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III. TRANSMISSION AND APPLICATION

By John Whitmore

"Production departments in general are great wasters of power." Gibson, *Industrial Management*, January, 1927.

Steam is used in reciprocating engines to develop mechanical power which may be transmitted throughout factories for all its uses by means of shafting, pulleys and belting; or it may be used in reciprocating engines or steam turbines direct-connected to electrical generators or air compressors. Either as live or exhaust steam it is used to operate low-pressure turbines, and for various manufacturing processes, and for the heating of buildings.

Electrical current is either alternating or direct, the one or the other form being best suited to particular purposes, or to particular conditions of transmission. It may be converted from either form to the other, and from higher to lower voltages or vice versa. There are friction losses in all power transmissions, and there are losses in all transformations of electrical current.

Electrical transmission and conversion losses are determined by metering. Mechanical power transmission losses are almost necessarily calculated, but may be tested by the known requirements of power for driving machines. But the latter also is an approximation as both the condition of the machines and the work performed are subject to continual variations.

In the preceding article I considered the determination of both quantities and prices of steam to be charged to manufacturing departments, or to individual processes or units of equipment, or to other uses such as boiler feed water heating or the factory heating system. I will consider here the determination of quantities and prices of electric current similarly to be charged to manufacturing departments and various ultimate uses.

Purchased current is usually alternating current of a high voltage, or it may be direct current. Probably current in both forms will be used in a factory with electrically driven machinery. If electric current is generated within the plant, it may be either alternating or direct, or separate generators may be operated to give current in the two forms. If current is received or generated in a single form and part of it is converted into the other form, the natural procedure in the accounting is to set up first an account representing the original current as purchased or generated, quantity, and total and unit cost. This current may be in part delivered and metered to manufacturing departments, and in part delivered and metered to sub-stations for conversion, let us say, from alternating to direct current. An account may then be set up for direct current of the voltage, or voltages, produced by the sub-station apparatus. To this account is charged the current delivered to the sub-station, and all the sub-station operating expenses and charges. The direct current delivered by the sub-station is metered, and a unit cost for this product is determined. If the alternating current is simply changed as to voltage, the same procedure is to be followed, a new account being opened at each stage for current in its new form and at its new cost.

As often as the cost of transmitted current is determined, it must include the cost of transmission to the point of such determination. The standing orders for the maintenance of transmission lines must be arranged to give the necessary separate figures.* There is a new determination of cost whenever current is transformed, and there is a final determination of cost when current is delivered to a manufacturing department or to other uses. The standing orders for the maintenance of transmission lines should correspond to all such successive stages of transmission, so that their monthly totals shall be brought into the accounts at the proper points.

The foregoing procedure is very simple and convenient, and it may be quite proper. If one purchases current one takes it in the form in which the central station delivers it. If one needs all or any part of it in another form, the change will give an increased cost to whatever part of it is converted. Similarly if one generates power, and uses it in both alternating and direct forms, the conditions may determine absolutely that all of it shall be generated in the one form or in the other, and some part of it converted. In either case it seems that the conversion costs must fall on the product of conversion.

I am not sure, however, that it is to be assumed that this would always be correct. Wherever a single generator is operated and part of the current is used as generated and part is converted, the question whether we have current in two forms at substantially

* Footnote relative to standing and special repair orders in the first of these three articles. See *The Journal of Accountancy*, October, 1931.

different costs per kilowatt hour, or whether we have current in two forms at a common cost per kilowatt hour, should I believe be considered afresh in the light of all the conditions.* If, as I have suggested, standard costs are calculated for the kilowatt hour of direct current and the kilowatt hour of alternating current, and if the two are derived from a single original source, any questions as to the attribution of expenses to the one or the other, or to both in common, will be independently and critically considered in the process of making these calculations, and the bookkeeping procedure will conform to the procedure in calculating the standard costs.

The usefulness of standard costs for the units of steam and electrical and other power is in part in its separation of a proportion of the expense of under-operated facilities from the cost of actual production. Power equipment is provided for full operation, and if when a factory is only partially operated, the power for such partial operation includes the full expense of operating the power plant, as also the cost of its lowered steam economy, and if the resulting cost of power is carried through to the cost of products, then however the costs of products may otherwise be relieved of the cost of idle facilities, some and at times a large amount of such expense is still borne in the power charges. As far as there is a constant standard of efficiency and a constant volume of production, standard costs and actual costs should be closely similar. If either of these conditions fails, it is better and sometimes essential that the expense be separated and shown plainly, rather than that it be allowed to flow untraced into the costs of products. The separation is very simple and complete if it is effected by the use of standard cost figures for the units of steam and electrical power in the way I have outlined in the first of these three articles.

This, of course, does not in the slightest degree affect the continuous statement of the actual costs of generation, conversion and transmission, but on the contrary maintains a continuous com-

* "In the case of an individual shop power plant in which the amount of power required by the shop is large, and there is no public service corporation to rely upon in the neighborhood, the question of direct or alternating current is partly dependent on the area covered by the plant, and partly dependent upon the need for adjustable speed motors. Alternating current is satisfactory both for small and for large plants from the viewpoint of distribution, but from this same viewpoint direct current is hardly suitable for a plant extending over a considerable area, because of the large drop in voltage due to the long lines required and the relatively low supply voltages usually employed with direct current systems of distribution. Adjustable speed motors are, however, mainly of the direct current type, and where their use is essential, it may be found desirable to employ alternating current for the main distribution circuits, and to transform from alternating to direct current by rotary converters or motor-generator sets, to meet the need of a source of direct current for motors of this type." (*Engineering of Power Plants*, Fernald & Orrok, p. 384.)

parison between the actual costs of power, in every form and at every stage, and the standards in which it is aimed to embody all practically attainable efficiencies of operation and all practically attainable economies of expenditure.

There are still electric power expenses to be incurred within the manufacturing departments, after the current has been metered thereto. These are primarily expenses of transmission and of the conversion of electrical current into mechanical power, that is, the expenses of transmission lines and motors. The cost of electric power in the machine rate (hereafter to be considered) is standardized on the basis of electric current input to the motors at the cost as metered to the department, plus the rate given by the electric power expense account of the department.

There are, however, special losses and expenses arising in the operation of electrical apparatus in the case of alternating current, due to variations of what is called the power factor of alternating current circuits. Electricity is measured in terms of amperes and volts, or watts. Amperes express the volume of current flowing, volts the pressure, and watts the effective power. In the case of direct current, amperes multiplied by volts equals watts. The power factor here is said to be "100 per cent., that is, the product of volts and amperes gives true power." * In the case of alternating current, there are what are called "apparent watts" (amperes multiplied by volts), and "true watts" or effective power, the difference between the two arising from induction characteristics of alternating current apparatus. The power factor here is defined as "the ratio of electric power in watts to volt-amperes."† Power factor depends largely upon the suitability of all the electrical equipment (from generator to motors) to the average load. If the load is below normal the power factor is low. With low power factor there are certain wastes.‡

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* *American Electricians' Handbook,* Terrell Croft, p. 21.

† Suplee's *Mechanical Engineering,* p. 748.
See also *American Electricians' Handbook,* Terrell Croft, p. 23, "Kilowatts and Kilovolt-amperes."

‡ "The effect of low power factor is to increase the current necessary for the transmission of a given amount of power over that current which would transmit the same power in a circuit of unity power factor. This excess of current does not, in itself, represent an additional expenditure of energy, that is, it does not require more coal burned under the boilers. It does, however, involve slight additional energy expenditure, because it increases the power loss in the conductors which it traverses. It has the further undesirable feature of decreasing the effective capacities of the generators." (*Practical Electricity,* Terrell Croft.)
Also the following: *Industrial Management;* August, 1922, "Disadvantage of Low Power Factor," George E. MacLean; January, 1925, "The dollar value of Wasted Kilowatts," E. S. Lincoln; March, 1925, "The dollars and cents of Low Power Factor," Ottomar H. Henschel; December, 1925, "Wastes in Electric Power Distribution," A. G. Darling.

Certain apparatus may be used to improve the power factor of an alternating current circuit, that is, to effect the realization of a larger percentage of kilovolt-amperes of "apparent power" in kilowatts of "real power." Such are static condensers and synchronous condensers, which improve the conditions but produce no mechanical power; and synchronous motors, which both improve the conditions and drive additional machinery.* These give an additional electric power expense, increasing the department electric power expense account.

If then a synchronous motor, in addition to improving the power factor, drives machinery for purposes to which current should be charged as consumed (as to those mentioned in the footnote below), I believe the current in kilowatt hours metered to the synchronous motor at the unit cost charged the department, plus the average unit expense then given by the department electric power expense account, must be regarded as giving a correct power charge to the air compressors or other units so driven. That is, although the synchronous motor is a machine of a special character, performing the two functions of improving the power factor and driving machinery, I believe no variation from the simple routine of the departmental power accounts need arise.

A chart of electrical transmission lines, from generators to delivery of current to departments, showing form of current and voltage, and all transformations of the current, and the locations of all meters, is absolutely necessary. A copy of this marked with the totals of all meter readings for the month must at the close of the month be furnished by the power department to the accounting department.

Electrical power having been metered to a manufacturing department, the accounting instrument by which the economy of its application may be measured is the machine rate,† that is, the calculation of the total charge for the operation of each machine per hour. The machine rate is especially applicable to the machine tools of machine shops, the hammers and presses of steel works, and other units of equipment having in general similar

* "The synchronous motor is frequently run light merely to improve power factor or to control the voltage at some part of the power system. When so used the motor is called a synchronous condenser. The motor may however deliver mechanical power and at the same time take either lagging or leading current. Its common applications are drives for motor-generator sets, ammonia compressors in refrigerating plants, rubber mills, and air compressors." (*Marks' Handbook*, p. 1981.)

† The study of the machine rate must always begin with A. Hamilton Church's "Proper Distribution of the Expense Burden." (*The Engineering Magazine*, 1901.)

characteristics. Where machines are small and numerous, the expenses may be calculated for groups of machines, and if there is a practically uniform relationship between machine costs and direct labor within each group, the machine costs may be standardized in relation to direct labor. Under such circumstances no machine rate is used, but the standardization of the machine expenses in relation to the direct labor affords a constant and fairly effective check upon them all.

In the compilation of the machine rate, all the annual expenses and charges in respect of the factory buildings (as far as they are used for the immediate operations of manufacturing) are reduced to an annual charge for the unit of factory floor space, and each machine is charged with its proportion according to the floor space occupied by it. The annual expenses and charges in respect of the machine itself are then calculated, that is, all constant expenses which have to be borne whether the machine is more or less fully operated. These constant expenses of the machine and its building floor space are then divided by the assumed hours of operation in the year. This is the initial hourly rate. Then the hourly running expenses, exclusive of direct labor, are calculated. The first of these is power. When all running expenses except direct labor have been added to the initial rate the total is the hourly rate for the operation of the machine, chargeable to production.

The determination of the power item in the machine rate is primarily the determination of the average power consumption of each machine when running. Or if the machine performs different operations, or if it runs at different times on light and heavy work, then there must be determined an average power consumption figure under each of such conditions. The power consumption determinations for the machine rates, and the power consumption determinations for the purpose of securing the suitability of motors and other electrical equipment to the load, are absolutely the same thing.

I believe the perfect fitness of the machine rate in relation to the cost of power, the continual check upon power expenditures and power consumptions, and the accuracy of the distribution to the costs of products, is only one item of its perfect fitness in all its relations. It embodies practically all standards of economies in the wide range of operations to which it is applicable; it is the means of perfect measurement of the utilization of factory capacity; it is the simplest instrument for the calculation of costs before manufacture and for their recording during manufacture, and is the one means of determining true cost figures. I am therefore not assuming its use merely to render complete the means of measuring the economy of power expenditures, but because there is a complete and unbroken series of necessities for its use.

I will not enter upon a description of the accounting procedure which the use of the machine rate involves, except to indicate the way in which it gives a comparison each month and for each department of the standard power consumption for the actual operations, with the power taken by the department.

The operated hours, as recorded and charged into the cost accounts for the products, are summed up for each machine for the month. The machines are listed on a form with columns for the hourly rate and the operated hours, and the extension of these for each machine; and with columns corresponding to the various component parts of the machine rate. There is therefore an electric power column in which the total kilowatt hours, the standard price including departmental electric power expense, and the extension of these, are written. When this has been done for all the machines in the department, the addition of the column gives the electric power accounted for in the month for comparison with the cost of the same to the department. If in addition to the power accounted for in the machine rates, power is metered to any special use, this of course, is to be taken into account.

With regard to power mechanically transmitted from prime mover to ultimate use, so close a check is scarcely practicable, but a very useful check can be obtained. It is plainly a matter of great importance. The friction losses are said to range from 40 to 60 per cent. of the total power transmitted by the engine.*

The conditions under which an accounting is to be obtained, and the limitations thereof, are stated in an article by Terrell Croft in *Industrial Management* December, 1924, as follows:

"There is no convenient simple device whereby energy which is transmitted mechanically may be metered. Tests may be made periodically and under average conditions. To find transmission and utilization leaks by testing, a graphic wattmeter it used. Although this is an electrical instrument, it can—wherever electrical energy is available—be employed effectively in locating

* *Engineering of Power Plants*, Fernald & Orrok, pp. 381 and 382.

leaks in purely mechanical transmissions and equipment. If it is desired to ascertain the power input of a purely mechanical device, such as a length of line shafting or a machine tool, then that device may be temporarily belt driven by a motor and the power input to the motor recorded on the graphic wattmeter."

The power engineer therefore should be able to furnish figures of the power consumption of machines, for incorporation in the machine rates, under these conditions also. There will be no available figures for the power delivered to departments, and all that will be possible will be to ascertain what the standard consumption amounts to for all the machines in the factory, according to all their operated hours in the month, and by comparison of the horse-power hours so accounted for, with the horse-power hours delivered by the engine in the same period, to state a figure for transmission losses. It is said that "friction losses in shafting and belting remain nearly constant at all loads."* In this respect therefore the indication given by comparison of power developed and power accounted for, is of a fairly clear character. Apparently losses in the transmission of mechanical power vary over a wide range, and I believe from various causes which need constant watching. These are conditions under which any accounting figures that approximate a correct statement must be of value.

The following may now be added to the monthly tabulations:

Steam gains and losses	—boilers	$————
	—transmission	————
Direct current gains and losses	—generators	————
	—conversion and transmission	————
Alternating current gains and losses	—generators	————
	—transformers and transmission	————

Departmental electric power balances:

differences between total electric power cost to the department and the same charged into the costs of products, through machine rates or otherwise—each department separately

Mechanical power:

(a) Developed by engine	horse power hours	————
(b) Accounted for in ultimate uses	horse power hours	————
(c) Transmission losses	percentage	————

* *Engineering of Power Plants*, Fernald & Orrok, p. 382.

The plan of accounts indicated herein may be summarized consecutively as follows:

IN THE GENERAL LEDGER

Coal	controlling the coal stores ledger
Water	distributed to power and other uses as metered
Power	controlling the power cost ledger
Power cost gains and losses	a single account of which the particulars are in the power cost ledger

IN THE POWER COST LEDGER

Coal unloading, storing, crushing, etc.
    with sub-accounts for the various expenses
Pulverized coal
    with sub-accounts for the various pulverizing plant expenses
Water treatment expenses
    a series of expense accounts as indicated in article I
Boiler operation expenses
    a series of expense accounts as indicated in article I
Boilers, or separate boiler accounts
Steam
Steam transmission
Steam suspense
    as described in article II
Reciprocating engine
    separately, except where driving a single unit, as an electric generator, and then a single ultimate account for engine and generator, with all desirable sub-accounts. Possibly also a single account for reciprocating engine and low-pressure or bleeder turbine using the engine exhaust.
Mechanical power
Mechanical power transmission
    with all desirable sub-accounts
Turbo-generators and turbo-compressors
    a single ultimate account for each set, with all desirable sub-accounts
Accounts for any other generators and air compressors
Electric power accounts, being an account for electric power
    in each form and of each voltage, with any desirable intermediate accounts
Compressed air
Compressed air transmission

Steam gains and losses	—boilers
	—transmission
Mechanical power gains and losses	—engines
	—transmission

Direct current gains and losses	—generators
	—conversion and transmission
Alternating current gains and losses	—generators
	—transformers and transmission
Compressed air gains and losses	—compression
	—transmission

It being understood that all the foregoing are in comparison with standards. General ledger account—contra to the general ledger power account.