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Cost Benefit Analysis for Electrical Loading Management for Transformers of a Barangay

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Abstract: - The study assessed the cost and benefit of electrical loading management of transformers. There is a serious occurrence of over and under loaded transformer which deeply affects the power quality or system loss and reliability of the distribution lines. Initially, the percent loading of the 27 transformers of Feeder 21 were identified using Microsoft Excel 2016. Then the identified transformers were classified to overload (greater than 70%), under loaded (less than 40%) and normal loaded (40-70%). Through this process, 3 solutions were identified: Solution I is changing the rating of transformer while Solution II is merging, and transferring of loads of transformer and Solution III is combining solution I and II. The three-solution used to identify the new percent loading to meet the normal percent loading (40-69%). Subsequently, the reduced Core and Copper Losses, Annual Energy Save, Savings and Benefit/Cost Ratio were computed and analyzed to determine the impact of loading management. The results shows that there was savings of Php 332,060.08 for Solution I, Php 92,043.09 for Solution II and Php 252,045.78 for Solution III. In the case of Benefit/Cost ratio should be greater than 1 (>1) for a project to be economically feasible and justifiable, for Solution I was 1.22, Solution II was 687.3 and 1.93 for Solution III. Based on the results of the study, Solution III was best among the three for it has met the criteria of all transformers were all in normal loaded (40-70%) condition, and greater than 1 benefit/cost ratio.

Key Words: — *Transformer, Amorphous, Cost Benefit.*

I. INTRODUCTION

Transformers are important part in the distribution system for delivering electricity for utilization. In today's modern world, uninterrupted usage of electricity is vital in all operations of a certain consumer. With the great demand of electricity, electrical loading conditions of the transformer were greatly affected by it, especially in the midst of the lockdowns that have happen.

For uninterruptible supply of electricity, loading conditions of transformer must be taken into account.

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For a transformer operating on an overloaded condition, not only the useful life is affected but also the electrical loss such as copper loss it can produce. In the same way in an underloaded condition, transformer usage is not maximized while the core loss it contributes [1].

Loading conditions of a transformer may be classified to [2]:

- Under loaded - Less than 40% percent loading
- Normal loaded - 40% to 70% percent loading
- Over loaded - greater than 70% loading

For an electric utility it is important to consider the loading condition of the transformer to operate and able to reach its useful life of 30 years [2-3]. Not only the useful life of the transformer but also the loss it can contribute. In this new era of technology amorphous core transformer makes its way in reducing the loss [4-5]. As seen in table 1 the comparison of the loss of a steel core and amorphous core transformer [6-7].

Table 1: Losses in the Transformer

KVA Rating	Steel Core		Amorphous Core	
	No-Load Losses	Full load Losses	No-Load Losses	Full load Losses
	kW (Coil)	kW (Copper)	kW (Coil)	kW (Copper)
10	0.058	0.18	0.012	0.12
15	0.077	0.215	0.015	0.195
25	0.108	0.295	0.018	0.29
37.5	0.153	0.4	0.03	0.36
50	0.167	0.49	0.032	0.5
75	0.275	0.7	0.045	0.65
100	0.44	0.9	0.05	0.85

Electrical loading management of transformer is a process that can minimize the cost of installation of transformer that can lead to reduction of electrical loss and improvement of the service in electric connectivity for the consumer. To achieve a normal loading condition, uprating or down rating may be done and merging or transferring of loading may also perform [8-9].

Every action taken for improvement of a service may have a financial aspect to be consider. Even in the case of loading management an amount of money is also be taken into account.

The loading condition of the transformer may provide a benefit or can interrupt the service of electricity [10]. Attaining the normal loading condition of a transformer for a continuous connectivity of electricity may require financial investment to be able to attain. With this, cost benefit analysis of the percent loading for transformer is needed.

The objective of the study is to assess the electrical loading of the transformer connected in a barangay. To classify the transformer to under loaded, normal loaded and overloaded. To determine the energy it can saved, the saving it can generate, cost and benefit of the solution to attain the normal loading of transformer.

This study will help in careful selection of solution in maintain the normal loading condition of transformer. Also, it can be an aid in monitoring of the transformer losses in can contribute in the distribution system.

The study will assess 27 transformers of a barangay with 2000 consumer. The study will implement the loading condition of underload or less than 40% loading, normal loaded or 40% - 70% loading, overload or greater 70%, and the residential power factor is 0.85. Three solutions were performed in the study: Solution 1: Changing a higher rating transformer for the overloaded transformers and a lower rating DT for underloaded transformer by Amorphous Core Transformers, Solution 2: Merging or Transferring of loads for the transformers that are near to each other whether under-loaded or overloaded, Solution 3: Combination of Solution 1 and Solution 2. For the cost benefit analysis, the interest rate will be 12% and the number of years of transformer is 30 years [11].

II. METHODOLOGY

2.1 Data Collection and Instrument

In Figure 1, shows the conceptual frame work of the study. The data needed in the study are the kVA rating of all the transformer connected in the distribution system. Also, the energy consumption per consumer per transformer from 2017-2020.

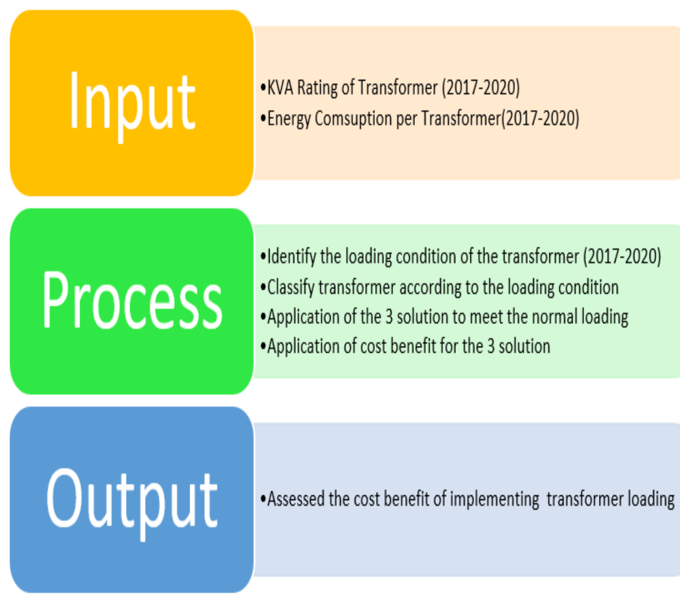

Fig.1. Conceptual Framework of the Study

2.2 Analysis of data in identifying the loading Condition of the transformer

The energy consumption and the kVA rating of the transformer will be used in determining the loading of the transformer (January 2017 – December 2019) using Microsoft Excel 365 applying the precent loading formula set by National Electrification Administration (NEA) System Loss Reduction Manual [2].

$$\% \, Loading = \frac{\text{kWhrDemand(month)}}{(\text{KVA}_{\text{TR}})\ (\text{PF})\ (720\text{H})} \quad (1)$$

When the percent loadings were determined, the transformer will be classified into:

- Under load – less than 40% percent loading
- Normal Load – 40% to 70% percent loading
- Over load – greater than 70% loading

2.3 Solution for the Loading Condition

After the classification of loading were identified. The three solutions in attaining the normal condition will be applied as follows:

- Changing a higher rating transformer for the overloaded transformers and a lower rating DT for underloaded transformer by Amorphous Core Transformers.
- Merging or transferring of loads for the transformers that are near to each other whether under-loaded or overloaded.
- By combining I and II.

2.4 Cost Benefit Analysis

After the three solutions were performed, the annual saving will be computed using the formulas [2]:

$$CoreLosses \frac{kWhr}{year} = (kWcore)(8760H) \quad (2)$$

$$Copper\ (Cu\ )Losses\ (kWhr)/year$$
$$= (kW\ @\ 100\%\ load)\ (\%\ loading)^2 (8760H) \quad (3)$$

$$\text{Annual Savings} = Annual\ Energy\ Save\ x \frac{Php}{kWhr} \quad (4)$$

Also, the cost benefit ratio of each solution will be determined using the formula [11]:

$$\text{AC} = \text{PW}\left[\frac{\text{i}(1+\text{i})^{\text{n}}}{(1+\text{i})^{\text{n}} - 1}\right] \quad (5)$$

$$\text{B/C} = \frac{\text{Annual Savings}}{\text{AC}} \quad (6)$$

For the best solution the B/C must be greater than 1

III. Results and Discussion

3.1 Loading Condition of Transformers

As seen in table 2, the loading conditions of the transformer were presented. Out of the 27-transformer installed, there are 10 underloaded transformer and 11 were overloaded from the 2017 to 2020.

Table 2: Loading Conditions of Transformers

Transformer Code	Rating (KVA)	Loading	Classification
T01	37.5	23.48	Underload
T02	75	14.73	Underload
T03	37.5	84.65	Overload
T04	75	11.59	Underload
T05	50	76.8	Overload
T06	75	18.8	Underload
T07	75	28.63	Underload
T08	25	52.86	Normal Load
T09	37.5	96.43	Overload
T10	37.5	48.02	Normal Load
T11	50	63.33	Normal Load
T12	50	64.44	Normal Load
T13	37.5	76.4	Overload
T14	75	29.32	Underload
T15	25	35.91	Underload
T16	25	31.16	Underload
T17	25	87.2	Overload
T18	15	92.15	Overload
T19	25	5.14	Underload
T20	15	99.1	Overload
T21	50	45.81	Normal Load
T22	50	45.56	Normal Load
T23	25	29.2	Underload
T24	25	73.7	Overload
T25	50	89.24	Overload
T26	50	93.23	Overload
T27	50	72.87	Overload

3.2 Solution to attain Normal Loading

B.1. Changing a higher rating transformer for the overloaded transformers and a lower rating DT for underloaded transformer by Amorphous Core Transformers.

The new rating of the overload and underload were seen in table 3. Using the uprating and downrating of amorphous core transformer the normal loading is now attain.

Table.3. New kVA rating and Loading using Amorphous Core

Transformer Code	New KVA Rating	New Loading
T01	15	58.70
T02	25	44.18
T03	50	63.48
T04	15	57.97
T05	75	51.20
T06	25	56.40
T07	37.5	57.26
T09	75	48.22
T13	50	57.30
T14	37.5	58.64
T15	15	59.85
T16	15	51.94
T17	37.5	58.14
T18	25	55.29
T19	10	12.86
T20	25	59.46
T23	15	48.66
T24	37.5	49.14
T25	75	59.49
T26	75	62.16
T27	75	48.58

B.2 Merging or Transferring of loads for the transformers that are near to each other whether under-loaded or overloaded.

For the solution 2, transferring or merging of load were possible to the transformer that are near to each other. In table 4 shows the transformer that are able to transfer or merge. Even some of the transformer can be merge there are some of the overload and underload transformer were not able to applied as shown in table 5.

Table.4. New loading condition using transferring or merging of Loads

Transformer Code	kVA Rating	Old Loading	New Loading
T01	37.5	23.48	11.74
T02	75	14.73	14.73
T03	37.5	84.65	42.32
Use T02			**68.79**
T04	75	11.59	11.59
T05	50	76.80	51.52
Use T04			**63.11**
T06	75	18.80	18.80
T07	75	28.63	28.63
Use T06			**47.43**
T14	75	29.32	29.32
T15	25	35.91	11.97
T16	25	31.16	10.39
Use T14			**51.68**
T18	15	92.15	55.24
T19	25	5.14	5.14
Use T19			**60.38**
T22	50	45.56	45.56
T23	25	29.20	14.65
Use T22			**60.21**

Table.5. List of transformers that were not able to use transfer or merge

Transformer Code	kVA Rating	Old Loading
T09	37.5	96.43
T13	37.5	76.40
T17	25	87.20
T20	15	99.10
T24	25	73.70
T25	50	89.24
T26	50	93.23
T27	50	72.87

B.3 Combining I and II.

By combining the Solution, I and II, the new loading and rating were presented in table 6 and 7. The list of the transformer that were not able to address the loading condition by uprating or downrating of the transformer to meet the normal loading.

Table.6. New loading condition using transferring or merging of Loads

Transformer Code	kVA Rating	Old Loading	New Loading
T01	37.5	23.48	11.74
T02	75	14.73	14.73
T03	37.5	84.65	42.32
Use T02			**68.79**
T04	75	11.59	11.59
T05	50	76.80	51.52
Use T04			**63.11**
T06	75	18.80	18.80
T07	75	28.63	28.63
Use T06			**47.43**
T14	75	29.32	29.32
T15	25	35.91	11.97
T16	25	31.16	10.39
Use T14			**51.68**
T18	15	92.15	55.24
T19	25	5.14	5.14
Use T19			**60.38**
T22	50	45.56	45.56
T23	25	29.20	14.65
Use T22			**60.21**

Table.7. New kVA rating and Loading using Amorphous Core

Transformer Code	New kVA Rating	New Loading
T09	75	48.22
T13	50	57.30
T17	37.5	58.14
T20	25	59.46
T24	37.5	49.14
T25	75	59.49
T26	75	62.16
T27	75	48.58

3.3 Cost of Solution I, II and III

C.1. Changing a higher rating transformer for the overloaded transformers and a lower rating DT for underloaded transformer by Amorphous Core Transformers.

In table 9, the price of each kVA rating of transformer were shown as set by the National Electrification Administration (NEA).

Table.9. Pricelist of Amorphous Core

Amorphous Core (kVA)	Price (Php)
10	58,000
15	69,000
25	83,000
37.5	102,500
50	119,800
75	161,750
100	185,000

Table 10 shows the amount of the cost in applying uprating or downrating using amorphous core transformer. The 21 transformers with underload and overload condition were change to attain the normal loading conditions. By doing this solution an amount of PHP 2,193,350 is needed.

Table.10. Cost of using Amorphous Core

Rating(kVA)	Quantity	Price	Cost
10	1	58,000	58,000
15	5	69,000	345,000
25	4	83,000	332,000
37.5	4	102,500	410,000
50	2	119,800	239,600
75	5	161,750	808,750
Total			**PHP 2,193,350**

C.2 Merging or Transferring of loads for the transformers that are near to each other whether under-loaded or overloaded.

By merging or transferring of loads, transformer ratings were just retained, and the needed equipment is a #2 ACSR to tap the loadings. The cost of the solution 2 is 1,080 Php as seen in the solution below:

#2 ACSR = 30 Php/meter

Length = 3 meters per tapping point x 2 wire x 6 tapping points
Wire Cost = 30 x 6 x 2 x3
Wire Cost = 1080 Php

C.3 Combining I and II.

The cost of applying solution three were shown in table 11, as seen in the solution below the total amount of Php 1,055, 880 is needed to meet the normal loading conditions.

Table.11. Cost of using Amorphous Core

Rating	Quantity	Price	Cost
25	1	83,000	83,000
37.5	2	102,500	205,000
50	1	119,800	119,800
75	4	161,750	647,000
Total			**PHP 1,054,800**

#2 ACSR = 30 Php/meter
Length = 3 meters per tapping point x 2 wire x 6 tapping points
Wire Cost = 30 x 6 x 2 x3
Wire Cost = 1080 Php

Total Cost = 1,054,800 + 1080 = Php 1, 055, 880

3.4 Cost Benefit Analysis

D.1. Changing a higher rating transformer for the overloaded transformers and a lower rating DT for underloaded transformer by Amorphous Core Transformers.

In table 12 and 13 shows the core and copper losses that can be saved using the amorphous core transformer. Not only that the loading condition was met but also in terms of reduction of losses is acquired.

Table.12. Core Loss Saved using Solution 1

Loading	Old Core Loss	New Core Loss	Difference
Underload	17169.6	1603.08	15566.52
Overload	13113.72	3372.6	9741.12
Total Core Loss Saved			**25307.64**

Table.13. Copper Loss Saved using Solution 1

Loading	Old Copper Loss	New Copper Loss	Difference
Underload	2466.60	6080.00	-3613.40
Overload	26591.87	15080.11	11511.77
Total Copper Loss Save			**7898.37**

Table 14 shows the total energy saved using solution 1, at a rate of 10 Php/kWh rate, the total saving it can generate is Php 332,060.08. For the Cost benefit ratio of solution 1, it was 1.22.

Table.14. Total Energy Saved and Savings in Php of Solution 1

Energy Saved	kWh
Core Loss	25307.64
Copper Loss	7898.37
Total	33206.01
Rate	10Php/kWh
PHP Savings	**Php 332,060.08**

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

$$AC = 2193350\left[\frac{0.12(1+.12)^{30}}{(1+.12)^{30} - 1}\right]$$

$$AC = 272290.49$$

$$B/C \; = \frac{\text{Annual Savings}}{AC} = \frac{332060.08}{272290.49}$$

$$B/C \; = 1.22$$

D.2 Merging or Transferring of loads for the transformers that are near to each other whether under-loaded or overloaded.

In table 15 and 16 shows the core and copper losses that can be saved using merging or transferring of load.

Table.15. Core Loss Saved using Solution 2

Core Loss	kWh
Old	31746.24
New	21681
Total Core Loss Save	10065.24

Table.16. Copper Loss Saved using Solution 2

Loading	Old Copper Loss
Old	29949.29
New	30810.22
Total Copper Loss Save	-860.93

Table 17 represents the total energy saved using solution II, at a rate of 10 Php/kWh rate, the total saving it can generate is Php 92, 043.09. For the Cost benefit ratio of solution 2, it was 687.30.

Table.17. Total Energy Saved and Savings in Php of Solution 2

Energy Saved	kWh
Core Loss	10065.24
Copper Loss	-860.93
Total	9204.31
Rate	10Php/kWh
PHP Savings	**Php 92,043.09**

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

$$\mathbf{AC} = 1080\left[\frac{0.12(1+.12)^{30}}{(1+.12)^{30} - 1}\right]$$

$$AC = 133.92$$

$$B/C = \frac{\text{Annual Savings}}{AC} = \frac{92043.09}{133.92}$$

$$B/C = 687.30$$

D. 3. Combining I and II.

For the solution three, the core and copper loss that can be saved were shown in table 18 and 19.

Table 18: Core Loss Saved using Solution 3

Solution	I	II
Core Loss	kWh	kWh
Old	9636	29949.29
New	2540.4	30810.22
Total Core Loss Save	7095.6	-860.93
Total Core Loss Save Solution 3		**6234.67**

Table.19. Copper Loss Saved using Solution 3

Solution	I	II
Copper Loss	kWh	kWh
Old	19950.37	31746.24
New	11045.70	21681.00
Total Copper Loss Save	8904.67	10065.24
Total Copper Loss Save Solution 3		**18969.91**

Table 20 represents the total energy saved using solution 3, at a rate of 10 Php/kWh rate, the total saving it can generate is Php 252, 045.78. For the Cost benefit ratio of solution 3, it was 1.93.

Table.20. Total Energy Saved and Savings in Php of Solution 3

Energy Saved	kWh
Core Loss	6,234.67
Copper Loss	18969.91
Total	25204.58
Rate	10Php/kWh
PHP Savings	**Php 252, 045.78**

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

$$AC = 1055880\left[\frac{0.12(1+.12)^{30}}{(1+.12)^{30} - 1}\right]$$

$$AC = 130929.12$$

$$B/C = \frac{\text{Annual Savings}}{AC} = \frac{252045.78}{130929.12}$$

$$B/C = 1.93$$

IV. SUMMARY

As shown in table 21, the cost, savings and cost benefit analysis were shown. Solution 1 and 3 were the highest in cost but in terms of the savings they also the highest. But in terms of the cost benefit analysis solution 2 is the highest compare with the two.

Table.21. Summary of cost, savings and cost benefit ratio for the solutions

Solution	**Cost**	**Savings**	**Cost Benefit Ratio**
1	PHP 2,193,350.00	PHP 332,060.08	1.22
2	PHP 1,080.00	PHP 92,043.09	687.30
3	PHP 1,055,880.00	PHP 252,045.78	1.93

V. Conclusion

From 2017-2020, the transformer connected 21 out of 27 were classified as under load and over load. From 21 transformer, 10 of which are underloaded and 11 were identified as overloaded. Applying three (3) solution to solve this loading condition to meet the normal loading. Solution 1 shows a great advantage in terms of savings and cost benefit analysis it meets the required value of greater than 1 but in terms of cost it has the highest. Solution 2 possess the best solution due to its lowest cost and higher value of cost benefit but there are some transformer loadings were not corrected. While solution 3 overcome the negative of solution 2 and solution 1, it has a lower cost compare to solution 1 and it has addressed the need loading correction for the transformer that were not able to merge. Compare to solution 1, solution cost benefit analysis is higher.

Recommendations:

For future works, the researchers recommend the use of load forecasting to identify how long the transformer will become overload and underload. Also, proper load monitor for the additional consumer that will be added for the transformer.

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