In this paper the operation of Huntly power station is discussed in terms of its projected role within the New Zealand electricity system. Aspects of coal supply including underground and opencast mining and coal stockpiling are considered using linear programming and Monte Carlo modelling techniques.

1. Introduction

Huntly power station which will soon be commissioned is expected to run as a hydro-firming station for several years. In this mode of operation Huntly would be expected to run at maximum capacity in years when inflows to the electricity system's storage lakes are low ('dry' years) and at minimum output when inflows are high ('wet' years) subject to there being demand for power.

When the four units at Huntly, each rated at 250 MW, are commissioned the station will have the capability of consuming some 2600 kt of coal per year. Even in the event of a very wet year there will always be approximately 350 kt of coal consumed in order to maintain full operational capability. Although the output of Huntly can vary widely there are limitations to the amount of variability that coal mining operations can accommodate. For this reason stockpiling of large quantities of coal must be investigated. However the problem cannot be confined to just the Huntly power station and mines. As the New Zealand electricity system is one integrated network the operation and coal storage at the power station should be treated as an integral part of this system.

2. Coal supply

In the Waikato region the recoverable coal reserves are estimated to be 425 million tonnes with approximately 340 million tonnes (80 percent) in the form of underground deposits with the remainder suitable for opencast mining. The recovery factors assumed are 50 percent for
underground coal and 90 percent for opencast, however some of the reserves may prove to be uneconomic to mine for power generation purposes.

The main source of coal for the Huntly power station will be the Huntly West underground mine which is designed to produce 1.2 million tonnes of coal per annum when in full production. It is expected during the next ten years that coal required in addition to that produced by the West mine will be supplied from opencast mines and as 'fines' from other mining operations in the area. When the power station becomes base-loaded it is likely that a new underground mine will be opened to avoid using large amounts of opencast coal.

Opencast coal is viewed as an important national reserve. Even if this coal can be mined more cheaply than that of underground coal it will only be used for power production when there is a shortfall in underground production and there is insufficient coal available from stock. Figure 1 shows the coal supply interactions between the power station, stockpile and the underground and opencast mines. There will always be a minimum quantity of coal maintained in stock as a contingency against mechanical failure or production problems at the West Mine. While this minimum quantity has yet to be finalised one month's supply for the station or about 350 kT is assumed. This may result in some opencast coal being stockpiled.

The following factors will affect the amount of coal required:

(i) demand for power
(ii) amount of storage at hydro storage lakes
(iii) Huntly unit commissioning schedule
(iv) allocation of Maui gas for electricity production
(v) commissioning of new stations, and
(vi) the performance of Huntly and existing stations.

As Huntly is a dual-fired coal/gas station Maui gas allocation is significant. From a national viewpoint it is desirable that New Zealand Electricity (NZE) use any gas allocated at a high load factor in order to recover valuable condensate and so offset the need to import additional oil. Another important feature of underground mining operations is the need to maintain a steady level of production. Although hydrology will swing from dry to wet conditions and new hydro stations may reduce the need for coal there can be little reduction in output from underground mines for workforce reasons. The coal stockpile will act as a buffer between the mines and the power station.

3 Methodology

The problem of coal supply to Huntly power station is complex involving a high degree of interaction/substitution within the electricity system. This paper examines the size of coal stockpile most appropriate to the mode of operation of the station and considers levels of both underground and opencast coal production. It should be realised that there is no unique solution to the allocation of coal to the station.

As previously mentioned two of the main uncertainties are the future demand for power and the hydro inflows. To gain insight into the operation of the power system with Huntly incorporated, a 15 year study period has been chosen from 1981 to 1995. A fixed expansion plan has been assumed based on the Report of the Electricity Sector Planning Committee[^1]. Demand forecasts used are given in the Report of the Electricity Sector Forecasting Committee[^2]. Two approaches to the problem have been adopted - linear programming and Monte Carlo simulation.

(a) Linear Programming (LP)

The reason for using this method was to obtain a lower bound on underground mining activity. It is recognised that, in general, optimisation techniques such as LP produce results which are too optimistic and are not able to be attained in practice. However the LP formulation has the advantage of being able to cope with the vast number of constraints that a mathematical model of a whole power system must have.

In the LP formulation the stochastic nature of future demand is captured by evaluating power system fuel costs for each of three demand scenarios weighted by a probability of occurrence. For each year of each demand set three hydrology states (wet, mean and dry) are considered which are also probability weighted. Thus for each year nine sub-problems are chosen to represent future uncertainty. The complete LP model has some 6300 rows and 9400 variables and takes 13 minutes CPU to solve using the MPSX/370 LP package and an IBM 3033 computer.
The coal supply sub-model pertaining to Huntly is now described.

Let the subscripts d, h and i represent demand, hydrology and the year respectively. The variables are defined thus:

- \( U_i \): underground production
- \( O_{dhi} \): opencast production
- \( E_{dhi} \): coal consumed by Huntly
- \( USTN_{dhi} \): underground coal to station
- \( USTK_{dhi} \): underground coal to stock
- \( OSTN_{dhi} \): opencast coal to station
- \( OSTK_{dhi} \): opencast coal to stock
- \( STKSTN_{dhi} \): stockpiled coal to station
- \( S_{di} \): expected end-of-year stock
- \( Send_{dhi} \): end-of-year stock
- \( \lambda_h \): probability of inflow state
- \( \lambda_d \): probability of demand state
- \( C \): cost of coal
- \( \beta_i \): discount factor = \( 1/(1 + I) \) where I is the discount rate

The problem -

Minimise:

\[ (U_i + (O_{dhi} + Send_{dhi}) \lambda_d \lambda_h)C \beta_i \] (1)

Subject to: material balance equations for underground and opencast coal

\[ U_i = USTN_{dhi} + USTK_{dhi} \] (2)

\[ O_{dhi} = OSTN_{dhi} + OSTK_{dhi} \] (3)

There is a limit to the rate of buildup in underground production so

\[ U_i \leq 1.25U_{i-1} \] (4)

The average end-of-year coal in stock is taken as the weighted sum of end-of-year stockpiles for each hydrology condition, for each demand

\[ S_{di} = \sum_h \lambda_h Send_{dhi} \] (5)

therefore the amount of coal available from stock is given by

\[ STKSTN_{dhi} \leq S_{di-1} \] (6)
Coal used by the station is

\[ E_{dhi} = USTN_{dhi} + OSTN_{dhi} + STKSTN_{dhi} \]  

(7)

and the resulting end-of-year coal in stock is

\[ S_{dhi} = OSTK_{dhi} + USTK_{dhi} + S_{d-1} - STKSTN_{dhi} \]  

(8)

In addition to the equations there are bounds on underground and open-cast coal production and the stockpile capacity.

(b) Monte Carlo Simulation

The process of sampling from probability distributions of random variables is known as Monte Carlo simulation. Probability distributions of future demand and the inflows into composite models of the North and South Island hydro systems are sampled. The samples become inputs to a simulation model of the electricity system. This model is a two island annual model with explicit representation of all thermal stations and full account of the inter-temporal relationships between hydro and coal storage systems.

Coal modelling within the Monte Carlo model is essentially the same as that of the LP model except that no approximations are made regarding the expected end-of-year stockpile for each demand state. The model is run for 1000 iterations through the sequence of 15 years taking about 45 seconds CPU. Thus the fuel cost of operating the power system and the associated stockpiling charge is determined for a combination of inflows for a given demand scenario which is obtained by sampling from a normal probability distribution whose mean is the expected demand for each future year. Probability distributions of discounted system fuel cost, coal in stock, open-cast consumption, generation by Huntly, hydro system storage and a host of other system parameters are obtained and used in the decision-making process. The Monte Carlo model highlights the complementary nature of the coal-hydro storage system. For instance, in the event of a succession of wet years when the coal stockpile fills surplus coal is burnt and hydro storage is conserved.

A heuristic approach is adopted using the simulation model to find a satisfactory level of underground production, (or coal supply from whatever source) coupled with a suitable stockpile capacity. The method is to try alternative levels of underground production using the solution to the LP as the lower bound and the maximum possible output from the West mine as the upper bound.

4 Results

Figure 2 shows some of the underground coal production scenarios evaluated with the aid of the power system simulation model. As expected the solution to the LP formulation (scenario 1) provided the lower bound. Scenarios 3 to 6 were derived by considering alternative years of achieving the designed maximum output of the West mine. The cross-hatched region indicates production levels that give least cost.
solutions. Between scenarios 3 and 5 and 4 and 6 the expected net present value (10% discount rate, 1981 money value) of fuel cost is within $10 million of the lowest cost region. In figure 3 the annual present worth costs of fuel are shown for scenarios 1, 2 and 3. Scenario 1 shows low costs in the immediate future but when Huntly moves into a base-loaded role the underground mine cannot supply at the required rate. The costs for scenario 2 are high initially because of the cost of mining and storing coal for several years before it is used.

The rate of underground coal production is the most significant of the indeterminate parameters associated with coal supply so initial studies to determine acceptable underground coal supplies are undertaken with a 2000 kT capacity stockpile. Figure 4 shows the expected amounts of end-of-year coal in stock for the three scenarios. Notice that if coal was taken from the West mine at the maximum rate a large stockpile would soon result. An alternative to such a large stockpile and high coal production is to limit the coal in stock by burning surplus coal and conserving hydro storage. This approach need not necessarily be more expensive as there is less interest payable on the cost of coal in stock and in the event of a dry year higher hydro storage coupled with the ability to draw on opencast coal reserves could result in significant fuel cost savings. However the electricity system does not have a large amount of hydro storage capacity in relation to the size of the hydro system and so if excess spillage is to be avoided generating at Huntly to conserve storage would have to be carefully planned. During the five year commissioning period of Huntly the amount of coal stockpiled should be commensurate with the station's capacity to burn coal and the underground production buildup to design output of the West mine.

Based on the previous discourse scenario 3 was chosen as a compromise for coal supply. A conservative solution would be to adopt scenario 5 for the next two to three years, then, if demands showed a decrease the build-up may be slowed down. To adopt a lower supply scenario could result in a shortage of coal if demands were to increase above those projected for the mid 1980s. Figure 5 shows the sources of expected coal burned by Huntly based on scenario 3. Studies have shown that under this scenario a 800 kT capacity stockpile is adequate. The amount of coal in such a stockpile in any one year may vary considerably as shown by the probability surface in figure 6. By analysing such graphs planners can attempt to reduce some of the uncertainty associated with operating a hydro-firming power station such as Huntly.

The results presented serve only as a guide for decision makers. There is a need for more detailed simulation work using a finer time scale as there is considerable variation in station generation patterns within each year. Demand forecasts will change from year to year and so will much of the information upon which this work is based, therefore it is essential that similar studies be repeated annually.
FIGURE 4: EXPECTED COAL IN STOCKPILE

FIGURE 5: EXPECTED COAL CONSUMPTION
5 Conclusion

This work has shown that the concept of a large capacity coal stockpile at Huntly is soundly based. If coal is accepted from the mines in quantities indicated by scenarios 3, 4 or 6 a stockpile capacity of 800 kT is sufficient. Mines production constraints may require that coal be taken by NZE according to scenarios 2 or 5 in which case provision should be made for a 1000 kT stockpile. Further, stockpiling large amounts of coal produced from underground mines is consistent with using opencast coal as a strategic reserve, that is, in large amounts only in dry years.

6 Acknowledgements

The author is grateful to the General Manager of New Zealand Electricity for permission to present this paper and to colleagues within the Ministry of Energy for providing information and advice during the course of this work.

7 References


(2) Report of the Electricity Sector Forecasting Committee, New Zealand Electricity, Wellington, 1991