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EVALUATION OF CLEANER COAL PLANT OPERABILITY

Analysis of the benefits of operational flexibility

PROJECT SUMMARY 284

CLEANER FOSSIL FUELS PROGRAMME
– CLEANER COAL R&D PROGRAMME

OBJECTIVES

- To develop a model that allows the value of operational flexibility (or the cost of inflexible plant) to be calculated.
- To apply that model for typical plant data for coal-fired integrated gasification combined cycle plant and conventional PF plant to calculate the benefits of operational flexibility.
- To apply the model to Integrated Gasification Combined Cycle (IGCC) plant with varying levels of integration (which affects start-up times) and also to optional hydrogen production.

SUMMARY

Clean power technologies have been developed to achieve high efficiencies and low emissions. However, in the current liberalised power market, electricity prices fluctuate, and thus the operational flexibility plays an important role in the plant profitability.

In order to determine the value of this flexibility, the profit that a plant can make is compared to the profit of a perfectly flexible plant (i.e. instantaneous start-up and shutdown times). The difference is the Operational Inflexibility Cost (OIC) – in effect the value of flexibility. Electricity prices from the UK Pool in 1997 were used as the source data for the time-varying electricity price. Realistic operational parameters were chosen for plant start-up times, ramp rates and costs.

The model has been developed and tested successfully. However, many assumptions about IGCC have been made due to the lack of good operational data and there is scope to further refine the scheduling algorithm so the results are indicative rather than definitive.

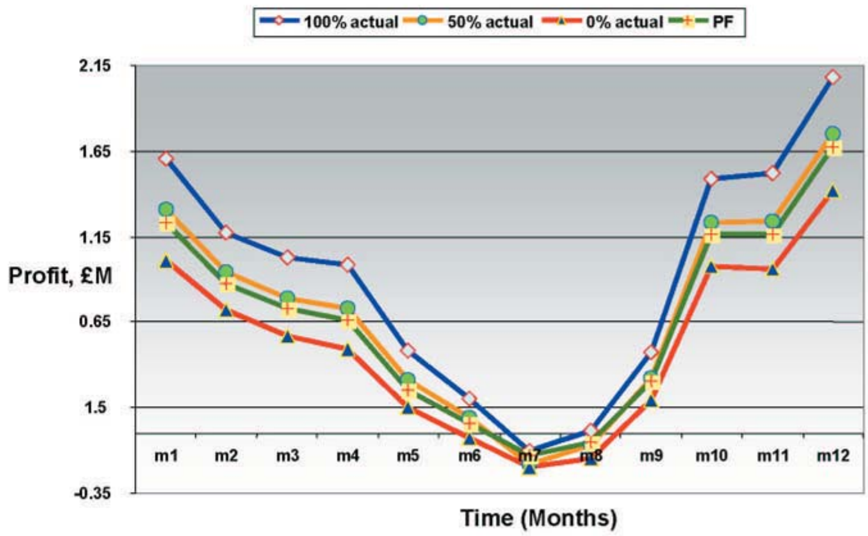

Figure 1. Profit (excluding fixed costs) against month for IGCC with varying levels of integration and PF, based on 1997 pool prices.

The calculated operational inflexibility costs ranged from between 0 (for base load operation) to about £2.5M p.a. (for about 50% utilisation) on a 250 MW unit. This income has a maximum capital value of about £100/kW.

Co-production of hydrogen (which allows the gasifier to stay on-load without the gas turbine in service), and the scheduling of maintenance have also been investigated and can be valued in the same way.

The model clearly shows that although the operational inflexibility cost can be significant, overall profitability is more dependent on the base capability of the plant. For the data used, the higher efficiencies of highly integrated IGCC more than offset the lower flexibility.

BACKGROUND

In liberalised power generation markets, there can be considerable rewards for being able to generate in a flexible manner and, conversely, the penalties incurred by an inflexible unit can be significant. Operational parameters such as start-up times, load-following ability and Minimum Stable Generation (MSG) are therefore of increasing interest both for existing units and in evaluating options for new plant.

However, there is a trade-off between high operational flexibility on the one hand and other desirable plant features, such as low running costs, high availability, high efficiency and minimum capital investment, on the other.

It is therefore desirable to be able to put a monetary value to increased plant flexibility in order to be able to determine if the benefit gained outweighs the costs incurred.

Development of clean coal technologies has often overlooked plant flexibility in pursuit of other goals, chiefly high efficiency and environmental performance. It was assumed that any new, high efficiency unit would be run base-load for its early years of operation and thus any losses associated with poor operational flexibility could be discounted, arising only towards the end of the station's life.

However, under liberalised power markets, this assumption can no longer safely be made. By way of example, both of the two large European coal-fired IGCC units, at Buggenum in the Netherlands and Puertollano in Spain, were designed and built for non-liberalised markets in which the units could be run at base-load. The designs chosen have a high degree of integration between the various parts of the overall IGCC process, sacrificing flexibility for high efficiency. The electricity markets of both Spain and the Netherlands have since been liberalised and, as a result, both units have struggled.

Falling prices mean that they are not always successful in bidding into the system as base load units; but their long start-up times prevent daily two-shift operation to catch peak prices. The very poor operational flexibility of IGCC has been identified by the Foresight Task Force as one of the major barriers to its adoption (Foresight, 1999).

In response, this project was set up by E.ON to investigate ways of putting a monetary cost to plant inflexibility. The project was undertaken in collaboration with UMISTs Department of Process Integration, who are world leaders in the science of process optimisation and who possess the necessary optimisation and computing expertise. The DTIs interest is primarily because of the importance of this subject to IGCC; however, the issue is of general applicability to all types of generating technology.

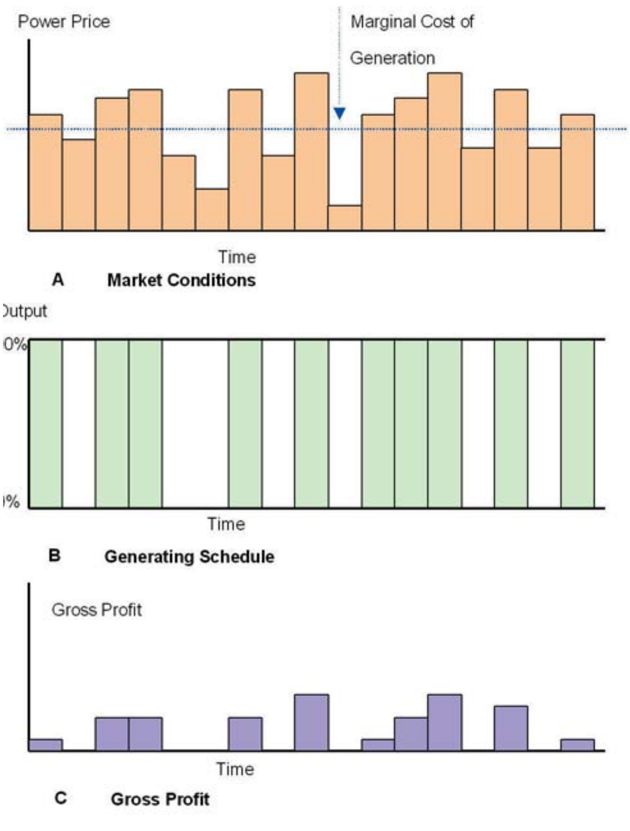

Figure 2. Operating Strategy for a perfectly flexible unit

METHODOLOGY

Operational Inflexibility Cost

The extent to which the operational flexibility of a unit affects its overall commercial performance depends on market conditions, in particular the price profile for the generated electricity.

For this study, the pool purchase price for 1997 was used to provide an example variation of price by time of day and by season.

In order to ascribe a cost to the inflexibility of a unit, the actual profitability of the plant (excluding fixed costs) was compared with the actual profitability of a notionally identical plant, but that was perfectly flexible. The perfectly flexible unit is defined as having zero start-up time, infinite loading and de-loading ramp rates and zero start-up cost. It is therefore able to run at full-load whenever the electricity price is above the margin cost of generation, and switch off whenever the price is below marginal cost. This is illustrated in Figure 2.

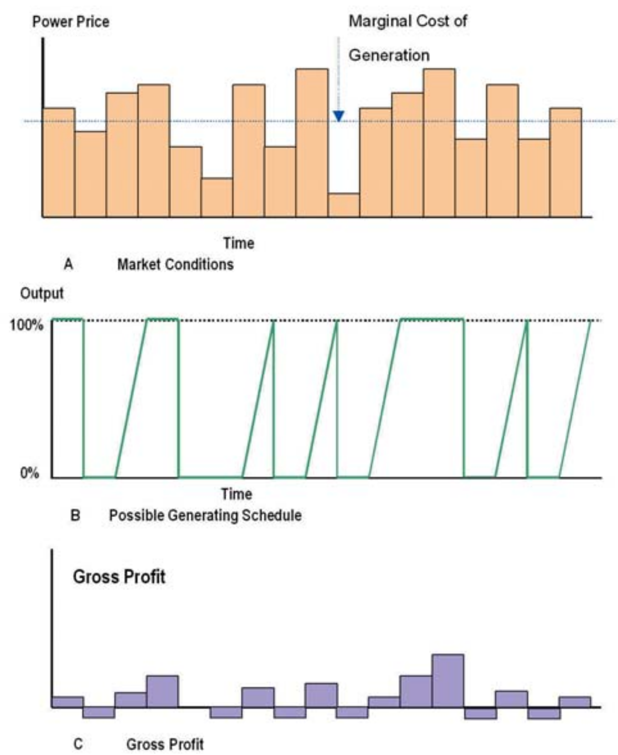

Figure 3. Operating Strategy for a real unit

For the real inflexible unit (Figure 3), the computer simulation seeks to choose a running regime that maximises overall profitability, but this inevitably results in some periods of operation at prices below marginal cost, and/or some periods of operation at reduced load when prices are above marginal cost.

The algorithm that has been developed uses basic input parameters such as the following: coal feed rate, ramp rates, load at synchronisation, load at MSG, full load output power and Air Separation Unit (ASU) power consumption/ MW generated. The objective is then to find the appropriate operational mode for each time period so as to increase the actual (achieved) profit and decrease the Operational Inflexibility Cost (OIC).

The algorithm provides an output of; the optimal operation for each period, optimal start-up and shutdown times, the optimal time taken for loading and de-loading the unit, the 'ideal' profit for an 'ideal' unit, the maximum profit that can be realised based on the operational strategy of the real unit. The OIC is the difference in profit between the real plant and the equivalent perfectly flexible unit.

HYDROGEN CO-PRODUCTION

One of the drawbacks of using gasifiers for power generation is the long start-up times that are required if the gasifier is cold (up to 100 hours). If the syngas from gasifier is converted to produce hydrogen when power generation is not required, then the gasifier can be kept warm. In this simulation, hydrogen was valued at £3/GJ.

Co-production of hydrogen (and the consequent extra income) is dependent on the degree of integration of the plant. If fully integrated, air for the gasifier is only available when the Gas Turbine (GT) is on load so hydrogen can only be produced when the GT is on load. For partially integrated or non-integrated plant, hydrogen can be produced when the GT is not running.

The algorithm operates in a similar manner to the algorithms for operational scheduling, but in addition will give the profit for the co-production of hydrogen.

RESULTS

The results here depend on the plant assumptions, fuel costs and electricity price. While realistic data has been used, the results should be taken as indicative because large differences in these input parameters occur from project to project. The main purpose of these results is to illustrate the success of the methodology.

Table 1 provides the headline results based on the assumptions made for 250 MW units. In this case a high cost of fuel (£2.2/GJ) was used to drive flexible running. Two different IGCC's were considered – one being designed for maximum efficiency with a fully integrated cycle (eg. GT providing compressed air to the ASU) denoted as 100% IGCC, one being a less efficient more flexible plant with no integration (denoted as 0% IGCC). Note that the quoted profit is simply income minus marginal cost of generation – it does not include any fixed or capital operating costs.

	efficient IGCC	flexible IGCC	PF
Off-load	36.1%	48.3%	45.0%
Ramping	9.0%	7.0%	7.7%
Full load (%)	54.6%	44.1%	48.4%
Actual profit, £M	11.1	6.50	8.11
Ideal profit, £M	13.2	8.74	10.5
OIC, £M	2.18	2.24	2.43

Table 1 – Results for 250 MW machines

The results show that even though the efficient IGCC is the least flexible (lowest ramp rates and longest start-up time), it has the lowest OIC. The reason is that it's higher efficiency allows it a longer operating period where power prices are above marginal costs. The higher efficiency makes operational flexibility less valuable.

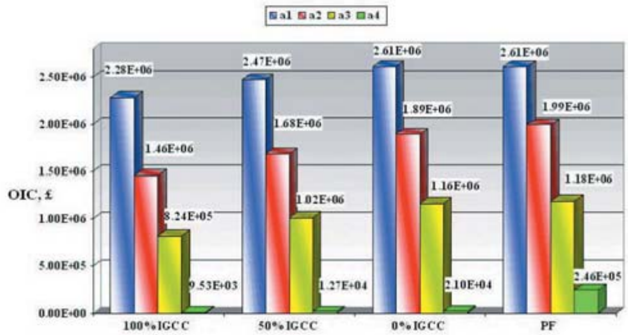

Figure 4. Operational Inflexibility Cost using different fuel prices; a1 = 2.2 £/GJ, a2 = 1.8 £/GJ, a3 = 1.4 £/GJ and a4 = 1.0 £/GJ.

Note that the OIC is significant – £2.3M per year has a capital value of about £100/kW, which is more than 10% of the cost of a new PF plant.

Figure 4 shows the effect of fuel price on this. (It also incorporate a 50% integrated IGCC, being partially integrated as this was deemed more realistic than the two extremes. The effect of changing the fuel price is to reduce the marginal cost of generation, and this increases the proportion of time the units run. The effect of this is to reduce the OIC, and for coal at £1/GJ, it is negligible for all technologies based on the assumptions made.

The results for hydrogen co-production show that, for an assumed value of hydrogen of £3/GJ, the flexible IGCC becomes more profitable than the efficient IGCC because it is able to cease generation but continue to make hydrogen when the electricity price is low, despite its lower cycle efficiency.

This same methodology was also successfully applied to maintenance scheduling.

CONCLUSIONS

- The methodology to value operational inflexibility has been developed and applied to coal-fired IGCC units and PF units.
- The calculated operational inflexibility costs ranged between 0 (for base load operation) and about £2.5M p.a. (for about 55% utilisation) on a 250 MW unit.
- Co-production of hydrogen (which allows the gasifier to stay on-load without the gas turbine in service), and the scheduling of maintenance have also been investigated and can be valued in the same way.
- The model clearly shows that overall profitability is more dependent on the base capability of the plant than its flexibility. For the data used, the higher efficiencies of highly integrated IGCC more than offset the higher operational inflexibility cost.
- The co-production of hydrogen is not affected by the efficiency, only by the degree of ASU integration. Thus, although the 100% integrated IGCC plant may be appropriate for power generation, the 0% and 50% integrated IGCC plants are ideal for the hydrogen co-production, as hydrogen can be produced when power is not generated. The selection between 0% and 50% IGCC plants depends on the hydrogen price and the electricity price.

- The higher the efficiency of the plant, the less relevant operational flexibility becomes, since high efficiency plant will run base load more often and for longer than lower efficiency plant (if all other factors are equal, such as fuel price, etc). The higher efficiencies of highly integrated IGCCs can offset the cost associated with the longer start up times of the gasifier, due to the increased likelihood of base load running).
- For maintenance scheduling, in the case that component relialibility information is used, instead of for a block of plant, identification of the component with the maximum profit loss can result. Thus , decisions can be made, if it is necessary to have back up components held in stock that will be able to operate while the first is repaired. In this case , additional capital cost for the back up components needs to be taken into account.

COST

The total cost of this project was £105,000 with the Department of Trade and Industry (DTI) contributing £50,000, and E.ON the balance.

DURATION

38 months – January 2000 to March 2003.

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