ESTIMATION OF TRANSMISSION AND DISTRIBUTION EQUIPMENT NEEDS

by

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PREFACE

This paper is the first in a series estimating the capital equipment needs, capital costs, and operation and maintenance expenses of the transmission and distribution systems in the electric power sector. Other papers currently in progress include a paper estimating the capital costs of transmission and distribution equipment, a paper estimating the expenses of operating and maintaining the transmission and distribution networks, and a paper investigating the allocation of capital costs and operation and maintenance expenses of the transmission and distribution subsystems to different classes of consumers.

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I. INTRODUCTION

In 1974, electric utilities in the United States budgeted 37% of their total planned capital expenditures (over $7 billion) for transmission and distribution equipment. To the author's knowledge, no study has been made which estimates, on an aggregated level, the transmission and distribution equipment needed to meet a certain demand. Since T & D contributes to such a large fraction of the rate base, it is important to be able to quantify the T & D equipment requirements as a function of the configuration of demand and the characteristics of the service area. The size and complexity of an electric power system make its careful planning important. The power company must design a system which supplies electric power to anyone desiring it. When designing the system, the power company has many factors to consider, including the size, location, and duration of the demand.

Modeling the planned power system assists the system planner and the economist alike with their tasks. With a properly constructed model, the demand for electric power and the equipment needed to supply the power may be forecasted given different assumptions and policy alternatives. Simulations through time help determine the long-range effects of a particular action. As part of a project to build a large engineering-econometric simulation model for electricity supply and demand[1], we have

[1] "A Regionalized Electricity Model", by Martin L. Baughman and Paul L. Joskow, paper presented at the ORSA-TIMS Conference, held in San Juan, Puerto Rico, October 16-18, 1974.

attempted to model and estimate the transmission and distribution equipment requirements for the utility industry. This report is restricted to the following question: Given the configuration of demand and the characteristics of the service area, what amount of transmission and distribution equipment is necessary to satisfy the demand? In particular, functions specifying the needs for five equipment items are discussed. These are for

1. Structure miles of transmission
2. Transmission substation capacity (K V A)
3. Distribution substation capacity (K V A)
4. Line transformer capacity (K V A)
5. Number of meters

For several reasons the study is confined to privately-owned electric utilities. The data available for privately-owned utilities are more complete than for the publicly owned utilities. The data for privately-owned utilities also were more even, i.e., no large annual swings were encountered. Finally, since privately-owned electric utilities, in terms of revenue, customers, electric sales, and total generation account for approximately 80% of the totals for the entire electric industry, little loss of generality is expected.

Selection of the state as the region of electric power consumption was predicated upon the availability of data. Regions such as those defined by the Bureau of Census make no greater economic sense since the boundaries of the Bureau of Census regions are still arbitrarily placed at state lines. Also, the increase in the number of observations commensurate with state detail should tend to overcome the arbitrariness of the power consumption region's definition.

Forty-seven "states" were defined. Maryland and the District

Columbia were aggregated into one region since some data sources did not separate figures for the two areas. Also, Alaska and Hawaii were excluded since the availability of data was not a certainty, and Nebraska was excluded since no privately-owned utilities operate in that state.

In order to keep the range of the study within a relatively narrow time span but yet provide a sufficiently large data base, observations of the variables were restricted to 1965 and later years. The data are annual and are the most recent available from the Federal Power Commission.

The present study raises but does not attempt to answer the question of whether electric utilities attempt to minimize costs. Perhaps the reason why the equipment needs of some states were over-estimated while the needs of others were underestimated is that, in the former set of states the utilities optimize more than they do in the later set of states. The assumption that utilities across the nation optimize to approximately the same degree preserves the validity of this study.

II. THE TRANSMISSION SYSTEM

The transmission system delivers the electric power to the demand for the power. It must have a sufficient capacity to meet the peak demand of the subregion which it supplies. Its two basic components are the transmission lines and the transmission sub-stations.

A. Transmission Line Needs

Transmission lines carry the electric power from the source of the power to the place where it is demanded. Lines may have different maximum voltage ratings; one line may be rated at 230 kilovolts while another may have a rating of 765 Kv.

Structure miles of transmission line were the units used to measure the quantity of transmission line in place. "Tower miles" or "pole miles" might be more descriptive terms. Structure miles of line differ from circuit miles in that when several lines are on one series of towers or poles, the mileage is counted as if only one line were in place. Capital investment in transmission lines is more accurately reflected by structure miles than by circuit miles, since the principal portion of investment is in the towers and easements. Though a measure such as giga-watt miles which accounts for the capacity of the lines might be better, such data were neither available nor readily derivable within acceptable tolerances.

One would expect the number of structure miles of transmission line needed to satisfy the demand for electric power to increase with the demand. And, in theory, one should not expect any difference between the amount of equipment needed to transmit a kilowatt for residential and small light and power consumption and the amount needed to transmit a kilowatt for large light and power consumption. If demand is held consiant, one would expect the area of the state to affect the need for transmission line. One can see that to transmit the same amount of energy to a larger area will require more structure miles of transmission line. One also might expect areas with a higher load density to need less line since the power transmitted could be carried in higher capacity lines. Also, areas which have higher load densities might be able to take greater advantage of noncoincident peaks. Load density may also be acting as a proxy for population concentration or industrial concentration, both of which should permit utilities in high load density areas to reduce the line needed through economies of scale.

Regressing structure miles against total electric sales, area of the state, and the load density gave the following results*:

$$SM = 1019.6 + .1920\ EST + .0318\ AREA - 965.5\ LD$$

$$(3.08) \qquad (24.1) \qquad (7.96) \qquad (-4.81)$$

$$R^2 = .758 \quad F(3,325) = 340$$

A regression with residential and small light and power sales separated from large light and power sales yielded coefficients within 5% of one another and insignificantly different.

All variables are significant and of the sign expected.

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* Numbers in parentheses under coefficients are t-statistics. A list of variable abbreviations may be found in the Appendix.

B. Transmission Substation Needs

The quantity of substation equipment in place was measured in volt-amperes of capacity.

The total transmission substation capacity in volt-amperes required to meet a certain demand is expected to be proportional to the level of demand for power, assuming that the ratio of the peak demand to the mean demand is constant for the different states for a particular class of consumers. The expectation was that the ratio for the residential and small light and power users was different from that for large light and power users. The results:

$$\underset{}{TSUB} = \underset{(2.20)}{674700} + \underset{(19.8)}{712.5\ ESRSM} + \underset{(12.3)}{523.2\ ESLLP}$$

$$R^2 = .910 \qquad F(2,326) = 1643$$

The coefficients for the two consumer classes were significantly different.

$$(t = 2.51)$$

III. THE DISTRIBUTION SYSTEM

The function of the distribution system is to deliver electric power to each customer demanding it, in an amount sufficient to satisfy the demand. Unlike for the transmission system planning is at a minimum, if it even exists, for the distribution system.

The distribution system may be divided into several basic components: the distribution substations, distribution poles and lines, line transformers, and meters.

A. Distribution Substation Needs

Distribution substation equipment was measured in volt-amperes of capacity. Note that the distinction between transmission substation equipment and distribution substation equipment is primarily one of degree. However, no matter where the line is drawn, large light and power users are defined by the utilities as those users which take their electric power directly from the transmission system; hence, the amount of distribution substation equipment is expected to be independent of the level of demand by large light and power users.

Expectations are that the level of demand by residential and small light and power users is positively related to the quantity of distribution substation equipment in use. Also, the larger the area served by a particular distribution system, the less localized the demand (given a constant demand); assuming that the more the demand is localized, the greater the economies of scale, one would expect the quantity of equipment to be needed to meet the given demand to be greater for larger areas.

Regressing residential and small light and power demand and area against distribution substation capacity gave the following results:

$$DSUB = 485.4\ ESRSM + 9.46\ AREA$$
$$(40.2) \qquad (2.45)$$

$$R^2 = .826 \quad F(1,327) = 1554$$

When large light and power demand was added to the right-hand side of the equation, its coefficient was very small and insignificant.

B. Line Transformer Needs

Line transformers were measured in volt-amperes of capacity. Residential and small light and power demand should determine the level of line transformer needs, assuming that the residential and small light and power users on the average have the same ratio of peak demand to mean demand from area to area. Still, to account for rural areas, one might expect to find that, given a constant demand, the larger the area, the more substation capacity needed, since in a more sparsely populated region each line transformer would be serving fewer customers. Large light and power demand, however, should be irrelevant. The results:

$$LT = 568.2\ ESRSM + 102.6\ ESLLP + 5.15\ AREA$$
$$(32.6) \qquad (5.09) \qquad (2.82)$$

$$R^2 = .937 \quad F(2,326) = 2412$$

Why large light and power demand should be significant is a mystery. One suggestion, not entirely satisfactory, is that large light and power users do need a certain amount of low-voltage power for office and administrative purposes.

C. Meter Needs

The obvious measure of the quantity of meter equipment in place is number of meters. One would expect the number of meters in use to be determined entirely by the number of customers of various types demanding power. Customers may be categorized into one of six types: residential and small light and power, large light and power, street and highway lighting, other public authorities, railroads, and interdepartmental. The last two categories account for only .01% of the total customers. The results:

$$MET = 1.006\ CUSRSM + 14.005\ CUSLLP + 7.282\ CUSPUB$$
$$(77.3) \qquad (9.09) \qquad (2.57)$$

$$R^2 = .989 \qquad F(2,326) = 15000$$

Railroads and interdepartmental were not significant, and separation of street and highway lighting from other public authorities yielded coefficients for these two categories which were significant but not significantly different from each other or from the large light and power coefficient. All coefficients in the above equation are significantly different from each other.

IV. STATISTICAL METHODS

All regressions were done using ordinary least squares techniques. While the observations are drawn from a seven-year period, they are drawn also from 47 "states"; the data were treated as cross-sectional. Heteroscedasticity problems were assumed not present to any important degree, since most variables were sums of figures for individual utilities within the "state", and errors tended to be damped for "states" with large power systems.

Tests for significant difference between coefficients were t-tests.

V. IMPLICATIONS

The results justify allocating the capital costs of transmission and distribution equipment per kilowatt-hour of sales differently to residential and small light and power users than to large light and power users. While transmission line equipment needs arise independently of which type user is being served, needs for all other categories of transmission and distribution equipment are related to the type of user being served. Transmission substation and distribution line transformer requirements are larger per kilowatt-hour of residential and small light and power demand than per kilowatt-hour of large light and power demand, and distribution substation requirements are independent of large light and power demand. Meter requirements, however, arise in far greater number per large light and power user than per residential and small light and power user.

SOURCES:

1. Statistical Abstract of the United States, 1972; Bureau of the Census.

2. Statistical Yearbook of the Electric Utility Industry; Edison Electric Institute, for the years 1965 through 1971.

3. Statistics of Privately Electric Utilities in the United States; Federal Power Commission, for the years 1965 through 1971.

APPENDIX: ABBREVIATIONS FOR, SOURCES OF, AND SOME STATISTICS OF THE DATA USED

ABBREVIATION	SOURCE	DESCRIPTION*	MEAN	MIN.	MAX.
AREA	1	Area of "states" in square miles	61436.5	1049	262134
CUSLLP	2	Number of large light and power customers	5487.3	22	33192
CUSPUB	2	Number of public authorities customers (including street and highway lighting customers)	4856.4	90	30157
CUSRSM	2	Number of residential and small light and power customers	1153330	26238	5994697
DSUB	3	Distribution substation capacity in K V A	5740618	66000	29753890
ESLLP	2	Annual energy sales to large light and power customers in millions of Kwh.	8533.4	208	46458
ESRSM	2	Annual energy sales to residential and small light and power customers in millions of Kwh.	10504.	332	62492
EST	2	Annual energy sales to all ultimate customers in millions of Kwh.	19807.4	565	95369
LD	EST/AREA	Load density in millions of Kwh. annually per square mile.	.6786	.0137	5.2440
LT	3	Line transformer capacity in K V A.	7226619	87152	36961310
MET	3	Number of meters.	1280082	20791	6517876
SM	3	Structure miles of transmission line	6122.0	0	27328
TSUB	3	Transmission substation capacity in K V A.	12623100	0	64472000

* NOTE: All data are for investor-owned utilities only