RETIREMENT MODELLING FOR THE LONG-TERM PLANNING OF THE REPLACEMENT OF DISTRIBUTION ASSETS

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Summary: Although the decision to replace distribution assets is usually based on consideration of the condition and hence reliability of the assets concerned, long-term modelling is nevertheless required for the strategic planning of a replacement programme. The paper discusses long-term forecasting of asset replacement derived from two main inputs, the age profiles of different categories of assets and their respective retirement profiles. Long-term modelling is used to evaluate the progressive impact of the retirement profile on the age profile of a given asset group and so derive a corresponding replacement forecast. In this process age is taken as a proxy for condition and hence reliability of the assets concerned. Retirement profiles can have a significant effect on the timing of forecast asset replacement expenditure; theoretically assets should be replaced only shortly before they become liable to fail and a considerable amount of work is presently being devoted to assessment of the lives of assets.

INTRODUCTION

The sizes of plant asset bases held by electricity utilities are growing steadily, asset populations are ageing and consequently increasing attention is being paid to asset management strategy. This is a particular concern in the United Kingdom where significant amounts of distribution assets were installed some 30 to 40 years ago. A key element of an asset management strategy is therefore the planning of the replacement or refurbishment of assets in order to maintain or enhance system performance. In this paper we describe a method of modelling the replacement of distribution assets.

For the purposes of long-term planning of the replacement of assets, age is taken as a proxy of condition and hence of performance of the assets concerned. Moreover the actual decision to replace or refurbish an asset is normally based not on age but on consideration of condition or, as is often the case, capacity, safety, operational, environmental or circuit diversion reasons. Long-term planning generally applies to the period in excess of about two or three years before the expected replacement of the asset concerned. Such a procedure is intended to predict the overall quantity of assets of a given type that are to be replaced with the corresponding actual assets for replacement being identified by specific factors such as condition.

ASSET LIVES

The table opposite summarises views of the lives in years of principal distribution assets in the United Kingdom.

Views of Asset Lives

Asset	**OFFER Model** [1]			**Industry view** [2]
	Start of re-placement	Average	Max. life	Average
Transformers				
Primary & MV ground - mounted	41	51	64	47 to 50
MV pole - mounted	20	41	55	43
Switchgear				
MV indoor	21	45	60	43
MV outdoor	11	35	51	30 to 37
LV indoor	26	47	65	46
LV outdoor	16	37	55	46
Overhead lines (132 kV)				
Line	31	62	91	
Towers				60
Conductors				35 to 45
Fittings				39
Overhead lines (< 132 kV)				
Line	15	46	75	
Wood poles				45
Conductors				35 to 45
Fittings				39
Cables				
132 kV	46	66	85	38 to 64
33 kV	36	65	90	38 to 64
11 kV PILC	46	75	100	70
LV PILC	62	91	115	78
LV non PILC	41	61	81	70

The term “asset life” is often used in a number of ways. It may mean the life at which replacement (or expiry) starts, the average life of the asset (life at which half the population has been replaced) or the maximum life (life at which all the asset population has been replaced). The terms “Engineering Life” or “Expected Life” are also used and are generally intended to mean the average life of an asset.

In practice a family of assets may be replaced over a range of ages according to a “retirement profile” or “survivor curve”, with defining points which may be described as the:

- age at which age-related failures (or replacements of assets) are considered to start
- average age of asset lives and
- age at which age-related failures are considered to cease (i.e. the maximum life attained by an asset).

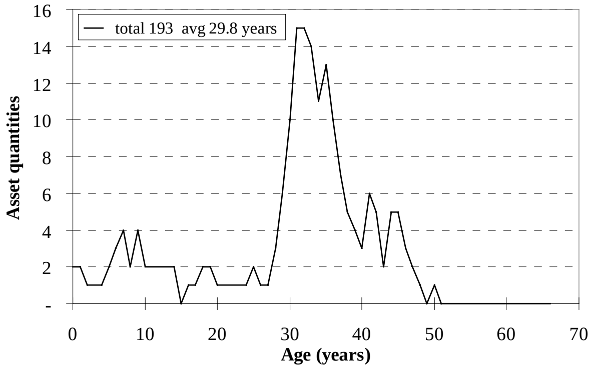

Figure 1. 66 & 132 kV Power transformers - Age Profile

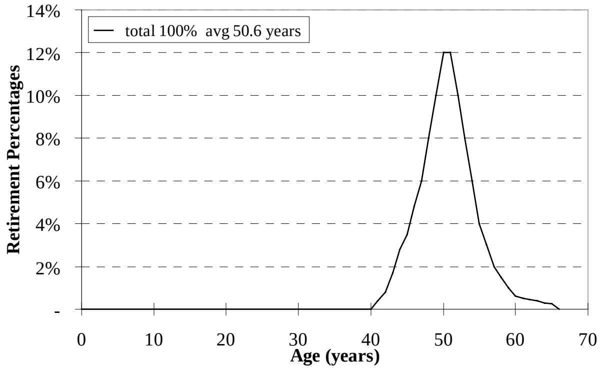

Figure 2. 66 & 132 kV Power transformers - Retirement Profile

The retirement profiles discussed in this paper are based on declarations by distribution companies of the ages by year at which proportions of given assets are replaced [1]. In some cases, particularly overhead lines and underground cables, the spread of ages over which assets are replaced may be appreciable. (The asset age profile and the corresponding retirement profile in the examples in Figures 1 and 2 are similar to those used for modelling asset replacement expenditure in regulatory Distribution Price Control Reviews in the United Kingdom.)

Another application of the concept of asset lives is in the book valuation of assets for which residual lives may be assessed from consideration of maximum lives and appropriate survivor curves (in the United Kingdom most distribution companies depreciate the values of their assets over a period of 40 years).

ASSET LIVES AND FAILURE RATES

In practice a utility would plan to replace an asset before there is a significant risk of it failing in service (i.e. before the onset of the “bath tub curve”) and to this end increasing use is being made of condition monitoring techniques [3].

A study [4] using data obtained from the National Fault and Interruption and Reporting Scheme (NAFIRS) in the United Kingdom investigated the relationship between asset age and failure rate. A definite upward trend was observed for faults caused by ageing and wear although the available data relating failure of an asset to its age was limited. An analysis of the hazard rates for pole and ground-mounted distribution transformers showed the onset of age and wear-related faults as occurring at ages similar to those of the onset of replacement in the OFFER model [1]. At the same time the hazard rates were noted as being very low indicating that the onset of age and wear related faults is likely to be slow.

Reference [5] describes a ‘replace on condition’ policy for transmission transformers in which the key parameters to be established are stated as being the age at which reliability begins to be reduced, together with an estimate of mean life based on the findings of a condition assessment programme. The statement is also made that according to available data for British transmission transformers, there is no detectable increase in failure rate with age. The failure probability density function shown for modelling purposes exhibits a very small, but finite, non-age related failure rate up to an age of about 35 years rising to a peak at an age of about 55 years.

The phenomenon of a small, but finite, non-age related failure rate in early years has been observed by the authors in the case of transmission lines in South America where the causes of failure have been severe weather and vandalism. This phenomenon was accordingly incorporated in the survivor curves used for modelling of asset replacement.

It may also be appropriate to identify and model separately defective groups of plant items with unexpectedly short lives. An example of such an item in the United Kingdom is the category of 11 kV overhead lines of light construction built to BS1320. These lines were built in the 1950s and have been found to be vulnerable to very severe weather conditions, such as the high winds experienced in recent winters.

ASSET LIVES AND CONDITION

Reference [6] describes a method of assessing the ages at which assets are replaced based on condition. The age profiles of the assets are modified according to the respective proportions of the assets that are in good condition (and therefore able to exceed their expected life) or in bad condition (in which case the effective expired life is increased).

MODELLING OF ASSET REPLACEMENT

Introduction

The spreadsheet model described in this paper makes use of two main inputs for each asset type that is modelled. The first input is the age profile of the asset type, indicating the number of assets still in service and the current age of those assets, for example 10 assets aged 1 year, 6 aged 2 years, 8 aged 3 years and so on. The second input is the retirement profile for the asset type. This gives the percentage of assets introduced at the same time which would be retired a certain number of years into the future, for example 5 per cent retired after 25 years, 8 per cent after 26 years, and so on.

When these two profiles are combined, the number of assets expected to be replaced in the next year can be calculated. The new assets introduced are then incorporated in the asset age profile. This process can then be continued into the future.

Calculation of projected costs of asset replacement

The expected costs for the new assets to be introduced in future years is found by multiplication of the quantities for each year by a suitable unit cost. This can be done for all significant asset groups to forecast longer-term expenditure on replacement assets. The principle of operation of the spreadsheet model is described below.

Asset age profiles

Asset age profiles are compiled from the asset database of the utility concerned and should represent the range of existing assets as accurately as possible; some grouping may however be required to keep the modelling to manageable proportions. Nevertheless in practice a distribution company may evaluate the replacement of about 100 individual asset classes.

Asset retirement profiles

Asset retirement profiles represent the ages at which the assets are being retired from the system. The profiles are expressed as the percentages of the original assets that would be expected to be retired in each year for a given number of years of operation. These percentages accumulate up to 100 per cent with the retirement of the oldest assets in their last year of operation.

In order to differentiate between the drivers for asset replacement, the causes of such retirement (e.g. condition, capacity, safety, operational, environmental or circuit diversion reasons) also need to be identified and taken into account.

Calculation of quantities of assets retired and introduced

The principle of the model is as follows. In any year, the number of each asset reaching a given age would be reduced by retirements. To determine the total number of assets retired of all ages, the calculation would then be repeated for each type and for each age. The total number of assets retired in any year is then obtained by summation of the results for that year. The calculation can then be done for the following years to predict the number of retirements for each year into the future. The modelling of replacement of assets is effected in this example by assuming that all of the assets retired in any year are replaced. The replacement assets then become a new total for assets that are less than one year old. This total is then added to the end of the asset age profile and is used in the calculation of replacement totals further into the future.

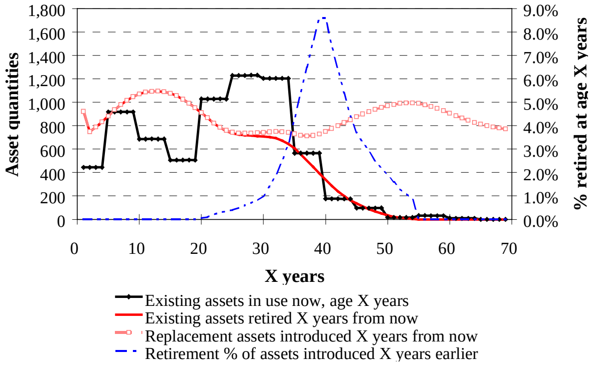

Figure 3. Age Profile with Retirement and Replacement Profiles with retirement % profile (for 11 kV pole mounted transformers)

Figure 3 demonstrates the interaction of age profile and percentage retirement profile on existing asset retirements and new asset introductions for a typical population of 11 kV pole-mounted transformers. Due to the influence of assets introduced in later years, the smooth solid line representing the projected retirement profile of the existing asset base diverges from the dotted line which represents quantities of replacement assets to be introduced in each year in future. This divergence begins at the point in the distant future at which replacement assets introduced in the near future begin to be replaced themselves in accordance with the same retirement profile being applied to the existing asset base.

The quantities of the replacement assets introduced which correspond to the chained line in Figure 3 are shown in the following table in summary form. The quantities are also given as percentages of the existing asset population (34,096 units in this example).

Introduction of New assets

Year no.	New Assets Qty	%
1	921	2.7%
2	748	2.2%
3	788	2.3%
4	833	2.4%
5	882	2.6%
1 - 5	4,172	12.2%

Year nos.	New Assets Qty	%
1 - 5	4,172	12.2%
6 - 10	5,045	14.8%
11 - 15	5,437	15.9%
16 - 20	4,934	14.5%
21 - 25	3.977	11.7%
1 - 25	23,565	69.1%

It will be appreciated that the replacement in the first five years is likely to be of principal interest since this represents the shorter term funding requirements, five years being a typical duration of a Regulatory Price Control.

Nevertheless where possible a distribution company is likely to aim, as a matter of business policy, to replace assets at an even rate to try to avoid any sharp increases in expenditure possibly reflecting major construction programmes in the past. It may be desirable to smooth future expenditure and avoid repetition of historic peaks due to the practical restraints on repeating such work, let alone the financial risk to the operator and the corresponding fluctuations in distribution charges to customers.

Sensitivity of replacement quantities to assumptions about retirement profiles

The retirement profiles have a significant effect upon the timing of forecast asset replacement expenditure. For example, if 100% of a particular type of asset was retired at a precise age in one year, this would result in a high peak of expenditure for that one year and nil expenditure on that type for many years before or after. This would result in a ‘spike’ in the expenditure requirement. Conversely, if the assets were retired over several years, but had the same average life as in the previous example, the expenditure would be distributed accordingly. The result would be a wider and lower peak which would represent lower annual levels of expenditure (but over a longer period of time). The investments would begin earlier and finish later than in the previous example, but would produce a smoothing effect on the annual requirements. In both cases, however, the average expenditure over the life would be the same.

This effect is demonstrated by the three examples in Figure 4. In each case, the age profile of the existing population is identical. The average expected life of the asset type is also identical at 40 years but the shape of the retirement profiles is different across the three examples.

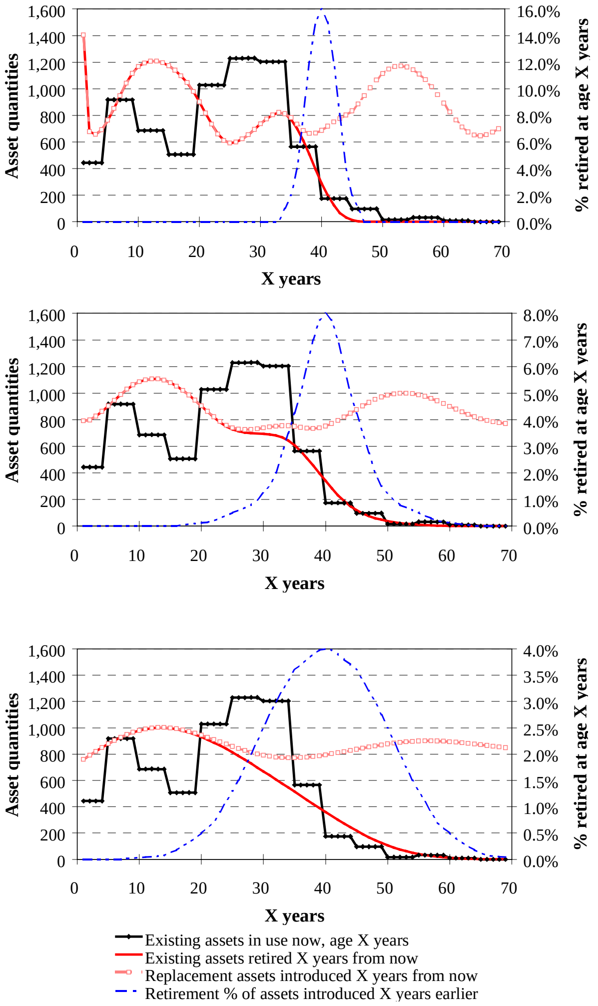

Figure 4. Comparison of Retirement and Replacement Profiles
for differing retirement % profiles (11 kV pole mounted transformers)

The first example envisages retirements of assets within a very narrow age band with a maximum of 16 per cent of the original populations being retired at age 40 years. The second and third examples show progressively broader age bands for retirements with maximum percentages of 8 and 4 per cent of the original populations being retired at age 40 years.

The smoothing effects of the broader and flatter retirement profiles upon the calculated annual replacement quantities are clearly visible in this comparison. The following table shows the effects of the smoothing on the first five years of the asset replacement across the three examples given.

Variation of replacement quantities with retirement profiles

	Narrow profile (max. 16% at yr 40)		Medium profile (max. 8% at yr 40)		Broad profile (max. 4% at yr 40)	
	New Assets		New Assets		New Assets	
	Qty	%	Qty	%	Qty	%
1	1,404	4.12%	792	2.32%	759	2.23%
2	677	1.98%	798	2.34%	790	2.32%
3	657	1.93%	826	2.42%	820	2.40%
4	692	2.03%	862	2.53%	850	2.49%
5	764	2.24%	903	2.65%	878	2.56%
Σ	4,194	12.30%	4,181	12.26%	4,097	12.02%

For the narrow retirement profile the high quantity of assets calculated to be replaced in year 1 reflects assets which have been retained in service (replacement deferred) to an age beyond that reflected in the profile. In practice such a year-on-year variation in replacement quantity would not occur (nor be planned) and the replacement would be more in accordance with that predicted from the medium and broad-based retirement profiles. We would also consider that a broader-based profile is likely to be the more practical case, reflecting varied service life, different operating environments and may be demonstrated by the range of age profiles obtained in practice.

TRENDS IN EUROPE

From our work in Europe, we would observe that existing assets are likely to be younger and asset lives are likely to be shorter than experienced in the United Kingdom, for example, for a number of reasons:

- higher load growth from a lower base resulting in replacement (of assets which are not necessarily life expired) for reasons of system reinforcement (Italy)
- extensive replacement of low capacity LV open wire overhead lines with ABC (Italy, France and Portugal)
- environmental - high PCB content distribution transformers replaced to comply with EU Directive and
- retrofitting of MV (6 to 24 kV) switchgear in Germany by 31 October 2000 to comply with requirements of DIN VDE 0101.

CONCLUSIONS

Modelling of the replacement of assets is an important tool for an Electricity Regulator (as in the United Kingdom) who has to ensure that the distribution companies are running their businesses in a responsible manner.

The development of a modelling tool as described in this paper is dependent on the corresponding development of plant databases, in particular the linking of plant age, condition and performance and the development of retirement profiles. We expect this process to become further refined in future.

Acknowledgement

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