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OPERATIONAL AND INSTITUTIONAL PROBLEMS OF ELECTRIC POWER DEVELOPMENT

by Sir Josiah Eccles

NOTE: This text is subject to editorial revision.

Some of the causes of diversity of costs per kilowatt hour have been touched upon in the companion paper on Basic Problems.

It will be clear that the economics of supply depend upon the size of system and how satisfactorily it is planned to give the right balance between capital cost and operating economy. The extent of operating economies will depend upon the degree of interconnection and the equipment that is provided - telephonic, telegraphic, remote metering - to assist in the implementation of system control, or "load despatching" as it is sometimes called.

To get the most economical operating results in a thermal system, the performance of each generating set, the cost per calorie of fuel delivered to each station, the location of the main load centres and the capacity of the various transmission lines and interconnectors must be known.

For any given condition of plant availability and given load distribution, it should be possible to regulate the output from individual sets so as to produce and deliver the total electricity at a minimum cost. Practical problems arise in that the incidence of plant and line outage varies and the relative demands of the load centres also vary.

System control and load despatching must be a continuous process if the most economical results are to be achieved.

The demand for electricity varies throughout the twenty-four hours of each day. It also varies according to the day of the week and the seasons. It is therefore necessary to forecast the generating regime from day to day, and to control it from minute to minute throughout the year if the best results are to be obtained.

Naturally the most economical plants need to be operated as far as possible at their full capacity all the time they are available and the less economical plants be brought into service in a descending order of merit so that the least economical is used to supply peak loads only.

/The economic

The economic performance of a generating set depends upon the cost per calorie of fuel delivered to the station, the thermal efficiency of the boiler/turbine unit and the transformation, transmission and distribution losses to the point of use.

In a system having over 200 generating stations, and perhaps 1 000 generating sets, the importance and complexity of accurate control are very great.

In large complex systems close control and speed of action under rapidly changing conditions can be facilitated by the use of computers programmed to give the most economical generating regime for any postulated or actual plant and line availability and load disposition. Smaller systems probably cannot afford the luxury of a computer service for this purpose and will therefore do the best they can from computations made by the central and regional control staffs. Fortunately such computations are very much simpler on small systems.

Of nearly equal importance is the need for a carefully organised maintenance programme in order to keep the more economical plants available for the highest possible number of hours in the year. Routine maintenance and operational techniques must be designed to prevent accidental outages. Major maintenance should be scheduled to take place outside the peak load season. Maintenance operations should be organised to limit outage time to the absolute minimum in which the repair or overhaul can be executed. All necessary materials should be ready and, if possible, the work should proceed continuously (three-shift working) from the moment that the plant is taken out of service and is cool enough to permit work to begin.

On a large system in Great Britain the non-availability of a 120 MW set may increase generating costs by as much as £2 500 per day through the compulsory operation of less economical plant.

For a given system and at constant prices the investment requirement is nearly proportional to the maximum demand. Stated another way, the investment per kilowatt-hour varies inversely to the load factor of the supply. Load factor, being the ratio of the average output to the maximum

/demand, is

demand, is also an appropriate measure of the degree of utilisation of the capital assets.

It is important therefore to economical operation that the system load factor should be high.

There is, however, a point beyond which an increase in load factor may increase the running costs of production per kilowatt-hour. If the load factor were 100% the demand would be constant throughout the year and, apart from inadvertent outages and maintenance, all the plant except that reserved for use against these contingencies would be operated at full capacity all the time. This would mean that all the plants that were available from the most economical to the least economical would be used for 8,760 hours per annum and the average operating cost of generation would be greater than on a system where there could be selective use of the generators according to their economic merit. This argument is inapplicable where all plants and stations are of the same economic performance, but in practice age and size of sets and differences in location of power stations usually preclude such a possibility.

Again, some seasonal variation in demand may be an advantage to permit plant to be overhauled during the lighter load periods. Failing this, additional plant will be necessary solely to enable the maintenance programme to be carried out. The lower operating costs to be expected from the new plant may not compensate for the additional capital charges which would be incurred.

However, broadly speaking, the investment per kilowatt-hour is inversely proportional to the load factor. This is an argument in favour of the highest possible load factor but in its practical application it must be moderated by the opposing trends in cost referred to above.

What steps can be taken to improve load factor? Basically two: (a) to develop a variety of load for different purposes, in industry, commerce, and in the home; diversity will thus be increased, with consequent improvement in load factor; (b) to encourage consumers to extend their hours of use of the supply and at the same time to reduce their demand during peak hours.

/The only

The only incentive the supply industry can give to these ends is the financial one, through their tariffs. The tariffs should as far as practicable be shaped to reflect the costs of supply. This will promote the best use of the economic resources of the country.

If the costs of supply vary appreciably as between different parts of the area of supply, there would be a case for dividing the area into zones and charging appropriate tariffs in each zone. The tariffs in a high cost zone should cover at least the costs which would be avoided if the zone did not exist, but it is not necessary for each zone to make its full contribution to the general overheads of the undertaking. Uniformity may therefore be possible and may be desirable for practical reasons. With zones, boundary troubles arise. On the other hand, averaging of costs over the whole area of supply may create difficulties in competing with alternative sources of heat or power in low cost zones; this may well be a major consideration. It is a matter of judgment according to the circumstances.

Costs of supply will vary with the load characteristics. Tariffs should be framed accordingly. In reflecting cost, the tariffs will, at the same time, promote the expansion of loads which improve the system load factor because within the limits referred to earlier it is these loads which cost least to supply, capital charges and overheads being spread over a larger consumption.

Consumers may be grouped for tariff purposes into reasonably homogeneous classes according to their load characteristics, e.g. large industrial, small industrial and commercial, domestic and farm consumers. There is bound to be a large measure of averaging within each class - particularly with small consumers. Only in the case of the large consumers can any degree of exact individual costing be made. Particularly for the small consumer, tariffs need to be cheap to administer, that is, require simple metering; also they should be in a form easily understood by, and reasonably acceptable to, the consumer.

The first step is to allocate the costs between the different consumer groups.

/Costs of

Costs of electricity supply fall broadly into four categories:

(a) Capacity or demand-related costs: interesting, depreciation and such other costs, as are broadly proportional to the kilowatt capacity of the power plant, transmission lines, etc., and hence to the system maximum demand.

(b) Running costs: costs which vary with the kilowatt-hours supplied. In a thermally based system they consist mainly of the cost of fuel consumed at the power stations together with a proportion of the power station maintenance costs and consumable stores.

(c) Consumer-related costs: costs of metering, meter reading, billing and collection, consumer service and publicity; these are primarily dependent on the number of consumers and can be allocated on that basis, with perhaps some weighting according to the size of consumer.

(d) Establishment and administration costs: that is, costs which are not dependent directly on demand, consumption, or number of consumers, but which rise as the size of the undertaking increases.

No difficulty arises in the allocation of running costs, and little with consumer-related costs.

The allocation of demand-related costs is not so straightforward. Because of diversity of demand between groups of consumers, the same equipment is used to supply them at different times in different degrees. As far as practicable demand-related costs should be allocated to consumer classes in accordance with their probability of contributing to the peak demand - the demand for which capacity is provided. In doing so, the different parts of the system should be considered separately, e.g. power stations, main transmission, and local distribution; while certain consumers may make a relatively small demand at times of the peak load on the power stations, their demand may nevertheless be at the maximum at the time of the peak load on the local distribution system.

The allocation of administration costs must necessarily be somewhat arbitrary. These costs could be apportioned between classes on a revenue basis but it may well be found expedient to adopt the basis of the use value of the supply to the consumer.

/So much

So much for allocation of costs between classes. How should the tariffs be formulated to recover these costs?

In the case of the larger industrial and commercial supplies, the cost of metering the consumer's maximum demand is justified, and the tariff can consist of a demand charge per kilowatt of the annual maximum demand of the consumer and a running charge per kilowatt-hour supplied. A third component might be included in the tariff, and indeed is sometimes included, to recover the consumer-related and establishment costs. But in the interests of simplicity and acceptability to the consumer a two-part tariff is more usual. "Consumer" and "establishment" costs are then spread over the demand and running components of the tariff; they might well be apportioned to the two components in equal shares. The part included in the running charge is best recovered in a first block of units per kilowatt of demand, corresponding to a relatively low load factor of use. Some of the demand-related costs are also sometimes included in this first block; this is justified by the higher diversity of low load factor supplies. In addition, a profit margin is necessary; it would be reasonable to reduce this margin in the running charge at the higher load factors. These considerations lead to a running charge containing two or three blocks of units per kilowatt, the price per unit decreasing as the units per kilowatt increase. This form of tariff not only reflects costs of supply closely but also encourages the consumer to improve his load factor. Because of the separate demand and running charges and because of the steps in the unit charge, the more kilowatt-hours the consumer takes per kilowatt of demand, the lower is his average price.

This two-part maximum demand tariff should differentiate both in the demand and running charge between supplies given at high voltage and low voltage. Supplies at high voltage require less transformation and no low voltage network. The cost of equipment to supply them is therefore less and the losses in transmission and distribution are also less.

/It has

It has been suggested above that the demand charge should be based on the metered annual maximum demand. For the larger supplies, this is the most accurate guide to peak responsibility. But if there is no pronounced seasonal variation in the demand of the industrial supplies in the area, the demand charge could, at a somewhat higher aggregate figure, be based on the consumer's maximum demand in each month without undue departure from costing principles. This basis is often preferred by the smaller industrial consumers and to offer such a tariff may make for good consumer relations. In the tariffs for the larger industrial and commercial supplies, it is common practice to include a fuel price variation clause which may be on the following lines: "The running charge shall be varied by 0.000X pence for each penny by which the cost of standard fuel delivered to the power stations differs from Y shillings per ton". Wage levels, the costs of materials, and the price of fuel tend to rise and fall together and instead of complicating the tariff by a separate wage clause the rate of variation in the fuel clause may include a margin towards variations in other costs.

For domestic and other small supplies, the tariff, while still two-part in form, would not generally include a metered maximum demand charge, for three reasons: first, the cost of the metering equipment would be out of proportion to the revenue received; secondly, there is high diversity between such small and individually low load factor supplies and in their case the consumer's individual maximum demand is not a fair reflection of the cost of supply; thirdly, for small supplies consumer costs assume a greater importance, relative to other costs.

For these small supplies, the initial charge - either a fixed quarterly sum or one or more initial blocks of high price kilowatt-hours - could be related to the size of the premise (domestic and possibly commercial) or to the installed capacity of the consumer's equipment (industrial and commercial), with a uniform follow-on rate per kilowatt-hour. For example, a domestic tariff would have a specified number of kilowatt-hours per quarter per room chargeable at, say, 6d. per kilowatt-hour and the remainder of the consumption at a lower rate of, say, 1 1/4d.

/What should

What should be the basis of the money content of the fixed charge (or its equivalent in the initial block)? The costs which can be identified as "consumer related costs" and "establishment and administration costs" should be included but how can the capital charges (depreciation and interest), on generation and distribution expenditure be most equitably recovered? They should in some way be related to the consumer's responsibility for the investment incurred in making the electricity supply available to him. But it is not easy to get a fair measure of this responsibility because of the wide diversity of demand.

A practical way out of this pricing dilemma is to allocate to the "fixed" component of the tariff the appropriate "consumer" and "establishment" costs and the capital, operational and administration charges in respect of the local low voltage distribution networks allocated to the consumer class, and to include in a follow-on price per kilowatt-hour the remaining capital and operating costs appropriate to that class of consumer. The follow-on price would then include the capital and operating costs of production and of the transmission and distribution system (other than of local distribution), plus and allowance for transmission and distribution losses, plus a margin of profit. The demand-related component of these costs would be converted to a price per kilowatt-hour on the basis of the average load factor of the consumer class.

This method of allocation of the group costs does not produce a particularly "promotional" form of tariff, but it has two advantages. One, the final price per kilowatt-hour ensures that the marginal costs of supplying additional requirements are covered (except, of course, when general costs are rising and have not yet been reflected in the tariffs) and, two, it results in a follow-on price that leaves some scope for offering attractive off-peak tariffs.

Tariffs, in general, must allow freedom to the consumer to take supplies as and when he requires them. This will be conditioned by the pattern of life and habits of the people and will result in substantial daily and seasonal variations in the demand on the undertaking. By

/offering attractive

offering attractive off-peak tariffs, however, consumers can be encouraged to use special appliances or adjust their organisation to enable more supplies to be taken at times convenient to the undertaking, that is, at times, other than at system peak, when there is spare capacity available. The cost of providing such supplies will be the incremental fuel, maintenance and administration costs together with the annual charges on any local capital expenditure involved in providng these supplies. The price charged should cover these costs with a margin for profit. Because the provision of the off-peak supplies does not increase the capital and other charges on the main production and distribution equipment, the price charged for them can be substantially lower than the average price for normal supplies. But equity to the normal consumer would seem to require that off-peak supplies should make some contribution to the cost of the main equipment. The extent of the contribution which can be obtained depends upon the use value of the supply to the consumer; low prices may have to be offered in order to attract these supplies. Even so, the ordinary consumer will benefit so long as the marginal costs of the off-peak supplies are more than covered.

In line with this principle, the demand charge in the normal industrial tariff may be related only to the consumer's maximum demand during specified potential peak periods and excess demands outside those periods charged at a substantially reduced rate. Thus a consumer taking supplies on the industrial two-part tariff can obtain what is effectively and off-peak price for any additional supplies taken outside the normal peak periods.

With tariffs for the smaller consumers, where there is no measured demand charge, there is no direct incentive to the consumer to restrict the peak demand or to improve the load factor of his supply. A special tariff for supplies available only during off-peak periods is therefore desirable. This can be a flat rate per kilowatt-hour, designed to cover at least the marginal costs of the supply as already outlined (any special capital expenditure involved being recovered separately). The difference between this rate and the charges under the normal tariffs can be substantial.

/Whether such

Whether such financial incentives are sufficient to provide an economic attraction for consumers to incur whatever cost and inconvenience is involved in taking off-peak supplies will depend upon local circumstances. In general, industrial processed with high electricity consumptions and low labour costs and thermal-storage heating installations are the most favourable fields of application.

The annex shows the form in which tariffs for different classes of consumer might be expressed. Money values have been inserted to simplify the presentation. The tariffs have been expressed in their simplest form and each electricity supply organisation will wish to add refinements to accord with their costs and cost structures.

The normal tariffs discussed above can only cover the general run of consumers. There should be flexibility to make special agreements to deal with exceptional circumstances. For example, where abnormal costs of connection are experienced, special treatment is warranted; in addition to the normal connection costs recovered by way of the normal tariff a capital contribution could be levied or revenue guarantee required. Special terms may be necessary to cater for unusual loading conditions and to encourage new applications. Equal treatment should, however, be given wherever the circumstances are the same.

It is, indeed a statutory requirement governing electricity supply in England and Wales that the Area Electricity Boards, in fixing tariffs and making agreements, shall not show undue preference to any person or class of persons. A further safeguard of consumer interests is the establishment by statute of consumer Consultative Councils. Before fixing or varying retail tariffs the Area Boards are obliged to consult with these Councils. Arising from their consideration of tariffs (and other questions) the Consultative Councils, may make representations to a central body, the Electricity Council, representative of the electricity supply industry and, failing satisfaction, to the responsible Minister. Individual consumers, or intending consumers, may, failing satisfaction in any approach by them to Consultative Councils, appeal to the above-mentioned central body. The central body may advise the Area Electricity

/Boards but

Boards but the Boards are autonomous bodies and the advice to them is not mandatory. If, however, the advice is not taken the central body can make representations to the Minister, who after investigation may give directions to the Area Board for remedying any defect he may find.

/Annex

Annex

TYPICAL ILLUSTRATIONS OF ELECTRICITY TARIFFS
(1) ANNUAL MAXIMUM DEMAND TARIFF

	High Voltage Supplies	Low Voltage Supplies
Maximum demand charge	£. s. d. per kW per annum	£. s. d. per kW per annum
First 200 kW	6.15. 0	7. 2. 0
Next 300 kW	6.10. 0	6.17. 0
Next 500 kW	6. 5. 0	6.12. 0
Over 1 000	6. 0. 0	6. 7. 0
Kilowatt-hour charge		
Units per kW of Maximum Demand	pence per unit	pence per unit
First 1 800 per annum	0.67	0.70
Next 2 520 " "	0.58	0.61
Over 4 320 " "	0.50	0.53
Fuel price adjustment		
For each penny Variation from 60 shillings per ton	Adjustment pence per unit 0.00059	Adjustment pence per unit 0.00063
Power factor adjustment	The maximum demand charge is increased by 1 per cent. for each 0.01 by which the average lagging power factor is less than 0.9	

/(2) TARIFFS

(2) TARIFFS FOR SMALL INDUSTRIAL AND COMMERCIAL SUPPLIES

Two-part tariff		Two-block tariff
Fixed charge per kW of installed equipment		Initial block of units per kW of installed equipment
per quarter		per quarter
Lighting:	£2.10s. 0d	Lighting: 160 Units at 6 pence per unit
Other load:	12s. 6d	Other load: 40 Units at 6 pence per unit
Unit charge		Final unit charge
1.2 pence per unit		1.2 pence per unit

/(3) DOMESTIC

(3) DOMESTIC TARIFFS

Two-part tariff	Two-block tariff
Fixed charge per quarter	Initial block of units per quarter
First 1 000 square feet of floor area: £1. 1s.0d	First 4 rooms 40 units at 6 pence per unit
Each additional 200 square feet of floor area: 2s.0d	Each additional room: 10 units at 6 pence per unit
Unit charge	Final unit charge
1.25 pence per unit	1.25 pence per unit

/SUMMARY

SUMMARY

Maximum operating economy depends on the continual and precise programming of system control and load despatching, so that load is always supplied by the most economical plant. In a large and complex system this is best achieved by computer programming, but smaller systems, in which the problems are inherently simpler, can attain satisfactory economies without recourse to computer service. A maintenance programme designed to prevent breakdowns, and to limit outage time for overhaul and repairs to a minimum is of nearly equal importance. Routine plant overhaul should take place outside the peak load season.

The load factor of a system is a useful indication of the degree of utilisation of capital assets. Various factors reduce the optimum economic load factor from 100 per cent but, in general, the investment per kilowatt is inversely proportional to load factor. Load factor may be improved by selective load development to increase diversity, and by encouraging extended hours of use with an accompanying reduction in demand at peak hours. Tariff incentives are the principal means by which the supply industry can encourage this improvement.

Tariffs should as far as practicable reflect the costs of supply and these will vary with the load characteristics of the consumer. Because exact individual costing is only possible for the large consumer, difficulties and anomalies are bound to exist, although the advantages of uniformity can over-rule these.

Consumers may be grouped into reasonably homogeneous classes and costs allocated under four main headings:

(a) Capacity or demand-related costs
(b) Running costs
(c) Consumer-related costs
(d) Establishment and administrative costs.

Of these factors, the allocation of demand-related costs is likely to provide most difficulty both because of the diversity of demand between groups of consumers and because demand must be considered in relation to the separate parts of the system, e.g. power stations, main transmission and local distribution all of which may have different peak load times.

The way in which tariffs are formulated to recover all these costs principally depends on the size of the supply to the consumer. Large industrial and commercial supply tariffs will consist of a measured maximum demand charge and a "running" charge per kilowatt-hour. Consumer-related and establishment costs may be apportioned between these two charges, or may form a third component. The "running" charge will be stepped to encourage improved load factors, and will usually include a fuel price variation clause. The demand charge can be based on annual or monthly maximum demand and the tariff should differentiate between high and low voltage supplies.

For domestic and other small supplies the metered maximum demand charge is not appropriate. It is replaced by a fixed quarterly sum or as an equivalent one or more initial blocks of high priced kilowatt-hours. Difficulties of a fair apportionment of capital charges on generation and distribution (other than local distribution) expenditure may be overcome by including these in the follow-on price, and one advantage of this is that attractive off-peak tariffs may be offered.

Off-peak supplies do not increase the capital and other charges on the main production and main distribution equipment and can therefore be offered at special rates. This principle may be extended to the normal maximum demand tariffs, in which demands in excess of those registered during potential peak periods may be charged at a substantially reduced rate. For smaller supplies a special off-peak tariff can be offered in the form of a flat rate per kilowatt-hour.

Special tariffs under agreements should be made to cover exceptional circumstances, e.g. for abnormal costs of connection or unusual loading conditions.

It is a statutory provision in England and Wales that Electricity Boards, in fixing tariffs and making agreements, shall not show undue preference to any person or class of persons, and as a further safeguard of consumer interests Consultative Councils have been formed by statute. Electricity Boards consult with the Councils before retail tariffs are varied, and on any matter affecting distribution in their area of supply.