Life-Cycle-Cost Considerations for Power Transformer Components - Trade-Off Calculation for Judgement of Design Alternatives

Konrad Roider

Maschinenfabrik Reinhausen GmbH,

Falkensteinstr. 8, 93059 Regensburg, Germany

k.roider@reinhausen.com

***Abstract*— Life-cycle costs of a product comprise purchase price as well as utilisation costs. While for office equipment, like printers and copy machines, there are various approaches to the so-called "total cost of ownership", the Life-Cycle-Cost calculation for equipment like power transformers is extremely complex - last but not least due to the long transformer lifetime of 30 years and more. This is the reason why purchase decisions for power transformers are still based on the purchase price only and why utilisation costs are often neglected. Nowadays, with innovative transformer components available, the comparison of transformer design alternatives can provide surprising results with regard to the cost optimum over the lifetime.**

I. Introduction

Innovative technologies applied in key components of power transformers can lead to a drastic reduction in maintenance requirements and thus to a considerable reduction of costs occurring during the future service over the lifetime of a transformer. Reduced maintenance requirements minimize shutdown times and thus improve transformer availability. This aspect is of particular importance to highly loaded systems and to systems without redundancy.

The application of new and innovative components in new transformers will be quite easy if they are cheaper substitutes to the standard components used so far. If innovative components only have a marginally higher purchase price than standard components, however, they are unlikely to be chosen by the transformer industry. Under the prevailing circumstances, this is a fully understandable situation.

Modern asset management organisations, however, have to meet the challenge of keeping or even increasing supply quality and – at the same time – reduce the internal costs. Asset management has to budget the costs of purchasing equipment as well as costs for operation, maintenance, repair and disposal of existing equipment. That is why asset managers are surely interested in the reduction of utilisation costs and need to know the cost-optimized solution.

II. Life-Cycle-Costs

A. General

Life-cycle costs (LCC) mean the cumulative costs of a product from its design to its disposal. According to DIN IEC 60300-3-3, the phases of a product life comprise conception, design and manufacturing as well as commissioning, operation maintenance and disposal [1].

Purchase costs, depending on the individual contract, may include commissioning costs and are usually known before a purchase decision is made. The remaining cost blocks represent the so-called utilisation costs, which often represent a main part of the LCC and – in many cases – exceed the purchase price of a product [1]. However, since these costs are more difficult to predict, they are often neglected when equipment is purchased.

Furthermore, it is recognized that the LCC of a product can be tremendously influenced during a product's conception and design phase. Once a product is manufactured, however, improvements can only be achieved by additional investments. The LCC-optimized solution, which could have been achieved during product conception, cannot be reached through later measures.

B. Transformer LCC

The transformer LCC cover the costs for purchase and commissioning of the unit, as well as the transformer utilisation costs. The transformer utilisation costs include the losses of the transformer, all the efforts spent for inspections, routine maintenance and for repair measures. Furthermore, a stochastic cost component for unplanned outages and their rectification, based on the existing experience of a population needs to be taken into consideration [2]. Cost calculations for all above-mentioned items must cover all aspects, such as material costs, labour costs, costs for non-availability of equipment, as well as overhead costs of the organisation.

Finally, disposal costs must not be neglected. While for the transformer itself, these costs occur at the end of its lifetime only, for any maintenance or repair measure during the lifetime, disposal of smaller quantities may become necessary. Typical examples are the oil of the On-Load Tap-Changer (OLTC) and the desiccant (pellets) of the dehydrating breathers of OLTC and main tank. Table I shows a summary of the transformer utilisation cost components and how often they occur.

TABLE I
TRANSFORMER UTILISATION COST COMPONENTS

Item	**Cost component**	**Frequency**	**Comment**
1	Transformer losses - iron losses - copper losses	always	Load-dependent
2	Inspections	6 months to 2 years	No service interruption
3	Maintenance and / or testing and / or diagnostic measure	2 to 7 years	Interruption of transformer service
4	Repair measures (leakages, corrosion, etc.)	Condition dependent	Based on findings during inspections
5	Stochastic cost component for major repair or replacement	Calculated for complete transformer population, taking average lifetime into account as well.	
6	Disposal costs: - OLTC oil - Complete unit	7 years 30-40 years	

Vital design alternatives for power transformers can be determined by the selection of key components. With regard to the complexity of a complete transformer LCC calculation, it seems much easier to compare two different transformer design options and to suppress all other items that are unchanged. This is the principle of the so-called trade-off calculation. Fig. 1 shows a trade-off diagram according to Taylor [3] comparing two variants with different acquisition costs and different future expenses. By reconstructing all utilisation costs incurred over the lifetime of the transformer for two different key components and relating the detected costs with each other it becomes obvious which design alternative is the most economical one over the lifetime.

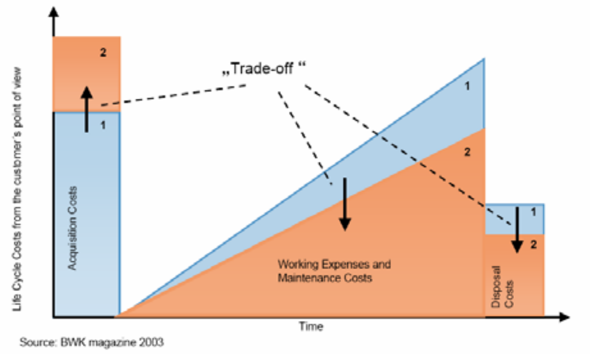

Fig. 1: “Trade-off” diagram

III. LCC COST COMPARISON

In the following, therefore the evaluation of the cost-optimized option for power transformers, based on the individual conditions of a transformer user, shall be demonstrated. For the calculation, On-Load Tap-Changers in conventional and in vacuum technology, as well as conventional and maintenance-free dehydrating breathers have been selected as examples.

A. On-Load Tap-Changer (OLTC)

The OLTC of a power transformer is needed to adjust the turn ratio of a power transformer under load. For decades, the standard OLTCs were equipped with arcing contacts, where under normal operating conditions, switching arcs occurred and resulted in an increased aging of OLTC oil and the involved OLTC components. These so-called OILTAP® OLTCs have proved to work reliably in the system. Typical maintenance intervals, of a maximum of 7 years service for such OILTAP® OLTCs, are accepted and established worldwide in users’ maintenance programs.

In contrast to conventional OLTCs with arcing contacts under oil, innovative VACUTAP® OLTCs (see Fig. 2) are equipped with vacuum interrupters and can do without maintenance time intervals. Preventive maintenance is due after 300,000 operations only.

Fig. 2: Photo of VACUTAP® diverter switch unit

Typical annual OLTC switching frequencies in transmission and distribution networks lie between 2,000 and 10,000 operations. With a transformer lifetime expectation of 30 years, it can be concluded that in almost all cases no maintenance job will become necessary throughout the transformer lifetime when using a VACUTAP® instead of an OILTAP® OLTC. In case maintenance becomes necessary, it will be a maximum of one maintenance job for a VACUTAP® in network application, compared to five or more maintenance jobs in case of OILTAP® OLTCs.

The future OLTC maintenance costs occur throughout the complete transformer life-cycle. In order to allow a comparison of two options by means of trade-off calculation for long-lasting capital equipment, such as power transformers, inflation and interest rate, must be considered. All cash values of future expenses must be referred to today's value, where the purchase decision is to be made. The following question must be answered: How much money do we have to put in a bank account today to enable us to pay all future OLTC maintenance expenses?

In order to answer this question, as a first step the costs of an individual maintenance job of an OILTAP® OLTC have to be determined. The essential cost blocks for such maintenance work are shown in Table II. The mentioned cash values in EUR shall serve as an example and were chosen conservatively for the majority of power supply companies.

TABLE II
OILTAP® OLTC MAINTENANCE COST CALCULATION

	Maintenance cost component		
	Item	**EUR Amount**	**Comment**
1	Maintenance material	400	Depends on OLTC type, age and no. of operations
2	Labour costs	1,800	Includes external service provider and own staff
3	Oil	1,200	Average 2 drums per maintenance including disposal of removed oil
4	Crane	300	If needed
5	Non-availability of transformer	500	Load dispatching, etc.
6	Administration and overhead costs	500	Staff training and qualification, warehouse, admin, etc.
	Total:	4,700	

Based on the total costs for one maintenance job of an OILTAP® OLTC of 4,700 EUR, an estimated transformer lifetime of 40 years, a maintenance frequency of 7 years, an interest rate of 5% and an inflation rate of 2%, a total amount of 13,320 EUR must be available now for payment of all future maintenance jobs.

If the compared design alternative, a VACUTAP® OLTC used with the power transformer, does not need maintenance, an additional amount of 13,320 EUR could be spent for this design alternative without increasing the total costs.

B. Dehydrating breathers

Conventional dehydrating breathers for the conservator of OLTC and transformer main tank consist of drying agent and a dust filter underneath. The dust filter is realized by means of an oil sump. Depending on the size of the breather, on the breathing activity of OLTC or main tank and on the outside atmospheric condition, the saturation of the drying will progress. Frequent inspections of the dehydrating breathers are necessary in order to either verify the good working condition or to indicate the need for replacement of the desiccant and for maintenance of the oil sump.

As an alternative to the aforementioned conventional breathers, there is a maintenance-free dehydrating breather available, the so-called Messko MTraB® (see Fig. 3). The MTraB® is equipped with a moisture sensor. Whenever the moisture content inside the breather compartment reaches a certain value, an automatic recycling process of the desiccant is initiated. Instead of the oil sump, the dust filter is realized by a sinter metal piece. Thus, the MTraB® does not require replacement of the desiccant or any other kind of additional maintenance.

Fig. 3: Photo of MTraB®, maintenance-free dehydrating breather

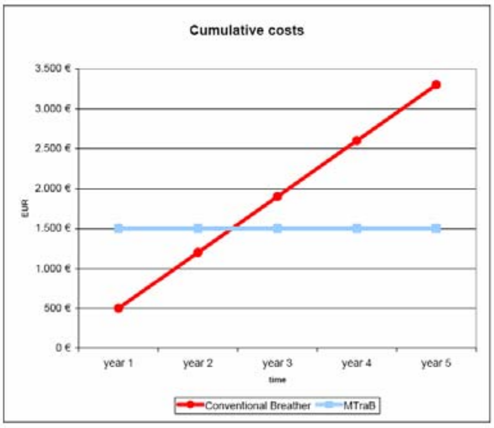

Fig. 4: Return on investment of MTraB®

Table III shows a comparison of costs and efforts to be spent in the case of a conventional and a maintenance-free dehydrating breather. Although these values may differ depending on an individual end-user's conditions, the values for this calculation were selected in a realistic dimension in order to serve as a typical example.

TABLE III
COMPARISON TABLE FOR DIFFERENT BREATHER OPTIONS

	Conventional breather		MTraB®
		Costs p.a.	
Changing intervals of the desiccant per year	4		N/A
Replacement costs for desiccant (4 kg x 4)	50 EUR	200 EUR	N/A
Annual maintenance time / h	4		N/A
Labour costs / h	50 EUR	200 EUR	
Miscellaneous costs (car, tools, travelling,..)		300 EUR	
Acquisition costs	500 EUR		1500 EUR
Annual costs		700	N/A

Based on Table III, a so-called return-on-investment calculation can be carried out. This calculation indicates after what length of time – based on the estimated costs – the MTraB® will return its investment. In the given example, this is the case after less than 2 years in service, where an additional investment of 1,000 EUR will have been compensated. Below, Fig. 4 shows the graph corresponding to the calculation input data.

IV. Conclusions

When it comes to the purchase price of a new transformer, using innovative transformer components is in some cases cost neutral; in other cases it increases the transformer price marginally compared with the total costs of the transformer.

A thorough comparison of transformer design variants by calculating the trade-off – or in the case of smaller items, the return on investment – with user-specific data, is a valuable support for the decision-making process.

Taking life-cycle-cost considerations as a basis for the decision on design variants rather than purely the minimum purchase price will help to avoid unnecessary expenses in the future and workload for future generations, as well as prevent waste of resources and, thus, contribute to a sustainable development of the power supply sector.

Acknowledgment

The author wishes to acknowledge Jürgen Schwarz, Dr. Siegfried Bauer, Klaus Hoepfl and Markus Stenzel for their cooperation in LCC project studies and, with it, for their contribution to this paper.

References

[1] DIN IEC 60300-3-3 "Zuverlässigkeitsmanagement (Dependability management)" Part 3*: Anwendungsleitfaden (Application guide),* Section 3: *Betrachtung der Lebenszykluskosten (Life cycle costing)*, p. 5, March 1999.

[2] W. B. Taylor, "The Use of Life Cycle Costing in Acquiring Physical Assets", *Long Range Planning*, vol. 14, paper 6, pp. 32 - 43, 1981.

[3] J. Bader, P. Müller, M. Lutz, H. Feld "Kostenoptimierung – Modell zur Berechnung der Kostenwirksamkeit von Investitionsprojekten," *Energiewirtschaft*, vol. 13, pp. 66-71, 2001.