Life Cycle Costing Study on Power Distribution Plant at Melaka

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ABSTRACT

As a strategic financial tool, Life Cycle Costing (LCC) is used to calculate the total cost of owning a power distribution system, from time of initial purchase through disposal. This research paper attempts to understand LCC thru the lens of Tenaga Nasional Berhad Power Distribution. This study takes advantage of a complete research methodology, that of review of literature, analysis of case studies and development of a conceptual framework for LCC in power distribution. The LCC process examines event costs, including initial costs, operating expenses, maintenance costs, and end of life costs. Initial costs deal with the outlay of buying equipment, installation and commissioning are included in it as these form a substantial part of the investment and hence, they should be managed carefully so as to be cost effective. The operating costs include energy losses, maintenance, labour and daily operational costs. Assessment of equipment and operations can greatly reduce these costs over the life of the system. Maintenance costs also include scheduled and unscheduled work such as inspections, testing, upgrading, that may further stretch out the life of the system and improve reliability of the system if proactively managed. Decommissioning, disposal and recycling costs or end of life costs, include the impacts related to terminating use and disposition of the equipment, can be minimized with proper planning and planning, thereby lowering costs and minimizing environmental impacts. The ability of LCC to identify cost effective and sustainable solutions is due to its evaluation of system design, technology selection and operational strategies. It focuses on energy loss–reduction approaches, maintenance cost-saving initiatives and minimizing environmental consequences to support sustainable infrastructure development. Furthermore, LCC helps support strategic decision making by providing comparisons between different types of investment, for example how long-term benefits, such as the provision of novel technologies like smart grids, compare against traditional technologies. This ensures that value over time is maximized, i.e. solutions are selected that allow the best value to be delivered over time. Even though LCC has many benefits, there are drawbacks as well. These include the need to gather precise and thorough data, project future expenses, and choose proper discount rates. Furthermore, the study may be impacted by unknowns pertaining to legislative changes and technology improvements. Decision makers need to make sure that LCC analyses are based on trustworthy data sources, updated often, and modified for evolving conditions to meet these concerns. Through this approach, electricity distribution systems may be planned, designed, and operated to maximize long-term sustainability, cost-effectiveness, and

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dependability. The finding of this research contributes to the body of knowledge on maintenance strategy deployment by highlighting the life cycle cost methodologies in a complementary manner. The research outcomes show the costing budget for the initial cost, operational cost and also the maintenance cost. It also can know which part or component that spend more money for maintenance that can be improvise those causes.

INTRODUCTION

Life cycle costing is the process of economic analysis that assesses the total cost of investment in and ownership and operation of the system or product to which the life cycle costing analysis is being applied. This procedure converts the operational limitations and functional criteria that apply to the system or product into a single cost measurement called life cycle cost. In turn, life cycle cost, or LCC, is defined as the overall cost of the system or product being studied throughout the course of its whole life, or the length of the research period, whichever is shorter. Hence, the life cycle of an asset that is tangible starts at the time of consideration for acquisition and concludes when it is ultimately removed from service for disposal or redistribution, marking the start of a new life cycle. All cash flows that take place throughout the course of the asset's life constitute the cost aspects of interest. As can be seen from the preceding definition of LCC, the LCC of an asset is the total of all expenses incurred on it, from the time of purchase until its eventual disposal [Anandakumar et al 2020]. Though opinions on the specific identification of expenses vary, most people believe that all expenditures should be included. A mathematical formula that represents the cost of an item or activity as a function of one or more independent variables is known as a cost estimation relationship.

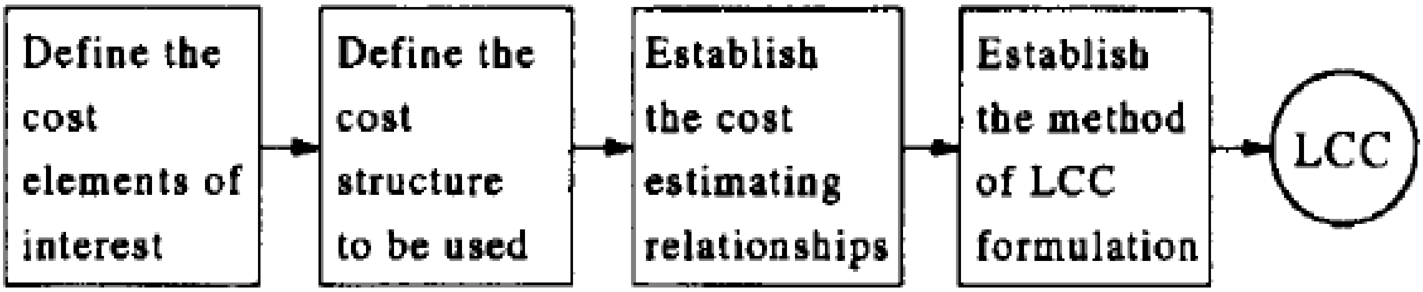

Figure 1. Harvey's Life Cycle Costing Procedure

Operation & Maintenance Costing

Usually, operation can be categories into three operating procedures which are standard, alternate, and emergency. Standard operating procedures is regular operations are performed to make sure the system is operating as intended while alternate operating procedures utilized when there isn't a regular operation of the system. The tasks that keep the assets in excellent operating order so they can perform as intended are referred to as maintenance. Maintenance can be categorized into many types such as routine or planned maintenance, predictive maintenance, preventive maintenance, and corrective maintenance. Routine or planned maintenance is planned out and executed using a calendar or basic schedule such as every month or every certain hour of run time. The preventive, run-to-failure, or predictive maintenance strategies which allow for the possibility of scheduling corrective maintenance are the foundation for this maintenance. Predictive maintenance is condition monitoring that used to forecast the possibility of asset failure [Jin, L et al 2017]. Predictive maintenance can be simple and affordable in some situations. In others, it could be quite expensive and complicated. Preventive maintenance carried out to keep everything in working order and prevent degradation. It is accomplished according to the asset's state and capacity to deliver the required level of service while it is still operational. Meanwhile, the corrective maintenance done after an asset or equipment has failed. Cost models involving general costs consists on mathematical formulations (but not exactly the same) of the type presented in Equation 1, where CT represents total maintenance cost, CA is appraisal cost, CP is preventive maintenance cost and CF is corrective maintenance cost [Saha, & Mollah (2021)].

$$C_T = C_P + C_A + C_F$$

Equation 1: Total Maintenance Calculation

Repair Cost

Repair can be defined as activity taken to repair or restore an item to its pre-damaged state after failure. When deciding whether to replace, repair, rehab, or leave a deteriorating asset alone, there are a lot of things to consider. Determining whether a repair is a good option will involve considering factors like asset risk, cost of repair options, whether the repair will provide sufficient additional asset life, whether the underlying asset has enough structural integrity left to be repaired, and whether the asset is already scheduled for future replacement. The goal of repair work is to return an asset to its pre-damage state, but improvement of the item is not anticipated. The malfunctioning asset is fixed so that it may work properly again. Instead, then replacing an old asset with a new one that staff members might not be acquainted with, especially if the material or kind of asset has changed in any way, repairing an existing asset allows the same, recognizable item to continue performing [Teixeira & Filho (2017)]

Replacement & Disposal Cost

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Replacement can be defined as replacement of an existing asset in its entirety when its useful life is coming to an end. This decision is influenced by a few factors, including the relative costs of replacement, rehabilitation, and repair the useful life of the replaced asset compared to that of the asset with repair and rehabilitation the necessity of preventing high risk events, replacing an asset without structural integrity to allow for rehabilitation or repair; and coordination with other asset replacement [Mirhosseini & Keynia(2021)]. An asset must be decommissioned, recycled, or disposed of when it is replaced or has reached the end of its useful life. Most decommissioned assets are abandoned in place, which means they are no longer in service but are still in their original position. Some assets can be recycled but if an asset has more life left in it, it may also be sold or given to another organization that could find use for it.

METHODOLOGY

The approach to studying LCC in power distribution is designed to provide a comprehensive analysis that supports decision-making aimed at maximizing both environmental and economic performance. This methodology section outlines the systematic process for conducting an in depth LCC analysis in the power distribution sector. It begins by defining the scope of the study and identifying the key components and stages of power distribution systems to be examined. The next steps include data collection, cost categorization, and the development of a robust analytical model. This process integrates various data sources and expert insights, meticulously calibrated to ensure accuracy and reliability. By adopting this structured and detailed approach, the research aims to deliver valuable insights to stakeholders, enabling them to make more strategic and informed decisions regarding the management of power distribution systems [Ustun & Goksen (2018)].

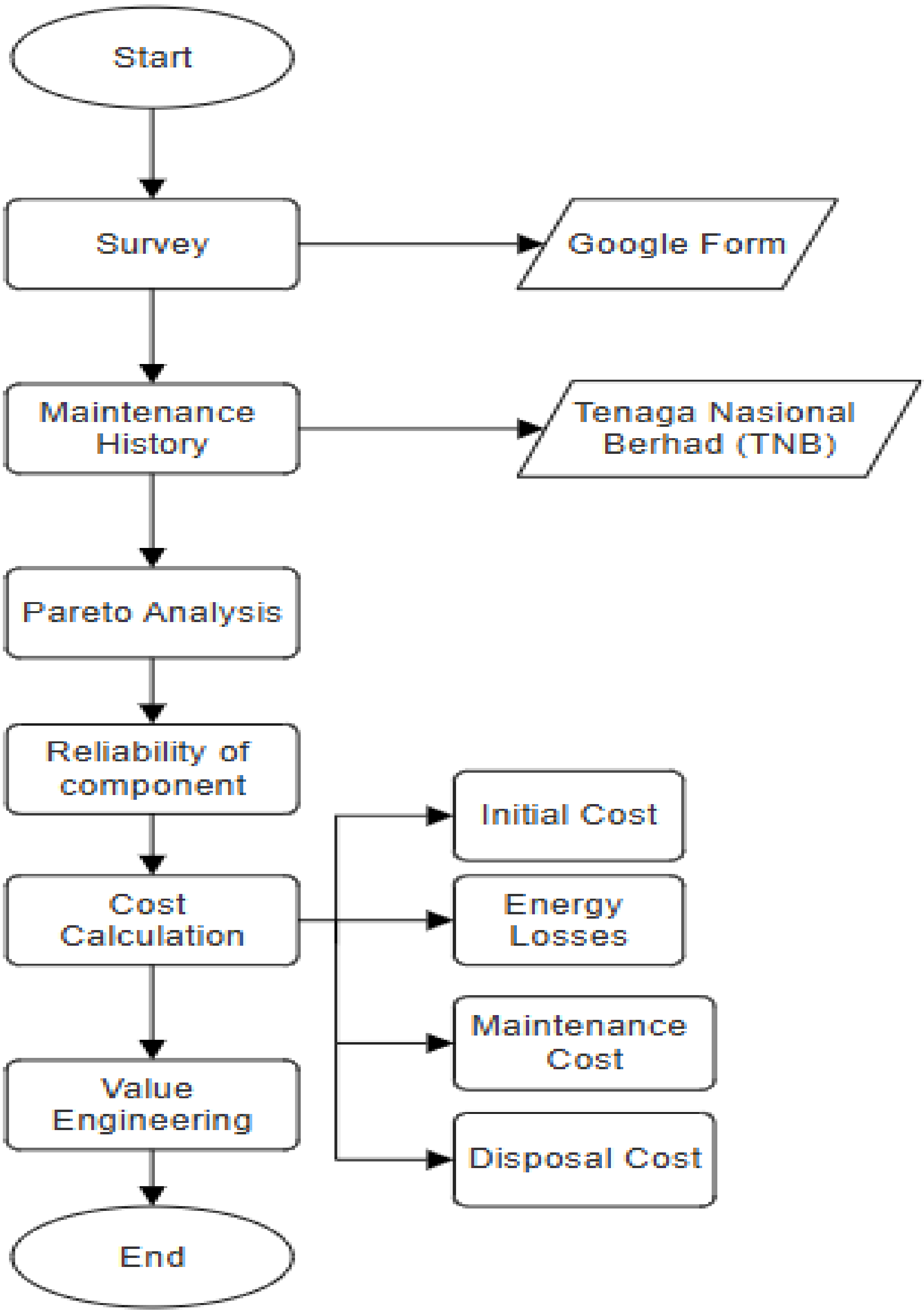

Figure 2 Flow Chart of Methodology

Maintenance History

To conduct a detailed life cycle costing (LCC) analysis for power distribution using historical data from Tenaga Nasional Berhad (TNB), a comprehensive approach to data collection is essential. These sources provide insights into the defect component that must diagnostic and troubleshoot in the substation area. There were 17 components such as busbar, bushing, cable sealing end, cap bank, circuit breaker, connector or clamp, current transformer, CVT or IVT, earth switch, earthing system, earthing transformer, flybus, LER or NER, reactor, surge arrester and VT. This data covers associated labour and material expenses as well as the frequency of routine inspections, small repairs, cleaning, and lubrication of equipment such distribution lines, transformers, and switchgear. The preventive maintenance schedule of TNB provides information on scheduled maintenance actions that are intended to avert equipment breakdowns. Examples of these activities include condition-based maintenance that is triggered by monitoring systems and the replacement of wear-prone components. This data details the two major components that have high frequency of preventive measures.

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Table 1. Preventive Maintenance Action

Component	Type of Preventive Maintenance Activities
Circuit Breaker	1. Change oil in compressor. 2. Monitoring leakage and top up oil in compressor. 3. Monitor leakage and top up SF6 in insulating medium. 4. Monitor leakage and top up oil in oil insulating medium.
Transformer	1. Monitor leakage and take scheduled outage to change the bushing LV. 2. Monitor leakage and take scheduled outage to repair the leaks in bushing Tertiary/Neutral 3. Monitor leakage and top up oil in cable box. 4. Monitor leakage and top up oil in conservator/Main tank/Cable box. 5. Monitor leakage and top up oil and take scheduled outage to repair the leaks in Radiator/Valves 6. Check oil quality in the insulating oil. 7. Monitor leakage and take scheduled outage to repair in the HV bushing.

Data on corrective maintenance, gathered from incident reports and emergency repair records, provides valuable insights into the costs associated with equipment failures and unplanned outages. This information includes details about the type and cause of malfunctions, response times, and the expenses for labor, materials, and additional equipment needed for repairs. It also highlights the key components that frequently require corrective actions, offering a clearer understanding of areas that demand attention.

Cross referencing maintenance data from various TNB sources, such as maintenance logs, financial reports, and operational records, is essential for ensuring accuracy and reliability. Integrating this data into a centralized database or maintenance management system allows for efficient analysis and monitoring. Regular updates to the system ensure that the Life Cycle Cost (LCC) analysis reflects current maintenance practices and costs accurately. By leveraging TNB's extensive archive of maintenance data, the LCC analysis can provide valuable insights into the strengths and weaknesses of different maintenance strategies. This helps optimize maintenance plans, improve equipment reliability, and reduce the overall life cycle costs of the power distribution system.

Pareto Analysis

The 80/20 rule, often demonstrated through a Pareto chart analysis, reveals that a small number of issues typically account for the majority of challenges. For example, it may show that a few failure modes are responsible for most system outages or that 20% of equipment types contribute to 80% of maintenance costs. This insight allows for the development of a targeted action plan that focuses on addressing the most critical problems first. Key strategies to improve service quality and reliability might include increasing preventative maintenance for vital components, upgrading or replacing frequently failing equipment, implementing energy saving measures, and resolving common customer complaints. Accurate and comprehensive data collection is fundamental to leveraging Pareto Analysis for enhancing power distribution systems. The process begins with gathering extensive data on factors influencing system performance, such as the frequency and duration of outages, maintenance costs, energy losses in the network, and equipment failures that impact service quality. Sources for this data might include historical maintenance logs, incident reports, energy audits, and customer service records. By organizing this information into categories like equipment failures, maintenance challenges, operational inefficiencies, and service quality concerns, critical areas of focus can be identified. This structured approach enables informed decision making to improve overall system performance and customer.

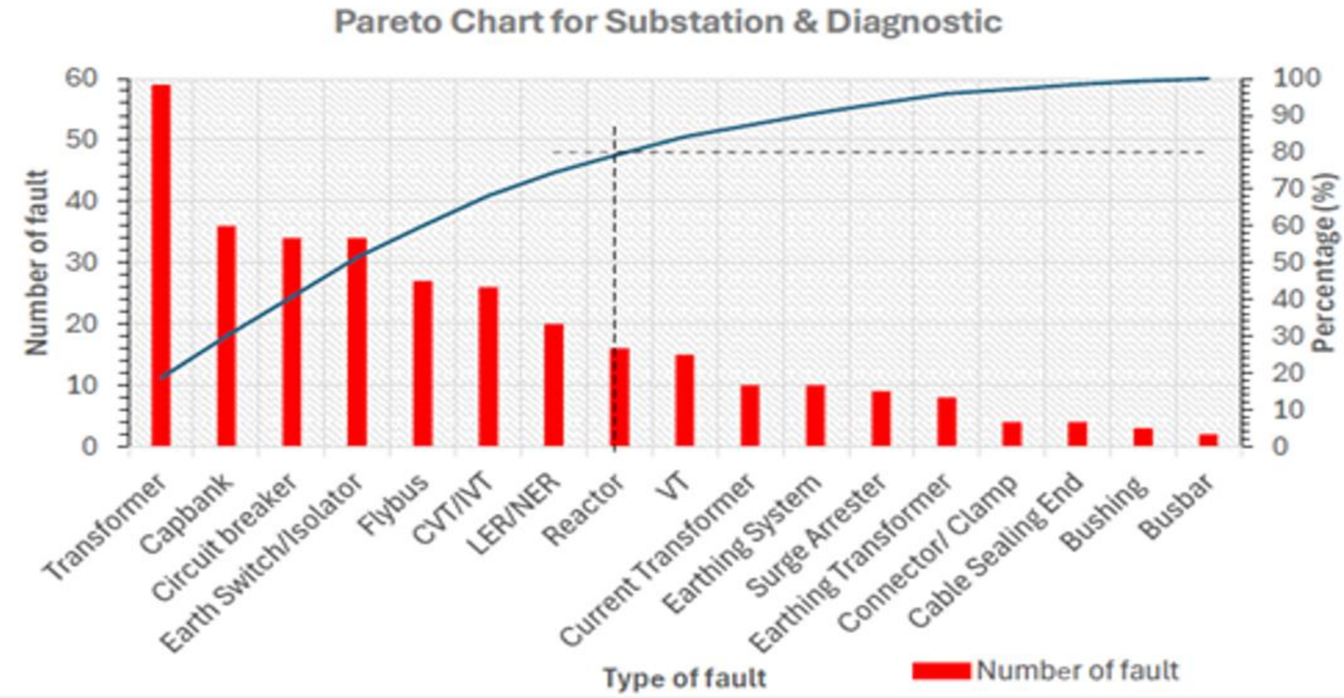

Figure 3. Pareto Chart for Substation & Diagnostic

Utilities like TNB can enhance system reliability, reduce costs, and improve customer satisfaction by using Pareto Analysis to focus on the most critical issues in power distribution. This systematic approach ensures that resources are allocated effectively, maximizing overall benefits.

Life Cycle Costing

A key first step in conducting a Life Cycle Costing (LCC) analysis for power distribution systems is identifying all relevant costs. This involves systematically cataloging expenses across every stage of the system's lifecycle, including design, construction, operation, maintenance, and disposal. Capital expenditures, incurred during the initial development phase, cover equipment purchases, installation costs, and engineering and design fees. Operational expenses arise throughout the system's lifespan and include costs for personnel, energy procurement, maintenance, and administrative overhead. End of life costs account for decommissioning, disposal, or replacement of old components, such as equipment disposal fees or costs for replacing outdated parts [Zhao et al (2024)]. Additionally, risk and contingency expenses are factored in to address uncertainties and unexpected events, like emergency repairs or insurance premiums. By thoroughly identifying these costs, the LCC analysis provides a comprehensive view of the financial requirements over the system's entire lifecycle. From the pareto analysis that had done, first two of the equipment were chosen to analyze the life cycle costing. The costing that involves analyzing start from initial acquisition costs, operating cost, maintenance costs that involve, overhaul costs and initial spares cost that involve.

RESULT

Data Collection

For this research, data collection involved quantitative collection of information from multiple sources which included manufacturer specifications, industry databases, historical operational records and survey. The data was collected to determine the effect of differences in each of the cost components of power distribution transformers matters throughout their life cycle. The primary data sources used for this study are as follows:

- ❖ Manufacturer Specifications: Capital expenditure, installation, and commissioning data were obtained from manufacturer datasheets as well as cost records.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VI June 2026

- Operational Records: Data from historical use of utility companies was used to get insights into routine maintenance, corrective maintenance, failure rates and energy efficiency.

- Industry Databases: Industry databases and publications were used to retrieve information regarding industry benchmarks and transformer efficiency losses.

- Google Form Survey: Data was collected using Google Forms survey tool to gather insights from industry professionals and serve as a validation of the data and to provide an in depth understanding of practical aspects around transformer maintenance and disposal at the end of its life.

Multiple sources were cross referenced and peer reviewed industry benchmarks were leveraged to ensure data reliability. The collected data was then further broken down into different cost items to be analyzed. The data was verified against industry standards and expert opinion to ensure it had been accurate. The data was compiled into a comprehensive dataset and life cycle cost for each component was calculated. Tables from the Google survey were used as data visualization tools to effectively compare the percentage contributions of corrective, predictive, and preventive maintenance to the total life cycle cost of power distribution transformers and thus to enable more insight by comparing the elements of the cost, for optimization.

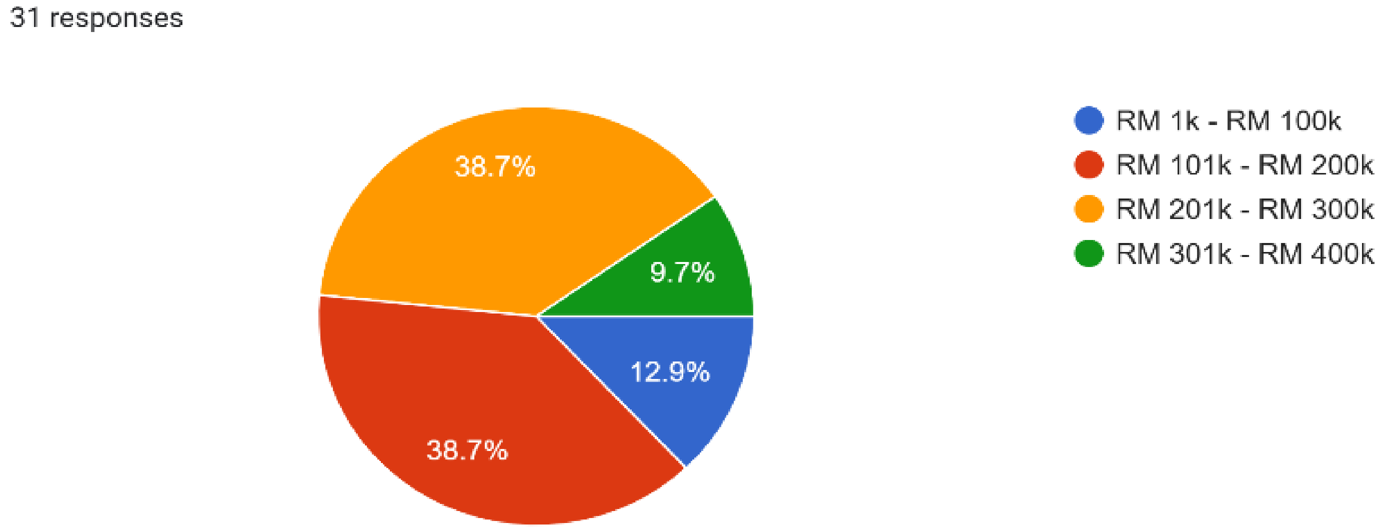

Figure 4. Survey Outcome on Corrective Maintenance Cost of Transformer for 1 year (including labor, material, testing and other cost)

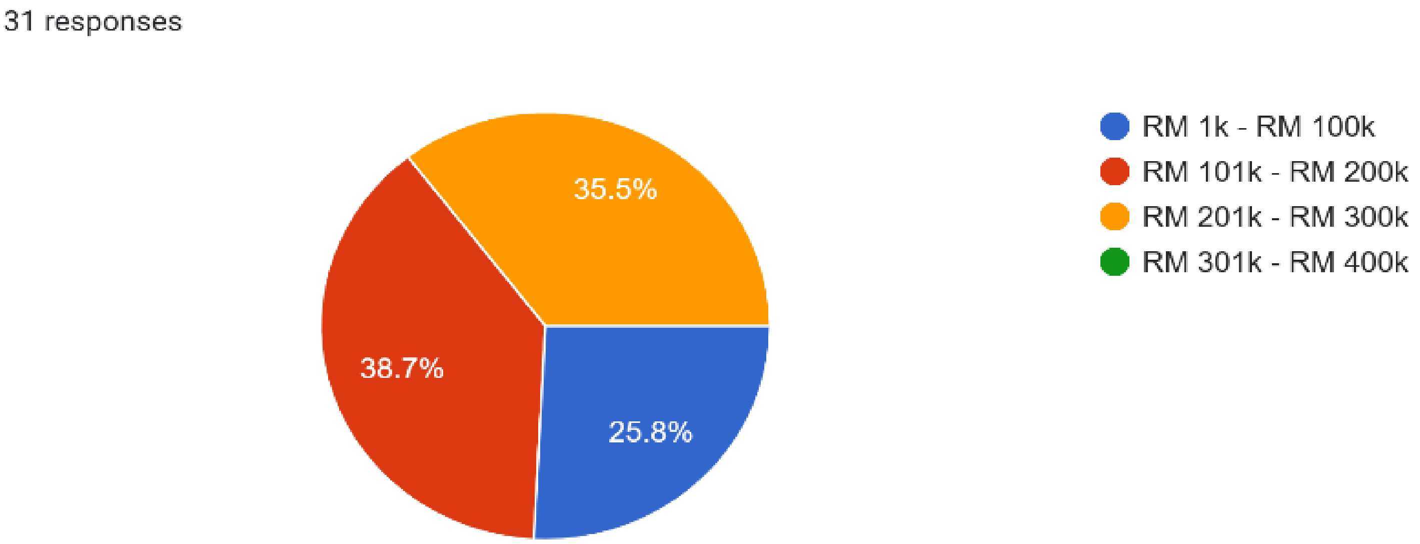

Figure 5. Survey Outcome on Preventive Maintenance Cost of Transformer for 1 year (including labor, material, testing and other cost)

Initial Cost Purchase

There are other things that come with the initial cost of a 132KV power distribution transformer that go beyond the base purchase price. The additional costs consist of transportation, installation, accessories, tax, civil works, and test and commissioning. These costs are to be understood to properly estimate the financial sanction to deploy a 132kV transformer and do a thorough Life Cycle costing (LCC). The initial procurement and installation of a 132 kV transformer are comprised of the following cost components, organized according to the **Table 2** below:

Table 2 Initial Cost Breakdown of a 132kv Power Distribution Transformer

Components	Cost Component Estimated Cost (MYR)
Transformer Base Cost	1,200,000
Transportation	90,000
Installation	180,000
Accessories and Auxiliaries	120,000
Taxes and Duties	180,000
Civil Works	90,000
Testing and Commissioning	42,000
Total Initial Cost	1,902,000

Corrective Maintenance

Corrective maintenance is action that is carried to restore equipment or systems after some failure has occurred. Corrective maintenance for power distribution transformers, mostly at 132KV and above in high load conditions, has an important role in the reliability of service and continuous service. This is a type of maintenance for which it is impossible, or at least

difficult, to predict or prevent through routine inspections and preventive maintenance. This section analyses the estimation corrective maintenance cost of power distribution transformers, with a detailed review of the failures occurred from 2004 to 2023. The following Table shows the corrective costs by failure type including the material, labour and downtime cost from 2004 to 2023.

Table 3 Estimated Cost for Corrective Maintenance for Transformer

Year	Failure Type	Estimated Cost (RM)
2007	Tap Changer	87,165
2010	Bushings	58,110
2011	Windings Insulation	145,170
2013	Tap Changer	69,642
2015	Tap Changer, Bushings	174,330
2016	Windings	116,220
2017	Tap Changer, Other Components	104,598
2018	Bushings, Windings	127,842

Preventive Maintenance

Proactive approach to preventing the failure of a 132kV power distribution transformer is the preventive maintenance of a 132kV power distribution transformer Scheduled inspections, testing, cleaning and minor repairs to identify potential problems before they become critical problems is all it involves. The key activities in visual inspections are for any visible signs of damage or wear, oil testing for insulation or cooling property issues, as well as bushing inspection to see that the components are functioning as they should. Thermography is also used to identify hot spots; partial discharge testing measures the condition of the insulation. Keeping the tap changer regularly maintained will allow it to run smoothly, and keeping the cooling system cleaned will keep

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the transformer from overheating which can shorten the lifespan of the transformer. Testing protection systems to verify they are working correct is another aspect of preventive maintenance.

Table 4 Estimated Preventive Maintenance Cost of Transformer

Year	Preventive Maintenance Activities	Estimated Cost (RM)
2014	Checking tightness of connections, cleaning	6,742.16
2015	Early inspection and testing of seals and contacts	13,493.92
2016	Regular monitoring of DGA and thermal conditions	13,502.58
2017	Auxiliary systems and cooling performance checks	11,259.27
2018	Enhanced diagnostics for bushing and core	13,429.35
2019	Periodic testing of transformer core and load	17,928.18
2020	Detailed oil analysis, contact wear assessments	17,952.52
2021	Periodic core remanence and auxiliary systems	20,226.91
2022	Early tap changer lubrication and oil testing	15,797.23
2023	Major diagnostics for end-of-life planning	20,249.45

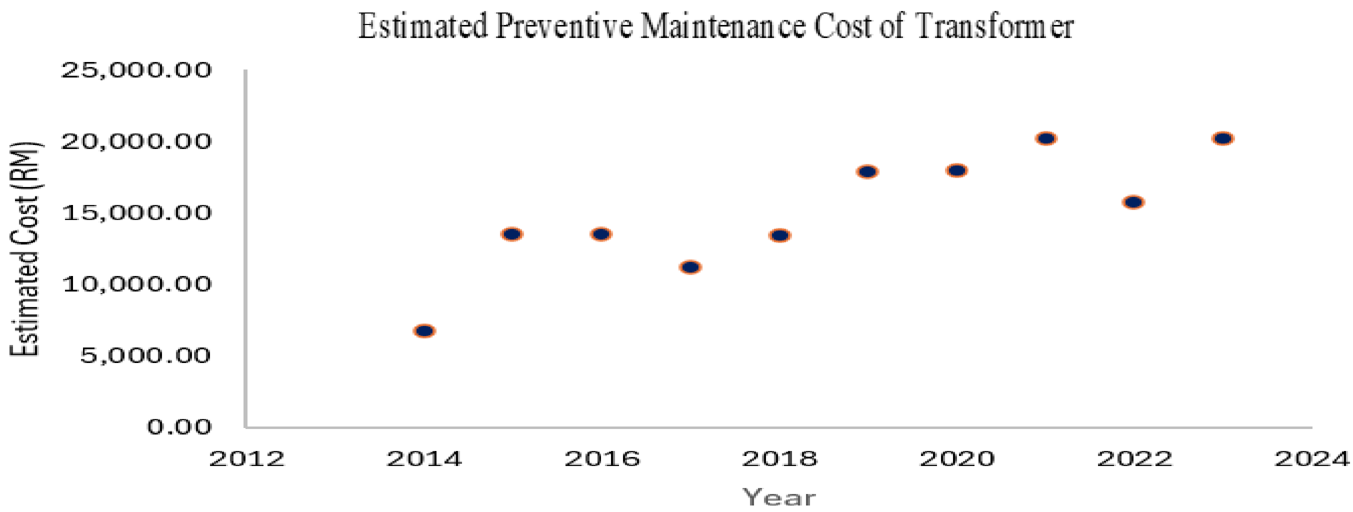

Figure 6. Estimated Preventive Maintenance Cost of Transformer between 2012 to 2024

Decommissioning Costs

The final stage of a transformer's service life in which it is decommissioned, is a series of activities aimed at safely removing a transformer from service and readying it for disposal or recycling. Usually, the first step to the decommissioning process is the disconnecting of the transformer from the electrical grid. Disconnection of the transformer involves shutting down the transformer to cut off electrical supply, and taking necessary safety measures to process decommissioning in order to exclude any risk of electric shock as well as system fault during discharge process. These tasks involve a high incidence of labour costs such as skilled personnel, such as electrical engineers and technicians, are required. The disconnection process is a heavy duty labour intensive process that requires specialized tools and equipment. From the survey the estimation of decommissioning cost depends on factors such as size, location and complexity of removal. Most of the surveyor select the range of cost between RM 20,000 to RM 30,000.

CONCLUSION

This study conducted a comprehensive evaluation of the Life Cycle Costing (LCC) of Power Distribution Systems, focusing on critical components like transformers, capacitor banks, and circuit breakers within Tenaga Nasional Berhad's (TNB) infrastructure. The research analyzed costs across the entire lifecycle, from initial procurement to operational expenses, maintenance strategies, and decommissioning, to provide insights into the financial management of power distribution assets. Findings revealed that transformers, particularly tap changers

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and bushings, account for a significant share of lifecycle costs due to frequent failures and high maintenance demands. Additionally, capacitor banks and circuit breakers were identified as key contributors to operational and corrective maintenance costs, highlighting areas requiring improvement. Pareto analysis demonstrated that a small number of components are responsible for the majority of issues, emphasizing the importance of allocating resources to these critical areas. While initial investment in predictive maintenance strategies is required, the study found them effective in reducing unexpected failures and extending the service life of essential equipment, resulting in long term economic benefits. It also integrated energy loss assessments into the LCC framework, demonstrating how proper capacitor placement minimizes reactive power losses, enhancing cost efficiency and reducing environmental impact. The research concludes that a structured LCC approach effectively leverages data to improve reliability, sustainability, and economic efficiency in power distribution systems.

REFERENCES

1. Anandakumar, M. G., & Varughese, K. T. (2020). Infrastructural Asset Management and Maintenance of System Health in Power Sector Utilities: An Overview. Power Research, CPRI, 16(1), 79.
2. Jin, L., Zhang, H., & Liu, H. (2017). Life cycle cost evaluation and optimization of capacitor bank systems in power distribution networks. IEEE Transactions on Power Delivery, 32(4), 1592-1600.
3. Mirhosseini, M., & Keynia, F. (2021). Asset management and maintenance programming for power distribution systems: A review. In IET Generation, Transmission and Distribution,Vol. 15, Issue 16, pp. 2287–2297). John Wiley and Sons Inc.
4. Saha, S. K., & Mollah, M. N. (2021). Life cycle cost analysis of distribution transformer selection in a power system. Energy, 214, 118691.
5. Teixeira, J., & Filho, M. (2017). Life cycle cost optimization of power transformers in an electrical distribution system. Renewable and Sustainable Energy Reviews, 78, 1337- 1345.
6. Turconi, R., Simonsen, C. G., Byriel, I. P., & Astrup, T. (2014). Life cycle assessment of the Danish electricity distribution network. The International Journal of Life Cycle Assessment, 19(1), 100–108.
7. Ustun, H., & Goksen, G. (2018). Analysis of life cycle cost and environmental impact of circuit breakers in power distribution networks. Environmental Impact Assessment Review, 71, 1-9.
8. Zhao, X., Gui, F., Chen, H., Fan, L., & Pan, P. (2024). Life Cycle Cost Estimation and Analysis of Transformers Based on Failure Rate. Applied Sciences, 14(3), 1210.