Rates for Electrical Energy and Service

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WITH the fact that nearly 500 bituminous coal mines in this vicinity are served wholly or in part by central station power service, this discussion of power rates has been prepared principally for the A. I. M. E. members, assuming that the members of the A. I. E. E. section of this joint meeting are more or less familiar with the various forms of rate schedules.

It is about as impossible to frame a power rate exactly correct for each consumer as it is for a life insurance company to name an exact rate (based on cost) for each risk that it assumes. Rates are necessarily based upon classifications, diversity factors and averages as well as costs of production. When the entire output is taken by one consumer an exact rate is a simple matter, but when thousands of consumers, distributed over a hundred or more square miles of territory, are served under all sorts of conditions, the preparation of equitable rate schedules is quite another matter.

An ideal schedule, especially for small consumers, would be one so simple that the purchase of service could be as easily made as visiting the grocery for staple articles. Most power schedules, even those available to small users, are so bewildering to the layman as to frequently breed distrust in their fairness and the "conscientious objectors" are generally more numerous among the smaller users.

The "straight line" meter rate, which is the simplest form of meter rate, has a constant unit price per kilowatt-hour, which does not vary on account of an increase or decrease in the number of units used, hence the average price is shown by a straight horizontal line. This form of rate schedule is generally confined to residence and small commercial business which carries a minimum monthly charge of 50 cents to \$1.50.

The "step" meter rate is one in which the entire consumption is billed at a single price, which depends upon the particular "step" within which the total consumption falls. It is generally expressed as follows:

10 cents per kw-hr. for	1 to 20 kw-hr.
8 " " " "	21 " 40 "
6 " " " "	41 " 100 "
5 " " " "	101 " 200 "
3 " " " "	more than 200 kw-hr.

The curve of operation of this form of schedule is shown in Fig. 1 and it is apparent at a glance that very slight variations in consumption will often create very material differences in unit prices and total bills, for instance, 180 kw-hr. at 5 cents = \$9.00 and 210 kw-hr.

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at 3 cents = \$6.30, an increase in consumption of one-sixth, reducing that total bill by 30 per cent. This form of rate has the further disadvantage of not being based upon load factor, which is a vital factor in costs.

The "block" meter rate provides a price or charge for any part or all of certain specified blocks of consumption, with reduced prices per kw-hr. for each succeeding block or any portion thereof. This rate is as easily understood by consumers as the step rate and it avoids the wide variations in prices and total bills, with relatively small differences in consumption, which is characteristic of the step rate. The influence of load factor on costs is ignored, but this defect is often corrected by providing a demand or ready-to-serve charge,

FIG. 1—STEP METER RATE

in addition to the energy charge, this combination method being known as the Hopkinson demand rate. The ordinary block rate is generally expressed as follows:

10 cents per kw-hr. for the first	20 kw-hr.
8 " " " " " next	20 "
6 " " " " " "	60 "
5 " " " " " "	100 "
3 " " " " " all excess over	200 kw-hr.

The bills under the block rate are figured as follows:

20 kw-hr. at 10 cents	= \$2.00
20 " at 8 "	= 1.60
35 " at 6 "	= 2.10

\$5.70

The average price paid under this bill is 7.6 cents per kw-hr.

The following block rate schedule is in use by an Ohio central station and this form of general power schedule is commonly used by smaller utilities.

5 cents per kw-hr. for	1 to 200 kw-hr.
4.5 " " " "	201 to 350 "
4 " " " "	351 to 550 "
3.5 " " " "	551 to 800 "
3 " " " "	801 to 1800 "
2.5 " " " "	1801 to 2500 "
2.25 " " " "	2501 to 3500 "
2 " " " "	3501 or over "

One consumer with a 5-h. p. motor (4.5 kw. demand) operating 200 hours per month at 80 per cent average load will use about 720 kw-hr. with a load factor of about 22.2 per cent, while another consumer with a 15-h. p. motor (13-kw. demand) often uses a similar amount of energy, with a load factor of about 7.7 per cent, both consumers paying identical unit and total costs for the service. The 15-h. p. consumer should

FIG. 2—BLOCK METER RATE

pay (based on a load factor cost basis) between 2 and 2.5 times the rate per kw-hr. that the 5-h. p. user should pay. This schedule probably yields a proper average return from the total power business, but it does not provide the proper relative returns from the high and low factor consumers.

The term "demand rate" is given to a method of charge which is based upon the capacity of a consumer's installation or his maximum demand, expressed in kilowatts or horse power (which may be either estimated or measured) during a given period of time, usually a month or a year.

The term "flat demand rate" is given to a charge for service based upon the user's installation of energy-consuming devices and is frequently modified by the "step" or "block" method. It is frequently used for residence service and is expressed as follows:

FIG. 3—WRIGHT DEMAND RATE

\$2.00 per month per 100 watts connected load, or
25.00 per year per horse power of connected load, or
50.00 per year per kw. for the first 25 kw. of demand.
30.00 per year per kw. for the excess above 25 kw.

The "Wright demand rate" is a method in which a maximum unit price is charged for a given amount of energy, with several reduced charges (on the block principle) for additional energy supplied, the rates being based upon the use of the maximum demand

(load factor basis) which may be either estimated or measured. This rate schedule is generally applied to the larger commercial lighting and power users and is expressed as follows:

- 10 cents per kw-hr. for the first 30 hr. use of the demand.
- 6 cents per kw-hr. for the next 30 hr. use of the demand.
- 4 cents per kw-hr. for all energy in excess of 60 hr. use of demand.

The bill for a consumer having 10 kw. of demand and a consumption of 750 kw-hr. (equivalent to 75 hours' use of the demand) is prepared as follows:

300 kw-hr. (30 hours × 10 kw.)	at 10 cents	= \$30.
300 " " "	at 6 " "	= 18.
150 " " "	at 4 " "	= 6.
		\$54.00

The average price per kw-hr. of energy used is 7.2 cents. The operation of this schedule is shown in Fig. 3.

The "Hopkinson demand rate" method consists of a demand charge to which is added an energy charge

FIG. 4—BLOCK HOPKINSON DEMAND RATE

based upon metered energy used. The demand charge is generally based on the connected load for small installations and upon a measured demand for large installations. This rate schedule is expressed as follows:

DEMAND CHARGE:

- \$2.40 per kw. per month for 50 or less kw. of demand.
- 2.00 per kw. per month for the excess over 50 kw. of demand.

ENERGY CHARGE:

- 5 cents per kw-hr. for the first 100 kw-hr. used.
- 3 cents per kw-hr. for the next 4000 kw-hr. used.
- 1 cent per kw-hr. for the excess over 500 kw-hr. per month.

The bill for a consumer having 100 kw. of demand and an energy consumption during the month of 7000 kw-hr. is prepared as follows:

DEMAND CHARGE:

50 kw. at \$2.40	=	\$120.
50 kw. at \$2.00	=	100.

\$220.00

ENERGY CHARGE:

1000 kw-hr. at 5 cents	=	\$50.
4000 kw-hr. at 3 " "	=	120.
2000 kw-hr. at 1 " "	=	20.

\$190.00

7000 kw-hr.	Total Bill	\$410.00
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The average price per kw-hr. of energy used is about 5.86 cents.

The operation of this schedule is shown in Fig. 4.

Curve A is the average rate per kw-hr. for 3 hours average daily use of the maximum demand and curve B is the same data for 8 hours use. Curves C and D show respectively the total bills for 3 hours and for 8 hours use of the demand.

The "Doherty rate," or "three charge rate" (proposed in 1900 by Mr. Henry L. Doherty) is a method consisting of a customer's charge (\$1.00) per month per meter) plus a demand charge, plus an energy

FIG. 5—COST OF DELIVERED ENERGY

charge for metered energy supplied. This form of schedule is not used in this vicinity, hence an explanation of it will not be made.

There is a tendency to question the merits of the "service-at-cost" method of rate fixing, which has been but little used in rates other than railway fares. The recent public statement of Mr. E. I. Lewis, Chairman of the Indiana Public Service Commission, is indicative of this tendency. The writer is of the opinion that it will not nor should not find any but very limited application in light and power rates.

Application has been recently made to the West Virginia Public Service Commission for the use of Zone rates for the purpose of "equalizing" the rates for electricity by providing an additional charge, for all consumers outside a given area, to compensate for additional expenses of transmission. This is an unusual method and is not likely to find very general approval, application or use even for very large and widely extended systems.

In most states the income of the utility from municipal street lighting service is given little or no consideration in connection with questions of commercial and domestic rates, this income being treated as a "voluntary" rate of the company (which the commission cannot change) and whether the contract is a source of profit or loss is not pertinent to the question of the reasonableness of other rates.

A general or large power rate schedule should be based upon and conform to a load factor cost curve. From records of annual kw-hr. output through plant switchboard, kw-hr. accounted for by consumers'

meters, station load factor, investment or property valuation and operating expenses, an average delivered cost curve, for all load factors, can be readily constructed. The rate of return on the investment or valuation and minor items, such as taxes and insurance, enter into the calculations, depreciation being made part of operating expenses.

The curve, Fig. 5, shows the relation of the cost of delivered energy to load factor, assuming, for convenience, that the cost of service at 100 per cent load factor is one cent. The "curve" from 75 per cent to 100 per cent load factor is almost exactly a straight line, the cost at 75 per cent being 1.119 of that at 100 per cent load factor. The cost of service at 50 per cent load factor is 1.357 that at 100 per cent and 1.213 that at 75 per cent load factor. Below 50 per cent the curve rises more sharply and the cost at 25 per cent load factor, which is fairly representative of a bituminous coal mine in this vicinity, is 1.525 that at 50 per cent load factor. The relation of costs at various other load factors is readily ascertained by reference to the curve.

Load factor expressed in hours use of demand is as follows:

Hours use per day	Equivalent Load Factor	Hours use per day	Equivalent. Load Factor
1	4.2%	13	54.3
2	8.3	14	58.3
3	12.5	15	62.5
4	16.6	16	66.6
5	20.8	17	72.
6	25.	18	75.
7	28.2	19	78.
8	33.3	20	84.
9	37.5	21	88.
10	41.7	22	92.
11	45.8	23	96.
12	50.	24	100.

The shape of this curve is derived from an annual revenue of 25 per cent of the investment or valuation, operating expenses at 60 per cent of the revenue, a return of 8 per cent on investment, reserves and surplus of 2 per cent of investment, one hour station peak loads of 80 per cent of plant capacity, a load factor of 50 per cent based on one hour peaks and 85 per cent of the output through station switchboard accounted for by consumers' meters.

The effect of "load factor" on the cost of production of coal (your own product) should be familiar to those in contact with mine operation cost accounts. Some of you have probably made estimates or "dreamed dreams" of what your production costs should or could be with a 100 per cent car and labor supply, a few pages of unfilled orders always ahead of you and 300 to 310 working days per year, in other words an 80 per cent to 85 per cent load factor, based on 365 days.

A mine has this advantage on "demand"; a large demand for coal for shipment tomorrow will be met

by shipping your output and the unfilled remainder may go forward the next day, or the next, or you may buy a few cars and fill out the order, the consumer meanwhile has a few days stock on hand. When you throw in the switches on your motors on hoists, fans, pumps, locomotives, tipples, mining machines, etc., all the power that you need must be delivered at that instant and for as long as you need it. You will pardon this garrulous remark, but the power company cannot ship you a "load of assorted amperes and volts" today and promise you another car tomorrow, and you have none in stock "to hang on your trolley wire."

In several power rate schedules, which the writer has analyzed, the demand or readiness-to-serve charge set up was found to be low in proportion to the total price paid for the service, resulting in a rate more favorable to the low load-factor consumer. In several sliding scale demand rates, which I have had occasion

FIG. 6—SCHEDULE "J" RATES

to examine, the variation of price per kw., between small and large demands, did not run even approximately true to the actual variations in cost of readiness-to-serve. Large power schedules generally provide for a measured demand, for an interval of 5 or 15 minutes or one hour.

Most large power rate schedules specify a demand charge and an energy charge (in addition to the demand charge), but the same total prices for service at various load factors can be made, without the use of a separate demand charge, by means of a relatively high rate for the "primary" block of energy used and a low rate for the secondary or tertiary blocks of energy. An example of this method is afforded by Schedule "J" of the West Penn Power Co., with which many of you are already familiar. This schedule provides a charge of 6 cents gross per kw-hr. for the first 70 hours use of the demand and $1\frac{1}{4}$ cents gross per kw-hr. for all energy in excess of the first 70 hours use, with block discounts of from $2\frac{1}{2}$ per cent to 43 per cent. The operation of Schedule "J" for a demand of 500 kw. and for 1000 kw. is shown in the curve, Fig. 6.

Where the franchise limitations of the maximum permissible rate for power service give a rate which is

below the cost of low load-factor service, a minimum bill is sometimes set up which will assist in avoiding a loss or a discrimination in favor of the low load-factor consumer. It often occurs that a utility is compelled, by its inability to name equitable rates for low load-factor users, to discriminate in its rate schedules against the high load-factor user, which is its most desirable business.

Most large power schedules penalize low power factor of the consumer's service. Some provide that the average power factor shall be the basis although the detriment occasioned by low power factor is almost invariably greatest during peak hours, the effect of low power factor at other hours being localized. The recording of the time and periods of low power factor and the complications and expense of figuring bills have led to the adoption of the average power factor as the commercial basis in rate schedules. Lightly loaded induction motors are generally the source of low power factor, and it often pays, on installations of any considerable size, to provide for power factor correction where penalties are attached to rate schedules.

Power rate schedules of one large utility provide that, for demands of more than 100 kv-a., a correction factor (on the kw-hr. used) shall be applied for average power factors above and below 85 per cent for the month.

Effective	Constant	Effective	Constant.
P. F.		P. F.	
100	0.951	80	1.023
95	0.965	75	1.05
90	0.981	70	1.0835
85	1.000	65	1.125

This method has several advantages and provides a penalty for less than 85 per cent power factor and a bonus for power factors above 85 per cent which, in my opinion, is the proper power factor in most cases for general application of unity meter registration in large power schedules.

In large power schedules, provision is sometimes made for a special and lower rate in consideration of the privilege of temporarily interrupting the service to the consumer in event of shortage of power. Many of you will probably realize the impracticability in most cases of controlling the service to certain users supplied from a large network of power circuits. A provision of this character often amounts to a special concession and a discriminatory rate, with the privilege of disconnection as an apparently plausible excuse.

The terms and conditions of contract are often but little less in importance than the rates themselves. The inclusion of instantaneous peak ratings, kv-a. rating penalties for even relatively high power factors, often results in considerable increases in the cost of service at given unit rates for demand and energy. The subject of terms and conditions of contract is too broad and complicated to discuss at this time.

There are numerous variations and combinations of the typical rates outlined above, also many methods of determining the amount of the maximum demand and of making a charge for it. A Wright demand schedule sometimes contains eight or ten steps of ratings, between 10 and 500 h. p. Straight line meter rates may be modified by several steps of discounts or reduced charges which vary with guaranteed minimum bills. Any of the various typical rates may carry 3 or 6 or 10 or any number of discounts. A block rate schedule may carry a list of 8 or 10 load-factor discounts. There are many minds at work on rate schedules and many conditions to be met, hence the numerous forms of schedules and of terms and conditions of contract.

The voltage regulation of the supply circuit often has a bearing on the cost and quality of the power service; for instance, kv-a. peaks (sometimes the basis of demand charges) are accentuated by low voltage, on certain types of equipment. The use of synchronous converters is sometimes not permissible because of inferior voltage regulation of the supply. The a-c. input being electrically connected (through the converter windings) to the d-c. feeders, the a-c. voltage fluctuations are reflected in the d-c. voltage. Excessive fluctuations in a-c. voltage generally result in serious operating difficulties with synchronous converters. Motor-generators afford much more reliable operation under these conditions, although the electrical efficiency is much lower than that of synchronous converters.

Synchronous converters, instead of motor-generators, were recently selected for two mine substations, where conditions for their use were favorable and no power factor correction was required, as the difference in efficiency at average loads gave an annual saving, in the over-all cost of power service for a 2000-ton mine, of \$3600. The question of motor-generator sets versus synchronous converters, for mine service, is often decided by factors other than power costs and it is possibly not pertinent to comment at length upon it.

Fuel costs form the major portion of plant operating expenses in all steam-driven plants, hence considerable variations in the cost or quality of coal must of necessity be reflected into rate schedules. In large and medium capacity modern turbo-generator plants the fuel cost is about two-thirds of the total station operating cost, hence, the tendency to higher steam pressures, highest possible vacuum and larger generating units.

It is not difficult, when the average fuel consumption in lb. per delivered kw-hr. is known, to construct an equitable factor for use in a coal cost variant clause, in a rate schedule. Similarly, a correction factor for variations in calorific value of fuel used can easily be worked out. Both provisions are sometimes incorporated in large or long term power contracts and rate schedules. In a recent contract, negotiated by

the writer, it was found that the utility was demanding a fuel cost provision which was nearly four times its actual fuel cost increase.

Heretofore, the application of coal cost clauses to rates has been confined to the larger power schedules whose energy costs carried a relatively large portion of fuel expense. A recent departure is noted in the coal clauses filed by the three more important companies in Greater New York, providing for a differential, for all consumers, of 0.05 cents per kw-hr. for each 10 cent change, from \$3.00 (average cost in 1916 when present rates were filed) in the cost per ton of coal. It of course, remains to be seen how generally this clause will be filed by other utilities.

The term "fair value", so frequently used in utility valuations for rate determinations, is often difficult to define accurately as a basis. Only that property "used and useful" in the supply of power service is appraised in rate fixing. Rates are often approved or disapproved upon estimates derived principally from operating cost records, as accurate valuations of physical and intangible property require much time and are generally very expensive and the cost must ultimately be borne by the consumers. The subject of valuation and its influence upon power rates is too extensive to form a part of this discussion, but those sufficiently interested can secure a copy of *Valuation of Public Utility Properties*, by Henry Floy, or *Valuation, Depreciation and the Rate-Base*, by Grunsky. A comprehensive outline of property accounting is contained in the *Classification of Accounts for Electric Companies* prescribed by the Public Service Commission of Pennsylvania. A similar classification is used by the Public Utilities Commission of Ohio.

The proper provision in cost accounts and the effect on rate schedules of "depreciation", so extensively discussed in rate problems are barely mentioned. The magnitude of depreciation depends, on the adequacy of prior maintenance and upon customs and individual peculiarities, and it is often an uncertain and somewhat theoretical quantity, but also a factor that should not be ignored or misused. The general subject of rates for electric power service is much too broad to admit of any but brief references to several factors of importance. A copy of *Principles of Depreciation*, by Salier, will inform you of the distinction between unit, composite and functional depreciation, obsolescence, inadequacy, etc.

It is an interesting fact that only a small part of an enormous public utility debt upon which interest has been defaulted is in electric light and power securities. A recent compilation of approximately \$500,000,000, shows that only about \$9,100,000, or 1.8 per cent of securities were in bonds of purely electric light and power companies and about \$41,278,000 or only 8.25 per cent were in combination railway and electric properties. The fact that during the very de-

cided "seller's market" of the war period, the price of electrical energy has been relatively very low as compared with most any commodity that you may name, is another fact of direct interest to you.

Accurate comparisons of rate schedules with average costs of delivered power will often show that a power company "lives upon and by virtue of its diversity factors."

Induction Motor Nomogram

A Movable Diagram for Reading all Performance Characteristics of any Three-Phase Induction Motor

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THE field of the circle diagram, aside from the design standpoint, is the determination of the characteristics of a motor without the necessity of actual loading.

Inasmuch as the full load value of current is quite low on the circle (15 to 20 per cent of its diameter) a large circle is required, of which only a small portion is utilized. Furthermore, a new circle must be drawn for each motor. For these reasons I have constructed a nomogram to depict the performance characteristics of three-phase, 60-cycle motors. This nomogram, Figs. 1 and 2, is based on the simple circle diagram and

the voltage, current and power for the locked rotor condition and the no-load condition and the primary resistance.

Calculate from the locked rotor values

$$R_e = \frac{W_1 + W_2}{3 I^2}$$

$$Z_e = \frac{E^2}{3 I^2}$$

$$X_e = \sqrt{Z_e^2 - R_e^2}$$

FIG. 1

utilizes the portion for values up to 150 per cent or 200 per cent rated load, depending on the particular motor.

In this nomogram, scales *T* and *U* are stationary, scales *A* to *S* are pivoted at *O* and move together and scales *V* and *W* slide vertically. The index numbers correspond to points on the circle diagram, any one of which might be chosen to determine values of the characteristics.

REQUIRED MOTOR DATA

The data required to use this nomogram are the same as those required to construct the circle diagram, namely

FIG. 2

W_1 and W_2 are the two wattmeter readings as commonly connected for reading the power, I is the current per terminal and E the voltage between terminals.

From the no-load readings, calculate

$$\text{kw.} = \frac{W_{01} + W_{02}}{1000}$$

$$I_0 \sin \theta = \sqrt{I_0^2 - \frac{(W_{01} + W_{02})}{3 E^2}}$$

The average primary resistance per phase, R_1 .

DIRECTIONS

For any particular motor arrange to use for the various quantities the scales as given in the following