ANEXO

CAPÍTULOS 1 Y 2 DEL INFORME N° 172

AGEING OF THE SYSTEM
IMPACT ON PLANING

WORKING GROUP 37-27, CIGRE, DECEMBER 2000

1. INTRODUCTION

In the past, the driving force for system modernisation has been load growth: equipment was replaced because its rating or characteristics were no longer compatible with the changing requirements due to steady and considerable load growth. Nowadays, in the low growth environment that prevails in many countries, many assets are rated sufficiently to fulfil their roles in electricity transmission up to the expiry of their lifetimes. Furthermore, the very large groups of assets installed during high growth periods are all likely to reach the end of their lives at about the same time.

In this context, CIGRÉ Working Group 37-27 was established with the following scope of work:

- Describe the age of equipment in different systems and different types of locations.
- Identify and where possible quantify system problems due to ageing.
- Identify equipment types subject to deterioration due to ageing and equipment types subject to technical obsolescence.
- Consider the range of options available to deal with ageing equipment in the system.
- Formulate guidelines for selecting the appropriate option.

The Working Group's full Terms of Reference are given in Appendix 2.

This report summarises the work of WG 37-27 that successfully accomplished the scope originally proposed. The statistics presented (Section 2) in this report show that many companies and countries have significant blocks of network assets that will approach the ends of their estimated lives in the coming years. The report (Section 3) indicates some of the possible consequences of ageing on the system. The scale of the problem of ageing assets facing many companies in the coming years requires the selection of one or more overall strategies, rather than addressing the issue on a case by case basis. A set of alternative generic strategies is presented (Section 4). A process is proposed for the selection of an appropriate strategy and identification of the factors that may dictate the eventual choice of strategy (Section 5).

This report does not cover details of total life management of equipment, specific life extension methods, etc. These issues have been and continue to be addressed by the relevant CIGRÉ study committees. Some of the relevant CIGRÉ activities are listed in Appendix 1.

The age profile for transmission equipment shows the growth in systems at 110 kV and above during the 1950's and continuing throughout the 1960's, gradually falling to today's investment levels, which again approximate to those of the late 1950's. Based on the information presented in this report, the population peak will enter the window of lifetime estimates over the next 10 years for almost all types of major equipment. This will undoubtedly have a major impact on planning, requiring careful consideration of the strategy required to tackle the growing population that is potentially nearing the end of useful life.

The prediction of end of useful life estimates is a formidable task and depends on many factors including climatic and environmental conditions, material quality, system loading conditions, maintenance practices, mechanical wear, spares obsolescence, safety concerns, system changes, poor reliability, and loss of skilled maintenance and repair personnel. Despite these difficulties, companies must attempt to estimate the remaining useful life of equipment. Sometime approaching the anticipated end of useful life of a transmission asset or group of assets, decisions have to be made on economic or reliability grounds as to the correct strategy for managing a particular asset or group of assets.

Five broad strategies to deal with ageing transmission equipment have been identified in this report. These are:

- Renewal by refurbishment: some components of an asset are replaced to bring the asset to an as-new condition
- Renewal by replacement: all components are replaced i.e. like-for-like replacement of the asset.
- Upgrading or renewal: the ageing assets are replaced or refurbished to a standard which provides an enhanced asset
- Network redesign: the opportunity is taken to implement a redesign (and hence an enhancement) of the system.
- Life-extension or deferral: increased maintenance and/or monitoring of existing equipment until other strategies can be implemented.

The timing of asset strategies is also critical, as replacing assets too early will result in a waste of money and asset life. Replacing assets too late will result in poor reliability and an increase in associated costs. A structured approach to deal with replacement of aged assets is thus required to optimise time of replacement. Prioritisation is proposed on the basis of a reliability-centred asset management strategy. This approach involves combining the aspects of equipment condition and equipment importance together for an overall ranking criticality.

Overall, the impact of ageing of the system on planning may be summarised as:

- The impact on system performance due either to failure of aged equipment or to the impact of replacement or refurbishment work on system performance;
- The need to include a replacement and refurbishment plan in system development plans;
- The need to provide resources, financial, manpower and expertise;
- Ageing offers opportunities for upgrading, modernising and reconfiguring the system to suit future needs.

The members of Working Group 37-27 were:

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Bente Bakka	Statnett	Norway
Gerd Balzer	University of Technology, Darmstadt	Germany
Tim Davies	Ontario Hydro Services Company	Canada
Alain Davriu	Electricité de France	France
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2. STATISTICS

2.1 Introduction

Ageing is an issue because all assets within an electricity network are subject to ageing and wear-out during their service life. Indeed, each asset has its own individual useful lifetime, but for simplification, utilities commonly apply generic lifetime figures to groups of similar assets with similar individual asset duties or operating regimes.

2.2 Data Collection

Statistics describing the ages and anticipated asset lives of equipment in systems at 110 kV or above were collected from the 13 countries represented in Working Group 37-27. The data collected covers over 180,000 circuit-kilometres of overhead lines and over 300,000 substation assets. The data collected covered the following categories of transmission assets:

- Overhead lines, conductors, towers and poles
- Cables
- Circuit breakers
- Switchgear bay equipment
- Transformers
- Gas insulated switchgear
- Protection
- Reactive compensation.

Details of asset populations for each category were collected in 5-year age bands. The age distributions for the most significant plant types are plotted as histograms in Figs. 2.1, 2.2 and 2.4 to 2.12. Plant items for which the populations represented by the survey responses are small, such as submarine cables, reactive compensation equipment etc., and plant items which were all far from approaching end-of-life, such as AAAC conductor, are not detailed in this section. More detailed results from the data collection are given in Appendix 3.

WG members also provided estimates of anticipated mean asset lives for each category of asset, together with the basis for the estimates. The means of the anticipated mean lifetime estimates for all major plant types are shown in Table 2.1. These, along with their standard deviations, are derived from the mean asset lives companies have assigned for equipment in their systems.

Table 2.1 – Asset Lives and Variances

Plant Type	System Voltage (kV)	Mean and Range of Asset Life Estimates (Years)	Standard Deviation (Years)	Reason for Asset Life Variances
Circuit Breakers				
Air	110-199	**41** (30 to 50)	6	Rating requirements, fault duty changes, maintenance costs, spares obsolescence, mechanical wear, safety, seal problems
	200-275	**41** (30 to 50)	6	
	≥345	**40** (30 to 50)	6	
Oil	110-199	**42** (30 to 50)	6	Rating requirements, fault duty changes, maintenance costs, spares obsolescence, mechanical wear, safety, seal problems
	200-275	**41** (30 to 50)	6	
	≥345	**38** (30 to 45)	5	
Gas	110-199	**43** (30 to 50)	6	Rating requirements, fault duty changes, maintenance costs, spares obsolescence, mechanical wear, safety, seal problems, seen as "less robust", environmental concern re SF6
	200-275	**42** (30 to 50)	6	
	≥345	**42** (30 to 50)	6	
Bay Assets				
Earth switches & disconnectors	≥110	**42** (30 to 50)	8	Rating requirements, maintenance costs, corrosion, mechanical wear
CTs – Oil	≥110	**39** (30 to 50)	7	Design weaknesses, seals
CVT's	≥110	**39** (30 to 50)	7	Moisture ingress, PCB contamination of oil
Transformers	≥110	**42** (32 to 55)	8	Design, loading, insulating paper & oil degradation, system faults, spares, rating requirements, high temperature, moisture levels
Indoor GIS	≥110	**42** (30 to 50)	8	Rating requirements/fault duty changes/ Maintenance costs/spares obsolescence/ Mechanical wear/safety/seal problems Environmental concern re SF6
Electro-mechanical protection	-	**32** (20 to 45)	9	Wear, contact erosion, reliability, verdigris, temperature extremes, skilled labour, spares, functionality, system design changes
ACSR-OHL				
"Normal" environment	≥110	**54** (40 to 80)	14	Climate, environment, corrosion, conductor grease levels, creep, mechanical fatigue, insulator failures, wind, precipitation, ice loading, pollution levels, material quality, high temperatures due to loading, joints, design
"Heavily polluted"	≥110	**46** (30 to 70)	15	
Towers				
Steel lattice	≥110	**63** (35 to 100)	21	Climate, environment, corrosion, maintenance, poor galvanising, ground conditions, concrete spalling, grillage corrosion, steel/concrete junction
Wood Poles	≥110	**44** (40 to 50)	4	Preservation treatment, rot, woodpeckers, insects, wind, precipitation
Cables Oil Filled	≥110	**51** (30 to 85)	20	Environmental concerns (oil leaks), backfill, sheath (oil reinforcing tape) corrosion, electrical/thermomechanical stress, loading, crystalline lead sheath

Several companies referred to instances where estimates of the remaining life of assets had to be revised following the discovery of previously unidentified life limiting factors.

The estimates of asset life are plotted with the age distribution histograms as windows delimited by vertical bars. The windows are centred on the mean estimate and with a window width equivalent to +/- 1 standard deviation. With the passage of time, the age distributions will move towards the right, while the lifetime windows remain static. The figures thus illustrate when the lifetimes of the main groups of transmission assets will begin to expire.

2.3 Overhead Lines and Underground Cables

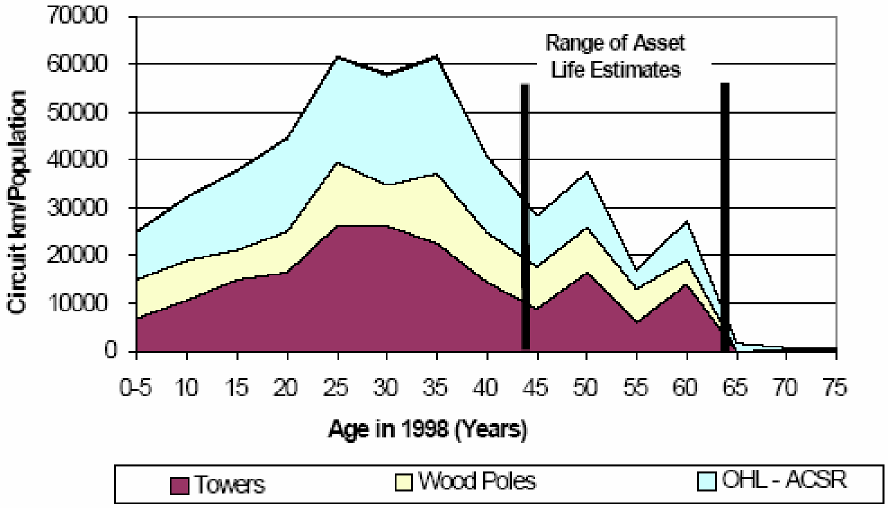

Fig. 2.1 **Age Distribution of Overhead Lines**

The age profile of all overhead lines (Fig. 2.1) shows that a significant population of overhead lines constructed in the late 1930's / early 1940's is still in operation, with the peak construction period being the 1960's. The anticipated mean asset lives range from 44 years for wood poles to 63 years for steel towers, with ACSR conductor between these extremes. Some overhead lines have already reached or exceeded their anticipated lives, indicating that renewal or life extension strategies are being pursued actively. Fig. 2.1 also shows that the population peak will enter the window of lifetime estimates over the next 10 years. Owners and operators will need to develop appropriate strategies before then.

2.3.1. Aluminium Conductor Steel Reinforced (ACSR):

The age distribution for fully greased Aluminium Conductor Steel Reinforced (ACSR) in a "normal" environment is shown in Fig. 2.2. The estimates of anticipated life have a mean of 54 years and standard deviation of 14 years. For heavily polluted conditions the mean estimate is 46 years (standard deviation 15 years).

Only 6% of the population has exceeded the mean life of 54 years, but 20% is currently within the mean asset life window and 42% will be over 40 years old in the next 10 years.

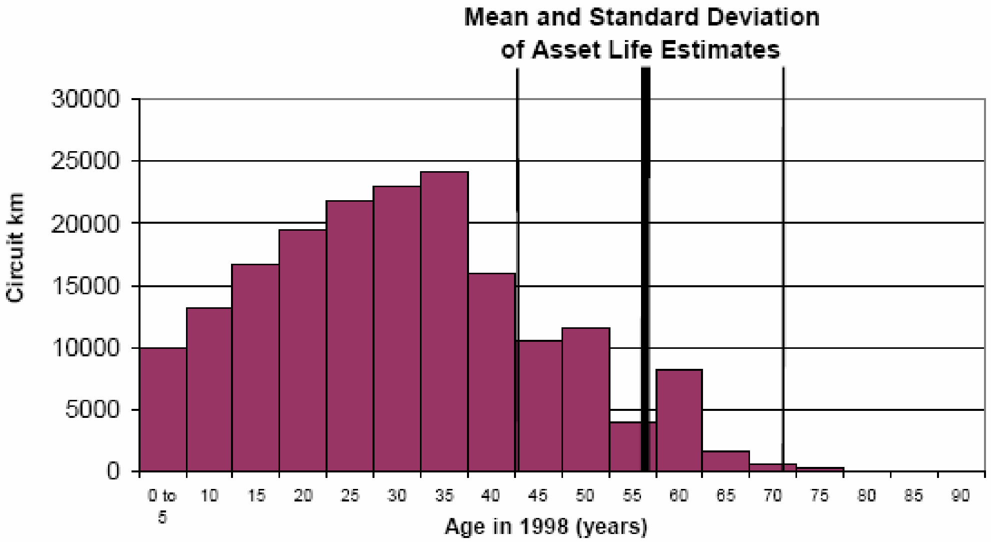

Fig. 2.2 Age Distribution and Life Estimates for ACSR

The variation in lifetime estimates is due to different climatic and environmental conditions, rate of corrosion, conductor grease levels, material quality and loading conditions. As pollution, wind and adverse climatic conditions increase, so the anticipated life falls to 46 years (standard deviation 15 years). The reduction in life expectancy depends on the specified and actual level of conductor greasing, conductor bundle configuration, pollution level, ice loading, material quality, joint design. Analysis of climatic conditions using the Köppens classification system (see panel) in conjunction with the life expectancy data shows that anticipated mean life increases as the climate moves from hot/wet to cold/wet (Fig. 2.3).

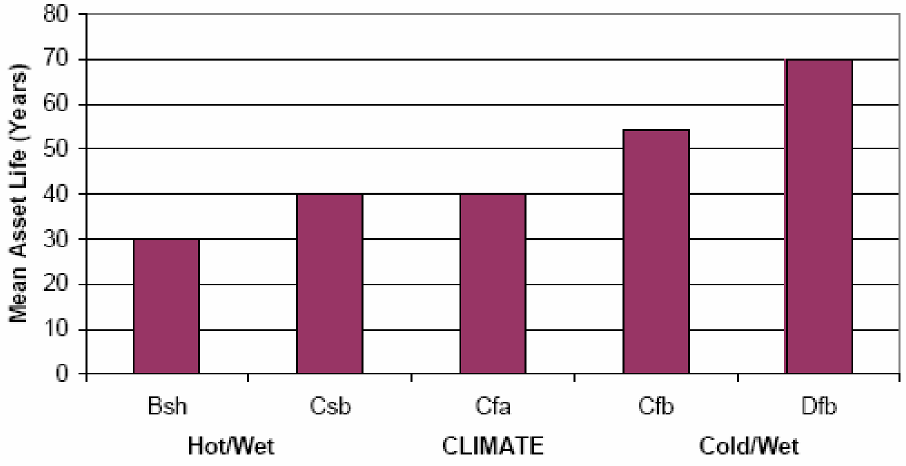

Fig. 2.3 Anticipated Life for ACSR in Different Climates (Köppens Classification)

The Köppens Climate Classification System

The Köppens climate classification system was developed in the early 1900's, and recognises 5 major climatic regions in the world, from A, tropical rainy climates to E, polar climates, which are further subdivided on the basis of rainfall, temperature. Countries in this report fall into the classifications shown in the following table.

Köppens Classification	Description	Dry Season	Temperature	
Bsh:	Semi-arid hot climate	All year	Mean annual	>18 Deg C
Csb:	Mid –latitude climate	dry summer	Mean of hottest month	<22 Deg C
Cfa:	Mid –latitude climate	no dry season	Mean of hottest month	>22 Deg C
Cfb:	Mid –latitude climate	no dry season	Mean of hottest month	<22 Deg C
Dfb:	Moist, severe winter	no dry season	Mean of coldest month	<-3 Deg C

Conductor corrosion and fitting wear are the main ageing mechanisms that impact on ACSR conductor, rather than technological obsolescence, though replacement offers the opportunity to utilise the latest advances and often enables a higher technical rating to be achieved with the same supporting structures.

2.3.2. Steel Lattice Towers

For steel lattice towers (Fig. 2.4), the mean estimate of life is 63 years (standard deviation 21 years). As with ACSR, the variation in estimates is due to different climatic and environmental conditions, maintenance practices and quality of galvanising and subsequent painting regimes. Ground conditions and erection practices affect the life of foundations.

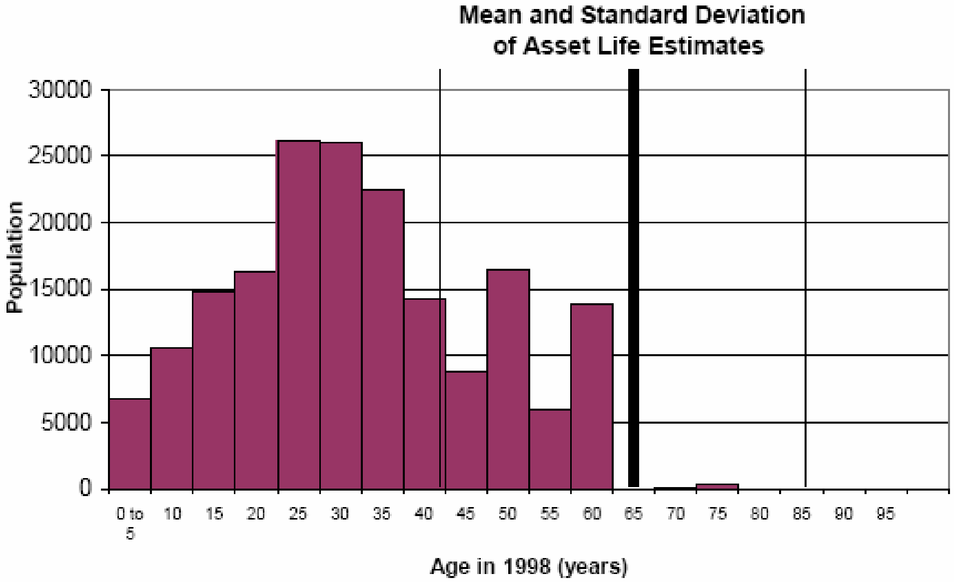

Fig. 2.4 Age Distribution and Life Estimates for Lattice Steel Towers

The statistics show that 8% of the population was constructed over 55 years ago and 25% now falls within the mean asset life window. However, the population peak is still some 40 years from the mean life, allowing time to consider replacement strategies.

Corrosion is the main ageing mechanism leading to end of life for steel towers. Normally the conductor will be replaced before the towers reach their end of life. The suitability of the towers for the new conductor must be assessed before replacement.

2.3.3. Wood Poles

For wood poles (Fig. 2.5) the mean lifetime estimate is 44 years with a standard deviation of 4 years. However, there is considerable variation of individual pole lifetimes. Many poles with ages greater than the mean lifetime estimates are still in service. Lifetime depends on preservation treatment, rot, woodpeckers, insects, wind, precipitation.

Broadly 38% of the population will be older than 40 years in the next 5 years and there will be a need to focus on the potential impact of this.

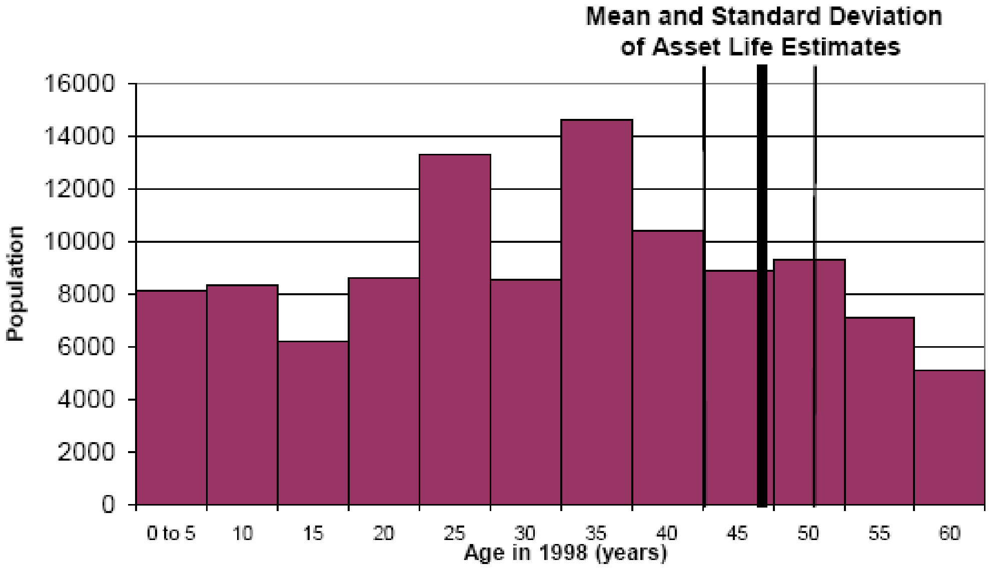

Fig. 2.5 **Age Distribution and Life Estimates for Wood Poles**

Deterioration due to the ageing effects of environment and attack from woodpeckers apply to this plant type rather than technical obsolescence, as the long service history proves.

2.3.4. Oil Filled Cables

The highest installation rate for cables was in the 1960's with only 5% older than 45 years, but 1% is actually over 60 years old. (Fig. 2.6) The anticipated mean asset life of 51 years (standard deviaiton 20 years) has variances due to ageing of the pressure retaining systems, including sheath failure due to reinforcing tape corrosion, thermo-mechanical stresses/design and thermal properties of the backfill.

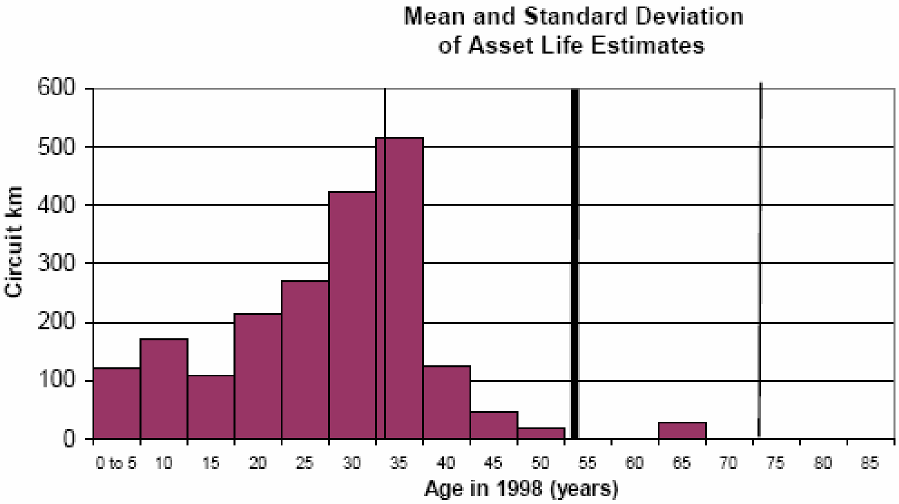

Fig. 2.6 **Age Distribution and Life Estimates for Underground Cables**

Concerns about the impact of oil leaks on the environment also raise the profile of this group as well as the high replacement costs involved. 36% of the cables are now within the mean asset life window but the end of life scenarios are varied enough to distribute the replacement impact over a significant period.

Technical obsolescence can render some cable systems redundant, particularly small populations of old gas filled designs, but for oil filled cables, the ageing effects of reinforcing tape and sheath corrosion, or electrical and mechanical stresses are the dominant end of life scenarios.

2.4 Substations

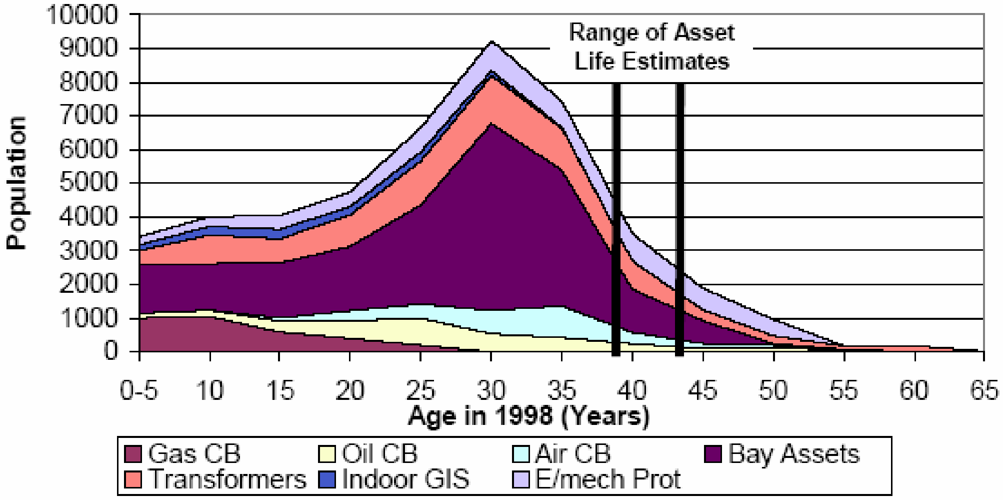

Fig. 2.7 **Age Distribution for Substations**

The age profile for substations (Fig. 2.7) shows the growth in systems at 110 kV and above during the 1950's and continuing throughout the 1960's, gradually falling to today's investment levels, which again approximate to those of the late 1950's. Developing technologies of air, oil and gas circuit breakers can be seen over this period at all voltage levels. The mean asset lives for the plant lie within 38 to 43 years (apart from electromechanical protection) and this highlights that over the next 10 years the population peak will have entered this window, and the impact on planning will be significant.

2.4.1. Circuit Breakers:

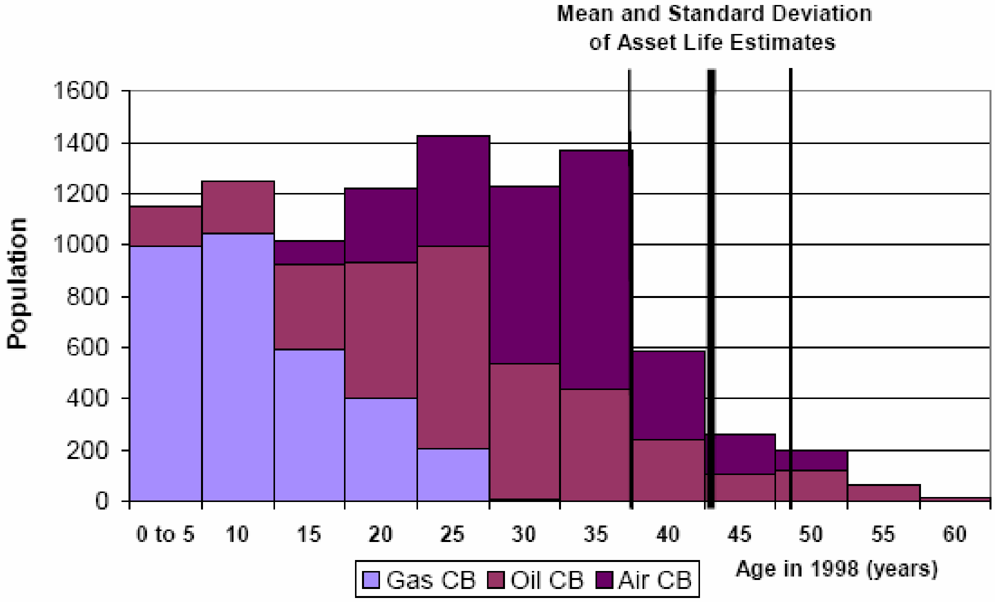

Fig. 2.8 **Age Distribution and Life Estimates for Circuit Breakers**

A life expectancy of 41 years (standard deviation 6 years) is anticipated for the whole population of circuit breakers, with only a slight life increase between early air technology and the latest SF6 gas technology (Fig 2.8). Variances in asset lives are a result of variations in mechanical wear, maintenance costs, problems with spares obsolescence and potential safety concerns. System rating or fault duty requirements can also result in variations in replacement requirements. Life extension has been undertaken on a small population of assets with 3% in the 45 – 60 year age bands.

Circuit breakers are subject to deterioration due to ageing mechanisms, such as seal deterioration, component breakdown etc. as well as technical obsolescence, as a result of advancing technology or the inability to satisfy developing system requirements.

2.4.2. Switchgear Bay Assets

Fig. 2.9 shows that Disconnectors, Earth Switches, Current Transformers (Oil) and Capacitor Voltage Transformers have a combined mean life expectancy of 40 years (standard deviation 7 years). Approaching 30% of the population falls within the mean asset life window of this group and whilst ageing is of growing importance, this plant group would not be the lead plant group with respect of addressing the effects of ageing but they would be taken into account with other assets. A steady percentage of the population has been added each year for the last 20 years though this will be expected to rise significantly over the next 10 years given that the population peak will reach life expectancy by then.

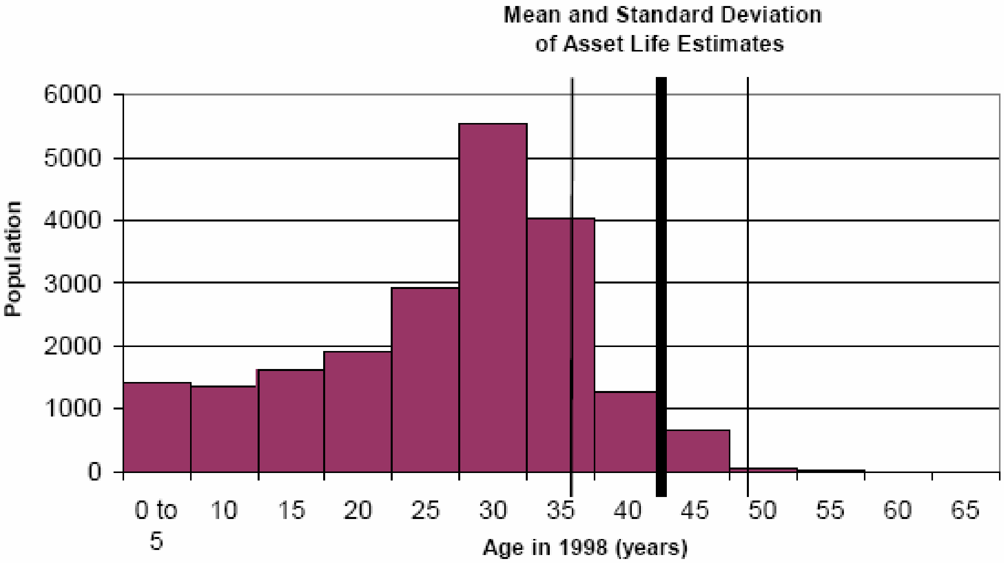

Fig. 2.9 **Age Distribution and Life Estimates for Bay Equipment (CT's, VT's, Disconnects, Earth Switches)**

Ageing is the main driver leading to direct replacement of this plant type, with insulation deterioration, seal deterioration, and corrosion taking effect, though a large population are replaced as a consequence of strategies employed to deal with other plant types.

2.4.3. Transformers

The age distribution for transformers (Fig. 2.10) shows that 4% of the population is in the 50 – 80 year old age band, 20% of the population is in or beyond the anticipated mean asset life window, (i.e. over 35 years old) and in the next 10 years over 50% of the population will be within the asset life window. Variation about the mean anticipated life of 42 years (standard deviation 8 years) is mainly attributable to the design and service regime the transformer has been exposed to. Ageing of transformers will undoubtedly have a major impact on planning, requiring careful consideration of the strategy required to tackle the growing population potentially nearing end of life.

Whilst transformers are subject to ageing processes, and technical advances with respect to lower losses etc. lead to improved designs, the main drivers leading to replacement are severe operating conditions, resultant insulation breakdown, initial design or inadequate system rating.

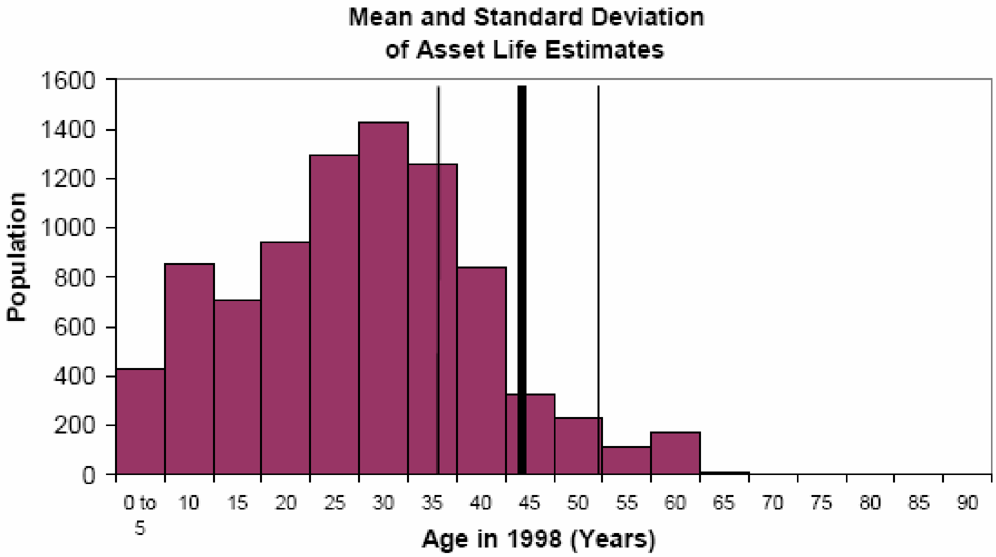

Fig. 2.10 **Age Distribution and Life Estimates for Transformers**

2.4.4. Indoor Gas Insulated Substations

Fig. 2.11 shows that the oldest installation in this plant group is some 10 years from reaching its mean anticipated life, the main importance of the statistics is to show the fact that no company has experience of end of life for GIS. The reason for life predictions are similar to gas circuit breakers with a modest anticipated increase in life over old technologies, but a hope of better system performance.

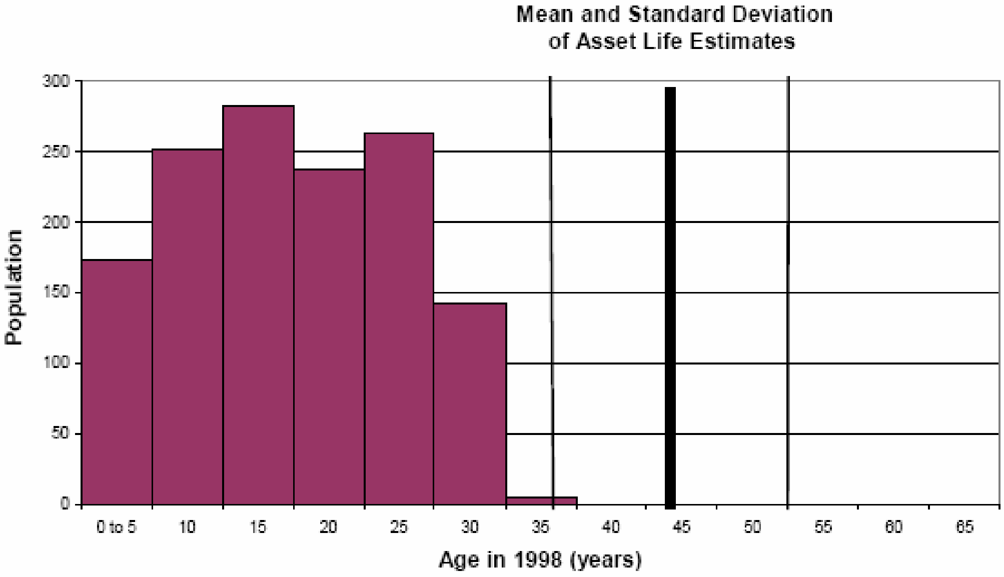

Fig. 2.11 **Age Distribution and Life Estimates for GIS**

2.4.5. Electromechanical Protection, Control and Intertripping

Fig 2.12 shows that 63% of the population of electromechanical protection, control and intertripping equipment is over 25 years old and into the mean asset life window of 32 years (standard deviation 9 years). Replacement technologies of static and latterly numerical (digital) protections have a shorter anticipated life, as with other electronic components, but individual component or software changes are anticipated to alleviate the system effects, with the electromechanical class having the more immediate planning impact. However poor performance by some solid state protections approaching their end of life are already being assigned a higher replacement priority than electromechanical relays.

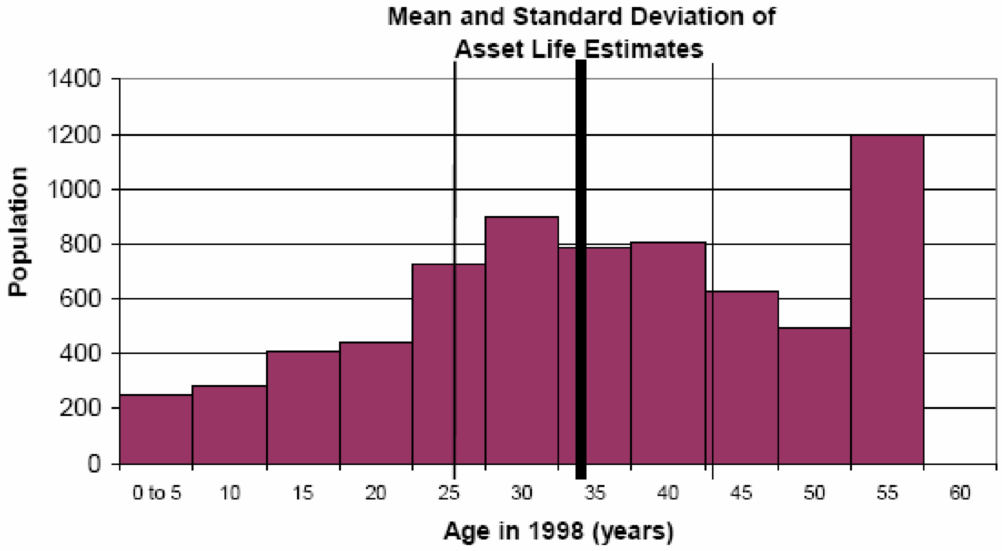

Fig. 2.12 Age Distribution and Life Estimates for Electro-Mechanical Protection

Electromechanical control and protection equipment is subject to deterioration as a result of electrical and mechanical stress, with obsolescence due to lack of spare parts and skilled maintenance and repair personnel playing a leading role as replacement drivers.