A LIFE CYCLE ANALYSIS STUDY OF COMPETING MV CABLE MATERIALS

Simon Sutton
Dow Chemical Company Ltd, UK
sjsutton@dow.com

ABSTRACT

A simple life cycle cost model has been developed to investigate the total cost of ownership for three competing MV cable designs; XLPE, water tree retardant XLPE (TR-XLPE) and EPR. The retained electrical breakdown strength from field aged cables and information obtained during qualification testing is used to provide estimates of the likely cable life. Using the model a number of factors have been investigated including installation environment, losses and expected cable life. Under all the scenarios considered TR-XLPE has the lowest total cost of ownership.

INTRODUCTION

Life Cycle Cost (LCC) analysis allows companies to assess the total cost of ownership when making an investment decision. Undertaking such an analysis allows factors other than just the initial price of an item to be considered in a systematic manner, thereby providing a robust method of comparing competing technologies and options. In the specific case of utilities additional factors that may be included in the LCC analysis may include losses, estimates of maintenance/repair costs throughout the asset life or differences in asset life [1].

This paper will explore these issues through a comparison of medium voltage (MV) cables (without a radial metallic water barrier) made with different insulation materials, namely, XLPE, water tree retardant XLPE (TR-XLPE) and EPR. The variation in materials between these cable designs impacts the cable cost, dielectric losses and life expectancy, all of which affect the life cycle cost.

THE MODEL

A simple LCC model has been developed using MS Excel. Inputs to the model include:

- Cable and installation cost
- Expected cable life
- End of life criteria – earliest onset of unreliability, number of failures before replacement
- Cost of repairing a failure
- Losses – conductor, dielectric, sheath

To take account of variations in cable life, the model output is calculated over more than a single life cycle; over an extended period more end of life events are achieved for a cable with a shorter life compared to one with a much longer life. Figure 1 shows a theoretical comparison of the number of expected failures for two cable technologies with different life expectancies throughout an eighty year period. Both cable types are assumed to be installed in year 1 and both cables start to experience failures 5 years before the end of life and subsequent replacement with the same cable type. Here cable type A is replaced for the first time after 25 years of service and cable type B after 40 years. Over an eighty year period, a circuit comprising of cable type A has been replaced more often and has experienced more failures than a circuit comprising of cable type B.

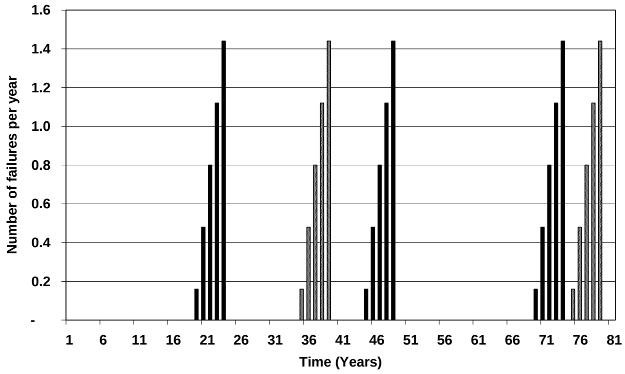

Figure 1: Number of failures experienced as a function of time for cables with different life expectancies: Cable A (solid bars), Cable B (stripped bars)

The increasing number of failures as the end of life is approached is an approximation to the upturn in the bath tub reliability curve. Within this simple model, burn in failures are assumed to be equally likely for all cable types considered here, since these are mainly caused by installation errors and are excluded from the calculations. Likewise failures throughout the life of the competing cable types caused by third party damage are independent of the cable type and are again excluded from the LCC analysis.

A factor is also included within the model to allow for the re-installation cost of a new circuit following the end of life of the existing circuit. For example, for cables in ducts, in year one the installation cost of cable and ducts would be considered but at the point of cable replacement, only the cables are considered since the ducts get reused.

The indirect financial consequences of failures such as loss of reputation, penalties from regulators or loss of revenue are not included in the model.

RESULTS

Cable Life

International standards and utility specifications allow asset owners to distinguish assets with acceptable performance from those which are unfit of purpose. MV cable standards, possibly uniquely, provide further information; at the end of an accelerated ageing test the cables are broken down providing the retained electrical strength. The standards require minimum breakdown strengths, which simplistically can be interpreted as a pass/fail criterion. However cable designs with consistently higher breakdown strength (than the minimum) tend to indicate materials which withstand the strict ageing conditions better and thus degrade less; in the field this is expected to provide for longer operating life.

Figure 2 shows breakdown data for a TR-XLPE insulated cable following European CENELEC HD 605 testing, with reference to CENELEC and more stringent German VDE (076-605/A3) performance requirements. For the test, six cables are subjected to two years of wet ageing before being broken down; more details of the testing can be found in [2]. This cable far exceeds the performance required by CENELEC and exceeds both German VDE Models.

An additional source of data that can be used to estimate cable life is field aged cables. Cables removed from service, eg. during diversion work, can be retained and subject to breakdown testing. Figure 3 shows such data for the three types of cable considered here [3, 4]. These data reflect the performance of cables under service conditions.

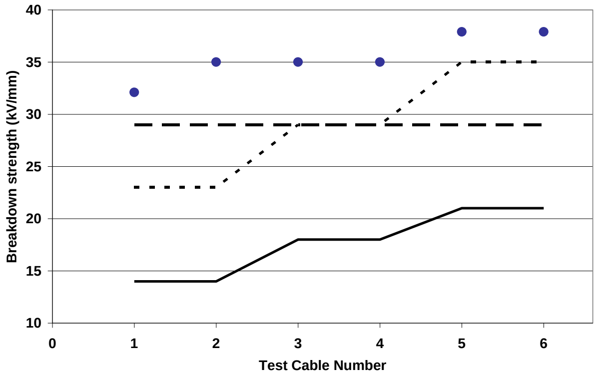

Figure 2: Set of breakdown results following two years of wet ageing according to the CENELEC protocol. Minimum pass level (solid line) and VDE options (dotted lines)

	XLPE	TR-XLPE	EPR
Conservative	25	40	40
Optimistic	30	50	45

Table 1: Cable lives scenarios used in the LCC analysis

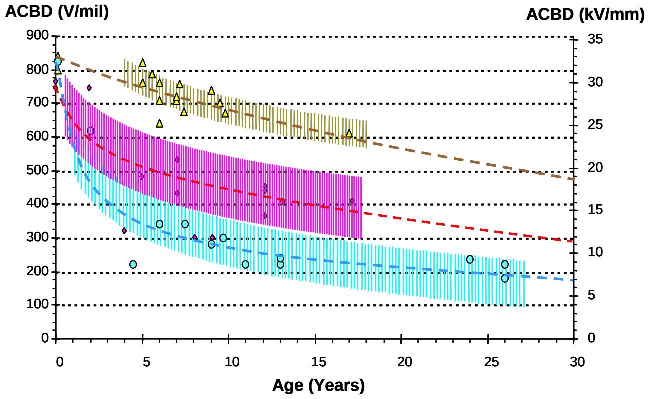

Figure 3: Reduction in breakdown strength as a function of years in service operation for XLPE (lower), EPR (middle) and TR-XLPE (upper)

Based on accelerated ageing tests and real world service data two sets of cable lives have been considered during the subsequent LCC analysis (Table 1); these can be considered a conservative and a more optimistic set of lives. Previously, work carried out by the Electric Power Research Institute (EPRI) concluded that cables made with either TR-XLPE and EPR should last in excess of 40 years [5].

It should be noted that cables made today are likely to be made from higher quality materials and have superior manufacturing control than those made 20 or more years ago. Hence assuming nothing else in the design changes it may be expected modern cables would last even longer under service conditions than those depicted in Figure 1.

Life Cycle Cost Analysis

Throughout the analysis all results have been normalised to the initial cost (€/m) of the cheapest cable (XLPE insulated). A 240 mm^2 25 kV cable design was chosen for the LCC analysis. The cost of dielectric losses has been calculated from the cable dimensions and properties of the different insulation materials. The dissipations factor (tan δ) of EPR varies considerably depending on the fillers used and the operation temperature of the cable; consequently, a typical value found in power cables of this voltage class and operating under moderate load conditions has been used.

The LCC of cables installed in rural and urban settings has also been considered. Installation costs vary depending on the precise ground conditions and ease with which cables can be installed. To simplify this issue, the installation cost has been referenced to the initial cable cost. For rural settings, where direct ploughing in of the cables is possible, the installation cost has been approximated as twice the cable cost, whereas a factor of five times has been used in an urban environment, such as a city centre. Since it isn't expected that the installation of any of the cable types would vary significantly in the same situation, all installation costs have been referenced to the XLPE cable cost.

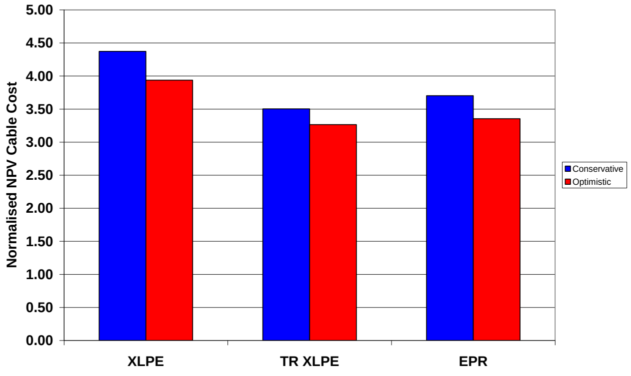

Figure 4: Normalised NPV life cycle costs calculated for the different life scenarios for all three MV cable insulations

Figure 4 shows the effect of modifying the lives of cables installed in a rural environment from the conservative to optimistic scenario (Table 1). Differences in initial cable costs and dielectric losses between the materials [6] have been factored into the result. Unsurprisingly as cable life is increased the LCC cost is reduced.

Utilities commonly cost the core losses in transformers, where the choice of metal can have a significant financial consequence throughout the life of the transformer [7]. However for cables it is much less common to take account of the conductor losses although these can amount to a significant fraction of the total life cycle costs [8].

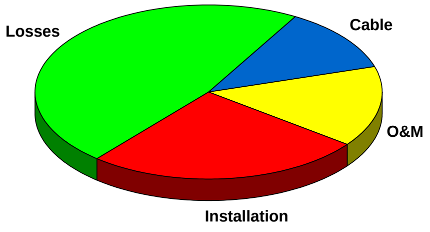

Figure 5: Pie chart showing breakdown of life cycle costs for a cable loaded to 75% maximum continuous load throughout its life installed in a rural environment

Figure 5 shows the breakdown of life cycle costs for a cable loaded to 75% maximum continuous load throughout its life installed in a rural environment. Almost 50% of the total is attributable to the conductor losses (the dielectric losses in comparison are very small). The financial impact of losses varies between utilities and depends ultimately on whom within the value chain pays for the losses [9].

Installation and re-installation accounts for roughly 25%, and 15% is associated with maintenance and the repair of failures as the end of life is approached on each successive life cycle. In this scenario, the actual cost of the cable only constitutes approximately 12% of the total life cycle cost. Within the cable segment less than 20% is attributable to the choice of insulation material [6].

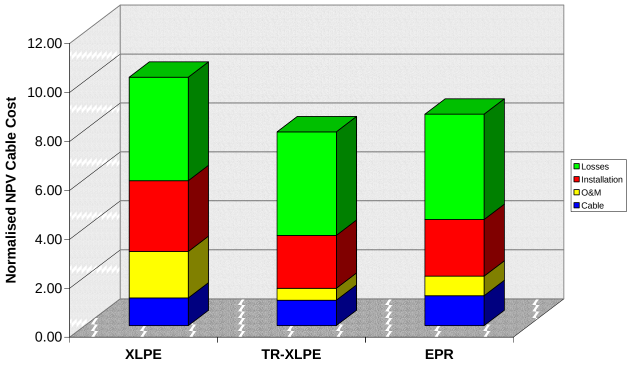

Figure 6: Normalised NPV life cycle costs calculated for rural installation including all considered factors for all three MV cable insulations

Figure 6 compares the LCC of all three cable technologies for the optimistic life condition (Table 1). In all cases the conductor losses are the same, due to the same loading factor and conductor size, however the dielectric losses are different. The cost of the initial rural installation is also the same. However differences in cable life expectancy, leads to different numbers of end of life events and associated failures, which in turn impacts on the O&M costs and re-installation costs leading to the differences in total LCC.

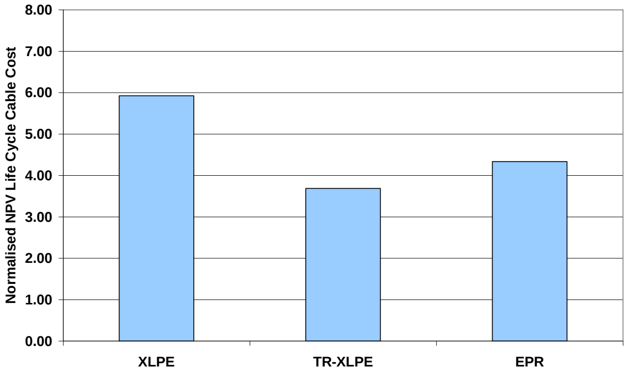

Figure 7: Normalised NPV life cycle costs calculated for rural installation excluding conductor losses for all three MV cable insulations

Figure 7 shows the same data as Figure 6 with the conductor losses removed. In this scenario TR-XLPE leads to the lowest total life cycle cost. Investigating the effect of installation environment and cable life leads to the result that in all cases considered here TR-XLPE offers the lowest total life cycle costs. Tables 2 and 3 show the additional cost incurred for both XLPE and EPR insulated cable relative to the NPV life cycle costs for TR-XLPE. Savings ranging from 30 to 45% compared to the XLPE insulated cable because of its shorter life expectancy. The lower savings for TR-XLPE compared to EPR are related to the smaller disparity in life expectancies of the two designs.

		Installation	
		Rural	**Urban**
Life Expectancy	**Conservative**	46.1%	36.6%
	Optimistic	40.3%	31.4%

Table 2: Additional cost of XLPE versus TR-XLPE

		Installation	
		Rural	**Urban**
Life Expectancy	**Conservative**	6.6%	3.6%
	Optimistic	13.3%	8.6%

Table 3: Additional cost of EPR versus TR-XLPE

DISCUSSION

Life cycle costing provides a rigorous method for comparing investment decisions when many factors may vary between the competing options. The analysis can contain as much information as is readily available, although some factors have been shown to be more important than others. In the case study considered here many of the factors are the same between the different options. Nevertheless this approach can be extended to comparing very different designs eg paper versus polymeric insulated cable, or cables of different conductor size [8].

Life expectancy is a key parameter in the analysis but also one of the more difficult to quantify. Nevertheless through using data generated from field aged cables, either breakdown data as reported here or from detailed forensic examinations, better estimates of cable life are possible. Where factors are not known precisely the application of a sensitivity analysis provides a rational approach to understanding their impact on the outcome of the model.

While the ideas considered here have been applied to a single asset type others have used a similar approach to study network optimization [10] or extended the concept beyond a simple economic analysis to also consider the environmental impacts of the asset [11, 12].

CONCLUSIONS

A simple life cycle cost model has been described which allows competing asset types to be quickly and easily compared. The model has been applied to three types of MV cable insulated with different materials. These materials impart different lives and losses on the cables. Data from accelerated ageing tests and field aged cables have been used to provide estimates of cable lives. A sensitivity analysis has been used to probe the influence of both cable life expectancy and installation environment on the outcome of the LCC model.

TR-XLPE insulated cables have been shown to be the most cost effective solution under all the conditions examined, with savings close to 50% in the most favourable case.

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