Substation Transformer Replacement Plan

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Abstract

About half of the Gainesville Regional Utilities (GRU) substation transformers are above their industry usage limit standard of 45 years and are prone to catastrophic failure. This study critical health data was captured using an asset management software, called Cascade. The health of each power transformers was measured by multiple criteria such as gassing, hazard factor, age, customer count, percent of loading, switch ability, priority customer factor and fault count. These factors were combined and weighted using a Risk Priority Numbers (RPN) that provided a total risk of failure value. From a total of 52 power transformers, the utility found as a result 32 power transformers with high risk of failure. Energy Supply manage 18 of those transformers and Energy Delivery manage 14 of those transformers. It was recommended and planned to start developing the engineering and procurement process to replace these transformers based on the risk priority and the operations configuration of the system.

Introduction

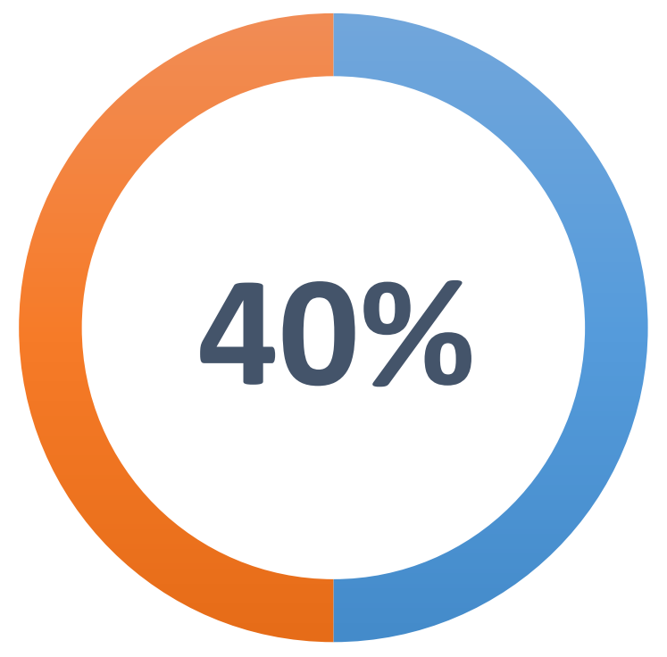
Substation Power Transformers are one of the most important and costliest assets in the power grid. The principal function of a transformer is to transform voltage levels. Currently, the level of reliability required of electricity companies causes a high degree of functional characteristics information of their equipment, particularly their transformers [1]. About half of the Gainesville Regional Utilities (GRU) substation transformers are above their industry usage limit standard of 45 years and are prone to catastrophic failure. The failure of the lone transformer at a substation, or failure of multiple transformers at substations could be devastating. These types of failure events have the potential to result in substantial and extended customer load interruption, as well as adverse environmental and safety outcomes. The economic implications involving the operation of equipment failures are complex; hence, electric grid assets are considered critical, then the integrity of each one of its components must ensure. This integrity can be achieved by implementing new technologies for monitoring and evaluating their performance [2].

Background

GRU aims to achieve asset management ISO 55000 certification by managing assets to deliver the best business value to its customers. The asset management program minimizes expenditures to keep pressure off customer prices; however, cost reduction must be balanced against critical network performance objectives. GRU's asset management objectives are broken into safety, regulatory compliance, environmental, economic, and customer service. GRU owns and operates 52 power transformers on its system distributed to 15 substations. About fifty-five percent (55%) of the power transformers are within the GRU age limits of 40 years or within the following ten years will reach way above the life expectancy per industry standard. The oldest transformer that GRU maintains was installed in the Kelly plant in 1963, now 58 years old. GRU currently has 52 transformers that either serve load or are generator step-ups in 15 substations to serve its 104,000 customers.

Problem

GRU has a total of 52 substation transformers. From that total, 21 transformers already are over the life expectancy of 45 years. In addition, 12 of those 21 transformers are equal/over 50 years plus of being in service. In addition to age, another critical factor is risk, which is a combination of factors described above. Cascade categorizes the risk based on multiple formulas and a predictive failure analysis algorithm. Ownership of the high-risk power transformer fleet is divided between Energy Supply and Energy Delivery departments. Currently, Energy Supply has most of the power transformers with high risk and over their useful life.



Transformers
Over 45 years

Methodology

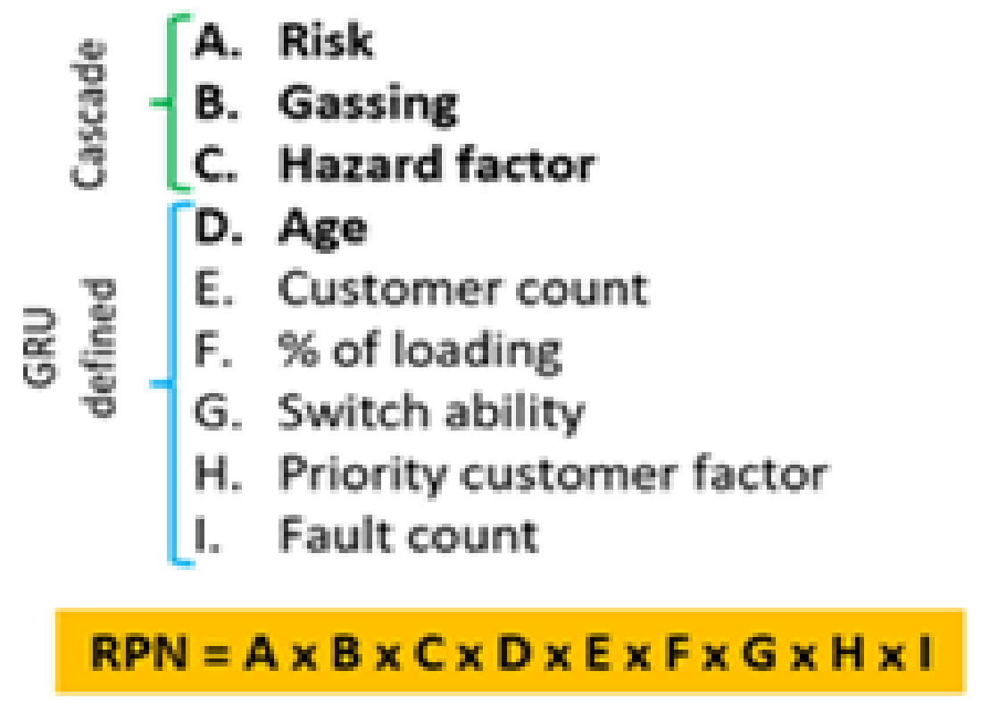
The proposed replacement program is a continuation of an existing risk-based replacement for the asset replacement management plan strategy (ARMP). This replacement program is a continuation of a current condition-based replacement strategy for substation transformers. The replacement of substation transformers is required due to the degradation of materials, components, and performance over their service life. If left to degrade, substation transformers will eventually fail in-service, potentially leading to an extended interruption of customer load and finally leading to catastrophic failure (with associated negative safety and environmental consequences). In general, the degradation of substation transformers results from the expected electrical and mechanical aging incurred during the regular operation of the transformers over a long period. Table 1 breakdown more in detail the types of failures that are evaluated at the time of power transformer failures. In addition, these internal and external factors are what it is tried to be avoided by performing preventive asset maintenance. However, some other factors also contribute to the need for replacement:

Table 1
Typical Causes of Transformer Failures

Internal	Insulation deterioration Loss of winding clamping Overheating Oxygen Moisture Contamination in the insulating oil Partial discharge
External	Design and manufacture Winding resonance Lightning strikes System switching operations System overload System faults (short circuit)

Results and Discussion

GRU has been capturing all transformer maintenance data in the Asset Management Software, Cascade since 2013 This data includes 75 equipment from 55 transformers and 20 LTC, 36 procedures and 914 inspection forms, 569 triggers points, 1,545 preventative, and 1,093 corrective maintenance work orders. The maintenance data provides valuable information about the transformer's risk status in Cascade, which is the multiplication of their criticality and health number. Individual transformer's criticality was found from their dissolve gas and fluid quality results, power factor testing, oil temperature, bushing, and cooling fan condition. Health is substation specific. The following formula calculates the risk priority numbers (RPN) of the individual transformer. The risk, gassing, hazard, and age have a high weight in RPN calculations to transformer’s status ranking, as shown in Figure 2.

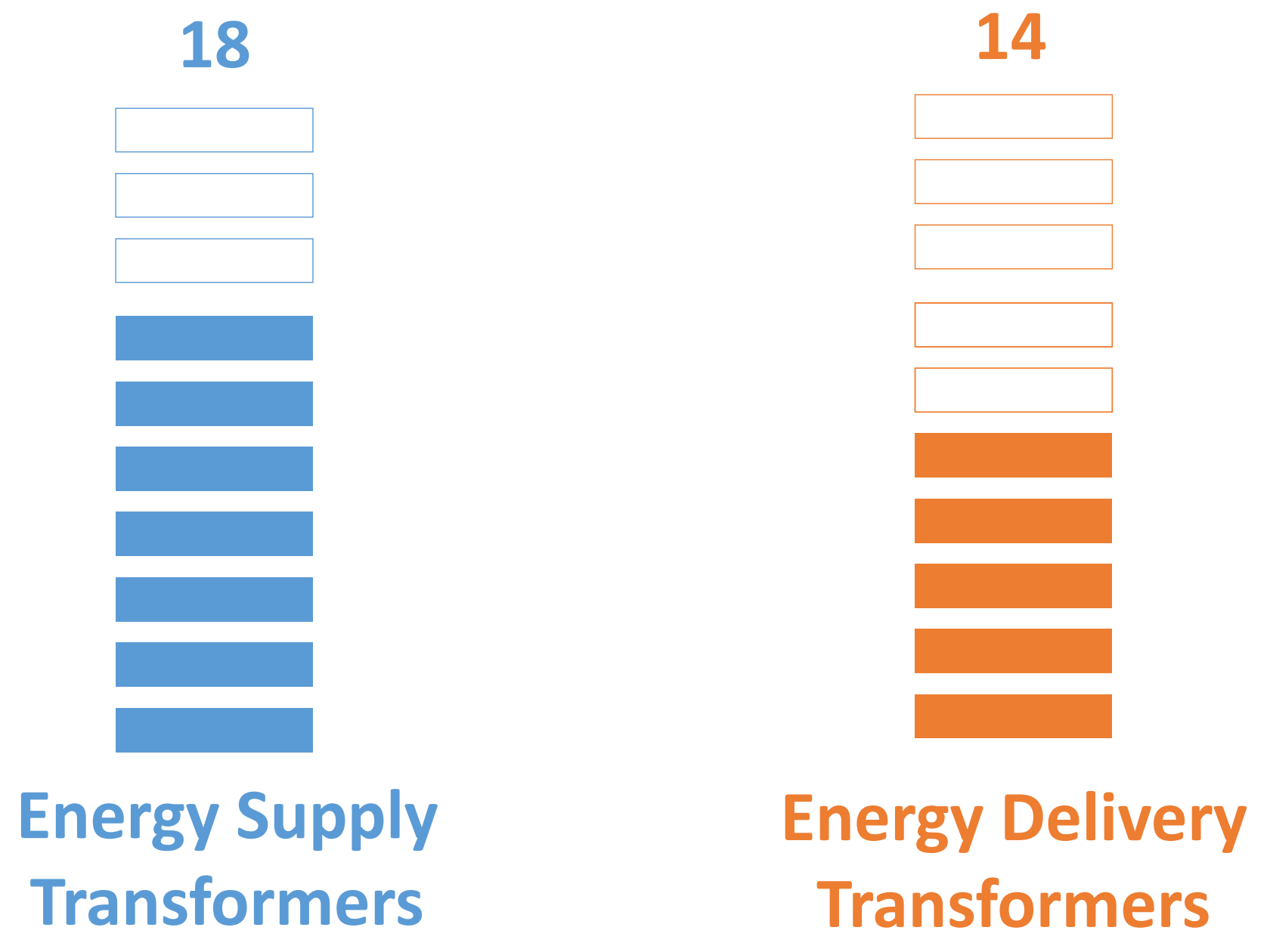


- A. **Risk**
- B. **Gassing**
- C. **Hazard factor**
- D. **Age**
- E. Customer count
- F. % of loading
- G. Switch ability
- H. Priority customer factor
- I. Fault count

RPN = A x B x C x D x E x F x G x H x I

Risk Priority Configuration

In addition to age, another critical factor is risk, which is a combination of factors described above. Cascade categorizes the risk based on multiple formulas and a predictive failure analysis algorithm. Ownership of the high-risk power transformer fleet is divided between Energy Supply and Energy Delivery departments. Currently, Energy Supply has most of the power transformers with high risk and over their useful life. The power transformers that need to be replaced are broken down below per department.



The decision to replace these legacy power transformers will provide ultimate technical and economic benefit to GRU. The Capital Improvement Project (CIP) costs at the final period are **$28,283,065.10**; IRR is **216**%, MIRR is **60**%, Profitability Index (PI) is **7.69**, and Payback [Breakeven] is in the 1st year after each annual investment. However, the Payback[Breakeven] will be in the 4th year if the onset of investment is considered. This financial data is only based on the 14 power transformers of Energy Delivery. Power transformers owned by Energy Supply have different configurations and potentially additional costs. It is important to mention these transformer replacements improve the reliability and resiliency of the substations, hence, would strengthen GRU's municipal revenue bonds.

Conclusions

Maintenance and inspection data, Cascade Software algorithm, and engineering analysis have shown that a substantial amount of GRU power transformers' health is at risk of failure and no longer meets industry standards. The transformers' status represents a high risk to the asset management strategy of GRU. The repair and rebuilding of the aged transformers is not practical considering their current status and finances. The probability of their catastrophic failure is high and repairing these transformers is not realistic. Any outage on one of these transformers will force an outage to thousands of customers for a period of up to 12-18 months. The only viable alternative is to continuously replace all of the power transformers recommended in this report. Completing the replacement will also address reliability concerns by avoiding potentially catastrophic damage to other equipment within the substations. Based on the engineering analysis, it is recommended that it is cost-effective to replace all 14 high-risk Energy Delivery power transformers with new transformers. It is crucial to take advantage of this time to plan and procure accordingly to replace these transformers and standardize a maximum of only two transformer manufacturers, which will be more cost-effective and productive to maintain.

The power transformers replacement plan is presented in the report.

Future Work

The Planning team recommends prioritizing these projects to be completed within the next 5 years before it becomes an emergency. The new transformers would allow the substation team to focus its ongoing maintenance program with other equipment on the system to improve the system's reliability of the GRU electrical grid. In addition, continue monitoring the health and risk of the transformers with less than 25 years, to be proactive with the maintenance and future replacement initiatives.

Acknowledgements

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References

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