Module 8: Economics of power plants

8.1. Objectives

On completion of this module, the student should be able to:

• understand the factors which determine the commercial viability of a power plant
• be able to quantify the major effects
• understand how the various cost components can be manipulated to optimise the commercial performance of a power plant.

8.2. Introduction

This module is not intended to cover all aspects of the economics of power plants. It is focussed on those aspects which have a large influence on the viability of a power generation business, but which may not be obvious or accounted for in standard practice. Knowledge of all the cost components in a business will equip plant engineers to make rational decisions about the utilisation of plant.

8.3. Some basic theory

8.3.1. The time value of money

8.3.1.1. Compound interest or future value

When money is invested with compounding interest, it will increase in value over time.

\[ FV = PV (1+r)^n \]

where

\[ FV \] = final value
\[ PV \] = initial amount invested
\[ r \] = fractional rate of interest per period
\[ n \] = number of periods

Example

$100 invested at 8 percent per annum for 5 years would be worth at the end of the period

\[ FV = 100 \times (1 + 0.08)^5 \]

\[ = 100 \times 1.4693 \]

\[ = 146.93 \]
8.3.1.2. Compound deflation or present value

Conversely to the compound interest formula, to amount to a set value in the future, a smaller amount needs to be invested with compounding interest now. Alternatively, an amount expected in the future is worth less today.

\[ PV = \frac{FV}{(1+r)^n} \]

where

- \( PV \) = present value
- \( FV \) = future value
- \( r \) = discount rate *
- \( n \) = number of periods

* Discount rate is the rate of compound interest an investor requires to achieve before making an investment. It will usually be higher than the current interest rate because the investor requires an additional return to cover the uncertainty (often called risk) in the investment.

**Example**

$100 to be spent in 10 years time with compound interest rate at 12 percent per annum would require a smaller present value to be invested now.

\[ PV = \frac{100}{(1 + 0.12)^{10}} = \frac{100}{3.1058} = 32.20 \]

Stated differently, an investor expecting an income of $100 in 10 years time when the discount rate is 12 percent p.a. compounding would regard that future value of $100 as being worth $32.20 immediately.

There are many slightly more complicated relationships (capital servicing charges, annuities, sinking funds, etc.) dealing with regular constant cash flows, but they are all derived from the formulae above.

8.3.1.3. Capital servicing charges

Provision for payment of interest and redemption of the original borrowing can be made using a capital recovery factor:

\[ R = P \cdot \left[ \frac{i(1+i)^n}{(1+i)^n-1} \right] \]

- \( R \) = value of each of a series of uniform payments
- \( P \) = principal borrowed
- \( i \) = fractional interest rate per period
- \( n \) = number of periods

The expression in square brackets is the capital recovery factor.

Most common spreadsheets have a good range of financial formulae. Definitions can vary between the different spreadsheet developers. Care is required in using these formulae, to make sure that the chosen function really represents the needs and intentions of the user.
8.3.2. Accounting rules

The Australian Accounting Standards Board has rules relating to the depreciation of assets (AASB 1021). The application of these rules by accountants is almost always time based, but there is provision for the use of methods based on the actual assessed remaining life (and earning capacity) of the asset. Depreciation is normally recognised as an expense.

The expenditure of plant life at a constant rate over time is a concept that is easily understood. What is not usually appreciated is that changes in operating conditions affect the rate of life consumption:

• Higher metal temperatures and higher metal stresses (resulting from higher operating pressures) both increase the rate of creep strain. This results in reduced creep life.
• Higher rates of change of temperature increase thermal stresses and the damage from individual fatigue and creep-fatigue cycles. The number of allowable cycles before component failure will be reduced. Because the useful life is a combination of creep life and fatigue life, the plant will then have a shorter remaining creep life, or fewer remaining fatigue cycles, or both.

8.4. Typical life cycle of plant

The life cycle of a typical plant might consist of the following steps:

• A need or an opportunity for a plant is conceived, and some technical feasibility studies and financial modelling will be undertaken. If the project is considered viable project financing will be put in place.
• Detail design, construction and commissioning follow. At the end of this stage, if the plant is capable of performing its designed duty, it has reached its maximum capital value.
• The plant will be operated, and with all the degradation processes such as erosion, corrosion, wear, creep, fatigue, creep-fatigue, etc. the value is decreased.
• Regular maintenance and inspection will partially restore the plant value.
• Major events such as life extension, re-rating, upgrading or refurbishment may make major capital injections or increase the earning capacity of the plant, and therefore increase the plant value.
• Eventually the plant is degraded or made obsolete by newer technology to the extent that it is uneconomic to keep operating. At this stage it will be shut down, decommissioned, and disposed of. The plant value will have reached a final value of $0.00.

8.5. Factors affecting economics

8.5.1. Capital costs

Capital costs are likely to be a major determining factor in initial planning for a power plant project. In circumstances where capital is limited (nearly always!) there will be drivers to reduce capital costs to limit the financing costs of a project. There is also a temptation to cut capital costs at the expense of future operating and maintenance costs. The effects of these competing factors is discussed in Section 6.3. The highest costs in a power plant project are usually capital and fuel.
For accounting purposes a general depreciation rate may be applied to capital values at each accounting period to allow for expected decreased utility of the plant as it ages. The depreciation expense in financial accounting does not necessarily reflect the physical degradation of the plant. Sound engineering input can rectify this situation.

8.5.2. Fuel

Fuel is likely to be the highest operating cost in a power station. It is fairly obvious that there will be strong drivers to reduce the cost of fuel. This can be achieved in various ways:

- maximise the efficiency of the existing plant to minimise fuel consumption
- modify the plant to burn different fuels
- purchase lower-cost fuel. This is only effective if the energy cost of the alternative fuel is lower than the starting position. Savings can be offset by increased costs in other areas such as fuel handling and preparation, operational limitations, furnace fouling, corrosion, erosion, flue gas cleaning and ash handling.

Decisions on purchasing of fuel need to be made on the basis of all the resulting effects. That is, unless the exact performance with a different fuel is known, test burns should be conducted to determine the effect of the fuel on such critical factors as:

- fuel burnout. The effects of fuel burnout are reflected in residual carbon in ash. Carbon in ash is a direct energy loss, but changes in regulatory attitudes to CO₂ emissions may make losses from carbon in ash less undesirable. Low NOx burner schemes tend to produce higher carbon in ash due to restricted oxygen supply during part of the combustion process. Carbon in ash represents a risk as combustion could take place further downstream in the process where it delivers no value and could damage the plant or process. It also reduces the saleability of the fly ash. The carbon in ash may have some inherent value because it should be in the form of char. This is an open structure with very large surface area, suitable for demanding filtration applications. The cost of separating and recovering the char may be justified if it increases the income from fly ash sales and carbon sale or re-use.
- flame stability. If the fuel burns unstably in the boiler it will pose an unacceptable risk of poor burnout or explosion.
- changes in heat absorption patterns in the boiler. This will change the rate of creep life degradation in the affected components. A cost can be attributed to the reduction in creep life.
- changes in erosion and corrosion patterns and rates. Observations on actual components may not be possible, but tests on material samples can provide useful guidance after the relatively short duration of test burns. The costs of erosion and corrosion can be quantified.
- changes in pulveriser performance. If pulverisers are unable to achieve full load, the loss in availability can be costed.
- changes in pulveriser wear rates. (This can be the largest single maintenance cost in a modern power plant.) The maintenance cost of pulverisers can be related easily to wear rates. Wear rates can be measured during trials, or predicted with less confidence from coal properties such as abrasion index.
8.5.3. Operating

8.5.3.1. Personnel costs

The highest cost of operating the plant is likely to be wages and salaries of the operating personnel. To extract the best performance from the plant these people need to be highly trained and consequently can expect to be adequately rewarded. Numerous strategies have been put in place to handle this situation:

- minimising the number of highly trained people on site at any time
- minimising the number of people working permanent shiftwork
- automating functions which do not require operator decision-making. Providing that there are enough people to provide safe operation of the plant, a small number trained in problem identification and solution is likely to be more effective than a large number with minimal training. Automation comes at a cost in capital and in on-going maintenance.

8.5.3.2. Operating conditions

Operation usually concentrates on running the plant within pre-defined limits. These limits will usually be set by the plant designers or manufacturers and finalised at commissioning.

Organisations with access to very good technical and costing advice may be able to re-optimise the plant operation by changing the operating parameters and limits. This requires, as a minimum, knowledge of:

1. The influence of major operating parameters on efficiency:
   - Main steam pressure
   - Main steam temperature
   - Reheat pressure
   - Reheat temperature
   - Flue gas exit temperature
   - Feed heaters in service
   - Condenser vacuum
   - Cooling water flow and temperature
   - Condenser fouling.

2. The influence of major operating parameters on safety and plant life:
   - Main steam pressure
   - Main steam temperature
   - Reheat pressure
   - Reheat temperature
   - Rates of change of load
   - Rates of change of temperature.

3. The effects of avoidable losses:
   - Throttling losses across feedwater control valves
   - Throttling losses across control dampers
   - Throttling losses across turbine governor valves
   - Heat losses due to leakage
   - Heat losses due to excessive blowdown.
These effects have been covered in detail earlier modules.

8.6. Cash flows—issues

8.6.1. Budgets are not always enough for optimum life management.

Many businesses impose budgets without proper knowledge of the consequences. A typical case is an arbitrarily chosen maintenance budget, often reduced by a percent from the previous year. If this situation cannot be overcome, the plant management must operate the plant within the budget.

The usual strategy is to delete or postpone essential maintenance. Plant engineers should be in a position to understand and quantify the consequences of these actions.

8.6.2. Short-term issues can prejudice the long-term life of the plant, e.g.

- Very high loading to take advantage of high energy prices. Creep life expenditure may exceed design expectations. This can be particularly important in reheater pipework where operating pressure and therefore operating stresses are directly related to turbine load. Creep rates are exponentially related to stresses.
- Maintenance may be postponed to avoid revenue loss or because there is a budget shortfall.
- There are numerous shutdowns for short-term financial gains such as when it appears that the cost of shutting down and restarting is less than the cost of continuing to operate over the same period.
- Rapid load changes are undertaken, driven by market conditions. This can have a dramatic effect on plant life due to the effects of fatigue and creep-fatigue resulting from thermal stresses.

Exercises later in this module will shed new light on this problem.

All these and other operating and maintenance costs need to be quantified to ensure that the true cost of plant operation is accounted for.

8.7. Costing of plant life expenditure

There is a need for knowledgeable people to assess all costs in order to be able to control the ‘financial controllers’. When all cost components are considered, there is often a compelling argument to pursue a particular technical course of action. Some examples are:

- There are often opportunities to change to the use of cheaper fuel. This may result in lower fuel costs, but could also result in higher costs from increased erosion and corrosion rates, reduced life of components and reduced efficiency.
- There is always an incentive to achieve longer runs between inspections to increase the proportion of time that the plant is able to generate income. It can also increase the risk of serious damage to the plant or extra repair costs. When these risks are costed, an obvious course of actions is revealed.
- In a competitive market there may be temptations to dispatch plant at rapid startup, loading and unloading rates to take advantage of high power prices. The enthusiasm for such actions may be tempered when the cost of plant life expenditure due to creep-fatigue is taken into account. A more likely outcome is that less aggressive startup and load change rates could be adopted and still have the benefit of the high power prices.

There are many possible ways to account for the cost of plant life expenditure. Some examples are given to take account of different business circumstances.
Financial model

The original financial model of the plant would have assumed that the plant started with an original value, and this value would decrease steadily over the life of the plant. The value at the end of the life of the project would be close to $0. This type of model is used for accounting and tax purposes.

Engineering Model

The value of the plant at any time should be a reflection of its ability to generate an income stream. The total of the income amounts (or perhaps profit amount) discounted back to present values is then a true reflection of the earning power of the asset.

Path 1: Defined and limited life

There is no plan to continue operation after the original plant life is exhausted. No major components will be replaced.

If a sequence of operations reduces the life of the plant, the future earning capacity of the plant is reduced by the lost income from generation over the period of the life reduction. Because of standardisation of component sizes and variations in operating conditions even within a single part of the plant, it would be almost impossible for all plant components to have identical useful lives. Therefore, when the first component reaches the end of its life, many other components will still have useful remaining life. Shutting the plant down at this stage loses the remaining earning capacity of the non-life expired plant.

This approach is not favoured for high value plant.

Path 2: Continuing and undefined future operation

It is planned to continue operation of the plant beyond the original planned life to an indefinite date. Major components will be replaced as they reach the end of their useful life.

If a sequence of operations reduces the life of plant components, the future earning capacity of the plant is not reduced. However, expenditure will be incurred in replacing the components. This is the usual business scenario applying in modern large power plants.

8.7.1. Costing of plant life expenditure

Components subject to degradation by creep alone will have a basic creep life at the design operating conditions. The actual operating conditions will include some fatigue cycles. Component life is exhausted when the sum of the creep life fractions and the fatigue life fractions reaches a predetermined value (less than 1). Some of the basic creep life will be sacrificed to allow for fatigue cycles.

Every fatigue cycle uses some potential creep life.

Example

A steam turbine is likely to be designed for about 200,000 hours running at full load and temperature, plus 2200 full fatigue cycles, plus 2200 half fatigue cycles. A full fatigue cycle comprises a startup at a maximum nominated rate and a shutdown at a maximum nominated rate. A half fatigue cycle consists of a startup at the maximum nominated rate, and a cooldown by natural cooling alone, i.e., a high stress start and a low stress shutdown. The underlying life of the turbine for creep alone could be well over 300,000 hours.
Each full fatigue cycle is estimated to be equivalent to about 30 hours of creep life. Every fatigue cycle will reduce the underlying creep life by some amount. Reckless operation such as imposing a some cycles of severity greater than a cold start, or a very large number of small cycles, will reduce the remaining available creep life.

Further calculations show that safe operating life under creep alone

\[ t_{\text{operating}} = 320,000 \text{ hrs} \]
\[ n_{f,\text{full}\_cycle} = 8,800 \]
\[ n_{f,\text{half}\_cycle} = 17,600 \]

The life fraction equation is

\[ \sum \frac{t_{r,\sigma}}{t_{\sigma}} + \sum \frac{n_{r,\sigma}}{n_{f,\tau,\sigma}} = D \quad (D < 1.0) \]

\[ \frac{200,000}{320,000} + \frac{2,200}{8,800} + \frac{2,200}{17,600} = 1.0 \]

In the first year at full load, 8760 hours of creep life are expended. For the purposes of this exercise assume that fatigue equivalent to 10 full cycles is accumulated in the same year.

**Life interactions**

Starting life fraction (start yr. 1) = 1.0

Creep life fraction used = \( 8,760 / 320,000 \)
= 0.027375

Fatigue life fraction used = 10 / 8,800
= 0.0011364

Total life fraction used = Creep life fraction + Fatigue life fraction
= 0.0285114

Remaining life fraction = 1.0 - 0.0285114
= 0.9714886

Remaining life (with no fatigue allowance) = 0.9714886 \times 320,000 \text{ hrs.}
= 310,876 hrs.

Creep life equivalent in year = 320,000 – 310,876 hrs.
= 9,124 hrs.

Fatigue contribution in year = 9,124 – 8760 hrs.
= 364 hrs.

This same process applies for each year, except that the remaining life fraction at the start of the year is the same as the remaining life fraction at the end of the previous year.
Life Effects of Creep and Fatigue

It is useful to be able to express all of the life effects in common terms such as remaining life hours in order to be able to translate them into financial terms.

**Life costing**

One method of costing life expenditure is to compare the remaining creep life at any time with the original creep life. (Consider it a remaining life fraction). The value of the component at any time is then

\[
V_n = V_{\text{new},n} \frac{t_{\text{rem},n}}{t_{\text{rem,new}}}
\]

where

- \(V_n\) = value of aged component at end of year \(n\).
- \(V_{\text{new},n}\) = value of new component at end of year \(n\).
- \(t_{\text{rem},n}\) = remaining life for creep only at end of year \(n\).
- \(t_{\text{rem,new}}\) = life of new component for creep only.

Comparison of \(V_n\) before and after an operation or sequence of operations allows an estimate to be made of the cost of those operations.

\[
\begin{align*}
C_0 &= \text{new cost of component at start of project} \\
C_n &= \text{new cost of component at end of year } n \\
r &= \text{fractional inflation rate} \\
n &= \text{year number}
\end{align*}
\]
CLFₙ = creep life fraction consumed in year n
FLFₙ = fatigue life fraction consumed in year n
RLFₙ = remaining life fraction at end of year n
Vₙ = value of component at end of year n
CLCₙ = cost of creep life expenditure in year n
FLCₙ = cost of fatigue life expenditure in year n
TLCₙ = cost of total life expenditure in year n

RLFₙ = RLFₙ₋₁ – CLFₙ – FLFₙ
Cₙ = C₀ x (1 + r)ⁿ
Vₙ = Cₙ x RLFₙ
TLCₙ = Vₙ₋₁ – Vₙ
CLCₙ = TLCₙ x CLFₙ / TLFₙ
FLCₙ = TLCₙ – CLCₙ

This method amounts to revaluing the assets every year, and would not normally be contemplated because as a one-off exercise it can be expensive. In the case of life costing, the consequences are so important that it is worth the effort. Also, if a good life management system is in place it should be easy to achieve this revaluation automatically.

Inflation rate = 3% / annum.
Component new cost, start yr. 1 = $10,000,000
Component new cost, end yr.6 = $10,000,000 x (1 + 0.03)⁶
= $11,940,523
Remaining life fraction, end yr. 6 = 0.82893182
Component value, end yr. 6 = $11,940,523 x 0.82893182
= $9,897,879
Component new cost, end yr.7 = $10,000,000 x (1 + 0.03)⁷
= $12,298,739
Remaining life fraction, end yr. 7 = 0.80042045
Component value, end yr. 7 = $12,298,739 x 0.80042045
= $9,844,162
Total life cost for year = $9,897,879 – $9,844,162
= $53,717
Creep life cost for year = Total life cost for year x CLF₇ / TLF₇
= $53,717 x 0.027375 / 0.02851136
= $51,576
Fatigue life cost for year = $53,717 - $51,576
= $2,141

In this case the cost of fatigue may appear to be relatively low. Increasing the operating stresses beyond the design limits, such as by increased thermal gradients, will cause a dramatic rise in fatigue life cost and a reduction in the useful life of the component.
Example

A boiler has been operating with average final superheater outlet temperature of 535 °C for the first 10 years of its life. Temperature variations across the boiler cause some of the outlet header inlet stubs to run 15 °C above the average temperature. It is proposed to raise the average superheater outlet temperature to 540 °C to take advantage of efficiency improvements. The fuel savings are expected to be $283,000/year. (See earlier example.)

No life assessment has been carried out, and it must be assumed that the material creep properties are at the lower bounds of the scatter band of test data. Under the current conditions the predicted creep life of the header (new) is about 221,000 hours. At the increased temperature the predicted header life (new) would be 168,000 hours.

The current cost of a new header is $600,000.

Assume inflation rate = 3%.

Calculate the effect on cost of life expenditure. For the purposes of this exercise, ignore fatigue effects.

The methodology for the previous example was used, except that no fatigue life fraction was applied. The remaining life fraction at the end of 10 years was applied to the shorter new creep life at the higher temperature.
Table 1: Extract from a spreadsheet to calculate cost of creep life expenditure for header. The sudden increase in cost between years 10 and 11 can be seen. (Source: Author)

<table>
<thead>
<tr>
<th>Time</th>
<th>Remaining creep life fraction at start of year</th>
<th>Remaining creep life at start of year</th>
<th>Creep life used during year</th>
<th>Remaining life</th>
<th>Remaining life fraction</th>
<th>Value of new header at end of year</th>
<th>Value of header at end of year</th>
<th>Cost of life consumption for year</th>
</tr>
</thead>
<tbody>
<tr>
<td>yrs.</td>
<td></td>
<td>hrs.</td>
<td>hrs.</td>
<td>hrs.</td>
<td></td>
<td>618,000</td>
<td>593,475</td>
<td>6,525</td>
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<td>8,760</td>
<td>211,982</td>
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</table>

Original creep life: 220741.5 hrs = 25.1988 yrs
Service to date: 87600 hrs = 10 years
Creep life fraction to date: 0.396844
Remaining creep life fraction: 0.603156
Creep life (new) at + 5 deg.C: 168,000 hrs. = 19.17808 yrs
Inflation rate: 3.00%
Cost of new header at start of year 1: $600,000
2.25Cr 1.0Mo Header

Figure 3: Remaining life over time. The increase in life consumption rate resulting from the increased operating temperature from year 10 onwards is evident. (Source: Author)

2.25Cr 1.0Mo Header Life Costs

Figure 4: Year-end value of header, and annual life consumption cost. The abrupt change resulting from the increase in operating temperature from year 10 onwards can be seen clearly. (Source: Author)
There are many components which would all experience this same temperature increase, so the cost in life expenditure over all these components would be considerable. Each component would have to be evaluated individually. Once again, these multiple assessments are well suited to automation.

8.8. Costing and plant optimisation

Plant will degrade in service, resulting in a mix of capital, operating, maintenance and plant life expenditure costs which depends on how the plant is operated. Individual components can cost millions of dollars and have replacement lead times in the order of years, and hence damage to these components can result in huge financial losses.

There is a wide range of cost mixes under which a plant can operate. Within this wide range there is likely to be a narrow range which will minimise costs for a particular set of inputs. There may be a disconnection between O&M costs and plant life costs because owners/operators do not understand the issues and costs surrounding plant life expenditure. There is a need to cost all components of plant operation so that the correct and intended mix of cost components is achieved.

The methodology described herein quantification of cost components which are not normally recognised or accounted for.

8.8.1. ‘Ideal’ situation

The best overall financial outcome is likely to be achieved when a plant owner designs, builds and operates a plant fully understanding all the cost components at all times. Plant operating conditions are then adjusted to optimise the trade-off between short-term profit and long-term life costs.

There would be a large effort to evaluate all the cost components with adequate precision. The thermodynamic processes are well documented, so that relationships between fuel costs, loading and operating conditions are not difficult to find. Each plant component is likely to have a unique life characteristic with operating conditions. Automation of calculations will allow easy extraction of the necessary relationships of life against operating temperatures and pressures.

8.8.2. Cost components

There are many components which contribute to the cost of production of electric power. Most of these have been referred to in some manner during the course to this point. The major components are now assembled to give an indication of how the final cost of electricity at the power station fence is derived.

8.8.2.1. Capital/capital servicing

Modern power plants are highly capital intensive. Owners are likely to borrow heavily to finance the acquisition of a power station, either by construction from new or by acquisition from a previous owner. It is not unusual for the cost of capital servicing to exceed 30 percent of the cost of power production.

Some organisations have built successful businesses by acquiring older plants with substantial remaining life, but at a substantial discount on the new price. Refurbishment is carried out where necessary, and the plant then operates and performs the same as a new plant of that technology but with much reduced capital servicing requirements. With the current interest in reducing greenhouse gas emissions, this strategy has fewer attractions because newer plants such as supercritical Rankine cycle and combined cycle plants are able to deliver higher efficiencies and therefore lower CO₂ intensity.
The providers of capital do so in the expectation of an adequate return. Lenders such as banks and other conventional financial institutions expect a return in line with current low-risk lending rates. They reduce their risk by securing their loans against the plant assets. In the event of failure of the business, the lenders have recourse to the sale of the assets to recover their investment loans. Plant owners carry a higher risk, as they do not have access to the full value of the assets because they are already secured by the lenders. Owners therefore expect a higher return on their capital to justify their higher risk. The owners’ expected rate of return is the discount rate.

8.8.2.2. Depreciation

Power plant equipment is not designed to last forever, and owners are allowed to claim an expense for taxation purposes to compensate for the ‘wearing out’ or obsolescence of their plant. Accounting standards (e.g., AASB 1021_8-97) require non-current assets that have limited useful lives (depreciable assets) to be depreciated over those useful lives and specify the manner in which this is to be done. The life of plant may be limited by its outright ability to perform its intended duty, or it may be rendered obsolete by changing technology or because associated equipment is no longer serviceable.

Where a plant has a long life, with its utility not being reduced significantly over time, straight line depreciation is used. The book value of the plant is reduced by a set fraction of the original value each year. Theoretically this process allows a plant to be depreciated to zero value.

Where a plant has declining utility over time, such as plant where performance or economy declines with age, it may be depreciated by the declining balance method. The book value of the plant is reduced by a set fraction of the value the previous year. This process cannot depreciate an asset to zero value. A residual value will remain at the end of the depreciation period.

These simple schemes for depreciation can obscure the fact that rates of plant degradation vary with mode of operation.

8.8.2.3. Energy inputs

Examples given throughout the text have illustrated the effect that different operating modes can have on plant efficiency. The cost of fuel input is calculated directly from energy generated and plant efficiency or heat rate.

8.8.2.4. Operation

The influences on operating costs have been described earlier. This category includes the cost of staff (and their support staff and facilities) to run the plant, and consumable purchases other than fuel and water. When plant requires continuous supervision, operating costs do not vary substantially with load.

8.8.2.5. Maintenance

Maintenance costs cover the expense of keeping the plant at a level of utility such that safety is maintained at the required high level, and the plant is capable of performing its required duty. Well-managed maintenance can be a determining factor in the success of a power generation business.

Maintenance is a study on its own, and this course is not intended to go into the finer details of maintenance management. For the purposes of this module, maintenance is considered to have fixed and variable components.
Fixed components are the result of processes which are time-base only, whereas variable components are affected by throughput volume such as pulveriser wear, boiler tube erosion, ductwork and airheater erosion, ash plant wear and erosion, high temperature component creep and fatigue.

8.9. A power costing model

The following example illustrates the effects of the various cost components on the final power cost. (The numbers are contrived, and simplified to suit this purpose.)

An owner builds a coal-fired power plant with a single boiler—turbogenerator unit with the following plant statistics:

- Unit capacity (MCR) = 500 MW
- Plant cost = $500,000,000
- Owner capital contribution = $200,000,000
- Capital borrowing = $300,000,000
- Coal specific energy = 20 MJ/kg.
- Coal cost = $30 / tonne
- Coal ash content (as received) = 20%
- Water cost = $1 / kl
- Heat rate at 100% load = 8800 kJ/kW-hr
- Heat rate at 50% load = 10,000 kJ/kW-hr
- Rate of decline in heat rate = 0.3% per year.
- Heat rate is restored at major overhauls.
- Fraction of plant affected by creep ($ value) = 30%
- Safe creep life at 100% MCR = 200,000 hrs
- Safe creep life at 50% MCR = 600,000 hrs
- Auxiliary power at 100% MCR = 7% of unit output
- Auxiliary power at 50% MCR = 10% of unit output
- Water usage rate = 9 kl/hr

The unit employs an air-cooled condenser.

- Planned life of project = 30 years
- Overhaul interval = 4 years
- Time to refurbishment = 16 years
- Capital borrowing rate = 7% p.a.
- Inflation rate = 3% p.a.
- Owner’s required discount rate = 12% p.a.
- Cost of overhaul = $5,000,000
- Cost of refurbishment = $30,000,000

Determine a minimum power price to meet the owner’s profit requirements.
Examine the effects of capacity factors changing over the range 60%, 70%, 80%, 90% on the following indicators:

- Owners’ minimum required power price
- Cost of creep life expenditure
- Depreciation amounts

**Working**

**Assumptions**

The unit operates at only two loadings—100% MCR and 50% MCR. The capacity factor is achieved by varying the proportion of time that the unit spends at each load. It is assumed that each unit runs for 8760 hours per year, and that the capacity factor accounts for time out of service.

\[
\text{Load.1} = 500 \text{ MW} \\
\text{Load.2} = 250 \text{ MW} \\
C = X \cdot 1 + (1-X) \cdot 0.5 \quad \text{where} \\
C = \text{capacity factor}, \\
X = \text{time fraction at 100\% load.}
\]

For capacity factor = 60%, \(X = 0.2\)

Taxation effects have been ignored. Where applicable, they add another degree of complexity, and can have a major effect on drivers for improved efficiency.

The following figures are all on an annual basis.

Annual financing charge ($300,000,000 over 30 years at 7\% p.a.)

\[= \$24,175,921\]

Generation at Load1 = Load.1 \times 8760 \text{ hrs} \times X

Generation at Load2 = Load.2 \times 8760 \text{ hrs} \times (1-X)

Heat Rate.1 at year n = Basic heat rate.1 \times (1 + \text{degradation rate}) \times (n - \text{year of last overhaul})

Heat Rate.2 at year n = Basic heat rate.2 \times (1 + \text{degradation rate}) \times (n - \text{year of last overhaul})

Energy input Load1 = Generation at Load1 \times \text{Heat Rate.1 at year n.}

Energy input Load2 = Generation at Load2 \times \text{Heat Rate.2 at year n.}

Energy in Total = Energy input Load1 + Energy input Load2

Coal consumed = Energy in Total / Coal Specific Energy

Ash production = Coal consumed \times \text{Coal ash content (as received)}

Aux. energy Load1 = Generation at Load1 \times \text{Aux. Power fraction Load1}

Aux. energy Load2 = Generation at Load2 \times \text{Aux. Power fraction Load2}

Aux. Energy Total = Aux. energy Load1 + Aux. energy Load2


Life fraction used at Load1 = \text{Hours run / Safe creep life at Load1}

Life fraction used at Load2 = \text{Hours run / Safe creep life at Load2}

Life fraction used for year = Life fraction used at Load1 + Life fraction used at Load2
Remaining life fraction at end of year  = Remaining life fraction at start of year
                – Life fraction used for year

Value of plant at start of year

Operation and Maintenance Costs
Coal cost, coal handling, coal pulverising, ash handling, fuel oil, water, variable O&M are all
multiplied out at their applicable rates. Fixed O&M is evaluated.
The total income required by the owners is the sum of the capital servicing costs, the
required return on investment, and O&M costs.
Owners’ desired power price  = Total income required / Energy sent out.
To obtain predicted costing and pricing, all costs except the capital servicing charge and the
owners’ required return on investment are inflated for each year.
The cost of life expenditure is illustrated in Figure 5. Standard accounting practice gives a nominal depreciation based on the capital inputs to the plant. These capital inputs are depreciated over their expected useful lives. For example, the value of a 4-yearly overhaul is depreciated over 4 years, as it is expected that the same basic expenditure will be required at the end of that period to restore the plant to its full functionality. As the majority of the plant will be rendered obsolete at age 30 years, the major refurbishment in year 16 will only be useful for the remaining 15 years of the life of the plant, and hence is depreciated over those 15 years.
Other major capital work such as generator rewinds, turbine upgrades or major electric motor replacements are depreciated in this same manner.

![Comparison of Life Expenditure Costs](image)

**Figure 5:** Data drawn from the spreadsheet referred to in Table 2, showing the ‘constant’ values for depreciation (dependent only on the capitalised value of the plant), compared with the wide range in cost of plant life expenditure as a result of different capacity factors. (Source: Author)

### 8.10. Conclusions

The important concepts covered in this module are:

- The commercial success of a power plant is governed by many factors. Many of these factors are determined at the project initiation and design stages.
- The capital cost is a dominating influence on the project success, as an overcapitalised plant will not be able to earn enough income to service the capital. An undercapitalised plant is unlikely to be able to meet the required performance targets.
- The costs associated with fuel—purchase, transport, storage, handling, milling, flue gas cleaning and ash collection and disposal—can also be very high. Every reasonable effort should be made to minimise fuel consumption because of the direct costs and flow-on effects of purchasing and burning coal.
- Efficiency should not be sought without regard for the competing costs of plant life expenditure.
- Careful plant operation can minimise the costs of plant life expenditure by minimising creep and fatigue effects.
- Knowledgeable people, knowing all the cost components affecting the cost of power production, can be in a strong position to ensure that plant is designed and operated to perform with high efficiency and high profitability.
Summary

When you finish this module you should be able to describe the major factors that affect the economics of power plants. You need to understand that some costs are overlooked when using standard accounting methods, whereas all cost components should be accounted for in order to fully understand a power generation business.

The learning objectives at the start of this module provide a detailed breakdown of the task described above. Make sure that you can do each activity listed in the learning objectives.

If you feel that you cannot achieve the learning objectives for this module, work through this Study Guide again and read the relevant sections from recommended books.

Remember that if you need assistance in your study, the lecturer and other University staff are there to assist you. We are only a phone call away.

Checklist

Use the following checklist to identify whether you achieved the essential elements of each of the enabling objectives and learning outcomes in this module.

<table>
<thead>
<tr>
<th>Performance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Financial Theory</td>
</tr>
<tr>
<td>☐ Demonstrate proficiency in the use of standard financial formulae.</td>
</tr>
<tr>
<td>☐ Be able to use the equivalent financial formulae provided in spreadsheets.</td>
</tr>
<tr>
<td>Factors Affecting Economics</td>
</tr>
<tr>
<td>☐ Demonstrate understanding of the various cost components in a power generation business, and the factors that affect them.</td>
</tr>
<tr>
<td>Cash Flows</td>
</tr>
<tr>
<td>☐ Describe the factors which should be taken into account in determining the full costs and benefits in changing the operating patterns of a plant.</td>
</tr>
<tr>
<td>Costing of Plant Life Expenditure</td>
</tr>
<tr>
<td>☐ Describe methods to determine the cost of plant operation.</td>
</tr>
<tr>
<td>Power Costing</td>
</tr>
<tr>
<td>☐ Describe methods which can be used to determine the underlying costs of power generation.</td>
</tr>
</tbody>
</table>