FORWARD CONTRACTS FOR THE OPERATION OF AN ELECTRICITY INDUSTRY UNDER SPOT PRICING

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Abstract - This paper reports a study of the use of *forward contracts* as risk sharing instruments for electricity industries operating under spot pricing. Forward contracts involve financial transactions or commitments which relate to a physical trade at a later time instance. Price setting and appropriate participant responses are discussed. Simulation studies are used to demonstrate that forward contracts offer participants an opportunity to reduce their risk exposure without removing the incentive to respond to higher spot prices.

Keywords - electricity pricing, power system operation under uncertainty, forward contracts, risk management

1. INTRODUCTION

The theory of electricity pricing has been discussed in [1, 4, 6, 9]. In order to encourage economically efficient behaviour from all participants in an electricity industry, the optimal pricing structure should be based on the Short Run Marginal Cost (SRMC).

Since SRMC is a function of the state of the supply and demand sides of the system, its values at future times are unknown. Only probabilistic forecasts can be made. This is referred to as spot pricing.

Spot pricing introduces additional uncertainty into demand side operation, in that the value of the price in the near term future will be unknown. In the absence of soundly based forecasts, participants usually make their own, often based on inappropriate assumptions such as constancy of prices in real terms. For economic efficiency, particularly in investment decisions, it is important that participants base their decisions on forecasted values of SRMC that take into account likely future system conditions such as supply/demand balance.

Forward contracts address two of the main difficulties which can arise with a number of pricing regimes but are particularly acute in spot pricing. They are:

- Reacting to prices and price forecasts in an uncertain environment can often cause difficulties for participants. For example, spot pricing can lead to fluctuations in short term profits for consumers (and third party producers of electrical energy), particularly if the consumer cannot reduce its load during a period of higher prices.
- Establishing a level for the SRMC can require substantial knowledge of the demand side. There is therefore a need for the supply and demand sides to share information relating to both the present and the future.

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Forward Contracts involve financial transactions or commitments which relate to a physical trade at a later time instance. They offer participants an opportunity to reduce their risk exposure without removing the incentive to respond to higher spot prices.

A forward contract purchased by a consumer is a commitment by the supplier to provide a specified amount of electrical energy at a future time. Once the contract has been purchased, the consumer is no longer exposed to the subsequent variations in price. However, in return the contract places an obligation on the consumer and the supplier, which can only be avoided by sale of the contract at the prevailing price.

A forward contract for a third party supplier of electrical energy, is similar: it is an agreement for the third party to supply the system with a fixed amount of energy at a later time. Again, the obligation can only be avoided by sale of the contract at the prevailing price. The following description is written in terms of consumers, however it is equally relevant to generation (with some sign changes).

Attention in this paper is restricted to consumers who are completely reliable in that there is no uncertainty about their plant characteristics over the life of the contract. The effects of consumer unreliability are discussed in [7, Ch. 9].

The application of forward contracts to electrical energy has not received much attention in the literature. Blackmon [3] reported an interesting initial study on the development of a futures market in electrical energy. However, there is a large body of literature relating to forward contracts and futures markets for commodities other than electrical energy [5, pp 302 - 353].

An illustrative example of forward contracts and a theoretical demonstration of their usefulness are given in Section 2 of this paper. Contract price setting and consumer responses are discussed in Sections 3 and 4. Further useful properties of forward contracts are illustrated by the numerical simulation results of Sections 5 and 6. In the former, a scenario simulation model is used while the later gives results from a probabilistic model. Conclusions are given in Section 7.

2. FORWARD CONTRACTS: ILLUSTRATIVE EXAMPLE

The operation of forward contracts is most conveniently illustrated by considering negotiations for trading electrical energy between a particular consumer and a monopoly supplier at some time, t, in the future, referred to as the spot time. However, these negotiations begin earlier at the first contract time, t_{c1}. Transactions relating to other spot times may also be occurring concurrently.

Forward contracts are then traded at intervals (called *contract times*) up to the spot time. At each contract time, the supplier makes a best estimate of the spot time SRMC, based on the state of the system (including both supply and demand sides) at that contract time. The consumer then sells back its existing contract and purchases a new one at that price. This enables the forward contract price to be regularly updated as the spot time is approached so that it contains the most recent system information.

Consider the following example with two contract times, t_{c1} and t_{c2} as shown in Figure 1. This example can easily be generalised to any number of contract times. Many practical situations would have a large number of contract times.

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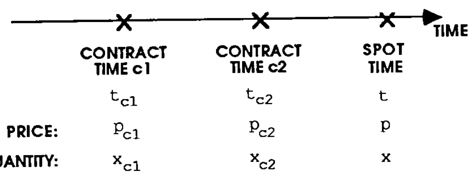

Figure 1: Contract and Spot Quantities.

At the first contract time t_{c1}, the supplier offers a

- contract price = p_{c1} (\$/MWh).

It is the supplier's best prediction of the SRMC at the spot time t, given the information available at the contract time t_{c1}, such as the present (time t_{c1}) state of the generation system (which units are available, which are unavailable, which conditions are likely to change, etc.) and the present forecast for load at time t.

In response, the consumer purchases a

- contract of size = x_{c1} (MWh).

The cost to the consumer of this transaction conducted at t_{c1} is

- net cost at $t_{c1} = p_{c1} \cdot x_{c1}$ (\$).

No further transactions take place at time t_{c1}.

At the subsequent contract time t_{c2}, based on the prevailing system conditions, a new

- contract price = p_{c2} (\$/MWh)

is calculated. The consumer responds by selling its original contract of size x_{c1} at the updated contract price p_{c2} and thus realising an income of $p_{c2} \cdot x_{c1}$. It then purchases a new contract with

- contract size = x_{c2} (MWh)

at the prevailing contract price p_{c2}, so that the contract purchase cost is $p_{c2} \cdot x_{c2}$. Thus the net cost to the consumer of transactions conducted at time t_{c2} is

- net cost at $t_{c2} = p_{c2} \cdot (x_{c2} - x_{c1})$ (\$).

At the spot time t, the price is set equal to the

- SRMC = p (\$/MWh)

The consumer responds by selling its last contract at this price, making an income of $p \cdot x_{c2}$ and purchasing

- spot energy consumption = x (MWh)

which costs $p \cdot x$. Thus the net cost to the consumer of transactions at the spot time t is

- net cost at spot time = $p \cdot (x - x_{c2})$ (\$).

Summing the net costs at contract times t_{c1} and t_{c2} and at the spot time t gives a total bill of

$$B = p_{c1} \cdot x_{c1} + p_{c2} \cdot (x_{c2} - x_{c1}) + p \cdot (x - x_{c2}) \quad (1)$$

$$= x_{c1} \cdot (p_{c1} - p_{c2}) + x_{c2} \cdot (p_{c2} - p) + p \cdot x \quad (2)$$

The following can be concluded from equations (1) and (2), assuming that the consumer's plant is fully reliable:

- If the consumer can avoid variations from the original contract (i.e. $x = x_{c2} = x_{c1}$) then the bill will be the initial contract cost, $p_{c1} \cdot x_{c1}$. Thus provided that the consumer can actually consume the amount it contracted for, it can "lock in" the contract price and avoid exposure to the risks of the fluctuating spot price.
- On the other hand, suppose that the second contract price is very much greater than the first (i.e. $p_{c2} \gg p_{c1}$). Then by setting the second contract amount to zero (i.e. $x_{c2} = 0$), the total bill is

$$B = x_{c1} \cdot (p_{c1} - p_{c2}) + p \cdot x \quad (3)$$

Thus the consumer can make a large forward contract profit of $x_{c1} \cdot (p_{c2} - p_{c1})$ regardless of the spot price.

At the spot time the consumer chooses the spot amount x in response the spot price p. If p is low despite the high p_{c2}, then the consumer can consume profitably as well as making a forward contract profit of $x_{c1} \cdot (p_{c2} - p_{c1})$. If p is high, then by not consuming (x = 0) the participant still makes the forward contract profit.

- Suppose that the contract prices are both small compared to the spot price (i.e. $p \gg p_{c1}$ and $p \gg p_{c2}$). If the consumer chooses to not consume at the spot time (i.e. x = 0), then the bill becomes

$$B = x_{c1} \cdot (p_{c1} - p_{c2}) + x_{c2} \cdot (p_{c2} - p) \quad (4)$$

The first term is small but the second is large and negative. Thus for consumers who can respond, the large profit on the sale of the forward contract forms a significant incentive to reduce load.

Thus forward contracts have the desirable feature of allowing participants to avoid the adverse effects of price fluctuations without removing the incentive to respond to periods of high prices. Renegotiation of forward contracts provides an incentive for participants to track system conditions as they evolve towards spot time. However, risk averse or inflexible consumers can still lock in a contract price by not varying from their initial contract.

To understand the practical advantages of forward contracts it is useful to examine a pricing scenario. First, suppose that a large generator fails between contract times t_{c1} and t_{c2} and it is not expected to be repaired until after the spot time t. Thus the contract price at t_{c2} would be much larger than that at t_{c1} (i.e. $p_{c2} \gg p_{c1}$). By selling its contract and not re-purchasing a new one, the consumer has achieved a profit. From the supply authority's perspective, a commitment to supplying a block of load using high running cost generators has been avoided.

Suppose, however, that the generator were to be unexpectedly repaired between the last contract time t_{c2} and the spot time t so that the spot price p would, in fact, be quite low. Then the consumer could consume profitably as well as making a forward contract profit and the supply authority can sell the cheap energy available from the repaired plant.

The generalisation of this example to include more than two contract times is straight forward. In equation (1), a cost of variation at each contract time is included. Each of these will be the product of the prevailing contract price and the difference between the new and old contract quantities.

An added advantage for the supply authority is that forward contracts provide a forecast of the load under various prices. Thus financial instruments aid both supply and demand side information discovery, where the signal to the demand side is the forward contract price and the signal to the supply side is the total size of contracts held by all consumers.

3. CONTRACT PRICE SETTING

It is clear from the above discussion that the contract price should be set to the best estimate of the spot price, given all the information available at the contract time. Mathematical analysis suggests that the most desirable statistical estimator is the conditional expected value. (See [8, pp 73-81] for a detailed discussion of conditional expectations in a general setting.)

In Appendix A it is shown that if at each contract time t_c the contract price p_c is set to the expected value of the SRMC at the spot time t, conditioned on all the available supply side and demand side information, i.e.

$$p_c = \mathcal{E}\{\text{SRMC AT t} \mid \text{SYSTEM CONDITION AT } t_c\} \quad (5)$$

then the expected contract profit is zero. Thus the long term average bill will equal the long term average SRMC bill and the forward contract component of the bill averages to zero in the long run. This is an equitable result in that it implies long term average revenue neutrality with respect to spot pricing.

In many electricity industries, the value of SRMC is usually low with infrequent, short duration episodes of higher values. These latter usually result from abnormally high system loads or coincident generator failures. If at a contract time, t_c, the system is in its normal state (i.e. low SRMC and no particular reason to believe the load will increase dramatically or that there will be significant generator failures) then the contract price p_c will be the low value of SRMC plus a small risk premium. The latter accounts for the small probability that the system will depart from the normal state (i.e. large load increases or major generator failures). Under most circumstances this probability, and hence the size of the risk premium, reduces as the contract time gets closer to the spot time.

On the other hand, if system conditions at the contract time indicate a significant probability that the SRMC will take on a high value, then the contract price will be large. This might be the case if, for example, a storm front is moving across the consumer area or a number of generators are in imminent danger of failing.

4. CONSUMER RESPONSES

Each individual participant will purchase contracts in response to contract prices according to the nature of its plant, its financial objectives and its attitude to risk. For a variety of cases, detailed models of the participant's response can be constructed [7, Ch. 9]. In this paper, attention will be restricted to the simplest class of participants, being those that are

- flexible: plant operation can be changed without advanced warning;
- memoryless: there are no inter-temporal links (defined in [6]) so that operational decisions at one time instant can be taken independently of decisions at all other time instants;
- reliable: there is no uncertainty about future plant characteristics over the life of the contract.

In the absence of forward contracts, the behaviour of such a participant in response to a spot price p is to choose a consumption level x which maximises the net benefit of consumption [6]; i.e. which solves

$$\max\{\mathcal{F}(x) - px : x \in \mathcal{S}\} \quad (6)$$

where

- $\mathcal{S}$ represents the constraints placed on consumption by, for example, the physical operation of the plant
- $\mathcal{F}(x)$ is the gross benefit of operating the plant excluding any charges for electrical energy. For example, for an industrial consumer, $\mathcal{F}(x)$ is the profit derived from sales minus the costs of all raw materials except electrical energy.

In the presence of forward contracts, the total net benefit will be

$$\mathcal{N} = \mathcal{F}(x) - B \quad (7)$$

where B is the spot plus forward contract bill defined in equations (1) and (2). At each contract time and at the spot time the participant will attempt to maximise $\mathcal{N}$.

To simplify the presentation, assume that there are only two contract times, t_{c1} and t_{c2}, as shown in Figure 1. However, the results derived below can easily be generalised. Suppose that x_{c1} has already been chosen and consider the problem of choosing x_{c2} after p_{c2} has been announced at time t_{c2}. The problem is to maximise

$$\mathcal{N}_{c2}(x_{c2}) = \mathcal{F}(x) - C_1 - p_{c2}\cdot x_{c2} - p\cdot(x - x_{c2}) \quad (8)$$

where $C_1 = x_{c1}\cdot(p_{c1} - p_{c2})$ which is a constant, unaffected by the choice of x_{c2}.

At time t_{c2}, the spot price, p, and hence the last term in equation (8) is unknown (although the latter can be shown to have an expected value of zero - see Appendix A). However, as argued above, the participant can avoid this uncertainty by deciding to hold the consumed amount x equal to the contracted amount x_{c2}. If this were to be the case, then equation (8) with $x = x_{c2}$ would become

$$\hat{\mathcal{N}}_{c2}(x_{c2}) = \mathcal{F}(x_{c2}) - C_1 - p_{c2}\cdot x_{c2} \quad (9)$$

with the constraint that $x_{c2} \in \mathcal{S}$. This then represents a "locked-in" value or "bottom line" for net benefit, which could possibly be improved upon at spot time t by a choice of x which differs from x_{c2}.

Choosing x_{c2} to maximise the locked-in profit $\hat{\mathcal{N}}_{c2}(x_{c2})$ involves solving

$$\max\{\mathcal{F}(x_{c2}) - px_{c2} : x_{c2} \in \mathcal{S}\} \quad (10)$$

Comparing equations (6) and (10) yields the following conclusion. The appropriate response to a forward contract price for participants obeying the above assumptions is to purchase a forward contract as if

- the contract were the actual amount to be consumed
- the contract price were the actual spot price.

By pursuing this strategy, at each contract time the participant "locks in" a net profit which could be realised by not varying subsequent contract amounts. This strategy gives the largest possible "locked in" profit. At each subsequent contract time the participant can at least maintain that level of guarantied profit and usually it is possible to improve upon it.

5. SCENARIO SIMULATION OF FORWARD CONTRACTS

In this section, in order to illustrate some of the basic features of the operations of forward contracts a simple scenario simulation model is used to examine system behaviour over time based on scenarios of generator failures and repairs. The supply side is represented as a monopoly with all thermal generating units. It is assumed that there are no inter-temporal links such as those introduced by fuel supply constraints. Each unit randomly fails and is repaired, thus introducing uncertainty into the supply model. The demand side is modelled as a memoryless, price responsive load with no uncertainty or inter-temporal links such as storage. Further details of the model can be found in [7, Ch. 8].

The assumptions of the model imply that the present value of the SRMC and forecasts of future SRMC values are determined by the set of presently available generators.

Comparisons are made of the industry's operation under two tariff regimes: an SRMC-based spot tariff and the same spot price plus forward contracts.

Table I: Parameters of the supply side.

UNIT	CAPACITY (MW)	VARIABLE COST ($/MWh)	ETBF (hours)	EDOF (hours)
1	460	7.8	460	40
2	460	12.5	460	40
3	660	13.0	550	50
4	300	14.3	940	60
5	190	50.0	ALWAYS AVAILABLE	
6	105	90.0	ALWAYS AVAILABLE	

The supply side of the system under study consists of six generators: four unreliable base load units and two completely reliable peaking units. Data for these units is given in Table I, where ETBF and EDOF respectively stand for Expected Time Between Failures and Expected Duration of each Failure.

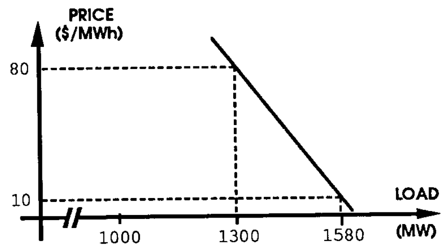

Figure 2: Demand side response to price.

Figure 2 illustrates the demand side response to price. This response is assumed to not change with time. Under the assumptions of this model, the demand side can be thought of as a single consumer.

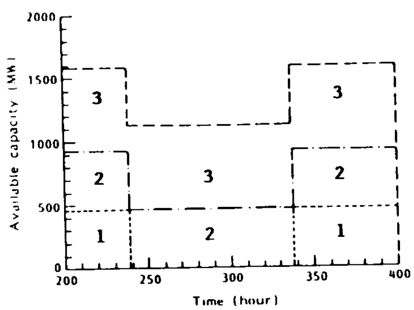

Figure 3: Scenario of available supply side units.

The particular scenario chosen for this study is illustrated in Figure 3, which plots available capacity against time. Only the interval from the 200th to the 400th hour is shown. At time zero, three base load units, 1, 2 and 3, are available. One of these units, number 1, fails at 240 hours, and is brought back on line at 340 hours. Unit 4 is under repair throughout the period. The times of failure and repair are not known in advance.

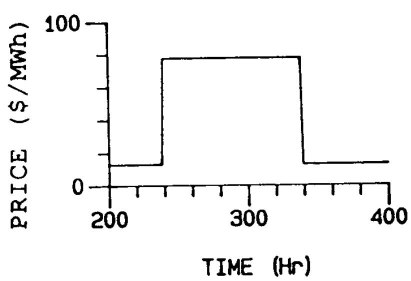

Figure 4: SRMC as a function of time

The behaviour of the spot price is shown in Figure 4. Before 240 hours and after 340 hours, with the three base load units available, the SRMC is determined by the running costs of unit 3, i.e. $ 13.0 /MWh and the load is about 1560 MW. However, between 240 and 340 hours, because unit 1 is unavailable, unit 5 is operated as well as some additional demand side options (DSO's - e.g. voluntary load curtailment, self generation), reducing the system load to 1240 MW. This is achieved with an SRMC which rises to almost $ 80 /MWh. Note that the additional 1560 – 1240 = 320 MW of DSO's which were operated during the failure of unit 1 obviated the need to either start up unit 6 or to force the shedding of some load.

Under the assumptions of the simulation model and, in particular, the absence of any inter-temporal links, the spot price and system load for the spot plus forward tariff are exactly the same as in the spot pricing case.

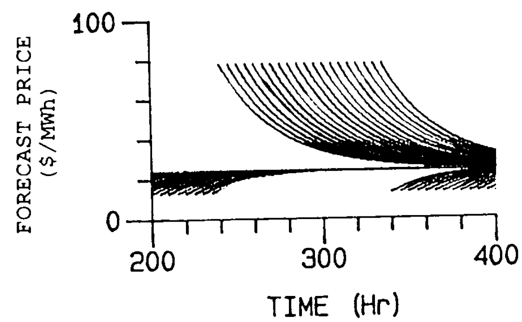

Figure 5: Forward contract prices. Each curve is the set of forecasts made at the time on the extreme left of the curve.

Figure 5 illustrates the price forecasts used for the forward contracts. Each curve refers to the set of price forecasts made at the time which is at the left hand end of that curve. The curve plots contract price as a function of the spot time. Thus, above each spot time are the prices which have been forecasted for it.

Consider two of these curves. First, the curve which begins at time 220 hours was produced when the system was in "good" condition (i.e. an abundance of cheap generation and low SRMC). However, the forecasted prices must take into account all possible generator failures that could occur between the contract and spot times. Hence forecasted prices contain a risk premium which increases with time as the present information becomes less relevant.

The second curve begins at time 300 hours when the system was in a much worse condition. There would have been an expectation of units 1 or 4 being repaired and hence forecasted prices tend to decrease for longer forecasting periods. It is interesting to note that all curves tend asymptotically to a value of about $ 24 /MWh. This is the long run expected value of SRMC which is independent of initial state.

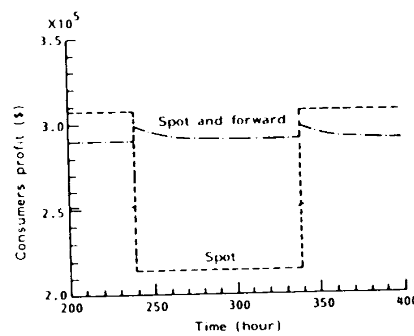

Figure 6: Demand side profits for the scenario illustrated in Figure 3.

Consumer profits for the spot and spot plus forward tariffs are shown in Figure 6 and supplier profits in Figure 7. The first point of interest is the direction of profit change for suppliers and consumers when the industry state changes. The curves show a marked contrast. In the spot case, the monopoly supplier shows greater profits during a plant outage, and consumers a corresponding reduction. Such a situation is not likely to promote maximum supplier technical efficiency, nor endear monopoly suppliers with their customers. Supplier profits under the spot plus forward tariff fall during a plant outage, while consumer profits tend to increase with worsening supply-side plant conditions as a result of the workings of the forward contract system.

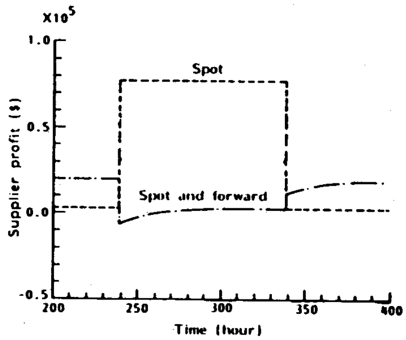

Figure 7: Supply side profits for the scenario illustrated in Figure 3.

These studies suggest the following conclusions, some of which also follow from theoretical considerations:

- Consumer and supplier profits tend to fluctuate more under a pure spot tariff than under a spot plus forward tariff.
- For a monopoly supplier operating under a spot tariff, supply-side plant outages are, in general, rewarded with a higher supply-side profit. Such a reward structure is neither equitable, nor conducive to encouraging maximum supply-side plant availability.
- Under a spot plus forward tariff, reliable consumers earn greater profits to the extent that they can respond to spot pricing signals. Reliable consumer plant which cannot profitably respond is protected from adverse profit changes.

Longer term sharing of profits between supplier and consumer are not resolved by these scenario studies.

6. PROBABILISTIC SIMULATION OF FORWARD CONTRACTS

The weakness of scenario analysis is that only one episode can be examined at a time. On the other hand, in probabilistic simulation the effects of each scenario and its relative likelihood are simultaneously considered.

In the model described in Section 5, each scenario has a certain probability of occurrence. This can be calculated from the probability of the various generator failures, non-failures, repairs and non-repairs which make up the state transitions in the scenario. Further, for each scenario any quantity of interest, such as profit for the supply or demand side, can be calculated. Thus, at least in principle, for each quantity of interest it would be possible to enumerate all its possible values and their probabilities of occurrence.

While expected values of these quantities would be easier to calculate, they do not contain sufficient information about the complete range or the relative likelihoods of various portions of the range. Thus, complete probability distributions are desirable.

When forward contracts are involved, the burden of developing the complete probability distributions by enumerating each scenario would render that approach computationally impossible for any but the smallest systems. Instead, a reverse time convolution algorithm has been developed, the details of which are given in [7, Appendix A1].

The probabilistic information is presented as Cumulative Density Functions (CDF's). For a random quantity v, the CDF is the function $F_v(\cdot)$ defined by

$$F_v(\zeta) = \Pr\{\ v \le \zeta\ \} \tag{11}$$

for each possible value ζ of v [8, p 23].

The models of the supply and demand sides of the industry studied in this section are the same as those in Section 5.

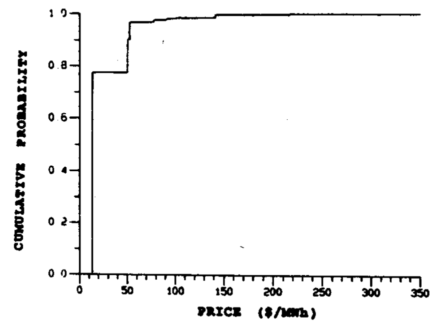

Figure 8: CDF of SRMC.

Figures 8 shows the CDF of the SRMC spot price. The most probable price is about $ 13 /MWh, corresponding to the variable cost of a base load generator. This occurs with a probability of about 79 %. The next most probable range for prices is around $ 50 /MWh, corresponding to unit 5 and some cheaper DSO's. There is a small probability of higher values, corresponding to unit 6 and the more expensive DSO's.

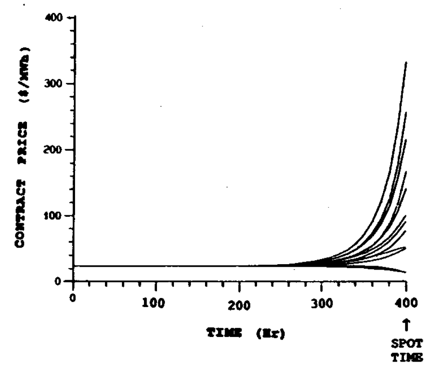

Figure 9: Trajectories of contract prices for each industry state.

Figure 9 shows the contract prices relating to spot consumption at time 400 hours. Contract prices are plotted as a function of contract time (i.e. time at which they are predicted). Each curve corresponds to a different industry state at the time of prediction. Thus for example, the uppermost curve gives the contract prices if all major generators are failed. For contract times more than about 200 hours before the spot time, the contract price is about $ 24 /MWh, regardless of the industry state.

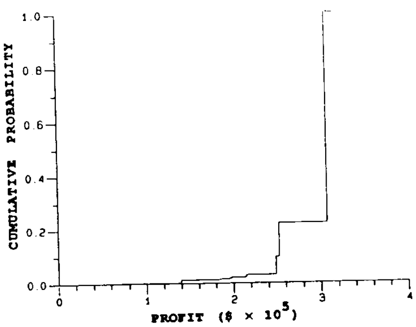

Figure 10: CDF of profit for demand side under Spot Tariff

Figures 10 and 11 show the CDF's for the demand side operating profit under the two tariff regimes. The consumer profits for the spot and spot plus forward tariffs have the same expected value in the absence of inter-temporal links. The spot case shows a large probability of large profits (e.g. above $ 300k) and a small possibility of low profits (e.g. below $ 180k). Figure 11 shows that the risk of low profits has been eliminated by forward contracts, at the expense of removing most of the possibility of very high profits (above $ 300k). This follows from the ability of fully reliable consumers during the contract process to lock in a forward contract price at $ 24 /MWh and never allow their profit position to worsen. Thus forward contracts make situations of supply constraint quite profitable for the fully reliable consumer. In return, however, consumers lose part of the high profit opportunity afforded by industry states with very low SRMC values (around $ 14 /MWh). For consumers with unreliable plant, forward contracts would not be quite so attractive.

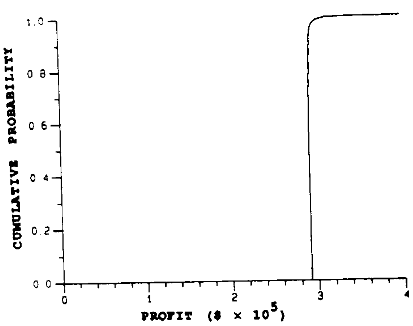

Figure 11: CDF of profit for demand side under Spot plus Forward Tariff

The CDF's of operating profits for the supply side under the two tariffs are shown in Figures 12 and 13. Under SRMC based spot pricing, the supply side only makes operating profits on those generators which are available for service and which have variable costs which are (strictly) less than the SRMC. Thus supply side profits will be small if there are abundant cheap base load units available and the SRMC is small. However, when the SRMC is high but there are still some cheap base load units available for service, then those units return a large operating profit. This is reflected in Figure 12 where the large probability of low profits corresponds to the states with abundant cheap base load units.

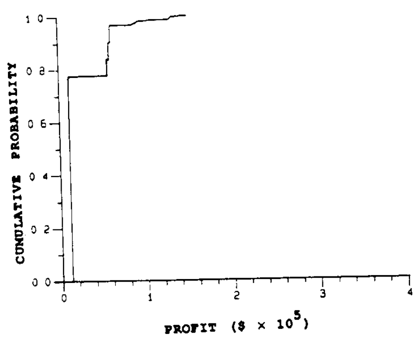

Figure 12: CDF of profit for supply side under Spot Tariff

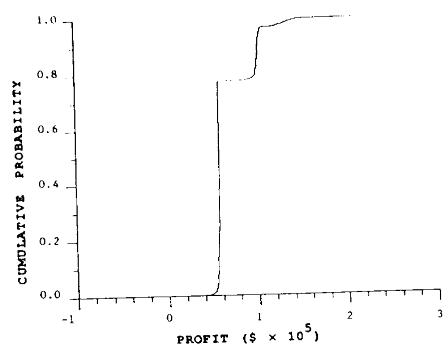

Figure 13: CDF of profit for supply side under Spot plus Forward tariff

The CDF for supply side profit under the spot plus forward tariff has a very low probability low profit tail which cannot be seen in Figure 13. This corresponds to those few scenarios where a state change during the contract period causes the SRMC to rise to a high value and remain there for the entire contract period. Thus forward contracts cause the supply side to accept from the demand side some of the risk associated with bad system conditions.

The results of the probabilistic simulation model, like the scenario studies, depend upon the relationship between installed supply and demand capacities. In reality, there would be on going adjustments in this balance, partly determined by price. For example, one might conclude from the above study that under a spot only tariff, since the supply side makes profit from periods of high SRMC, it has no incentive to maintain high reliability levels of base load plant. However, extended periods of high values of SRMC would encourage investment in competing sources such as DSO's like third party generation with lower operating costs. Thus a dominant supplier which did not adequately maintain its base load units would face decreasing market shares.

It can be concluded that forward contracts offer a way of sharing between supply and demand sides the risks associated with periods of supply constraints. However, by assuming a completely reliable demand side, the model used in these studies placed all the unreliability on the supply side. Initial studies suggest that the benefits are still available with unreliable consumers.

7. CONCLUSIONS

The use of forward contracts for risk sharing and information discovery has been discussed. Forward contracts are particularly useful for coordinating supply and demand side operations decisions under spot pricing. They allow inflexible or risk averse participants to lock in a suitable contract price for electrical energy and avoid the adverse effects of price fluctuations, while not removing the incentives for more flexible participants to respond to spot prices.

Forward contracts do not however provide information or incentives for investment decisions in load reduction equipment or demand side generation with variable costs that are above the long term average SRMC. A second form of financial instrument - options - is required for that task [7, Ch. 7].

Two simulation models were used to examine the effects of forward contracts. The first model uses scenario studies to examine the effects of random generator failures and repairs on supply and demand side operating profits. The second model generates complete probabilistic information about the quantities of interest.

As in any simulation study, conclusions are limited by the data set being simulated. However, it is possible to conclude that in practice spot plus forward contracts tariffs are likely to have a number of desirable advantages, while still exhibiting many of the beneficial features of simple spot tariffs. In particular, forward contracts are a useful instrument for sharing risk between the demand and supply sides.

APPENDIX A: DERIVATION OF CONTRACT PRICING RESULT

The following is a brief outline of the proof of the contract price setting result in Section 3. Let θ_{c1}, θ_{c2} and θ represent the states of the supply and demand sides of the industry at times t_{c1}, t_{c2} and t, respectively. Each of these θ's contains all the information available at the that time. Thus it is reasonable to assume that the θ process is Markov [8, pp 112 - 123].

Suppose then that the contract prices are set according to equation (5) i.e. for j = 1,2

$$p_{cj} = \mathcal{E}\left\{ p(\theta) | \theta_{cj} \right\} \qquad \text{(A1)}$$

which is thus a function of only θ_{cj}. Note that the dependence of the spot price, p, on the state at spot time, θ, is shown explicitly. It is also reasonable to assume that x_{cj} is chosen based on θ_{cj} (this includes basing the decision on p_{cj}), so that for j = 1,2

$$x_{cj} = x_{cj}(\theta_{cj}) \qquad \text{(A2)}$$

Thus in equation (2),

$$\mathcal{E}\left\{ x_{c1} \cdot (p_{c1} - p_{c2}) | \theta_{c1} \right\} = x_{c1}(\theta_{c1}) \cdot \mathcal{E}\left\{ (p_{c1} - p_{c2}) | \theta_{c1} \right\} \qquad \text{(A3)}$$

But because of equation (A2) and the Markov property of θ,

$$\mathcal{E}\left\{ p_{c1} | \theta_{c1} \right\} = p_{c1} = \mathcal{E}\left\{ p_{c2} | \theta_{c1} \right\} \qquad \text{(A4)}$$

where the right hand equality is derived using the "tower smoothing" result [2, p 398]. Thus the right hand side of equation (A3) is zero. Since this is true with probability 1, it follows that

$$\mathcal{E}\left\{ x_{c1} \cdot (p_{c1} - p_{c2}) \right\} = 0 \qquad \text{(A5)}$$

A similar conclusion holds for the second term in equation (2) so that

$$\mathcal{E}\left\{ B \right\} = \mathcal{E}\left\{ p \cdot x \right\} \qquad \text{(A6)}$$

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