CONDITION ASSESSMENT AND LIFE EXTENSION

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Contents

Summary

Over the past century, steam power generating units have increased in capacity and efficiency. The rate of increase, however, slowed as certain limits were approached. The result is that power plants currently reaching the end of their anticipated life are not so different in capacity and efficiency as to justify their retirement on the basis of age alone. Extended operation is in fact a bonus for the power generating utility as the initial capital investment should have been recovered by this time. Provided the plant is in generally sound condition, the option of refurbishing it for extended operation is thus often favourable.

Most materials, particularly those subject to high stresses and temperatures, deteriorate with time and may eventually fail. Critical components, therefore, have a certain life. When this has been expended, the component must be replaced. Ideally the life of all major components should be equal to the planned life of the plant. In practice this is not the case. Some components reach the end of their life sooner than anticipated and some components still have some life remaining at the end of the planned life. At various stages during the lifetime of the plant it is therefore necessary to be able to check for material deterioration and to predict the life remaining for certain critical components. Hence the science of condition assessment and life extension.

Condition assessment of components is based on the life history of components subject to adverse conditions and supported by various testing methods to measure material deterioration. Such testing methods are normally non-destructive though, in some cases, small samples may be extracted for destructive testing. A comparison with known material behaviour, as determined by laboratory testing, is then made.

High cycle mechanical stress, low cycle thermal stress, excessive temperature and adverse environmental chemistry all result in crack development and propagation. Cracking is therefore one of the most important indicators of material condition. The ability of a material to withstand the onset and growth of such defects is a measure of the remaining useful life. A knowledge of material behaviour combined with reliable condition assessment techniques allows remaining component life to be assessed with a reasonable degree of accuracy.

1. Refurbishment Versus Replacement

1.1 General Economic Factors

Any thermal power plant has three key factors affecting its viability, namely, capital cost, thermal efficiency and plant life. To some degree they are interdependent. Capital cost is usually measured as expenditure per installed capacity, that is, $ MW^{-1}. Since various components of the steam cycle have been developed over many years and been standardized to a great degree, capital costs for thermal power plants are fairly uniform. A characteristic of the power industry is that it is the most capital intensive industry producing a common marketable product. This makes the industry rather conservative with regard to the design and construction of new power plants. Ultimately the plant has to operate for twenty to twenty five years in order to generate sufficient power to obtain a return on the investment. Usually the required finance is obtained as a loan which must be repaid with interest within the anticipated life of the plant.

The price of the electricity is then set to cover the capital repayments and operating costs. The major part of the operating costs is the fuel cost. This is determined by local conditions and world fuel prices. Some plants are located close to a source of cheap fuel while others obtain fuel on the world market. This ultimately affects the price of the electricity. Nevertheless for any given conditions or locality the thermal efficiency has a direct influence on the viability of the plant. Thermal efficiency is simply the ratio of electrical power produced over rate of fuel energy consumption or MW : MJ s^{-1}. A high thermal efficiency means a low rate of fuel consumption and less expenditure of fuel to obtain a given amount of electrical power. Often the inverse of efficiency, that is, heat rate, is used to describe plant performance. Heat rate is measured as heat consumption per unit of electricity produced or kJ : kWh.

Due to the conversion from hours to seconds this value is around 10 000 kJ kWh^{-1} for typical fossil fuel fired plants. It is naturally desirable for a power plant to have a high thermal efficiency. This can affect the capital cost slightly as high efficiency plants will invariably have additional or more expensive components to improve the steam cycle efficiency. Usually, where fuel costs are high, there is a tendency to increase capital expenditure and improve efficiency to offset anticipated high operating costs.

Finally there is plant life. For the plant to be economical, it must operate for its anticipated life without major failures and consequent repair costs beyond those which were anticipated at the beginning of its life. As with efficiency, increased capital expenditure on certain components can reduce the risk of failure and provide increased assurance that the plant will reach the end of its life without a major failure.

Naturally there are always unforeseen circumstances causing premature failure, just as there are unpredictable events affecting fuel prices, and power generating utilities have to adapt their financing strategies to compensate for such changes.

1.2 Development and Evolution

Over the past century, power generating plants have evolved to take account of changing circumstances and new developments. The rapid growth in electrical technology allowed for easier generation, transmission and distribution of electrical power. This promoted the use of electricity and increased demand for it. Larger generating stations in turn required improvements to the steam cycle. An important driving force in the development of centralised generating plants was the conversion from traditional mechanical drives to electric motors in many industries.

Once established, the development in the associated technologies was rapid and great advances were made both in efficiency and in reliability. Later this growth rate became much slower as the limits of the technology were approached. This is evident in the changes in the size of turbine-generators, size of fossil boilers and nuclear reactors, and the thermal efficiency of power plants over the past century.

Table 1 shows the period of most rapid growth in unit size and the approach to limiting steam conditions. Economies of scale dictate that a single large unit is more economical and cheaper to build and operate than several small ones. There are however physical limits to the size of major components such as boiler furnaces and electrical generators. Similarly thermal efficiency is limited by the steam cycle temperatures and consequently materials of construction.

The net result was a rapid evolution in electrical technology and plant design from about 1900 to about 1940, a marked increase in unit capacity and thermal efficiency from about 1930 to 1970 and a slow development in thermal efficiency and component reliability from about 1970 to 2000.

Unit size (MW)	Steam conditions (MPa)	(°C)	Year first unit commissioned
30	4.1	454	1941
60	6.2	482	1952
100	10.3	566	1956
100	10.3	524	1957
120	10.3	538	1958
200	15.9	566	1959
275	15.9	566	1962
300	15.9	566	1963
350	15.9	566	1964
375	*24.1	*593	1965
500	15.9	566	1965
500	15.9	538	1968
660	15.9	566	1973
660	15.9	538	1976

*Supercritical steam conditions.

Table 1 Development of plant sizes and steam conditions
(adapted from British Electricity International “Modern Power Station Practice”)

Two major factors have affected the power industry in the last few decades. One has been the reduced rate of growth in demand for electric power in industrialised countries. The industrial market has fully converted from mechanical to electrical drives and the domestic market is saturated with electrical appliances. The slowdown in industrial production has however been offset by the increase in information services. Generally the growth rate in power demand at the turn of the century was about half of what it was about 40 years previously. The other is the difference in efficiency between “new” and “old” plants. There is not a large difference in efficiency between power plants built in say 1960 and 1990 whereas there was a very significant difference between those built in 1930 and 1960. Thus around 1960 the general philosophy was to retire old plants and replace them with more efficient plants usually having larger units. This made good economic sense as the new larger plants had lower fuel costs and benefitted from economies of scale. However these plants thirty years later in 1990 were not much worse with regard to efficiency and capacity than those currently being built. Thus it then made good economic sense to keep them operating and to save the capital cost of completely new replacement plants. Hence the newer philosophy of refurbishment rather than replacement. With the reduced rate of growth in electric power demand there is also less need for additional generating equipment and comparatively more resources have been put into refurbishment.

1.3 Factors Affecting Refurbishment

When a power plant reaches the end of its planned life, the loans initially obtained to finance its construction will have been repaid. Assuming that no additional major costs requiring extending financing have occurred, the plant can continue to operate free of capital cost repayments. Financially this is very attractive and such plants often become those producing the cheapest power for the power utility. There are of course some drawbacks. An aging plants tends to have a higher maintenance cost as components wear out. Also major components may be reaching the end of their life expectancy and have to be replaced at a cost not previously accounted for. Furthermore the thermal efficiency may have deteriorated resulting in slightly higher operating costs. If the remaining life of all components subject to deterioration can be assessed and the cost of those requiring replacement determined, then the price of refurbishing the plant and its expected future operating life can be ascertained. If this is economical with respect to replacement of the whole plant, then refurbishment is desirable. This is often the case with larger units in more modern power plants.

Thermal efficiency is generally related to the steam conditions in the power plant. The reheating and feedwater heating arrangement can also affect the efficiency, if not of a standard configuration. For many years, steam pressures and temperatures were standardised at around 16 MPa and 540°C respectively, as indicated in Table 1. This means that power plants have reflected similar and consistent efficiencies over a long period of time making "old" and "new" plants little different with regard to this. There have however been technological advances with respect to steam flow conditions in the turbine. Newer turbines have blading of more refined shape to smooth the flow of steam and to be less subject to wear in service. The consequent improvement in turbine internal efficiency has increased the thermal cycle efficiency. Advantage can be taken of this improved technology during refurbishment by replacing turbine internal components with those of advanced design. The final result is a power plant with better overall performance than when it was originally built. There is also the consideration of plant siting and infrastructure. The plant may be conveniently located on a site with all needed facilities and convenient access to fuel supplies and the grid system. A completely new plant may have to be built in a less convenient site and may be subject to a lengthy environmental assessment process. Such considerations may favour refurbishment.

Sometimes refurbishment is associated with a change in fuel, for example, solid fuel (coal) to liquid fuel (oil) where changing circumstances have made the latter cheaper. The capital expense of refurbishment is then offset by the lower future operating costs.

There is also the philosophical aspect of sustainability of resources where the reuse of existing materials is desirable. Refurbishment allows the reuse of most structural material and saves the energy required to manufacture and install equivalent new components in a replacement plant.

2. Material Characteristics

2.1 Aging Considerations

In a power plant, various components are subject to high stress and high temperature. For some there is cyclic stress as well and most high temperature components experience temperature transients during certain plant operations. For such components, alloy steels are generally used as they are best able to sustain these adverse conditions without deformation or failure. There are, however, limits. Ultimately any steel alloy will soften at a high enough temperature or deform under a high enough stress. It is a knowledge of these limits that allows designers to select operating conditions that will be within the limits so that the components do not fail in service. It is, however, not quite as simple as this. Materials, in particular steel alloys, are subject to aging when subject to adverse stress and temperature. Thus, after a period of time, they may fail at a stress level lower than that which they could sustain when new. They may also develop cracks or deform excessively after a long period in service. Eventually a point is reached when such components must be replaced to ensure that the plant can continue to operate safely without risk of component failure. This point in time, if it is able to be determined in advance, can be used to define the life of the plant. Ideally all critical components should reach this point at about the same time so that the plant can be retired or refurbished after an optimal service life. In practice, however, operational conditions may not be as originally planned and certain components may be subject to additional unforeseen conditions which accelerate aging or wear. It is therefore necessary to assess the condition of all critical components periodically and to estimate their remaining life. Thus there are two important considerations. Firstly, the properties of the original materials of construction must be known. Secondly, the deterioration of the materials in service must be ascertained.

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Biographical Sketch

Robin Chaplin obtained a B.Sc. and M.Sc. in mechanical engineering from University of Cape Town. Between these two periods of study he spent two years gaining experience in the operation and maintenance of coal fired power plants in South Africa. He subsequently spent a further year gaining experience on research and prototype nuclear reactors in South Africa and the United Kingdom and obtained a M.Sc. in nuclear engineering from Imperial College of London University. On returning and taking up a position in the head office of Eskom he spent some twelve years initially in project management and then as head of steam turbine specialists. During this period he was involved with the construction of Ruacana Hydro Power Station in Namibia and Koeberg Nuclear Power Station in South Africa being responsible for the underground mechanical equipment and civil structures and for the mechanical balance-of-plant equipment at the respective plants. Continuing his interests in power plant modelling and simulation he obtained a Ph.D. in mechanical engineering from Queens University in Canada and was subsequently appointed as Chair in Power Plant Engineering at the University of New Brunswick. Here he teaches thermodynamics and fluid mechanics and specialised courses in nuclear and power plant engineering in the Department of Chemical Engineering. An important function is involvement in the plant operator and shift supervisor training programs at Point Lepreau Nuclear Generating Station. This includes the development of material and the teaching of courses in both nuclear and non-nuclear aspects of the program.