GENERATING STATIONS

Economic Elements of Electrical Design

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GENERATING STATIONS

To

JOHN CASTLEREAGH PARKER

Teacher and Friend

PREFACE

Electric power production, the most vital factor in our industrial life, has reached an all-time high. The advent of full demand for electrical power occasioned by peak production in industry together with domestic use associated with an expanded national income has produced continuous new records in the country's generator capacity and energy consumption. With station capacities at 61,000,000 kw in 1949 it is estimated that by 1955 peak load requirements may be 80,000,000 kw. By the same time energy output is expected to increase 36 per cent above the present 6 billion kwhr per week. Consequently there is a tremendous and universal demand for added power capacity in new stations and in extensions of older plants together with all the associated equipment of transformers, transmission and distribution circuits, switchgear, etc.

Because of the considerable increase in the price of fuel, designers are adopting strikingly more efficient thermal cycles leading upward to 2,000 lb. 1050°F with reheat at 1000°F. The use of oil as a fuel for electric generating stations is increasing rapidly both on its economic merits in certain situations and as an offset to the numerous interruptions in coal supply. As a parallel solution, there is additional incentive to develop large hydro powers even though they may require long transmissions to reach the market. Sweden is building a 380-kv transmission line to carry 250 Mw 600 miles. France, at its Chevilly experimental station, is studying behavior of lines to be used in building a 400-kv system, and in the United States the Tidd test project has energized lines at 500 kv. Economic justification for the use of these high voltages may require good load factors and circuit loadings of 300 to 400 Mw per circuit with greatly increased circuit-breaker interrupting capacities. These have already reached 10,000 Mva for 230 kv at Grand Coulee.

In meeting the important problem always associated with power supply there is increased activity in supplying the reactive kilovolt-amperes for utility systems with capacitors permanently connected at the load on the feeders, at the substations, and on the generator bus. Some of these can be arranged for switching, and in special cases synchronous condensers find application because of their continuous regulating performance. As examples to relieve loading on the generators and transmission system, Pennsylvania Power and Light has installed 90,000 kvar of switched capacitors and Public Service Electric and Gas of New Jersey has 1,000-

Mvar supply distributed 57 per cent in generators, 18 per cent in synchronous condensers, and 25 per cent in static capacitors.

Special thanks are due to the engineers and officers of many power companies, the Tennessee Valley Authority, the Wisconsin Public Service Commission, the U.S. Bureau of Reclamation, and the electrical and diesel manufacturing companies for data furnished and courtesies extended. Many engineers and economists have generously allowed the use of their work, for which acknowledgment is made in the text. Also numerous references have been made to statistics and developments in the standard engineering publications in order to encourage the student to use these sources.

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ANN ARBOR, MICH.
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CHAPTER I

ELEMENTARY PRINCIPLES OF CORPORATE FINANCE

1. The Economic Motive. With the exception of the construction of works of art or memorial buildings, all engineering projects are undertaken from an economic motive, either direct or indirect. In particular, the design and construction of a power system are undertaken for the purpose of producing power to be sold at a profit, either to other persons or, virtually, to the owner himself for use in his principal business. In either case, the object is to produce the power as cheaply as possible, taking into account the quality of the power produced. Indeed, this quality will in itself affect the cheapness or expensiveness of the product, since a bad power service is likely to be very expensive in the long run.

The cheapest power is not necessarily produced by the most efficient plant, since in general it will involve a great deal more investment to secure such a plant than would be required to secure a less efficient plant. The difference between real engineering and the mere technical selection of the academically best lies in the proper proportioning of investment and operating cost.

We are not unfamiliar with a very inexact form of expression of this general idea of evaluating efficiency in machines. A man, on being shown a superlatively fine automobile, may admit its excellencies while deciding that for him they are not worth the higher price charged for such a car. The engineer must be in a position to determine with reasonable certainty whether a higher degree of efficiency justifies the greater investment involved, whether more assured continuity of service, greater safety, further ease of operation, or additional automatic features are worth their extra cost, and in order to accomplish this must have some fundamental understanding of the economics back of his design. Usually, other things being equal, the more expensive the first cost of the design, the cheaper it will be to operate the plant, and vice versa. Note that here we have to compare original construction costs, incurred within a comparatively brief time, with those recurring costs which are repeated year by year and day by day. Therefore in all plants an itemized record of plant performance and cost of operation must be kept in order to obtain economic results. These and the capital accounts are almost universally kept in accordance with the Uniform System of Accounts prescribed on

Jan. 1, 1938, by the state Public Utility Commissions and the Federal Power Commission. The value of such records lies in the fact that they will inform the engineer as to the exact costs at all times and enable him to proceed intelligently in reducing the losses. In view of the long-continued rise in prices for equipment and materials, it is important that the designer hold the investment cost to a minimum. Such reduction not only will be valuable in itself but will also have a beneficial influence on operating costs, since about 60 per cent of the latter is proportional to physical plant. Reduction in the capital costs can be effected by careful attention to the following suggestions:[1] (1) Use equipment up to its highest economic limit of loading, especially for short-time overloads occurring frequently in case of emergency. (2) Provide wattless capacity at the loads to derive the greatest kilowatt system capacity per dollar of investment. (3) Encourage high load-factor loads. (4) Eliminate spare equipment where the superior reliability of modern equipment will suffice, and avoid the pyramiding of probabilities in considering reliability of operation. (5) Encourage standardization of methods and equipment. (6) Simplify system layout, and reduce component parts to a minimum.

2. The Preliminary Report and Estimate. In reporting upon the feasibility of any power project, the engineer, as has been customary, must consider all its economic phases: the cost of the system, the amount and uniformity of the power that can be developed, the available market that might justify the power development, the price at which the power can be sold, and all the charges and expenses involved in the construction and operation of the plant. In recent years, public opinion has come to recognize that electric power supply is a vital and necessary modern service, that it is a fundamental element in our industrial life which must be adequate and assured even for wartime expansion, and that it is a dominating factor in the recent Federal programs for social and economic betterment in the South, the Missouri Valley, and the Northwest. Hence the report should consider also the general social aspects of the problem. That is, if the engineering project is to be valuable to humanity, the value of the *benefits* to be derived from the construction must be greater than the cost of doing without it.[2]

In the case of fuel-burning plants, the costs are generally fairly well known, although plans may have to be modified during construction, extras may be allowed, and severe weather conditions and storms often

[1] Monteith, A. C., Modern Equipment Reliability Affords System Savings, *Elec. World*, June 10, 1944.

[2] See discussion of Humanities in Engineering Education, by Prof. J. K. Finch, *Soc. Promotion Eng. Educ. Jour.*, April, 1934.

delay the progress and add greatly to the cost of the work. On the other hand, each hydraulic project presents many special problems. In developing a water power, the hazards are much greater not only in the construction of the property but in the operation and maintenance.[1] The structures have to be built in and across a river where flood and ice conditions may raise the ultimate cost of construction by a large contingency item.

In addition to the cost of the hydro plant itself, large investments have to be made for auxiliary steam power; for navigation and flood-control works; for storage reservoirs; for dams, canals, fish ladders, and log chutes; for land and flowage rights; for new roads and embankments; and for long high-voltage transmission lines with their switching and substations, all of which result in very high fixed charges to be carried by the development throughout its life. In spite of the many hydroelectric plants built in the last 10 years and the wide publicity given to their economic significance, the general public and even some technical writers still concentrate all their attention on the low operating costs of producing hydro kilowatthours at the plant switchboard some hundred miles away from the market. They forget or ignore entirely that the maximum power will not be available in the dry-season flows and must be replaced by other power and that the fixed charges on the plant and all the fixed and operating charges on such transmission lines as will be necessary for the hydro development but not for a steam plant must be added to the operating-plant cost to determine the total cost as delivered at the load. When the real total cost is thus considered, the excessive profits which have been thought to exist in every water project will be found to be largely nonexistent. As an alternative, the engineer should consider whether a fuel-burning plant at the load point would not furnish the power at a lesser total cost, having as it would the advantages of a saving of the transmission cost, the smaller investment per kilovolt-ampere, and the reliability of a full available power capacity unaffected by drought or flood.

3. Initial and Annual Costs. The construction and operating costs mentioned above, the one being lump sums paid once and for all during construction, the other occurring each year of the plant's operation, are incommensurate. To render them commensurate, we shall express the lump sums in terms of the annual costs necessitated by the consignment of such capital to the project. There will then be annually two recurring costs:

1. Fixed or overhead costs—which do not vary with the operation of the plant.

[1] See Barrows, "Water Power Engineering," McGraw-Hill Book Company, Inc.

2. Operating or direct costs—dependent on the manner and extent of the operation of the plant.

Figure 1-1 shows the production expense and fixed charges of 102 stations operating in 1947. Several plants were built in the 1930 to 1945 period, but some stations had units installed as early as 1910 which had been retained because of the great need for output. So great was the load that peaks were commonly 120 to 130 per cent of rated capacity. It will be noted that the average cost of net kilowatthours at the bus was

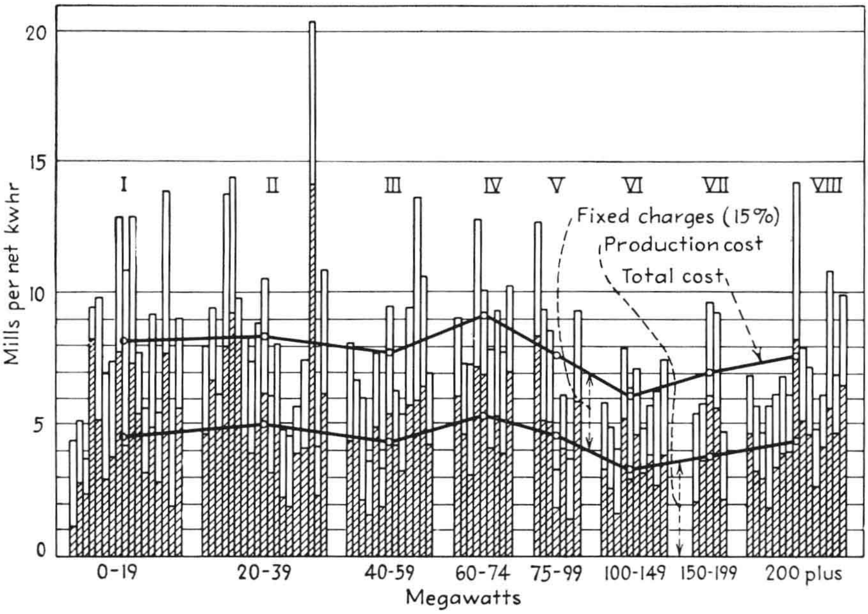

FIG. 1-1. Production expense and fixed charges for 102 stations operating in 1947. (*Elec. World, July* 3, 1948.)

about 7.5 mills with the average production cost at 4.5 mills and the fixed charges at 3.0 mills.

4. Fixed Costs. These will consist of

1. Taxes.
2. Insurance.
3. Depreciation (wearing out of the depreciable part of the plant, augmented by obsolescence).
4. Money use (interest and bond discount, dividends).
5. Risk insurance (profit).

5. Operating Costs. These will be made up of

1. Fuel.
2. Wages.
3. Supervision.
4. Water, oil, waste, and supplies.
5. Repairs and maintenance.

6. Taxes. A corporation engaged in generating and selling electric power or gas, like an ordinary householder, is subject to the general property tax, *i.e.*, the tax on real estate and personal property. Generating and substations, transmission and distribution systems, and gas, water, and steam mains are considered as personal property and assessed where they are located. For example, the tax rate for the city of Ann Arbor for the year 1950 was $35.72 per thousand. The Michigan State Tax Commission imposes a tax for the primary school fund on the utilities based on the average property tax rate of Michigan communities. The 1947 rate was $27.38 per $1,000 valuation.

At the time of organization of the corporation, in addition to the trustee's fees, fees for engraving, etc., the state of Michigan will charge an organization or incorporating fee of 50 cts. for each $1,000 of capitalization. This usually will be capitalized.

There is also the franchise privilege fee. The state of Michigan charges 2.5 mills on the paid-up capital and surplus of the preceding year from a minimum tax, set at $10, up to a maximum tax of $50,000. In addition, the state of Michigan charges a general sales tax of 3 per cent on sales of electricity. Many of the other states levy on gross receipts or on a kilowatthour basis; *e.g.*, New York State has made permanent its 2 per cent gross income tax on all utilities, which was passed as an emergency tax in 1937.[1] The Rhode Island Legislature voted to maintain its 2½ per cent tax on gross receipts of electric utilities,[2] and Clarksdale, Miss., in reviewing a 25-year franchise, charged the Mississippi Power and Light Company 2 per cent of gross revenues from residential and commercial sales.[3] Effective Jan. 1, 1948, Roanoke, Va., taxes all electric, gas, and telephone bills 5 per cent.[4] New York City has renewed for 3 years its 3 per cent tax on gross receipts of utilities.[5] Boston Edison reports that it pays 11.8 per cent of its total income in state and municipal taxes.[6]

[1] *Elec. World,* Apr. 5, 1947.
[2] June 14, 1947.
[3] Dec. 11, 1948.
[4] Jan. 3, 1948.
[5] June 18, 1949.
[6] Dec. 24, 1949.