TRANCO:**A COMPUTER PROGRAM FOR ESTIMATING THE
COST OF ELECTRICAL POWER TRANSMISSION**

L. D. VAN HEES
E. L. KELLEY, JR.

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TABLE OF CONTENTS

LIST OF FIGURES	v
LIST OF TABLES	v
INTRODUCTION	1
SUMMARY	1
DISCUSSION	3
Transmission System Capital Cost.	3
General Transmission Line Cost Equation	5
Right-of-Way.	5
Material	6
Labor	8
Specific Transmission Line Capital Cost	9
Transmission Facilities	9
Compensation Networks	10
Terminal Equipment	10
Transmission Facilities Capital Cost Breakdown	12
Power Transmission Cost	14
Annual Expenses	14
Operating and Maintenance Cost	15
Line Losses	15
Interest and Depreciation	17
Taxes.	19
Line Capability and Line Factor	19
Power Transmission Cost Expression	21

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LIST OF FIGURES

		<u>Page</u>
1	Map of United States Showing 9 Geographic Regions	4
2	Series Compensation Costs	11
3	Cost of Terminal Equipment	13
4	Transmission Line Losses	16

LIST OF TABLES

I	Right-of-Way Costs Per Acre in the Program	6
II	Geographic Material Cost Indices and Escalation Factors for Nine Regions of U.S.*	7
III	Geographic Labor Cost Indices and Escalation Factors for the Nine Regions of the U.S.*	9
IV	Line Length Limits for Various Voltages	17
V	Interest Rates	18
VI	Life of System	19
VII	Two-Dimensional Array to Select the Proper Sinking Fund Factor	20
VIII	System Capabilities	21

TRANCO: A COMPUTER PROGRAM FOR ESTIMATING THE COST
OF ELECTRICAL POWER TRANSMISSION

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INTRODUCTION

The cost of electrical power transmission is usually approximately 10% of the total cost of power delivered to the consumer. Although the transmission costs less than either the generation or distribution, it is significant enough to affect powerplant siting and electrical system planning. For this reason, it is desirable to have available the means to predict with reasonable accuracy the cost of power transmission.

Capital costs of electrical power transmission systems depend on the system voltage, type of terrain, year of construction, interest rate, geographic location, economic life, and a number of less important variables. Included in the capital cost are the transmission line and transmission facilities. The annual cost of power transmission is derived by combining the yearly operating expenses and capital cost. The unit transmission costs are, of course, a function of the energy transmitted over the system.

The computer program described in this report not only estimates the capital cost, annual expenses and transmission cost of transmission systems, but escalates these costs to the projected construction year which makes it of greater use in electrical system planning.

SUMMARY

A computer program has been developed to estimate the cost of electrical power transmission with the line voltage, type of terrain, date of construction,

interest rate, geographic location and economic life of the system treated as variables. Characteristics of thirty transmission systems under construction or which have been placed in operation across the United States since 1965 were investigated and typical lines were picked for 230 KV, 345 KV and 500 KV. From these data an equation was developed relating the costs of transmission lines as a function of voltage and is expressed as:

$$ATCC = \left[56,000 \left(\frac{KV}{500} \right) + 10,000 + RW \right] 1.15$$

where

ATCC = 1966 U.S. average transmission line cost per mile

KV = voltage of the system in KV

RW = cost of right-of-way per mile

and

1.15 = indirect cost factor.

The average transmission line cost per mile is broken down into material and labor in order to localize to a given region and escalate properly for the year of construction. Each of these items is broken down into a fixed expense, which is the same for all voltages, and an expense that varies with voltage. Right-of-way costs are figured on a per acre basis.

Curves were drawn to relate the 1966 U.S. average transmission facility expenses for transmission systems of different voltage levels. Equations were derived from these data. Costs were broken down into the necessary components to allow escalation to be calculated.

The program, from the input data of line voltage, type of terrain, construction date, interest rate, economic life and geographic location, calculates

the capital cost, annual operating expenses, and transmission cost for the system with costs escalated to the year of construction.

Two test cases were run, and the results agreed within 5.1% of the actual published costs.

DISCUSSION

TRANCO is written to estimate the cost of electrical power transmission with line voltage, terrain, date of construction, interest rate, geographic location and economic life of the system treated as variables. Included in the transmission system are the transmission line and transmission facilities.

Transmission System Capital Cost

Characteristics of transmission systems under construction or placed in operation since 1965 were investigated,⁽¹⁾ and typical lines were picked for 230 KV, 345 KV and 500 KV - the three most popular voltages in use. Equations were derived to relate the costs of transmission lines of voltages over this range to the costs of a 500 KV line. A limited amount of information was available on 765 KV lines, but the relationship appears to hold at this voltage. Included in the capital cost of a transmission system are the costs of the transmission line and transmission facilities. The last item includes the terminal equipment and compensation network.

In order to properly calculate and escalate capital costs of the transmission system, the costs are broken down into material, labor and equipment. Material and labor both must be localized to and escalated according to one of the nine regions of the U.S.⁽²⁾ as shown on Figure 1. Equipment expenses are considered to be the same throughout the U.S. and are broken down into factory labor and factory material. These costs are then escalated according to a national escalation factor.

FIGURE 1
Map of United States Showing 9 Geographic Regions

General Transmission Line Cost Equation

The capital cost of transmission lines was found to vary according to

$$ATCC = \left[56,000 \left(\frac{KV}{500} \right) + 10,000 + RW \right] 1.15$$

where

ATCC = 1966 U.S. average transmission line cost per mile

KV = voltage of system in KV

RW = right-of-way cost per mile

and

1.15 = indirect cost factor.

For the convenience of the reader in following the development of the derivatives, a foldout sheet on Page 23 has been provided with definitions of all the symbols used in this report.

The above equation is a general expression of the 1966 U.S. average transmission line cost based on thirty transmission systems investigated. In the following sections, this expression is broken down into equations for material, labor and right-of-way, and with the exception of right-of-way, they are localized to a given region and escalated to the year of construction. These components are then recombined in order to find the total cost for a given region and construction year.

Right-of-Way - The right-of-way expense includes the costs for the use of the land and for clearing the right-of-way. The width of the right-of-way ranges from 125 ft for a 230 KV line to 225 ft for a 765 KV line, and was found to vary as:

$$\text{width} = \left(\frac{KV}{500} \right)^{0.432} \times 175 \text{ feet}$$

By knowing the width of the right-of-way, the number of acres and the total right-of-way expense per mile can be found if the per-acre cost of land is known.

By using information received from electric utilities across the U.S., approximations were made to meet different right-of-way conditions. Four values were chosen ranging from 300 dollars per acre for unused level land to 2,400 dollars per acre for extremely rough terrain or highly populated land. The land values and the corresponding computer call numbers are shown in Table I. Any one (or a combination) of the four values can be used in the program or, if the actual land value is known, it can be used in the program as an alternate. If several different known values are to be used, these values can be averaged according to the number of miles of each. This average and the total number of miles is then used in the program.

TABLE I
RIGHT-OF-WAY COSTS PER ACRE IN THE PROGRAM

<u>NUMR</u>	<u>Cost Per Acre</u> <u>(dollars)</u>
1	300
2	600
3	1500
4	2400

Material - Included in the cost of material is a portion which is constant for lines of all voltages and a portion which varies with the voltage. The fixed expense covers the cost of fill for access roads, fencing for right-of-way, etc. The variable expense covers the actual material for construction

of the line. Material costs vary over a wide range for transmission lines of the same voltage depending on the type and weight of towers used, type and number of conductors, number of insulators and arrangement adopted. For the use in TRANCO, material expenses were based on the most popular equipment used for lines of each of the three reference voltages. In the case of the 500 KV line, the towers were steel - weighing about 21,000 pounds apiece. Two 1780 ACSR (aluminum cable steel reinforced) conductors per phase (six total) were assumed. The 1966 U.S. average cost for material for a transmission line of a given voltage is found from:

$$ACM = 35,000 \left(\frac{KV}{500} \right) + 6000 \text{ dollars per mile}$$

To adjust this cost to a given region, this value is multiplied by a geographic construction material cost index PM. The United States is divided into nine regions⁽²⁾ as shown on Figure 1 and the construction material cost index for each region can be found on Table II. These regional costs are derived from 1966 cost data by:

$$CM = (ACM) (PM).$$

TABLE II

GEOGRAPHIC MATERIAL COST INDICES AND
ESCALATION FACTORS FOR NINE REGIONS OF U.S.*

<u>Region</u>	<u>PM</u>	<u>C</u>
1	1.0342	0.02195
2	1.0616	0.02165
3	1.0137	0.02527
4	1.0000	0.02514
5	1.0034	0.02689
6	0.9863	0.02684
7	0.9932	0.02666
8	0.9212	0.02729
9	0.9769	0.02656

* See Figure 1

This 1966 cost can then be escalated to the year of construction by using the escalation factor C, for each region (also given in Table I) as:

$$CM_x = CM (1+(C)(X))$$

where

CM_x = material cost for given year and region

and

X = number of years to be escalated (Year-1966)

The values of PM and C for the nine regions are in the program and only the number of the region as shown on Figure 1 must be submitted as input.

Labor - The cost of labor is made up of a fixed cost which is the same for transmission lines of all voltages, and a variable cost which changes with the voltage. The fixed portion is labor cost for roads, fencing, etc., with the variable portion being for the actual construction of the line. The U.S. average labor cost for a transmission line based on 1966 data varies according to

$$ACL = 20,500 \left(\frac{KV}{500} \right) + 4,000 \text{ dollars per mile}$$

The U.S. average can then be adjusted to a given region as shown on Figure 1 and escalated to a given year according to

$$CL_x = (ACL) (PL) (B)^x$$

where

CL_x = labor cost for given year and region

PL = geographic labor cost index

B = geographic labor cost escalation factor

and

X = number of years to be escalated (Year-1966).

The values of PL and B for the nine regions can be found in Table III. In most cases the workers to perform the labor on a transmission system will come from the cities in that region. Therefore, the values for PL and B were found by averaging the values of PL and B from the cities in that specific region.⁽²⁾ The proper values of PL and B are selected by submitting the number of the desired region in the program.

Specific Transmission Line Capital Cost - The direct cost of the transmission line for a given year and location is given by:

$$TCCDIR = RW + CM_x + CL_x.$$

Cost data available from electric utilities across the U.S. show that indirect expenses come to about 15% of the direct costs. Therefore, the total capital cost of the transmission line is given by:

$$TCC = 1.15 TCCDIR.$$

TABLE III

GEOGRAPHIC LABOR COST INDICES AND ESCALATION FACTORS
FOR THE NINE REGIONS OF THE U.S.*

<u>Region</u>	<u>PL</u>	<u>B</u>
1	1.15	1.0620
2	0.88	1.0649
3	0.69	1.0468
4	0.96	1.0473
5	1.03	1.0517
6	0.69	1.0602
7	0.61	1.0660
8	1.09	1.0465
9	0.94	1.0480

* See Figure 1

Transmission Facilities

Transmission facility costs are made up of the compensation network and terminal equipment expenses.

Compensation Networks - Included in the cost of compensation networks are the costs of series capacitors and shunt reactors. Compensation is not necessary for transmission lines of less than several hundred miles^(3,4) and will be ignored for most transmission lines for which this program will be used. The use of series capacitors increases the capability of a line of a given length, or increases the distance which a given load can be transmitted. Shunt reactors are used to limit the voltage and improve the stability of long transmission lines.

The National Power Survey⁽³⁾ was used to predict the cost of compensating networks. Prices were adjusted to 1966 and the curves were drawn on Figure 2. Straight line approximations were drawn for the curves, and the cost, using the approximated straight lines, was found to vary according to:

$$CC = \left[\left(\frac{KV}{500} \right)^{1.835} \times .041 \right] + \left[\frac{M_T - 200}{780} \times .00808 \right] \left[M_T - 200 \right] \times 10^6$$

where

CC = compensation cost

M_T = total mileage of line.

Terminal Equipment - The terminal equipment includes the transformers to step the voltage up from generation level to transmission level and down to subtransmission level, with all necessary connections and breakers. The generation level is assumed to be 20 KV and the subtransmission level is assumed to be 230 KV. In the case of a transmission voltage of 230 KV, the subtransmission level is assumed to be 115 KV. Assumption of a subtransmission level of other than 230 KV or 115 KV would have little effect on the cost of power transmission because the differences in the costs for circuit breakers and transformers will tend to offset each other.

FIGURE 2
Series Compensation Costs

The costs of the substations include transformers, circuit breakers, etc. Also included is the cost for the site, site development and indirect expenses. The National Power Survey⁽³⁾ was used to find the 1966 U.S. average cost for several voltages. From this information the curve on Figure 3 was drawn. The equation for this curve was found to be:

$$TEC = \left[12.41 \left(\frac{KV}{500} \right)^2 - 12.55 \left(\frac{KV}{500} \right) + 4.64 \right] \times 10^6$$

where

TEC = 1966 U.S. average terminal equipment cost (dollars).

Transmission Facilities Capital Cost Breakdown - The total U.S.

average cost of transmission facilities for 1966 is:

$$TF = CC + TEC$$

where

TF = 1966 U.S. average transmission facilities cost.

Included in TF are costs for material, labor, equipment, other direct construction costs and all indirect costs. Based on the National Power Survey,⁽³⁾ the indirect costs were found to average 21% of the total cost. In order to localize and escalate with respect to a specific region, the direct cost must be calculated and subdivided into construction material, construction labor and equipment costs. The total 1966 U.S. average direct cost for transmission facilities is given by:

$$TFDIR = .79 TF$$

Equipment costs, as stated previously, are broken down into factory labor and factory material and are escalated according to national escalation factors.⁽²⁾ The total direct cost was broken down with the aid of information

FIGURE 3
Cost of Terminal Equipment

supplied by construction firms and power utilities, and were then localized and escalated as follows:

$$TFCM_x = .06 \text{ TFDIR (PM) (1 + (C)(X)) construction material}$$

$$TFCL_x = .14 \text{ TFDIR (PL) (B)^X construction labor}$$

$$TFFM_x = .40 \text{ TFDIR (1 + .0254 (X)) factory material}$$

$$TFFL_x = .40 \text{ TFDIR (1.0363)^X factory labor}$$

where PM, C, PL and B are found in Tables II and III.

Each of these costs are direct expenses for a given region and year of construction, and they are combined to find the total direct cost. As stated previously, 21% of the total capital cost is for indirect expenses. From this fact and the fact that the total capital cost is equal to the sum of the direct and indirect expenses, it was found that the indirect expenses were equal to 27% of the direct expenses and

$$TFCC = 1.27 (TFCM_x + TFCL_x + TFFM_x + TFFL_x)$$

where

TFCC = transmission facilities cost for a given region and year
in dollars.

Power Transmission Cost

The annual transmission cost was found by deriving an equation for the yearly expenses. The unit transmission cost is a function of the amount of energy transmitted per year.

Annual Expenses

Annual expenses which must be considered are operation and maintenance, line losses, interest, depreciation and taxes. Also necessary are the line capability and line factor.

Operating and Maintenance Cost - In this program the annual operating and maintenance expenses are assumed to be 1% of the total capital cost of the transmission system. This assumption is based on information obtained from electric utilities and the National Power Survey.⁽³⁾

Line Losses - Transmission line loss curves for 345 KV, 500 KV and 700 KV⁽³⁾ are shown plotted on Figure 4 along with the straight-line approximations. These curves are based on 100% annual line factor. Using the straight-line approximations, the line losses in KW vary according to:

$$LL = .174 \left(\frac{KV}{500} \right) \times 10^3 \times M_T$$

where

M_T = total length of the line.

This equation is based on a load of 100% capability. It is assumed that the voltage of the system is kept relatively constant, and the load is delivered at a unity power factor. Therefore, the power transmitted is directly proportional to the current flow in the system. A system carrying 100% capability the year round would be carrying full load or 100% current, and would have a line factor of 1.

$$LF = \frac{\text{average system power}}{\text{system capability}}$$

where

LF = line factor.

A system operating at 50% capability the year round then, would be carrying one-half of full load or 50% current, and would have a line factor of 50%. Under these assumptions the line factor is directly proportional to the percentage of full load current. Since the major portion of line losses

FIGURE 4
Transmission Line Losses

are $I^2 R$ losses, and the system power is kept as close to a constant as possible the year round, the line losses are assumed to be proportional to the square of the line factor. Therefore, the cost of power losses in the system is given by:

$$CLL = 8260 (LL) (LF)^2 (CNVTR) \times 10^{-3}$$

where

CLL = annual cost of line losses in dollars

8760 = hours in a year to convert to KWHR

and

CNVTR = cost of power losses in mills/kW-hr.

This equation will give close approximation for line loss expenses as long as the line length does not exceed the limits shown in Table IV and noted on Figure 4.

TABLE IV

LINE LENGTH LIMITS FOR VARIOUS VOLTAGES

<u>Voltage (KV)</u>	<u>Limit (Miles)</u>
230	500
345	650
500	750
700	1000

If known, the unit power cost for calculating the cost of line losses can be used as input. If unknown, the program will assign a value of 4 mills/kW-hr.

Interest and Depreciation - It is assumed in TRANCO that bonds will be issued to finance the construction of the transmission system. At

the end of each year during the life of the system an interest payment must be made to the bond holders. At the end of the life of the system, the bonds will be redeemed in full. An interest rate from 3% to 9% in jumps of 1/2% can be chosen in the program by submitting the number JCOIN, corresponding to the desired interest rate as shown on Table V.

TABLE V
INTEREST RATES

<u>JCOIN</u>	<u>Interest Rate (%)</u>
1	3
2	3 1/2
3	4
4	4 1/2
5	5
6	5 1/2
7	6
8	6 1/2
9	7
10	7 1/2
11	8
12	8 1/2
13	9

The interest rate picked from Table V will be used in calculating the interest payment each year, but a sinking fund factor based on an interest rate of 1% less will be used to calculate the depreciation. The reasons for this is that the amount set aside for depreciation is calculated on the basis that this money will be drawing interest for the remaining life of the system. In most cases the interest drawn will be less than the interest paid out. The proper sinking fund factor for the life of the system can be picked by submitting the proper number KCODE corresponding to the life of the system as shown in Table VI.

TABLE VI
LIFE OF SYSTEM

<u>KCODE</u>	<u>Life</u>
1	25
2	30
3	35
4	40
5	45
6	50
7	55
8	60
9	65
10	70
11	75

Table VII shows the two-dimensional array which is in the program to select the sinking fund factor corresponding to the proper numbers JCOIN and KCODE.

Taxes - Investigation, backed by the National Power Survey,⁽²⁾ has shown that taxes for investor-owned utilities can be estimated as 2.5% of the total capital cost of the system. This value or any other value desired should be entered in fraction form as input.

Line Capability and Line Factor - Line capabilities for the typical lines covered by this program vary approximately as the square of the voltage.^(5,6)

$$CAP = \left(\frac{KV}{500} \right)^2 \times 10^3 \text{ MW}$$

The capability for the four main voltage levels used in this report are shown in Table VIII.

TABLE VII
TWO-DIMENSIONAL ARRAY TO SELECT THE
PROPER SINKING FUND FACTOR

<u>Life</u> <u>Years</u>	<u>2%</u>	<u>2 1/2%</u>	<u>3%</u>	<u>3 1/2%</u>	<u>4%</u>	<u>4 1/2%</u>	<u>5%</u>	<u>5 1/2%</u>	<u>6%</u>	<u>6 1/2%</u>	<u>7%</u>	<u>7 1/2%</u>	<u>8%</u>
25	.03122	.02928	.02743	.02567	.02401	.02244	.02095	.01955	.01823	.01698	.01581	.01471	.01368
30	.02465	.02278	.02102	.01937	.01783	.01639	.01505	.01381	.01265	.01158	.01059	.00967	.00883
35	.02000	.01821	.01654	.01500	.01358	.01227	.01107	.00997	.00897	.00806	.00723	.00648	.00580
40	.01656	.01484	.01326	.01183	.01052	.00934	.00828	.00732	.00646	.00569	.00501	.00440	.00386
45	.01391	.01227	.01079	.00945	.00826	.00720	.00626	.00543	.00470	.00406	.00350	.00301	.00259
50	.01182	.01026	.00887	.00765	.00655	.00560	.00478	.00406	.00344	.00291	.00246	.00207	.00174
55	.01014	.00865	.00735	.00621	.00523	.00439	.00367	.00305	.00254	.00210	.00174	.00143	.00118
60	.00877	.00735	.00613	.00509	.00420	.00345	.00283	.00231	.00188	.00152	.00123	.00099	.00080
65	.00763	.00628	.00515	.00419	.00339	.00273	.00219	.00175	.00139	.00110	.00087	.00069	.00054
70	.00667	.00540	.00434	.00346	.00275	.00217	.00170	.00133	.00103	.00080	.00062	.00048	.00037
75	.00586	.00465	.00367	.00287	.00223	.00172	.00132	.00101	.00077	.00058	.00044	.00033	.00025

TABLE VIII

SYSTEM CAPABILITIES

<u>System Voltage (KV)</u>	<u>System Capability (MW)</u>
230	211
345	476
500	1000
700	1960

Any desired line factor can be used in the program, but if none is specified the program will assign a value of 0.7.

Power Transmission Cost Expression - The cost of power transmission is given by:

$$TC = \frac{(OAM + CLL + DEP + INT + TAXES)}{8760 \text{ CAP} \times LF}$$

where

OAM = operation and maintenance cost per year
 CLL = line loss costs per year
 DEP = depreciation cost per year
 INT = interest cost per year
 TAXES = tax cost per year
 CAP = capability in KW
 LF = line factor.

The transmission cost is given in mills/kW-hr.

RESULTS

For the convenience of the reader, instructions for the use of TRANCO are in Appendix I. Two test cases were run using TRANCO and the capital

cost of the transmission lines agreed within 5.1% of the actual cost. The test case using the TVA line from Johnsonville, Tennessee to the Arkansas state line is presented in Appendix II. The capital cost of this line calculated by TRANCO was \$14,202,000 compared with the published cost of \$14,170,000.⁽⁷⁾ Although this represents an error of only 0.2%, this close approximation is fortuitous. Included in the published cost of the transmission line was one-half of the expense of crossing the Mississippi River, which is not considered in the program. It was anticipated that the capital cost would be 2 to 3% higher because the line was under construction during the period from the fall of 1963 to the spring of 1965, and the program calculations are based on and calculated from 1966 data. The above mentioned extra cost has offset the lower cost of construction prior to 1966. The other test case was run for a Bonneville Power Administration line; the calculated transmission line cost was 5.1% higher than the actual cost. The latter was the cost as of December 1967 when the line was essentially completed but not all costs were recorded. Any additional costs that may be added in later will tend to decrease the difference in the two costs. In Appendix II the cost of power transmission can be noted. There was no published cost for comparison, but from all available information the cost appears to be a close approximation.

On the basis of these two successful test runs it is felt that the program will give good approximations of capital costs and power transmission costs and project these costs several years into the future. However, the labor, material, and equipment localization and escalation figures in the program should be reviewed periodically and adjusted as necessary to keep the program updated.

LIST OF VARIABLES

ATCC	1966 U.S. average transmission line cost per mile
KV	system voltage in KV
RW	right-of-way cost per mile
ACM	1966 U.S. average transmission line material cost per mile
CM	1966 U.S. transmission line material cost for a given region
PM	geographic construction material cost index
CM _x	transmission line material cost for given year and region
C	geographic construction material cost escalation index
X	number of years to be escalated (year-1966)
ACL	1966 U.S. average transmission line labor cost per mile
CL _x	transmission line labor cost for a given year and region
PL	geographic labor cost index
B	geographic construction labor cost escalation factor
TCCDIR	direct capital cost per mile of transmission line for given year and region
CC	1966 U.S. average compensation cost
M _T	total mileage of the line
TEC	1966 U.S. average terminal equipment cost
TF	1966 U.S. average transmission facilities cost
TFDIR	1966 U.S. average direct cost of transmission facilities
TFCM _x	direct cost of transmission facilities construction material for year and region
TFCL _x	direct cost of transmission facilities construction labor for year and region
TFFM _x	direct cost of transmission facilities factory material for year and region
TFFL _x	direct cost of transmission facilities factory labor for year and region
TFCC	transmission facilities cost for given region and year
LL	line losses for system
LF	line factor
CLL	annual cost of line losses in dollars
CNVT	cost of energy losses in mills per KWH
OAM	annual cost of operation and maintenance
DEP	annual depreciation expense
INT	annual interest cost
TAXES	annual cost of taxes
CAP	capability of system in KW

REFERENCES

1. L. M. Olmsted and A. J. Stegeman, "EHV Today's Design, Tomorrow's Plans," Electrical World, 95-118, November 15, 1965.
2. T. A. Shank, E. L. Kelley and J. B. Burnham, "CAPCOST: A Program to Calculate Escalated Nuclear Power Plant Capital Costs," Pacific Northwest Laboratory, Richland, Washington, to be issued.
3. Subcommittee of the Generating Stations Special Technical Committee, C. P. Gamble, Chairman, National Power Survey, 1964, Vols. I and II.
4. G. D. Brewer and others, "The Use of Series Capacitors to Obtain Maximum EHV Transmission Capability," IEEE Transactions 1090-1102, November 1964.
5. H. D. Carey, "EHV Substation Equipment Challenges Both Designer and Manufacturer," Power Engineering, 58-60, December 1965.
6. H. P. St.Clair and E. L. Peterson, "System Economics of Extra-High-Voltage Transmission," AIEE Transactions, 841-851, Vol. 70 1951.
7. K. B. Metcalf, Jr., "Details on One of TVA's First EHV Transmission Lines: Johnsonville-Memphis," Power Engineering, 50-51, September 1967.
8. K. M. Klein. Unpublished Data. Bonneville Power Administration, December 1967. (Personal communication)

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BNWL-743

APPENDIX I

APPENDIX ITRANCO INPUT INSTRUCTIONS

<u>Card Number</u>	<u>Columns</u>	<u>Format</u>	<u>Code Name</u>	<u>Comments</u>
1	1-72	(12A6)	BCD	Any BCD (comment to be written out) information describing the run.
2	1-5	I5	IYEAR	Year of proposed construction.
	6-10	I5	NREG	Number of geographical regions the line will cross.
	11-15	I5	JCOIN	Reference number (1-9) to select proper interest rate. (See Table V).
	16-20	I5	KCODE	Reference number (1-11) to select economic life of system. (See Table 6).
3	1-10	E10.4	FKV	System voltage.
	11-20	E10.4	FLF	Line factor. (If none is given code will use 0.7).
	21-30	E10.4	CNVTR	Cost of line losses in mills/kW-hr. If none are given, code will use 4.0.
	31-40	E10.4	RWC	Actual cost of right of way. (If this is not known, approximations can be selected on card number 4.) If approximations on card 4 are used, leave blank.
	41-50	E10.4	TM	Total miles of line. If approximations on card 4 are used, leave blank.
	51-60	E10.4	TAX	Fraction of total capital cost for taxes. (Suggested value for investor-owned utilities 0.025).
4*	1-5	I5	NUMR	Geographical region number for this line set.

* NOTE: One of these cards must be used for each geographical region the line goes through. (See NREG.)

APPENDIX I (continued)

<u>Card Number</u>	<u>Columns</u>	<u>Format</u>	<u>Code Name</u>	<u>Comments</u>
4 *	6-15	E10.4	RMILES(1)	Miles of line with right-of-way costs at \$300.00 per acre.
	16-25	E10.4	RMILES(2)	Miles of line with right-of-way costs at \$600.00 per acre.
	26-35	E10.4	RMILES(3)	Miles of line with right-of-way costs at \$1500.00 per acre.
	36-45	E10.4	RMILES(4)	Miles of line with right-of-way costs at \$2400.00 per acre.

BNWL-743

APPENDIX II

PROGRAM TRANCO OUTPUT

RUN ON TVA JOHNSONVILLE TO ARKANSAS STATE LINE TRANSMISSION LINE.

LINE CHARACTERISTICS

VOLTAGE = 5.00000+02 KV.
 CAPABILITY = 1.00000+03 MW.
 CONSTRUCTION YEAR = 1966
 GEOGRAPHIC REGION NUMBER = 6
 LINE FACTOR = 7.000+01 PERCENT
 LENGTH = 155.0 MILES
 TERRAIN NUMBER

	(NO. 1)	(NO. 2)	(NO. 3)	(NO. 4)
MILES OF EACH TERRAIN	.0	118.0	.0	37.0
RIGHT OF WAY COST PER ACRE (DOLLARS)	3.000+02	6.000+02	1.500+03	2.400+03
ACTUAL RIGHT OF WAY COSTS (DOLLARS) =	-0.00000			

ECONOMICS DATA

INTEREST RATE = 4.500+00 PERCENT *
 LIFETIME = 50 YEARS *
 UNIT COST OF LINE LOSSES = 4.00000+00 MILLS/KWHR *

CALCULATED CAPITAL COSTS (DOLLARS)

TRANSMISSION LINE = 1.42022+07
 TRANSMISSION FACILITIES = 4.31519+06
 TOTAL CAPITAL COST = 1.85174+07

ANNUAL EXPENSES (DOLLARS)

OPERATION AND MAINTENANCE = 1.85174+05
 TAXES = 0.00000 *
 INTEREST = 8.33284+05
 DEPRECIATION = 1.41658+05
 LINE LOSSES = 4.63064+05

COST OF POWER TRANSMISSION = 2.64707-01 MILLS/KW.HR.

* Input Data Estimated by Authors.

APPENDIX II

-29-

BNWL-743

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00100      1*      C      PROGRAM TRanco
00101      2*      DIMENSION BCD(12)
00103      3*      DIMENSION B(9),PL(9),PM(9), C(9), RW(4),RMILES(4), COIN(13),
00103      4*      1CODE(13,11),LIFE(11)
00104      5*      DATA (COIN(J), J=1,13) /
00104      6*      1.030,.035,.040,.045,.050,.055,.060,.065,.070,.075,.080,.085,.090 /
00106      7*      DATA (( CODE(J,K), J=1,13),K=1,9 ) / .03122,.02928,.02743,
00106      8*      1.02567,.02401,.02244,.02095,.01955,.01823,.01698,.01581,
00106      9*      2.01471,.01368,.02465,.02278,.02102,.01937,.01783,.01639,
00106     10*      3.01505,.01381,.01265,.01158,.01059,.00967,.00883,.02000,
00106     11*      4.01821,.01654,.01500,.01358,.01227,.01107,.00997,.00897,
00106     12*      5.00806,.00723,.00648,.00580,.01656,.01484,.01326,.01183,
00106     13*      6.01052,.00934,.00828,.00732,.00646,.00569,.00501,.00440,
00106     14*      7.00386,.01391,.01227,.01079,.00945,.00826,.00720,.00626,
00106     15*      8.00543,.00470,.00406,.00350,.00301,.00259,.01182,.01026,
00106     16*      9.00887,.00765,.00655,.00560,.00478,.00406,.00344,.00291,
00106     17*      A.00246,.00207,.00174,.01014,.00865,.00735,.00621,.00523,
00106     18*      B.00439,.00367,.00305,.00254,.00210,.00124,.00143,.00118,
00106     19*      C.00877,.00735,.00613,.00509,.00420,.00345,.00283,.00231,
00106     20*      D.00188,.00152,.00123,.00099,.00080,.00763,.00628,.00515,
00106     21*      E.00419,.00339,.00273,.00219,.00175,.00139,.00110,.00087,
00106     22*      F.00069,.00054 /
00110     23*      DATA (( CODE(J,K), J=1,13),K= 10,11) /
00110     24*      1 .00667,.00540,.00434,.00346,.00275,.00217,
00110     25*      2.00170,.00133,.00103,.00080,.00062,.00048,.00037,.00586,
00110     26*      3.00465,.00367,.00287,.00223,.00172,.00132,.00101,.00077,
00110     27*      4.00058,.00044,.00033,.00025 /
00112     28*      DATA (B(I),I=1,9) / 1.062, 1.0649, 1.0468, 1.04729, 1.0517,
00112     29*      1 1.0602, 1.0660, 1.0465, 1.0480 /
00114     30*      DATA (PL(I),I=1,9) / 1.15, 0.88, 0.69, 0.96, 1.03, 0.69, 0.61,
00114     31*      1 1.09, 0.94 /
00116     32*      DATA (PM(I),I=1,9) / 1.0342, 1.0616, 1.0137, 1.0000, 1.0034,
00116     33*      1 0.9863, 0.9932, 0.9212, 0.9760 /
00120     34*      DATA (C(I),I=1,9) / 0.02195, 0.02165, 0.02527, 0.02514, 0.02689,
00120     35*      1 0.02684, 0.02666, 0.02729, 0.02656 /
00122     36*      DATA (RW(I),I=1,4) / 300.0, 600.0, 1500.0, 2400.0 /
00124     37*      DATA (LIFE(K),K=1,11) / 25,30,35,40,45,50,55,60,65,70,75 /
00124     38*      C
00124     39*      C
00126     40*      READ (5,1010) BCD
00134     41*      1010 FORMAT ( 12A6)
00135     42*      READ (5,1001) IYEAR,NREG,JCOIN,KCODE
00143     43*      1001 FORMAT (4I5)
00144     44*      READ (5,1011) FKV,FLF,CNVTR,RWC,TM,TAX
00154     45*      1011 FORMAT (6E10.4)
00155     46*      IF( FLF) 15,10,15
00160     47*      10 FLF = .7

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00161 48* 15 CONTINUE
00162 49* FLF1 = FLF * 10.0 **2
00163 50* RRV = FKV / 500.0
00164 51* RRV1 = RRV * 35500.0 + 6000.0
00165 52* RRV2 = RRV * 20500. + 4000.0
00166 53* RRV3 = RRV ** 1.835 * .041
00167 54* RRV4 = RRV * RRV * 10.0 ** 6
00170 55* RRV5 = RRV ** .432 * 21.21
00171 56* J = IYEAR - 1966
00172 57* CAP1 = RRV4 * 10.0 ** -3
00173 58* TTCC = 0.0
00174 59* AMILES = 0.0
00174 60* C LCOP TO CALC. TOTAL CAPITAL COST.
00175 61* DO 50 N =1,NREG
00200 62* READ (5,1000) NUMR, (RMILES(I),I=1,4)
00207 63* 1000 FORMAT (I5,4E10.4)
00210 64* TOTM = TM
00211 65* IF (TOTM) 17,17,23
00214 66* 17 DO 20 L = 1,4
00217 67* 20 TOTM = TOTM + RMILES(L)
00221 68* 23 IF (TOTM - 220.0) 25,25,30
00224 69* 25 TEST1 = 0.0
00225 70* RMLS = 0.0
00226 71* GO TO 35
00227 72* 30 RMLS = TOTM - 220.0
00230 73* TEST1 = (RMLS/760.0) * 0.00806
00231 74* 35 CONTINUE
00232 75* CM = (RRV1 * PM(NUMR)) * (1.0 + C(NUMR) * J)
00233 76* CL = RRV2 * PL(NUMR) * (B(NUMR)) ** J
00234 77* AMILES = AMILES + TOTM
00235 78* TCC = 0.0
00235 79* C CALC. MILAGE COST FOR EACH REGION IN PROBLEM.
00236 80* IF (RWC) 37,40,37
00241 81* 37 RW1 = RRV5 * RWC
00242 82* TCC = TCC + (RW1 + CM + CL) * 1.15 * TOTM
00243 83* GO TO 51
00244 84* 40 DO 50 K = 1,4
00247 85* RW1 = RRV5 * RW(K)
00250 86* TCC = TCC + (RW1 + CM + CL) * 1.15 * RMILES(K)
00251 87* 50 CONTINUE
00254 88* 51 CONTINUE
00255 89* TFC = (((12.41 * RRV * PKV) - (12.55 * RRV) + 4.64) + ((RRV3 +
00255 90* 1TEST1) * RMLS)) * 10.0 ** 6
00255 91* C INSERT NO. 1
00256 92* TFD1R = .79* TFC
00257 93* TFCM = .06 * TFD1R * PM(NUMR) * (1. + C(NUMR) * J)
00260 94* TFCL = .14 * TFD1R * PL(NUMR) * (B(NUMR)) ** J
00261 95* TFCM = .40 * TFD1R * (1. + .0254 * J)
00262 96* TFCL = .40 * TFD1R * (1.0363 ** J)

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00263 97*      TFCC = (TFCM + TFCL + TFFM + TFFL) * 1.27
00263 98*      C      END INSERT NO. 1
00264 99*      FLF1 = FLF * 10.** 2
00265 100*     TTCC = TTCC + TCC + TFCC
00266 101*     IF (CNVTR) 65,60,65
00271 102*     60 CNVTR = 4.0
00272 103*     65 CONTINUE
00273 104*     CNVTR1 = CNVTR * 10.0 ** -3
00274 105*     RINT = COIN(JCOIN) * 100.0
00275 106*     FLL = (( RKV * .174) * AMILES * 10.0**3 * 8760.0) * CNVTR 1*FLF**2
00276 107*     OAM = .01 * TTCC
00277 108*     DEP = CODE(JCOIN,KCODE) * TTCC
00300 109*     FINT = COIN(JCOIN) * TTCC
00301 110*     TAXES = TAX * TTCC
00302 111*     CAP = RKV4 * 8760.0
00303 112*     CAP1 = RKV4 * 10.** -3
00303 113*     C      CALC TC IN MILLS/KWR
00304 114*     TC = (( OAM + FLL + DEP + FINT + TAXES) * 10.0 **3) / (FLF * CAP)
00305 115*     WRITE (6,2000) BCD
00313 116*     2000 FORMAT ( 23H1 PROGRAM TRANCO OUTPUT // 10X, 12A6 )
00314 117*     WRITE (6,2001) FKV, CAP1, IYEAR, NUMR, FLF1, TOTM, (RMILES(I),I=1,
00314 118*     14),(RW(I),I=1,4),RWC
00335 119*     2001 FORMAT ( /// 30H      LINE CHARACTERISTICS // 15X, 9HVOLTAGE
00335 120*     1= 1PE12.5, 4H KV./ 15X,12HCAPABILITY = 1PE12.5, 4H MW. / 15X,
00335 121*     220HCONSTRUCTION YEAR = 14, / 15X,27HGEOGRAPHIC REGION NUMBER = ,
00335 122*     3 I2 / 15X, 13HLINE FACTOR = 1PE10.3, 8H PERCENT / 15X, 8HLENGT
00335 123*     4H =0PF6.1, 6H MILES / 15X, 14HTERRAIN NUMBER , 29X, 47H(NO. 1)
00335 124*     5 (NO. 2) (NO. 3) (NO. 4) // 15X,21HMILES OF EACH TERR
00335 125*     6AIN 25X, F6.1,6X,F6.1,7X,F6.1,7X,F6.1 / 15X, 36HRIGHT OF WAY COST
00335 126*     7 PER ACRE (DOLLARS) , 6X, 4(1PE10.3,3X) /
00335 127*     8 15X, 37HACTUAL RIGHT OF WAY COSTS (DOLLARS) = 1PE12.5 )
00336 128*     WRITE ( 6,2002) RINT, LIFE(KCODE),CNVTR
00343 129*     2002 FORMAT (/// 24H      ECONOMICS DATA // 15X, 15HINTEREST RATE
00343 130*     1 = 1PE10.3, 8H PERCENT / 15X, 10HLIFETIME = 15, 6H YEARS /
00343 131*     2 15X, 26HUNIT COST OF LINE LOSSES = 1PE12.5, 11H MILLS/KWHR )
00344 132*     WRITE (6,2003) TCC, OAM, TFCC, TAXES,TTCC,FINT, DEP, FLL
00356 133*     2003 FORMAT (/// 44H      CALCULATED CAPITAL COSTS (DOLLARS), 22X,
00356 134*     1 25HANNUAL EXPENSES (DOLLARS) // 15X 19HTRANSMISSION LINE = ,
00356 135*     2 1PE12.5, 24X, 27HOPERATION AND MAINTENANCE = 1PE12.5 / 15X,
00356 136*     3 25HTRANSMISSION FACILITIES = 1PE12.5, 18X, 7HTAXES =,1PE12.5 /
00356 137*     4 15X, 20HTOTAL CAPITAL COST = 1PE12.5, 23X, 10HINTEREST = 1PE12.5
00356 138*     5 / 70X, 14HDEPRECIATION = 1PE12.5 /70X,13HLINE LOSSES = 1PE12.5 )
00357 139*     WRITE (6,2004) TC
00362 140*     2004 FORMAT (//// 33H      COST OF POWER TRANSMISSION = 1PE12.5, 13H MI
00362 141*     1LLS/KW.HR. )
00363 142*     STOP
00364 143*     END

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