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Functional and Economic Considerations of an Electrical Line Feeding Large Concentration Loads

Seth O. Lewis

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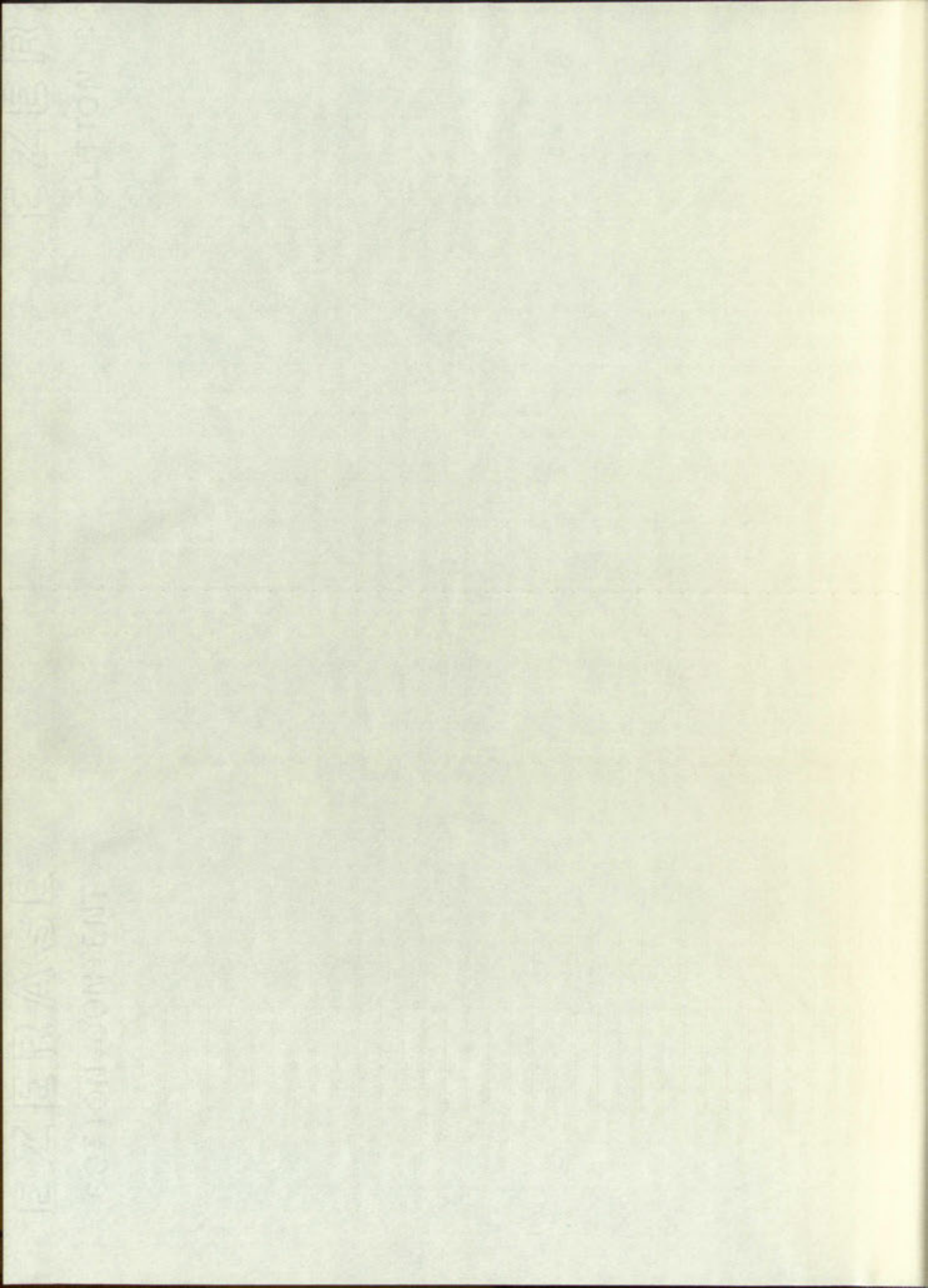


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FUNCTIONAL AND ECONOMIC CONSIDERATIONS OF
AN ELECTRIC LINE FEEDING LARGE CONCENTRATED LOADS

By

Seth O. Lewis

A Thesis

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Electrical Engineering

The University of New Mexico

1960

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This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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May 9, 1960

Date

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M.A. in the Department of
University of California, Los Angeles

DATE OF SUBMISSION

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1950

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PREFACE

University graduate work in the electrical power field is seldom attempted today because extensive research is needed to fulfill the nation's requirements for elaborate radar and communication networks. It is even difficult for a University to offer enough credit hours in electrical power for one to achieve a Master's Degree because the enrollment in such courses is too small to meet minimum requirements. The growth of the power companies in the United States, however, has equaled or surpassed that of most concerns in this country. This growth has accompanying problems which require a higher level of education than that provided by a Bachelor of Science Degree. The companies in some cases have paid a higher cost than was necessary for their systems, without a higher or better performance, because their engineers lacked the knowledge afforded by University graduate work. A better educational background may equip the engineer with the knowledge and methods of deriving much greater long-range economy and better system performance for his electrical system.

One of the problems encountered by the author while working as assistant planning engineer for an electrical utility company was the selection, without extensive computations and graphs, of an economic system of supplying load and also the most economical size of a transmission line conductor. A knowledge of methods to determine

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MEMO

University Graduate School, the Graduate School, and the
College of Arts and Sciences, have been established today.
The Graduate School is the nucleus of the university's
graduate education. It is even more important than the
College of Arts and Sciences in that it is the only place
where the enrollment in each department is kept to a minimum.
The growth of the Graduate School is the result of the
university's expansion and the need for a higher level of
graduate education. This growth has been rapid and has
exceeded the level of education in other parts of the
country. The expansion in the Graduate School is a result
of the need for a higher level of education and the
need for a higher level of research. The Graduate School
has been established to meet these needs and to provide
a higher level of education and research. The Graduate
School is the nucleus of the university's graduate
education and is the only place where the enrollment
in each department is kept to a minimum.

One of the primary responsibilities of the Graduate School
is to provide a high level of education and research. The
Graduate School is the nucleus of the university's
graduate education and is the only place where the
enrollment in each department is kept to a minimum.
The Graduate School is the nucleus of the university's
graduate education and is the only place where the
enrollment in each department is kept to a minimum.

and/or improve line performance was also required. This thesis has been prepared to give an engineer that information, which he would usually get only on a graduate level in a University, necessary to determine the economical method of supplying load and of determining transmission line performance. An original method has been developed which will tell the engineer very quickly, with little calculating and no graphs, the conductor size that will give him the most overall economy for a transmission line.

The author is indebted to the engineers and administrators of the Public Service Company of New Mexico for their suggestions and for the use of the company's name in the illustrative problem in Chapter IV. The assistance and critical analysis of Rex A. Tynes of the Public Service Company has been particularly helpful. The aid of Daniel P. Sheldon in developing and checking the various formulas was appreciated. Gratitude is expressed also to Ahmed Erteza and E. L. Jordan, Staff Members of the Electrical Engineering Department at the University of New Mexico, for their patience, cooperation, and adept guidance during the development of this thesis.

and/or improve line performance was also required. This study has been prepared to give an engineer that information, which is usually not available, on a grade's level in a University, necessary to determine the statistical method of applying that method of determining transmission line performance. An original method has been developed which will tell the engineer very quickly, with little calculation and no graphs, the number, size and type of lines that will give the best overall economy for a transmission line.

The author is indebted to the engineers and administrators of the Public Service Company of New Jersey for their suggestions and for the use of the company's name in the title of this report in Chapter IV. The statistics and material given in the Appendix of the Public Service Company has been particularly helpful. The aid of Daniel P. Shultz in developing and checking the various formulas was appreciated. Credits in various ways to the author and E. J. Larkin, Chief Engineer of the Electrical Engineering Department at the University of New Jersey, for their criticism, suggestions and helpful assistance during the development of this thesis.

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..... New lines
..... Present and projected loads
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..... Additional generating capacity
..... Power of the Northwest
..... Plans
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CHAPTER I

INTRODUCTION

The electrical power companies of the United States have experienced an average annual load growth of six and eight-tenths per cent during the last twenty-five years. In the rapidly growing southwestern United States the growth has varied from nine to twelve per cent and the growth of electrical load in the Albuquerque, New Mexico, area has increased annually at the average rate of eleven and two-tenths per cent for the past several years. This growth has required the power companies to continuously increase their generating capacities. Due to the remoteness of fuel and water sources, the generating plants have often been located at distances far from the loads to be served and long transmission lines have been required to transfer the power from the remote power plants to the load locations. The characteristics of the transmission lines have been determined to provide satisfactory service conditions and to achieve the most economical transmission of power.

This paper discusses the considerations required for selecting particular characteristics of the line and presents an original method of obtaining the most economical solution. A typical problem at the Public Service Company of New Mexico is solved to illustrate the usefulness of this method.

REPORT

APPENDIX

The electrical power system of the United States is a complex system which has developed over a period of many years. It is a system which has grown in size and complexity as the needs of the country have increased. The system is a result of the efforts of many individuals and organizations who have worked to improve the efficiency and reliability of the power supply. The system is a result of the efforts of many individuals and organizations who have worked to improve the efficiency and reliability of the power supply. The system is a result of the efforts of many individuals and organizations who have worked to improve the efficiency and reliability of the power supply.

This report discusses the various aspects of the electrical power system. It covers the generation, transmission, and distribution of electricity. It also discusses the various types of power plants and the different methods of generating electricity. The report also discusses the various types of transmission lines and the different methods of distributing electricity. The report also discusses the various types of electrical equipment and the different methods of maintaining and repairing this equipment.



CHAPTER II

GENERAL FUNCTIONAL AND ECONOMIC CONSIDERATIONS
FOR NEW TRANSMISSION LINESA. Voltage

The first alternating current line over which power was transmitted was constructed in Italy in 1886. The line operated at 2,000 volts, it was seventeen miles long, and it was built to transmit 150 horsepower.¹

Transmission voltages have progressively increased and today transmission lines exist which operate at 380,000 volts.² Experimental lines have been built to study operating voltages up to 500,000 volts³ and the General Electric Company is constructing an experimental line to test operating voltages up to 750,000 volts.⁴

In selecting the transmission voltage, consideration must be

¹C. A. Powel et al., Electrical Transmission and Distribution Reference Book (3d ed.; East Pittsburgh, Pennsylvania: Westinghouse Electric and Manufacturing Company, 1944), p. 4.

²George V. Boll, "Extra High Voltage Transmission on 3 Continents," Elec. World, v. CXLIX, (May 26, 1958), pp. 356-359.

³L. M. Robertson, "High Altitude 500 KV Corona Tests in Colorado," Elec. Engr., v. LXXVI, #4, (April, 1957), pp. 286-293.

⁴P. A. Abetti, "Project EHV," Elec. Engr., v. LXXVII, LXXVIII, (August, 1958), pp. 669-673.

given to the existing and probable future voltages in the vicinity of the line to be built. These considerations may be as important a factor as line losses or voltage regulation. The advantage of being able to interconnect adjoining power districts at a common voltage may outweigh a choice of voltage based on lowest immediate cost. If the contemplated transmission line is remote from any existing system, a complete study of all factors may be required to select the voltage. The initial and operating cost which corresponds to various voltages and various conductor sizes and types may be tabulated to select the most economical voltage.

A committee formed jointly by the National Electric Light Association and the National Electrical Manufacturers' Association published a report in 1930 which recommended "preferred voltages."⁵ The electrical manufacturers have standardized their equipment on these preferred voltages since 1930, and equipment for other voltages is usually more costly.

B. Conductor Size and Type

The type and size of the conductor for a planned transmission line will depend to a large extent on the voltage that is to be used. If the voltage is to be selected on the basis of a connection to an

⁵Powel, loc. cit.

given to the existing and proposed lines...
of the line to be built...
a factor as the losses in the line...
being able to determine the...
voltage may occur...
cost. If the...
existing system...
before the...
to various...
lated to...
A...
and the...
published a report...
The electrical...
these...
is...
B. Construction...
The...
line will...
If the...

Total... 377

existing line, it is important that the operating voltage be established before other planning is done or calculations are commenced. The minimum conductor resistance may then be calculated from the fixed charges on the line, and the allowable line loss. This calculation, and an example of it, is explained further in Chapter III of this Thesis.

The contour of the land will usually determine the length of spans in a transmission line. The length of spans may then be used to select the type of conductor, copper or ACSR, but the type will generally be determined on a "cost per unit resistance" basis.⁶ The calculation referred to in the previous paragraph may be required for each type of conductor considered.

If the transmission line is not to be connected to existing lines, the most economical conductor size for each operating voltage which is considered can be decided by using the formulas developed in Chapter III. If more than one type of conductor is investigated, the least expensive conductor size for each type can be found by the same formulas.

C. Load Characteristics

Before any transmission line can be built or even planned, the characteristics of the load to be served must be determined in

⁶"Cost per unit resistance" means the cost of losses due to resistance in a mile of conductor.

existing time, it is important to have a clear understanding of the
limited nature of the available data and the extent to which the
The minimum number of samples required for a given study is
fixed largely on the basis of the standard deviation of the
factor, and on the basis of the desired accuracy of the estimate
of the mean.

The extent of the data available for a given study is
often in a limited form. The number of samples available may be
to select the type of experiment, a given factor, or a given
generally its determination is based on the standard deviation of the
estimate of the mean for the factor, and on the desired accuracy of
for each type of experiment.

If the results of the experiment are to be used for
then, the more economical method is to use a smaller number of
which is considered to be a more reliable estimate of the mean
in Chapter III. It may be seen from the above that the
the least expensive method is to use a smaller number of samples
used for this purpose.

3. Local Characteristics

Before any measurements are made it is important to know
the characteristics of the material to be measured. It is
the most important factor in the selection of the method of
measurement.

order that load capacity for the line can be established. If load characteristics cannot be determined in advance of construction, then they must be estimated. The most economical line can be found normally for only one set of load characteristics. When these characteristics change, a new set of computations must be made.

1. Load Size and Growth

The load size is defined as the peak demand which will occur for a given line. The life of a planned transmission line and the maximum load to be served by the line during its lifetime are estimated in order that load capacity for the line can be established. The future load is calculated by projection of past peaks to a future date corresponding to the lifetime of the line. For example, if a hypothetical load had annual peaks from 1940 to 1958 as shown in the following table, either a curve could be drawn or a "compound interest" formula might be written to estimate future loads as given for the years 1960 to 1964.

TABLE 1
PAST AND PREDICTED PEAK LOAD, HYPOTHETICAL CASE

| Year | Peak Load, kw | Year | Peak Load, kw |
|------|---------------|------|---------------|
| 1940 | 1000 | 1954 | 2580 |
| 1942 | 1150 | 1956 | 2960 |
| 1944 | 1310 | 1958 | 3380 |
| 1946 | 1500 | 1960 | 3880 |
| 1948 | 1720 | 1962 | 4440 |
| 1950 | 1970 | 1964 | 5080 |
| 1952 | 2250 | | |

order that the...
 characteristics...
 must be...
 only for...
 tables...

1. Load Size and...

The load size is defined as...
 for a given...
 maximum load...
 stated in order...
 The future load...
 data corresponding...
 hypothetical load...
 following table...
 formula which is...

TABLE I

PARTIAL LIST OF...

| Year | Load Size, lb | Load Size, lb | Load Size, lb |
|------|---------------|---------------|---------------|
| 1930 | 1000 | 1000 | 1000 |
| 1931 | 1100 | 1100 | 1100 |
| 1932 | 1200 | 1200 | 1200 |
| 1933 | 1300 | 1300 | 1300 |
| 1934 | 1400 | 1400 | 1400 |
| 1935 | 1500 | 1500 | 1500 |
| 1936 | 1600 | 1600 | 1600 |
| 1937 | 1700 | 1700 | 1700 |
| 1938 | 1800 | 1800 | 1800 |
| 1939 | 1900 | 1900 | 1900 |
| 1940 | 2000 | 2000 | 2000 |

The formula would appear as follows:

$$i = \left[\left(\frac{A}{P} \right)^{1/n} - 1 \right] (100\%)$$

where

- i = per cent of annual load increase
- P = load at a given time
- n = number of years from the time of P to the year in which A occurred.
- A = load after a number of years, n.

The compound interest formula has become widely used by the electric power companies of the United States to estimate future loads. In some instances, however, the growth of a company may be found to vary considerably from this formula. In these instances it is necessary to consider special influences, both past and present, which have affected the load growth and to use skill and judgment from direct experience in establishing a reasonably accurate "trend" of the future growth. The experiences of most electric power companies in the United States, however, have empirically proved the validity of the compound interest formula for estimating future loads. When this method is used, the per cent rate of growth may be found by selecting any two known peaks and substituting in the formula. If the years 1944 and 1950 were selected from the above table, the substitution would be made as follows:

P = 1310; A = 1970; and n = 6 years

$$i = \left[\left(\frac{1970}{1310} \right)^{1/6} - 1 \right] (100\%) = 7 \text{ per cent increase per year}$$

The formula which appears is follows:

$$z = \left[\frac{W}{V} \left(\frac{1}{z} \right) \right]^{1/2}$$

where

- z = per cent of annual load increase
- W = load of a given year
- V = number of years over which the load is taken A is constant
- A = load after a number of years, z

The expected interval between load increases is

electric power companies of the United States business

in some instances, however, the amount of a load of any given year

very considerably from the load of the previous year.

It is possible to estimate the load of any given year

have affected the load of the previous year.

need experience in which the load of the previous year is

future years. The number of years over which the load is

the United States, however, the amount of a load of any given year

the expected interval between load increases is

this method is used to estimate the load of any given year

selecting any two years which are available in the

the years 1911 and 1912 were selected from the load of the

selection would be made as follows:

$$z = \left[\frac{W}{V} \left(\frac{1}{z} \right) \right]^{1/2}$$

$$z = \left[\frac{W}{V} \left(\frac{1}{z} \right) \right]^{1/2}$$

When the above method of estimating loads is used, a history three times as long as the estimated future should be used, if possible. If a lesser period is used, an inaccurate estimate may result from unusual business conditions. For example, estimates of peak electrical loads for the City of Albuquerque for the five year period 1950-1955 would have proven too high if the estimates were made from the load experience of the period 1945-1950. Albuquerque experienced an unusual surge in electrical demand during the last half of the 1940's and this surge would have been reflected in the 1950's estimates. If, however, the 1950-1955 loads were estimated from a formula or curve developed for the period 1935 to 1950, the estimated loads would have closely approximated the actual loads.

2. Load Factor

The load factor is defined, for the purposes of this Thesis, as the fraction of full load that the line carries. The load factor can be found for any period of time such as a day, month, or year; but the annual load factor is of more interest in a transmission line economic analysis. The annual load factor for a transmission line is found by dividing the load, in kilowatt-hours, transmitted in one year by the product of the line capacity, in kilowatts, and the number of hours in a year. For a new line the kilowatt-hours transmitted can only be approximated, but some data is usually available for making reasonably accurate estimates. The past load experience of a

When the above method of analysis is applied to the data
three times as long as the original series, the results are
shown. It is found that the results are very similar to those
from annual business statistics. The results are shown in the
electrical loads for the city of Chicago for the year 1950-1955
1950-1955 would have proved to be the same as the results shown
the load statistics of the city of Chicago. The results are shown
an unusual surge in electrical load. The results are shown in
1950's and this surge would have been expected to be the same
series. It is found that the results are very similar to those
and it is found that the results are very similar to those
loads would have shown a similar trend.

3. Load Factor

The load factor is defined as the ratio of the average
as the fraction of the total load which is used during the
can be found for any period of time. The results are shown
has the annual load factor. The results are shown in the
economic analysis. The results are shown in the
found by dividing the total load by the number of hours in the
year by the product of the number of hours in the year. The
per of hours in the year. The results are shown in the
ted can only be approximated, but the results are shown in
making research and development. The results are shown in

company will give an indication of the load that may be transmitted over the line. The planned operating procedure of the company must then be the primary consideration. Economics may indicate that the major block of power demand can be served from the new line and other facilities be used only for peak load demands. The cost per kilowatt-hour at the load bus will prove whether this plan is more economical or whether the new line should be used primarily for peak demands.

3. Reliability Requirements

The reliability requirement of the load to be served is a primary concern of the transmission line designer. Some electrical loads cannot be dropped except under emergency conditions. Such loads may require stand-by generators, or they may require service from more than one transmission line. Two or more transmission lines from a remote site to such a load may not increase capacity but they do increase reliability.

A transmission line may be made very resistant to outages caused by adverse weather conditions such as wind, ice, lightning, etc. Two overhead ground wires and sufficient lightning arrestors will prevent most outages caused by lightning. Increased conductor spacing, guy wires at all points of stress, short span lengths, ice removal equipment, and over-size construction materials will avert outages caused by ice and wind. To include all of these devices into a single transmission line would cause the cost of the line to

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outgoing will give satisfaction of the...
over the first...
then be...
major block of...
facilities be used...
hour at the...
on whether...

3. Reliability

The...
primary concern...
loads cannot be...
may require...
than one...
tracks also...
therefore...

A...
caused by...
etc. Two...
will prevent...
question, the...
removal...
outages...
a single...

00

1940

approximate the cost of two separate lines without the devices. Two lines would provide greater assurance of continuous service than the one expensive line. A line outage is usually caused by a local condition such as a weak point in a conductor or lightning striking a line. Even if two separate lines are physically close together the lightning would strike only one of them at a particular time. An outage caused by a lightning strike would normally be corrected and the line would be restored to service before the second line could be struck by lightning. In a similar manner, if ice caused a conductor to break, it is unlikely that the two lines would have a conductor weak point at the same geographical location. Adverse weather at a conductor weak point on one line would cause service on only that one line to be interrupted. The two separate lines would also give protection from load interruptions caused by adverse conditions such as floods, snow slides, and crashes of mechanized equipment, i.e., airplanes, automobiles, etc. Loop feeds are presently being utilized by many companies when more than one line is required to a particular point. Transmission lines in the loop feed configuration, although starting and ending at the same points, may be separated by several miles. This type of system would further increase reliability by eliminating the possibility of one event, such as extreme ice loading or an airplane crash, causing two lines to be put out of service.

CHAPTER III

ECONOMIC MAXIMUM RESISTANCE

Present practice in the electric power industry is to select a desirable conductor size for the anticipated load and to make a cost analysis of different generation and transmission methods on the basis of that one conductor. A method, which as far as is known is original with the author, is presented in this chapter to determine that conductor size which will give equal cost at the load point for different generation locations. An original method to determine the most economical conductor size is also presented.

Kelvin's law for the most economical conductor states, "The most economical area of conductor is that for which the annual cost of energy wasted is equal to the interest on that portion of the capital outlay which may be considered as proportional to the weight of conductor used."¹ The formulas in this chapter may be considered an extension of this law with the inclusion of other cost factors such as maintenance, taxes, etc. The formulas presented here may also be considered as reducing this law to the solution for only one value, a value which will establish a conductor size of maximum economy. Another formula given here makes the "equal cost" conductor size, described in the above paragraph, easily attainable.

The method presented in this chapter will have the following

¹A. E. Knowlton (ed.), Standard Handbook for Electrical Engineers (New York: McGraw-Hill, 1949), p. 1173.

THEORY OF THE...

Recent advances in the theory of the...
 a detailed analysis of the...
 the basis of the...
 is obtained when...
 nine last...
 point for...
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advantages: (1) The economic feasibility of remote generation can be quickly determined. (2) That conductor size which will give equal load center power cost for generation at a remote site or at the load center is readily ascertained. This conductor size will generally represent the minimum size conductor for a transmission line from the remote site. (3) That conductor size which will provide the most economy may be quickly computed.

The cost of power generation at a remote site must be less than the generation cost at the load center to make the remote generation plan feasible. The difference in cost is used to determine the minimum and the most economical size conductor which may be used for the transmission line. All cost factors of the line must be included to make the computations realistic, however. These factors are: (1) maintenance cost of the line; (2) cost of line power losses; and (3) fixed charges on the cost of the line. These charges include interest, taxes, profit, etc.

With these factors an equation may be established for the total cost at the load center of power generated at a remote location.

$$T = S + M + L + F$$

where

T = total cost per kilowatt-hour at the load center for power generated at a remote location.²

²Definitions of all symbols in the formulas of this chapter are given in Appendix I.

advantages: (1) The concrete contains a large percentage of
 so quickly substituted. (2) The concrete is a very light
 equal to other forms of concrete, and is a very light weight
 the load capacity, usually a minimum. The concrete is a
 generally preferred, the minimum also depends on the
 line from the center line. (3) The concrete is a very light
 side the most readily substituted.

The cost of concrete is a factor which must be
 than the concrete cost of the other forms of concrete.
 than other forms. The minimum is a factor which must be
 minimum and the most economical form of concrete is the
 the minimum line. All other forms of concrete are a
 to take the same form of concrete, the cost is a factor

- (1) substituted concrete is a factor which must be
 and (2) substituted concrete is a factor which must be
 other factors, such as, etc.

With other factors substituted, the cost is a factor
 total cost of the concrete is a factor which must be
 than.

$1 = 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10 + 11 + 12 + 13 + 14 + 15 + 16 + 17 + 18 + 19 + 20$
 where
 $1 = 2000 \text{ lbs. per sq. ft.} \times 100 \text{ sq. ft.} = 200,000 \text{ lbs.}$
 $2 = 2000 \text{ lbs. per sq. ft.} \times 100 \text{ sq. ft.} = 200,000 \text{ lbs.}$
 $3 = 2000 \text{ lbs. per sq. ft.} \times 100 \text{ sq. ft.} = 200,000 \text{ lbs.}$

The minimum of all the forms of concrete is a factor
 are given in Appendix I.

- S = generation cost per kilowatt-hour at the remote site
 M = total transmission line maintenance cost per kilowatt-hour
 L = cost of transmission line power losses per kilowatt-hour
 F = cost of fixed charges on the transmission line per kilowatt-hour

The last two parts, L and F, of the equation contain variables. The power losses, L, will vary with the resistance of the conductor and the fixed charges, F, will vary with the size of the conductor. If these two parts could be made to contain the same variable, the equation could be solved for that particular variable which would make the load center power cost the same for generation at either location. Also, with only one variable in the equation, the cost could be differentiated with respect to that variable and the most economical conductor size could be found.

The cost in dollars of line losses per kilowatt-hour is expressed as

$$\text{Cost of losses} = \frac{3 I^2 R H S (10^{-3})}{Y}$$

where

- I^2 = average of the current squared over a year
 R = total resistance of line per phase
 H = number of hours per year
 S = generation cost per kilowatt-hour at remote site
 Y = total kilowatt-hours transmitted per year

The only variables in the equation are R, the resistance, and I, the current. The resistance will be found in formulas developed in a later part of this chapter. The current is the square root of the mean squares of the current, and thus is dependent on the form of

- 1 - Total number of specimens
- 2 - Total number of specimens in each lot
- 3 - Total number of specimens in each lot (continued)
- 4 - Total number of specimens in each lot (continued)
- 5 - Total number of specimens in each lot (continued)

The first part of the report is a general description of the power factor, which will vary with the number of specimens in the three groups. It will vary with the number of specimens in these two groups and will be related to the number of specimens in each of the three groups. The first part of the report is a general description of the power factor, which will vary with the number of specimens in the three groups. It will vary with the number of specimens in these two groups and will be related to the number of specimens in each of the three groups. The first part of the report is a general description of the power factor, which will vary with the number of specimens in the three groups. It will vary with the number of specimens in these two groups and will be related to the number of specimens in each of the three groups.

July 27, 1955

- 1 - Total number of specimens
- 2 - Total number of specimens in each lot
- 3 - Total number of specimens in each lot (continued)
- 4 - Total number of specimens in each lot (continued)
- 5 - Total number of specimens in each lot (continued)

The only variation in the number of specimens in each lot is the number of specimens in each lot. The number of specimens in each lot is related to the number of specimens in each lot. The number of specimens in each lot is related to the number of specimens in each lot. The number of specimens in each lot is related to the number of specimens in each lot.

the load curve. The load curve is not accurately described by the load factor, but over a limited area and period of years the ratio of the kilowatt-hours to the kilowatt peak varies with the load factor.³ Such a relation is generally determined empirically. By using the load factor relation the current can be considered a constant for the computation of line losses.

The annual fixed charges on the cost of a transmission line are ordinarily listed as a percentage of the total original cost of that line. If a transmission line cost D dollars per mile to build, and the line is Z miles long, the annual fixed charges in dollars, X , on the line are

$$X = (K) (D) (Z),$$

where K is the fraction of the original cost which the annual fixed charges represent.

The cost per mile, D , in the above equation can be considered in two parts: (1) the cost of the line less conductor and (2) the cost of the conductor. The above equation then becomes

$$X = KZ (B+3E)$$

where B is the cost per mile of the line less conductor and E is the cost of the conductor per mile per phase.

The cost of the line, less conductor, will include rights-of-way, pole line structures, lightning protection, and labor costs. These costs have been found to be nearly constant for all sizes of

³Knowlton, loc. cit.

the load curve. The load curve is the graph of the
load factor, but with a load factor of 1.0 at the
of the highest-peak load. The load factor is the
cor. Such a load factor is a load factor of 1.0.
Using the load factor, the load factor is a load
stands for the maximum load factor.
The actual load factor is a load factor of 1.0.
and ordinary load factor is a load factor of 1.0.
that line. If a load factor of 1.0 is a load factor
and the line is a load factor of 1.0, the load factor
I, on the line is a load factor of 1.0.

$$I = \frac{L}{L_0} \quad (1)$$

where L is the load factor, L_0 is the load factor
changes respectively.
The load factor, L , is the load factor of the load
in two parts: (1) the load factor of the load
cost of the load factor. The load factor is a load factor

$$L = L_0 \quad (2)$$

where L_0 is the load factor of the load factor, L is the
cost of the load factor, L_0 is the load factor.
The cost of the load factor, L , is the load factor
way, both like structures, including overhead, and
these costs are used for the load factor of the load

conductors.⁴ Some companies with favorable land contours and weather conditions have found the cost of the line-less-conductor to actually decrease with increased conductor size.⁵ The decrease was realized from the fewer number of support structures required for the larger conductor. The larger the conductor the greater its mechanical strength. If the land contour will permit longer spans, and if the wind force and ice loading do not require additional mechanical strength, the cost of the line-less-conductor may be made less for larger conductors by increasing the average span length. Some areas which experience high winds and ice loading will require additional mechanical strength with increasing conductor size because the larger conductor area will raise the wind and ice forces on the structures. The cost of the increased mechanical strength for these cases are offset by the longer spans and the cost of the line-less-conductor becomes nearly a constant for all sizes of conductor.

⁴J. M. Henderson and A. J. Wood, "Conductor Economics on High Voltage Transmission System," Power Apparatus and Systems, (New York: A.I.E.E., Aug., 1957). The authors of this article prepared curves for lines with steel tower supports but stated that the curves were ". . . also representative of those obtained with other construction types such as . . . wood pole, etc.". The curves presented in the article show an increasing total line cost for rising conductor cost but the increase is due to the larger conductor and not to the structure for the conductor.

⁵Ralph G. Yerk, "Transmission Design and Construction," a paper presented to the Tulsa Section of the American Institute of Electrical Engineers, Nov. 20, 1947.

condition. The first part of the paper is devoted to a
discussion of the general principles of the theory of
the function of the function. The second part is devoted
to a discussion of the function of the function. The
third part is devoted to a discussion of the function
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the function. The tenth part is devoted to a
discussion of the function of the function.

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Geological Survey
Washington, D. C.
1911

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Geological Survey
Washington, D. C.
1911

In those cases where larger conductor sizes require additional mechanical strength the additional cost may be represented as a percentage of the conductor price. That is, the conductor price may be multiplied by a constant which will reflect the change in price of transmission line structures as the conductor size changes. The cost of the line-less-conductor would still be treated as a constant in this case. An alternate to this procedure would be to multiply the cost of the transmission line structures by a factor which represents the increase in structure price as the conductor size increases. Either of these methods could be included in the formulas in the remainder of this chapter. The formulas have been developed, however, without including either of these factors due to the reasons given in the above paragraph.

The cost on the conductor will vary because the fixed charges will increase as the conductor size increases. The cost per mile per phase of the conductor, E , may be equated as

$$E = W \text{ (pounds per mile)}$$

where W = conductor cost per pound.

Since the cost per pound for a conductor is approximately the same for all sizes of wire, the only variable in the formula is the pounds per mile. The pounds per mile will vary directly with the size of the conductor. If this variable and the line loss variable in the equation on page 12 can be made the same, then the formula on page 11 can be solved for that conductor size which will make the load center

In these cases the first part of the equation is a function of the second part, and the second part is a function of the first part. This is a typical example of a system of equations where the variables are interdependent. The first part of the equation is a function of the second part, and the second part is a function of the first part. This is a typical example of a system of equations where the variables are interdependent. The first part of the equation is a function of the second part, and the second part is a function of the first part. This is a typical example of a system of equations where the variables are interdependent.

The same is true for the second part of the equation. The first part of the equation is a function of the second part, and the second part is a function of the first part. This is a typical example of a system of equations where the variables are interdependent. The first part of the equation is a function of the second part, and the second part is a function of the first part. This is a typical example of a system of equations where the variables are interdependent.

$$x = y + z$$

where x = constant part of the equation, y = variable part of the equation, and z = variable part of the equation. This is a typical example of a system of equations where the variables are interdependent. The first part of the equation is a function of the second part, and the second part is a function of the first part. This is a typical example of a system of equations where the variables are interdependent.

Thus the first part of the equation is a function of the second part, and the second part is a function of the first part. This is a typical example of a system of equations where the variables are interdependent. The first part of the equation is a function of the second part, and the second part is a function of the first part. This is a typical example of a system of equations where the variables are interdependent. The first part of the equation is a function of the second part, and the second part is a function of the first part. This is a typical example of a system of equations where the variables are interdependent.

cost the same for the two generation locations. The size which will be the most economical can also be found.

Appendix II shows that the weight multiplied by the resistance is approximately a constant for all conductors; i.e., the resistance varies inversely with the weight. For 30/7ACSR conductor the

$$(wt/mile/phase) \times (resistance/mile/phase) = 850 \text{ or } wt/phase/mile = \frac{850}{resistance/phase/mile} .$$

The cost per mile per phase of the conductor is $E = (W) \frac{(850)}{r}$ where r = resistance in ohms per mile per phase of the conductor. The annual fixed charge on the line, from the equation on page 13 is

$$X = (K) (Z) (B) + 3(K) (Z) (W) \frac{850}{r} .$$

The formula may be generalized by using the letter G to represent the constant of pounds/mile/phase to resistance/mile/phase. The formula then becomes

$$X = (K) (Z) (B) + \frac{3KZWG}{r} .$$

Dividing this value by Y , the total kilowatt-hours per year, will give the cost of the fixed charges per kilowatt-hour, F .

The maintenance cost, M , in the formula on page 11 is usually expressed as annual cost per mile. To get this in cost per kilowatt-hours the annual cost per mile is multiplied by the length of the line and divided by the kilowatt-hours per year. That is

$$M = \frac{mZ}{Y} \text{ where } m \text{ is the annual maintenance cost per mile.}$$

The formula on page 11 for the total cost per kilowatt-hour of power

cost the same for the first year, the second year, and the third year. The cost of the first year is \$100, the second year is \$100, and the third year is \$100. The total cost is \$300. The cost of the first year is \$100, the second year is \$100, and the third year is \$100. The total cost is \$300. The cost of the first year is \$100, the second year is \$100, and the third year is \$100. The total cost is \$300.

$$\frac{100}{100} = 1$$

The cost of the first year is \$100, the second year is \$100, and the third year is \$100. The total cost is \$300. The cost of the first year is \$100, the second year is \$100, and the third year is \$100. The total cost is \$300. The cost of the first year is \$100, the second year is \$100, and the third year is \$100. The total cost is \$300.

$$Y = (1) \cdot (1) + (1) \cdot (1) + (1) \cdot (1)$$

The formula for the total cost is $Y = (1) \cdot (1) + (1) \cdot (1) + (1) \cdot (1)$. The formula for the total cost is $Y = (1) \cdot (1) + (1) \cdot (1) + (1) \cdot (1)$. The formula for the total cost is $Y = (1) \cdot (1) + (1) \cdot (1) + (1) \cdot (1)$.

$$Y = (1) \cdot (1) + (1) \cdot (1) + (1) \cdot (1)$$

Dividing this value by 3, the total cost is \$100. The total cost is \$100. The total cost is \$100. The total cost is \$100. The total cost is \$100. The total cost is \$100. The total cost is \$100.

The total cost is \$100. The total cost is \$100. The total cost is \$100. The total cost is \$100. The total cost is \$100. The total cost is \$100. The total cost is \$100.

The formula for the total cost is $Y = (1) \cdot (1) + (1) \cdot (1) + (1) \cdot (1)$. The formula for the total cost is $Y = (1) \cdot (1) + (1) \cdot (1) + (1) \cdot (1)$. The formula for the total cost is $Y = (1) \cdot (1) + (1) \cdot (1) + (1) \cdot (1)$.

generated at a remote location may now be written as

$$T = S + M + L + F$$

$$T = S + \frac{mZ}{Y} + \frac{3I^2_{RHS} 10^{-3}}{Y} + \frac{KZB}{Y} + \frac{3KZWG}{Yr}$$

$$T = S + \left[\frac{(m + KB)}{Y} \right] Z + \frac{3}{Y} \left[I^2_{RHS} 10^{-3} + \frac{KZWG}{r} \right]$$

Only the last two parts of this equation contain variables.

If the total resistance of the line, R, is made equal to the resistance per mile, r, times the length of the line, then the third part of the equation becomes $\frac{3I^2_r ZHS10^{-3}}{Y}$ and the total equation becomes

$$T = S + \left[\frac{m + KB}{Y} \right] Z + 3 \frac{Z}{Y} \left[I^2_{rHS} 10^{-3} + \frac{KWG}{r} \right]$$

clearing the constants

$$T = S + \left[\frac{m + KB}{Y} \right] Z + \frac{3Z}{Y} \left[8.76I^2_{Sr} + \frac{KWG}{r} \right]$$

This equation contains only one variable, r. If the cost of power generation at the load center is greater than the cost at a remote site, the above equation may be set equal to the cost at the load center and the equality solved for r. With the solved value of r the conductor size which will give equal load center costs for the two generation locations will be found.

If the formula above is differentiated with respect to resistance and set equal to zero, that value of r which will identify

generated by a regular ...

$$T = S + U + V$$

$$T = S + U + V$$

$$T = S + U + V$$

only the last two terms of this expansion ...
If the total number of the ...
states per site ...
part of the expansion ...
becomes

$$T = S + U + V$$

$$T = S + U + V$$

This equation ...
generates ...
note also ...
least center ...
the condition ...
two generators ...
If the ...
states and ...

the most economical size of conductor will be found. The formula is differentiated as follows:

$$T = S + \frac{(m + K B)}{Y} Z + \frac{3Z}{Y} \left[I^2 r HS 10^{-3} + K W \frac{G}{r} \right]$$

$$\frac{dT}{dr} = \frac{3Z}{Y} \left[I^2 HS 10^{-3} - K (W) \frac{G}{r^2} \right]$$

Setting this equation equal to zero and solving for r

$$\begin{aligned} r &= \frac{1}{I} \sqrt{\frac{(K) (W) (G)}{HS 10^{-3}}} \\ &= \frac{0.338}{I} \sqrt{\frac{(K) (W) (G)}{S}} \end{aligned}$$

The resistance found by this formula represents the most economical resistance in ohms for the conductor in a transmission line. The resistance can be converted to conductor size by reference to Appendix II. The formula may be used for different types of conductors by using the proper value for G as found in Appendix II.

The most important part of the analysis is the

differentiation of the function

$$f(x) = \frac{1}{2} \ln \left(\frac{1+x}{1-x} \right) + \frac{1}{2} \arctan \left(\frac{x}{\sqrt{1-x^2}} \right)$$

$$\left[\frac{d}{dx} \left(\frac{1}{2} \ln \left(\frac{1+x}{1-x} \right) + \frac{1}{2} \arctan \left(\frac{x}{\sqrt{1-x^2}} \right) \right) \right]$$

Setting this equal to zero we find that

$$\frac{1}{2} \frac{1}{1-x^2} - \frac{1}{2} \frac{x}{1-x^2} = 0$$

$$\frac{1-x}{1-x^2} = \frac{x}{1-x^2}$$

The solutions to this equation are

which are the roots of the characteristic equation

The roots are $\pm \frac{1}{\sqrt{2}}$ and $\pm \frac{i}{\sqrt{2}}$

Appendix II. The characteristic equation of the

is given by $\lambda^2 + 2\lambda + 2 = 0$

CHAPTER IV

EXAMPLE OF FORMULAS FOR ECONOMIC CONDUCTOR SIZES

To illustrate the use of the formulas in the preceding chapter, a problem which applied to the Public Service Company of New Mexico will be solved. The solution is designed to illustrate the use of the formulas. Factors concerning future loads, material and labor costs, generation policy and generation costs which are not known to the author may change these final answers. To arrive at a final solution it would be necessary to include these factors and solve the formulas again. The following work will suffice to illustrate the usefulness of the formulas.

A. System of the Public Service Company of New Mexico

The Public Service Company of New Mexico now serves an interconnected electrical load which has an annual peak demand in excess of 125,000kw. It has transmission lines operating at 115,000 volts and it is interconnected with one private electric power company, three electric cooperatives, and the U. S. Bureau of Reclamation.

The company began operation as a subsidiary of the Cities Services Incorporated of New York, New York. Each city which now is a part of the Public Service Company of New Mexico formerly had its own generating plant and only part of them were interconnected. Generating plants were located at Las Vegas, Santa Fe, Bernalillo,

CORPORATION

BOARD

MEMORANDUM FOR THE BOARD

To illustrate the nature of the problem, it is pointed out that a provision which requires the Board to consider the use of the foundation, in addition to the other uses of the labor costs, is not a solution. It is known to the Board that the only way to solve the problem is to provide the foundation with a separate account. This will require the revision of the foundation's charter.

A. System of the Foundation's Charter

The Foundation's Charter is the only document which connects the Foundation with the Corporation. It is a document which is not only a legal instrument, but also a statement of the Corporation's policy. The current policy is to provide the Foundation with a separate account. This policy is based on the fact that the Foundation is a separate entity, and it is necessary to provide it with a separate account. The Corporation's policy is to provide the Foundation with a separate account, and this policy is based on the fact that the Foundation is a separate entity.

Albuquerque, Belen, and Deming. The loads were served in many instances directly from the generator bus without being transformed to a higher voltage. As the system grew, Belen, Albuquerque, and Santa Fe were interconnected with a 44,000 volt line.

Las Vegas was connected to the system in 1953 by a 115,000 volt line, but the line has been operated at 44,000 volts; the 44,000 volt operation will continue until the Las Vegas load increases. A USBR 115,000 volt line was connected to the Public Service Company of New Mexico at Albuquerque and at Deming in 1953. El Paso Electric Company is connected to the same 115,000 volt line.

Today the Public Service Company of New Mexico has four generating plants in operation. Three of the operating plants are located at Albuquerque: Prager, Person and Reeves Stations. The other operating plant is in Santa Fe. The company now transmits its large quantities of power over 115,000 volt lines. The 44,000 volt lines, which were originally the transmission lines, have been made a part of a subtransmission system. The 44,000 volt lines feed substations which step voltage down to the distribution voltage, 4,160 volts or 12,700 volts. The subtransmission system is used in both Albuquerque and Santa Fe. The 44,000 volt lines are still used as transmission lines for areas outside but proximate to the larger cities. The loads in these areas are not large enough to justify the 115,000 volt transmission line. Belen is connected to the Albuquerque system by two 44,000 volt lines; these lines form a loop feed to Belen.

CONFIDENTIAL

Albuquerque, Santa Fe, and Las Alamos, New Mexico, are the only...
stresses directly from the...
to a higher voltage...
Santa Fe was...
has been...
this line...
this operation...
USNR 115,000...
low losses...
density is...
Today...
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tion of power...
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Santa Fe...
these lines...

B. Planned Line

A generating plant which could utilize the cheap fuels in the northwest corner of New Mexico has been planned. To reach its heaviest load center the Public Service Company of New Mexico would have to build a transmission line from the generating plant to Albuquerque.

All transmission lines within the state of New Mexico are shown in Figure 1. The figure shows that the highest operating voltage in the state is 115,000 volts. The new line from the generating plant in northwestern New Mexico is drawn in to show its future place in the Public Service Company of New Mexico system. The line as drawn is approximately 120 miles long.

C. Present and Predicted Loads

A transmission line built from the Northwest area in New Mexico to the City of Albuquerque could serve other areas along the route of the line. The Public Service Company of New Mexico has not contracted to sell any power from such a line, however, so any loads that may be served can only be estimated. The planning for the transmission line should account for any loads of this nature which may occur. For the purpose of the problem two points called Point A and Point B have been selected and assigned load values which are typical for medium size New Mexico cities.

A gas engine which would be used in the
the normal number of gas engines has been
highest load during the winter months
have to build a gas engine that will be
durable.

All transmission lines which are shown
shown in Figure 1. The lines shown in the
village in the area is in 1923. The lines
also shown in Figure 2. The lines shown in
place in the public service system of
as shown in Figure 3.

6. Present and Proposed Lines

A transmission line which is shown in
to the City of Alameda and which is shown
the line. The public service system of
to sell any power that is produced
served can only be satisfied. The lines
should extend for any length of time
purpose of the public service system
been selected and installed. The lines
also New Mexico.

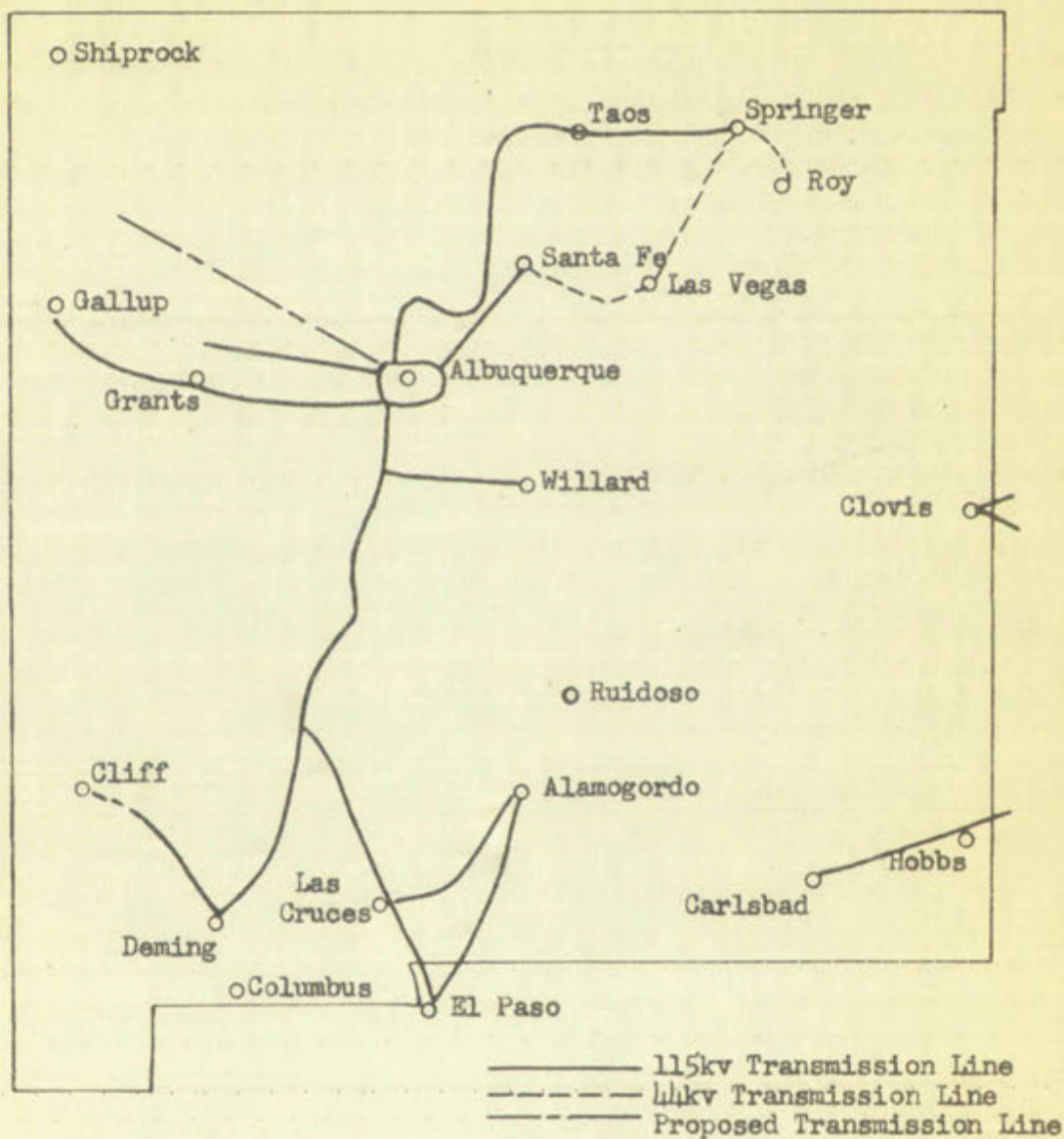
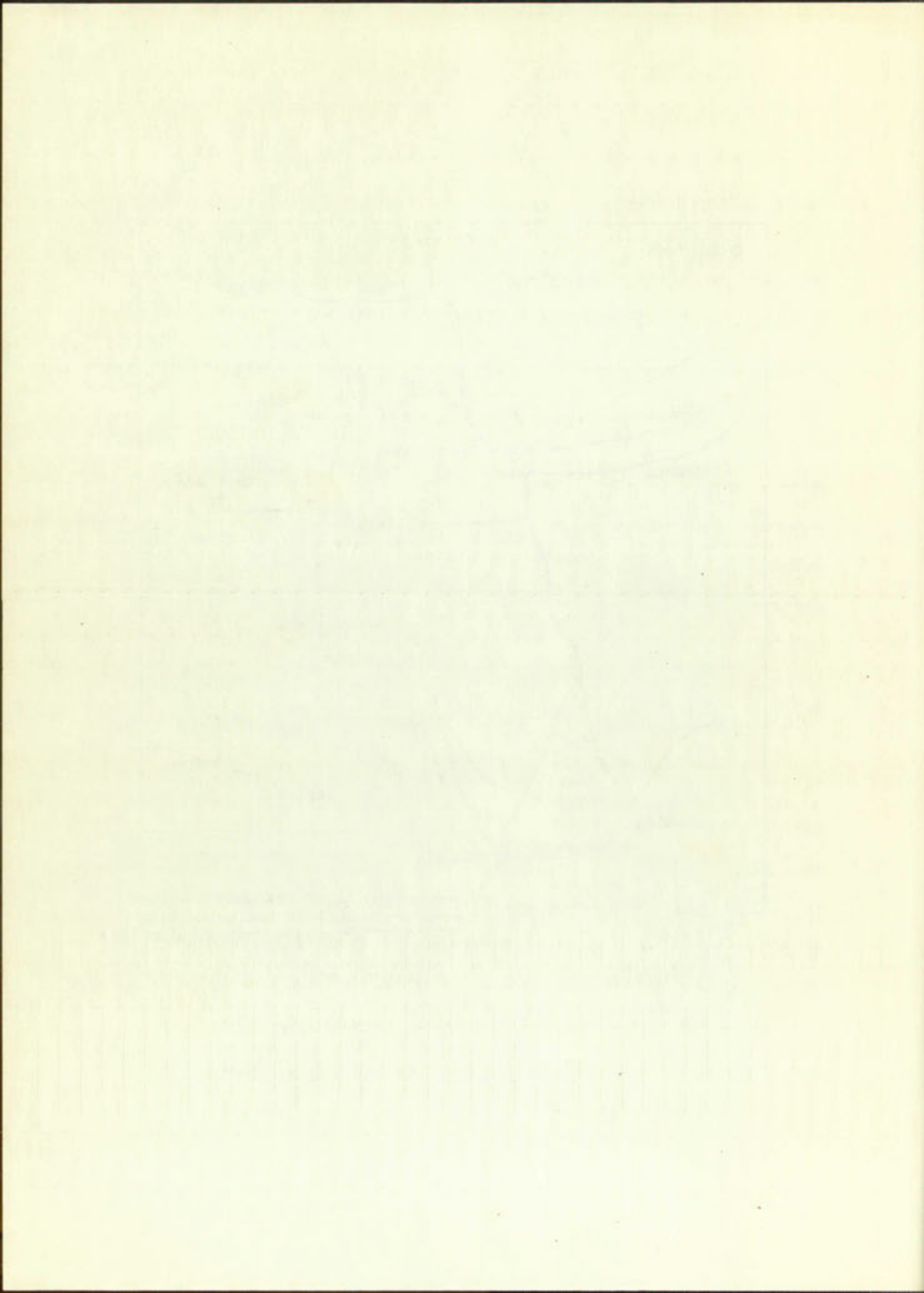


Figure 1. Transmission lines in the state of New Mexico



1. Loads at Point A

The city which Point A represents would have a population of approximately 12,000 people, and it would have had annual peak loads since 1930 as listed in Table 2.

TABLE 2
ANNUAL PEAK LOADS OF CITY A FROM 1930 TO 1958

| Year | Peak Load, kw | Year | Peak Load, kw |
|----------------|------------------|----------------|------------------|
| 1930 | 1997 | 1945 | 6680 |
| 1931 | 2160 | 1946 | 7440 |
| 1932 | 2270 | 1947 | 7920 |
| 1933 | 2530 | 1948 | 8500 |
| 1934 | 2760 | 1949 | 9040 |
| 1935 | 2980 | 1950 | 9700 |
| 1936 | 3310 | 1951 | 10450 |
| 1937 | 3630 | 1952 | 11600 |
| 1938 | 3940 | 1953 | 12440 |
| 1939 | 4410 | 1954 | 13500 |
| 1940 | 5070 | 1955 | 14600 |
| 1941 | 5560 | 1956 | 16000 |
| 1942 | 5430 | 1957 | 17220 |
| 1943 | 5780 | 1958 | 18650 |
| 1944 | 6070 | | |

The plot on semi-log paper of the load values in Table 2 is shown in Figure 2. This curve shows that the loads have increased annually at an average rate of 8.3 per cent. The increased percentage is obtained by the method given in Chapter II. Using the 8.3 per cent annual increase, the predicted loads for the next eight years are shown in Table 3.

The first series of tests was made with a load of approximately 12,000 lbs., and the second series of tests was made with a load of 10,000 lbs.

ANNUAL MEAN LOADS ON THE BRIDGE

| Year | Mean Load (lbs.) |
|------|------------------|
| 1930 | 12,000 |
| 1931 | 12,000 |
| 1932 | 12,000 |
| 1933 | 12,000 |
| 1934 | 12,000 |
| 1935 | 12,000 |
| 1936 | 12,000 |
| 1937 | 12,000 |
| 1938 | 12,000 |
| 1939 | 12,000 |
| 1940 | 12,000 |
| 1941 | 12,000 |
| 1942 | 12,000 |
| 1943 | 12,000 |
| 1944 | 12,000 |
| 1945 | 12,000 |
| 1946 | 12,000 |
| 1947 | 12,000 |
| 1948 | 12,000 |
| 1949 | 12,000 |
| 1950 | 12,000 |

The first series of tests was made with a load of approximately 12,000 lbs. and the second series of tests was made with a load of 10,000 lbs. The results of these tests are shown in Figure 1. The first series of tests was made with a load of 12,000 lbs. and the second series of tests was made with a load of 10,000 lbs. The results of these tests are shown in Figure 1. The first series of tests was made with a load of 12,000 lbs. and the second series of tests was made with a load of 10,000 lbs. The results of these tests are shown in Figure 1.

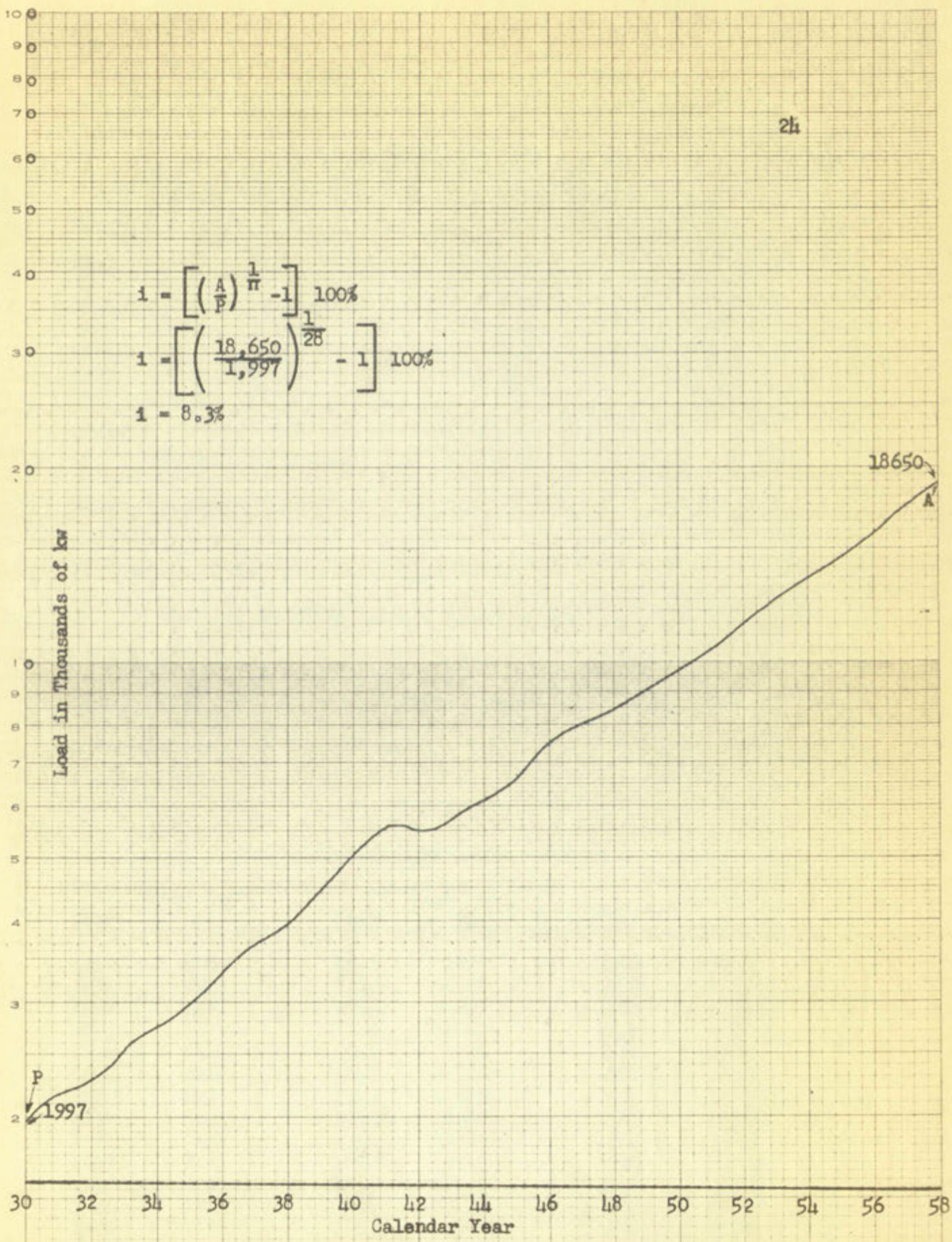


Figure 2. Load Growth Curve of City A

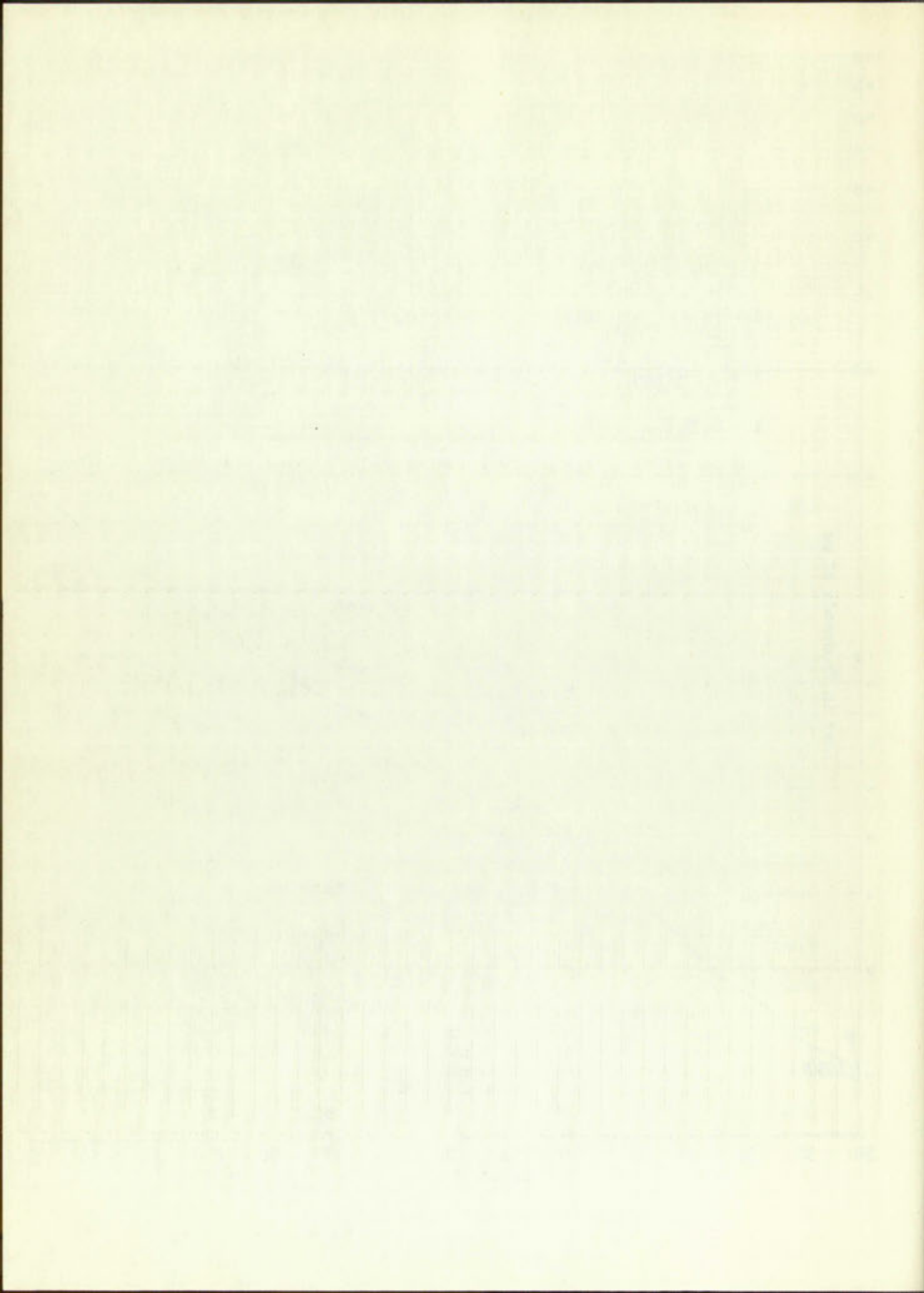


TABLE 3

PREDICTED PEAK LOADS FOR CITY A FROM 1959 TO 1968

| Year | Predicted Load, kw | Year | Predicted Load, kw |
|----------------|-----------------------|----------------|-----------------------|
| 1959 | 20200 | 1964 | 31300 |
| 1960 | 21920 | 1965 | 33900 |
| 1961 | 23740 | 1966 | 36700 |
| 1962 | 25700 | 1967 | 39750 |
| 1963 | 28900 | 1968 | 43100 |

Point A is located approximately twenty-one miles from the remote generating plant.

2. Loads at Point B

The city at Point B would have characteristics similar to city A, but it would have a 1959 population of approximately 18,000 people. Its past annual electrical peaks and its estimated future peaks are tabulated in Table 4.

TABLE 4

PAST AND PREDICTED LOADS FOR CITY B

| Year | Peak Load, kw | Year | Peak Load, kw | Year | Peak Load, kw |
|------|------------------|------|------------------|------|------------------|
| 1930 | 4800 | 1943 | 9820 | 1956 | 26300 |
| 1931 | 5070 | 1944 | 10300 | 1957 | 27340 |
| 1932 | 5230 | 1945 | 11000 | 1958 | 29140 |
| 1933 | 5180 | 1946 | 11940 | 1959 | 31050 |
| 1934 | 5360 | 1947 | 13800 | 1960 | 33100 |
| 1935 | 5950 | 1948 | 15700 | 1961 | 35300 |
| 1936 | 6400 | 1949 | 17640 | 1962 | 37650 |
| 1937 | 6590 | 1950 | 18680 | 1963 | 40100 |
| 1938 | 7210 | 1951 | 19830 | 1964 | 42900 |
| 1939 | 7880 | 1952 | 21010 | 1965 | 45600 |
| 1940 | 8400 | 1953 | 21890 | 1966 | 48600 |
| 1941 | 9000 | 1954 | 23150 | 1967 | 51900 |
| 1942 | 9030 | 1955 | 24700 | 1968 | 55300 |

RESERVED FOR THE CITY OF NEW YORK

| Year | Amount | Year | Amount |
|------|--------|------|--------|
| 1959 | 2000 | 1954 | 1500 |
| 1960 | 2100 | 1955 | 1600 |
| 1961 | 2200 | 1956 | 1700 |
| 1962 | 2300 | 1957 | 1800 |
| 1963 | 2400 | 1958 | 1900 |

Point A is located on the north side of the river, near the intersection of the river and the highway.

The city of New York is a world of opportunity and growth. It is a city of ideas and innovation, a city that has shaped the future of the world. The city of New York is a city of dreams and aspirations, a city that has inspired the world to reach for the stars.

NEW YORK STATE DEPARTMENT OF TAXATION

| Year | Amount | Year | Amount |
|------|--------|------|--------|
| 1950 | 1000 | 1955 | 1500 |
| 1951 | 1100 | 1956 | 1600 |
| 1952 | 1200 | 1957 | 1700 |
| 1953 | 1300 | 1958 | 1800 |
| 1954 | 1400 | 1959 | 1900 |
| 1955 | 1500 | 1960 | 2000 |
| 1956 | 1600 | 1961 | 2100 |
| 1957 | 1700 | 1962 | 2200 |
| 1958 | 1800 | 1963 | 2300 |
| 1959 | 1900 | 1964 | 2400 |
| 1960 | 2000 | 1965 | 2500 |

The average annual load growth computed from the values of past load experience in Table 4 is 6.63 per cent. This growth average was used to compute the estimated loads.

Point B is located approximately forty-five miles from Albuquerque.

3. Loads at Albuquerque

Since all cities served by the Public Service Company of New Mexico, at the present time, are connected by transmission lines to the Albuquerque electrical system, and since 90 per cent of the existing generating capacity is located at Albuquerque, the entire electrical load of the Public Service Company of New Mexico may be considered to be located at Albuquerque. In the past, the Albuquerque system has accounted for approximately 80 per cent of the total system peak. The system peaks of the Public Service Company of New Mexico since 1934 are given in Table 5.

TABLE 5

PEAK LOADS OF THE PUBLIC SERVICE COMPANY
OF NEW MEXICO FROM 1934 TO 1958

| Year | Peak Load, kw | Year | Peak Load, kw | Year | Peak Load, kw |
|------|------------------|------|------------------|------|------------------|
| 1934 | 9050 | 1942 | 16100 | 1950 | 51010 |
| 1935 | 10780 | 1943 | 18030 | 1951 | 60880 |
| 1936 | 12050 | 1944 | 19240 | 1952 | 70680 |
| 1937 | 12680 | 1945 | 23900 | 1953 | 75320 |
| 1938 | 13650 | 1946 | 27240 | 1954 | 85130 |
| 1939 | 15570 | 1947 | 31350 | 1955 | 93130 |
| 1940 | 16590 | 1948 | 35920 | 1956 | 105860 |
| 1941 | 17670 | 1949 | 43140 | 1957 | 115000 |
| | | | | 1958 | 130000 |

UNITED STATES DEPARTMENT OF AGRICULTURE

The average annual loss of wheat in the United States during the period 1911-1921 was 1,000,000 bushels, or 1.0 percent of the total production. This loss was due to various causes, including drought, insect pests, and diseases.

Since all wheat raised in the United States is consumed in this country, it is necessary to determine the amount of wheat that is produced in excess of the domestic requirements.

Methods of the Bureau of Entomology and Plant Quarantine have been used to determine the amount of wheat that is lost to insects and diseases. The results of these studies are given in Table 1.

TABLE 1

LOSS OF WHEAT TO INSECTS AND DISEASES IN THE UNITED STATES, 1911-1921

| Year | Total loss, bushels | Loss to insects, bushels | Loss to diseases, bushels |
|------|---------------------|--------------------------|---------------------------|
| 1911 | 1,000,000 | 500,000 | 500,000 |
| 1912 | 1,000,000 | 500,000 | 500,000 |
| 1913 | 1,000,000 | 500,000 | 500,000 |
| 1914 | 1,000,000 | 500,000 | 500,000 |
| 1915 | 1,000,000 | 500,000 | 500,000 |
| 1916 | 1,000,000 | 500,000 | 500,000 |
| 1917 | 1,000,000 | 500,000 | 500,000 |
| 1918 | 1,000,000 | 500,000 | 500,000 |
| 1919 | 1,000,000 | 500,000 | 500,000 |
| 1920 | 1,000,000 | 500,000 | 500,000 |
| 1921 | 1,000,000 | 500,000 | 500,000 |

These system peaks are plotted and the per cent of yearly increase, 11.7 per cent, is computed in Figure 3. The estimated future demands for the system are shown in Table 6.

TABLE 6
ESTIMATED PEAK LOADS FOR
THE PUBLIC SERVICE COMPANY OF NEW MEXICO

| Year | Predicted Peak Load, kw | Year | Predicted Peak Load, kw |
|------|----------------------------|------|----------------------------|
| 1959 | 145200 | 1965 | 281000 |
| 1960 | 162000 | 1966 | 314500 |
| 1961 | 181000 | 1967 | 352000 |
| 1962 | 212000 | 1968 | 393500 |
| 1963 | 226000 | 1969 | 441000 |
| 1964 | 252000 | | |

As indicated by the above tables, the load growth computations were made prior to the peak load of 1959. The actual peak load which was recorded in 1959 was considerably above that shown in Table 6. The unusual increase was due primarily to connections to large industrial users which had supplied their own power or had obtained it from other utilities previous to 1959. This type of connection, which will be known to the utility load growth estimator, must be included in the growth analysis. The net effect of such loads is to move the load growth curve up by an amount equal to that which these unusual loads will add to the system peak. Neglecting this high peak for 1959 will not effect the illustrations here so the unusual peak condition has not been included in this study.

These figures were obtained from the...
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The... for the... is...

Table 1

THE... OF...

| Year | ... | ... |
|------|-----|-----|
| 1959 | ... | ... |
| 1960 | ... | ... |
| 1961 | ... | ... |
| 1962 | ... | ... |
| 1963 | ... | ... |
| 1964 | ... | ... |

As indicated by the...
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 in Table 2. The...
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i = per cent of annual increase

$$i = \left(\frac{A}{P}\right)^{1/n} - 1$$

$$n = 1958 - 1934 = 24$$

$$i = \left(\frac{130,000}{9,050}\right)^{1/24} - 1$$

$$i = 0.1176$$

$$i = 11.76\%$$

$A = 130,000\text{kw}$

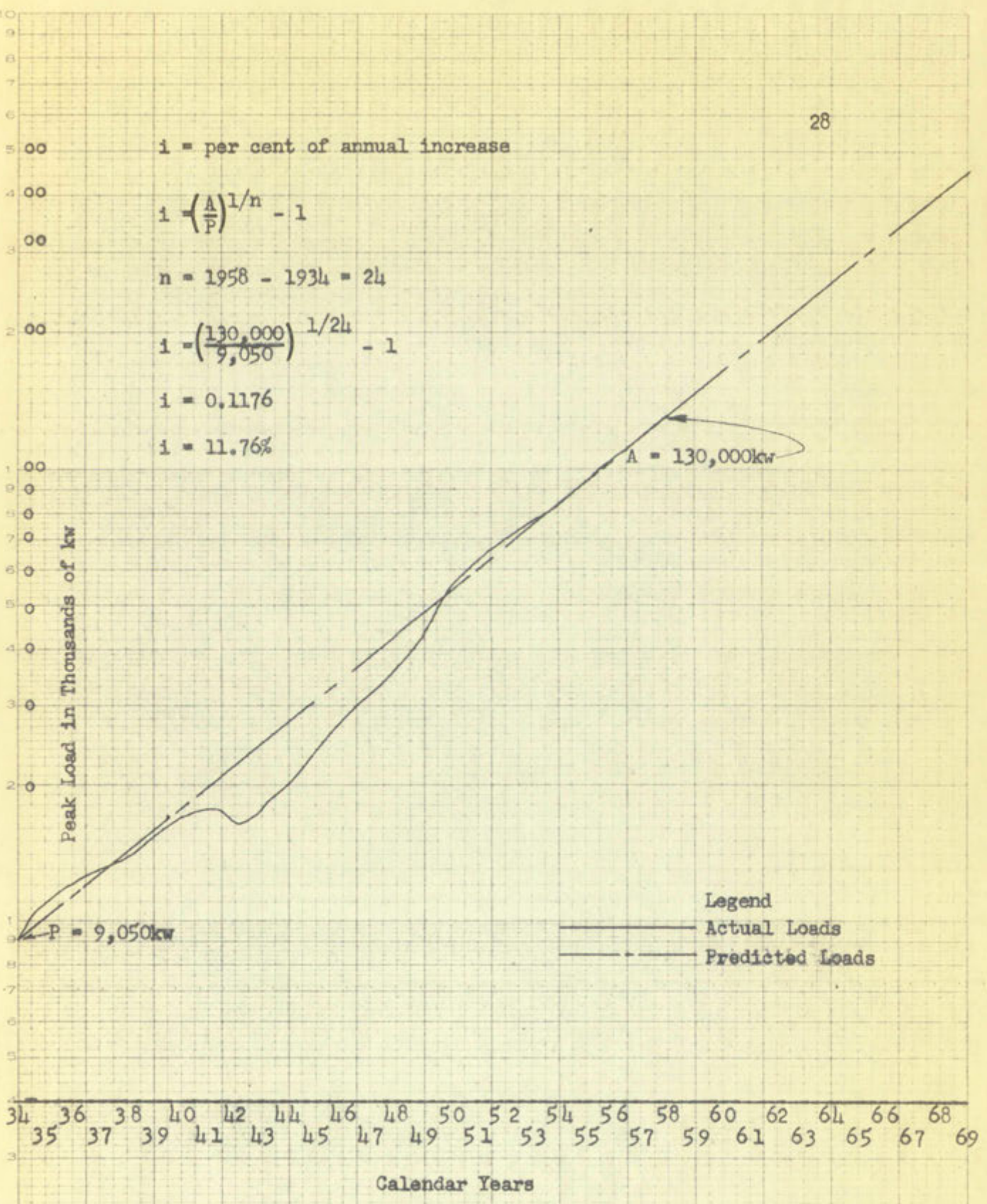
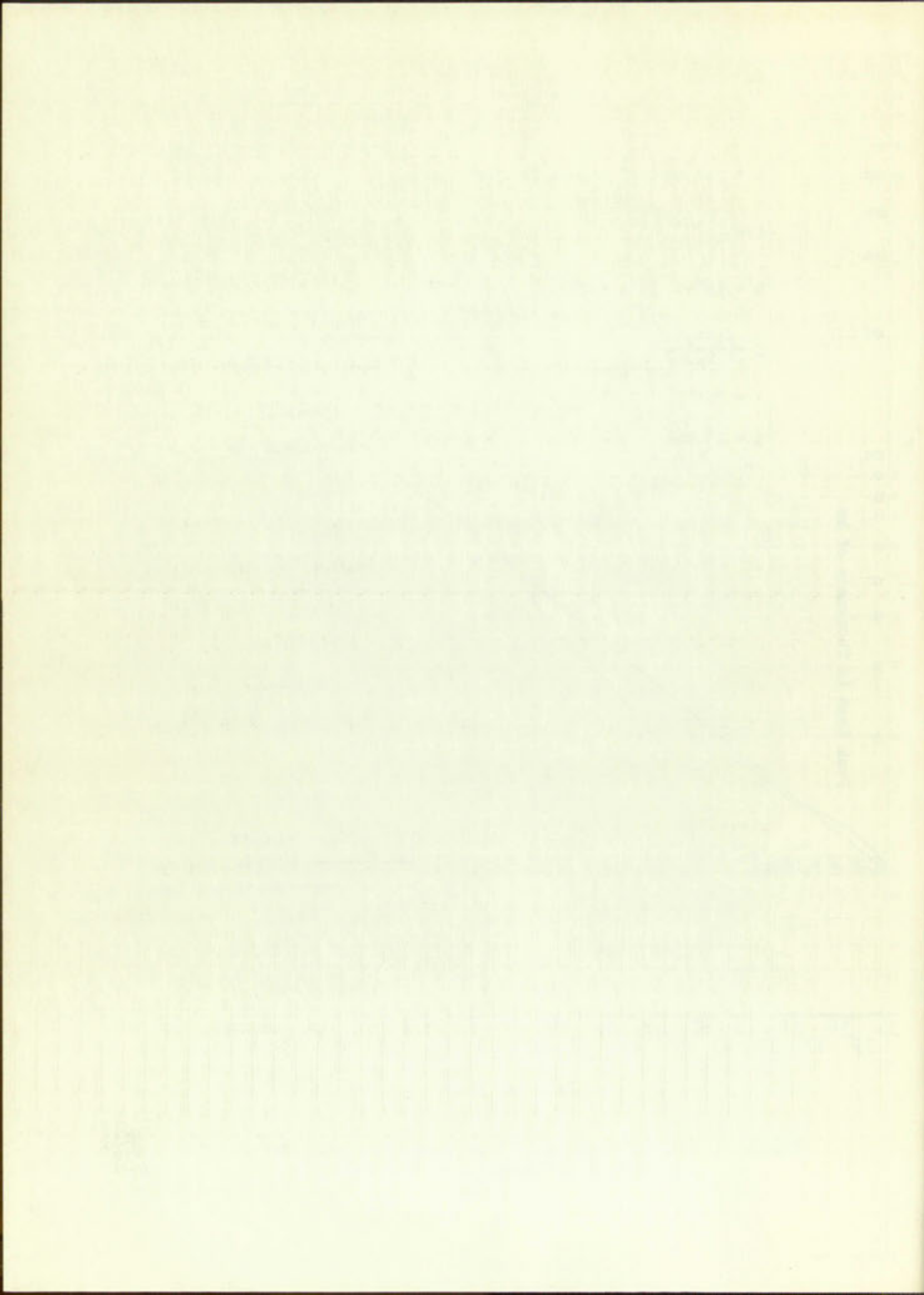


Figure 3. Plot of Peak Loads for Albuquerque and Computation of Per Cent of Annual Load Increase



D. Comparative Power Cost

An economic analysis of a transmission line versus additional generating capacity at Albuquerque needs to include only the present Public Service Company of New Mexico system. The cities, A and B, described above would be served only if the transmission line were built, but their loads must be considered when the characteristics of the line, such as voltage regulation, are determined. The loads of cities A and B should not be included, however, in a study being made to decide if the transmission line should be built or if new generating capacity should be added at Albuquerque. To make the generator-transmission line decision, the Albuquerque bus cost of a kilowatt-hour by the two generation methods will be equated. The Albuquerque bus cost of the remotely generated power must contain all cost factors of the transmission line as listed in Chapter III, as well as the generation cost.

E. Additional Generating Capacity at Albuquerque

The Reeves Power Plant on the north side of Albuquerque has a 40,000kw generator as its first operating unit and a second 40,000kw generator will be operating in 1960. The present plans call for a 60,000kw generator to be added when the system load requires it. The purchase of the 60,000kw generator may be delayed, however, if the proposed transmission line is built. The Public Service Company of New Mexico has operating experience and statistics on the cost of

The present condition of the power plant is such that it is not possible to generate power by the existing means in which it is now being generated. It is necessary to install a new power plant which will be capable of generating power by the use of the water power available at the site. The proposed power plant will be a run-of-river type which will not require the construction of a dam. The power plant will be located at the site of the old power plant and will be connected to the existing transmission lines. The power plant will be capable of generating power at a rate of 10,000 kilowatts per hour. The power plant will be owned and operated by the same company which owns and operates the existing power plant. The power plant will be a run-of-river type which will not require the construction of a dam. The power plant will be located at the site of the old power plant and will be connected to the existing transmission lines. The power plant will be capable of generating power at a rate of 10,000 kilowatts per hour. The power plant will be owned and operated by the same company which owns and operates the existing power plant.

2. Additional Power Plant

The proposed power plant will be a run-of-river type which will not require the construction of a dam. The power plant will be located at the site of the old power plant and will be connected to the existing transmission lines. The power plant will be capable of generating power at a rate of 10,000 kilowatts per hour. The power plant will be owned and operated by the same company which owns and operates the existing power plant. The power plant will be a run-of-river type which will not require the construction of a dam. The power plant will be located at the site of the old power plant and will be connected to the existing transmission lines. The power plant will be capable of generating power at a rate of 10,000 kilowatts per hour. The power plant will be owned and operated by the same company which owns and operates the existing power plant.

OFFICE OF THE ENGINEER

generation on two 30,000kw generators at its Person Station and on the 40,000kw generator at Reeves Station. The generation cost for the second 40,000kw generator at Reeves Station can be estimated closely by the experience gained from the existing generators. The cost of generation for this generator has been estimated to be \$0.0049 per kilowatt-hour. This includes all fixed and operating costs for power at the power plant.

F. Power at the Northwest New Mexico Generating Plant

Two sizes of plant have been studied for the northwest New Mexico plant; one would have a generation cost of \$0.0041 per kilowatt-hour and a larger plant would have a generation cost of \$0.0040 per kilowatt-hour. These costs represent the power plant costs as did the Reeves Station costs. The cost of a kilowatt-hour at the larger plant will be used for the problem studied in this chapter.

G. Reliability

To provide more reliable service to its customers, the operating procedure of the Public Service Company of New Mexico has been to make available excess generating capacity equal to that of its largest generating unit. This policy permits the company to eliminate most outages due to generation difficulty. Enough "spare" generators are kept spinning to pick up all load in the event the largest generator is disabled for whatever reason. This policy also provides the company with capacity enough to perform necessary maintenance work on

their generators during the light load season of the year.

The transmission line being studied will be treated as a generating unit for application of the excess-generator policy. The load delivered by the line to the Albuquerque system will be limited to the amount of excess generating capacity available. This limit does not include the loads delivered to the cities A and B along the route of the line, however. The excess generating capacity is found in Appendix III, and it is shown that the least excess capacity is approximately 75,000kw.

The 75,000kw limit to the Albuquerque system by the transmission line will effectively limit the life of the line to 1963. This does not mean that the line will last only to 1963, but rather that additional generating capacity, or transmission lines from the northwestern New Mexico area, will be required before the peak load of 1964 occurs.

H. Economic Maximum Resistance Calculations

A 115,000 volt transmission line has been selected for the illustrative problem which follows on the basis of economical connection to existing lines and as the voltage which will best illustrate the use of the formulas developed in Chapter III. Determination of operational difficulties can also be best illustrated by the selection of the 115,000 volt transmission line.

The cost of maintenance for a 115,000 volt transmission line

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has been estimated as \$150/mile/year. The cost of constructing a 115,000 volt transmission line, less conductor, has been estimated as \$9,000/mile, and the annual fixed charges on the line have been computed to be 15.1 per cent per year. The estimates have been made from construction and maintenance cost experiences of power companies, and the fixed charges percentage is derived in Appendix IV.

To arrive at the number of kilowatt-hours per year which will be transmitted over the line from the northwest New Mexico area, it has been assumed that the line will be given a good load factor. The Albuquerque generators would be used to carry the remaining portion of the base load, and they would supply the peak demands. This practice may cause the Albuquerque cost of generation to increase slightly above the cost which would be experienced when the Albuquerque generators carried the entire load. The additional cost would be caused by the lower efficiency of generators when operated below full rating and of the generation labor cost; the labor cost would be nearly the same for either condition of loading on the generators. The total amount of the increase for a year should be computed and the value added to the cost of generation at the northwestern New Mexico plant. This addition would cause the effective generation cost of the remote generating plant to be increased slightly. Since the Albuquerque generators would continue to carry approximately two-thirds or better of the base load, the increase in Albuquerque generation cost as a result of base loading the transmission line is

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considered slight. For this reason the increased generation cost at Albuquerque which results from assigning a high load factor to the transmission line has been neglected. The load factor assigned to the line for the following computations is 90 per cent. The annual kilowatt-hours may now be calculated:

$$Y = (\text{load factor}) (\text{hours/year}) (\text{line peak loading}) \\ = (0.90) (8760) (75,000) = 5.912 \times 10^8 \text{ kwhr/year}$$

Assuming a power factor of 90 per cent lagging the average current may be found:

$$I = \frac{\text{kwhr/year}}{(\text{power factor}) (\text{voltage}) (\text{hours/year}) (\sqrt{3})} \\ = \frac{5.912 \times 10^8}{(0.9) (115,000) (8760) (\sqrt{3})} = 379 \text{ amperes}$$

As discussed in Chapter III, for a limited area and period of years, the average current, as computed above, may be treated as the square root current of the mean square current and consequently used to compute power losses. A high load factor, as the 90 per cent used in the illustrative problem, makes the current computed in the above manner even more nearly the true value of the square root of the mean square current. The current computed above, therefore, will be used in this manner for the computations which follow.

The formula for total load center cost of power generated at a remote site, which was developed in the previous chapter, may be set equal to the Albuquerque generation cost and solved for r , the resistance per mile per phase. The conductor size will be found

considered... the... to the... annual...

$$Y = \dots$$

Assuming... current...

$$Y = \dots$$

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STATION

which will make the Albuquerque cost of the two generation methods the same. The formula is solved as follows:

$$T = S + \frac{(m + KB)Z}{Y} + \frac{3Z}{Y} \left[I^2 \text{ rHS } 10^{-3} + \frac{\text{KWG}}{r} \right]$$

$$T-S - \frac{(m + KB)Z}{Y} = \frac{3Z}{Y} \left[I^2 \text{ rHS } 10^{-3} + \frac{\text{KWG}}{r} \right]$$

$T = \$0.0049/\text{kwhr}$
 $S = \$0.0040$
 $M = \$150/\text{mile}$
 $K = 15.1\%$
 $B = \$9,000/\text{mile}$
 $Z = 120 \text{ miles}$
 $Y = 5.912 \times 10^8 \text{ kwhr/year}$
 $I = 379 \text{ amperes}$
 $H = 8760 \text{ hours/year}$
 $W = \$0.35/\text{lb}^1$
 $G = 850 \text{ for } 30/7\text{ACSR}^2$

The left side of the equation is

$$T-S - \frac{m + KB}{Y} Z = 0.0049 - 0.0040 - \frac{150 + (0.151)(9000)}{5.912 \times 10^8} (120)$$

$$= 5.937 \times 10^{-4}$$

The right side of the equation is

$$\frac{3Z}{Y} \left[I^2 \text{ rHS } 10^{-3} + \frac{\text{KWG}}{r} \right] = \frac{3(120)}{5.912 \times 10^8} \left[(379)^2 (8760) (.004) 10^{-3} r \right]$$

$$+ \frac{(0.151)(0.35)(850)}{r} = 3.065 \times 10^{-3} r + \frac{2.736 \times 10^{-5}}{r}$$

Equating the values of the two sides gives

$$5.937 \times 10^{-4} = 3.065 \times 10^{-3} r + \frac{2.736 \times 10^{-5}}{r}$$

$$30.65r^2 - 5.937r + 0.2736 = 0$$

¹Approximate current price for ACSR conductor.

²Found in Appendix II.

which will make the denominators of the two fractions the same. The formula is as follows:

$$T = \frac{a + (n-1)d}{2}$$

$$S = \frac{n}{2} [2a + (n-1)d]$$

- 1 = 1000
- 2 = 1000
- 3 = 1000
- 4 = 1000
- 5 = 1000
- 6 = 1000
- 7 = 1000
- 8 = 1000
- 9 = 1000
- 10 = 1000

The left side of the equation is

$$T = \frac{1000 + 1000}{2} = 1000$$

The right side of the equation is

$$S = \frac{10}{2} [2(1000) + (10-1)(0)] = 50000$$

Since the value of the left side is

$$1000 \neq 50000$$

¹Arithmetic series sum formula
²Sum of squares formula

$$r = \frac{5.937 \pm \sqrt{(5.937)^2 - 4(30.65)(0.2736)}}{2(30.65)}$$

$$= 0.09685 \pm .02126$$

$$= 0.0756 \text{ or } 0.118 \text{ ohms/mile/phase}$$

These resistances correspond to 900 million circular mills and to 1431 million circular mills ACSR conductors. This means that a 900 or 1431 million circular mills ACSR conductor on a transmission line 120 miles long will give equal Albuquerque cost for power generated at \$0.0049/kwhr at Albuquerque or at \$0.0040/kwhr at the other end of the transmission line.

It may be noted that actual resistances are 0.1185 and 0.0760 ohms for the 900 and 1431 million circular mills ACSR conductors respectively. These sizes, however, are the "standard sizes" with resistances most nearly the solved values.

The conductor size which will be the most economical may be found by the formula

$$r = \frac{0.338}{I} \sqrt{\frac{KWG}{S}}$$

which was developed in the preceding chapter.

Using the values

$$K = 15.1\%$$

$$W = \$0.35/\text{lb}$$

$$G = 850 \text{ for } 30/7 \text{ ACSR}$$

$$S = \$0.0040/\text{kwhr}$$

$$I = 379 \text{ amperes}$$

The resistance of the most economic conductor size is:

$$r = \frac{0.12 \sqrt{1.0}}{1.0} = 0.12$$

$$= 0.0025 \times 0.01$$

$$= 0.000025 \text{ or } 2.5 \times 10^{-5}$$

These two values represent the standard deviation and so the 95% confidence interval of the mean is 0.000025 ± 0.000025 or 0.000000 to 0.000050. The 95% confidence interval of the mean is 0.000025 ± 0.000025 or 0.000000 to 0.000050. The 95% confidence interval of the mean is 0.000025 ± 0.000025 or 0.000000 to 0.000050. The 95% confidence interval of the mean is 0.000025 ± 0.000025 or 0.000000 to 0.000050.

It can be seen that the standard deviation is 0.000025. The 95% confidence interval of the mean is 0.000025 ± 0.000025 or 0.000000 to 0.000050. The 95% confidence interval of the mean is 0.000025 ± 0.000025 or 0.000000 to 0.000050. The 95% confidence interval of the mean is 0.000025 ± 0.000025 or 0.000000 to 0.000050.

The standard deviation is 0.000025. The 95% confidence interval of the mean is 0.000025 ± 0.000025 or 0.000000 to 0.000050. The 95% confidence interval of the mean is 0.000025 ± 0.000025 or 0.000000 to 0.000050.

$$r = \frac{0.12 \sqrt{1.0}}{1.0}$$

which was obtained by the method of least squares. Using the value

- 1 = 1.0
- 2 = 0.01
- 3 = 0.0001
- 4 = 0.000001
- 5 = 0.00000001

The total error of the method is 0.000025. The 95% confidence interval of the mean is 0.000025 ± 0.000025 or 0.000000 to 0.000050. The 95% confidence interval of the mean is 0.000025 ± 0.000025 or 0.000000 to 0.000050.

$$r = \frac{0.338}{379} \sqrt{\frac{0.151 (35) (850)}{0.0040}} = \frac{(.338)}{379} (105.8)$$

$$= 0.0943 \text{ ohms/mile/phase}$$

This resistance value corresponds to a conductor size of 1113 million circular mills, ACSR. This means that if other line characteristics are satisfactory, the most economy will be achieved by generating power in the northwest area of New Mexico and transmitting it to Albuquerque over a transmission line built with a 1113 million circular mills, ACSR conductor.

A curve of the Albuquerque cost of remotely generated power versus the resistance of the transmission line conductor is given in Figure 4. The figure graphically identifies the above value as the most economical conductor size.

The effect of the above solutions may be seen from the tabulation of costs for various parts of the line. Using the same values of load current, generation costs, etc., as was used in the previous calculations the cost of various parts of the line are tabulated in Table 7 for two of the conductor sizes found above. All values are for ACSR conductor.

TABLE 7

ANNUAL COST OF TRANSMISSION LINE FROM
NORTHWESTERN NEW MEXICO TO ALBUQUERQUE--TWO CONDUCTOR SIZES

| Size | 9000 MCM | 1113 MCM |
|----------------------------|----------------|----------------|
| I ² R cost/year | \$ 214,727 | \$ 175,577 |
| Fixed charges/year | 279,500 | 306,859 |
| Maintenance cost/year | <u>180,000</u> | <u>180,000</u> |
| TOTAL | \$ 674,227 | \$ 662,430 |

$$V = \sqrt{\frac{2gH}{1 + K}} \quad (1)$$

The velocity of flow in a pipe is given by the equation (1) where \$V\$ is the velocity of flow in ft/sec, \$H\$ is the head in ft, and \$K\$ is the loss coefficient. The loss coefficient \$K\$ is a function of the Reynolds number and the relative roughness of the pipe. The loss coefficient \$K\$ is given by the equation (2) where \$Re\$ is the Reynolds number and \$e/D\$ is the relative roughness of the pipe.

The effect of the roughness of the pipe on the velocity of flow is shown in Figure 1. The velocity of flow increases with the roughness of the pipe. The velocity of flow is also affected by the diameter of the pipe. The velocity of flow increases with the diameter of the pipe.

The effect of the diameter of the pipe on the velocity of flow is shown in Figure 2. The velocity of flow increases with the diameter of the pipe. The velocity of flow is also affected by the roughness of the pipe. The velocity of flow increases with the roughness of the pipe.

Table 1 for the velocity of flow in a pipe. The velocity of flow is given in ft/sec. The diameter of the pipe is given in inches. The roughness of the pipe is given in inches.

TABLE 1

VELOCITY OF FLOW IN A PIPE

| Diameter, in. | Roughness, in. | Velocity, ft/sec |
|---------------|---|------------------|
| 12 | 0.0001 | 10.0 |
| 12 | 0.0005 | 10.5 |
| 12 | 0.001 | 11.0 |
| 12 | 0.005 | 12.0 |
| 12 | 0.01 | 13.0 |
| 12 | 0.05 | 15.0 |
| 12 | 0.1 | 16.0 |
| 12 | 0.5 | 18.0 |
| 12 | 1.0 | 19.0 |
| 12 | 5.0 | 22.0 |
| 12 | 10.0 | 23.0 |
| 12 | 50.0 | 25.0 |
| 12 | 100.0 | 26.0 |
| 12 | 500.0 | 28.0 |
| 12 | 1000.0 | 29.0 |
| 12 | 5000.0 | 30.0 |
| 12 | 10000.0 | 31.0 |
| 12 | 50000.0 | 32.0 |
| 12 | 100000.0 | 33.0 |
| 12 | 500000.0 | 34.0 |
| 12 | 1000000.0 | 35.0 |
| 12 | 5000000.0 | 36.0 |
| 12 | 10000000.0 | 37.0 |
| 12 | 50000000.0 | 38.0 |
| 12 | 100000000.0 | 39.0 |
| 12 | 500000000.0 | 40.0 |
| 12 | 1000000000.0 | 41.0 |
| 12 | 5000000000.0 | 42.0 |
| 12 | 10000000000.0 | 43.0 |
| 12 | 50000000000.0 | 44.0 |
| 12 | 100000000000.0 | 45.0 |
| 12 | 500000000000.0 | 46.0 |
| 12 | 1000000000000.0 | 47.0 |
| 12 | 5000000000000.0 | 48.0 |
| 12 | 10000000000000.0 | 49.0 |
| 12 | 50000000000000.0 | 50.0 |
| 12 | 100000000000000.0 | 51.0 |
| 12 | 500000000000000.0 | 52.0 |
| 12 | 1000000000000000.0 | 53.0 |
| 12 | 5000000000000000.0 | 54.0 |
| 12 | 10000000000000000.0 | 55.0 |
| 12 | 50000000000000000.0 | 56.0 |
| 12 | 100000000000000000.0 | 57.0 |
| 12 | 500000000000000000.0 | 58.0 |
| 12 | 1000000000000000000.0 | 59.0 |
| 12 | 5000000000000000000.0 | 60.0 |
| 12 | 10000000000000000000.0 | 61.0 |
| 12 | 50000000000000000000.0 | 62.0 |
| 12 | 100000000000000000000.0 | 63.0 |
| 12 | 500000000000000000000.0 | 64.0 |
| 12 | 1000000000000000000000.0 | 65.0 |
| 12 | 5000000000000000000000.0 | 66.0 |
| 12 | 10000000000000000000000.0 | 67.0 |
| 12 | 50000000000000000000000.0 | 68.0 |
| 12 | 100000000000000000000000.0 | 69.0 |
| 12 | 500000000000000000000000.0 | 70.0 |
| 12 | 1000000000000000000000000.0 | 71.0 |
| 12 | 5000000000000000000000000.0 | 72.0 |
| 12 | 10000000000000000000000000.0 | 73.0 |
| 12 | 50000000000000000000000000.0 | 74.0 |
| 12 | 100000000000000000000000000.0 | 75.0 |
| 12 | 500000000000000000000000000.0 | 76.0 |
| 12 | 1000000000000000000000000000.0 | 77.0 |
| 12 | 5000000000000000000000000000.0 | 78.0 |
| 12 | 10000000000000000000000000000.0 | 79.0 |
| 12 | 50000000000000000000000000000.0 | 80.0 |
| 12 | 100000000000000000000000000000.0 | 81.0 |
| 12 | 500000000000000000000000000000.0 | 82.0 |
| 12 | 1000000000000000000000000000000.0 | 83.0 |
| 12 | 5000000000000000000000000000000.0 | 84.0 |
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| 12 | 100000000000000000000000000000000000000.0 | 99.0 |
| 12 | 500000000000000000000000000000000000000.0 | 100.0 |

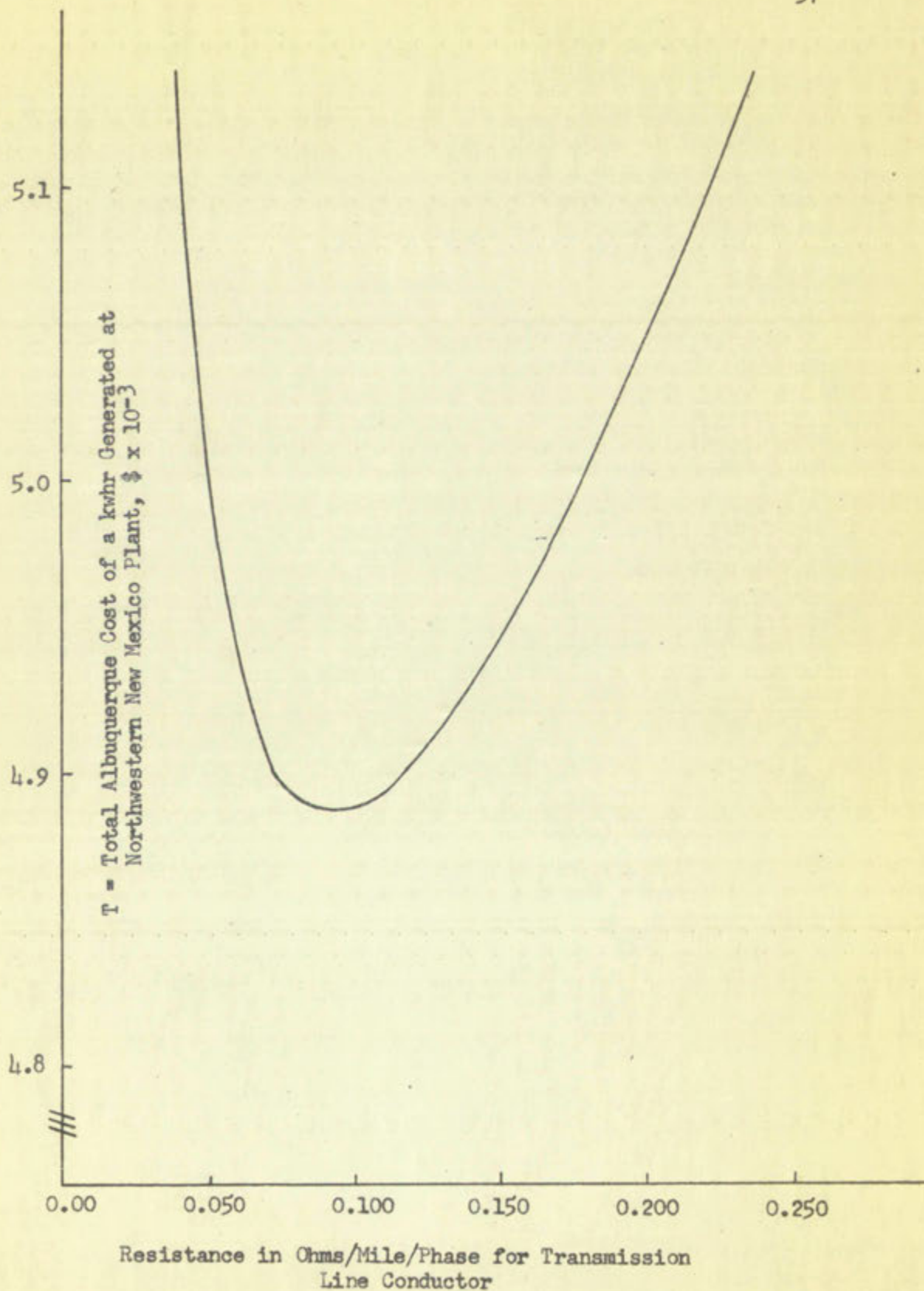
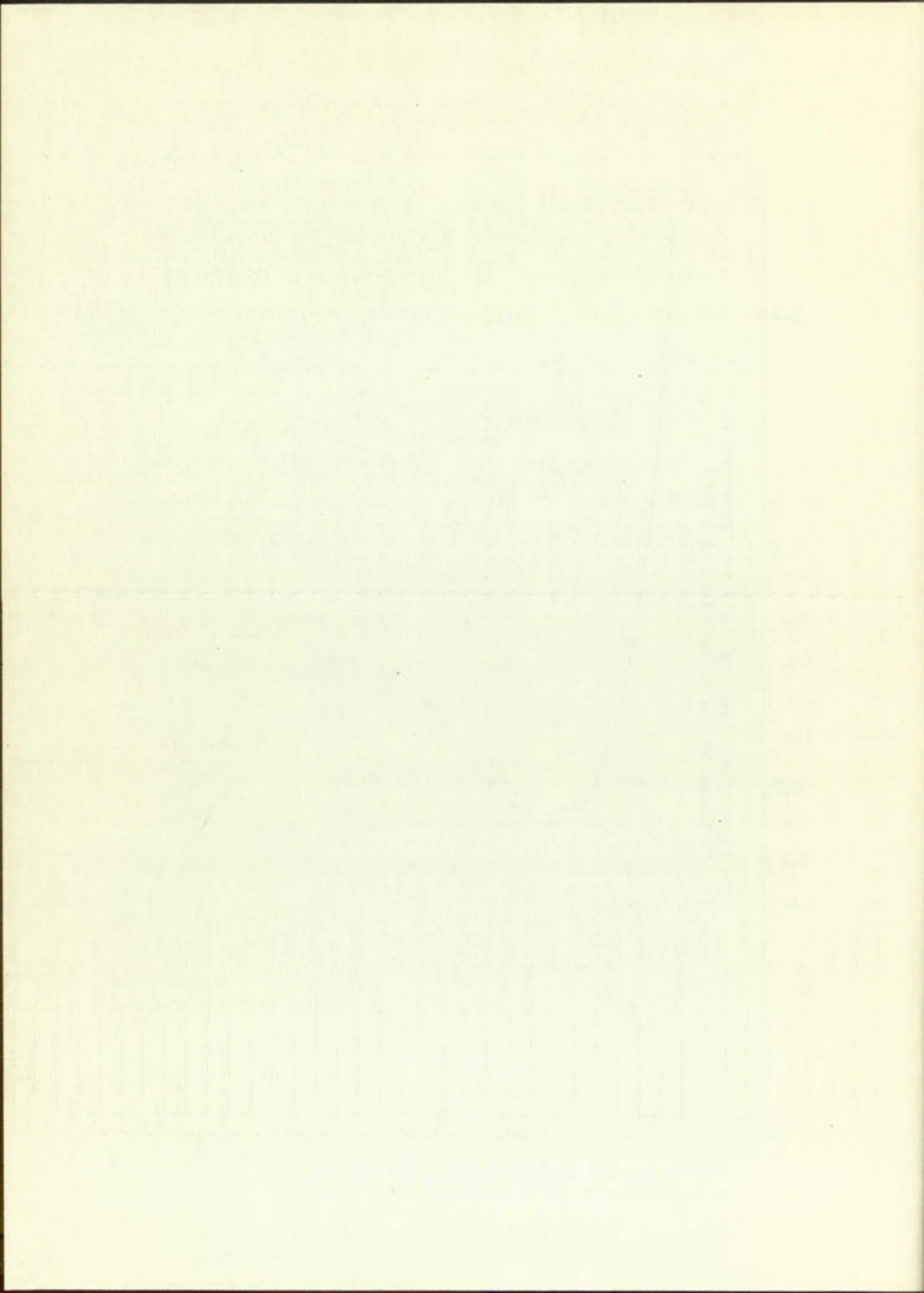


Figure 4. Curve of Albuquerque Cost of Remotely Generated Power versus Conductor Resistance



I. Voltage Regulation Check

The potential savings of a generation and transmission line may not be realized if the per cent of voltage drop is large. The per cent of voltage drop is defined as:

Voltage Drop Percentage =

$$\frac{\text{Sending end voltage} - \text{Receiving end voltage}}{\text{Sending end voltage}} \times 100\%$$

The receiving end voltage for the transmission line described in the previous chapter was selected as 115,000 volts. The sending end voltage may be found by calculating the voltage drop in the line and adding it to the receiving end voltage.

The voltage drop may be found by resolving the line constants into an equivalent Pi representation. Any high voltage line must account for the capacitance charging of the line and the Pi representation is one of the simpler methods of doing this. The Pi representation is shown in the diagram below. In the diagram Y_S and Y_R equal one-half of the capacitance "load" of the line, X equals the line inductive reactance, R equals the line resistance, and E_S equals the sending end voltage.

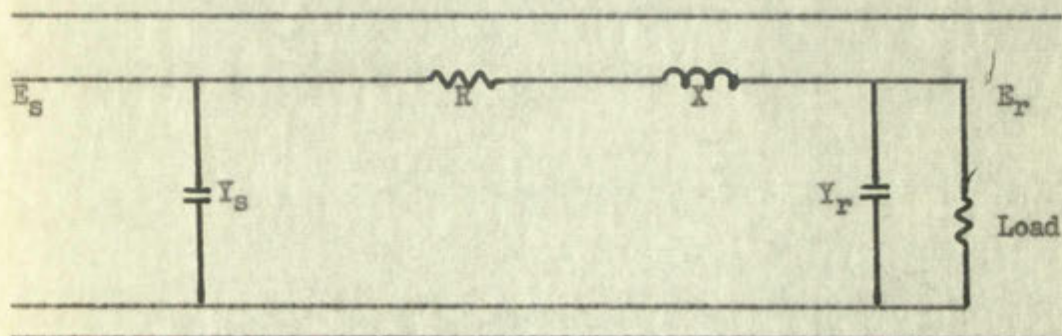


Figure 5. Equivalent Pi Representation

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1. Voltage Resistor

The power dissipated in a resistor is given by the product of the voltage across it and the current through it. If the voltage is V and the current is I , the power is $P = VI$. If the voltage is V and the resistance is R , the current is $I = V/R$, and the power is $P = V^2/R$. If the current is I and the resistance is R , the voltage is $V = IR$, and the power is $P = I^2R$.

2. Series and Parallel

The resistance of two resistors in series is the sum of their resistances. If the resistances are R_1 and R_2 , the total resistance is $R = R_1 + R_2$. The voltage across each resistor is proportional to its resistance. If the total voltage is V , the voltage across R_1 is $V_1 = V \cdot R_1 / (R_1 + R_2)$ and the voltage across R_2 is $V_2 = V \cdot R_2 / (R_1 + R_2)$.

The voltage drop across a resistor is proportional to its resistance. If the total voltage is V and the total resistance is R , the voltage across a resistor of resistance R_1 is $V_1 = V \cdot R_1 / R$. The current through a resistor is proportional to the voltage across it and inversely proportional to its resistance. If the voltage across a resistor is V_1 and its resistance is R_1 , the current through it is $I_1 = V_1 / R_1$. The total current through a series combination of resistors is the same as the current through each resistor.

series and voltage.

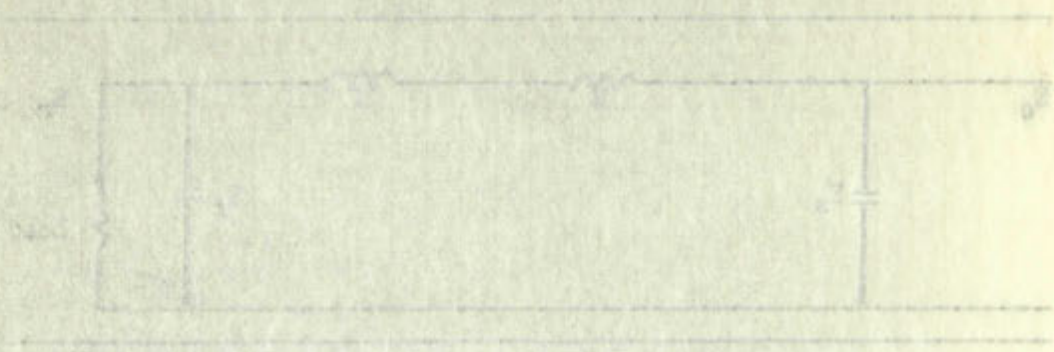


Figure 1. Series combination of two resistors.

The sending end voltage may be found by the formula

$$E_s = E_r + (I_s \cos \theta + j I_s \sin \theta) (X + R)$$

The formula is made applicable to long lines by adding the current of I_r and I_s to the load current.³ I_s is equal to the line current, I_L , when the charging current is negligible.

The transmission line would have a "one line" diagram as illustrated in Figure 6.

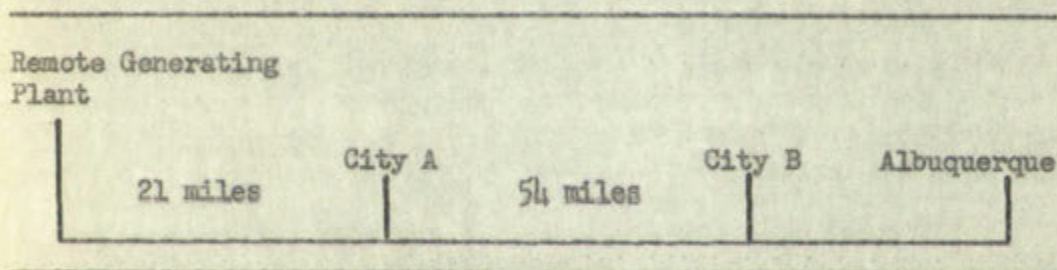


Figure 6. One line diagram of proposed transmission line

This diagram may be simplified from three sections to two sections by dividing the load of city B between city A and Albuquerque. The one line diagram for the simplified system is shown in Figure 7.

³Correction factors are required for long lines due to the distributed line characteristics being lumped in the equivalent "Pi" circuit. These corrections are $z' = z \frac{\sinh \theta}{\theta}$ where $z = R + jX$ and $\frac{y'}{2} = \frac{y}{2} = \frac{\tanh \theta/2}{\theta/2}$. See L. F. Woodruff, Principles of Electric Power Transmission, (N. Y., N. Y.: John Wiley & Sons, 1949), p. 114.

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The resulting and with the aid of the formula

$$I_2 = I_1 + I_2 + I_3 + \dots + I_n$$
the formula is used to determine the total current
of I_1 and I_2 to the load circuit. It is assumed that the current
 I_1 when the circuit is open is equal to I_2 .

The procedure is the same as for the circuit in
illustrated in Figure 1.

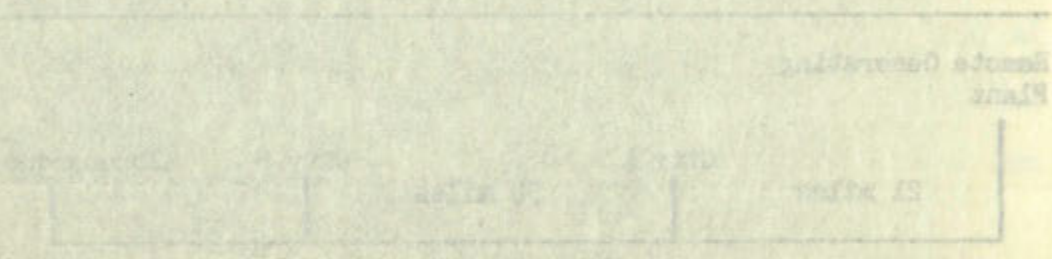


Figure 2. The circuit diagram of a circuit with a voltage source
This circuit is a series circuit with a voltage source and
resistors. The circuit is divided into sections by dividing it
into two parts. The first part is the series combination of the
voltage source and the first resistor. The second part is the
parallel combination of the two resistors.

The circuit diagram is shown in Figure 2. The circuit is a series
circuit with a voltage source and resistors. The circuit is divided
into two parts. The first part is the series combination of the
voltage source and the first resistor. The second part is the
parallel combination of the two resistors.

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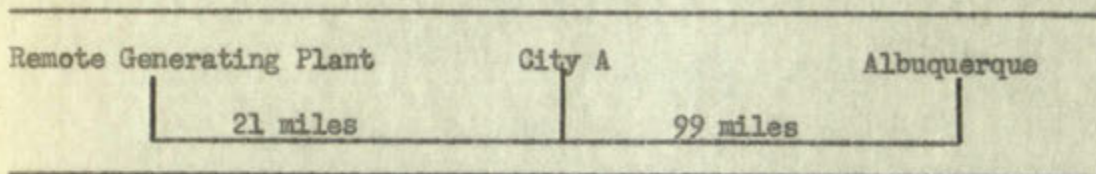


Figure 7. Simplified one line diagram of proposed transmission line

To make the two diagrams' electrical equivalents, the load of city B must be divided between city A and Albuquerque in inverse proportions of the distance between city B and the other cities. For example, that portion of B's load which is added to city A's load is found as

$$\text{Load}_{B \text{ to } A} = \frac{(\text{B's total load}) (45)}{99}$$

The load conditions of 1963 will be used for this problem because it was found in Appendix III that a second line from north-west New Mexico or additional generating capacity at Albuquerque would be required for the year 1964. The 1963 load of city B, 40,000kw, is divided as follows:

To city A

$$L_{B \text{ to } A} = \frac{(40,100) (45)}{99} = 18,230\text{kw}$$

To Albuquerque

$$L_{B \text{ to } Alb} = \frac{(40,100) (54)}{99} = 21,870\text{kw}$$

The load of city A for the equivalent two-section diagram = 28,900 + 18,230 = 43,130kw. With 75,000kw delivered to the city of Albuquerque as explained in Section G of this chapter, the total

| | | |
|----------|--------|--------|
| Revenue | 10,000 | 10,000 |
| Expenses | 5,000 | 5,000 |
| Surplus | 5,000 | 5,000 |

Figure 7. Division of the total surplus of 5,000 units between the two cities. The surplus is divided equally between the two cities, with each city receiving 2,500 units.

The total surplus of 5,000 units is divided equally between the two cities, with each city receiving 2,500 units. This division is based on the principle of equal representation.

To city A: $\frac{5,000}{2} = 2,500$
 To city B: $\frac{5,000}{2} = 2,500$

The total surplus of 5,000 units is divided equally between the two cities, with each city receiving 2,500 units. This division is based on the principle of equal representation.

Albuquerque load for the two-section diagram is $75,000 + 21,870 = 96,870\text{kw}$. The one line diagram may now be redrawn as follows:

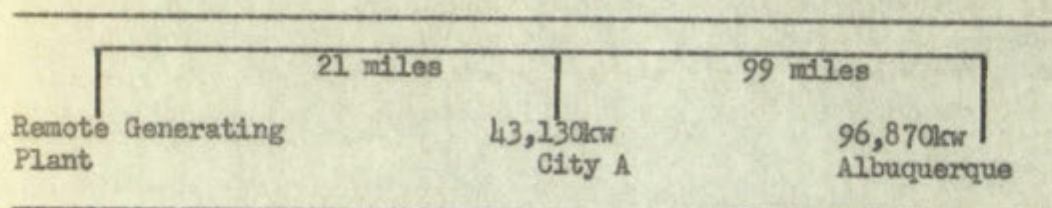


Figure 8. Equivalent one diagram of proposed transmission line

The constants for the Pi section will be found on a per mile basis to make them usable for both sections of the line.

The capacitance in farads per mile is found by the formula⁴

$$C = \frac{1940 \times 10^{-11}}{\log_{10} \frac{D-r}{r}}$$

Where

$D =$ geometric mean distance between conductors = 14.5 feet⁵

$r =$ radius of conductor = 0.581 inches for 900 mcm AGSR conductor

$$C = \frac{1940 \times 10^{-11}}{\log_{10} \frac{(12)(14.5) - 0.581}{0.581}} = 1.406 \times 10^{-8} \text{ farads/mile}$$

The capacitive susceptance, b , is given by⁶

$$b = 277fC$$

⁴R. M. Kerchner and G. F. Corcoran, Alternating Current Circuits, (2d ed., N.Y., N.Y.: John Wiley, 1943), p. 387.

⁵Value of 14.5 is a typical value. See R. W. Robbins and F. S. Rothe, G.E. Network Analyzers, (Schenectady, N.Y.: Apparatus Department, General Electric Company, 1950), p. 23.

⁶R. M. Kerchner and G. F. Corcoran, op. cit., p. 390.

Abstracts from the Proceedings of the International Conference on the Physics of the Earth and Planetary Interiors, 1974, Boulder, Colorado, USA.



Figure 1. Schematic diagram of the Earth's interior showing the lithosphere, asthenosphere, and mantle. The lithosphere is the rigid uppermost layer, the asthenosphere is the layer below it, and the mantle is the layer below that.

$$C = \frac{1000 \times 10^3}{1000 \times 10^3} = 1$$

where

C = coefficient of thermal expansion
 T = temperature of the mantle
 ΔT = change in temperature

$$C = \frac{1}{T} \left(\frac{\Delta V}{V} \right) = \frac{1}{T} \left(\frac{\Delta \rho}{\rho} \right)$$

The coefficient of thermal expansion is defined as the relative change in volume per unit change in temperature.

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where

f = frequency = 60 cycles/sec for power systems

$b = 2 (60) \pi (1.406 \times 10^{-8}) = 5.3 \times 10^{-6}$ mho/mile/phase

$Y = jb = j 5.3 \times 10^{-6}$ mho/mile/phase

The inductive reactance/mile/phase, X , may be computed from the formula⁷

$$X = j \left[0.2794 \log_{10} \frac{2D}{2r} \right] \left[X \text{ internal} \right]$$

The inductive reactance/mile for the line under study was found to be 0.717 ohm/mile/phase.

The 60cps resistance per mile per phase at 50°C may be found from resistance tables to be 0.1185 ohms per mile per phase.

If the receiving end voltage at Albuquerque is 66,400 volts, i.e., $\frac{115,000}{\sqrt{3}}$, the voltage at Point A is the sum of the 66,400 plus the line drop between Albuquerque and city A. The drop is equal to the product of the receiving end current times the impedance of the line, Z_r . The receiving end current in this case is equal to the load current at the assumed 90 per cent power factor plus the current through the capacitive shunt in the "Pi" circuit, $\frac{Y}{2}$.

$$\begin{aligned} Z_r &= (r + jx) (\text{distance}) = (0.1185 + j 0.717) (99) \\ &= 11.73 + j 70.98 = 71.8 \angle 80.6^\circ \end{aligned}$$

$$\begin{aligned} I_r &= I_{\text{load}} + I_{Y_2} = \frac{kw}{KV (\sqrt{3}) (\text{Power Factor})} \angle -25.8^\circ + \frac{Y}{2\sqrt{3}} (\text{miles}) \\ &= \frac{96,870}{115 (\sqrt{3}) (0.90)} \angle -25.8^\circ + \frac{j 5.3 \times 10^{-6}}{2} \frac{115,000}{\sqrt{3}} \quad (120) \end{aligned}$$

⁷Robbins and Rothe, op. cit., p. 25.

The relative resistance of the line is found to be 0.17 ohms per mile.

The open circuit resistance of the line is found to be 1.15 ohms per mile.

From resistance tables for a 100,000 volt line, the resistance is found to be 0.17 ohms per mile.

If the resistance of the line is 0.17 ohms per mile, the resistance of the line is 1.15 ohms per mile.

$$I = 1 \left[\frac{0.17 \times 1000}{1000} \right] \left[\frac{1000}{1000} \right]$$

The relative resistance of the line is found to be 0.17 ohms per mile.

The open circuit resistance of the line is found to be 1.15 ohms per mile.

From resistance tables for a 100,000 volt line, the resistance is found to be 0.17 ohms per mile.

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If the resistance of the line is 0.17 ohms per mile, the resistance of the line is 1.15 ohms per mile.

The relative resistance of the line is found to be 0.17 ohms per mile.

$$I_r = 540 \angle -25.8^\circ + 21.1 \angle 90^\circ = 531 \angle -23.8^\circ \text{ amperes}$$

$$\begin{aligned} I_r Z_r &= (531 \angle -23.8^\circ) (71.8 \angle 80.6^\circ) = 38,100 \angle 56.8^\circ \\ &= 20,800 + j 31,900 \text{ volts} \end{aligned}$$

If the loads of cities A and B are neglected, the voltage at the northwestern New Mexico plant, which is necessary to deliver 115,000 volts at Albuquerque, is found to be

$$E_{nw} = E_{Alb} + E_{drop} = E_{Alb} + I_r Z_r$$

I_r in this case is the Albuquerque load current $379 \angle -258^\circ$ amperes plus the capacitive charging current of the line, $21.1 \angle 90^\circ$ amperes.

$$I_r = 341 - j 165 + j 21.1 = 341 - j 143.9 = 370 \angle -22.9^\circ$$

$$\begin{aligned} Z_r &= (0.1185 + j 0.717) 120 = (0.726 \angle 80.6^\circ) 120 \\ &= 87.12 \angle 80.6^\circ \text{ ohms} \end{aligned}$$

$$\begin{aligned} I_r Z_r &= (370 \angle -22.9^\circ) (87.12 \angle 80.6^\circ) = 32,230 \angle 57.7^\circ \text{ volts} \\ &= 17,200 + j 27,270 \text{ volts} \end{aligned}$$

$$\begin{aligned} E_{nw} &= (66,400 + j 0.0) + (17,200 + j 27,270) = 83,600 + \\ & \quad j 27,270 = 87,900 \angle 18.1^\circ \text{ volts} \end{aligned}$$

These voltage values show that the voltage drop of the line would be too large for satisfactory operation. The voltage drop may be lowered, however, by installing capacitors at the receiving end of the line. The fixed charges of the capacitors must be included in the computations for the economic conductor size. The least number of capacitors, and, therefore, the most economical approach, would be achieved by connecting the capacitors in series with the

$17 = 208 - 22.17 + 21.2(1.01) = 211.95$ dollars
 $18 = 211.95 - 22.2(1.01) + 21.2(1.01)^2 = 216.02$
 $= 219.99$

If the amount of interest is not to exceed \$2000, then the amount at the end of the 18th year is \$219.99.

$19 = 219.99 - 22.3(1.01) + 21.2(1.01)^3 = 224.19$
 $20 = 224.19 - 22.4(1.01) + 21.2(1.01)^4 = 228.58$
 $21 = 228.58 - 22.5(1.01) + 21.2(1.01)^5 = 233.07$
 $22 = 233.07 - 22.6(1.01) + 21.2(1.01)^6 = 237.66$

$23 = 237.66 - 22.7(1.01) + 21.2(1.01)^7 = 242.34$
 $24 = 242.34 - 22.8(1.01) + 21.2(1.01)^8 = 247.11$
 $25 = 247.11 - 22.9(1.01) + 21.2(1.01)^9 = 251.98$

$26 = 251.98 - 23.0(1.01) + 21.2(1.01)^{10} = 256.94$
 $27 = 256.94 - 23.1(1.01) + 21.2(1.01)^{11} = 261.99$
 $28 = 261.99 - 23.2(1.01) + 21.2(1.01)^{12} = 267.14$

These values are all positive, and the amount of money at the end of each year would be too large for the bank to handle. The amount of money at the end of the 18th year is \$219.99, and the amount of money at the end of the 19th year is \$224.19. The amount of money at the end of the 20th year is \$228.58, and the amount of money at the end of the 21st year is \$233.07. The amount of money at the end of the 22nd year is \$237.66, and the amount of money at the end of the 23rd year is \$242.34. The amount of money at the end of the 24th year is \$247.11, and the amount of money at the end of the 25th year is \$251.98. The amount of money at the end of the 26th year is \$256.94, and the amount of money at the end of the 27th year is \$261.99. The amount of money at the end of the 28th year is \$267.14.



line. The objection to this practice is the high voltages developed across the capacitors during line surges. This disadvantage may be overcome, however, by connecting arcing horns around the capacitors. A high voltage across the capacitors would thus be dissipated by an arc across the horns and the capacitors would not be damaged. The amount of capacitance required would be that quantity which would make the line capacitive impedance equal to the line inductive impedance. The capacitive impedance, therefore, must be $(0.717)(120) = 86.04$ ohms. The capacitors required to obtain the impedance is

$$C = \frac{1}{2\pi fX} = \frac{1}{2\pi (60)(86.04)} = 3.095 \times 10^{-5} \text{ farads}$$

At peak load conditions the KVAR required would be

$$I^2 X_C = (379)^2 (86.04) = 1.236 \times 10^7 \text{ VAR's} = 1236 \text{ KVAR'S}$$

Estimating the installed cost of the capacitors at \$200.00 per KVAR, the total cost would be \$247,200. The fixed charges on this cost would be $(2.472 \times 10^5)(0.151) = \$37,327$, and the cost per kilowatt-hour would be

$$\frac{3.7327 \times 10^4}{5.912 \times 10^8} = 6.31 \times 10^{-5} = \$0.0000631/\text{kwhr}$$

This value must be subtracted from the left side of the following equation which was used in Section H of this chapter

$$T-S \frac{(m + KB)}{Y} Z = \frac{Z}{Y} \left[(I_{RHS}^2 10^{-3}) + \frac{KWG}{r} \right]$$

The extension of this analysis to include a larger number of modes is straightforward. The only modification is that the summation over modes must now include all modes up to the cut-off frequency. The resulting expression for the admittance is then given by

$$Y(\omega) = \sum_{n=1}^{\infty} \frac{1}{j\omega L_n + R_n + \frac{1}{j\omega C_n}}$$

where L_n , R_n , and C_n are the inductance, resistance, and capacitance of the n th mode, respectively. The admittance is a function of frequency ω and is complex-valued. The real part represents the conductance and the imaginary part represents the susceptance.

is

$$Y(\omega) = \sum_{n=1}^{\infty} \frac{1}{j\omega L_n + R_n + \frac{1}{j\omega C_n}}$$

At low frequencies, the admittance is dominated by the first mode. The admittance is then approximately given by

$$Y(\omega) \approx \frac{1}{j\omega L_1 + R_1 + \frac{1}{j\omega C_1}}$$

where L_1 , R_1 , and C_1 are the inductance, resistance, and capacitance of the first mode, respectively. The admittance is a function of frequency ω and is complex-valued. The real part represents the conductance and the imaginary part represents the susceptance.

$$Y(\omega) \approx \frac{1}{j\omega L_1 + R_1 + \frac{1}{j\omega C_1}}$$

This value is a complex number. The real part represents the conductance and the imaginary part represents the susceptance. The admittance is a function of frequency ω and is complex-valued.

$$Y(\omega) \approx \frac{1}{j\omega L_1 + R_1 + \frac{1}{j\omega C_1}}$$

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$$5.937 \times 10^{-4} - 6.31 \times 10^{-5} = 3.065 \times 10^{-3}r + \frac{2.736 \times 10^{-5}}{r}$$

$$r = \frac{0.5306 \pm \sqrt{0.2812 - 0.3354}}{2(0.5306)}$$

It is seen that the value under the radical sign is negative. This means that the additional cost of capacitors to give satisfactory voltage regulation would make the transmission line and remote generation scheme uneconomical as compared to power generated at the load center.

An alternate plan to the capacitors would be to supply the capacitive KVAR's from the generators at Albuquerque. Excess generating capacity equal to the largest generating unit is kept spinning at the Albuquerque generating plants as described in Section G of this chapter. This excess capacity could be used to supply the capacitance KVAR's to improve the voltage regulation. Such a transmission scheme may present stability difficulties, however. These difficulties may be visualized by reducing the proposed generator and transmission system to a single load and to single generators at both Albuquerque and the remote generating plant. To study these difficulties, the condition of maximum load will be taken for the year 1963 with the proposed transmission line supplying 75,000kw. The loads of cities A and B will be omitted in this stability study. The Albuquerque generators will supply capacitive KVAR's to the transmission line in sufficient quantity to limit the voltage drop to 5 per cent. At these conditions the transmission line will be removed from

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It is seen that the value of the ratio $\frac{V_{out}}{V_{in}}$ is unity. This means that the output voltage is equal to the input voltage. The voltage regulation is zero. This is the ideal case. In practice, the voltage regulation is not zero. This is due to the internal resistance of the transformer and the load resistance. The voltage regulation is given by the following equation:

$$\text{Voltage Regulation} = \frac{V_{no-load} - V_{full-load}}{V_{full-load}} \times 100\%$$

where $V_{no-load}$ is the output voltage at no-load and $V_{full-load}$ is the output voltage at full-load. The voltage regulation is zero when the load resistance is infinite. This is the ideal case. In practice, the load resistance is finite. This is due to the load connected to the transformer. The voltage regulation is given by the following equation:

$$\text{Voltage Regulation} = \frac{I_{no-load} R_{eq} - I_{full-load} R_{eq}}{I_{full-load} R_{eq}} \times 100\%$$

where $I_{no-load}$ is the no-load current and $I_{full-load}$ is the full-load current. The voltage regulation is zero when the load current is zero. This is the ideal case. In practice, the load current is not zero. This is due to the load connected to the transformer. The voltage regulation is given by the following equation:

$$\text{Voltage Regulation} = \frac{I_{no-load} R_{eq} - I_{full-load} R_{eq}}{I_{full-load} R_{eq}} \times 100\%$$

where R_{eq} is the equivalent resistance of the transformer. The voltage regulation is zero when the load current is zero. This is the ideal case. In practice, the load current is not zero. This is due to the load connected to the transformer. The voltage regulation is given by the following equation:

$$\text{Voltage Regulation} = \frac{I_{no-load} R_{eq} - I_{full-load} R_{eq}}{I_{full-load} R_{eq}} \times 100\%$$

where $I_{no-load}$ is the no-load current and $I_{full-load}$ is the full-load current. The voltage regulation is zero when the load current is zero. This is the ideal case. In practice, the load current is not zero. This is due to the load connected to the transformer. The voltage regulation is given by the following equation:

$$\text{Voltage Regulation} = \frac{I_{no-load} R_{eq} - I_{full-load} R_{eq}}{I_{full-load} R_{eq}} \times 100\%$$

where R_{eq} is the equivalent resistance of the transformer. The voltage regulation is zero when the load current is zero. This is the ideal case. In practice, the load current is not zero. This is due to the load connected to the transformer. The voltage regulation is given by the following equation:

the Albuquerque System to simulate an outage from a line fault and the stability of the remaining Albuquerque System will be investigated.

The Albuquerque System with the proposed transmission line connected is represented by the following diagram:

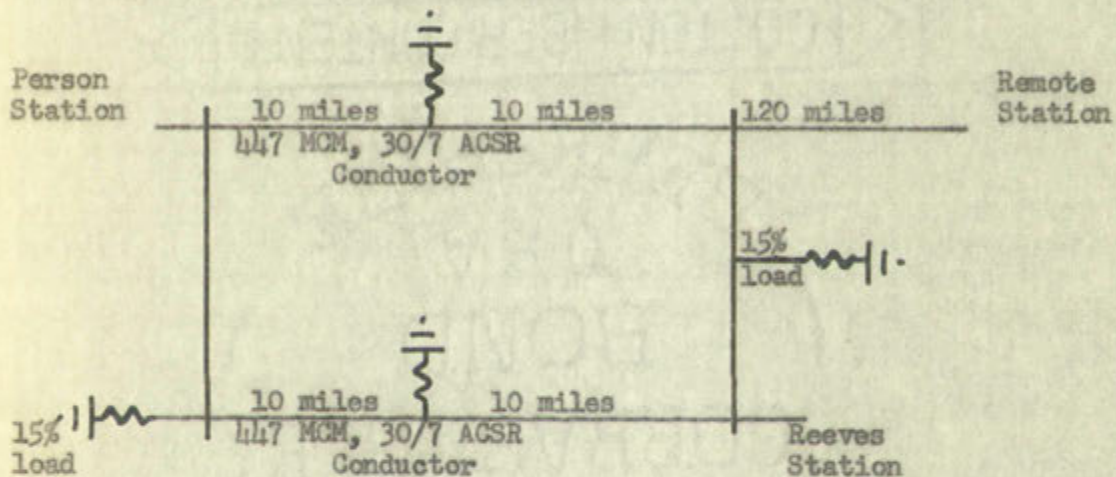


Figure 9. One line diagram, Albuquerque 115kv Electric System and proposed line from northwestern New Mexico

This system may be reduced to the following:

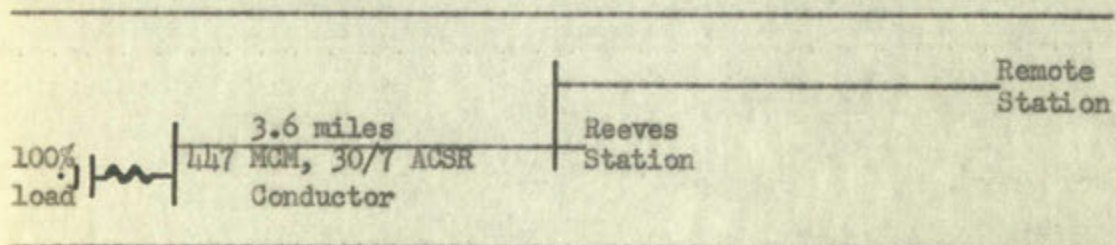


Figure 10. Equivalent one line diagram, Albuquerque 115kv Electric System

The peak load for the year 1963 is 226,000kw. With 75,000kw

The following table shows the results of the analysis of the samples collected in the field in the vicinity of the station during the period from 1911 to 1913. The samples were collected in the following order:

| Station | Date | Sample No. | Analysis |
|-----------|------|------------|----------|
| Station 1 | 1911 | 1 | ... |
| Station 2 | 1912 | 2 | ... |
| Station 3 | 1913 | 3 | ... |

Figure 1. The first sample, collected in the field in 1911, and the second sample, collected in the field in 1912.

The results are given in the following table:

| Station | Date | Sample No. | Analysis |
|-----------|------|------------|----------|
| Station 1 | 1911 | 1 | ... |
| Station 2 | 1912 | 2 | ... |
| Station 3 | 1913 | 3 | ... |

Figure 2. The first sample, collected in the field in 1911, and the second sample, collected in the field in 1912.

The first sample was collected in the year 1911, and the second sample was collected in the year 1912.

being supplied from the remote transmission line, the Albuquerque generation load is 151,000kw.

Since the line is short, the charging and conductance current is neglected. The receiving end current is then equal to the sending end current and is found as follows

$$I_L = \frac{\text{KVA}}{\sqrt{3} (\text{KV}) (\text{power factor})} = \frac{226,000}{\sqrt{3} (115) (.9)} = 1262 \text{ amp}$$

The line impedance from the Albuquerque generators to the load is:

Resistance for 447 MCM, 30/7 ACSR conductor = 0.216 ohms/mile.

Inductive reactance for the above conductor at 19.6 feet equivalent spacing = 0.780 ohms/mile.

$$Z = 3.6 (0.216 + j 0.780) = 0.756 + j 2.73.$$

The impedance of the step-down transformer at the load is equivalent to the impedances of all the load transformers connected in parallel. On a 115,000 volt base this impedance is assumed to be 4.61 ohms, i.e., $X_t = 4.61$ ohms. The resistance is neglected in transformers greater than 500 KVA capacity because the inductive reactance is very large compared to the resistance.⁸

For these conditions the impedance between the load and the 115,000 volt bus at the Albuquerque generating station is

$$Z_{B-L} = 0.756 + j 2.73 + 4.61 = 0.756 + j 7.34 = 7.38 \angle 84.1^\circ$$

⁸J. E. Hobson and R. L. Witzke, "Power Transformers and Reactors," Electrical Transmission and Distribution Reference Book, (3d ed.; East Penn. Westinghouse Co., 1944), p. 401.

being notified that the order transmitted has been
questioned in the U.S. Office.

Since the time is short, the Director has a great deal
to do in regard to the receiving and forwarding of
orders and returns and a great deal of work.

$$I^2 = \frac{L^2}{V^2} \left(\frac{1}{1 - \frac{v^2}{c^2}} \right)^{3/2}$$

The time required for the transmission of the light

is

$$t = \frac{L}{V} \left(\frac{1}{1 - \frac{v^2}{c^2}} \right)^{3/2}$$

Relative motion of the light and the observer
equivalent to the motion of the observer.

$$t = \frac{L}{V} \left(\frac{1}{1 - \frac{v^2}{c^2}} \right)^{3/2}$$

The frequency of the light as seen by the observer
equivalent to the frequency of the light as seen by the
observer. At a distance of 100,000 miles the frequency is
1.01 times, i.e., $f = 1.01 f_0$, and the wavelength is
transmitted greater than the wavelength of the light as
seen in very large amounts in the laboratory.

For these conditions the frequency of the light as
seen is 1.01 times that of the light as seen in the
laboratory.

$$f = 1.01 f_0 = 1.01 \times 10^{14} \text{ Hz}$$

8. The speed of light is constant in all directions
and is independent of the motion of the source or
the observer.

The Albuquerque generating station 115,000 volt bus is taken as the reference voltage, i.e., $V_S = \frac{115,000}{\sqrt{3}} = 66,400$ volts. The load voltage then becomes

$V_L = (66,400 + j 0.0) - (Z_{B-L}) (I \angle \theta)$ where θ = load power factor angle

$$\begin{aligned} V_L &= 66,400 - (7.38 \angle 84.1^\circ) (1262 \angle -25.90^\circ) \\ &= 66,400 - 9314 \angle 58.2^\circ = 62,100 \angle -7.33^\circ \end{aligned}$$

The load current supplied by the transmission line from the northwestern area of New Mexico is

$$I_{T-L} = \frac{75,000}{115 \sqrt{3} (0.9)} = 418 \angle -25.90^\circ$$

The northwestern New Mexico transmission line impedance from page 43 is $87.12 \angle 80.6^\circ$ ohms. To limit the voltage drop to 5 per cent the "effective" line power factor can be found from the equality

$$\begin{aligned} E_{TW} &= \sqrt{V_S + IZ \cos(\theta_1 + \theta_2)}^2 + I^2 Z \sin(\theta_1 + \theta_2)}^2 \\ &= \sqrt{V_S^2 + 2V_S I Z \cos(\theta_1 + \theta_2) + I^2 Z^2} \end{aligned}$$

where

E_{TW} = voltage on transmission line at the remote generating station

V_S = Albuquerque generating station bus voltage = $\frac{115KV}{\sqrt{3}}$

I = magnitude of line current

Z = magnitude of the line impedance = $120 (0.1185 + j 0.717)$
= 87.12

θ_1 = power factor angle

θ_2 = impedance angle = 80.6°

The diagram shows a circuit with a load voltage V_L and a source voltage V_S . The load is connected in series with the source.

$$V_L = V_S - I R_{int}$$

$$I = \frac{V_S - V_L}{R_{int}}$$

The load current I_L is equal to the source current I_S .

$$I_L = \frac{V_S - V_L}{R_{int}}$$

The maximum power transfer theorem states that the maximum power is transferred to the load when the load resistance is equal to the source resistance.

$$P_L = I_L^2 R_L = \left(\frac{V_S - V_L}{R_{int}} \right)^2 R_L$$

where

- V_S = source voltage
- R_{int} = internal resistance of the source
- R_L = load resistance
- I_L = load current
- V_L = load voltage
- P_L = load power

The equation now becomes

$$E_{TW} = \sqrt{4.41 \times 10^9 + 1.157 \times 10^7 I \cos (\theta_1 + 80.6^\circ) + 7.6 \times 10^3 I^2}$$

If the value of $(I \cos \theta_1)$ is held constant, to supply the 75,000kw, and θ_1 is varied, a curve of E_{TW} versus θ_1 can be drawn. The minimum power factor angle, θ_1 , which corresponds to the voltage representing maximum line drop, can be selected from the curve. For the study under discussion the angle was found to be 18.5° . This means that the transmission line current must be

$$\frac{418 \cos 25.9^\circ}{\cos 18.5^\circ} = 398 \angle 18.5^\circ \text{ amperes}$$

The Albuquerque generators must supply all the capacitive part of the current. Therefore, the Albuquerque generator supply to the transmission line

$$418 \sin 25.9^\circ + 398 \sin 18.5^\circ = 376 \angle 90^\circ + 126 \angle 90^\circ \text{ amperes}$$

The load current supplied by the Albuquerque generators on a 115,000 volt base is

$$\frac{226,000\text{KVA} - 75,000\text{KVA}}{115 (\sqrt{3}) (0.9)} = 843 \angle -25.9^\circ = 758 - j 368 \text{ amperes}$$

The total current supplied by the Albuquerque generators is

$$758 - j 368 + j 502 = 758 + j 134 = 770 \angle 10^\circ \text{ amperes}$$

The impedance of the generator is equivalent to the impedance of all Albuquerque generators connected in parallel. For the present illustration this equivalent impedance is assumed to be 7.5 ohms on a

CONTRACTS

FOR

The operation now occurs

$x_m = \sqrt{\frac{1}{2} \frac{1 + \cos \theta}{1 - \cos \theta}}$

If the value of θ is 0° , $x_m = 1$.
If $\theta = 90^\circ$, $x_m = \sqrt{\frac{1}{2}}$.
If $\theta = 180^\circ$, $x_m = 0$.

The minimum power factor is $\frac{1}{2}$ when $\theta = 90^\circ$.
The maximum power factor is 1 when $\theta = 0^\circ$ or 180° .

The study made indicates that the power factor is $\frac{1}{2}$ when $\theta = 90^\circ$.

It seems that the conventional treatment of

$$\frac{1}{2} \frac{1 + \cos \theta}{1 - \cos \theta} = \frac{1}{2} \frac{1 + \cos \theta}{1 - \cos \theta}$$

The algebraic process is not correct in this part of the circuit. Therefore, the algebraic process is not correct in this part of the circuit.

The load current is $I_L = \frac{V_L}{Z_L}$.

The load current is $I_L = \frac{V_L}{Z_L}$.

$$\frac{1}{2} \frac{1 + \cos \theta}{1 - \cos \theta} = \frac{1}{2} \frac{1 + \cos \theta}{1 - \cos \theta}$$

The total current supplied by the generator is $I_T = I_L + I_C$.

The impedance of the generator is $Z_G = R_G + jX_G$.

The impedance of the generator is $Z_G = R_G + jX_G$.

of all algebraic expressions concerning the power factor.

Illustration of the operation of the generator is shown in Figure 1.

115,000 volt base, i.e., $X_d = 7.5$ ohms. If the step-up transformer at the generator is assumed to have the same impedance as the step-down transformer at the load then the total impedance from the internal voltage of the generators and the Albuquerque 115,000 volt bus is

$$j 7.5 + 4.7 = j 12.2 \text{ ohms}$$

The generator internal voltage is then

$$E_g = (66,400 + j 0.0) + (770 \angle 10^\circ) (12.2 \angle 90^\circ) = 65,500 \angle 8.1^\circ$$

The electrical angle between the generator voltage and the load voltage is

$$\delta = 8.10^\circ + 7.33^\circ = 15.43^\circ$$

The maximum synchronizing power⁹ is found by the formula

$$P_m = \frac{151,000\text{KVA}}{\sin 15.43^\circ} = 567,000\text{KVA}$$

The "swing" curve is found by the same formula. The curve for the problem is shown in Figure 11.

The system is initially operating at the 15.43° on the abscissa of the stability curve. If the transmission line to northwestern New Mexico is suddenly disconnected from the system, the Albuquerque generators immediately have 75,000kw to pick up. This increase is shown by the line at twenty-four degrees. The criteria for stability is that the area blocked in above the curve between 15.43° and 24° must not be greater than the area under the curve between 24° and $(180^\circ - 24^\circ) = 156^\circ$. A visual inspection of the curve

⁹Maximum synchronizing power is defined as the power available to restore stability after a transient condition. The maximum synchronizing power is equal to the maximum transfer of power from the generators to the load.

115,000 volt bus, ... at the generator ... down ... central voltage ... bus is

The generator ...
 $R = (1.00 + j0.05) \times 10^{-3}$
The equivalent ... load voltage is

$V = 1.10 \times 10^5$
The ... for the ...

The system is ... stability of the ... vectors ...

Algebraic ... for stability ... 15.13 ...

shows this system would retain stability if it were required only to pick up the additional 75,000kw. When the line to the remote station is suddenly disconnected from the Albuquerque System, the Albuquerque generators are also required to change power factor quickly due to the leading power factor current the generators have been supplying to the northwestern New Mexico line. The generator voltage will become

$$E_g = 66,400 \angle 0^\circ + (12.2 \angle 90^\circ) (1262 \angle -25.9^\circ) = 74,400 \angle 10.75^\circ$$

The electrical angle between the generator voltage and load, therefore, increases $10.75^\circ - 8.10^\circ = 2.65^\circ$. This angle is added to the load angle and a vertical line is drawn to the load curve. This angle, $24.0^\circ + 2.65^\circ = 26.65^\circ$, intersects the load curve at approximately 254,000kw. The transient power drawn from the system is represented by the area "abca" in Figure 11. The system will regain stability if the area "abca" is less than the area "dP_mdb." The point d is on the curve at $180^\circ - 26.65^\circ = 153.35^\circ$. A visual inspection of Figure 11 shows that this system will regain stability. If the visual inspection did not give an obvious answer, the areas could be found by integrating the curve between the indicated limits and comparing the two areas.

The above analysis shows, for the circuit values and assumption made, that the excess generating capacity at Albuquerque could be used to supply capacitive KVAR's to the transmission line from the remote generating station. These capacitive KVAR's could be

about this space will show the lines in the figure
to give up the electrical energy, which is the
station is usually divided into two parts, the
Aluminum conductors and steel reinforcement
usually are so the loading is not on the
been applying to the steel reinforcement, the
voltage will become

$E = 0.5, 100 \text{ (or } 0.5 \text{ kV) } \times \text{ length} \times \text{cross-section}$
The electrical angle between the two wires is
therefore, distance is $10^3 \times 0.5 \times 0.5 = 0.25 \times 10^6$
the load angle and a constant angle is a part of the load angle. The
angle, $20.00 + 0.500 = 20.500$, therefore, the angle is a part
usually 20,000kV. The constant angle is usually 20,000kV
represented by the angle in the figure. The angle will
usually it has angle $10^3 \times 0.5 \times 0.5 = 0.25 \times 10^6$. The angle
is on the curve as $10^3 \times 0.5 \times 0.5 = 0.25 \times 10^6$. The angle
Figure 11 shows that this angle will be a constant angle. The angle
inspection the angle is the angle. The angle is usually
by inspection the angle is the angle. The angle is usually
the two wires.
The angle is usually $10^3 \times 0.5 \times 0.5 = 0.25 \times 10^6$. The angle
from angle, that the angle is usually $10^3 \times 0.5 \times 0.5 = 0.25 \times 10^6$.
be used to supply energy or $10^3 \times 0.5 \times 0.5 = 0.25 \times 10^6$. The angle
the remote generation station. The angle is usually $10^3 \times 0.5 \times 0.5 = 0.25 \times 10^6$.

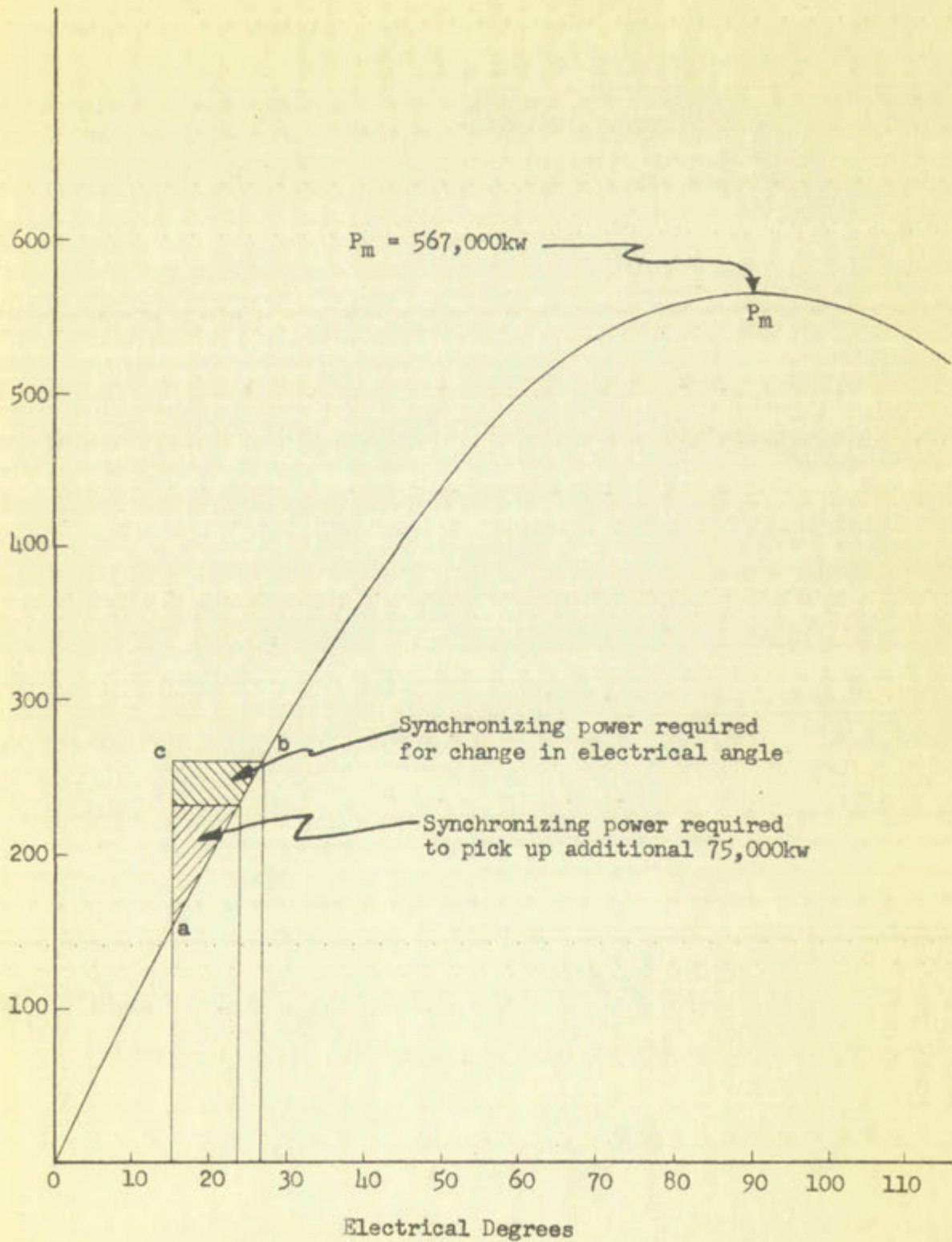
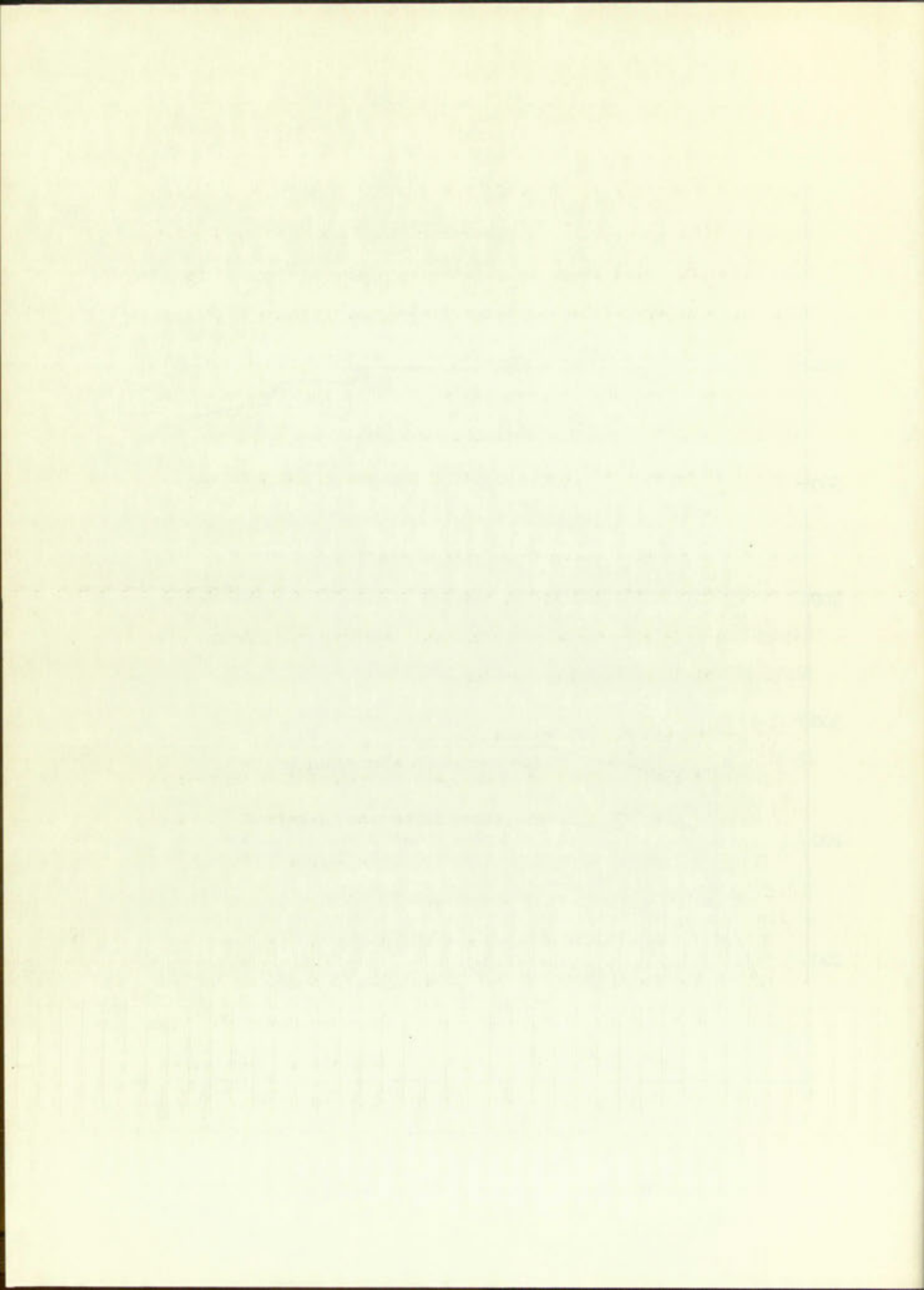


Figure 11. Swing Curve for Albuquerque System



supplied in quantity to limit the transmission line voltage drop to 5 per cent and an outage of the northwestern New Mexico transmission line would not cause instability in the Albuquerque System. Therefore, the analysis of Section H of this chapter indicates the conductor sizes for the equal Albuquerque cost for generation at either Albuquerque or northwestern New Mexico and also the conductor size that will give the greatest economic advantage. Supplying the large quantity of capacitive KVAR's to the transmission line does not require additional generating capacity on the line at Albuquerque because the Albuquerque generators change power factors to supply most of the KVAR's without exceeding the KVA ratings of the generators. The spinning excess capacity is utilized to supply the KVA not provided by changing the power factor.

J. Other Voltage Considerations

As stated in the first paragraph of Section H of this chapter, a voltage of 115,000 volts was selected because it best illustrated the use of the formulas developed in Chapter III, and it best illustrated the determination of transmission line difficulties. A higher voltage would not present the voltage regulation difficulties as vividly as did the 115,000 volts. If a higher voltage were to be selected for the study, a "rule of thumb" which has been widely used by utilities in the past would indicate that a voltage three times the magnitude of existing lines be studied. For the Public Service

supplied in quantity to the...
5 per cent and for...
line would not cause...
fore, the analysis of...
not since for the...
Albuquerque or...
that will give the...
quantity of...
quite essential...
cause the...
of the...
the...
vided by...

4. Other...

As stated in the...
a volume of...
the use of...
created the...
volume would...
vividly as...
collected for...
by utilizing...
the magnitude of...

Company of New Mexico this voltage would be $3(115,000) = 345,000$ volts. The loads of the Public Service Company of New Mexico would not justify the investment required for a transmission line of this voltage. Also, recent studies have indicated that 230,000 volt transmission lines are often more economical if due consideration is given in the cost analysis to dual lines or excess generating capacity which provide reliability.¹⁰

The 230,000 volt transmission line has been studied by the formulas developed in Chapter III. In these studies the following assumptions were made:

Peak line loading = 160,000kw
 Line load factor = 75 per cent
 System load factor = 65 per cent
 Length of line = 120 miles
 Cost of maintenance = \$200.00 per mile per year
 Annual fixed charges = 15.1 per cent
 Increase in cost of Albuquerque generation due to good load factor on transmission line = \$0.0025 per kwhr
 Cost of Albuquerque generation without proposed transmission line = \$0.0049
 Cost of generation at northwestern New Mexico plant = \$0.0040
 Power factor of load = 90 per cent
 Square root of the mean square current = average line load current
 Cost of the 230,000 volt line without conductor = \$18,000 per mile
 Peak system load = 221,000kw

With these conditions the most economical conductor was found to be the largest size attainable, but the scheme was found uneconomical.

¹⁰Electrical World, "Utilities Offer 230KV Plan for Five-State Rocky Mountain Area," November 30, 1959, pp. 86-89.

Company of New York and London...
The Board of Directors...
not finally...
voltage...
attention...
in the...
provides...

The \$50,000...
formulas...
assumptions...

For this...
This...
System...
Amount...
Interest...
Loss...
Cost...
Cost...
Lower...
Form...
Loss...
Cost...
Form...
Loss...
Cost...

also...
to be...

That is, for the above conditions it would be more economical to install additional generating capacity at Albuquerque than to build a 230,000 volt transmission line from a generating plant located 120 miles from Albuquerque. A change of some of the above assumptions, however, could change this result and make the 230,000 volt line a greater savings than a 115,000 volt line. No further pursuit of this subject will be made, however, since the general methods of procedure and the use of formulas developed in this thesis have been fully illustrated.

K. Conclusions

The Public Service Company of New Mexico can economically build a 115,000 volt transmission line 120 miles long from Albuquerque to northwestern New Mexico to serve the Albuquerque system load. This conclusion is based on prices and assumptions given in Chapter IV of this paper. The transmission line must be supplied capacitive KVAR's from Albuquerque to give the line satisfactory voltage-drop characteristics and these KVAR's must be supplied at no additional investment cost. If additional investments were required for installing capacitors, the plan would be uneconomical due to the annual fixed charges on the capacitors. The capacitive KVAR's can be supplied by Albuquerque generators which are already supplying load not provided by the transmission line and which are kept running for emergency stand-by capacity. Supplying the KVAR's from the Albuquerque generators would require no additional investment to maintain

desired transmission line voltage characteristics. The leading power factor required of the generators supplying the capacitive KVAR's would cause no stability difficulties in case the transmission line to the remote generating plant were disconnected from the Albuquerque system. The electrical angle between the generator and load would change only a slight amount and the 75,000kw being supplied by the transmission line could be picked up by the Albuquerque generators without stability difficulties. These conclusions are based on the assumptions and calculations of the previous section of this paper. All calculations were made for 900 million circular mills conductors in the proposed transmission line because that is the size of conductor which makes the cost of the northwestern New Mexico generated power equal the cost of power from Albuquerque generators.

The transmission voltage for the line studies was selected as 115,000 volts on the basis of economy of connection to existing transmission systems and for illustrative purposes as explained in previous sections of this Thesis. A higher voltage would give better voltage regulation but the installation cost, and thus the fixed charges cost per kilowatt-hour, would increase. Computations which have been made for voltages above 115,000 volts have shown these voltages to be uneconomical. The results would be affected considerably, however, by differences in the various load and cost values which were used.

APPENDIX I

KEY TO FORMULA SYMBOLS OF CHAPTER III

| | |
|---|---|
| A | Peak load at a known time, kw |
| B | Cost per mile in dollars of line less conductor |
| C | Generation cost in dollars per kwhr at load center |
| D | Total cost per mile of line in dollars |
| E | Cost of conductor per mile in dollars |
| F | Cost in dollars of fixed charges per kwhr |
| G | Constant for pounds per mile conversion to resistance per mile |
| H | Hours per year |
| I | Average current flow in amperes |
| K | Per cent of original cost for annual fixed charges |
| L | Cost of line power losses per kwhr |
| M | Annual transmission line maintenance cost |
| m | Annual transmission line maintenance cost per mile per kwhr |
| P | Peak load in future in kw |
| R | Total resistance of transmission line in ohms per phase |
| r | Resistance of line per mile per phase |
| S | Generation cost per kwhr at remote generating site |
| T | Total cost per year per kwhr at Albuquerque of remotely generated power |
| W | Cost per pound of conductor |
| X | Total amount of fixed charges in dollars |
| Y | Total kwhr per year |
| Z | Length of line in miles |

THE 1930S

| | |
|------|-----|
| 1930 | 1 |
| 1931 | 2 |
| 1932 | 3 |
| 1933 | 4 |
| 1934 | 5 |
| 1935 | 6 |
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| 1939 | 10 |
| 1940 | 11 |
| 1941 | 12 |
| 1942 | 13 |
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| 2015 | 86 |
| 2016 | 87 |
| 2017 | 88 |
| 2018 | 89 |
| 2019 | 90 |
| 2020 | 91 |
| 2021 | 92 |
| 2022 | 93 |
| 2023 | 94 |
| 2024 | 95 |
| 2025 | 96 |
| 2026 | 97 |
| 2027 | 98 |
| 2028 | 99 |
| 2029 | 100 |

APPENDIX II
 CONSTANTS OF WEIGHT TIMES RESISTANCE
 FOR VARIOUS CONDUCTORS

ACSR 26/7 Stranding

| <u>Size</u> <u>MCM</u> | <u>Weight</u> <u>#/mile</u> | <u>Resistance</u> <u>ohms/mile</u> | <u>Constant</u> <u>Wt x ohms</u> |
|-------------------------------|--------------------------------|---------------------------------------|-------------------------------------|
| 266.8 | 1939 | 0.3850 | 747 |
| 300.0 | 2179 | 0.3420 | 745 |
| 336.4 | 2446 | 0.3060 | 748 |
| 397.5 | 2888 | 0.2590 | 748 |
| 477.0 | 3468 | 0.2160 | 749 |
| 556.5 | 4045 | 0.1859 | 751 |
| 605.0 | 4395 | 0.1720 | 755 |
| Average Constant, (wt) (ohms) | | | <u>747.6</u> |

ACSR 30/7 Stranding

| | | | |
|-------------------------------|------|--------|------------|
| 300.0 | 2473 | 0.3420 | 846 |
| 336.4 | 2783 | 0.3060 | 850 |
| 397.5 | 3288 | 0.2590 | 851 |
| 477.0 | 3946 | 0.2160 | 851 |
| 500.0 | 4122 | 0.2060 | 849 |
| 556.5 | 4604 | 0.1859 | 855 |
| Average Constant, (wt) (ohms) | | | <u>850</u> |

Hard-drawn Copper, Stranded

| | | | |
|-------------------------------|------|--------|------------|
| 1/0 | 1720 | 0.5502 | 946 |
| 2/0 | 2169 | 0.4365 | 947 |
| 3/0 | 2736 | 0.3462 | 947 |
| 4/0 | 3450 | 0.2745 | 947 |
| 250 | 4076 | 0.2323 | 947 |
| 300 | 4891 | 0.1936 | 947 |
| 350 | 5706 | 0.1660 | 947 |
| 400 | 6521 | 0.1452 | 947 |
| 450 | 7336 | 0.1291 | 947 |
| 500 | 8151 | 0.1162 | 947 |
| 550 | 8966 | 0.1056 | 947 |
| 600 | 9781 | 0.0968 | 947 |
| Average Constant, (wt) (ohms) | | | <u>947</u> |

COFFEE TABLE
BOARD

EXHIBIT NO. 1

| Size | Weight | Volume | Capacity |
|---------------|--------|---------|----------|
| 24" x 36" | 1200 | 1200 | 1200 |
| 30" x 42" | 1500 | 1500 | 1500 |
| 36" x 48" | 1800 | 1800 | 1800 |
| 42" x 54" | 2100 | 2100 | 2100 |
| 48" x 60" | 2400 | 2400 | 2400 |
| 54" x 66" | 2700 | 2700 | 2700 |
| 60" x 72" | 3000 | 3000 | 3000 |
| 66" x 78" | 3300 | 3300 | 3300 |
| 72" x 84" | 3600 | 3600 | 3600 |
| 78" x 90" | 3900 | 3900 | 3900 |
| 84" x 96" | 4200 | 4200 | 4200 |
| 90" x 102" | 4500 | 4500 | 4500 |
| 96" x 108" | 4800 | 4800 | 4800 |
| 102" x 114" | 5100 | 5100 | 5100 |
| 108" x 120" | 5400 | 5400 | 5400 |
| 114" x 126" | 5700 | 5700 | 5700 |
| 120" x 132" | 6000 | 6000 | 6000 |
| 126" x 138" | 6300 | 6300 | 6300 |
| 132" x 144" | 6600 | 6600 | 6600 |
| 138" x 150" | 6900 | 6900 | 6900 |
| 144" x 156" | 7200 | 7200 | 7200 |
| 150" x 162" | 7500 | 7500 | 7500 |
| 156" x 168" | 7800 | 7800 | 7800 |
| 162" x 174" | 8100 | 8100 | 8100 |
| 168" x 180" | 8400 | 8400 | 8400 |
| 174" x 186" | 8700 | 8700 | 8700 |
| 180" x 192" | 9000 | 9000 | 9000 |
| 186" x 198" | 9300 | 9300 | 9300 |
| 192" x 204" | 9600 | 9600 | 9600 |
| 198" x 210" | 9900 | 9900 | 9900 |
| 204" x 216" | 10200 | 10200 | 10200 |
| 210" x 222" | 10500 | 10500 | 10500 |
| 216" x 228" | 10800 | 10800 | 10800 |
| 222" x 234" | 11100 | 11100 | 11100 |
| 228" x 240" | 11400 | 11400 | 11400 |
| 234" x 246" | 11700 | 11700 | 11700 |
| 240" x 252" | 12000 | 12000 | 12000 |
| 246" x 258" | 12300 | 12300 | 12300 |
| 252" x 264" | 12600 | 12600 | 12600 |
| 258" x 270" | 12900 | 12900 | 12900 |
| 264" x 276" | 13200 | 13200 | 13200 |
| 270" x 282" | 13500 | 13500 | 13500 |
| 276" x 288" | 13800 | 13800 | 13800 |
| 282" x 294" | 14100 | 14100 | 14100 |
| 288" x 300" | 14400 | 14400 | 14400 |
| 294" x 306" | 14700 | 14700 | 14700 |
| 300" x 312" | 15000 | 15000 | 15000 |
| 306" x 318" | 15300 | 15300 | 15300 |
| 312" x 324" | 15600 | 15600 | 15600 |
| 318" x 330" | 15900 | 15900 | 15900 |
| 324" x 336" | 16200 | 16200 | 16200 |
| 330" x 342" | 16500 | 16500 | 16500 |
| 336" x 348" | 16800 | 16800 | 16800 |
| 342" x 354" | 17100 | 17100 | 17100 |
| 348" x 360" | 17400 | 17400 | 17400 |
| 354" x 366" | 17700 | 17700 | 17700 |
| 360" x 372" | 18000 | 18000 | 18000 |
| 366" x 378" | 18300 | 18300 | 18300 |
| 372" x 384" | 18600 | 18600 | 18600 |
| 378" x 390" | 18900 | 18900 | 18900 |
| 384" x 396" | 19200 | 19200 | 19200 |
| 390" x 402" | 19500 | 19500 | 19500 |
| 396" x 408" | 19800 | 19800 | 19800 |
| 402" x 414" | 20100 | 20100 | 20100 |
| 408" x 420" | 20400 | 20400 | 20400 |
| 414" x 426" | 20700 | 20700 | 20700 |
| 420" x 432" | 21000 | 21000 | 21000 |
| 426" x 438" | 21300 | 21300 | 21300 |
| 432" x 444" | 21600 | 21600 | 21600 |
| 438" x 450" | 21900 | 21900 | 21900 |
| 444" x 456" | 22200 | 22200 | 22200 |
| 450" x 462" | 22500 | 22500 | 22500 |
| 456" x 468" | 22800 | 22800 | 22800 |
| 462" x 474" | 23100 | 23100 | 23100 |
| 468" x 480" | 23400 | 23400 | 23400 |
| 474" x 486" | 23700 | 23700 | 23700 |
| 480" x 492" | 24000 | 24000 | 24000 |
| 486" x 498" | 24300 | 24300 | 24300 |
| 492" x 504" | 24600 | 24600 | 24600 |
| 498" x 510" | 24900 | 24900 | 24900 |
| 504" x 516" | 25200 | 25200 | 25200 |
| 510" x 522" | 25500 | 25500 | 25500 |
| 516" x 528" | 25800 | 25800 | 25800 |
| 522" x 534" | 26100 | 26100 | 26100 |
| 528" x 540" | 26400 | 26400 | 26400 |
| 534" x 546" | 26700 | 26700 | 26700 |
| 540" x 552" | 27000 | 27000 | 27000 |
| 546" x 558" | 27300 | 27300 | 27300 |
| 552" x 564" | 27600 | 27600 | 27600 |
| 558" x 570" | 27900 | 27900 | 27900 |
| 564" x 576" | 28200 | 28200 | 28200 |
| 570" x 582" | 28500 | 28500 | 28500 |
| 576" x 588" | 28800 | 28800 | 28800 |
| 582" x 594" | 29100 | 29100 | 29100 |
| 588" x 600" | 29400 | 29400 | 29400 |
| 594" x 606" | 29700 | 29700 | 29700 |
| 600" x 612" | 30000 | 30000 | 30000 |
| 606" x 618" | 30300 | 30300 | 30300 |
| 612" x 624" | 30600 | 30600 | 30600 |
| 618" x 630" | 30900 | 30900 | 30900 |
| 624" x 636" | 31200 | 31200 | 31200 |
| 630" x 642" | 31500 | 31500 | 31500 |
| 636" x 648" | 31800 | 31800 | 31800 |
| 642" x 654" | 32100 | 32100 | 32100 |
| 648" x 660" | 32400 | 32400 | 32400 |
| 654" x 666" | 32700 | 32700 | 32700 |
| 660" x 672" | 33000 | 33000 | 33000 |
| 666" x 678" | 33300 | 33300 | 33300 |
| 672" x 684" | 33600 | 33600 | 33600 |
| 678" x 690" | 33900 | 33900 | 33900 |
| 684" x 696" | 34200 | 34200 | 34200 |
| 690" x 702" | 34500 | 34500 | 34500 |
| 696" x 708" | 34800 | 34800 | 34800 |
| 702" x 714" | 35100 | 35100 | 35100 |
| 708" x 720" | 35400 | 35400 | 35400 |
| 714" x 726" | 35700 | 35700 | 35700 |
| 720" x 732" | 36000 | 36000 | 36000 |
| 726" x 738" | 36300 | 36300 | 36300 |
| 732" x 744" | 36600 | 36600 | 36600 |
| 738" x 750" | 36900 | 36900 | 36900 |
| 744" x 756" | 37200 | 37200 | 37200 |
| 750" x 762" | 37500 | 37500 | 37500 |
| 756" x 768" | 37800 | 37800 | 37800 |
| 762" x 774" | 38100 | 38100 | 38100 |
| 768" x 780" | 38400 | 38400 | 38400 |
| 774" x 786" | 38700 | 38700 | 38700 |
| 780" x 792" | 39000 | 39000 | 39000 |
| 786" x 798" | 39300 | 39300 | 39300 |
| 792" x 804" | 39600 | 39600 | 39600 |
| 798" x 810" | 39900 | 39900 | 39900 |
| 804" x 816" | 40200 | 40200 | 40200 |
| 810" x 822" | 40500 | 40500 | 40500 |
| 816" x 828" | 40800 | 40800 | 40800 |
| 822" x 834" | 41100 | 41100 | 41100 |
| 828" x 840" | 41400 | 41400 | 41400 |
| 834" x 846" | 41700 | 41700 | 41700 |
| 840" x 852" | 42000 | 42000 | 42000 |
| 846" x 858" | 42300 | 42300 | 42300 |
| 852" x 864" | 42600 | 42600 | 42600 |
| 858" x 870" | 42900 | 42900 | 42900 |
| 864" x 876" | 43200 | 43200 | 43200 |
| 870" x 882" | 43500 | 43500 | 43500 |
| 876" x 888" | 43800 | 43800 | 43800 |
| 882" x 894" | 44100 | 44100 | 44100 |
| 888" x 900" | 44400 | 44400 | 44400 |
| 894" x 906" | 44700 | 44700 | 44700 |
| 900" x 912" | 45000 | 45000 | 45000 |
| 906" x 918" | 45300 | 45300 | 45300 |
| 912" x 924" | 45600 | 45600 | 45600 |
| 918" x 930" | 45900 | 45900 | 45900 |
| 924" x 936" | 46200 | 46200 | 46200 |
| 930" x 942" | 46500 | 46500 | 46500 |
| 936" x 948" | 46800 | 46800 | 46800 |
| 942" x 954" | 47100 | 47100 | 47100 |
| 948" x 960" | 47400 | 47400 | 47400 |
| 954" x 966" | 47700 | 47700 | 47700 |
| 960" x 972" | 48000 | 48000 | 48000 |
| 966" x 978" | 48300 | 48300 | 48300 |
| 972" x 984" | 48600 | 48600 | 48600 |
| 978" x 990" | 48900 | 48900 | 48900 |
| 984" x 996" | 49200 | 49200 | 49200 |
| 990" x 1002" | 49500 | 49500 | 49500 |
| 996" x 1008" | 49800 | 49800 | 49800 |
| 1002" x 1014" | 50100 | 50100 | 50100 |
| 1008" x 1020" | 50400 | 50400 | 50400 |
| 1014" x 1026" | 50700 | 50700 | 50700 |
| 1020" x 1032" | 51000 | 51000 | 51000 |
| 1026" x 1038" | 51300 | 51300 | 51300 |
| 1032" x 1044" | 51600 | 51600 | 51600 |
| 1038" x 1050" | 51900 | 51900 | 51900 |
| 1044" x 1056" | 52200 | 52200 | 52200 |
| 1050" x 1062" | 52500 | 52500 | 52500 |
| 1056" x 1068" | 52800 | 52800 | 52800 |
| 1062" x 1074" | 53100 | 53100 | 53100 |
| 1068" x 1080" | 53400 | 53400 | 53400 |
| 1074" x 1086" | 53700 | 53700 | 53700 |
| 1080" x 1092" | 54000 | 54000 | 54000 |
| 1086" x 1098" | 54300 | 54300 | 54300 |
| 1092" x 1104" | 54600 | 54600 | 54600 |
| 1098" x 1110" | 54900 | 54900 | 54900 |
| 1104" x 1116" | 55200 | 55200 | 55200 |
| 1110" x 1122" | 55500 | 55500 | 55500 |
| 1116" x 1128" | 55800 | 55800 | 55800 |
| 1122" x 1134" | 56100 | 56100 | 56100 |
| 1128" x 1140" | 56400 | 56400 | 56400 |
| 1134" x 1146" | 56700 | 56700 | 56700 |
| 1140" x 1152" | 57000 | 57000 | 57000 |
| 1146" x 1158" | 57300 | 57300 | 57300 |
| 1152" x 1164" | 57600 | 57600 | 57600 |
| 1158" x 1170" | 57900 | 57900 | 57900 |
| 1164" x 1176" | 58200 | 58200 | 58200 |
| 1170" x 1182" | 58500 | 58500 | 58500 |
| 1176" x 1188" | 58800 | 58800 | 58800 |
| 1182" x 1194" | 59100 | 59100 | 59100 |
| 1188" x 1200" | 59400 | 59400 | 59400 |
| 1194" x 1206" | 59700 | 59700 | 59700 |
| 1200" x 1212" | 60000 | 60000 | 60000 |
| 1206" x 1218" | 60300 | 60300 | 60300 |
| 1212" x 1224" | 60600 | 60600 | 60600 |
| 1218" x 1230" | 60900 | 60900 | 60900 |
| 1224" x 1236" | 61200 | 61200 | 61200 |
| 1230" x 1242" | 61500 | 61500 | 61500 |
| 1236" x 1248" | 61800 | 61800 | 61800 |
| 1242" x 1254" | 62100 | 62100 | 62100 |
| 1248" x 1260" | 62400 | 62400 | 62400 |
| 1254" x 1266" | 62700 | 62700 | 62700 |
| 1260" x 1272" | 63000 | 63000 | 63000 |
| 1266" x 1278" | 63300 | 63300 | 63300 |
| 1272" x 1284" | 63600 | 63600 | 63600 |
| 1278" x 1290" | 63900 | 63900 | 63900 |
| 1284" x 1296" | 64200 | 64200 | 64200 |
| 1290" x 1302" | 64500 | 64500 | 64500 |
| 1296" x 1308" | 64800 | 64800 | 64800 |
| 1302" x 1314" | 65100 | 65100 | 65100 |
| 1308" x 1320" | 65400 | 65400 | 65400 |
| 1314" x 1326" | 65700 | 65700 | 65700 |
| 1320" x 1332" | 66000 | 66000 | 66000 |
| 1326" x 1338" | 66300 | 66300 | 66300 |
| 1332" x 1344" | 66600 | 66600 | 66600 |
| 1338" x 1350" | 66900 | 66900 | 66900 |
| 1344" x 1356" | 67200 | 67200 | 67200 |
| 1350" x 1362" | 67500 | 67500</ | |

APPENDIX III

GENERATING CAPACITY

Existing Generating Capacity

| | |
|--------------------------------|------------------|
| 1. Prager Station | 33,000kw |
| 2. Person Station | 125,000kw |
| 3. Reeves Station ¹ | 50,000kw |
| 4. Santa Fe Station | 23,000kw |
| 5. From USBR Tie | 15,000kw |
| 6. From Plains Co-op | 15,000kw |
| TOTAL | <u>253,000kw</u> |

Computation of Excess Generating Capacity

| | | | | |
|------------------------------|------|------------------|------|------------------|
| Year | 1959 | 1960 | 1961 | 1962 |
| Generating Capacity, mw | 253 | 303 ² | 303 | 303 |
| Peak Load ³ | 145 | 162 | 181 | 202 |
| Excess Capacity ⁴ | 108 | 147 | 122 | 101 |
| Year | 1963 | 1964 | 1965 | 1966 |
| Generating Capacity, mw | 303 | 365 ² | 365 | 428 ² |
| Peak Load | 226 | 252 | 281 | 315 |
| Excess Capacity | 77 | 113 | 84 | 113 |

¹40mw generator with 50mw peak capacity.

²New generator installed in Albuquerque or additional transmission lines from the northwestern New Mexico plant provides the additional capacity.

³From the table on Page 27.

⁴High excess capacities will probably be used by the USBR or the Plains Co-operative.

COTTON

COTTON

COTTON

1. Project Status
2. Project Status
3. Project Status
4. Project Status
5. Project Status
6. Project Status

| Year | Generating Capacity, MW | Peak Load | Annual Generation |
|------|-------------------------|-----------|-------------------|
| 1970 | 100 | 100 | 100 |
| 1971 | 100 | 100 | 100 |
| 1972 | 100 | 100 | 100 |
| 1973 | 100 | 100 | 100 |
| 1974 | 100 | 100 | 100 |
| 1975 | 100 | 100 | 100 |
| 1976 | 100 | 100 | 100 |
| 1977 | 100 | 100 | 100 |
| 1978 | 100 | 100 | 100 |
| 1979 | 100 | 100 | 100 |
| 1980 | 100 | 100 | 100 |

1. Not available at this time.

2. The project is scheduled for completion in 1975.

3. The project is scheduled for completion in 1975.

4. The project is scheduled for completion in 1975.

5. The project is scheduled for completion in 1975.

6. The project is scheduled for completion in 1975.

APPENDIX IV

COMPUTATION OF FIXED CHARGES PERCENTAGE

An investment of an electric utility company must, as a minimum, either EARN or SAVE enough money to offset all annual fixed charges, including income return on the property, over and above operation and maintenance expense associated with the investment. The following tabulation shows the elements involved in the fixed charges and the approximate percentage annual charges of each element in terms of investment dollars.

| | |
|--|--------|
| Depreciation--recovery of investment | 3.0% |
| Advalorem property tax--assessed at 4% on 50% of value | 2.0% |
| Net rate of return on company rate base--or total investment as fixed by the Public Service Commission | 6.05% |
| State and Federal income tax ¹ | 4.05% |
| TOTAL | 15.10% |

¹Interest on borrowed money is deductible for income tax purposes, and assuming that 60 per cent of the investment dollar is borrowed at 4 per cent interest, then the interest deduction is 0.60 (0.04) = 2.4% which is deductible from the allowed earnings.

Earnings are as allowed after income tax. Therefore, it is necessary to compute the gross earnings necessary to return 6.05% after taxes, except that interest on borrowed money is deductible for tax purposes. Thus, to compute the annual income tax increment to be assigned the investment dollar, a composite Federal and State income tax rate of 52.5% is assumed and the following computation is made:

$$\frac{6.05 - 2.4}{47.5} = 7.7\% \text{ gross earning required}$$

The per cent of investment required for the income tax increment is:

$$7.7 (52.5) = 4.05\%$$

UNITED STATES DEPARTMENT OF THE INTERIOR

to investigate the possibility of...
mineral, water, and other...
discovery, including...
operations and management...
The following...
changes and...
made in terms of...

Department of the Interior
Bureau of Land Management
Washington, D.C. 20240
Date: _____
By: _____
Special Agent in Charge

Investigation of...
purpose, and...
purchased...
(0.00) - 2.10...

...
necessary to...
after...
for...
to be...
...
is...

$$\frac{0.00 - 2.10}{0.00} = -2.10$$

The...
...

$$0.00 - 2.10 = -2.10$$

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