THE ROLE OF ARTIFICIAL INTELLIGENCE METHODS IN THE DEMAND-SIDE MANAGEMENT ACTIVITIES OF DYNAMIC ELECTRICITY PRICING

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ABSTRACT

For a variety of reasons the increase in generating capacity forecast for South Africa did not materialize resulting in capacity constraints being experienced. Demand-side management has been instituted by the utility in order to curtail demand growth in the peak supply periods. Using fundamental supply and demand theory together with certain unique aspects surrounding the supply of electricity, this paper illustrates that for consumers that have the ability to shift electrical load at short notice, the concept of dynamic pricing is more practical. The paper concludes by proposing a method using artificial intelligence techniques to optimise the cost of electricity to such a consumer.

1. INTRODUCTION

It was predicted in 1972 that an additional 59 000MW(e) of coal-burning generating capacity would have to be installed in South Africa by the turn of the century [1]. The low economic growth of the South African economy during the 1980s and early 1990s rendered this forecast inaccurate and resulted in the over capacity in terms of electricity supply seen during the early 1990s. The second half of the 1990s saw significantly higher economic growth [2] and this has resulted, in the absence of electricity generating capacity increases, in the electricity generating constraint currently being experienced in South Africa.

The use of electricity is either in the form of an input material in the production process or in the form of an operating expense supporting the production process. In the first case the electricity cost enjoys a high profile in terms of input cost and as such gives substance to the statement that the unit cost of electricity can be reduced by matching demand to production potential of the electricity, i.e. the generating capacity [3].

Demand-side management (DSM) is defined as deliberate interventions on customer sites by the electricity supply industry to reduce the cost of supply by changing the shape and/or the magnitude of the load [4].

The three decades prior to the mid 1990s saw the load shape of Eskom, the South African electricity supply utility, become more "peaky" as a result of changing demand patterns [5]. The steadily deteriorating system load factor led to the realization by Eskom during the 1980s that some form of DSM strategy would have to be followed [5].

DSM is one method by which the efficiency of the utilization of resources can be improved [6] which will have the effect of minimizing the cost of electricity. It is, however, also felt that a competitive market for electricity is necessary to provide the incentives to hold prices down to marginal cost and thus minimize the cost of electricity [7]. In order to encompass the economic issues surrounding DSM, Roos & Kern [8] refer to industrial load management (ILM), that includes DSM activities initiated by the utility and customer. A very important part of ILM is the financial incentive in the form of dynamic pricing.

The remainder of the paper addresses the issues surrounding the dynamic pricing of electricity, after considering the standard DSM issues surrounding the time-of-use (TOU) tariff. Conclusion is reached via a proposal of a methodology for using real-time information together with artificial intelligence techniques to optimise the total electricity cost in an industrial operation.

2. DYNAMIC PRICING AS A DSM TOOL

It is noted by Munasinghe [9] that price is an effective "soft" technique of demand control. There must however be a distinction made between the time-invariant pricing method, and the time-dependent pricing. The time-invariant prices are typically the standard tariffs that are normally delineated on a TOU and seasonal basis. These tariff structures can form the basis of bi-lateral contracts in the real-time electricity markets so that the consumer of electricity can control the risk of the volatility of the dynamic electricity prices.

Kallio [10] noted that his research on the real-time pricing of electricity in Finland yielded very promising results and that dynamic tariffs can be used to influence the peak consumption of electricity. In addition, the adoption of the dynamic tariffs was easy utilizing technology available at the time of writing. Artificial intelligence methods should make the adoption of the dynamic tariffs and the optimisation thereof equally as easy.

One of the consumer barriers noted by Lane [11] to DSM revolves around the issue of energy costs being unimportant to the consumer. In cases where electricity is a major input to the production process, the cost thereof is a parameter that can be controlled if the consumer can shift load between peak and off-peak periods together with the supply utility being able to offer some sort of dynamic pricing system. The dynamic pricing of electricity also negates the aversion of consumers to DSM being contractually binding at times when there is slack on the electricity supply system, i.e. when the maximum demands of the consumer and the supply utility are not coincident.

2.1 DEMAND ELASTICITY

Although it is claimed by Stoft [7] that electricity markets are almost completely insensitive to price fluctuations, Ruff [12] claims that there is a belief that small decreases in demand are able to cause large decreases in the price of electricity. The statement is qualified by Ruff [12] himself, however, by stating that the market for electricity is still not efficient as there is a transfer of economic rent from the suppliers to the consumers.

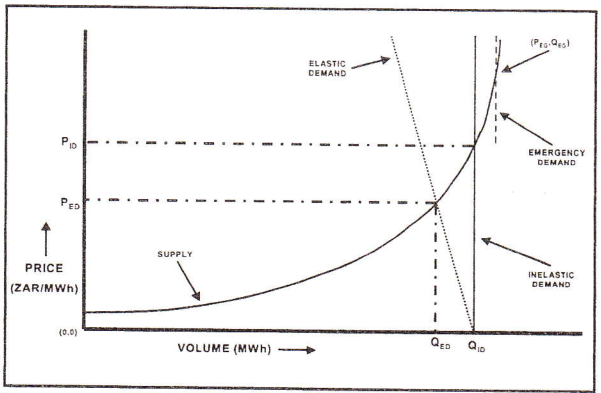

Figure 1: Market supply curve illustrating inelastic and elastic demand

In spite of the reservations that have been expressed about the non-reactivity of demand to price, the illustration contained in figure 1 shows that a certain amount of elasticity in the demand for electricity has an effect on the price. Assume that the supply/demand scenario depicted in figure 1 is for a single hour in a peak time period.

At an inelastic demand of Q_{ID} (represented by the vertical unbroken line), the equilibrium price for the electricity supply in the single period is P_{ID}. The indication here is that if the consumers of the electricity are only exposed to time-invariant price P_{ID} then the market will clear at a demand of Q_{ID} [13]. Hirst & Kirby [13] claim that even with some of the consumers being modestly sensitive to price, the market will clear at a lower demand of Q_{ED} with a lower price of P_{ED}. In a case such as this it is not only the consumers that have the price elasticity that benefit from the lower price, but all consumers in the particular period. Ruff [12] discusses the economic benefits of a responsive demand such as the one described above. The reduction in the demand in response to the price reduces the total supply-side costs plus the demand-side costs of meeting the consumers total demand as given by Q_{ED} [12].

At times of generating capacity constraints figure 1 illustrates that the price of the electricity will reduce as the demand is reduced. From the supply point of view the price can be used to influence the level of demand thereby increasing the load factor of the supply system as a whole.

According to Eskom [14] this has also been evident in the standard TOU tariff (Megaflex) that has undergone a series of structural changes in the last few years. The changes in the energy costs in the relative TOU periods have supported the DSM programme. The changes in the Megaflex TOU tariff energy costs for the period starting 1991 are illustrated in figure 2 below.

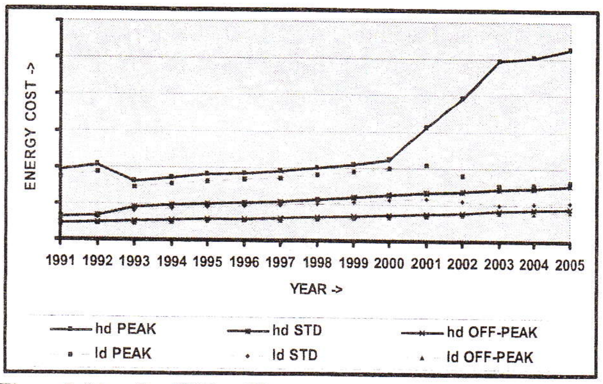

Figure 2: Megaflex TOU tariff energy costs

There are several issues to note *vis-à-vis* the representation in figure 2. They are

- From 1991 to the year 2000 the changes in the tariffs in the TOU periods and the high demand and low demand seasons have been reasonably consistent,
- in the period 1992 – 1993 there was a decrease in the energy cost in the peak period, both in the high demand and low demand seasons. This was accompanied by a relative increase in the energy cost in the standard TOU period, and
- the year 2001 saw the first of the disparate increases in the price of energy in the peak TOU period in the high demand season signifying the start of the structural changes to the tariff.

The illustration in figure 2 also confirms the statement by Campbell [15] that the peaking stations are more expensive to run than the base load stations and that the average price of electricity will be increased by the greater amount of peaking capacity required. The price increase in the peak period has, in the opinion of Eskom [14], resulted in the shifting of a certain proportion of demand in the high demand season. The conclusion that can be reached is that demand can be influenced by the price that the consumers are exposed to.

The importance of this issue is evident in the strategy that a consumer follows when hedging a fixed consumption of electricity using the standard TOU tariff. The claim by Stoft [7] that the electricity market is almost completely insensitive to price fluctuations is qualified by himself

stating that wholesale price fluctuations are not usually passed on to retail customers.
Eskom has fixed targets in terms of DSM that have to be reached over a 25 year period. In the year 2003, a total load saving achieved amounted to only 43% of the target with 99% of the saving as a result of a demand market participation (DMP) project [14]. This performance indicates that the dynamic pricing of electricity, which is essentially DMP based, deserves active pursuance as a complimentary option to DSM.

2.2 MARKET PRICE DETERMINATION

In order to illustrate the influence of the level of demand as forecast by an electricity system operator on the electricity price, consider figure 3 below. The assumptions inherent in this analysis are that

- the market is competitive and that no single generator can influence the market, i.e. does not have market power, and
- that the market clearing price provides the economic incentive for a generator to produce as scheduled, i.e. that the generator has given genuine marginal costs.

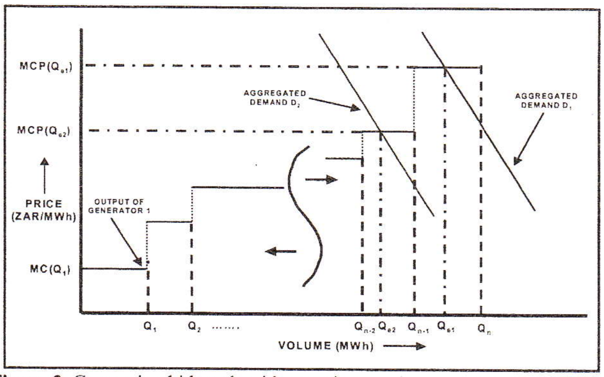

Figure 3: Generation bid stack with superimposed aggregated demand

The method by which the price is determined is as follows.

- The hourly load on the system is forecast, or it may be determined by demand bids [16],
- the generation bids are aggregated by a system operator to give the system supply curve as is shown in figure 1 above,
- the point at which the hourly load, defining the demand, intersects with the supply curve defines the market clearing price (MCP) which is then the price of the electricity in that hour, and
- after the MCP is set additional markets open to handle system constraints such as transmission limitations and system integrity issues [16].

3. DYNAMIC ELECTRICITY PRICING

Dynamic electricity prices are distinguished from the classical TOU tariffs by the potential they exhibit of many more price levels and a greater variability in the prices applicable to different hours of the day [3]. Dynamic tariffs can take on a number of forms with the interruptible tariff being the simplest [15]. The other principal forms of dynamic tariff are the day-ahead pricing and real-time pricing.

The distinction between day-ahead prices and real-time prices is sometimes very fuzzy with the terms being used interchangeably. For the purpose of this discussion the day-ahead prices are the prices fixed at least 18 hours in advance and they are the prices that are normally forecast and used in the planning process. The real-time price is the one that is determined at very short notice that caters for the immediate and unforeseen occurrences in the system that require the system to be rebalanced, i.e. the ancillary market.

The different markets are defined by Shahidehpour, Yamin & Li [17] as

- the day-ahead forward market is a forward market that is used for scheduling resources at each hour of the following day. Both energy and ancillary services can be traded in the forward market, and
- the real-time market is used to ensure the reliability of the power system by balancing it in real-time.

3.1 PRICE VOLATILITY

Although Stoft [7] notes that deregulation is not equivalent to perfect competition, deregulation is a prerequisite for the institution of a competitive market. The relative difficulty of storing electricity to match supply and demand in the deregulated supply system makes it prone to very large fluctuations in the spot price [18] where a competitive market for electricity is operating. A feature of a competitive market is the variability of the price and the unique aspects of the supply of electricity cause the price to very often be even more volatile than the price of any other commodity [13]. The volatility is, however, not regarded as random and it is thus possible to identify certain patterns and rules pertaining to the market volatility [16]. The significance of being able to identify patterns and being able to apply rules to the aspect of the price volatility will become evident in the next section.

In his discussion on the barriers that consumers have to price responsive demand, Hirst [19] claims that most consumers do not want to face volatile prices because the volatile prices are equated with higher bills. There is not the realisation on the part of consumers that the high prices in a few hours of the year are more than offset by low prices during the rest of the year [19]. Hirst & Kirby [13] note that the statistics for the hourly prices are skewed towards the lower prices.

The demand response, as shown in figure 1, will also have the effect of reducing the volatility of the prices [13]. This should render the predictability of the forecast prices more accurate in the longer run.

A detailed discussion of the mathematics of volatility and the different measures thereof would not add a tremendous

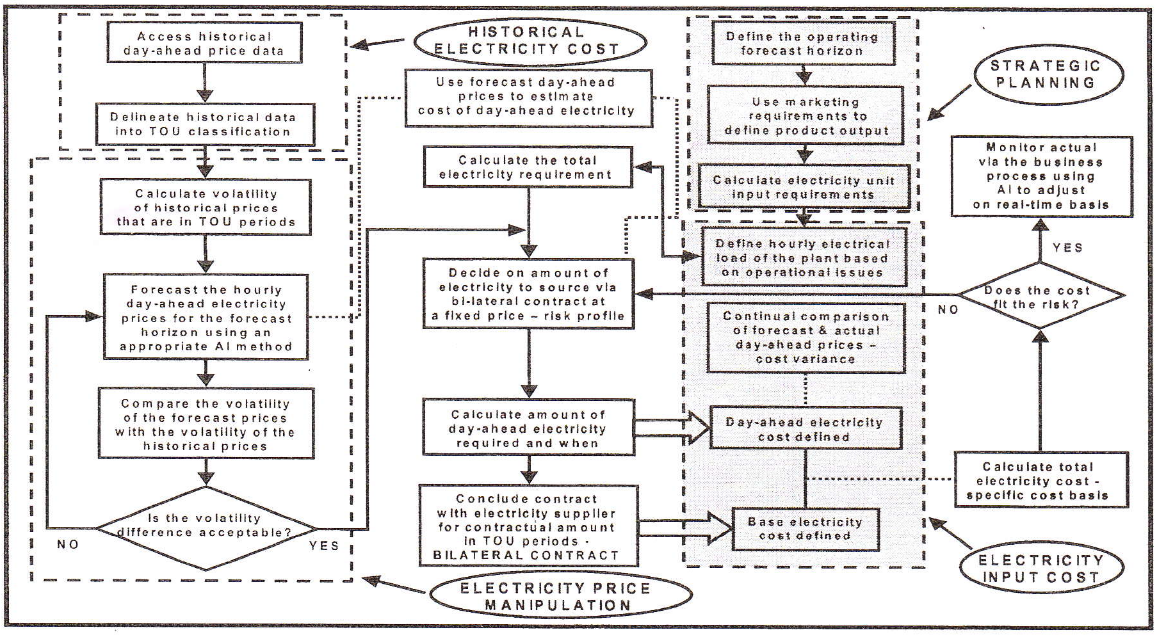

Figure 4: Flowchart illustrating forecasting procedure

amount of value to this paper. It is, however, clear that the issue of volatility is pervasive in the study of the the real-time aspects of the pricing of electricity. For additional detail on the subject of volatility, the reader is referred to the texts by Eydeland & Wolyneic [16], Shahidehpour, **et al.** [17], Hull [18] and Krapels [20].

4. ARTIFICIAL INTELLIGENCE METHODS

The issues that have been discussed so far are principally applicable to the supply-side of the equation. The price volatility is probably the aspect of dynamic pricing that has the most influence on the demand-side. It is the volatility that makes the application of the dynamic pricing to DSM activities worthwhile. In the discussion on the long-run effects of real-time electricity pricing, Borenstein [21] notes there are societal gains to be achieved by real-time pricing of electricity and the benefits can be substantial even with small demand elasticities. The immediate benefit to consumers that have the ability to swing load at short notice is in the form of lower electricity costs.

The important aspects from the point of view of a consumer are firstly, the load and price management with respect to the forecasting of each, and secondly the real-time decision making. The load and price management activities revolve around the forecasting of these parameters for a set period into the future. The real- time decision-making will be very largely influenced by the accuracy of the price forecast together with the conditions prevailing in the real-time market.

4.1 LOAD AND PRICE MANAGEMENT

Figure 4 illustrates the procedure whereby the electricity consumption of a large consumer is matched to the forecast conditions of price in the electricity market in order to minimize the cost of electricity in the production process.

As with almost all business processes the starting point is a strategic planning one. The consumption of electricity is determined by the marketing requirements of the primary product. The requirement of electrical units defines the basis upon which the hourly electrical load of the plant is defined. Operational issues such as planned maintenance, upstream and downstream constraints; etc will also influence the schedule of hourly electrical load.

The second activity here is the forecasting of the day-ahead electricity prices so that the price forecast for a particular hour in the planning horizon can be matched to the load for that hour that has been calculated previously. The cost of electricity based on a forecast of the day-ahead prices of the electricity is thus defined. The amount of electricity that the consumer purchases is then divided into an allocation to a bi-lateral contract whereby a certain amount of price risk is hedged, with the remainder being allocated by the consumer to the day-ahead and real-time markets. A consumer may also hedge a certain amount of risk by purchasing forward contracts for the future supply of electricity [22] as a complimentary aspect of the bi-lateral contract. If operational conditions dictate as such and the owner of the forward contract for the supply of the electricity is not in a position to utilize the electricity, the contract may then be traded in the market.

The mechanics of forecasting the day-ahead price is where the artificial intelligence (AI) methods are of importance. The forecasting of the price of electricity is an issue that has only gained prominence with the restructuring of the electricity industry [17]. From the point of view of the consumer, the forecasting of the load tends to be very mechanistic based on some ancillary strategic planning issue. The forecasting of price is of a higher priority as it may, in many cases, have a significant influence on a final product cost structure. Shahidehpour, **et al.** [17] note that there are various methods proposed but they vary from the extremely complex to implement to the questionable accuracy of the simple methods. The conclusion of Shahidehpour, **et al.** [17] is that the artificial neural network (ANN) provides the most simple and powerful tool for practical forecasting. The accuracy of the forecasts may be an issue due to the limited number of physical factors that are considered in the forecasting of the price. Two of the difficulties noted by Shahidehpour, **et al.** [17] are the subjective nature of the bidding strategies of market participants, and the influence of price spikes, which are a distinctive aspect of the electricity market. The procedure illustrated in figure 4 makes provision for comparing the volatility of the forecast prices to the actual historical prices and repeating the forecast if necessary. The historical and forecast prices may also be delineated into TOU periods, which would render the volatility in each period more comparable, and the forecasting by ANN more robust.

Eydeland & Wolyniec [16] make reference to the statistical concept of "mean reversion" being applicable to the electricity prices. With this being the case, the historical prices can conceivably be used to forecast future electricity prices by capturing a pattern of the historical prices within a TOU period.

4.2 REAL-TIME MONITORING OF THE COST

The final area where artificial intelligence methods have a significant role to play in the real-time aspects of electricity sourcing is in the monitoring of the prevailing real-time issues. The importance of this results from the existence of the real-time (ancillary) electricity market where the balancing of the supply-demand relationship within the electricity market occurs.

It is noted by Hirst [23] that day-ahead prices might be higher than the real-time prices as a result of certain consumers being willing to pay higher prices to protect themselves from the higher volatility of the real-time markets. Although the prices in the markets may differ, Hirst [23] proceeds to note that the differences between the day-ahead and real-time prices will be arbitraged by risk-neutral market participants. For a consumer that is a market follower, this is of academic interest and not important in terms of electricity cost minimization. The artificial intelligence technology that is available to a consumer that participates in the day-ahead and real-time markets in order to maximize the return on participation in the markets is a knowledge-based expert system.

The issues surrounding the implementation of a robust knowledge-based expert system are well documented and will not be addressed here. There are, however, certain aspects that need detailed attention for such a system to be self sustaining and useful. The first requirement is that the knowledge that the system operates on has a very high integrity. This knowledge is generated from the electrical consumption data of the load together with the day-ahead and real-time prices from the utility. Borenstein, Jaske & Rosenfeld [24] refer to advanced metering and data communication systems being required. Hardware configurations to meet these metering and data collection requirements are common today.

The second, and complimentary, requirement is that a rational set of rules be formulated to enable robust decisions based on historical performance to be made. With a target electricity cost based on the forecasting described previously, the expert system must be developed in such a way that future consumer loads can be adjusted based on the performance in the period to date. The application of this procedure may in fact result in the adjustment of the forecast load profile.

5. CONCLUSION

By giving consideration to the supply aspects of electricity in the deregulated competitive environment it was shown that demand is elastic. Although the pricing signals in the standard TOU tariffs are very sluggish, it is evident that the demand for electricity does react to the price. In order to restrict the growth of demand, particularly in peak periods, the electricity supply utility has introduced a program of DSM.

In an attempt to counter the rigidity of the application of DSM, the reaction of certain classes of consumer to pricing signals can be used to apply a dynamic form of DSM referred to as DMP. A prerequisite for the effective application of the DMP mode of demand curtailment is the ability of a consumer to shift load in response to pricing signals. This paper proposes AI methods to assist in the control of such an operation.

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The paper is presented by Anthony Hearn.