ENGINEERING ESTIMATES OF TRANSMISSION AND DISTRIBUTION EQUIPMENT COSTS

by

Sergio G. Sequeira and Martin L. Baughman

Working Paper
MIT-EL 75-002WP

March 13, 1975

PREFACE

This paper is the second 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 or completed include a paper estimating the capital equipment requirements for transmission and distribution, 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.

S.G.S.

M.L.B.

ENGINEERING ESTIMATES OF TRANSMISSION AND DISTRIBUTION EQUIPMENT COSTS

by

Sergio G. Sequeira and Martin L. Baughman

This document reviews data on the costs of distribution transformers (for both overhead and underground systems), distribution substations, transmission and distribution lines, transmission substations and the cost of metering systems, for both residential and large commercial and industrial consumers. Wherever the data were available, the costs were derived from aggregate company sources. This was possible for transmission lines, distribution lines, and transmission substations, where the results were derived from data published by Electrical World's Annual Statistical Report. For distribution substations, line transformers, and metering systems, data from New England Company sources were used.

Tables 1 and 2 show recent aggregate average costs for transmission and distribution lines for both overhead and underground systems. As some utilities consider 69 KV to be distribution, while others think of it as transmission, this voltage level is included in both tables. Substation costs appear on Table 3. All of the data in Electric World is subdivided for the nine regions of the U.S. (New England, Middle Atlantic, East North Central. West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific). Each year date are contained data on new expenditures for transmission lines, distribution lines, and substations, and the

physical quantities of new lines and substations energized. The new lines are given in units of circuit, cable or pole miles for overhead transmission systems (above 69 KV), underground transmission systems (above 69 KV) and distribution systems (below 69 KV), respectively. The new substations are given in units of MVA of installed capacity. Cost estimates for each equipment category in each of the nine regions are computed via a three year moving average. The units are in dollars per mile for transmission and distribution lines, and dollars per MVA of installed capacity for substations.

From these three tables, we note a consistent trend where the Middle Atlantic, Pacific and New England regions have the highest costs, followed by the Mountain, East North Central and South Atlantic regions, and finally by the East South Central, West South Central and West North Central regions.

Tables 4, 5, 6 give historical trends in costs for transmission lines and substations. Table 4 gives data for average national transmission lines costs for selected years between 1950 and 1972. These were computed from a ratio of national expenditures for transmission (reported by the Edison Electric Institute) divided by total gross increments in transmission capability (in circuit miles as reported by EEI, assuming a 2% and 3% rate of depreciation). These figure show that average costs per circuit mile have been escalating at about 3%/yr over the period.

Table 5 further breaksdown these costs for two voltage classes of underground and overhead lines for each of the nine census regions of the country. The regional variation is quite large. The central states exhibit the lowest costs and the Mountain and Middle Atlantic states exhibit the highest costs. The cost of line construction in the rugged mountain terrain is probably what makes that region's

costs so high, while the high land premium in the densely populated Middle Atlantic states is probably the large contributing factor there. Note also that in 1971-1973, the cost per mile of underground transmission is about 8 times that for overhead.

Table 6 shows the historical trends in substation costs. It appers over the period from 1953 to 1963, these costs declined at a rate of about 4.6% per year. Between 1963 and 1973, however, the costs leveled out or increased slightly, with the largest increases exhibited in the more densely populated coastal states and the Mountain region.

The aggregated average substation costs of Table 3 can be compared to point estimates of distribution substation costs on Table 7. The latter shows costs for specific distribution substations for two different voltage ratios obtained from Boston Edison. It can be seen that the costs shown in Table 7 are slightly higher, but this is probably because the substation costs in Table 3 are for both transmission and distribution substations. The lesser costs in Table 3 reflect economies of scale brought about by higher capacity in the transmission substations. (Electric World simply lists substations energized and new expenditures for substations in each year, without making any distinction between transmission and distribution substations).

For comparison, tables 8 through 12 show additional point estimates of costs (in dollars per KVA) for installed capacity of one and three phase overhead and underground transformers. Economies of scale exist in all cases, with figures running from 5 to 55 dollars per KVA for one phase overhead transformers, 9 to 22 dollars KVA for three phase overhead transformers, 10 to 31 dollars per KVA for one phase underground transformers and 50 to 78 dollars per KVA for three phase underground transformers. As expected underground transformers show higher costs than overhead transformers.

The costs of various metering services are shown on Table 13. There it can be seen that the installed cost of a simple residential single phase watt-hour meter is on the order of $25.00 (including $6.50 for installation). For a large industrial customer, however, with a recording demand meter, the transformers required for connection, and installation, the cost is in the range of $1200-1400 per meter.

CONCLUSIONS

For use in the regionalized electricity supply model, the data contained in this report suggest the following numbers might be appropriate.

Transmission Structure Miles

The U.S. average cost for all transmission was around $110,000 per structure mile in 1972, escalating at a real rate of 6% per year. The costs varied by region according to:

New England	123,000
Middle Atlantic	261,000
East North Central	97,000
West North Central	61,000
South Atlantic	126,000
East South Central	74,000
West South Central	58,000
Mountain	77,000
Pacific	155,000

Substations:

The average U.S. cost for substations was $8.80/KVA. For the past ten years these have shown little or no real escalation because economies of scale have helped to offset real escalation in per unit costs. The geographical variation in costs was recorded to be the following:

New England	$10.80
Middle Atlantic	10.10
East North Central	9.20
West North Central	7.30
South Atlantic	7.70
East South Central	5.20
West South Central	7.90
Mountain	12.70
Pacific	12.00

Line Transformers

No good average costs for line transformers were available. Based upon the relative point estimate per unit costs, however, an average cost of $1\frac{1}{2}$ times that for substations probably would be sufficient.

Meters:

For metering systems, $25 per residential customers and $1000 per lage light and power customer seems appropriate.

TRANSMISSION LINES COSTS*

Aggregate Averages (1971, 1972, 1973)

	Overhead Lines		Underground Lines	
	345 KV and above	Above 69 KV Through 230 KV	230 to 345 KV	Above 69 KV Through 161 KV
New England	150	107	-	447
Middle Atlantic	379	143	1243	259
East North Central	118	76	702	578
West North Central	88	34	-	163
South Atlantic	177	76	563(1)	389(1)
East South Central	97	51	-	496
West South Central	57	39	-	243
Mountain	231(1)	56	1032(2)	597
Pacific	161	70	813(1)	579
TOTAL U. S.	145	63	1049	488

*Average for 1971, 1972 and 1973. In thousands of dollar per structure mile, for overhead transmission, and in thousands of dollars per cable mile for underground transmission.

(1) Projected costs, as opposed to actual costs.

(2) Projected costs for 1972, 1973 and 1974

Source: Electrical World, various issues

TABLE 1

PRIMARY DISTRIBUTION LINES COSTS*

Aggregate Averages

(1971, 1972, 1973)

	Overhead 69 KV and Below	Underground 69 KV and below
New England	36	98
Middle Atlantic	41	98
East North Central	24	43
West North Central	13	18
South Atlantic	23	46
East South Central	16	39
West South Central	14	28
Mountain	20	35
Pacific	51	62
TOTAL U. S.	22	45

* Average for 1971, 1972 and 1973. In thousands of dollars per pole mile

Source: Electrical World, various issues.

TABLE 2

SUBSTATION COSTS*

Aggregate Averages

	1970	1971	1972	1973	Average for 1970-71-72	Average for 1971-72-73
New England	12.5	9.0	9.1	15.1	10.0	10.8
Middle Atlantic	15.9	13.4	12.4	7.6	13.7	10.1
East North Central	9.6	7.7	12.1	8.4	9.6	9.2
West North Central	6.4	9.0	6.2	7.1	7.1	7.3
South Atlantic	6.5	7.9	7.9	7.0	7.5	7.7
East South Central	12.1	14.0	3.0	7.5	5.4	5.2
West South Central	6.0	6.5	7.3	10.9	6.7	7.9
Mountain	14.3	11.1	11.4	10.0	13.0	12.0
Pacific	12.4	12.3	14.3	10.0	13.0	12.0
TOTAL U.S.	9.5	9.1	8.1	8.8	8.8	8.7

*In thousands of dollars per MVA of installed capacity

Source: Electrical World, various issues

TABLE 3

TRENDS IN TRANSMISSION LINE COSTS

Aggregate Averages

YEAR	(1) CONST EXP. $ 10^6	(2) YEAR END Current Mi.	(3) C O S T $(000)/CM	(4) C O S T $(000)/CM
1972	1748	392,141	111	89
1971	1806	384,037	102	84
1970	1680	373,763	81	69
1969	1554	360,216	94	77
1968	1503	350,618	94	78
1967	1323	341,524	71	60
1966	1137	329,348	71	59
1965	940	319,790	72	58
1964	824	313,033	68	54
1963	644	307,027	48	39
1962	609	299,706	51	34
1961	579	290,770	45	37
1960	537	283,474	41	34
1959	554	276,002	-	-
⋮				
1955	434	248,644	34	29
1954	464	240,844	-	-
⋮				
1950	280	208,044	19	17
1949	275	197,529	-	-

(1) + (2) Source: Edison Electric Institute Statistical Yearbooks

(3) : Costs assuming 2% rate of depreciation.

(4) : Costs assuming 3% rate of depreciation.

TABLE 4

Three Year Aggregate Averages

REGION	YEAR	$(000)/Structure Mile		$(000)/Cable Mile	
		Overhead		Underground	
		High Voltage	Low Voltage	High Voltage	Low Voltage
NEW ENGLAND	73-71	150	107	-	447
	70-68	122	82	-	400
	67-65	205	69	-	280
MIDDLE ATLANTIC	73-71	379	143	1243	259
	70-68	254	83	220	180
	67-65	111	68	171	145
EAST NORTH CENTRAL	73-71	118	76	702[i]	578
	70-68	111	48	569	762
	67-65	100	38	-	141
WEST NORTH CENTRAL	73-71	88	34	-	163[i]
	70-68	47	25	-	224
	67-65	45	21	-	24[i]
SOUTH ATLANTIC	73-71	177	76	260	1086
	70-68	292	60	571[i]	570
	67-65	59	38	-	367
EAST SOUTH CENTRAL	73-71	97	51	-	-
	70-68	63	33	-	-
	67-65	130	32	-	-
WEST SOUTH CENTRAL	73-71	57	39	-	239
	70-68	83	35	-	397
	67-65	64	29	-	47
MOUNTAIN	73-71	296	56	-	597
	70-68	95	29	-	767
	67-65	34	24	-	131
PACIFIC	73-71	161	70	-	579
	70-68	60	60	-	595
	67-65	128	34	905	281
TOTAL U. S.	73-71	145	63	1049	488
	70-68	90	45	700	451
	67-65	76	33	185	145

Source: Electrical World, Annual Statistical Report: various issues

i = insignificant

TABLE 5

TRENDS IN SUBSTATION COSTS

Aggregate Averages

	1953 1954 1955	1954 1955 1956	1955 1956 1957	1956 1957 1958	1957 1958 1959	1958 1959 1960	1959 1960 1961	1960 1961 1962	1961 1962 1963	1962 1963 1964	1963 1964 1965	1964 1965 1966	1965 1966 1967	1966 1967 1968	1967 1968 1969	1968 1969 1970	1969 1970 1971	1970 1971 1972	1971 1972 1973
New England	11.3	11.5	10.5	10.3	9.2	9.7	8.8	8.8	7.3	7.2	7.2	10.3	11.3	11.9	11.0	11.6	10.7	10.0	10.8
Middle Atlantic	14.7	16.0	15.2	14.1	13.5	13.7	12.7	10.7	9.8	10.2	9.5	10.7	10.4	10.7	12.4	13.0	13.7	13.7	10.1
East North Central	13.7	14.5	14.8	15.7	14.6	13.2	11.8	10.6	9.2	8.6	8.4	8.4	7.4	8.3	11.8	10.4	9.2	9.6	9.2
West North Central	14.6	14.5	14.9	12.8	12.0	11.1	10.3	8.2	8.7	8.2	10.2	8.6	8.6	7.9	7.7	7.9	7.9	7.1	7.3
South Atlantic	11.9	11.8	10.1	8.6	6.8	7.0	6.9	6.3	5.6	5.4	5.7	5.8	6.4	7.8	8.2	7.8	7.4	7.5	7.7
East South Central	10.4	8.3	8.8	11.3	11.9	10.3	10.4	9.4	7.4	6.7	7.7	7.4	7.8	8.1	10.4	11.0	12.1	5.4	5.2
West South Central	9.7	8.3	8.5	8.5	8.6	7.5	6.4	6.2	6.4	7.4	7.9	7.2	6.2	5.9	6.3	6.7	6.5	6.7	7.9
Mountain	17.4	13.5	11.5	10.2	10.7	11.3	11.8	9.5	6.3	6.7	7.1	9.2	8.6	8.9	9.9	12.4	13.3	12.0	12.7
Pacific	14.5	12.1	12.2	12.0	13.3	14.1	13.5	13.0	11.7	10.8	12.3	12.5	12.1	12.5	13.4	14.4	13.3	13.0	12.0
TOTAL U.S.	12.7	12.2	12.1	11.8	11.4	10.9	10.2	9.3	8.2	8.0	7.8	8.3	8.2	9.2	9.7	10.1	9.6	8.8	8.7

*In thousands of dollars per MVA of installed capacity

Source: Electrical World, various issues.

TABLE 6

DISTRIBUTION SUBSTATIONS COSTS

Point Estimates

KV_1 / KV_2	Installed Capacity (MVA)	Firm Capacity (MVA)	$ / MVA of Installed Capacity	$ / MVA of Firm Capacity
13.8/4.16	15	10.6	18.80 (1)	26.60 (1)
13.8/4.16	13.5	8.75	14.80 (2)	22.80 (2)
11.5/13.8	280	150	7.50 (2)	14.00 (3)
11.5/13.8	280	150	7.60 (3)	14.30 (3)
11.5/13.8	80	50	10.80 (3)	17.30 (3)

(1) 1967 Costs

(2) 1970 Costs

(3) 1973 Costs

Source: Boston Edison Company

TABLE 7

COSTS FOR 1 PHASE OVERHEAD TRANSFORMERS*

Point Estimates

KVA	$	$/KVA
5	275.49	55
10	274.80	27
15	430.23	29
25	337.66	14
30	466.71	16
$37\frac{1}{2}$	562.32	15
50	522.38	10
75	943.40	13
100	951.13	10
167	1,349.24	8
250	1,650.17	7
333	2,096.04	6
500	2,645.90	5
833	4,533.55	5

* 1973 Costs

$ Average installed Cost

Source: Edward Gulachenski, N.E.E.S.

TABLE 8

COSTS FOR 3 PHASE OVERHEAD TRANSFORMERS*

Point Estimates

KVA	$	$/KVA
30	671.34	22.4
45	886.72	19.7
75	1,024.46	13.7
112 1/2	1,390.27	12.4
150	1,605.93	10.7

* 1973 Costs

$ Average installed costs

Source: Edward Gulachenski, New England Electric System

TABLE 9

COSTS FOR 1 and 3 PHASE OVERHEAD TRANSFORMERS*

Point Estimates

K V A	ø	V_1/V	C_1	C_2	$\frac{S}{KVA}$
25	1	120/240	325	125	18
50	1	120/240	375	125	10
75	1	120/240	600	125	9.7
100	1	120/240	658	125	7.8
167	1	120/240	1025	125	7.3
45	3	240/480	600	125	16
45	3	120/208	625	125	16.7
75	3	240/480	950	125	14.3
112 $\frac{1}{2}$	3	120/240	1000	125	10
112 $\frac{1}{2}$	3	120/208	1250	125	12.2
112 $\frac{1}{2}$	3	277/480	1275	125	12.4
150	3	120/240	1250	125	9.2
150	3	120/208	1350	125	9.8
150	3	277/480	1350	125	9.8

ø - Number of Phases

C_1 - Capital Costs

C_2 - Installation Cost

$S = C_1 + C_2$

*1973 Costs

Source: Boston Edison Company

TABLE 10

COSTS FOR 1 PHASE UNDERGROUND TRANSFORMERS *

Point Estimates

K V A	$	$/KVA
15	468.37	31.2
25	557.42	22.3
37 1/2	606.00	16.2
50	557.46	11.1
75	892.27	11.9
100	1,053.46	10.5
167	1,672.56	10.0

*1973 Costs

$ Average Installed Costs

Source: Edward Gulachenski, New England Electric System

TABLE 11

COSTS FOR 1 and 3 PHASE UNDERGROUND DISTRIBUTION TRANSFORMERS*

Point Estimates

KVA	Ø	V_1/V_2	C_1	C_2	$\frac{S}{KVA}$	
100	1	120/240	1200	125	13.3	
112 1/2	3	240/480	1425	125	13.8	
112 1/2	3	120/280	1525	125	14.7	
112 1/2	3	277/480	1850	125	17.6	
150	3	240/480	2375	125	16.7	
225	3	240/480	2500	250	12.2	
225	3	120/208	3100	250	14.9	
300	3	240/480	2500	350	9.5	estimated
300	3	120/208	2775	350	10.4	
300	3	277/480	2775	350	10.4	
500	3	120/208	3475	350	7.7	
500	3	240/480	3300	350	7.3	
500	3	277/480	3475	350	7.7	
750	3	120/208	4000	350	5.8	
1000	3	240/480	4300	350	4.7	
1000	3	277/480	4400	350	4.8	

Ø - Number of Phases C_1 - Capital Cost

C_2 - Installation cost $S = C_1 + C_2$

*1973 Costs

Source: Boston Edison Company

TABLE 12

METERS COSTS

Point Estimates - $1973

	$
° Residential and Small Commercial Consumer (1)	
- Single-Phase meter (2)	25.00
- One hour demand meter (2)	69.36
° Large Commercial and Industrial Consumer (3)	
- Recording Demand meter	600.00
- Watt hour meter	200.00
- Potential Transformer	
Connected to 14 KV Line	244.00
Connected to 4 KV Line	150.00
- Current Transformer	
Connected to 14 KV Line	
Demand < 1000 KVA	210.00
~ 2500 KVA	226.00
Connected to 4 KV Line	
Demand ~ 200 KVA	150.00
° TOTAL	$1150-$1370

(1) Demand less than 48 KW

(2) Includes $6.50 for installation cost

(3) Installation cost of $50-100, per customer, not included

Source: Thomas Pearson, Boston Edison Company

TABLE 13