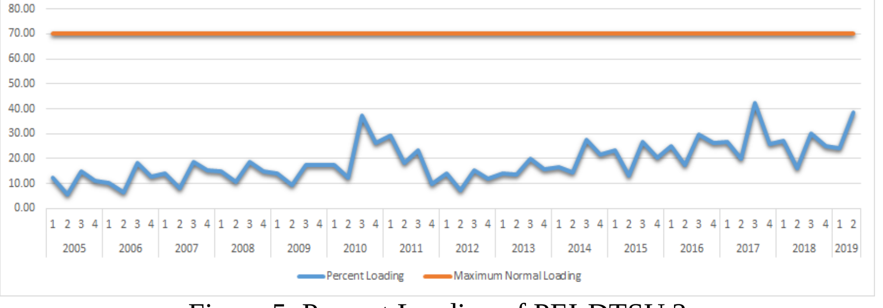

Figure 5: Percent Loading of PEI-DTSU 2

The percent loading of PEI-DTSU 3 in Figure 6 shows nearly a normal loading condition. In 2017 3rd quarter, the percent loading it almost reached the maximum normal loading of 70%. From the 3rd quarter of 2018 up to the 2nd quarter of 2019, the percent loading is nearly 70%. The gap of the allowable and the demand became narrower as shown.

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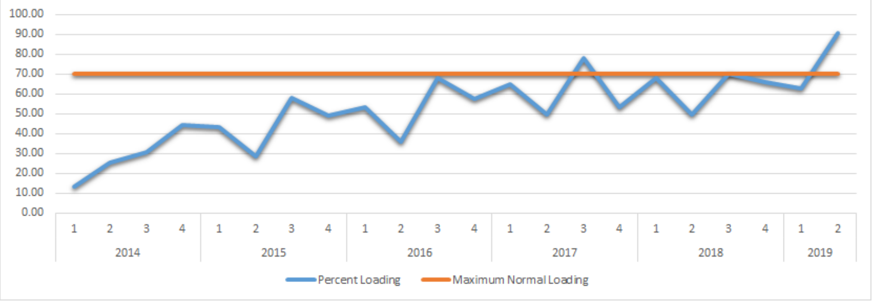

Figure 6: Percent Loading of PEI-DTSU 3

Figure 7 shows the maximum percent loading of PEI-DTSU 4 reached 19.18% in the 3rd quarter of 2018. The transformer is still not fully utilized and a large gap to the normal loading condition and the actual loading condition, with this, PEI-DTSU 4 can cater additional demand needed by the institution.

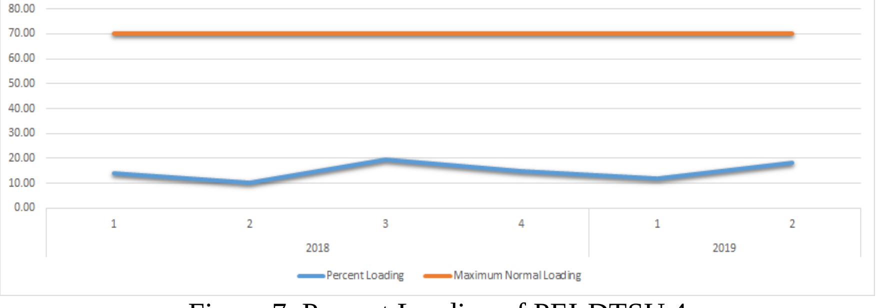

Figure 7: Percent Loading of PEI-DTSU 4

3.3 Forecasting per quarter in 5 years ahead

In the study, four forecasting model was used for the transformers to test the best of fit of percent loading shown in Table 1, 2, 3 and 4, respectively. For PEI-DTSU 1, the polynomial model had been chosen because of least MAE, MSE, and MAPE, as seen in Table 1.

Table 1: Measure of Accuracy for PEI-DTSU 1

Function	Measure of Accuracy		
	MAE	MSE	MAPE
Linear	12.184	245.043	23.118%
Exponential	12.491	247.344	22.793%
2nd Degree Polynomial	12.160	243.080	23.065%
3rd Degree Polynomial	12.190	248.334	23.604%

The 2nd-degree polynomial model for the quarterly percent loading from 2005- 2019 is expressed as

$$f(x) = a_1 x^2 + a_2 x + a_3 \quad (5)$$

where $a_1 = 0.0056$

$a_2 = 0.4615$

$a_3 = 40.732$

x = year

The researchers have used the polynomial model to project the five (5) years ahead quarterly loading for PEI-DTSU 1, as seen in Figure 8. The graph shows that the transformer will operate in an overloaded condition which will cause power failure in the long run.

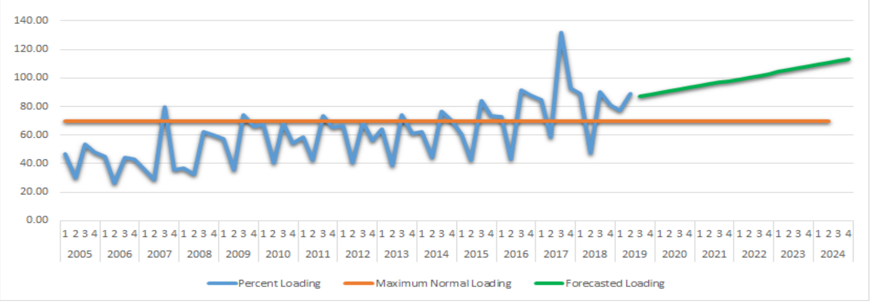

Figure 8 PEI-DTSU 1 Percent Loading and Forecasted Loading

In the case of PEI-DTSU 2, a 2nd-degree polynomial model was the best due to the lower value of MAE and MSE compare for the other forecast model.

Table 2: Measure of Accuracy for PEI-DTSU 2

Function	Measure of Accuracy		
	MAE	MSE	MAPE
Linear	4.634	37.872	29.132%
Exponential	8.353	118.442	38.959%
2nd Degree Polynomial	4.568	37.270	28.829%
3rd Degree Polynomial	4.686	39.718	27.482%

For PEI-DTSU 2, the forecasted quarterly percent loading was attained by using the 2nd-degree polynomial model

$$f(x) = b_1 x^2 + b_2 x + b_3 \qquad (6)$$

where $b_1 = 0.0031$

$b_2 = 0.1107$

$b_3 = 11.942$

x = year

In the case of PEI-DTSU 2, the polynomial model applied still there is a large gap between allotted loading before it can reach the maximum limit of 70% as seen in Figure 9. Even in the forecasted per quarter for five years ahead there are still more rooms for the additional demand for energy.

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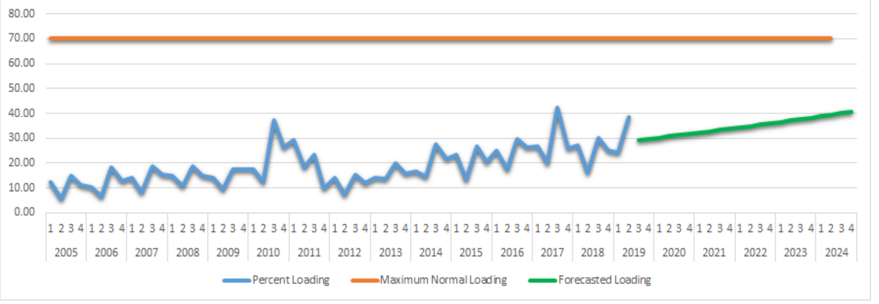

Figure 9: PEI-DTSU 2 Percent Loading and Forecasted Loading

In Table 3, the lowest MAE, MSE and MAPE is the 3rd-degree polynomial model. But the forecasted value was too high, which reached 67.3%. The next model must be the 2nd-degree polynomial model, but the predicted model drops for a negative value. The next best model falls to the linear model to forecast the percent loading for PEI-DTSU 3.

Table 3: Measure of Accuracy for PEI-DTSU 3

Function	Measure of Accuracy		
	MAE	MSE	MAPE
Linear	9.427	116.132	22.540%
Exponential	10.365	141.366	23.477%
2nd Degree Polynomial	8.426	107.466	18.887%
3rd Degree Polynomial	7.624	92.488	15.670%

For PEI-DTSU 3 the linear mathematical model for the quarterly percent loading is interpret as

$$f(x) = c_1 x + c_2 \qquad (7)$$

where $C_1 = 2.2988$

$C_2 = 26.259$

x = year

PEI-DTSU 3 exceeds the maximum normal loading of 70% as shown in Figure 10. For the forecasted values it shows that the transformer will become overloaded that will be a disadvantage to its operation.

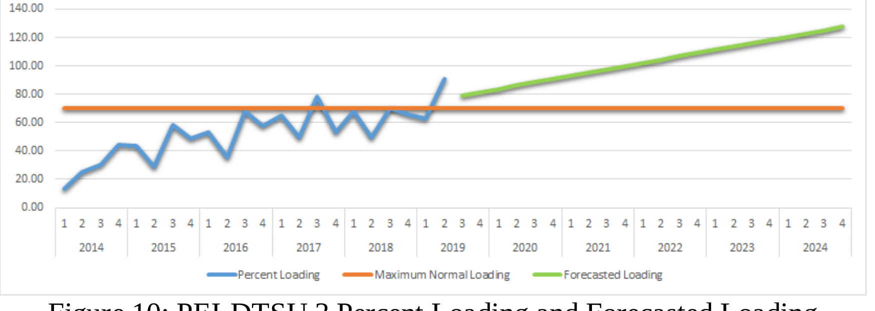

Figure 10: PEI-DTSU 3 Percent Loading and Forecasted Loading

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Comparing the test of the accuracy of the three models, as shown in table 4, 3rd-degree polynomial was the least value of MAE, MSE and MAPE. On the other hand, this forecasted model drops its forecasted values. The next lower MAE and MAPE was the Exponential model to forecast the data for the PEI-DTSU4 for this scenario.

Table 4: Measure of Accuracy for PEI-DTSU 4

Function	Measure of Accuracy		
	MAE	MSE	MAPE
Linear	2.565	9.259	18.299%
Exponential	2.547	9.338	17.795%
2nd Degree Polynomial	2.972	13.359	19.089%
3rd Degree Polynomial	2.396	8.487	17.741%

PEI-DTSU 4 the mathematical exponential model for the forecasted quarterly percent loading is expressed as

$$f(x) = d_1 e^{d_2 x} \qquad (8)$$

where $d_1 = 12.539$

d_2 =0.0.411

x = year

PEI-DTSU 4 has a wider percent loading gap, as seen in Figure 11. Even in the forecasted linear model in the five years ahead, the loading condition is around 40 percent.

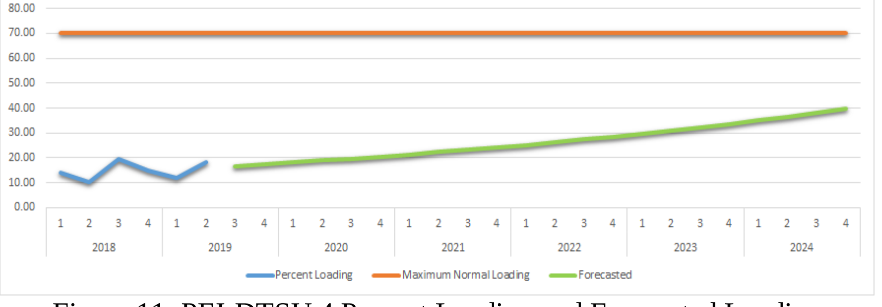

Figure 11: PEI-DTSU 4 Percent Loading and Forecasted Loading

PEI administration must take into consideration is the gap between the allowable percent loading conditions and the demand loading of the transformer for maximum utilization.

4.0 CONCLUSION

The time-series analysis shows that from 2005 to 2019 percent loading of the four transformers installed in PEI were increased evidently. PEI-DTSU 1 and PEI-DTSU 3 percent loading per quarter increased at a rate of 1.31 and 4.84% respectively. Maximum percent loading reached 113.49% and 127.41% respective to PEI-DTSU 1 and 3. This case is an overloaded condition that can cause power interruption and can damage the transformer. PEI-DTSU 2 and PEI-DTSU 4 had increased by 1.44% and 4.2% per quarter respectively, since the transformer was not overloaded additional energy demand can be catered. Even a maximum 40.64% and 39.63% loading for PEI-DTSU 2 and PEI-DTSU 4 for their forecasted five (5) years ahead still there is more room for additional electrical loadings

5.0 RECOMMENDATION

For future studies, quantifying the connected electrical loads per transformer will of importance. Determination for all the building connected is necessary to provide necessary measures to limit or conserve energy to make the transformers maintain normal loading conditions. Relocations of some of the building electrical loads to the transformers such as PEI-DTSU 2 and PEI-DTSU 4 must take for consideration because these transformers are underutilized. For future study, auditing of the loadings can be considered to optimize the utilization.

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