FACTORS AFFECTING POWER COST

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INTRODUCTION

Very few of those people not connected with power companies realize the many factors which have to be considered in determining the cost of power or the problems to be solved in establishing an equitable rate system. This has naturally led to a general prejudice toward the public utilities as a whole, and has in a measure been responsible for much unfavorable legislation.

It is for the purpose of giving some idea of the complexity of the factors involved, and the effects of these factors on power cost and rates that this thesis is undertaken.

As one factor involves to a greater of less extent other factors, it is necessary in many cases to consider the relation between the different factors. In so far is possible, however, each factor is discussed separately, with the point of view of the customer rather than that of the engineer in mind. Technical explanations have been necessary in a few cases, but the economies of the problem have been stressed for the most part.

It must be understood that in so brief a paper all factors cannot be discussed, nor minute details carefully analyzed, therefore, this paper is somewhat in the nature of a summary.

FACTORS AFFECTING POWER COSTS

I. Property Value.

In the public utility field the rates for service have been based on two fundamental theories. The first is the value of service theory which states that the utility is entitled to as high a rate as the service will allow. In other words the utility should charge the highest rate possible and still keep its customers. The second theory states that the gross income of any utility should be such that a fair profit on the fair value of the property will be realized after all costs are paid.[1.] This is the theory on which our rates are based today. The fair value of the property is therefore the rate base, the determination of which is difficult.

The determination of the fair value of the property involves many factors which are subject to controversy. Possibly the best method of arriving at this value is by determining the cost necessary to reproduce the plant. The question immediately presents itself as to whether the cost of duplicating the plant will be the cost of reproduction under present conditions or under the conditions existing when the plant was originally constructed. If the station has been in operation for a number of years these conditions might differ considerably. For example, the prices of labor and material before and during the last war are not the same as prices at the present time. The physical conditions would also differ in the two cases. Such work as

1. J. G. Tarboux, Economies of Electric Service, Page 449, Sec. 13,6th Edition of Standard Handbook of Electrical Engineering. McGraw Hill Pub. Co.

grubbing, grading and the removal of buildings necessary under original conditions might not be necessary under present conditions due to the development and progress of the country. [1]

Because of these difficulties the tendency has been to assume the construction under the original physical condition and to take the price of materials as the average price over a period of years. Many of the materials used in power production have very unstable prices, however, and some doubt has arisen as to whether the average price over any particular period should be taken. This has led to the split inventory method, and the trend method of determining the prices of materials.[1] In the split inventory method "Pre-war values are applied to pre-war property." [2] In the "trend method" the values applied are those which would have prevailed had the general trend in prices continued unchanged. It is also logical to suppose that the values used to determine the rate base should be those values prevailing during the time the rates would be in force.

The appraisal by the cost of reproduction method involves the preparation of an inventory of the items of property and their prices determined by one of the methods in the preceding paragraph, and also including certain physical and non-physical overheads.

The physical overheads might include the labor and material items which have disappeared or for various reasons cannot be listed such as sag, waste, shortage, cartage, freight, storage, construction and equipment tools, temporary structures,

1. Nash, Economies of Public Utilities, Page 119 (1925) McGraw Hill Book Company, Inc. N.Y. 1925. 2. Op. Cit. p. 119

losses due to storms and strikes, delays in material, etc. [1] These items are commonly designated as ommissions and contingencies, and are usually included in the labor and supply cost. The remainder of the overhead charges include the cost of administration, engineering supervision, insurance, taxes, interest and financing.

The non-physical overhead charges consist of the costs of promotion, organization, cash working capital, raparian rights, franchise value and going value. An explanation of these items might be of aid in understanding their significance.

Promotion costs include the charges of the person who promotes the establishment of a new enterprise and his helpers.

Organization costs are those costs necessary to incorporate the project, pay for the legal service involved therein, and the costs of securing franchise and other rights.

Working capital is that capital necessary to supply labor, material and other expenses included in carrying the project to completion.

Raparian rights apply only to hydro-electric developments and may be defined as the difference in cost of delivery of hydro-electric power and the same cost of the most economical substitute.

Franchise value is not usually included in appraisals now. This cost is generally listed under organization, and may be considered as the cost of the franchise. (See organization.)

1. Nash. L.R, Economics of Public Utilities, p. 121, McGraw Hill Book Company, Inc., N. Y. 1425.

The going value is the difference in value of a plant in successful operation, and a similar plant just completed and not yet put in operation. [1] This item is not clearly defined and frequently becomes the object of controversy.

Depreciation. This item does not enter into the cost of a new plant, but comes into being after the plant has been in service for some time, beginning at the time the plant is started operating. [2] Depreciation may be divided into two classes, namely, physical depreciation and functional depreciation.

Physical depreciation is that depreciation in value due to use and the effect of the elements.[3]

Functional depreciation may be due to one or more of three different causes. (a) Depreciation due to obsolesence. This is brought about by new inventions and improvements in equipment or methods. (b) Depreciation due to supersession or change in public habits, and legislative or other acts. (c) Depreciation due "to inadequacy resulting from business expansion and the need of larger units."

There are arguments both for and against depreciation deductions in making an appraisal. Mr. Nash presents both sides very clearly. To quote in full, "property begins to wear out from the time it is first devoted to public use, and its continued use causes a gradual demunition in value until, when its useful

1. Nash, L.R. "Economics of Public Utilities, p. 136, McGraw Hill Book Co. Inc., N.Y.1925.2 Tarboux, J.G. Economics of Electric Service, p. 452, Sec. 13. 6th Edition Standard Handbook of Elec. Engr. McGraw Hill Book Co. 3. Mead, D. W. Water Power Engr. p. 673, McGraw Hill Book Company, 1920.

life is ended, its value other than for salvage has entirely disappeared. It is assumed that a reasonable accurate estimate can be made of useful life and that the rate at which value decreases and accrued depreciation increases is substantially uniform. It is contended that each customer of a public utility should, therefore, contribute to the exhaustion or consumption of property devoted in his service in proportion to his use of the property, and that in determining his contribution uniformity of loss in value may be properly assumed. If each customer actually makes such contribution and the aggregate of these contributions is assembled in a depreciation reserve this reserve at any time will measure the accrued depreciation in the property, and when, in conformity to the estimated useful life, the property has been wholly consumed, the reserve will be sufficient to indemnify investors for the loss in value." [1]

"Still other engineers who reject the theory that useful life can be predicted with the accuracy above assumed, have contented themselves by making in appraisals only such deductions for depreciation as is appropriate to take care of deferred maintenance or other factors which cause loss in operating efficiency and possibly with some further recognition of obsolesence and inadequacy already definitely accrued. Such engineers sometimes compute the so called present worth of existing property elements by determining the total cost including operation and fixed charges of performing the same service by new and most efficient obtainable facilities, deducting from this total cost the cost of operating the existing property in question and capitalizing

1. Nash, L.R. "Economics of Public Utilities," p. 182, McGraw Hill Pub. Co. Inc., 1925.

the balance of the assumed fixed charge rate." [1.]

The argument against depreciation deduction is that in most public utilities the cost of a single element is so small as compared to the cost of the total property that these elements may be maintained and renewed, and the cost of so doing charged to the operating expense. Then there would be no retirement reserve accumulated, and consequently no depreciation deductions should be made.

It is to be noted that the useful life of any piece of equipment cannot be closely estimated, and barring accidents the most accurate determination will usually be in error as much as five or ten years, depending, of course, on the character of the material. The quality of the material and the conditions of service vary under such wide ranges that closer approximations are impossible. With the development of the x-ray for inspection purposes, and with uniform production methods, the variation in the quality of material may be lessened, and the expected life be more closely approximated. Some of our best engineers, however, differ quite radically as to the useful life of any particular piece of equipment. Table No. 1 shows the results of the useful estimated life of different materials. [2.] The wide limits should be noted. Table No. 2 shows life expectation of various materials. [3.] These values are the average of a number of results covering a wide

1. Nash, L.R., Economics of Public Utilities, p. 183, McGraw Hill Book Co. 1925. 2. Nash. L.R., Economies of Public Utilities, p. 74, McGraw Hill Book Co. 1925. 3. Tarboux, J.G., Economics of Electric Service. p. 453, Sec. 13, 6th Edi-

range of conditions. From similar tables the rate of the depreciation charges may be calculated.

To provide for depreciation in value a retirement reserve is accumulated through charges. These charges are arrived at by the use of the life expectation tables. For example, looking in table No. 2 we see that the expected useful life of turbine driven generators is twenty years. Then the charges to be made for the retirement reserve would be, assuming straight line variation, $\frac{100}{20}\%$ or 5% of the cost of the turbine per year. By cost of the turbine is meant the net cost, or "the original cost plus the removal cost minus the salvage value." [1.] This is the straight line method.

The sinking fund or amortization method assumes that the reserve fund is invested and bears interest. This, of course, lowers the rate.

The retirement reserve method is to accumulate the reserve through credits from operating expenses or surplus or both. This method of accumulating the reserve should be left somewhat flexible and subject to the judgment of the management. [2.]

Under this method it is assumed that the retirement reserve is for the replacement of large and costly units. The minor repairs and replacements are usually charged to operating or maintenance expenses. In large systems where the cost of a single unit is small in comparison with the total cost of the

tion Standard Handbook of Electrical Engineers. McGraw Hill Book Co. 1. Tarboux, J.G., Economics of Electric Service p. 452. Standard Handbook Elec. Engr. Sec. 6, 13th Edition.
2. Op. Cit. p. 455.

property, the depreciation reserve might be neglected altogether and replacements charged to operating costs.

The size of the retirement to be accumulated depends on the size, condition and character of the property. A well maintained and stable property will require a smaller reserve than one subject to serious failures and accidents.[1] A plant with complicated units subject to obsolesence or supersession, conversely, will require a larger reserve. The same effect is produced in a plant in a rapidly growing community. More units will necessarily be retired than where conditions are more stable. The conclusion is that a property with normal growth about 15% is sufficient, and that a provision of 20% of the investment is sufficient to meet further requirements. Some operators maintain that 10% is sufficient. So within reasonable limits the range is from 10% to 20% with 15% as an average.[2]

Factors Affecting Value of Investments.

Public utilities, operating as they do under franchises, have no competition, and the income is less subject to marked fluctuation. It is true, nevertheless, that frequent adjustments in rates are necessary to insure stability of income distributions, or else the rates will have to be high enough to allow for reasonable fluctuations. It is therefore "the problem of the regulatory commissions to determine a percentage to

1. Nash, L.R., Economics of Public Utilities p. 197, McGraw Hill Book Co. 1925.

2. Nash, L.R., Economics of Public Utilities, p. 198, McGraw Hill Book Co. 1925.

to be applied to the rate base, also fixed by them, which will yield a distributable income sufficiently free to attract capital to the business in competition with other needs of capital which in the aggregate far outweigh the needs of the public utility group.[1.] The public utility should, considering the above statement, expect some outside financing of comparatively high yields, and not depend solely on the issuing of bonds which have relatively low yields. The difference in yield in the two cases is of course due to the relative risk involved. The risk factor[2] in junior financing will be high calling for a high yield.

The income taxes have affected public utility economics in that these taxes have driven capital from this field and other industrial fields into tax-exempt securities, thus placing a restriction on the available investment funds of the public utility. This restriction can but result in an increase in the rates. Statistics from the U. S. Treasury Department show the following decreasing number of individual taxpayers of over $1,000,000.00 income since the taxes were levied.[3]

Year	Number of Taxpayers	Year	Number of taxpayers of over $1,000.000. income
1916	206	1919	65
1917	141	1920	33
1918	67	1921	31

In determining the fair return on investment the brokerage and legal expenses must be taken into account, and sufficient al-

1. Nash, L.R., Economics of Public Utilities, p. 207, McGraw Hill Book Co. 2. Op. Cit. p. 208. 3. Nash, L.R., Economics of Public Utilities, p. 214. McGraw Hill Book Company, 1925.

lowance made to take care of these items. Brokerage includes the costs and profits involved in the sale of securities, and also the risk incurred when the securities are purchased outright by the brokers.

Legal expenses include fees of attorneys, the fees for engraving plates, printing of bonds, printing and recording of mortgages, fees for filing with state authorities, etc.

Finally, the factor of surplus must be considered. The surplus is necessary to provide stability of income to investors and also to make the securities attractive by maintaining the credit. As the income is never stable due primarily to its varied and complicated sources which includes interest on bonds and loans, dividends on stock, etc., rates cannot be adjusted quickly enough to meet the requirements of a fair return. The rates, then, may determine the amount of accumulated surplus just as in the retirement reserve.

II. Maintenance Costs.

There is no definite line of demarkation between maintenance and depreciation, the separating line usually being taken arbitrarily.[1.] As a rule the low priced units are charged to maintenance and the high priced units to the retirement expense.[2]

The factors affecting maintenance costs are: defective construction, improper selection of machinery, lax maintenance, and lack of foresight of the operators.

It is said that defective design is the most common cause of high maintenance costs.[1] This has probably been true in the past and to a certain extent at the present, however, it is difficult to tell the extent to which this factor has affected maintenance cost in either case.

Defective construction may prove very serious, especially in hydro-electric developments. A dam that springs a leak, or one which is washed out during flood causes a great expense. Such serious contingencies, however, would probably not be classed as maintenance expense. In the steam power plants, the foundations may be inadequate, the construction might be defective, the workmanship in the mechanical units might be of an inferior grade, etc.

Again, the most suitable machinery might not have been selected. As an extreme case, a 25 cycle generator could not supply a 60 cycle market without a loss in efficiency. Such a selection might involve replacement at great cost as well as to increase the depreciation rate.

1. Tarboux, J.G., Economics of Electric Service, p. 956, Standard Handbook of Electrical Engr. Sec.6, 13th Edition, McGraw Hill Book Co. 2. Ibid. p. 456.

Many expensive repairs might be eliminated by an occasional inspection by some expert who is unfamiliar with the plant. Those in charge of a plant might overlook small defective conditions because these defects develop gradually, while one unfamiliar with the plant would notice these defects immediately. The operators in constant charge of a plant become so accustomed to the daily routine that they tend to perform their duties in a more or less mechanical fashion, and fail to look ahead to try and prevent breakdown.[1]

For determining the maintenance costs, the plants have been classified, and different condensed systems of determining the costs applied to each grade.[2]

Grade A. - Properties which have an income of $250,000.00 or more. For this class a full detailed classification is used as shown below.

Grade B. - Properties having an income from $50,000.00 to $250,000.00. A more condensed classification is used.

Grade C. - Properties having an income of $10,000.00 to $50,000.00. A still more condensed form is used.

Grade D. - Properties having an income below $10,000.00. For this grade a simple system is employed.

1. Maynz, T., Boiler House Maintenance, p. 189, V. 35, Natl. Engr. 1931.

2. Nash, L.R., Economics of Public Utilities, p. 82, McGraw Hill Book Company, 1925.

For Grade A the classification contains the following items:

Maintenance of stations and buildings.

" " furnaces and boilers.

" " boiler apparatus.

" " steam accessories.

" " " engines.

" " turbo generator units.

" " Main generators.

" " exciting apparatus.

" " control and protection equipment.

" " transformers and convertors.

" " miscellaneous power plant equipment.

Table No. 3 gives some idea of the various costs. The range is from 4% to 8% of the total expense.

High maintenance costs increase the cost of power production and necessitates an increase in the rates.

III. Operating Costs.

The cost of operating a plant includes the costs of superintendence and labor, fuel, water and supplies. In some cases minor repairs are charged to operating costs rather than to maintenance costs. The costs incidental to transmitting and distributing the power should not be neglected. Ordinarily, taxes are included in operating costs though they have nothing to do with the actual physical operation of the plant.

Superintendence and labor costs vary from .03 to .20 cents per Kw. hr. The larger the plant, the smaller the number of men employed per kw. hr., and the smaller this cost.

The fuel cost is the largest of the operating costs , and varies from about .10 to .30 cents per kw. hr. This expense amounts to about three times that of all of the other operating expenses.

The costs of water, lubricants and supplies might be taken as one sum. This cost is least of the operating expenses, ranging from .003 to .015 cents per kw. hr.

In distribution systems the cost of testing meters, which may be charged to wages, is an important item. Meters as a rule run slower with the passing of time, and the error thus resulting is in the customer's favor. It is necessary to adjust the meters at intervals to eliminate this error in so far as is possible. The frequency of testing should be such that the saving as effected is equal to the cost of testing.

All of the operating expenses depend on the size and location of the plant and general operating conditions. It has been found that these costs vary quite definitely with the load factor.

In a study of the relation of operating costs to load factor, Prof. J. G. Tarboux found that the operating expenses varied inversely as the local factor and was an exponential function of the same.[1]

The use of automatic equipment has cut down the operating costs and also increased the precision of operations by removing the human element. The fact that the installation of automatic equipment increases the fixed charges should not be overlooked, however, this increased cost is ordinarily small in comparison with the savings obtained, and the installation is justified.

In order to express the efficiency and character of operations in simple terms the "operating ratio" has been developed. The operating ratio is the ratio of expenses to revenues.[2] This ratio may be made to include taxes and other incidental expenses. To test the correctness of the ratio the following rule may be used:

The operating ratio expressed in percent should be less than 100-10 times the ratio of investment to earnings, or,

$R < 100-10\frac{I}{E}$ [3]. The stability of a plant is indicated by this ratio, and may vary within wide limits from 20% to 70%.

1. Tarboux.

2. Nash.

3. Nash, L.R., Economics of Public Utilities, p. 294, McGraw Hill Book Company, 1925.

IV. Load Factor.

The load factor of a plant greatly effects the cost of producing power, and could easily mean the difference between success and failure of a new power plant.

The load factor is defined in the standardization rules of the American Institute of Electrical Engineers as follows: "The load factor of a plant or system is the ratio of the average to the maximum power during a certain period of time such as a day, month or year, and the maximum is taken over a short interval of the maximum load within that period. In each case the interval of maximum load should be definitely specified."

The effect of low load factor is to increase the cost of producing the power. A simple example will serve to illustrate the effect. Suppose a 100,000 kw. plant is installed at a cost of $1,000,000.00. The annual cost of operation including fixed charges might be 25% of the initial cost, or $250,000.00. Therefore, the cost of each killowatt of maximum load would be $25,000 ÷ 100,000.= $25.00 per year. If the load factor is 100 percent, that is, if the plant works at its maximum capacity 24 hours per day, then the cost per kw. hr. is $\frac{2500}{365 X 24} = .285$ cents. Now suppose that the plant is operated at its maximum capacity for only 12 hours per day. The total cost of power may be reduced to say $20,000 per year. The cost per kw. hr. of maximum load would be decreased to $20. per year, but the cost per kw. hr. generated would be $\frac{.2000}{365x12} = .456$ cents which is a 60% increase over a 100% load factor.

In actual practice the load varies from time to time. The curve representing this variation then is a rather irregular curve, the maximum capacity of the plant being utilized only a small percentage of the time. This results in a low load factor, possibly 60% or less. If we should apply this load factor to the above example the annual maximum kw. cost per year would still be \$20,000 but the cost of 12 hr. power will be $\$20.00 \div 0.60 =$ \$33.33 and the cost per kw. hr. would be $\frac{3333}{365 \times 12} = .76$ cents or 2.65 times as great as in the first case.

A low load factor necessarily means a greater reserve capacity. The equipment to provide this additional capacity and therefore the investment. A large investment for the power produced would mean large fixed charges and greater production cost than would occur in a plant with high load factor.

The load factor depends on the type of service for which the power is supplied, whether for lighting, industrial service or both.

Variations in efficiency, fuel consumption, maintenance and labor are caused by load factor. In a study of the relation of load factor to operating costs, Prof. J. G. Tarboux found that the operating costs varied inversely as the load factor, and was an exponential function of the same. [1]

In order to increase the load factor some companies give special rates as an inducement to use "off peak" power. Such proceeding decreases the maximum load and raises the average load. The rates generally allowed to large users of power who can take advantage of this varies within rather wide limits, usually from 50% to 75% of the regular rates.

1. J.G.Tarboux, Economics of Electric Service, p. 461, Standard Handbook of Electrical Engr. Section 6, 13th Edition, McGraw Hill Book Co.

V. Power Factor.

A low power factor does not necessarily mean inefficient operation, however, the wattless current which flows under such conditions causes losses in the line and other equipment due to heating. It is interesting to note that the heating effect at 70.7% power factor is just twice as great as at a 100% power factor.

The magnatude of the wattless or magnetizing current depends on the reactance of the circuit. All electrical devices having high reactance cause low power factor. These devices are those with electro magnets, and for the most part are power producing devices. Induction motors, induction furnaces, arc furnaces, and welding machines produce low power factors. The only machines which do not produce this effect are the separately excited machines. As induction motors make up such a large portion of the power load, the major cause of low power factor may be attributed to this machine. As the magnetizing current of these machines is about constant it becomes proportionately larger for small loads, thus lowering the power factor.

Transformers require a magnetizing current which has very little effect at full load, but as it remains practically constant it is proportionately larger for small loads. This magnetizing current is in a sense cumulative in that a low power factor requires larger magnetizing current. [1.]

In systems of large capacity it is necessary to use current limiting reactors to limit the current in case of fault.

1. N.E.L.A. p. 177, v. 88, 1931.

These reactors are on the line continuously and tend to reduce the power factor. [1]

The auxiliary load at the station is generally quite large, and if carried by induction motors the power factor of the load will probably be considerably lower than is necessary. It is obvious that the auxiliary load should conform to the same power factor requirements as the customer's load.

Power factor may be corrected by over excited cynchronous motors, but this entails an increased installation cost, and therefore higher fixed charges. Nevertheless the saving, especially to large power companies more than justifies the expense. [2]

The effect of low power factor is, from an economic standpoint, the same as that of a low load factor. Increased capacity has to be provided to supply the exciting current. This increases the investment. In addition to this there are the heat losses previously referred to which increase the operating costs. Thus both the fixed charges and operating costs are increased.

With few exceptions the power companies have done nothing of particular importance in reducing the demand for wattless current, nor have they made an effort to adjust the rates so that the customer who uses this current will pay for the increased operating expense necessary to supply the demand. "They are supplying two services which are in a sense independent of each other, and billing on the basis of a customer's use of one." [3.] This results in an inequitable charge.

1. N.E.L.A., p. 177, V.88, 1931. 2.Nash,L.R., Economics of Public Utilities, p. 252, McGraw Hill Pub. Co. 1925. 3. N.E.L.A. p. 177, V. 88, 1931.

The customer's power factor might be corrected to a certain extent by seeing that all motors are of the correct size for the load, or make the rates such that the customer will be induced to buy corrective devices.

The Kv-a method of selling power would be a solution to the problem, but meters to measure the power in terms of the Kv-a are too expensive to be of practical value now. Frequently clauses are written into the rate schedule which impose a penalty on users that operate on a power factor less than 80%.[1]

1. Nash, L.R., Economics of Public Utilities, p. 252, McGraw Hill Pub. Co. 1925.

VI. EFFICIENCY.

The efficiency of a power plant affects the cost of power production considerably. Efficiency is usually expressed in percent, and in the case of steam plants is measured by the fuel used per killowatt hour. As the fuel is the largest of the operating costs, a reduction in this cost by an increase in efficiency is of importance.

Station efficiency depends on the size of the station, size and refinement of equipment, whether interconnected or not, and several minor influences. A small station cannot be expected to obtain as high an efficiency as that obtained by a larger station, nor an isolated station the efficiency of one interconnected with a power system. The lower limit for fuel burning stations is about 2.5 pounds of coal per killowatt hour, and the upper limit about 1.25 pounds per killowatt hour. This upper limit is as a rule obtained only by interconnected stations. For oil burning stations, one pound of oil may be taken as equal to two and one-half pounds of coal.[1.]

With a hydro plant the efficiency is of the greatest importance when there is not ample storage facilities, and water has to be saved. In this case, by interconnection the generators may be run at their most efficient load, and then more power be delivered for the same quantity of water utilized than would otherwise be the case. As the head under which a turbine operates affects its efficiency the total result, under most conditions, is cumulative in effect, in that increased efficiency of

1. Nash, L.R., Economics of Public Utilities, p. 402, McGraw Hill Book Company, 1925.

the generators results in a saving of water which tends to increase the head, which in turn increases the efficiency of the turbine. The higher the efficiency of the hydro-units, the less time the reserve steam units will have to be operated and consequently the lower the fuel cost.

The great hindrance to more efficient operation has been the lack of incentive. With the public utilities, "the general practice has been to accept reasonable actual operating expenses and taxes, suitable provisions for property retirements or depreciation, and a fair return upon the value of the property as factors in the cost of service to be covered by the rates determined." [1.]

As the fair return has thus been made a fixed rate, all cost elements are more or less fixed. Such regulation as can be seen, does not provide any incentive for efficient operation as any increase in the revenues so obtained is promptly transferred to the customers through rate reductions. This in turn results in a tendency toward stagnation which is harmful to all concerned.

Some thought has been given to this situation by the commissions,[2] and an endeavor made to classify the utilities according to the efficiency, continuity of service, business development etc., and applying an elaborate system of rates involving these classifications. The impossibility of accurately determining the merits of any particular plant or system according to the above factors has limited the application of such a system of rates.

1. Nash,L.R., Ec. Pub. U. p.103, McGraw Hill Co. 1925
2. Nash, L.R. Ec. Pub. U. p.110, McGraw Hill Co. 1925

VII. Interconnection.

Interconnected systems are able to reduce their power costs by the saving in fuel thus obtained. In such systems the least efficient plant may be held in reserve to carry peak loads or to take up a portion of the regular load in case of a breakdown, thereby increasing the overall efficiency of the system.[1.] A further advantage is the reduction in investment. In isolated plants it is necessary to carry reserve capacity to furnish peak loads and to carry a portion of the load in case of a breakdown. The increase in investment required to supply the reserve capacity is a large percentage of the total investment. The fixed charges are thus raised and therefore the cost of power. By interconnection the reserve capacity may be furnished by one station or relay units in only a few stations as breakdowns are not apt to occur simultaneously in all stations. Thus the investment represented by this reserve capacity is a small percentage of the total and the fixed charges consequently less.

The size and location of a plant are the determining factors in interconnection. Small, widely separate stations will not, as a rule, effect a great enough saving in reserve capacity and operating costs to pay the fixed charges on a long transmission line. Stations located a great distance from a coal supply, where the cost of delivery and the cost of coal is high may benefit by interconnection as the saving in fuel and other costs will more than justify the building of a long line.[2.]

1. Nash, L.R., Ec. Pub. Ut. p. 402, McGraw Hill Pub. Co. 1925. 2. Nash, L.R., Ec. Pub. Ut. p. 402.

Interconnections are being made at present where no advantages are apparent, though unforseen advantages usually develop. [1]

The present tendency is toward further interconnection and more complicated networks of power systems.

1. Nash, L. R., Economics of Public Utilities, p. 402..

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3. Morrow, L.W.W., "Power Costs in Large Plants" p. 827, Electrical World, V. 92, 1931.

4. Nash, L. R., "Economics of Public Utilities," McGraw-Hill Pub. Co., Inc. 1925.

5. Tarboux, J. G., "Economics of Electric Service", p. 452, Standard Handbook of Electrical Engineers, Sec. 13, 6th Edition.

IX. Appendix TABLE I.

Divergent Estimates of Operating Life Of

Electric Property[1]

Class of Material	Useful Life Years		
	Minimum	Maximum	Average
Building and structures:			
Buildings (frame)	20	40	26.7
Buildings (mill construction)	40	100	60.8
Buildings (fireproof)	60	100	90
Dam (wood, earth)	15	50	31.7
Flumes (masonry)	50	100	75
Flumes (wood)	5	20	13.3
Conduit for wire (terra cotta)	40	100	70
Power Generation:			
Water Wheels	20	50	28.8
Engines (steam)	10	50	26.3
Turbines	20	25	21
Boilers	5	20	14.2
Condensing system	15	20	18.8
Piping system	5	25	19.2
Generators	15	25	21.3
Converters	15	25	21.7
Transformers	20	30	25.8
Switchboard Apparatus	20	30	24
Coal handling machinery	5	20	13

1. Nash, L.R., Economics of Public Utilities, p. 74. McGraw Hill Pub. Co. 1925.

TABLE II.

Typical Life Expectation Table for power plant Equipment[1].

Class of Equipment	Years of Life	Authority	Controlling Cause
Belting	20-25	Wisconsin R.R. Commission	D
Boilers (fire tube)	10-15	"	D
Boilers (water tube)	20-30	"	D
Buildings (masonry)	75	"	O
Buildings, wood, frame, or second class	50	"	D&O
Chimneys & stacks, masonry	30	Barker	O
Chimneys & stacks, steel	10	"	D
Condensers	20-30	Chicago Trac.Val.Com.	D
Conveyors, coal or ash	10	Wisconsin, R.R. Com.	D
Engines, gas	10-15	"	D&O
Engines, steam, high speed	15-20	"	D
Engines, steam, low speed	25-30	"	D&O
Feed water heaters	20-30	"	D
Fuel oil equipment	25	Chicago Trac.Val.Com.	D
Generators motors and Converters:			
High speed	15	Barker	D
Slow Speed	20	"	O
New types	20	Wisconsin R.R.Com.	D
Old types	15	"	O
Turbine Driven	20	"	D
Lightning arresters	15-20	"	D
Pipes and pipe covering	20-30	"	O&D
Pumps:			
Boiler feed	15-20	"	D
Small centrifugal	20-30	"	D
Shafting	20-40	"	O
Station Wiring	30	"	O&D
Stokers	20	Chicago Trac.Val.Com.	D
Storage batteries	15	Wisconsin R.R. Com.	D
Switchboard instruments and wiring	25-30	"	O&D
Switchboards:			
Old types	20-30	"	O
New types	15-20	"	O
Turbines:			
Hydraulic, old types	25-40	"	O
Hydraulic, new types	30-50	"	O
Steam, large units	20	"	D&O
Auxiliary units	10-20	Barker	D&O
Transformers, station	20	Wisconsin R.R. Com.	O&D
Wire:			
Insulated copper line	10-15	"	D
Lead Covered aerial cable	10-15	"	D&O
Lead Covered underground cable	20-25	"	O

Table II. (continued)

Note: D denotes deterioration; O denotes obsolesence.

1. Tarboux, J. G., "Economics of Electric Service", p. 454, Standard Handbook of Electrical Engineers, Sec. 6, 13th Edition.

TABLE III.

Summary of Cost of Representative

Power Station[1].

Station	A	B	C
Approximate Rating	100,000+	50,000-	100,000-
Number of Generators	3	1	2
Number of Boilers	15	6	4
Fuel used	oil and gas	oil and gas	coal
Fuel Equipment			Pulverizers
Steam Pressure	375	375	400
Steam Temperature	725	700	700
Operating Data:			
Period covered (months)	12	12	6
Total Kw. Hrs. generated	250,000,000	175,000,000	80,000,000
Net Kw. hrs. generated	242,000,000	168,000,000	75,000,000
Average B.t.u. in fuel	(oil 1100 (gas 19,000	(oil 1100 (gas 18,910	13,800
Number of men (all shifts)	160	66	70
Operating Costs:			
Fuel (cents per kw.hr.)	.205	.224	.241
Wages and supplies	.115	.077	.076
Water, lubrication and supplies	.010		.005
Miscellaneous	.002	.041	.007
Total	.332	.342	.329

Station	D	E	F	G
Approximate Rating	100,000-	250,000+	200,000+	300,000+
Number of Generators	2	4	5	5
Number of Boilers	8	16	10	11
Fuel used	Coal	Coal	Coal	Coal
Fuel equipment	Stokers	Stokers	Pulv.	Pulv.
Steam Pressure	100	325	300	375
Steam temperature	725	690	700	690
Operating Data:				
Period covered (months)	12	12	12	12
Total kw.hrs. generated	298,000,000	715,000,000	653,000,000	842.000,000
Net kw. hrs. generated	279,000,000	678,000,000	613,000,000	792,000,000
Averate B.T.u. in fud	10,600	13,300	11,300	13,000
No. of men (all shifts)	162	352	225	245

1. Morrow, L.W.W. "Power Cost in Large Plants, p. 827. Electrical world, v. 92, 1931

TABLE III.
(Continued)

Station	D	E	F	G
Operating Costs:				
Fuel (cents per kw.hr.)	.271	.325	.224	.229
Wages & supplies	.076	.086	.041	.044
Water, lubrication and supplies	.016	.012	.005	.041
Miscellaneous	.003		.037	
Total	.366	.423	.307	.287

Station	A	B	C
Maintenance Cost:			
Buildings	.003	.005	.009
Boiler plant	.023	.026	.025
Prime movers & Auxiliaries	.022	.009	.002
Generating & Electric Equipment	included above	inc. above	.001
Miscellaneous	.001		.001
Total	.049	.040	.038
Investment Cost:			
Preparing site	75,000	65,000	
Foundation Substructures	1,700,000	125,000	
Superstructures	2,200,000	1,000,000	
Fuel handling and preparation	200,000	20,000	
Boilers & Accessories	3,500,000	900,000	
Piping	1,000,000	200,000	
Generators & Condensers	3,200,000	1,200,000	
Electric Equipment in switch house	1,300,000	250,000	
General Data:			
Million B.t.u. used	14,200	2700	1180
Fuel cost used per million B.t.u.	35	136	154
Load factor	18	53	51
Use factor	20	53	41

(continued on next page)

TABLE III.
(Continued)

Station	A	B	C
B.t.u. per net kw. hr.	58,700	16,400	15,600
B.t.u. per gross kw. hr.	55,600	15,800	14,400
Thermal efficiency (net basis)	4.4	15.5	16.3
Unit Costs:			
Total Station cost dollars per kv-a	100	128	85
Building cost dollars per kv-a	27	25	
Equipment cost dollars per kv-a	71	71	
Total fixed charges	0.89	.366	.146
Total fixed charges 15% basis (cents per kw. hr.)	0.38	.382	.366
Total cost in cents per kw. hr.	1.27	.748	.512

TABLE III.
(Continued)

Station	D	E	F	G
Maintenance Cost:				
Buildings	.005	.008	.0032	.005
Boiler plant	.041	.027	.0241	.023
Prime movers & Auxiliaries	.006	.009	.0060	.001
Generating & Electric Equipment	.001	.010	.0023	included above
Miscellaneous	.003	.001		.003
Total	.056	.055	.0365	.032
Investment Cost:				
Preparing Site		4,000,000		1,000,000
Foundation Substructures	1,400,000	included above		12,000,000
Superstructures	2,000,000	10,300,000		5,300,000
Fuel handling and preparation	100,000	included above		1,200,000
Boilers & Accessories	2,600,000	20,000,000		4,800,000
Piping	500,000	included above		2,700,000
Generators & Condensers	2,000,000	" "		5,200,000
Electric Equipment in switch house	inc. above	" "		1,000,000
General Data:				
Million B.t.u. used	4200	11,560	10,320	13,200
Fuel cost per million B.t.u.	171	191	134	154
Load factor	43	40	96	53
Use factor	39	30	36	34
B.t.u. per net kw. hr.	15,180	17,000	16,700	15,700
B.t.u. per gross kw. hr.	14,200	16,152	15,800	14,200
Thermal efficiency (net basis)	16.8	14.9	15.2	16.22
Unit Costs:				
Total station cost dollars per kv-a	130	127	121	81
Building cost dollars per kv-a	38	52		21
Equipment cost dollars per kv-a	90	71		55
Total fixed charges	.592	.436	.613	.431
Total fixed charges 15% basis (cents per kw. hr.)	.421	.478	.343	.319
Total cost in cents per kw.hr.	1.013	.914	.956	.750

X. APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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