Electricity tariffs with particular reference to New South Wales

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Recommended Citation
ELECTRICITY TARIFFS

WITH PARTICULAR REFERENCE TO

NEW SOUTH WALES

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A THESIS PRESENTED TO THE DEPARTMENT OF
ECONOMICS WOLLONGONG UNIVERSITY COLLEGE
THE UNIVERSITY OF NEW SOUTH WALES

6TH SEPTEMBER 1968
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The electricity supply industry consists of the conversion of other forms of energy into electrical energy and its delivery to consumers.

As there is not at the present time an economic method of storing electrical energy, it is necessary for this product to be manufactured, delivered and consumed at the same time.

These aspects, together with an explanation of the terms used and the classification of costs commonly employed are described in Sections 1 and 2.

The simultaneous production and consumption of electricity requires the existence of capacity to meet the highest rate of consumption desired. If the rate of consumption were uniform hour-by-hour, day-by-day and week-by-week then full use of capacity could be realised. However hourly, daily and weekly variations in rate of consumption result in periods of surplus capacity. The problems created in cost allocation by consumers having different load patterns are introduced in Section 3.

There are persuasive reasons for monopolistic control of the electricity industry. Because this control is often in the hands of the State the modus operandi is to aim for the lowest possible average cost per unit of output. In a decreasing cost industry this is synonymous with maximising output as discussed in Sections 4 and 5.
The next two sections show how second-degree price discrimination is used to increase output. The maximisation conditions for a two-price system are indicated. A new graphical representation is also presented.

Section 8 reviews briefly the structure of the electricity supply industry in New South Wales and indicates some possible defects in the pricing systems.

The more recent "marginal cost" approach to electricity pricing is outlined in Section 9 which also describes the new bulk-supply tariffs introduced in 1967-68 by the Central Electricity Generating Board of the United Kingdom. New South Wales tariffs are further examined in the context of the C.E.G.B. "marginal" tariff and an analysis of load curves of the Illawarra County Council for the months of January and May 1968 is carried out in the final Section.
1. GENERAL ASPECTS OF ELECTRICITY SUPPLY

When a customer purchases an article from a retail store then it is obvious that the customer purchases only one thing - that particular commodity.

Suppose however that a customer buys sugar from a supermarket and agrees with the supermarket proprietor that the purchase price of the sugar includes delivery. Then two things are purchased - firstly the commodity, and secondly its transport from the point of sale to the point of consumption.

Suppose further that the sugar will be supplied in any quantity up to a maximum of - say - one ton per day, and the sugar must be available immediately on request. Not in five minutes time when the salesman has finished dealing with another customer; not in an hour when the delivery truck returns; but immediately. The customer is buying four things

(i) the commodity

(ii) the right to immediate supply on request

(iii) the right to a certain maximum rate of consumption

and (iv) delivery.

In order to meet requirement (ii) the retailer is obliged to tie up resources to ensure that transport is available immediately whenever required. To meet requirement (iii) he must have sufficient quantities of sugar on hand at all times.
Imagine now that it is not possible to store sugar in its familiar crystal form, but that it is necessary to make sugar from sugar-cane only as and when required. Then the retailer would need direct access to manufacturing facilities to meet the calls upon him by his exacting client.

Such a situation will not, of course, be met by supermarket proprietors. But this situation is exactly analogous to that which is constantly experienced by electricity supply authorities in their ordinary day-to-day operations.

With electricity, the quantity of electricity sold represents energy and is measured in units called "kilowatt hours" — usually abbreviated to "kWh".

The rate at which electricity is used is the power and this is measured in "kilowatts" (kW) or "megawatts" (MW). \(1 \text{ MW} = 1000 \text{ kW}\). The highest rate of consumption in a given period is termed the "maximum demand" for the period. The rate of usage at any particular time is termed the "demand".

It is normal for a consumer's demand to vary throughout the day, and the ratio of the average demand to the maximum demand is called the "load factor" of that consumer for the period considered.

Electricity is conveyed from the alternators at the power stations through transmission and distribution lines to the consumers' terminals. The transmission and distribution system of an electricity network is its transport system.
2. **THE COST OF SUPPLYING A CONSUMER**

The dominant factor in an analysis of costs of supplying a consumer is the inability to store electricity. Plant must be available throughout an electricity system with sufficient capacity to meet the highest system demand likely at any time, including allowance for plant failure.

There are hour-by-hour variations in the demand of a consumer. A consumer's load (demand) pattern also depends on the day of the week and the time of the year. A load pattern can conveniently be represented by plotting a graph of the consumer's load over a twenty-four hour period.

Furthermore, consumers have load curves which exhibit typical features characteristic of similar types of consumers, but quite different from the characteristics of other types of consumers.

The features of principal interest in load curves are the consumer's maximum demand and the time of day it occurs, and the load factor which is a measure of the "peakiness" of the load curve.

It is convenient in considering costs to group together all consumers with similar load characteristics into classes. Classifications commonly employed are:

1. Domestic
2. Small commercial and industrial
3. Large commercial and industrial
4. Rural (farms)
5. Off-peak
6. Street lighting
7. Bulk supply.
Load curves of typical classes and the total load curve for all classes added together are illustrated in Diagram 1.

The electricity purchased by the customer has four attributes of value to the customer. The fundamental one is the energy content, as it is the energy which is converted in the consumers' appliances to heat, work, light, images on a television screen and so on. The energy is the basic commodity being purchased. The second and third components are the ability to obtain at any time electricity at the rate required by the customer. The fourth desirable quality of electricity is its delivery right to the point of consumption.

Each of these factors involves the electricity supply authority in some costs which are usually classified differently into three sections for the purpose of investigating the costs of supplying consumers and the method of recovering these costs by periodic charges.

CUSTOMER COSTS are due to the existence of the customer. They include interest, rent and maintenance charges on meters, service wires and fuses and part of the distribution system. They also cover a share of operation and administrative costs and meter reading and customer billing expenses.

ENERGY COSTS are proportional to the energy production in kilowatt hours.

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1 These load curves are for the Illawarra County Council for June 1967. Minor irregularities have been smoothed out and so the curves are approximate only.

Diagram 1

Typical load curves for various consumer classes.
DEMAND COSTS are costs incurred by the electricity authority in making available sufficient capacity to meet the maximum demand at any point on the system.

In practice one of the difficulties encountered is the allocation of costs between "energy" and "demand" categories. One point of view is that the energy costs "...should include only those items which are proportional to the actual units (kWh) generated - i.e., chiefly the fuel and some other generation working expenses," whereas the "demand" cost centre will "...include all capital charges on the plant and buildings, maintenance ..., rents and rates. It must also include the majority of the management and operating expenses, wages and salaries."

On the other hand it has been argued that energy cannot be produced without capacity, and that at least some capacity costs should be allocated indivisibly to the "energy" cost centre. One method is to allocate capacity costs to the "energy" cost centre on the basis of the average system demand. If electricity could be stored, preferably at the point of use, then electricity for the peak hours could be manufactured during off-peak periods and so reduce the amount of capacity required to meet system maximum demands. At the same time, capacity which would otherwise be idle overnight and during weekends would be fully utilised. In fact, the system production would be constant.

at the *average* value of consumption demand (provided capacity was optimised) and so all energy and demand costs could be allocated to the "energy" cost centre. This lends credibility to the method.

Because electricity cannot be stored, economically, and average demand differs from maximum demand, such a method would in practice allocate to the "demand" costs charges proportional to the difference between maximum demand and average demand.

An indication of the approach to the allocation of energy and demand costs by New South Wales electricity supply authorities is given in table 1.

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>ITEM</th>
<th>DEMAND COST %</th>
<th>ENERGY COST %</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>HYDRO-ELECTRIC POWER STATIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Water storages</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>2.</td>
<td>Balance</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>STEAM POWER STATIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Fuel</td>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td>2.</td>
<td>Generation stores, oil, water and sundries</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>3.</td>
<td>Management expenses and wages</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>4.</td>
<td>Maintenance and repairs</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>5.</td>
<td>Interest, depreciation and insurance, coal handling plant</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Interest, depreciation and insurance, excluding coal handling plant</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>INTERNAL COMBUSTION POWER STATIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Fuel</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Generation stores, oil, water and sundries</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>3.</td>
<td>Management expenses and wages</td>
<td>75</td>
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</tr>
<tr>
<td>4.</td>
<td>Maintenance and repairs</td>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>5.</td>
<td>Interest, depreciation and insurance</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

The electricity supply authority requires an equitable means of sharing its costs among all consumers.

Several distinct steps are involved before such a method can be obtained.

Firstly, the authority must decide the principle to be used in charging individual consumers. The usual method is to select one or more individual load characteristics such as energy consumption, maximum demand (and time of occurrence) and load factor.

The next step is to divide the costs of the electricity supply authority into subdivisions, such as those described above, which can be related to the selected consumer load characteristics.

The third stage is to obtain information on typical load characteristics for each class of consumer. At this point the total costs could be divided among the classes in accordance with the predetermined principles evolved initially. Individual customer costs could then be assessed as a proportion of the class cost.

The usual sequel to this step-by-step process is the formulation of tariffs which, for a public supply authority, ideally just recover from each consumer his cost-contribution.

3. DEMAND DIVERSITY

One further aspect of demand requires special consideration. The maximum demands of different consumers occur at different times of the day. The maximum demand of the system as a whole is considerably less than the sum of the maximum demands of all the consumers connected.
This effect, the non-coincidence of maximum demands, is described as "diversity". The "diversity factor" is the ratio of the sum of the maximum demands of individual consumers to their maximum simultaneous demand. Diversity factor is always greater than or equal to one.

The "coincidence factor" is the reciprocal of the diversity factor and so is always less than or equal to one.

In considering the maximum demand of an electricity system the fundamental period is 12 months. This period includes the normal seasonal variations in temperature to which the maximum demand is very sensitive. The supply system must have sufficient capacity to meet the annual maximum demand which occurs during the Australian winter.

Referring to diagram 1, the system load reaches a maximum during the period 5.30 p.m. to 6.00 p.m. and at the same time the domestic consumer class load curve also experiences its maximum value. However it is not the time of maximum demand of other classes of consumers.

Now the capacity of the electricity system has been planned to meet the maximum (annual) system demand. The "demand" costs incurred in providing sufficient capacity must be divided amongst the various classes in a suitable way. But because all classes do not experience a simultaneous maximum demand there exists demand diversity, the benefits of which should be shared equitably.

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Maximum demand is usually measured by finding the highest average value of demand in any thirty minute interval during the demand assessment period.
Unfortunately no one has yet devised a system for allocating capacity costs which is economically sound, simple, fair and practicable. Systems employed to a greater or lesser extent by electricity supply authorities throughout the world are described below.

The first is the Peak Responsibility system. This method allocates capacity costs on the basis of class demand at the time of system maximum demand. Thus if one class of consumers has no demand when system demand is highest, then that class is not required to contribute to capacity costs.

Whilst at first glance this method appears reasonable, it overlooks the fact that capacity at "off-peak" times cannot exist until and unless capacity exists to meet the "on-peak" demands. This joint product aspect of electricity system capacity is analogous to the classical examples of joint products such as beef and hides, and that of lint and cotton seed. It has been described as "time-jointness". Hence, electricity supplied at any given time is, in a significant sense, a different product from electricity supplied at any other time.

The method suffers a further disadvantage. A consumer class contributing little to system maximum demand will face lower tariffs than those met by customers in a class bearing a full demand allocation. One could expect this to cause demand in the former class to rise and that of the latter class to fall. This could result in a new peak occurring at a different time of the day and necessitating a reallocation of demand costs appropriate to the class demands at the time of the new peak.

The system is unstable and little used.

The second system used for allocation of "demand" costs is the Undiversified Demand method. Here each consumer class is allocated capacity costs in proportion to the maximum demand of the consumer class irrespective of the time of occurrence. Each class is charged the same amount per kW of demand.

This method goes to the opposite extreme to that of the Peak Responsibility method. In the Undiversified Demand method the consumer class will pay the same for demand irrespective of time of maximum demand or the extent to which the demand was sustained.

Three examples will illustrate the apparent injustice of the method -
(i) a consumer with a load factor of 100%. This consumer will certainly contribute to maximum system demand, and he fully utilises his share of plant.
(ii) a consumer using electricity only for a short period - say one hour-daily, but whose maximum demand occurs at the time of system maximum demand although his load factor may be only 5%
(iii) a consumer similar to (ii) whose maximum demand occurs early in the morning when system demand is a maximum.

All three consumers would be allocated the same demand charge under the Undiversified Demand method, which is unsatisfactory because it fails to take into account time or duration of maximum demand and hence gives the consumer no incentive to operate in a way which will tend to reduce system maximum demand.
The third system of allocation of "demand" costs may be described as Demand and Consumption methods. The simplest of this group of methods is often called "Greene's Method" after the original proponent.

In Greene's method, system capacity costs are attributed to two factors:

(i) the sum of the undiversified class maximum demands
(ii) total energy consumption.

These costs are divided amongst the various classes in such a way that the class with a relatively high load factor will pay lower demand charges per kWh of consumption than will the class with a relatively low load factor.

Thus a key feature of Greene's method is the relative reduction in average costs per kilowatt hour as load factor rises.

This method of allocation is used in New South Wales by the Sydney County Council, the largest electricity distribution authority in this State.

Greene's Method has been refined by reducing the times during which demand and energy consumption are considered to the potential peak period. The potential peak period includes all times except those during which there is no probability of a system maximum demand occurring even if no "demand" costs were allocated to electricity consumed. This

A further variation of Greene's Method is known as the Average and Excess Demand (AED) Method.

This method firstly divides the system maximum demand into two components, the average demand and the remainder which is called "system excess demand". Next, each class maximum demand is divided in the same way, considering only potential peak periods.

The total demand cost is then apportioned to the classes in the proportion of its two subdivisions. This is the method recommended by the Electricity Authority of N.S.W. for use by electricity supply authorities in New South Wales.

4. MONOPOLY

The industry of production and distribution of electricity is almost universally a monopoly. Throughout Asia and Europe, the industry is in the hands of Municipal and State authorities. The major exception is the United States of America. Table 2 indicates the ownership of Electricity generation resources in the U.S.A. in 1954.

1 The method was first advanced by the Electricity Supply Technology Section of the British Electrical and Allied Research Association.

2 Electricity Authority, op. cit., pp. 6-7

TABLE 2

<table>
<thead>
<tr>
<th>Investor-owned companies</th>
<th>kWh generated in 1954 (x10^9)</th>
<th>per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial for own use</td>
<td>371.1</td>
<td>68.2</td>
</tr>
<tr>
<td>Co-operatives, Municipal systems, Federal Agencies etc.</td>
<td>73.0</td>
<td>13.4</td>
</tr>
<tr>
<td>Total kWh generated</td>
<td>100.5</td>
<td>18.4</td>
</tr>
</tbody>
</table>

But even here there are Regulatory Authorities interested in limiting earnings to a fair return, and at the same time ensuring an adequate quality of service.

The reasons for monopoly control are not hard to find. First, the economies of large-scale production are great. Associated with the economies of scale is the extremely high capital investment required to construct the means of production and distribution of electricity. 

1 This is illustrated in Table 3 for the U.S.A.

TABLE 3

<table>
<thead>
<tr>
<th>Plant Investment per Employee and per Dollar of Annual Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Investment per employee</td>
</tr>
<tr>
<td>Electric Utilities</td>
</tr>
<tr>
<td>Gas and Pipeline Industry</td>
</tr>
<tr>
<td>Railroads</td>
</tr>
<tr>
<td>Telephone Companies</td>
</tr>
<tr>
<td>100 largest manufacturers</td>
</tr>
</tbody>
</table>

Ibid. p.2
The contrast between the public utilities and the hundred largest manufacturers is notable. The division of the electricity market by competitive suppliers would cause a serious rise in costs and a waste of resources.

The second reason for the existence of monopoly control of the electricity industry is the great benefit derived from the effects of diversity. The diversity factor rises as the number of consumers connected to a system increases. The effect of this is to reduce the amount of plant required per kilowatt of undiversified demand. The fact is that the cost of providing capacity to supply two consumers is less than twice that to supply one.

The third force pointing to monopoly is the physical difficulty in building more than one power line in streets. Even if the space were available, the inefficiency and lack of aesthetic appeal are obvious. Furthermore, it is unlikely that two competitors would both find rural extensions to small settlements economic.

A power system must hold available reserve capacity at all levels to meet emergencies imposed by the failure of plant. Also, excess capacity will always exist at some levels on a growing electricity system due to the need to make capacity increases in relatively large increments. If more than one electricity supply organisation operates, then each will have some reserve and some excess capacity. The amount of this capacity would be considerably less with only one authority.
There are other factors suggesting that electricity supply should be a State-controlled monopoly. They tend to be social or political rather than economic in nature.

(i) the duty to serve all comers
(ii) the duty to render adequate service
(iii) the duty to serve at reasonable rates
(iv) the duty to serve without unjust discrimination.
(v) ability to raise capital at a lower cost than private enterprise.

Indirect competition is provided for electricity from alternative forms of energy - gas, oil, coal. There may be competition between electricity authorities to offer terms to new industries attractive enough to entice the industries to site factories in the area of a particular authority. This form of competition may be governed by political as well as economic motives, and is only likely to be effective when electricity costs form a major part of the costs of production for the particular industry, e.g. the electro-chemical processes involved in the reduction of aluminium, copper and zinc.

5. MOTIVES

It is now appropriate to consider the motives of the management of an electricity supply authority. Two possibilities are considered:
(i) that the authority will attempt to maximise profit

or (ii) that the authority seeks to minimise the average total cost of its product. Because the electricity industry is a reducing-cost industry, this aim can be achieved by maximising output.

These alternatives have been described as either a "profits" basis or a "costs" basis. A business enterprise could be expected to aim for "profits" operation whilst local authority undertakings will tend to work towards a "costs" basis.

This may be further justification for the control of these monopolies to be vested in Municipal and State Authorities, particularly as the monopolistic profit available may be very large, for "profits" operation, by comparison with the profitability of businesses working under the influence of strong competitive forces. It is significant that in the United States regulatory authorities exercise profit control over the free enterprise electric utilities.

On the other hand it is said that

The electricity industry has completely failed to set up a pricing system which will enable it to produce amounts of electricity which are in the national interest. It is interested only in selling as much as possible, consistent with governing costs, and not in the least in selling the right amount.

In the following discussion it is assumed that Australian electricity supply authorities operate on the "costs" principle.


Little, op. cit., p. 151.
Now if a "profits" basis is used, there will only be one particular set of marketing devices which will maximise profits.

On the other hand when the aim is to maximise output, it must be recognised that the "time-jointness" of demand, referred to in Section 5, will involve some arbitrary assumption as to the relative desirability of on-peak demand vis-a-vis off-peak demand. The overall costs of capacity will be known; the method of dividing these costs between demands which occur at different times of the day will depend on the supply authority's preference for high or low load-factor.

The same could be said for time-jointness of energy and indeed to energy-demand jointness.

Any investigation of a complex subject will often commence with simplifying restraints which are progressively relaxed. Although the length of this paper will preclude a full investigation of electricity, this will not be held as an excuse for not undertaking a simple analysis.

6. PRICE DISCRIMINATION

"The act of selling the same article (goods or services), produced under a single control, at different prices to different buyers is known as price discrimination."

With the sale of electricity, a more precise definition is necessary to allow for the existence of temporal, geographic or qualitative

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differences in the product without invalidating comparison. The following is such a definition "... a seller practices price discrimination if the relative prices he charges for the various units of his product or products are disproportionate to the relative costs of production of the units sold".

For price discrimination to exist, certain conditions must pre-exist. These are:

(i) imperfect competition. This is certainly the case with the monopolistic electricity industry.

(ii) ability to separate and keep separate the several markets. In practice this means that buyers in the high-cost markets cannot move into the low-cost markets, nor can low-cost buyers resell to high-cost buyers. Electricity users are obliged to buy from the electricity authority at the tariff set by the authority, and are prevented by statute or regulation from reselling.

(iii) before it is worthwhile discriminating between two markets, the markets must have different elasticities of demand.

The electricity industry finds the conditions necessary for price discrimination do exist. Price discrimination is widely practiced throughout the industry.

Several more important types of price discrimination may be distinguished in the sale of electricity.

(i) Peak-Off Peak discrimination results when the same rates are charged for electricity consumed during peak demand periods and during non-peak periods.

(ii) Block discrimination occurs when a consumer is offered a set number of kilowatt hours of energy (a "block") at a certain price each, and a further block at a lower unit rate. The number of blocks may be two or more, the unit rate decreasing progressively. A tariff utilizing block discrimination is known as a "block tariff" and is often constructed with a knowledge of the consumer class load curve.

(iii) Inter-class discrimination applies different rates to different classes of consumer not because of different costs of supplying each class, but because the different demand curves make this desirable under the aims of the electric utility, or for some "social" reason.

(iv) Geographic discrimination exists when remote, low density consumers with high "consumer" costs enjoy the same tariff
as that applied to high-density urban consumers close to bulk supply points.

Sometimes there is justification in the use of discrimination; for example block tariffs are often used to recover quickly the fixed "consumer" costs from each consumer. It will be shown that the use of discrimination will enable an electricity supply authority to increase output and at the same time to reduce average costs.

Of course there are occasions when discrimination has no economic justification. Class discrimination is one example where, for instance, phrases such as "ability to pay", "what the traffic will bear" are directed towards commercial consumers.

7. MARKET EQUILIBRIUM FOR MONOPOLY

In order to examine the economic possibilities available to a monopolist by varying price and output it is desirable to study supply and demand relationships.

The cost of supplying individual consumers consists of a number of independent factors as shown above. These factors include energy consumption, maximum demand, diversity, load factor etc. However, in order to have a starting point, the simplifying assumption is made that all units of output of electricity are completely homogeneous.

Ibid. pp. 150 - 171.
It is also assumed that the relationships studied are essentially long-run.

The market facing the monopolist electricity supply authority will express its wish to consume electricity by buying a certain quantity at a given price. At a lower price more is purchased and vice versa.

The demand function representing the number of units \( X \) of a commodity exchanged per period in the market at a price \( P \) is, by convention, expressed in the form \( X = X(P) \) - i.e., price is the independent variable, ceteris paribus.

If perfect competition exists then by definition it is beyond the ability of a buyer or seller to change the market price of a commodity. To each individual buyer or seller price is the independent variable.

However, with a monopoly the one producer can set the selling price and allow the quantity of his product to be determined by the market. Alternatively, he can fix the rate of production and allow the price to be determined by the competitive bidding of his customers. The question of whether price, or quantity, is the independent variable (ceteris paribus) is pedantic.

In the following analysis of market equilibrium for a monopoly it is assumed, for convenience, that the price of electricity is related to the quantity purchased by the function \( D = D(X) \), where \( D \) represents the price per unit of electricity at which the market is prepared to purchase \( X \) units of output per period.
The total costs expended by the authority in supplying electricity is given by \( TC = C(X) \).

The total revenue (TR) of the electricity utility (which is identical with the total expenditure by consumers) will be \( TR = X \cdot D(X) \).

Marginal revenue \( MR = \frac{d}{dX} (X \cdot D(X)) \)

\[ = D(X) + X \cdot D'(X) \]

Average revenue \( AR = \frac{TR}{X} \)

\[ = \frac{X \cdot D(X)}{X} \]

\[ = D(X) \]

so that the demand function also represents average revenue.

The total cost \( TC = C(X) \)

so marginal cost \( MC = C'(X) \)

and average total cost \( ATC = \frac{C(X)}{X} \)

These relationships are shown on diagrams 2 and 3. Both diagrams have on the horizontal axis Units of Output per Period \( X \).

The total cost curve is drawn on Diagram 2 and found to intersect with the TR curve at two points \( A_1 \) and \( C_1 \). These are break-even output rates at which total revenue just equals total costs. At any output rate between \( X_a \) and \( X_c \) units per period the electricity utility would show a profit. The maximum profit is at the intermediate point \( X_B \) units per period where the difference between TR (curve 1) and TC is a maximum. The profit is \( \beta(B_2 - B_1) \) per period.

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1 For the diagrams the functions \( D = (a - X)^2 \) and \( TC = b + cX \) have been used. \( a, b \) and \( c \) are constants.
TOTAL REVENUE, TOTAL COST, $
However it has already been indicated that the guiding principle of the electricity supply authority is the "costs" motive and, although the analysis which follows is equally valid on a "profits" basis, only the "costs" motive will be considered in detail.

Referring to Diagram 3, the ATC curve intersects the D curve (ATR curve 1) at points A₂ and C₂. Thus price per unit of output can range between P_c up to P_a with a maximum profit price P_b determined from the point of intersection B₃ of the MR (curve 1) and the MC functions. The "costs" basis price is P_c cents per unit, with output X_c units per period.

So far, this is a fairly conventional analysis of a monopolistic situation. But suppose now that the utility just achieves its planned output of X_c units per period at P_c cents per unit. The utility will then be confronted with the section of the demand function and the total cost function for X_c. Then a new Total Revenue curve TR (curve 2) can be derived from the demand function commencing at point C₁ on Diagram 2.

If the undertaking uses its price-discriminatory ability to sell to a "separate" market, then TR (curve 2) will be higher than the TC function until point E₂ is reached (Diagram 2).

Point E₂ represents a new break-even condition. The output of the electricity authority can be increased to a new level of X_c units per period, at which rate revenue will just equal costs.

Referring again to Diagram 5, a new ATR (curve 2) is obtained and this intersects with the ATC function at point E₂. The price corresponding to an output of X_c units per period is P_c cents per unit, but this lower
price will apply only to the units of output $X_e - X_c$.

If all units of output were sold at the lower price $P_e$ then from Diagram 2 the total revenue would be $E_4$ with a loss for the period of $2(E_3 - E_4)$.

Because of its monopolistic nature together with the ability to apply price discrimination, the electricity supply authority is thus able to extend its output per period from the "normal" one-price equilibrium $X_c$ at price $P_c$ cents per unit to a new two-price discriminatory level of output $X_e$ by selling $X_c$ units at $P_c$ cents per unit and $X_e - X_c$ units at $P_e$ cents per unit.

Under these new conditions,

\[ TR = X_c D(X) \quad \text{for} \quad 0 < X < X_c \]
\[ TR = X_c D(X_c) \quad \text{for} \quad X = X_c \]

and \[ TR = X_c D(X_c) + (X - X_c) D(X) \quad \text{for} \quad X_c < X \]

Also \[ TC = C(X) \quad \text{for} \quad \text{all} \quad X \]

At the new equilibrium output of $X_e$ units per period,

\[ TC = TR \]

i.e. \[ C(X_e) = X_c D(X_c) + (X_e - X_c) \]

rearranging,

\[ D(X_e) = \frac{C(X_e) - X_c D(X_c)}{X_e - X_c} \]

This is equivalent to the statement

\[ P_e = \frac{Re - Rc}{X_e - X_c} = \text{average variable cost between} \quad C_1 \quad \text{and} \quad P_1 \]

by referring to Diagrams 2 and 3.
This result can be seen in Diagram 3 at point $E_g$, when the demand curve $D$ intersects the average variable cost curve at point $E_g$.

It so happens in this case that at the point of intersection $E_g$, the demand price $P_e$ is also equal to the marginal cost. This is not true in general and occurs here as a result of the assumption that the TC is linear, in which case $AVC = MC = \text{constant}$.

In general the marginal cost may be higher than, equal to or less than the price $P_e$ associated with the demand curve $D$ for the additional discriminative output $X_e - X_o$. However as economies of scale generally appear to still be available in electricity production, then it follows that $MC < P_e$.

With a cost function such as that of Diagram 2 reflecting economies of scale, any method of increasing total output whilst applying the "costs" criterion will result in lower average costs per unit although price discrimination is an essential element. Provided the benefits are equitably shared among consumers, increase in output with Total Revenue equal to Total Costs is therefore a proper aim of an electric utility.

How then can maximum output be achieved?

With a two-price discriminatory structure, assume that the output with the higher selling price, associated with the Total Revenue TR (curve 1), is a value of $X_g$ units per period. Let the total output after selling units of output at the lower (discriminatory) price be $X_g$ units per period.
Then \( TR = X_f \cdot D(X_f) + (X_g - X_f) \cdot D(X_g) \)

and \( TC = C(X_g) \)

From the "costs" criterion,

\[ TC = TR \]

\[ C(X_g) = X_f \cdot D(X_f) + (X_g - X_f) \cdot D(X_g) \]  \hspace{1cm} (1)

Differentiating with respect to \( X_f \),

\[ C'(X_g) \cdot \frac{dX_g}{dX_f} = D(X_f) + X_f \cdot D'(X_f) + (\frac{dX_g}{dX_f} - 1) \cdot D(X_g) + (X_g - X_f) \cdot D'(X_g) \cdot \frac{dX_g}{dX_f} \]

\[ \frac{dX_g}{dX_f} = \frac{D(X_f) + X_f \cdot D'(X_f) - D(X_g)}{C'(X_g) - D(X_g) - (X_g - X_f) \cdot D'(X_g)} \]

For a maximum output of \( X_g \), \( \frac{dX_g}{dX_f} = 0 \) (and \( \frac{d^2X_g}{dX_f^2} \) is negative)

Hence \( D(X_f) + X_f \cdot D'(X_f) - D(X_g) = 0 \)  \hspace{1cm} (2)

\[ D(X_g) = D(X_f) + X_f \cdot D'(X_f) \]

\[ D(X_g) = \frac{d}{dX_f} (X_f \cdot D(X_f)) \]  \hspace{1cm} (3)

Now \( D(X_g) \) is the lower discriminatory selling price \( P_g \) for the output \( X_g - X_f \), and \( \frac{d}{dX_f} (X_f \cdot D(X_f)) \) is the marginal revenue of the \( TR \) (Curve 1) function for an output of \( X_f \).

Thus the condition to be satisfied to give a maximum output on a "costs" basis with a two-price discriminatory structure is that the lower price is equal to the marginal revenue of the last unit sold at the higher price. This is the meaning of equation (5).

The magnitudes of the two outputs \( X_f \) and \( X_g \) can be found by solving equations (1) and (2) simultaneously. The associated prices can then be derived.
In the particular case illustrated in Diagrams 2 and 5 the higher and lower price outputs before maximisation of output are \( X_c \) units at price \( P_c \) and \( (X_e - X_c) \) units at \( P_e \).

At \( X_c \) units of output the marginal revenue (MR curve 1) is negative. On two-price output maximisation the marginal revenue of the last unit sold at the higher price will rise to some point between 0 and \( P_e \). The higher selling price will thus rise from \( P_c \) to a value between \( P_c \) and \( P_b \). The output at the lower selling price will extend beyond \( X_e \) and the new lower selling price will be below \( P_e \) - i.e. less than marginal cost.

There are two significant implications of these results:

(i) Second degree price discrimination can be used to increase total break-even output and reduce average cost per unit.

(ii) Under conditions of maximised output the lower price may be less than marginal cost. This is justified on the grounds that it affords an equitable means of dispersing the surplus of revenue over costs gained for the higher priced output.

This analysis is original and, it is hoped, justifies the practice commonly followed by electricity authorities of block discrimination.

It is emphasised that other forms of discrimination do not have economic justification but block discrimination does provided it is shared equally amongst all consumers.

The analysis is far from complete. It could be developed by introducing the possibility of more than two blocks and by introducing separate parameters for demand, energy, load factor and so on. But such an analysis is beyond the scope of this paper.
Davidson has developed a detailed study of block price discrimination in his book (op. cit.). However, his study is primarily confined to a "profits" basis, and he illustrates his models with diagrams using only price and cost per unit v. quantity. I believe that the Total Revenue, Total Cost v. Quantity diagram more clearly illustrates the mechanisms described. Using the "profits" assumption, Davidson compares outputs and average rates with four pricing policies, including Uniform Monopoly pricing, under various parametric conditions. He concludes that Block pricing will always result in a greater output than Uniform Monopoly pricing, with average rates equal or higher with Block pricing, but not lower.

Joan Robinson, under her assumption that the monopolist acts on the principle of maximizing his profit, has also considered the effect on prices and output of a system of discriminatory prices.

Under a single price the maximum output will be achieved, when average costs are falling, if the imposed price is that at which demand price and average cost are equal. This, however, involves a waste, since there would be a considerable rate of output, beyond that at which demand price was equal to average cost, over which demand price exceeded marginal cost; and since demand price is supposed to measure marginal utility, it is desirable that this additional output should be produced. This waste could be partly eliminated and a larger output could be achieved if it were possible to impose discriminating prices. The average revenue under uncontrolled price discrimination is greater than under uncontrolled simple monopoly, and the largest possible output will be that for which the average revenue of a discriminating monopolist would be equal to his average cost.

1 Davidson, op. cit. p.162.
2 Ibid., p.203.
3 Ibid., p.68.
This conclusion, in common with that of Davidson, has failed to realise the possibility of lower average cost (and, equally, lower average revenue) with monopolistic discrimination based on the "costs" criterion.

2. ELECTRICITY SUPPLY IN N.S.W.

It is common practice throughout the world to divide the electricity supply industry into two major segments:

(i) The generation and transmission of electricity in bulk, and
(ii) Retail electricity suppliers, buying in bulk and selling electricity to final consumers.

The economics of large scale generation of electricity are such that bulk suppliers often exist to a large extent independent of State boundaries.

On the other hand diseconomies of scale begin when the number of customers supplied by a retail supplier becomes too large or the geographic area of supply too spread-out.

In N.S.W., the bulk supply authority is the statutory Electricity Commission of New South Wales (E.C. N.S.W.) which was constituted under the Electricity Commission Act 1950 - 1961. For the year ended 1967 the Electricity Commission sold 12,852 million kilowatt-hours with a maximum demand of 3,268MW. (The maximum demand has since exceeded 4,000MW.)

The N.S.W. transmission system is interconnected with that of Victoria through the Snowy Mountains Scheme. During 1966-67 the E.C. N.S.W. purchased 8.2% of its energy requirements from the Snowy Mountains Scheme and 2.1% from the State Electricity Commission of Victoria.¹

The retail sale of electricity to the public is carried out by thirty-four County Councils (consisting of groups of shire and municipal councils) and eight franchise holders and others. New South Wales is notable for the degree of concentration of the users of electricity. Sixty per cent of the load is in the Sydney Metropolitan area, and 85% is within 100 miles of Sydney.\(^1\)

The Electricity Authority of New South Wales is a regulatory body, constituted for the purpose of promotion, co-ordination, development, expansion, extension and improvement of electricity supply throughout the State.\(^5\)

The Electricity Authority, which was established under the Electricity Development Act, 1945 - 1965, has power under Section 57 (2) (e) of the Act to prescribe the form and basis of retail tariffs.\(^4\) So far the Authority has not exercised these powers, and has confined its activities to the preparation of two brochures on Costing and Tariff Framing. These are for the guidance of the County Councils. Thus the retail electricity supply authorities in N.S.W. autonomously set their own tariffs. Consequently there is a vast range of bases and rates used by these authorities, and these are set out in a publication of the

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\(^1\) Report of the Electricity Authority of New South Wales for the year ended 30th June 1966 p. 58.

\(^2\) Ibid., p. 7.


The retail authorities have been severely criticised for the "... frequent absence of any cost bases for the differences in rates faced by different consumer classes ..." For example, existing domestic tariffs fail to recognise the contribution of the domestic class to system maximum demand, and higher peak consumption should not be encouraged by lower rates as is the present practice.

Corresponding tariffs for several large, medium and small county councils are set out in table 4. "Whilst there are some minor differences in the conditions under which the tariffs are offered by the county councils, these do not explain the wide variations in rates.

<table>
<thead>
<tr>
<th>Retailing County Council</th>
<th>No. of Annual Consumers</th>
<th>Annual Sales as at 1966/67 million kWh</th>
<th>Energy rates in cents per kWh</th>
<th>Domestic Last Block</th>
<th>Domestic Off-Peak Block</th>
<th>Domestic High Voltage</th>
<th>Minimum Air Conditioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sydney</td>
<td>500</td>
<td>4,933</td>
<td>1.86</td>
<td>1.07</td>
<td>0.436</td>
<td>2.69</td>
<td></td>
</tr>
<tr>
<td>Prospect</td>
<td>160</td>
<td>1,549</td>
<td>1.55</td>
<td>0.55</td>
<td>0.471</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Shortland</td>
<td>95</td>
<td>626</td>
<td>1.93</td>
<td>1.0</td>
<td>0.491</td>
<td>2.08</td>
<td></td>
</tr>
<tr>
<td>St. George</td>
<td>65</td>
<td>364</td>
<td>1.84</td>
<td>0.7</td>
<td>0.435</td>
<td>N/A</td>
<td>2.635</td>
</tr>
<tr>
<td>Mackellar</td>
<td>62</td>
<td>297</td>
<td>1.85</td>
<td>0.8</td>
<td>1.0</td>
<td>1.4</td>
<td>1.85</td>
</tr>
<tr>
<td>Illawarra</td>
<td>54</td>
<td>405</td>
<td>1.83</td>
<td>0.7</td>
<td>0.516</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Monaro</td>
<td>65</td>
<td>48</td>
<td>2.0</td>
<td>1.1</td>
<td>N/A</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Tumut River</td>
<td>5.9</td>
<td>30</td>
<td>2.0</td>
<td>1.0</td>
<td>0.75</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Macleay River</td>
<td>5.7</td>
<td>31</td>
<td>1.8</td>
<td>1.1</td>
<td>N/A</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>

1 The Electricity Authority of New South Wales, Current Tariff Schedules.
2 Electricity Supply Authorities in New South Wales (1967).
4 Ibid., p. 570.
Frank Maguire, who retired in 1965 after five years as assistant general manager of the Sydney County Council, deprecates the dominance of domestic power consumption in New South Wales. He points to the ratio of domestic consumption to total consumption in other countries as set out in table 5. Whilst the standard of living is not uniform in these countries (and living standard is a most important factor in per capita electricity consumption), one would not expect the United States and Canada to have only two-thirds of the N.S.W. percentage. Maguire suggests that elsewhere than N.S.W., coal and oil heating are used more extensively for home heating.

It is the domestic peak which creates the evening system maximum demand, yet most county councils continue to conduct advertising campaigns designed to encourage more and more electrical appliances which will contribute to this peak demand but be little used at other times of the day.

The faster they convert people to higher electricity consumption, the faster must the Government divert massive capital funds from hospital, school and other pressing construction needs in order to install the plant required to supply domestic power at peak times. Either this or blackout.

There is strong evidence of misallocation of resources. This subject will be considered again: before doing so it is appropriate to look at the tariffs charged by the E.C.N.S.W. Retail electricity authorities pay for bulk electricity supplies about half of their total income.

The E.C.N.S.W. has a uniform two-part tariff throughout the State. The Commission's tariff for the last seven years is set out in table 6.

<table>
<thead>
<tr>
<th>Year</th>
<th>Energy charge</th>
<th>Maximum demand charge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base Rate</td>
<td>for supply at 53kW and over</td>
</tr>
<tr>
<td></td>
<td>(cents per kWh)</td>
<td>($ per kW per month)</td>
</tr>
<tr>
<td>1961</td>
<td>0.6625</td>
<td>1.95</td>
</tr>
<tr>
<td>1962</td>
<td>0.6292</td>
<td>1.95</td>
</tr>
<tr>
<td>1963</td>
<td>0.6292</td>
<td>1.85</td>
</tr>
<tr>
<td>1964</td>
<td>0.4667</td>
<td>1.95</td>
</tr>
<tr>
<td>1965</td>
<td>0.4485</td>
<td>1.95</td>
</tr>
<tr>
<td>1966</td>
<td>0.4480</td>
<td>1.95</td>
</tr>
<tr>
<td>1967</td>
<td>0.4480</td>
<td>1.85</td>
</tr>
<tr>
<td>1968</td>
<td>0.4480</td>
<td>1.85</td>
</tr>
</tbody>
</table>

Whilst energy charges have fallen by around a third in the period covered by that table, demand charges have fallen by less than 6%.

The general fall in rates, which can be attributed to economies of scale, is contrary to the movement of consumers price index in the same period. The relatively smaller fall in demand charges may be due to increased capital intensity. Or it may be due to a deliverer's pricing policy of the Commission designed to recover a higher proportion of revenue from retail supply authorities with lower load factors (i.e. "peakier" loads) as suggested by Kolsen.

9. MARGINAL COST PRICING

The marginal cost of a product may be defined as the extra cost incurred in producing one extra unit of output. In the context of the electricity supply industry, marginal cost may be presumed to have three aspects:

(i) marginal energy cost
(ii) marginal demand cost
(iii) marginal consumer cost.

In a capitalist free-enterprise economy the price system has three functions. It determines

1. **What commodities shall be produced and in what quantities?** That is, how much and which of alternative goods and services shall be produced?

2. **How shall goods be produced?** That is, by whom and with what resources and in what technological manner are they to be produced?

3. **For whom are goods to be produced?** That is, who is to enjoy and get the benefit of the goods and services provided?

With a market operating under conditions of perfect competition there are many buyers and sellers, and none is able to influence the market price of the product. Thus the marginal revenue of a firm is identical with the price of the product. If the firm operates on the principle of profit maximisation then, for maximum profit, marginal cost (= marginal revenue) = market price.

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The "marginal cost" school has arisen from the "marginal cost = price" condition for efficient resource allocation under perfect competition. The aim is that "... the price of electricity in terms of other goods is equal to its marginal cost in terms of other goods," or alternatively "... to maximize the sum of producers' and consumers' surpluses."

Bonbright proposes that all rates be set at marginal costs. A deficiency in total revenue of the electricity supply authority is balanced by a tax-financed subsidy. A surplus is returned to State finances.

Turvey has added supplementary provisions to care for short-run and long-run conditions. He says

... the optimum requires price to exceed marginal running cost in periods when demand is high by amounts which will both restrict demand to capacity output in all of those periods and which sums up over them to equal the marginal cost of capacity. In other periods price must equal marginal cost.

Now the electricity supply industry is commonly (and with some justification) held to operate under conditions of decreasing unit costs with rising output. Indeed this is a major reason for the monopolistic nature of the industry, as small companies would tend to merge to produce the same output at lower unit cost.

Under these conditions of decreasing costs, with a simple (one-price) monopoly, marginal cost is always less than average total cost whether the "profits" or "costs" mode of operation is followed. The selling price will be equal to or greater than the average total cost (see diagram 3).

The advocates of marginal-cost pricing consider the price under these conditions to be the wrong price to perform the three-fold function of the price system. Equally, the sale of electricity at less than marginal cost by using price discrimination is contrary to the principles of marginal-cost pricing.

The philosophy is viewed with the deepest of suspicion by the electricity industry; for example Rockwell has said "... at the best a tariff based on incremental ‘Costs’ is a plausible expedient which is employed to obtain additional business which could not be obtained at allocated ‘Cost’.”

It is interesting to consider the shape of marginal cost curves for energy and demand both in the short term and in the long term. "Short term" is considered to be a period during which productive capacity cannot be varied. "Long term" is a period sufficiently long to allow any part of the capacity of the generation and distribution system to be varied.

An electricity supply authority will operate its most efficient plant in preference to the least efficient plant. Due to technological development and to the physical size of plant involved, new generating plant is more efficient than older plant and is therefore operated

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1 Rockwell, op. cit. Appendix V, p. 2.
as base load. Thus when new capacity is added to the system, older and less efficient plant is relegated to peak load operation, running for a few hours each day in the colder months only. This low load-factor mode of operation in itself results in lower efficiency, particularly for thermal plant (i.e. coal-fired boilers and steam turbines).

The results of this is that the system energy - cost curve is increasing in the short run. Thus marginal cost rises with output. This is illustrated in Table 7. However, in the long run energy costs are decreasing, ceteris paribus.

**TABLE 7**

<table>
<thead>
<tr>
<th>Time</th>
<th>January</th>
<th>April</th>
<th>July</th>
<th>October</th>
</tr>
</thead>
<tbody>
<tr>
<td>0100</td>
<td>0.40</td>
<td>0.56</td>
<td>0.56</td>
<td>0.52</td>
</tr>
<tr>
<td>0200</td>
<td>0.44</td>
<td>0.56</td>
<td>0.54</td>
<td>0.20</td>
</tr>
<tr>
<td>0300</td>
<td>0.32</td>
<td>0.52</td>
<td>0.42</td>
<td>0.20</td>
</tr>
<tr>
<td>0400</td>
<td>0.16</td>
<td>0.52</td>
<td>0.42</td>
<td>0.14</td>
</tr>
<tr>
<td>0500</td>
<td>0.16</td>
<td>0.43</td>
<td>0.42</td>
<td>0.14</td>
</tr>
<tr>
<td>0600</td>
<td>0.16</td>
<td>0.43</td>
<td>0.44</td>
<td>0.14</td>
</tr>
<tr>
<td>0700</td>
<td>0.44</td>
<td>0.58</td>
<td>0.60</td>
<td>0.20</td>
</tr>
<tr>
<td>0800</td>
<td>0.47</td>
<td>0.60</td>
<td>0.70</td>
<td>0.40</td>
</tr>
<tr>
<td>0900</td>
<td>0.47</td>
<td>0.70</td>
<td>0.64</td>
<td>0.56</td>
</tr>
<tr>
<td>1000</td>
<td>0.47</td>
<td>0.56</td>
<td>0.64</td>
<td>0.54</td>
</tr>
<tr>
<td>1100</td>
<td>0.47</td>
<td>0.56</td>
<td>0.64</td>
<td>0.54</td>
</tr>
<tr>
<td>1200</td>
<td>0.47</td>
<td>0.59</td>
<td>0.64</td>
<td>0.54</td>
</tr>
<tr>
<td>1300</td>
<td>0.47</td>
<td>0.59</td>
<td>0.64</td>
<td>0.54</td>
</tr>
<tr>
<td>1400</td>
<td>0.47</td>
<td>0.59</td>
<td>0.64</td>
<td>0.54</td>
</tr>
<tr>
<td>1500</td>
<td>0.47</td>
<td>0.59</td>
<td>0.64</td>
<td>0.54</td>
</tr>
<tr>
<td>1600</td>
<td>0.47</td>
<td>0.59</td>
<td>0.64</td>
<td>0.54</td>
</tr>
<tr>
<td>1700</td>
<td>0.47</td>
<td>0.59</td>
<td>0.54</td>
<td>0.54</td>
</tr>
<tr>
<td>1800</td>
<td>0.47</td>
<td>0.61</td>
<td>1.00</td>
<td>0.53</td>
</tr>
<tr>
<td>1900</td>
<td>0.47</td>
<td>0.61</td>
<td>1.00</td>
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<td>2000</td>
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<td>0.64</td>
<td>0.53</td>
</tr>
<tr>
<td>2100</td>
<td>0.47</td>
<td>0.59</td>
<td>0.62</td>
<td>0.53</td>
</tr>
<tr>
<td>2200</td>
<td>0.47</td>
<td>0.56</td>
<td>0.62</td>
<td>0.34</td>
</tr>
<tr>
<td>2300</td>
<td>0.47</td>
<td>0.56</td>
<td>0.56</td>
<td>0.34</td>
</tr>
<tr>
<td>2400</td>
<td>0.47</td>
<td>0.56</td>
<td>0.56</td>
<td>0.34</td>
</tr>
</tbody>
</table>

1 Figures provided by the State Electricity Commission of Victoria (the bulk supply electricity authority of that State), as cited by C.G. Peirsor, "Some Aspects of the Cost of Supplying Electricity in Victoria." The Economic Record XXXIII (December 1966) p. 307.
We now turn to the consideration of marginal cost of supplying the capacity component of electricity.

With regard to short-run capacity costs, either the additional capacity sought exists, or it does not.

In the first case, the marginal cost of utilising surplus capacity is zero. In an expanding market some spare capacity is normal due to the need to increase capacity in advance of consumer requirements and in relatively large increments.

In the second case, excess demand can be suppressed by raising all demand charges temporarily until additional (long-run) capacity can be provided. The increased charges will eliminate marginal users.

The long-run capacity case is not so simple.

The electricity authority will aim to select for installation new generating plant which will result in the lowest overall costs. This may involve a choice between peak-load plant and base-load plant. Peak-load plant is characterised by higher energy costs and lower capacity costs than those associated with base load plant. Total costs may be lowered if additional peak-load requirements are met by replacing existing base-load plant with new, more efficient base-load plant and shifting the old plant to peak-load operation. In this case the cost of additional capacity at peak times will not be the capacity cost of new plant; in fact it will be the capacity cost of old plant which has been shifted from base-load operation to peak-load operation.

Because of the technological nature of new base load plant, the capacity costs associated with it may actually be higher than those of the base load is displaced. On the other hand energy costs will be
less, and the net effect on base load costs (capacity plus energy) will be a reduction.

Relegated peak-load plant will probably also exhibit higher capacity costs and lower energy costs than those applying before the installation of additional plant, but with average costs lower.

A further complication arises from the alternative types of generating plants available, and internal technical choice. For example, hydro-electric installations can produce only a certain average output of energy dependent upon the annual flow of water available. Seasonal water-flow fluctuations necessitate the installation of water storage and once this exists the electricity supply authority has the choice of designing generators with a large capacity running only over peak periods, or a smaller capacity for continuous running. Maximum capacity can be increased by collecting the water which passes through the turbines during peak periods and using low-cost base load plant to pump the water back to the storage reservoir during times of low system demand. Such a method is known as pumped storage.

Recently the trend both in Australia and overseas has been to increasingly use hydro-electric power stations to meet the extreme system peak load. In the Snowy Mountains Scheme, Tumut 1 and 2 power stations were commissioned in 1959 - 62 to operate at a capacity factor of 52%. The Murray 1 and 2 power stations, currently coming into service, are designed for an average capacity factor of 17%, whilst Tumut 3 power station will have 1,500MW of generating capacity
installed in 1974 and will operate with a capacity factor of 47% using pumped storage.

Thus we seem to be back where we started. We find that, at least from the point of view of a bulk supply authority, energy and demand costs are not independent over time. Furthermore, there are both long-run and short-run factors involved if we allow "short-run" to include time-of-day considerations.

When an electricity supply authority carries out both functions of generation and distribution, these problems are not thrown sharply into relief. When they are separate, as they are in the U.K. and in N.S.W., the situation is different. The bulk-supply authority must set rates at which retailers may purchase electricity. If these rates do not truly reflect costs, then there is the probability that some sort of economic distortion will develop — either too much or too little electricity purchased, with the financial incentive for efficient resource allocation removed.

Such a situation has arisen in the U.K., where the Central Electricity Generating Board (C.E.G.B.) supplies twelve Area Boards.

Until 1962-65 the CEB charged a straight two-part tariff based on annual maximum demand and energy consumption of each Area Board.

In 1962-65 "day" energy consumption was charged at a higher rate than energy used between 13 p.m. and 7 a.m. The basis of demand.
charges was changed to the Board's demands at the time of the C.E.G.B. maximum demand (i.e. diversified demand basis).

For the year 1867-68 a further major change was made. There were three energy rates in the new tariff:

(a) "Peak Period" energy, consumed between 8 a.m. and noon, and 4.30 to 6.30 p.m. during the two winter months of December and January (excluding Saturdays, Sundays, Christmas Day and Boxing Day). This rate applies for about 260 hours per year.

(b) A "Day" rate for all energy supplied between 7 a.m. and 11 p.m. except that supplied during the "Peak Periods". Annually about 5,800 hours.

(c) A "Night" rate for energy supplied between 11 p.m. and 7 a.m. throughout the year - about 2,900 hours.

The single demand charge was replaced with two charges which, in essence, charge an Area Board approx. £10 per kW per annum for 90% of its maximum demand (a "basic capacity" charge). The actual method of measuring demand is complicated, but the "basic" and "peak" components of an Area Board's demand are determined on a system (diversified) basis.

2 Ibid. pp. 48 - 51.
This new tariff has been labelled by the C.E.G.B. as a "marginal cost" tariff but, in my opinion, this is not so in the terms set out by Professor Bonbright and H.S. Soutakker. It has been described as an attempt to more closely relate tariffs and costs, brought about by the fear of widespread use by the Area Boards of gas turbines for meeting peak loads.

If the Area Boards individually find the use of peak-load-clipping plant economic, then the bulk-supply authority should be able to carry this out more effectively because of the larger scale of its operations.

The changes in the C.E.G.B. tariffs are a recognition of the fact that demand, energy and load factor are intimately related. The effect of this relationship is illustrated in Diagram 4. The average cost per unit of output for peak-load plant is lower than that for base-load plant with a low load factor and vice versa with a high load factor. In the diagram a load factor of 20% could be supplied by either base load or peak load plant at the same average cost.

How have other supply authorities throughout the world dealt with this problem? Strangely, the U.S.A. seems to be in the rearguard.

Electricité de France offers the "tarif vert" to high voltage consumers. It incorporates demand and energy charges which are influenced by time-of-day and time-of-year factors and geographic considerations. The low-voltage consumer nominates his maximum

Ibid. p. 65.
Diagram 4

Comparison of Average Total Costs of Running Peak Load Plant and Base Load Plant
demand and is charged accordingly. Should he exceed his nominated maximum demand a circuit breaker operates automatically. Frequent interruptions would cause a consumer to subscribe to a higher demand.

Most Swiss low-voltage tariffs differentiate between summer and winter tariffs.

Originally Norwegian consumers paid a kilowatt charge and no kilowatt hour charge. Now the load/rate tariff is common. With this tariff the consumer subscribes to a certain kilowatt demand level of his choice, for which he pays a fairly large rate. Energy consumed below the subscribed rate is cheap; energy above the subscribed rate costs about five times the lower rate.

The French and Norwegian retail tariffs induce a higher system load factor.

10. THE N.S.W. BULK SUPPLY TARIFF

Details of the actual tariff for the past seven years are set out in Table 6. The purpose of this section is to consider briefly whether the tariff suffers from the same disabilities which led the C.E.G.B. to introduce higher energy charges and lower demand charges for peak consumption.

Firstly, it is necessary to note that the E.C.N.S.W. bulk supply demand charge is based on a monthly reset, not the annual reset used by the C.E.G.B. On the basis that the level of system capacity is set by annual maximum system demand, monthly demand resets will favour

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these retailers with a poor annual load factor and penalise those with a better load factor.

In order to examine the effect of the bulk supply tariff on a retailer, load curves for the Illawarra County Council were examined for the months of January and May 1968. The daily load curves for each full calendar month were divided into fifteen-minute intervals and a frequency distribution drawn for each month. These are illustrated in diagrams 5(a) and 5(b).

Cumulative distributions were then prepared, from which diagram 6 was drawn. This diagram shows for January and May the percentage of the number of hours in the period during which the Council load exceeded the stated percentage of the monthly maximum demand. For example, in January the Council load exceeded 90% of the January maximum demand for only 1.4% of the month. In May, the Council load exceeded 90% of the May maximum demand for only 1.2% of the month.

This means that the Illawarra County Council is paying 10% of its demand charges for demand which is sustained for 1.4% of the period or less. This would certainly indicate the justification of peak load plant.

In N.S.W. the approval of the Electricity Authority is required before any electricity retailer installs generating plant. However an alternative method of peak load reduction is widely practiced by these authorities. This is the system of load control achieved by superimposing a control signal through the power system distribution circuits to operate relays switching off certain loads such as hot-water heaters over the peak periods, and offering consumers a special
DIAGRAM 5
FREQUENCY DISTRIBUTION OF SYSTEM LOAD
ILLANKARA COUNTY COUNCIL

(a) 4th Jan 1968 to 31st Jan 1968 incl.
(b) 4th May 1968 to 31st May 1968 incl.

Number of Quarter-Hour Periods at Stated Load During 4-Week Period

System Load (MW)

10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

July 3, 1968
low tariff for such controlled load.

The system achieves limited peak-load reduction with an investment which can be measured in dollars per kilowatt of load reduction. Millions of dollars are being spent on these systems in N.S.W. to effect peak load reduction. As far as I can ascertain, no detailed analysis has been made to compare the economics of these schemes with the alternative of direct installation of peak-load generating plant either by the various County Councils or by the E.C.N.S.W. Nor is sufficient being done by the retailers to offer tariffs to the final consumers which will give these consumers sufficient incentive to moderate their consumption during peak periods.

An overall simultaneous review of bulk supply tariffs, retail tariffs and existing and alternative means of peak load reduction is urgently needed for electricity supply in N.S.W.
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