PAPER No. 208.

ON THE FUNDAMENTALS OF RATE FIXING FOR ELECTRICAL UNDERTAKINGS.

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In deciding what rates must be charged for electrical energy the first calculation to be made is the one to determine what return per unit on all the units available for sale is necessary to pay interest and depreciation on the capital invested and the operation and maintenance charges on the plant, transmission and distribution lines, and transformers of the undertaking. The number of the units which can be sold is not the same as the number which can be generated, because a certain number of the units generated are used on works for plant operation, pumps, lights, etc.; a certain number are lost in transformation, transmission and distribution, and all these must be deducted from the total number generated before we can arrive at the number for sale.

To appreciate the details which follow, it is necessary to understand the action of electric equipment when in use.

A transformer for instance consists of an iron core round which are wound two sets of copper conductors, one set of these windings being energized from the source of Alternating Current power. This sets up oscillating lines of magneto motive force in the iron core and as the second set of conductors are wound round the same core, the reverse process is set up in these conductors, or to put it more clearly, the lines of magneto motive force in the core set up by the passage of electric current through the first set of coils generates current in the second set of coils and the ratio of the voltage and current in the second set is directly proportionate to the ratio of the number of turns of the two windings.

Now at full load such a transformer may have an efficiency of 97 per cent but at light load 60 per cent and at no load there are still losses going on due to the effect of hysteresis in the iron core.

A transformer serving residential areas is very rarely operating at full load or maximum efficiency as will be readily understood when one remembers that lights are usually only in use for 2 or 3 hours out of the 24; heaters, refrigerators, irons, fans all use power spasmodically, yet the transformer has to be big enough to take them all; though, when several residences are connected to the same transformer, allowances can be made which help in this respect, but even under the best conditions transformers in residential areas are rarely working at a good efficiency for more than 3 hours out of the 24 and often are almost completely unloaded for 16 or 17 hours per day. During all this time of light or no load, power is being used for which no return is made to the supplier; just to keep the transformers in readiness for instant service as and when required.

Transmission losses are a question of design. They may vary from 5 to 20 per cent. depending on the money expended in putting up conductors of heavy section, and are generally dependent on the cost of energy production compared with the cost of money at the time of building such lines.

The first calculation then really consists of finding the number of units available for sale and then the return which must be obtained from their sale. Suppose a generating station could deliver continuously 10,000 kw. to the transmission lines, the units available for transmission would be 10,000× the number of hours in a year, namely, 8760. If the transmission line was designed for 10 per cent losses and 10 per cent loss is taken as the value of the loss in the main transformation, then 20 per cent. of the units will be used before the power will be available at the main substations for distribution by the distribution net work. In this net work again we have losses in the lines and losses in the local transformers, so that another 20 per cent. will in general be lost here and approximately 40 per cent. of the units generated under these circumstances will never reach the consumer. Of course this would only be true under the conditions laid down above. In the case of a large consumer, say a mill consuming 1000 kws. working 16 hours per day, 6 days a week or even 8 hours per day, things are very much better and in actual practice with a mingling of large loads and residential lighting loads the figures given above are greatly modified, but I have gone into these figures to show one reason, why the rate for energy used in residences is so much more than for bulk supply for mills or factories. Having ascertained by calculations taking into account the factors mentioned above the number of units which can be sold and therefore the average rate at which they must be sold to give a reasonable return on the capital invested and to pay the operation and manitenance charges, we next examine the load from two aspects :—

(i) its quantity;
(ii) its quality.

The quantity of the load is usually obtained by direct canvass of the prospective consumers and the results of such a canvass are compared with known figures of the consumption of electric energy per capita of towns or villages as similar in numbers and industrial conditions as can be found. For instance if the canvass shows the area to be strongly industrialized, it is compared with strongly industrialized area elsewhere; if mainly residential with a residential area and so on and this comparison gives a valuable check on the accuracy and completeness of the canvass. The figures then are divided into domestic and industrial and the possible revenue calculated from a basis of assumed rates. The canvass is next examined as to the quality of the load or shall we say from the standpoint of the prospective consumers. If factories exist their costs of production are obtained from the factory owners, if special processes are being operated or developed, their probable cost of operation by electrical energy or by other means are calculated and compared. In fact a consideration of the entire problem is made from the standpoint of the consumer; can he afford to change to electric drive ? Can he economically use electricity for his business, and if so, at what rate ?

When this analysis is complete, we may find that the rate that certain industries can economically afford to pay is below the average return required and this is often the case in specialized processes work where heat either for the reduction of metals or as steam has to be employed; for electrical energy is itself a manufactured article and must be used in economical appliances to compete with crude materials such as coal or wood in the production of heat.

The canvassed load can now be divided into five groups :—

(*a*) Domestic,

(*b*) Small industrial motors,

(*c*) Large industrial motors,

(*d*) Special process consumers, and

(*e*) Bulk Supply to Licensees.

Group (*a*) can afford to pay the highest price, because electricity is here competing with other methods of light production and they are all costly and except for electricity more or less unsatisfactory and troublesome. The ordinary oil lamp besides giving a poor light is expensive for to the cost of the oil used is added chimney replacements, wicks, and waste from spilling of oil. The lamps have to be maintained and it has been established that electricity at even 6 annas per unit can and does successfully compete with other methods of producing light.

In group (*b*), electricity is competing with small oil engines which are costly in up-keep both for fuel, lubricating oil and repairs and such engines to be run at all economically must be run over considerable periods at one time besides requiring fairly expert management. Electricity therefore with its ease of operation and instant response to load demands is easily first in this field also ; and power sold at from $1\frac{1}{2}$ to two annas per unit can succesfully compete.

In group (*c*) matters are not so simple, because here electrical energy has to compete with steam turbines and the size of the loads, and their continuity enable steam engines and other equipment to operate at higher efficiencies than in groups (*a*) and (*b*). These large factories can maintain their own engineering staff and the rates charged for electrical energy supplied have in recent years declined on account of the increase in efficiency of boilers and steam turbines, so that prices varying from 7 to 9 pies is all that can be expected from this type of load.

The special process consumers of group (*d*) form a special problem and in dealing with them the greater flexibility of the electric drive with its individual motor control has to compete against the fact that the consumer must use heat in the manufacture of his product and therefore may install boilers or furnaces or both and often at small extra expense, since he may have to install boilers to raise steam for a portion of the manufacturing process and can install slightly larger boilers and his own electric generating plant and thus get the advantage of electric drive for his factory from his own steam driven plant.

In some cases also the refuse from the raw material from which this product is manufactured can be utilized as fuel which of course gives the consumer a further advantage.

In order to make it worth while for such a consumer to take electric supply, the rate for energy cannot usually exceed 5 pies per unit but it is economic for the consumer to utilize the electric supply at this price, since if no turbines are installed for electric generation, low pressure steam only can be raised for process work and this equipment is much less expensive and requires very much less skilled maintenance.

In group (*e*), the same considerations as those mentioned under group (c) have to be considered and supply should be considered for prices ranging from 7 to 9 pies depending on the size of the plant under consideration. We have now ascertained the probable demand under each of the 5 groups; by calculation and from experience. We know approximately the rate at which each group may be expected to purchase energy and now we must find the number of units we may expect to sell to each group. That is, we must estimate the load factor. The load factor is the percentage of load used in any given period, referred to the quantity represented by the continuous use of the full power for the whole period. For example, if a bungalow has 20 lamps of 40 watts each, the connected load would be 800 watts. If these 20 lamps were burned 8 hours per night the " daily " load factor would be $8/24 = \frac{1}{3}$ or $33\frac{1}{3}$ per cent.

In industrial plants the load factor is subject to variation not only due to the length of time the factories run but also the loads on the machine. A saw for instance only takes its full load when it is cutting and very little when running idle while the timber is being brought to the saw bench. Similarly a shaping machine working only on the forward stroke of the cutting tool can never have a load factor much above 50 per cent and with changing cutting tools, etc., usually has a load factor of less than 30 per cent for the period the machine is in use, which period may itself be only 8 hours out of the 24 so that the true load factor to such a machine will be only about 10 per cent.

Cement mills, spinning and weaving factories, large flour mills which run continuously night and day, 6 days per week, have a daily load factor of 80 to 85 per cent and a monthly one of 70 per cent. Domestic lighting usually average only 5 per cent. because very seldom are all the lights on at the same time for any lengthy period except at the time of festivals or ceremonies. Applying these well established factors to the figures of "demand" or load obtained for the groups above, we get the number of units likely to be consumed in each case. Multiplying these numbers by the average rate which we consider reasonable, the probable revenue is obtained, and this compared with the annual charges gives the first rough idea as to whether or not the scheme is likely to be an economic success.

Having now examined broadly the method employed in making preliminary investigation as to what rates may be, it is of interest to examine the various items more in detail.

The first point to be determined is of course the capital expenditure on the undertaking and this at first might appear to be a very simple matter and yet it can be most complicated. The first question which comes up is that of the inclusion of interest on expenditure during construction being added to the actual outlay as part of the capital charge. Now the Courts have decided that the basis of value for rate making should be the fair present value of the property used regardless of the amount of the original investment. There is, therefore, at once room for argument as to whether or not this interest charge should be included in any estimation of the fair present value since if the construction had been hastened a smaller amount of interest would have been charged but on the other hand the speeding of the rate of progress might have cost more than the added interest.

The next item for consideration is the rate of interest to be allowed in the calculations. Since in a private Company this rate of interest is a return on capital invested from which the share-holders obtain their return for their courage in investing their money in the undertaking and it has been decided that the evaluation of public utility properties includes certain intangible non-physical elements which should be evaluated and allowed as an addition to the material sensible elements. It is, therefore, necessary that in considering the rates to be charged due thought should be given to the conditions and risks involved and that the rate of interest should not be merely the bank rate, for if that only is allowed, it is impossible to attract capital to these enterprises.

In dealing with the question of operation and maintenance charges, it is necessary to decide the method employed in dealing with distribution and transmission lines, because it is possible to come to entirely erroneous conclusions unless care is taken to find whether replacements which maintain the value of the network at the same or a higher value than the original cost are charged to maintenance. For instance supposing that a distribution line built in a street was originally installed in order to cater for a load of 500 kw. but with the growth of a load it has become necessary to augment that line in order to care for a load of a 1000 kw., and the cost of increasing the conductor size or running an additional circuit on the same poles is charged to maintenance and at the same time depreciation is allowed on the network as a whole, the result will be that on the maturity of the depreciation fund, that is to say when it has reached the value of the capital invested, the Company will have a fund equal to their original investment and in addition a reticulation network either equal in value or more valuable than the original network installed by them and will thus have been enabled to make double provision for the retirement of the moneys originally invested by them.

The operation costs of course have to take into consideration, distance from rail head, difficulties of getting supplies, transport costs, living conditions for staff which may necessitate increased wages or allowances on account of the undesirability of the locality as well as the supply of consumable stores and spare part replacements.

In dealing with depreciation, we immediately find ourselves in a maze of opinions. Depreciation is designed to supply a fund from which it is possible to recover the cost of renewing exhausted physical parts of considerable value. Where the cost of individual parts renewed is relatively an insignificant part of the total operating expense, the expenditures are included as part of operating expenses under the head of Maintenance, but in the case of other elements of property costing relatively large sums and lasting a number of years, it is difficult even for experts to agree as to the proper method of handling the costs and providing for the expenditures necessary when renewing such elements. One basis which is not infrequently attempted is to give each element a rate of depreciation corresponding to its length of life, thus concrete footings, dams, weirs which may be considered to have a life of 200 years are depreciated at ½ per cent while electrical machinery which may become obsolete in 10 years is depreciated at 10 per cent. Then taking the money invested in each element, strike, for the undertaking as a whole, an average life and base the depreciation of the whole undertaking at this average rate. This of course is very rough indeed, because it does not take into consideration the junk or scrap value of the plant and even assuming that the plant ceased to operate as such at the end of the specified period it would still have some value depending upon metal prices at the time, local conditions and the market available for the commodities it had to offer.

Another system which is used very largely with Government concerns is to establish a Debenture Fund; making payments of certain amounts in each year which at the end of the specified period (very frequently 33 years) at compound interest will pay off the entire Debenture issue which supplied the original capital for the building of the undertaking. This brief explanation of the fundamental elements in rate making may give some idea as to the complexity of the question and no further comment will be made on this aspect of the case.

We will now proceed to discuss the form of rate, which has a distinct effect upon the progress or otherwise of any electrical undertaking. As explained in the opening paragraphs of this paper, various kinds of load are more remunerative to the Electric Supply Authority than others or to put it more crudely, those consumers who make most consistent use of the equipment and services belonging to a Company are of more value to that Company than those who utilize the equipment installed for their benefit to a lesser extent. Furthermore since each consumer has to have bills sent to him and is an expense to the Supplying Authority by reason of the employees maintained for keeping his service in order, reading his meter, preparing his bills, keeping his account, etc., the bigger the return which is obtained from each consumer the more beneficial will be the position of the Supplying Authority. It is also to be observed that the more units a consumer takes from the equipment supplied by the Company the less the capital expenditure necessary on the part of the Company to enable them to sell the larger number of units, therefore a rate should be so arranged that the larger the number of units consumed the less the charge, but this alone is not satisfactory, because if a consumer has an installation of 10 kw. and another consumer has an installation of 100 kw. although both use the same number of units and therefore get the same rate, the consumer with 100 kw. installation is holding for his private use a very much more expensive equipment than the consumer with the 10 kw. installation. A rate, therefore, should take into consideration not only the number of units consumed but also the quantity of material held for the sole use of a consumer or in other words the load factor.

The fixation of rates in consideration of the above points requires a Two-Part Tariff, *i. e.*, one which has one charge based on the maximum demand or the connected load which must be paid irrespective of the number of units consumed, and a unit charge which is levied per unit consumed. In some countries this demand or connected load charge is known as a readiness-to-serve-charge and this really describes it better than anything else inasmuch as it will be a charge made by the Supply Authority to cover the cost of supplying and maintaining the equipment which is in readiness at all times to serve the consumer.

In deciding the details of such a rate, it is necessary to sub-divide the annual cost into variables and fixed charges or fixed expenses. Fixed charges include interest, depreciation, taxes, insurance, etc., on the cost of the Power House apparatus, transformers, transmission lines, distribution networks, services, etc., while the variables cover the repairs, oil, waste, incidentals and that portion of the staff which has to be augmented as the load increases or the fixed charges are those which are consistent irrespective of the energy output of the plant and should be divided among the customers in proportion to their maximum demands for power, so that each customer should pay the fixed charges and expenses on the apparatus set aside for his use, while the variable expenses are those varying with the energy output of the plant and these should be divided among the consumers in proportion to the energy they consume in a fixed time.

It is evident from the above that an equitable basis of rates is one made up of a reservation charge (readiness-to-serve charge), a fixed amount per kw. per year or month for each kw. of maximum demand plus a charge for power on a basis of an amount per unit, which amount should vary theoretically with the load factor. In practice, any such mathematical accuracy as this method would entail in arriving at a proper charge, would be impracticable since the load factor varies from time to time. Therefore the rates are struck by utilizing average figures for load factor for the various types of consumers as explained earlier in this paper and the total return per unit from this rate is checked against the return necessary to maintain the electrical undertaking on a self-supporting basis.

No reference in this paper has been made to the introduction of what is known as a minimum charge, because it should be understood that where a Two-Part Tariff has been installed, the fixed demand should be paid whether any units are used by the consumer or not during any billing period and this in itself constitutes a minimum charge.

DISCUSSION

The **Author** in introducing his paper said that it was an endeavour to explain the considerations upon which all rates must be based and to point out that a rate to be just and fair both to the supply authority and the consumer must take into consideration three factors :—

(1) the amount of power which must be reserved by the supplier so as to meet the greatest instantaneous demand which the equipment of a consumer was capable of making on the supply plant,

(2) the frequency or length of duration of this maximum demand,

(3) the number of units used over a specified period in relation to the maximum of peak demands mentioned before.

The paper also was intended, the Author said, to emphasize the fact that the average cost per unit generated and distributed could not be the selling price in all cases and while all units generated must be sold, it was necessary in an ordinary community to sell some units at a higher rate than others in order to keep the average return per unit slightly above the cost of generation and distribution to allow for line and transformation losses.

Mr. **N. Thornton** said that the Author had explained clearly the necessity for a two-part tariff in order to obtain equitable charging for the supply of electrical energy to all consumers and had indicated that one part of the tariff should be based either on the maximum demand or the connected load of the consumer, both of which factors were intended to serve as a measure of the quantity of apparatus to be reserved for the consumers' use.

In this connection it was interesting to note that the necessity for a two-part tariff was first appreciated in the Electrical Industry by Dr. Hopkinson who in a presidential address to the Junior Engineering Society as far back as 1892, drew attention to the fact that the expenses of an undertaking could be divided broadly into two classes, one of which was quite independent of the extent to which the undertaking was used and the other depending upon the amount of energy consumed.

He proceeded to suggest that the charge for a service should bear some relation to the cost of rendering it and stated that the ideal method of charge was a fixed charge per quarter proportioned to the greatest supply the consumer would take and a charge by metering for the actual consumption.

This really was the birth of the two-part tariff system which was brought into practice in Great Britain very shortly after.

In the early days of the application of the two-part tariff system in Britain the supplies were mainly of a domestic nature and Maximum Demand Indicators were actually employed on the supply to ordinary domestic dwellings.

The Maximum Demand Indicator, however, was not regarded favourably by the domestic consumer owing to his difficulty in understanding the variations in the reading obtained from one period to another or the difference in readings obtained for similar adjacent premises. Neither was the Maximum Demand Indicator for domestic supplies looked upon favourably by the Supply Industry on account of the cost which the use of such indicators involved.

Therefore it was not long before the use of Maximum Demand Indicators on domestic supplies was discarded and alternative methods of assessing " the readiness to serve " charges were adopted.

The most popular of the alternative methods was a fixed charge based upon, either

(*a*) the ratable value, or

(*b*) the floor area of the premises in question. Both of these methods are still extensively used in Britain.

Neither of these methods had the same degree of accuracy as that of the Maximum Demand Indicator, but they were more easy of application and did not involve expenditure on any additional equipment.

The basis depending upon ratable value of the property obviously could not be applied in this country owing to the absence of regular assessments, whilst the basis depending upon the floor area of the premises would not be satisfactory as it tended to penalize houses or property with large rooms which were so desirable in these parts.

Therefore almost the only suitable alternative basis for the determination of " the readiness to serve " charge, was that of the connected load and this was the basis generally adopted throughout the Punjab for supply to domestic consumers.

Mr. **V. F. Crichley** said that the paper brought out clearly and forcibly the complexity of the many factors to be considered in the formation of electricity supply tariffs which would be equitable to the consumers and the undertaking. The wide divergence of opinion which still existed with regard to the most suitable type of tariff was reflected in the large number of tariffs in use to-day. The methods of charge adopted by electricity supply undertakings comprised the following main groups :—

(*a*) Multi-part tariffs.

(*b*) Flat Rates.

(*c*) Block Tariffs.

The majority of those undertakings which offered a multi-part tariff adopted a two-part tariff consisting of a fixed charge and a unit charge. Many different methods of assessing the fixed charge were in use, such as maximum demand in kW., maximum demand in kVA, connected load, whilst in the case of domestic consumers the fixed charge was frequently based on floor area, ratable value, or on the number of main rooms in the house, *i.e.*, excluding box rooms, bath rooms, store rooms, etc. The flat rate system either for power or domestic loads had considerable disadvantages. It took no account of the maximum rate at which electricity was used by a consumer and gave no discount for quantity in accordance with the general practice adopted in connection with the sale of other commodities.

The block rate system which consisted essentially of a series of flat rates provided a discount for quantity. It had the disadvantage of making no allowance for power factor or maximum demand. In order to counteract the latter disadvantage a straight block rate tariff was sometimes replaced by a block rate tariff with a fixed charge based on maximum demand so that this method of charge was really a disguised two-part tariff.

The two-part tariff with a fixed charge and an energy charge per unit was the most equitable to the undertaking and to the consumer of the three methods of charge referred to above. The Speaker said that the fixed charge and the energy charge per unit should preferably have a sliding scale based on connected load or maximum demand in kW. or kVA. Power charges for large consumers were frequently fixed on a competitive as against a cost basis. Such a consideration, however, did not apply to the same extent in the case of domestic and small power consumers as the alternative sources of energy for lighting and power could not compete with the rates which can be offered by the average electrical undertaking. The two-part tariff adopted should be as simple as possible in character so as to be suitable for the large majority of consumers and equitable both to them and to the electricity supply undertaking. In India at the present time the majority of undertakings adopted the flat rate tariff both for domestic and power supplies.

An increase in consumption and revenue would probably be realized provided that a suitable two-part tariff were adopted, the unit charge being as low as practicable. The complexity of the various issues to be taken into account in arriving at suitable tariffs for an electricity supply undertaking resulted in the tariffs adopted being to some extent the result of compromise and expediency.

Mr. **D.A. Howell** stated that the Author had mentioned on page 3 of his Paper that electric power sold at from 1½ to 2 annas per unit could successfully compete with small oil engines which were stated to be costly on upkeep and repairs.

He did not know whether this statement was intended by the Author to apply universally or only to Punjab conditions, but actually, he did not consider it should be accepted without certain definite qualifications.

Oil and diesel engines of modern design were much more economical and reliable than those produced some years ago and such engines driving pumping installations in this Province could successfully compete with electric power sold at much lower rates than 1½ to 2 annas per unit.

At one waterworks in the north of this Province, oil engines had, a few years ago, been replaced by electric motors operated on electric power supply sold at 9 annas per unit and at this rate there was little saving in cost as compared with the oil engines, in spite of the comparatively high cost of oil.

At another small water supply installation, the Speaker had negotiated rates for electric power supply of 1·1 annas per unit as he found that this was the best price to compete with small crude oil engines. In the south-west of the Punjab and still more so in Sind where, owing to lower railway freight from the port, the cost of diesel oil was less, the cost of electric power would need to be reduced below the figures he had quoted, in order to compete with oil or diesel engines; while in the neighbourhood of Karachi itself, where the cost of oil was very low, the competitive rates for electric power would have to be reduced to a still lower figure.

The **Author**, replying, said that the discussion on his Paper had been very helpful and he was grateful to those who had contributed such helpful criticism for they had brought forth certain points which required to be emphasized probably more strongly than he had done in his Paper. They had brought out the fact that the Maximum Demand Indicator was an instrument costing so much that its installation in the case of every consumer was not economically possible and therefore various methods of obtaining the same result without going to the expense of installing such meters had been tried and these had taken the form of fixed charges based on the ratable value of the property or the floor area or the connected load.

The discussion on the cost of utilizing diesel engines was also productive inasmuch as, it cleared a point which had not been emphasized in the Paper, namely, that in order to afford a diesel engine any chance of competing with electric supply at reasonable rates, the load on the oil engine must be as nearly consistent and as continuous as possible. Therefore an engine driving a pump against a non-variable head for reasonably long hours at a time, so that the excessive cost due to starting and stopping the engine were not an important portion of the total running cost, was ideally situated for competing with electric supply, whereas a load which was both variable and non-continuous could best be met by the characteristics of the electric motor.

ERRATA.

Page 13 line 8, after word "observation" insert "tank".
Page 14 line 15, after word "diameter" omit the semi-colon.
Page 16 line 2 for "Stop cock 'E'" read "Stop cock of tank 'E'."
Page 16 line 17 for "E" read "A".
Page 16 last line for "equal" read "equivalent".
Page 19 line 3 from bottom for "when" read "but".