INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact Factor: 6.078
(Volume 8, Issue 3 - V8I3-1409)
Available online at: https://www.ijariit.com

Technical Loss Reduction on Feeder-3 of an Electric Cooperative in Pampanga, Anao Substation by Feeder Reconductoring

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ABSTRACT

A technical loss reduction program has been activated by distribution utilities due to the increasing electricity demand. This paper focuses on the analysis of reconductoring the existing Feeder 3 with 3-phase, 2/0 conductors, ACSR, and 19.6 km in length. Feeder reconductoring is a technique where the existing conductor of the feeder is replaced by a more prominent conductor of optimal size and length. Two alternatives had been proposed; 4/0 conductor size was proposed in Alternative 1, while 336 size conductor was proposed in Alternative 2 in reconductoring the existing feeder. Technical loss reduction analysis, voltage regulation analysis, and cost-benefit analysis were performed to determine what alternative reduce the technical loss significantly, improve the voltage regulation, increase the capacity of the wire and be more economical to the distribution utility. Considering the results, Alternative 2 accounts for the highest reduction in technical loss, with an average of 65.8% technical loss reduction from 2022 to 2023. Also, Alternative 2 has the most significant improvement in voltage regulation with an average of 1.39% regulation due to low voltage drop. In terms of economic factors, implementing Alternative 2 is more beneficial to the distribution utility and can save 1,532.54 MWh of energy from 2022 to 2031. If converted into a monetary unit, the distribution utility can save Php 14,620,462.32. Implementing Alternative 2 is attainable and justifiable since the Benefit/Cost ratio is greater than 1.

Keywords: *Technical Loss, Reconductoring, Electric Cooperative*

1. INTRODUCTION

The electrical distribution system is an essential part of the supply chain (Siddiqui & Sarwar, 2013) and is designed to provide electrical energy to end-users. However, it is well-known that not all energy delivered to a distribution utility reaches the end-user (Navarni, Sharma & Sapra, 2012). A portion of energy being delivered to the end-user will always be wasted in the form of heat or noise, causing Distribution System Loss (DSL) (PSME Advocacy Group, 2019). According to Keoliya & Vaidya (2013), the DSL has two components, namely, Technical and Non-Technical Losses. Arya et al. (2013) mentioned that non-technical losses occur due to unnoticed meter problems or when electricity is stolen in fraud, billing errors, and unpaid energy bills. In contrast, Viegas et al. (2017) indicated that technical losses occur naturally due to the unavoidable dissipation of electric energy from the electrical components such as feeder conductors.

The feeder accounts for most technical losses in a distribution system (Energy Regulatory Commission, 2017). Due to the underlying physical processes, these conductor losses cannot be eliminated, but their minimization is an ongoing research topic in optimizing the distribution system (Rodriguez et al., 2021). Hence, Qureshi & Mahmood (2009) argued that it requires special attention to achieve significant reductions in loss figures. A technique to reduce these is changing the wires of overhead lines or feeders with a more prominent conductor or reconductoring (Eduave & Daquiado, 2016). Seethalekshmi, Trived, and Ramamoorty (2002) stated that it is essential to plan a system with the utmost caution to keep losses as low as possible while still providing a higher quality supply.

Dhanoa and Brar (2015) eloquently stated that feeder reconductoring is a technique where the existing conductor of the feeder is replaced by a more prominent conductor of optimal size and length. This approach is utilized when the existing conductor is no longer optimal due to rapid load growth, deterioration, or off-size. Replacing the existing conductor with a more prominent conductor will reduce technical loss and be more economical. Dhanoa and Brar (2015), in their study, added that the benefits of feeder reconductoring, such as increased feeder capacity to meet increased load demand and improved voltage regulation, will contribute to a decrease in losses.

Many researchers and authors have researched feeder reconductoring. According to the study of Eduave and Daquido (2016), by feeder reconductoring on 3-phase, four-wire primary distribution line of a feeder on Electric Cooperative (E.C.) in Mindanao with 2/0 conductor wire size to ACSR 3/0, AWG 6/1 with the total length of the overhead line 20,344.0, the technical loss could be reduced by 8%. Sarwar and Siddiqui (2018) proposed a method that is a high voltage distribution system (HVDS) along with reconductoring. It was then compared to the existing feeder to determine how much technical loss would be reduced. The comparison reveals that the technical loss of the existing feeder is 15%, much higher than the technical loss of HVDS with reconductoring 7.2%. Myat, Myint, and Phyu (2018) studied that the most critical section in the electrical power distribution system is to reduce the distribution line losses and their cost. The distribution losses are decreased in this study by applying a voltage upgrade technique and upgrading the conductor size. According to the simulation result, the percentage loss in the existing system with the old conductor is 5.26 %, much higher than the larger conductor size with 11-kV, which has 3.96 %.

Electric power demand has risen dramatically as a result of electric energy's supremacy over all other types of energy, and the growth of power generation and transmission has been significantly hampered by a lack of resources, environmental limitations, and privatization in developing nations (Anumaka, 2012) like the Philippines. Hence, the reconductoring method is suitable for a developing country with significant annual account growth rates (Myat, Myint, & Phyu, 2018). The Philippines is a developing country subdivided into 81 provinces, including the Pampanga. The province of Pampanga is energized by four Private Distribution Utilities (PDUs) and four Electric Cooperatives (E.C.s), including Pampanga Rural Electric Service Cooperative (PRESCO), Inc. The distribution utility has three distribution feeders: Feeders 1,2, and 3, that provide electrical energy to residential consumers, street lights, public buildings, and a water system covering five barangays of Arayat, one barangay of Magalang, four barangays of Sta. Ana and 24 barangays of Mexico. As indicated in the 2020 shares of energy sales of PRESCO, customers such as street lights, water systems, and public buildings only accounted for 2.22% of energy sales due to the low number of connections. In contrast, residential customers account for most energy sales at 75.88% due to increased consumers. The number of residential consumers is expected to grow at an average of 4.52% annually (Power Supply Procurement Plan, 2021). As stated in the Historical Consumption Data of PRESCO, from the year 2016 to 2020, the peak demand of PRESCO increased from 8.83 MW to 14.14 MW, with an annual average increase rate of 7%.

From the year 2021, among the three feeders of PRESCO, Feeder 3 accounts for the highest peak load with 8,527.93 MW (Figure 1) which serves barangays of Anao, San Juan, Laput, Concepcion, Santa Cruz, Balas, portion of San Patricio, San Pablo, Santo Rosario, San Roque, San Agustine, San Vicente, San Miguel, Divisoria, Masamat and Sabanilla, San Vicente, San Miguel, Divisoria, Masamat and Sabanilla.

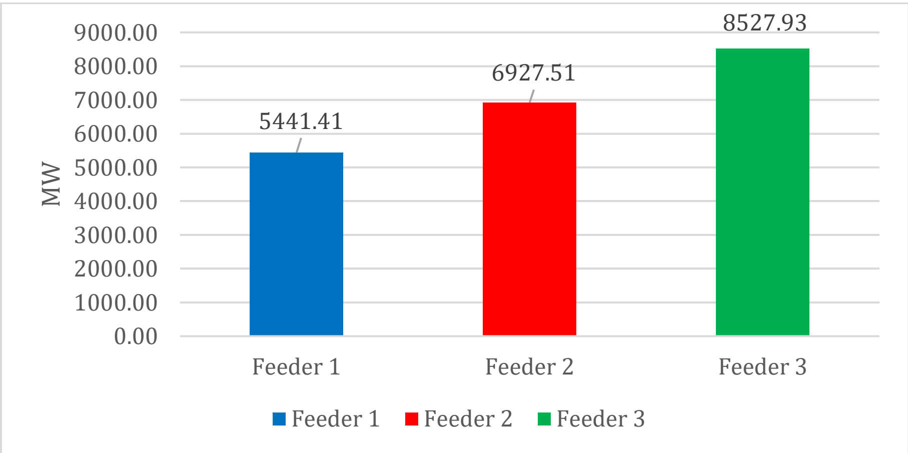

Figure 1. 2021 Peak Load Per Feeder

Within the same period, Feeder 3 also accounts for the highest feeder conductor loss with 96, 772.61 kWh (Figure 2). It was noticed that Feeder 3 with 360 ampacity is overloaded with 103.6% loading due to the increasing demand for electricity annually with a peak line current of 373 A. The peak line current already exceeded the required ampacity of the Feeder 3 conductor. Hence, feeder reconductoring is a suitable method to propose since feeder reconductoring reduces the technical loss and increases the capacity of the feeder conductor (Dhanoa & Brar, 2015).

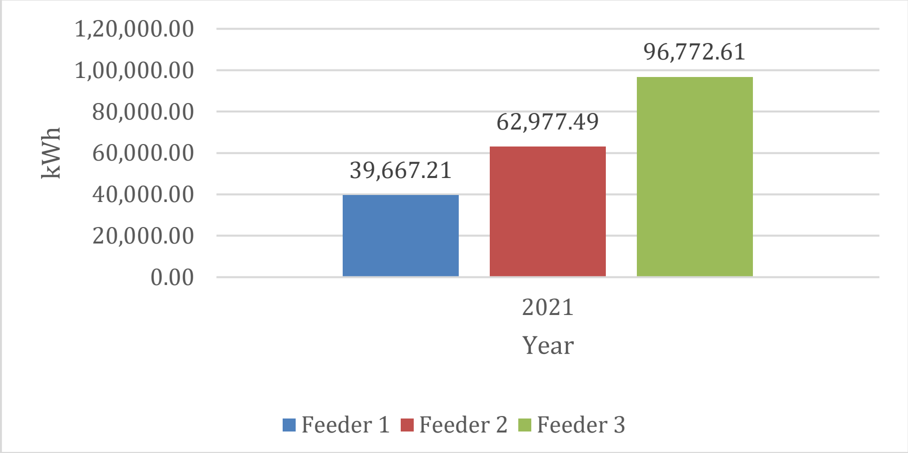

Figure 2. Conductor Loss Per Feeder

The study aims to propose two alternatives in reconducting the existing 3-phase, 2/0 conductors, ACSR with 19.6 km in length Feeder 3. The proposed alternatives were analyzed by performing technical loss reduction analysis, voltage regulation analysis and cost benefit analysis and then compared to the existing feeder to determine what alternative reduced the technical loss significantly, improved the voltage regulation of Feeder 3 and more economical. Lastly, load forecasting was executed to forecast the future loads. This study aids an improvement of the system of PRESCO by feeder reconductoring. The study helps the electric cooperative reduce technical loss, increase the capacity of Feeder 3, and exploit financial gains. It also helps the consumers increase their satisfaction since feeder reconductoring improves voltage regulation (Dhanoa & Brar, 2015).

This study did not cover the analysis of the Non-Technical Loss of PRESCO in reducing the system loss and focused on Technical Loss analysis. The study focused on analyzing the conductor loss of the primary line to determine the reduction of technical loss and did not cover the technical losses on transformers, secondary lines, and service drop

2. METHODS

A. Data Collection and Instrument

This study gathered the necessary data: the peak demand from 2017 to 2021, length, size, type, phase, load and power factor, and system voltage of the existing feeder conductor from PRESCO. These data are analyzed to determine the objectives of the study. The conceptual framework shows the study's input, process, and output (Figure 3). The input or the data gathered from the electric cooperative are analyzed using load forecasting, technical loss reduction analysis, voltage regulation analysis, and cost-benefit analysis to determine what best alternative reduced the technical loss, significantly improved the voltage regulation, and was more economical.

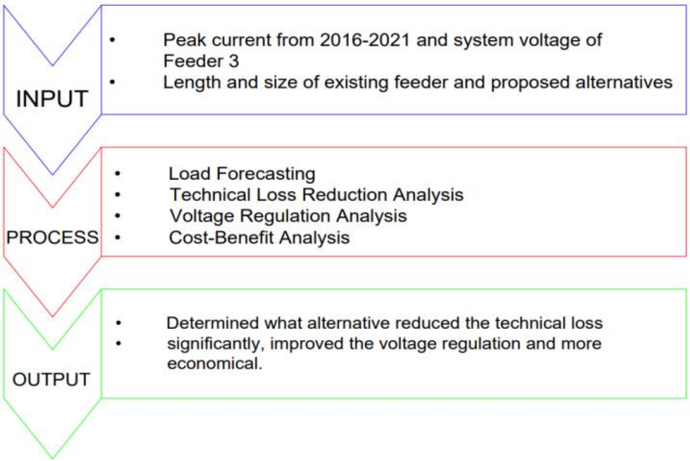

Figure 3. Conceptual Framework

B. Load Forecasting

The linear regression method was performed using the formula from U.P. National Engineering Center. Liner regression method was used since the peak demand from 2017-2021 was constantly increasing in a linear manner annually.

Electrical load forecasting can be classified into four categories according to period of forecast, namely; very short term, short term, medium term and long term (U.P. National Engineering Center). This study used a long term load forecasting to forecast the peak current of Feeder 3 for the next ten years (from 2022 to 2031) since it is the average life expectancy of a project.

$$Y = A + BX \quad \text{Eq. (1)}$$

$$b = \frac{n\Sigma X_i Y_i - \Sigma X_i \Sigma Y_i}{n\sum Xi^2 - (\sum X_i)^2} \quad \text{Eq. (2)}$$

$$a = \frac{\Sigma Y_i - b\Sigma X_i}{n} \quad \text{Eq. (3)}$$

The software to be used is QM (for Windows Version 5) for the statistical treatment to identify the Mean Absolute Percent Error (MAPE), Mean Absolute Error (MAE) and Mean Absolute Deviation (MAD).

1. Mean Absolute Percent Error (MAPE) - is calculated using the absolute error in each period divided by the observed values that are evident for that period. Then, averaging those fixed percentages.

$$MAPE = \frac{\sum_{t=1}^{t=t} |A_t - F_t|}{t} \quad \text{Eq. (4)}$$

2. Mean Absolute Error (MAE) - it is a measure of how close the forecasted value to the actual value

$$MAE = \frac{\sum_{t=1}^{t=t} |A_t - F_t|}{t} \quad \text{Eq. (5)}$$

3. Mean Absolute Deviation (MAD) - it is the average of the absolute value, or the difference between actual values and their average value, and is used for the calculation of demand variability.

$$MAD = \frac{\sum_{t=1}^{t=t} |xi - \mu|}{t} \quad \text{Eq. (6)}$$

The Westinghouse House T&D Conductor Table from Paserba (2019) from his Westinghouse Electric & Manufacturing Company's Electrical Transmission and Distribution Reference Book was used to identify the proper sizes of wire to be proposed.

C. Technical Loss Reduction Analysis

The study performed technical loss reduction analysis by applying the formulas from National Electrification Administration (System Loss Reduction Manual, DX3430, Engineering Bulletin). The existing conductor loss was compared to the computed conductor loss of both proposed alternatives to determine how much technical loss is reduced.

Following is a generally accepted formula from NEA for the computations of conductor loss:

$$Annual\ Conductor\ Loss = \frac{(kW)^2(R)(S)[(0.85 \times LF^2) + (0.15 \times LF)] \times 8760}{(kV)^2(PF)(P)(1000)} \quad \text{Eq. (7)}$$

where:

kW = peak line load in kilowatts
R = resistance in ohms per phase per kilometer of line
S = line length in kilometers
LF = line load factor
PF = power factor per unit
P = number of phases

D. Voltage Regulation Analysis

The voltage regulation of proposed alternatives was calculated and then compared to the voltage regulation of existing Feeder 3 to determine what method obtained the optimal improvement on voltage regulation, using the formula from Willis (2004) in his Power Distribution Planning Reference Book.

$$\%VR = \frac{Vs - Vr}{Vr} \times 100 \quad \text{Eq. (8)}$$

where:

VR = Voltage Regulation
Vs = Sending Voltage
Vr = Receiving Voltage

Data from PRESCO were gathered to get the value for Vs, and to compute for Vr; equation 7 was used.

$$Vr = VL - VD \quad \text{Eq. (9)}$$

where:

VL = line voltage
VD = voltage drop
Using the equation below, V.D. can be determined.

$$VD = I \times \sqrt{R^2 + X^2} \text{ .... Eq. (10)}$$

where:

R = resistance

X= reactance

To get the values for R and X should be identified. The Westinghouse House T&D Conductor Table from Paserba (2019) from his Westinghouse Electric & Manufacturing Company's Electrical Transmission and Distribution Reference Book was used as a reference.

E. Cost-benefit analysis

Benefit-cost ratio analysis was performed to determine what alternative is more economical for the distribution utility using the from the study of Gomez (2021).

$$Annual\ Energy\ Save = Loss_{Existing} - Loss_{Alternative\ X} \text{ ....Eq. (11)}$$

Then, annual energy saved is converted into monetary units (Peso) to get annual savings using the formula:

$$Annual\ Savings = Annual\ Energy\ Save \times \frac{Php}{kWh} \text{ .... Eq. (12)}$$

Annual Savings was identified to determine the ROI and Benefit/Cost Ratio

ROI can be determined using the formula:

$$ROI = \frac{Cost\ of\ Investment}{Annual\ Savings} \text{ .... Eq. (13)}$$

This study considered the material cost, labor cost, contingency fund, engineering and handling cost, and vat cost to compute the total cost of investments.

The benefits cost ratio should be greater than one for a project to be economically feasible and justifiable (>1). To determine the Benefit/Cost Ratio of the two proposed alternatives, eq. 14 and 15 were used.

$$AC = PW\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \text{ .... Eq. (14)}$$

$$B/C = \frac{Annual\ Savings}{AC} \text{ .... Eq. (15)}$$

where:

AC = Annual Cost

PW = Present Worth Cost

i = effective interest rate per year

n = estimated life of the project in years will be determined using load forecasting

B/C = Benefit/Cost Ratio

3. RESULTS AND DISCUSSION

A. Load Forecasting

Figure 4 shows the peak current from 2017-2021 and forecasted peak current of Feeder 3 from 2022 to 2031 using the linear regression method. As seen from 2022 to 2031, Feeder 3 with a 2/0 size conductor will be overloaded since the existing feeder is only 360 ampacity. Based on the forecasted peak current, two alternatives are proposed to increase the ampacity of the wire.

Alternative 1: Use a 4/0 size conductor in reconductoring the existing 2/0 size Feeder 3 with 480 ampacities.

Alternative 2: Use a 336 size conductor in reconductoring the existing 2/0 size Feeder 3 with 670 ampacities.

The feeder conductors' proposed sizes are more prominent than the existing feeder and optimal enough to sustain future loads. The 4/0 conductor will last until 2026, while the 336 conductors will last until 2031.

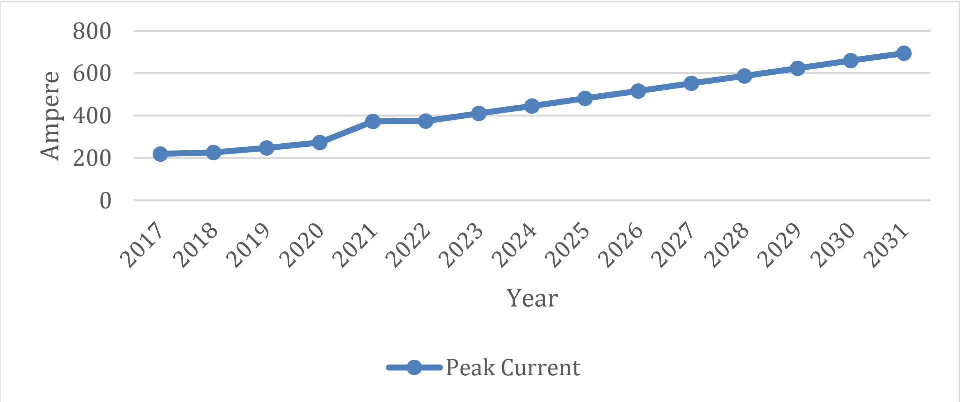

Figure 4. Peak Current (2017-2031)

Using QM software, Table 1 shows that linear regression method was a excellent method to perform in this study since least values of MAPE, MAE (Bias) and MAD were calculated.

Table 1. Error Analysis of Load Forecasting Method

	Actual	Forecast	Error	|Error|	Error^2	|Pct Error|
Past Period 1	219.1	196.5	22.6	22.6	510.76	10.315%
Past Period 2	225.6	232.1	-6.5	6.5	42.25	2.881%
Past Period 3	247.2	267.6	-20.4	20.4	416.16	8.252%
Past Period 4	273.3	303.2	-29.9	29.9	894.012	10.94%
Past Period 5	373	338.7	34.3	34.3	1176.489	9.196%
TOTALS	1338.2		.1	113.7	3039.671	41.585%
AVERAGE	267.64		.02	22.74	607.934	8.317%
			(Bias)	(MAD)	(MSE)	(MAPE)
				Std err	31.831	

B. Technical Loss Reduction

The graphical representation of conductor loss and reduction in technical loss is shown in Figures 4-5. Figure 4 shows the conductor loss comparison of existing feeders, Alternative 1 and Alternative 2 from 2022 to 2031. In 2022, the existing feeder accounts for the highest conductor loss compared to the computed conductor loss of Alternative 1 and 2. Among the two alternatives, Alternative 2 has the lowest conductor loss due to the larger size of the conductor. The size of the conductor has an impact on the conductor loss of Feeder 3; as the size of the conductor increases, the conductor loss decreases.

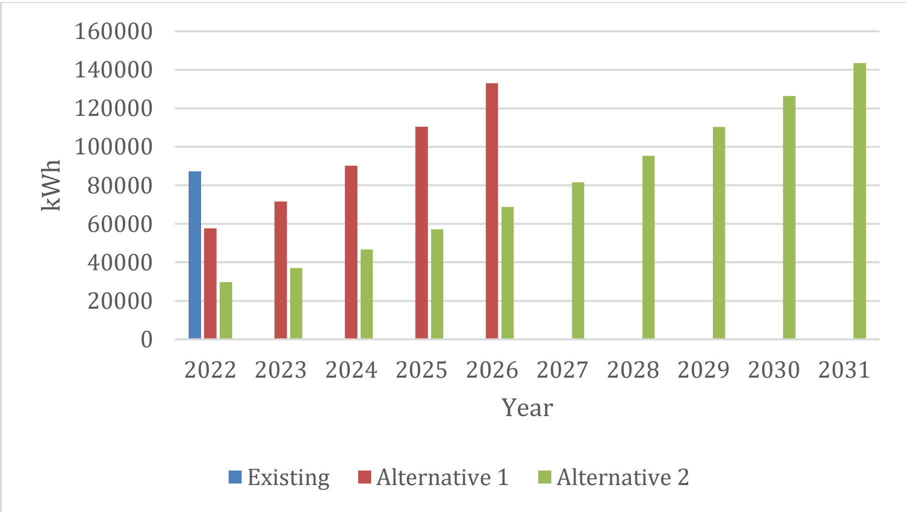

Figure 5. Conductor Loss (2022-2031)

As seen in Figure 6, Alternative 1 accounts for the highest reduction in technical loss compared to the technical loss reduction of Alternative 2. Feeder reconductoring made a significant impact in the reduction of technical loss; this was majorly due to the less resistance on the thicker wire. In Alternative 2, the technical loss could be reduced by 65.8% annually, much more significant than the 33.8% reduction in technical loss of Alternative 1.

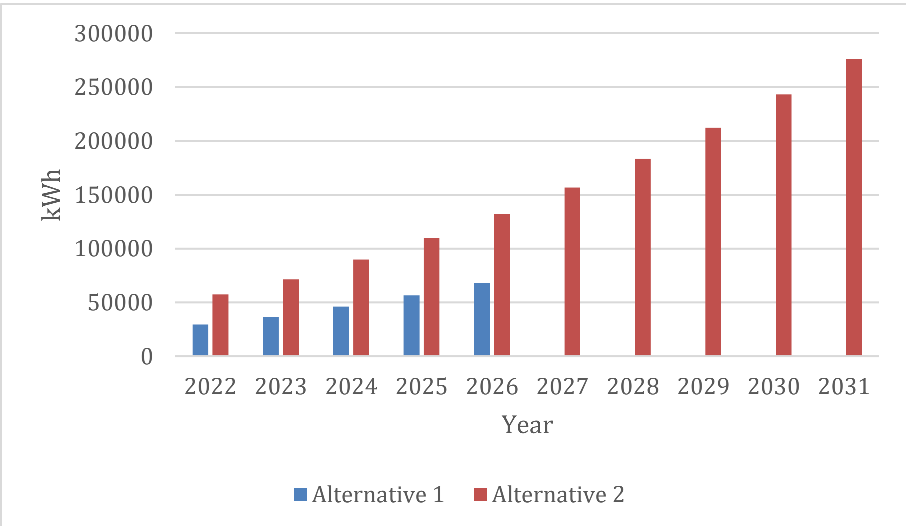

Figure 6. Technical Loss Reduction (2022-2031)

C. Voltage Regulation

Table 1 shows the voltage regulation of existing and proposed alternatives from 2022 to 2030. Even though the existing feeder did not exceed the allowable voltage regulation of 10%, its reduction is still an essential part of an electric cooperative to increase the satisfaction of consumers. Based on the computed values, Alternative 2 with 336 size has the most significant improvement in voltage regulation due to low voltage drop compared to Alternative 1 with 4/0 size of conductor. The size of the conductor plays a vital role in the voltage regulation of a feeder. A more prominent conductor with less resistance and reactance has a low voltage drop than a smaller conductor. Feeder reconductoring reduces the technical loss of the feeder and improves voltage regulation. On average, voltage drop could be reduced by 84 V annually by implementing Alternative 1. However, by implementing Alternative 2, the voltage drop could be reduced by184 V.

Table 1. Voltage Regulation (2022-2031)

Year	Voltage Drop (V)			Voltage Regulation (%)		
	2/0	4/0	336	2/0	4/0	336
2022	255.885	198.966	126.624	1.977	1.530	0.969
2023	280.154	217.837	138.634	2.168	1.678	1.061
2024	304.492	236.761	150.677	2.361	1.826	1.155
2025	328.761	255.631	162.687	2.554	1.975	1.248
2026	353.098	274.555	174.730	2.749	2.124	1.341
2027	377.367	293.426	186.740	2.943	2.273	1.435
2028	401.705	312.350	198.783	3.139	2.424	1.529
2029	425.974	331.220	210.793	3.335	2.574	1.623
2030	450.311	350.144	222.836	3.532	2.725	1.717
2031	474.580	369.015	234.846	3.729	2.876	1.811

D. Cost-Benefit Ratio

Table 2 presents the savings comparison between the two alternatives. From 2022 to 2031, Alternative 2 has the highest annual savings with Php 1,462,046.232 compared to Alternative 1 with Php 452,082.524 savings annually. The annual savings depends on the energy saved by the electric cooperative; the greater the energy saved annually, the higher the accumulated annual savings. The electric cooperative can save 153,254.322 kWh of energy annually by implementing Alternative 2, which is much greater than Alternative 1 with 47,388.105 kWh of energy saved.

Table 2. Savings (2022-2030)

YEAR	Alternative 1 Energy Save (kWh)	Alternative 2 Energy Save (kWh)	Alternative 1 Savings (Php)	Alternative 2 Savings (Php)
2022	29,507.755	57,361.558	281,503.981	547,229.261
2023	36,667.654	71,280.034	349,809.423	680,011.527
2024	46,163.368	89,739.213	440,398.529	856,112.091
2025	56,520.017	109,872.006	539,200.962	1,048,178.940
2026	68,081.732	132,347.387	649,499.728	1,262,594.067
2027	-	156,851.120	-	1,496,359.683
2028	-	183,548.912	-	1,751,056.619
2029	-	212,260.828	-	2,024,968.300
2030	-	243,181.032	-	2,319,947.044
2031	-	276,101.131	-	2,634,004.790
TOTAL:	236,940.526	1,532,543.220	2,260,412.622	14,620,462.323
Annual:	47,388.105	153,254.322	452,082.524	1,462,046.232

In Table 3, the total investment cost of Alternatives 1 and 2 are shown. This study considered the material cost, labor cost (30% of the material cost), engineering and handling cost (5% of the material cost) and contingency fund (10% of the material cost (Eduave &Daquido, 2016). Among the two alternatives, Alternative 1 is less expensive with Php 5,882,940 total cost compared to Alternative 2 with Php 9,549,120. The material cost significantly impacts the total investment cost; the conductor used in Alternative 2 is more expensive than Alternative 1 since the conductor used in Alternative 2 is more prominent in size.

Table 3. Cost of Investment

TOTAL INVESTMENT					
ALTERNATIVES	MATERIAL COST (PHP)	LABOR COST (PHP)	ENG'G & HANDLING COST (PHP)	CONTINGENCY FUND (PHP)	TOTAL COST (PHP)
Alternative 1	4,057,200.00	1,217,160.00	202,860.00	405,720.00	5,882,940.00
Alternative 2	6,585,600.00	1,975,680.00	329,280.00	658,560.00	9,549,120.00

In Table 4, the total investment cost can be recovered after six and a half years by implementing Alternative 2 compared to Alternative 1 with 26 years of recovery period. Even though the total investment cost of Alternative 2 is expensive, it can be recovered through annual savings.

Table 4. Return of Investment

RETURN OF INVESTMENTS			
Alternatives	Annual Savings	Total Investments	ROI
Alternative 1	226,041.262	5,882,940.00	26.026
Alternative 2	1,462,046.232	9,549,120.00	6.531

Having a conservative assumption, at an interest rate of 6% (Eduave &Daquido, 2016), the annual cost of Alternative 2 is more expensive than Alternative 1. Despite the annual cost of Alternative 2, as shown in Table 5, Alternative 2 is feasible and justifiable since the computed B/C ratio is greater than 1.

Table 5. Benefit-Cost Ratio

Benefit/Cost Ratio		
Alternatives	Annual Cost	B/C
Alternative 1	799,303.046	0.283
Alternative 2	1,297,419.437	1.127

4. CONCLUSION

The conductor loss accounts for most technical losses in a distribution system. In the past years, the technical loss of Feeder 3 has been continuously increasing due to increasing demand. This study proposed two alternatives in reconductoring the existing 3-phase, 2/0 conductors, ACSR with a length of 19.6 km to reduce the technical loss, increase the capacity of Feeder 3, improve the voltage regulation and be more economical. Considering the results obtained from this study, Alternative 2 with 336 sizes of conductor accounts for the highest reduction in technical loss and has the most significant improvement in voltage regulation. By implementing Alternative 2, the distribution utility can save 1,532.54 MWh of energy from 2022 to 2031. In terms of monetary units, the distribution utility can accumulate Php 14,620,462.32 of savings within the same period. Alternative 2 is attainable and justifiable since the computed value of the Benefit/Cost ratio is greater than 1.

5. RECOMMENDATION

For future works, the researchers recommend using power flow analysis software to segregate the technical loss from the system loss to attain a more accurate result. For future improvements, consider computing the transformer loss, secondary line loss, and service drop, which also contribute to the technical loss.

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