A REPLACEMENT CONSIDERATION
IN CONDUCTOR ECONOMICS

A Thesis

by

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ABSTRACT

A Replacement Consideration in Conductor Economics (August 1977)

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This thesis deals with the subject of conductor economics. Its uniqueness is based upon the introduction and determination of replacements as a means of obtaining minimum investment and operating costs.

A computer program is designed in order to implement this idea. Major emphasis is placed upon allowing for the inclusion into the program of any reasonable changes in the characterization of the model.

Results covering a wide range of operating and initial conditions are presented. Finally, a method which deals with bundled and mixed conductor installation is developed.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Professor John S. Denison for his help and support throughout the research and writing of this thesis. The authors thanks are expressed to Dr. Alton D. Patton, Dr. Darald J. Hartfiel and Dr. Stephen K. Jones, members of the committee, for their suggestions throughout the elaboration of this thesis.

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NOMENCLATURE

SYMBOL	
AI:	Interest rate.
APE:	Amortization period.
ACL(K,I):	Annual cost of losses.
CCOND:	Cost of conductor ($/lbs)
CINST:	Cost to install (conductor) ($/lbs)
CK:	Growth rate of current.
CRF:	Capital recovery factor
CVALUE(K):	Proportionality factor for salvage value of conductor K.
FINMIN(I):	Cost of the best installation for I years. (Salvage value of the last conductor for that installation is not included.
N:	Number of years under study.
NCON:	Number of conductors in study.
NN(M,I):	Most economic conductor for years M to I.
NNL(KNCDTS, NFINAL):	Denotes optimum number of years in first period for an installation of KNCDTS conductors, in time and a total of KFINAL years.
PAC(K,I):	Annual investment cost of conductor K.
PACCRF(K,I):	Annual investment cost of conductor K excluding taxes, insurance, operations and maintenance.
PACO(NCDTS,I):	Annuities paid on initial investment of conductor being replaced.
PW(K,I):	Present worth of annual cost of conductor K at year I.

REMOVE(K,I):	Cost to remove conductor K at year I.
SHAPE:	Parameter of salvage value equation
SPPWF:	Discounting factor.
TMIN(NFINAL):	Total cost of an installation for NFINAL years with one replacement at year I.
TPW(K,I):	Present worth of total annuities on conductor K up to year I.
TPWWSA(K,I):	As previous term but including net salvage value.
USPWF:	Discounting factor for end-of-period payments.
VALUE(K,I):	Salvage value of conductor K after I years of use.

CHAPTER I

INTRODUCTION

With the rising costs of oil and its by-products, methods for more efficient energy production, transmission and utilization are being developed. As an attempt to contribute to this trend, this thesis deals with the transmission part of the problem, more precisely with the always present problem of economic conductor sizing.

A computer program is developed that yields the best strategy to follow in electric line conductor selection and replacement schedule so that optimum conductor utilization, from an economic viewpoint, over a long period of time will be achieved.

Flexibility is maintained by permitting the user to select the parameters such as conductor cost,[1] inflation rate, interest rate,[2] load growth rate, depreciation method,[3,4] salvage value evaluation and some others that will best fit his own system conditions.

Previous work has been done on optimum conductor sizing for a uniformly distributed type of load.[3,5,6]

The journal IEEE Transactions on Power Apparatus and Systems is used as a pattern for format and style.

Although consideration has been given to load growth effects [6,7,8] the study of replacement feasibility under these conditions has been ignored.

The purpose of this thesis is to investigate this latter subject and its effects in optimum conductor selection for installation and replacement schedules in the long run.

Decisions over which scheme to adopt are based primarily on the magnitude of the difference in total costs. In general, storage facilities, variance of economic and physical factors and a good engineering judgement will dictate the policy to follow. It is suggested for whatever policy being adopted to realize a new study just before the new replacement is due so that possible changes in original assumptions may be included.

An approach to the problem of conductor sizing and replacements by means of dynamic programming is stated. The equations necessary in order to follow the logic of the solution are listed with their explanations. Although this method presents a general function to be optimized, its actual implementation may not necessarily follow all the described steps. In this thesis, the solution presented has been arbitrarily chosen, in as far as DP (Dynamic Programming) is concerned. Even when some basic ideas coincide, explicit application of DP techniques were not considered at the time the program was created.

The method of solution is described qualitatively first and then quantitatively by following the steps prescribed by the program. Results representative of typical case studies are included. These cover variations in salvage value modeling and their effects on replacement policy. Some of the other cases presented deal with specific conditions imposed by inflationary and interest rates.

A simple but straight forward approach to bundling and mixed replacements, that is, single conductors replaced by bundled installations is enclosed. Consideration is given to the very usual case where the conductor installation is already in service.

CHAPTER II

REVIEW OF THE LITERATURE

This thesis does not constitute the only contribution to the subject of conductor economics. It would not be likely, that man would constantly look for new and better ways of producing energy and yet take no action in improving, technically or economically the ways of transmitting it. Although there has been some suggestions[7,9] on how to approach the problem of optimum conductor replacement, no effective implementation of this method is currently available. Some of the other work pertains to economic sizing as related to distribution loading, varying load and other factors which will next be discussed.

Kelvin's Law

Stated simply it defines the most economic size of conductor as the one which results in annual waste-energy costs equal to annual investment costs. This defines a situation where investment costs are directly proportional to the area of the conductor, and the energy costs are inversely proportional to it. This case can be simply approximated by an equation of the form presented in the Appendix. Basically, this type of procedure was used for conductor sizing type of problems during the first half of this century. When more realistic conditions like distributed loads, time varying loads, conductor costs as a function of the design of supporting structures,[9] future replacements and some other factors are taken into consideration, the problem of optimum conductor sizing becomes much more complex than a simple Kelvin's Law problem.

Conductor Sizing for a Distributed Load

It usually happens that the load in a distribution line is not constant throughout its length, but systematically decreases as it reaches to its end, that is for a radial type of distribution line. A paper[5] dealing with the subject of conductor sizing, for long radials with evenly distributed loads, presented the use of combinations of different conductor sizes along the length of the line as a mean to minimize losses. It was proven that the use of three specific sizes in a combination is more economical than the use of only one or two sizes for a typical radial installation. The paper omitted different annual costs due to possible variation in hardware costs for each of the conductors treated. Even if the final cost of the combination turned out to be the most economical, it is clear from some of the graphs presented in that paper that the difference in total costs if only the larger conductor were used were not of considerable magnitude. The use of conductor combinations find its application primarily in radial and uniformly distributed lines. This method arises from the fact that generally in radial distribution lines, the use of only one optimum conductor along the line may result in a conductor that is too small at the sending end and too large at the remote end.

This situation may result from the use of a correction factor[4] to account for the degree of distributed loading. Even if this were the case, the use of only one conductor would be justified as long as the current will not exceed the carrying capacity of the conductor. Anyhow, most of today's systems are interconnected and such a severe variation between two extremes of a line is almost rare. With this assumption, the program developed in this thesis ignores this condition (radial distributed loads), altogether. Nevertheless, provisions for incorporating the use of a correction factor have been made.

Time Varying Load Without Replacements

In the past a conductor was selected that would safely handle the load with some safety factor. Load growth was seldom considered. A paper[6] which considers the effects of load growth and the effects of the time value of money on economic conductor sizing is available in the literature. It presented in a straight forward manner and by direct application of Kelvin's Law a way to solve the problem of conductor optimization. The three major subdivisions of the total cost of this kind of installation, the demand cost, the energy cost, and the so-called fixed charges are thoroughly explained in the referred paper. Although it presents an analytical solution to the problem of conductor sizing with varying load, it completely avoids the introduction of replacements as a mean for diminishing revenue requirements.

The literature available on the subject of conductor economics is not very profuse. Most of the work done deals with direct application of Kelvin's Law and a few comments on replacement economics.

CHAPTER III

STATEMENT AND SOLUTION OF THE PROBLEM

An Approach by DP (Dynamic Programming)

The purpose of dynamic programming is to optimize a criterion function subject to constraints.

The dynamic programming problem is defined in terms of five entities:[10] the state, the stage, the decision space, the transformation function and the criterion function. The state is specified by the set of parameters necessary to make the current and all future decisions. A stage exists every time a decision is to be made. The decision space is the space of all possible decision variables. It may be a function, as it is in our case, of the system at any stage. The transformation function relates the new state to the old one. Finally, the criterion function which expresses the performance of the system, the total cost of the different alternatives in our case and is a function of all the decisions made and the initial stage.

Let r_N denote the total cost of certain conductor installation

$$r_N = EC(D_n)+FC(D_n)+ (D_n-D_{n-1})F(D_{n-1}) \qquad (1)$$

$$\delta(D_n - D_{n-1}) = \begin{cases} 1 & \text{if } D_n - D_{n-1} \neq 0 \\ 0 & \text{Otherwise.} \end{cases} \qquad (2)$$

$$\bar{D} = \begin{bmatrix} D_1 \\ D_2 \\ \vdots \\ D_n \end{bmatrix} \qquad (3)$$

The vector $\bar{D}$ represents the vector of decision variables made in every stage of the study. Specifically D_i represents the conductor in the line at year i. $EC(D_n)$ is the present worth of annual energy and demand costs if conductor D_n were in service that year. $FC(D_n)$ is the present worth of fixed charges corresponding to conductor D_n. $F(D_{n-1})$ represents the present worth of the unamortized investment of conductor D_{n-1} on the line at the time (n-1) minus the net salvage value of the same conductor. The problem is to find the optimum r_N or what is the same the optimum vector of decision variables that will optimize the criterion function.

In the so called forward multistage[11] analysis, the study starts at year 1, with a given initial stage X_0 and through a series of transformations usually dependent on the decision variables and input states it finally terminates at state X_N. Figure 1 shows the corresponding flow diagrams.

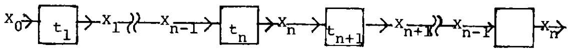

Figure 1. Forward Multistage System

The t_1, ... t_N terms which represent the transformations, merely define the relationship between input and output. They express each component of the output state as a function of the input state and the decision variable, Y-t(X,D). Where X denotes the input and D the decision variable.

A serial multistage system consist of a set of stages joined together in a series so that the output of one becomes the input of the next. The transformation t at each stage is a function of the input to the stage and the decision variable. In a graphical sense this may be represented by:

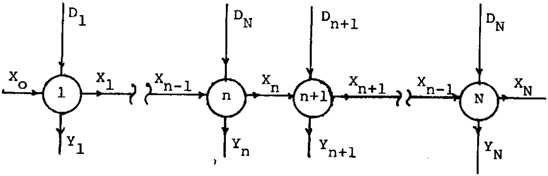

Figure 2. Multistage Decision System

For the n-stage system the transformation is:

$$X_n = t_N(D_n, X_{n-1}) \tag{4}$$

The $r_1, r_2, \ldots r_N$ terms represent the cost incurred by choosing certain decision variables at stages 1,2, ... N. Clearly each one of them is a function of the input, output and decision variable at a particular stage.

$$r = r(X_0, X_1 D_1) \tag{5}$$

but since $X_1 = t(X_0, D)$ (6)

$$r = r(X_0, D) \tag{7}$$

This states that the independent variables affecting the stage cost are X and D since these two uniquely specify the output.

The stage cost is defined by:

$$r_n = r_n(X_{n-1}, D_n) \tag{8}$$

From the transformations, it follows that X_{n-1} depends only on the decisions made prior to and including stage n-1, $(D_1, D_2, \ldots D_{n-1})$ and X_0. Or,

$$\begin{aligned} X_{n-1} &= t_{n-1}(X_{n-2}, D_{n-1}) = t_{n-1}(t_{n-2}(X_{n-3}, D_{n-2}) D_{n-1}) \\ &= t_{n-1}(X_{n-2}, D_{n-2}, D_{n-1}) = t_{n-1}(t_{n-3}(X_{n-4}, D_{n-3}), \\ &\qquad D_{n-2}, D_{n-1}) \\ &= t_{n-1}(X_{n-4}, D_{n-3}, D_{n-2}, D_{n-1}) = t_n(X_0, D_1, D_2 \ldots D_{n-1}) \end{aligned} \tag{9}$$

Combining equation (9) with the cost function, it follows that the cost of stage n depends only on the decisions $(D_1, D_2 \ldots D_{n-1})$ and X_0. That is,

$$\begin{aligned} r_n &= r_n(X_{n-1}, D_n) = r_n(t_n(X_0, D_1, D_2 \ldots D_{n-1}), D_n) \\ r_n &= r_n(X_0, D_1, D_2 \ldots D_n) \end{aligned} \tag{10}$$

From which we can deduce, that D_n affects the cost from stages n to N only.

It is suggested to think of the decision variables as the conductor being chosen at each stage. The sequential order or the stages forces the decisions to be determined as functions of what came before. The state variables, X, are introduced in order to summarize these decisions. The criterion function to be minimized will be formed by the total present worth of the distinct stages.

The total cost R_N from stages one through N is some function of the individual stage costs.

$$R_N(X_0,X_1, \dots X_{n-1},D_1,D_2, \dots D_n) = g(r_1(X_0,D_1), r_2(X_1,D_2), \dots r_N(X_{N-1},D_N)) \tag{11}$$

But from previous equations we found that $(X_1,X_2, \dots X_{N-1})$ can be eliminated from the individual state costs and consequently from total cost. Eqt. 6 & 7.

$$R_N(X_0,D_1,D_2, \dots D_N) = g(r_1(X_0,D_1),r_2(X_0,D_1,D_2), \dots r_N(X_0,D_1,D_2, \dots D_N) \tag{12}$$

The N-stage minimization problem becomes then that of minizing the total cost R_N over the decision variables $(D_1,D_2, \dots D_N)$, thus finding the optimal cost as a function of the initial state X_0. The vector of decision variables, $(D_1,D_2, \dots D_N)$, represents the conductor scheduled to be used in each particular year i. Denote $F_N(X_0)$ as the minimum N-stage cost.

Subject to $X_y = t_n(D_N, X_{n-1})$,

$$F_N(X_0) = \min_{D_1, D_N} \left\{ y \left[r_1(X_0, D_1), r_2(X_0, D_2), \ldots r_N(X_{N-1}, D_N) \right] \right\} \tag{13}$$

$$= \min_{D_1, D_N} \left[r_1(X_0, D_1) + r_2(X_1, D_2) + \ldots r_N(X_{N-1}, D_N) \right]$$

$$F_N(X_0) = \min_{D_1, D_n} \left[r_1(X_0, D_1) + r_2(X_0, D_1, D_2) + \ldots r_N(X_0, D_1, D_2, \ldots D_N) \right]. \tag{14}$$

Equations 13 and 14 represent the criterion function. In its present form, it would mean solving one optimization problem, in which decisions are interdependent. An easier way of dealing with this problem is to decompose it into N (number of decision variables) subproblems. Individual solutions are then combined to obtain the solution to the original problem. Note that in:

$$F_N(X_0) = \min_{D_1, D_N} \left[r_1(X_0, D_1) + r_2(X_1, D_2) + \ldots r_N(X_{N-1}, D_N 0) \right] \tag{15}$$

1) The first stage does not depend on $D_2, D_3, \ldots D_N$.
2) For arbitrary real-valued functions $h_1(u_1)$ and $h_2(u_1, u_2)$.

$$\min_{U_1,U_2}\left[h_1(U_1)+h_2(U_1,U_2)\right] = \min_{U_1}\left[h_1(U_1) + \min_{U_2}\left[h_2(U_1,U_2)\right]\right] \tag{16}$$

Then,

$$f_N(X_0) = \min_{D_1}\left[r_1(X_0,D_1) + \min_{D_2,D_N}\left[r_2(X_1,D_2)+ \ldots + r_N(X_{N-1},D_N)\right]\right] \tag{17}$$

$$\text{subject to } X_n = t_n(D_n,X_{n-1})$$

From the definition of $F_N(X_0)$ it follows that

$$F_{N-1}(X_1) = \min_{D_2,D_N}\left[r_2(X_1,D_2)+ \ldots + r_N(X_{N-1},D_N)\right] \tag{18}$$

Which represents the stage costs from the second stage up to stage N, for a total of N-1 stages. Where now, X_1 is the initial state. It then follows from eqt. 17,

$$F_N(X_0) = \min_{D_1}\left[r_1(X_0,D_1)+F_{N-1}(X_1)\right] = \min_{D_1}\left[r_1(X_0,D_1)+F_{N-1}(t_1(X_0,D_1))\right] \tag{19}$$

Define

$$Q_1(X_0,D_1)=r_1(X_0,D_1)+F_{N-1}(t_1(X_0,D_1)) \tag{20}$$

Determining $F_N(X_0)$, and $D_1=D_1$ optimum, given $F_{N-1}(X_1)$ is simply a one stage initial state optimization problem with state variable X_0, decision variable D_1 and cost Q_1, that is,

$$F_N(X_0) = \min_{D_1}\left[Q_1(X_0,D_1)\right] \tag{21}$$

At this point the original N-stage problem is divided into two smaller problems

1) $$F_{N-1}(X_1) = \min_{D_2,D_N}\left[r_2(X_1,D_2) + \dots + r_N(X_{N-1},D_N)\right] \tag{22}$$

2) $$F_N(X_0) = \min_{D_1} Q_1(X_0,D_1) = \min_{D_1}\left[r_1(X_0,D_1) + F_{N-1}(t_1(X_0,D_1))\right] \tag{23}$$

By treating $F_{N-1}(X_1)$ and then $F_{N-2}(X_2)$, ... $F_2(X_{N-2})$ the same way as $F_N(X_0)$, the original problem is decomposed into N-one stage optimization problems.

Figure 3., shows graphically how the problem is divided into N stages before being solved.

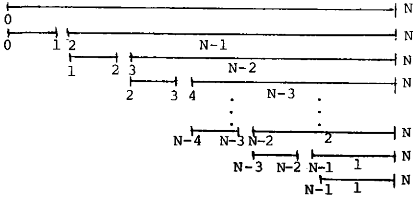

Figure 3. Single Stage Representation

Starting with the N stage, the solution is obtained by backwards substitution. Note that D_N does not affect the cost for stages less than N.

Although the problem is theoretically solvable at this point, application of these relations to the real problem may be done in several different ways and generally depending on the nature of the problem itself. In general, the stages, states and transformations may not be in the original problem. They would have to be constructed as to make the recursive solution of the problem possible. This is why, DP is more considered an approach[10] than an algorithm.

As previously stated in the introduction, a direct application of dynamic programming to the solution of this problem has been avoided. Nevertheless, the method of solution divides the complex multistage problem into many single stage problems in the same manner as it is done in dynamic programming.

Minimization is first done over all possible conductors in similar periods of time and then over adequate time intervals.

This procedure yields the desired optimum conductor and replacement years. An explanation of these ideas are presented in more detail in the following sections.

Method of Solution

Due to the large amount of calculations involved in the search for the optimum replacement policy, the use of a computer program plays an important role in the development of this thesis. The program is written in the Fortran IV language and is designed to fit almost any requirement from the user.

A Statement and Solution of the Problem.

As in most engineering economic studies both the first cost and the operating cost are functions of the same design variable, in this case the area of the conductor. The first cost increasing directly with the area and the operating cost inversely.

In the study of conductor economics, the function to be minimized is composed of three major components: annual investment cost, annual energy cost and annual demand cost. The first component also known as the fixed charges component of the total annual cost, will consist generally of:

1. Interest on Money
2. Repayment or amortization
3. Operation, maintenance and other costs
4. Taxes
5. Insurance and Casualties
6. Replacement

The interest should be representative of the cost of new money. Or that amount required to bring new capital to the utility.

Generally if the single conductor optimization study is to be done, the period of years over which the costs are evaluated should be the physical life of the line. All costs are then considered over the same period giving a fully amortized line at the end of the period. In the case of future replacements, usually the new installation takes place before the estimated life of the first conductor is over. In this case even if the first conductor has not been fully amortized, it has a certain salvage value which can be subtracted from the cost of the new installation. Annuities on the investment of the old installation remain to be paid for the rest of its assumed life. Practically this may be done by converting the resulting series of annuities into a single lump sum at the time of replacement.

Operating and maintenance costs are generally composed of:

a) Material Cost: Cost of material required for operation and maintenance, cost of handling and storing of this material, taxes resulting from procurement of these materials and cost of purchasing, inspecting and accounting for materials.

b) Labor Cost: Should include direct payroll, cost, provisions for vacations, sickness and so forth, tools and work equipment.

c) Other Costs: Power and energy for driving equipment, crop damage, tree trimming, etc.

Taxes, insurance and casualty are also expressed as a percentage of the installed cost.

The replacement factor which accounts for certain adjustments necessary whenever a replacement is made. For example, after a conductor has been replaced for another one, the fixed charges will consist now of those of the new conductor plus those on the old one, but only due to the recovery of capital. Omitting the tax, insurance, operation and maintenance components.

The second component of the annual cost equation is the energy charge, which is just the cost of the kwhr-losses in the line each year. It is made up of the product of the cost per Kwhr produced, times the number of hours in a period (year), times the yearly peak load, times the loss factor. Where the last term is defined as the ratio of kilowatt hours of loss during a period over the hours in a period times the peak loss in kilowatts. In the expression for the energy cost, (see Appendix) the current represents the yearly peak current.

The last component, the demand charge, is the cost which is incurred to maintain sufficient system capacity to supply the I^2R losses. It is defined also as the annual cost of the extra investment in equipment needed to supply these kwhr-losses. In calculating the demand charge there should be a kw of installed capacity in order to produce it. In recent years this idea has been subjected to further study since it has been noted that one added kw of load or of loss at a time of system peak cannot even be observed on recording instruments. Therefore, it can neither affect reported peak loads nor any schedule of capacity installations. This last statement raises the question: How large must this incremental load be in order to result in recognizable incremental carrying charges? Obviously a line must be drawn somewhere, or one could argue that the company's total load could be supplied without incurring in any carrying charges at all. Whichever of the two statements is correct, it is of no consequence to this work. What is presented here is a method of solution, and the values assigned to the variables are chosen according to the criterion of the user.

The basic case involves calculation of the cost of demand and energy components every year. Investment cost, also known as fixed charges remains more or less constant throughout the life of the conductor. If the economic choice is done based on the minimum revenue requirement method, it is necessary to refer all annual costs to present worth, add them up and find the constant-annuity that would represent these requirements. It is clear that if this is to be done, the life of the project must be known beforehand. The program is designed to make economic comparisons based upon total present worth values rather than utilizing the levelized sums of the minimum revenue requirement or the annual cost method.

In the more complicated cases, where replacements are introduced it is necessary to determine in what years to make the replacements and what conductors to use. A qualitative description of the program is presented next.

The single or basic case is solved first. In this case the most economical conductor for a given number of years is found. As stated earlier, the load is allowed to vary in all the years under study. The time scale is divided in the following way:

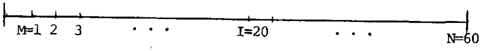

Figure 4

Time Scale (M=1)

where M is the initial year, I the final year of interest and N is the total number of years over which the study is done. Note that for each possible M (M can go from 1 to N) there can be N-M segments of time, starting from M and each of these segments has its own appropriate economical conductor. In the specific case where N = 60 and M = 5.

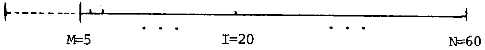

Figure 5

Time Scale (M=5)

there are N-M = 55 possible segments starting from M and ending at I, where I ranges from M = 1 to N. There are a total of $\sum_{N=1}^{N-1}$ (N-n) possible segments each with its own economical conductor.

It is possible to calculate the total cost for each conductor from year M to year I. This is done by adding the investment cost at year M to the successive annuities paid on energy and demand losses up to year I. If salvage value is to be included, it is calculated according to the number of years of use, namely I-M+1, and subtracted from the total cost. In any case, the cost of removing the conductor at year I is also added. Due to the time value of money, additions and subtractions are done in a present worth basis. Consequently costs occurring along the time scale have to be discounted to a reference year.

The present worth value of the total cost for a conductor installation at year M up to year I with salvage value, if any and removal cost being included is known. Finding the most economic conductor in this period becomes a matter of minimization between all the conductors in the study.

The two conductor case, in which only one replacement is involved is next treated. The time scale is divided in as many as two period combinations as can be made to fit in a total of x number of years. X ranges from two (number of conductor case) to N. For example, if X, the final year is ten, the time scale can then be divided into (1-9,2-8,3-7,4-6,5-5,6-4,7-3,8-2,9-1), combinations, where the first digit will denote the number of years in the second period. Next, the program calculates the total present worth cost for every one of these combinations. Thus, for the 4-6 combination, the program will use that conductor which resulted most economical in the basic or single case study for four years, and the most economical in the second period which starts at year M=5 and ends at year 10. The same is done with each of the remaining eight combinations. The best possible combination of two conductors in a period of ten years is found by minimization over all calculated costs. This will yield by definition the most economical combination of two conductors (one replacement) for a total of ten years and the appropriate year of replacement.

The annual fixed charges of the conductor in the first period are carried along in the second period also. Although they remain a constant annuity their magnitude is usually reduced due to nonexistent charges on insurance, maintenance and taxes from then, the replacement year, up to the last year of its amortization period. Even when this is generally the case provision is taken for any other factor such as a rise in the rate of return, that may affect the annuity on original investment.

This particular case, for a total of 10 years can be extended as the total number of years under study ranges from 2 (number of conductor case) to N. After storing the values found for each total number of years the program proceeds to check for savings produced by using two conductors (one replacement) instead of one for every possible total number of years. If there are no savings produced for any given number of total years, the program will stop here. This would mean that going to the three conductor study, would be unnecessary since it would clearly result to be more expensive for the same number of years. On the other hand, if savings are obtained by introducing a replacement, then there is a possibility that savings would also be produced by using two replacements. In this case the program will advance to the three conductor case (original conductor is replaced twice). Now, the final years will range from three (number of conductors in study), to N. Again, for every final year all possible combinations of two periods of varying length are studied. The difference from the two conductor case being basically that now the conductors to use in the first period would be those obtained in the two conductor study for any length of time that the first period would take on. Minimization over possible replacement years is done in the same manner as in the two conductor case, producing the optimum three conductor combination (two replacements) for a number of total years. Note that not only the modified fixed charges of the first replacement are included in the annual costs of the new installation but also those of the second conductor if it has not been already amortized.

Checking for savings comes next and the process is repeated until there are no more savings produced by adding up more replacements for any number of years.

Program Analysis

This portion of the thesis presents a step by step explanation of the logic or procedures observed in the program. It is to be studied and carefully read by any user interested in the use of the program. Details concerning data, control and type of study desired are extensively exposed in this section.

Constants to be read in as data are represented by the following symbols:

CURENO:	Peak current during the first year of study. To be used only if currents in successive years are expressed as a function of initial current.
N:	Total number of years under study. It could also be referred to as the planning horizon of the project.
CK:	Rate of growth of current. Expressed as a decimal. It is of any significance only if a compounding type of growth is used.
AI:	Annual interest, cost of money. Interest rate to be used in all discounting operations.
CCOND:	Cost of conductor. ($/pounds.)
CINST:	Cost of installing the conductor. ($/pound)
CRF:	Capital recovery factor to be applied in the recovery of initial investment.

CKWHRL:	Cost of kilowatt hour losses. ($/kwhr.)
CKWL:	Cost of Kilowatt demand losses. ($/kw.)
NCON:	Number of conductors in the study. Possible values that the decision variable can take.
FL:	Loss factor. Expressed as a decimal.
TOMI:	Taxes, operations, maintenance and insurance expenses paid on conductor. It is a constant percentage of initial investment. Expressed as a decimal.
APE:	Amortization period, in years.
K1:	Factor to adjust salvage value of conductor when removed.
K2:	Factor to adjust removal cost of conductor at the time of replacement.
SHARE:	Constant used in modeling the shape of the salvage value curve.
CINFL1:	Inflationary rate of conductor cost (as a decimal).
CINFL2:	Inflationary rate of installation cost (as a decimal).
CINFL3:	Inflationary rate of Kwhr losses cost (as a decimal).
CINFL4:	Inflationary rate of Kw-demand cost (as a decimal).
R(I),W(I):	Resistance and weight of each conductor to be studied. In ohms/mile and lbs/mile respectively.
CONDUC(I):	MCM notation corresponding to each conductor.
OLDCDT:	If a conductor is in the line prior to the study, this constant (an integer) stands for CONDUC(OLDCDT) in MCM. If no such conductor exists this has value 0.

CWORTH: Present worth of such conductor expressed as a fraction of the cost of a similar conductor today.

NYRSUP: Number of years that the old conductor has been in the line. To be used in calculating salvage value and unamortized capital.

Values assigned to the control indices are next read. NPRINT controls the output list of the annual current, annual energy and demand losses, annual investment or fixed charges, present worth of the annual cost and the total present worth for each conductor installation in every year from M=1 to N (number of years under study) where M is increased by a unit every time the listing is completed and the process repeated until M is greater than NPRINT. If no such a list is desired make NPRINT equal to zero. The second control index, USABLE, is a factor used to adjust the annuities paid on a conductor after it has been removed from a line. It is a control index in the sense that it defines a special case (when it has value zero), that will be discussed in another section. LDATA produces a list of the data whenever a nonzero integer value is assigned to it.

Single payment present worth factors as well as uniform series present worth factors are next calculated for each year under study. The currents for each year are calculated by an appropriate formula or read in as data; whichever way is more practical to the user. The program then proceeds to calculate the salvage value, VALUE K,I), of conductor K after I years of use. A general expression is included in the program. Removal cost of conductor K at year I, REMOVE (K,I) is calculated for every K and I of interest. It is assumed to be a function of the installation cost. Each one of the last two terms, has a factor of proportionality CVALUE (K) and CREMOV(K) respectively for each conductor K to allow for a higher degree of freedom in the calculations.

As it has been mentioned earlier, the annual cost of the project, in this case a conductor installation, is composed of three major components. These are represented in the program by the following symbols. PAC(K,I) which corresponds to the annual cost of putting up a new conductor K in a line at year I. AKWHRL, defines the annual cost of kilwatt hour losses. It is a function of the conductor size and the current at any given year. AKWL, defines the annual cost of the demand component. Together with the first term it composes the operational costs of the project and for a specific conductor K at year I are represented by ACL(I,I). Finally, PAC(K,I) which corresponds to the annual cost of putting up a new conductor K in a line at year I.

This term is composed of the initial investment times the effective capital recovery factor which reflects the effects of the real capital recovery factor, due to return and depreciation, and the annuities paid on taxes, insurance, maintenance, labor and other items.

When a conductor is replaced the annuities on its initial investment continue to be paid along with investment, energy and demand costs for the new conductor. That is, if the old conductor has not been completely amortized at the time of replacement. To account for this detail, PACCRF(K,I) is defined in the program as the annuity paid on the replaced conductor K due to capital recovery factor, return and depreciation, only if it was purchased at year I. A factor of proportionality, USABLE multiplies this equation in case that alterations to CRF have to be made for one reason or another.

For both PAC(K,I) and PACCRF(K,I) the difference on installation costs for each conductor is assumed to be proportional to their weight. By changing the values of CCOND (cost of conductor #/lb.) and CINST (cost of installation $/lb.) the cost of hardware, poles or towers, right of way and some other items may be included. If the difference in cost of installation due to structures, hardware and so on cannot be approximated by this weight proportionality a method to cope with this problem is suggested.

Define a matrix EXT(NCON,NCON), where NCON was defined as the total number of conductors under study.

$$
\begin{bmatrix}
EXT(1,1) & EXT(1,2) & EXT(1,3) & \cdots & EXT(1,NCON) \\
EXT(2,1) & EXT(2,2) & EXT(2,3) & \cdots & EXT(2,NCON) \\
\cdot & \cdot & EXT(3,3) & \cdots & \cdots \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdots & \cdots & EXT(K,K) & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
EXT(NCON,1) & \cdots & \cdots & \cdots & EXT(NCON,NCON)
\end{bmatrix}
$$

Figure 6.

Matrix of hardware and structure costs.

The main diagonal terms represent the extra cost on investment due to poles, hardware and any other costs of this type associated with a particular conductor K. The elements above the diagonal represent costs incurred when a replacement is made from conductor K to conductor I. Assuming that 1,2, ... NCON is increasing order of conductor size, the elements below the main diagonal are approximated to zero, since a negligible cost is produced in structure modifications by going from a large conductor to a small one. The suggested matrix can then be employed to represent hardware costs of a particular conductor K, or structure modifications on poles or towers due to replacements by larger conductors and ranging from small reinforcement schemes up to complete new structures depending on the size of the new conductor.

Back to the analysis of the program, it next proceeds to divide the time scale in different periods of time by selecting a starting year M=1 and a final year taking values from I=M-1 to I=N. See Fig. 1 and Fig. 2. For every value of M in the range M=1 to M=N the process is repeated. At the same time the following quantities are computed: PW(K,I), present worth of the total cost of having conductor K installed at year I. It is the product of the single payment present worth factor times the energy and demand costs in that year plus PAC(K,M), the annuity on the conductor bought at year M. TPW(K,I) represents the sum of all the PW(K,() from year M up to year I.

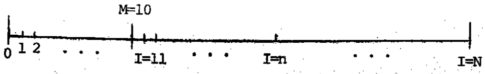

Figure 7. PW and TPW in the time scale.

In the case illustrated in Figure 7, with M=5 and I=n the expression for TPW(K,I) is:

TPW(K,I) n)=PW(K,5)+PW(K,6)+ . . . + PW(K,N=1)+ PW(K,n)

TPW(K,n) stands for the total cost, referred to year 0, of having conductor K in the line from year 5 to year n. Similarly for each different M:

M=1	TPW(K,I=n)=PW(K,1)+ . . . . + PW(K,n-1)+PW(K,n)	M≤n≤N
M=2	TPW(K,I=n)=PW(K,w)+PW(K,3)+.+ PW(K,n-1)+PW(K,n)	
M=3	TPW(K,I=n)-PW(K,3)+PW(K,4)+.+ PW(K,n-1)+PW(K,n)	
.		
.		
.		
M=N	TPW(K,I N)=PW(K,N)	

Figure 8. Total Present Worth TPW Table.

In a similar way TPWWSA(K,I), the total present worth of conductor K including salvage value at year I is computed. It is by definition TPW(K,I) plus the un-amortized cost of the conductor minus its salvage value. The cost of removing the conductor is included also.

It should be mentioned that in all these computations provision was made to include inflationary effects when desired. The reason being that inflation often plays a major role in determining labor and material costs.

If desired, a list of current, energy and demand losses, investment annuities, total annual cost, present worth and total present worth of the installation with and without salvage value is produced. This is done for all conductors and all years ranging from I=M-1 to I=N for any chosen $M \epsilon (1,N)$.

At this point we know what the total present worth cost of installing conductor K at year $M \epsilon (1,N)$ including costs of operation up to year I, where I goes from M to N. The minimum total cost and its corresponding optimum conductor is then found for every possible interval of time (M,I). Where M is the initial year and I the last year in that period.

By comparing each conductor's current carrying capacity with the current at a given year I, the search over the optimum conductor in the period (M,I) is reduced. Note that for each $M \epsilon (1,N)$ once a conductor has been disqualified at a given year I=n, $M \leq I \leq N$, due to insufficient current capacity in that year it is automatically exclude of further comparisons in all remaining years up to year N. The reasoning is based on that once the current capacity of the conductor has been exceeded it becomes useless for all practical purposes regardless of how the current behaves in the rest of the period. Consequently, it need not be considered in the search for the optimum conductor for that particular period.

The entry NN(M,I) is used to denote the best conductor in the period (M,I) and the minimum total cost is represented by TPWWSA(NN(M,I),I).

Optimum conductors without replacement with their respective ACSR (MCM) notation and their total present worth TPW are next listed for all years from 1 to N. Note that since TPW does not include salvage value, the cost figures which appear in the no-replacement table represent those of the optimum conductor left in the line for a specific number of years. This last part constitutes what has been defined as case #1, or the no-replacement case in this thesis.

In the next step, the first replacement is introduced. The appropriate conductor and the year of replacement will be found. For this case and all others involving replacements the following procedure is executed by the program. Whenever a replacement is made we can consider the time scale to be divided at that point.

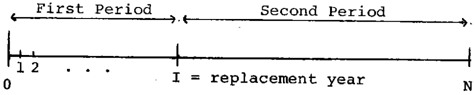

Figure 9. A Replacement in the time scale.

If two conductors, an original and its replacement, are being considered, the best possible combination or the one that will result in the lowest annual cost will certainly be composed of the more economic conductor in each period. By changing the year of replacement various optimal combinations can be formed. A process of minimization over all these combinations will produce our best choice of conductors for a given number of years. This same reasoning holds true when more than one replacement is introduced. It is then necessary to divide the time scale into two periods. This is done in the program the following way: Let NCDTS≤I≤N-1 where I is the last year of the first period (in which the old conductor, installation is up) and NCDTS is the number of conductors scheduled to be used in that period. Let I+1< NFINAL≤N where NFINAL denotes the end of the second period (during which the replacement is up). By varying NFINAL over its range for each value of I all possible combinations of two periods in NFINAL years are found. For each I, NFINAL pair the program computes TMIN(I,NFINAL). In a 2 (n) conductor case it represents the total cost of an installation with the first (n-1) conductor in the line from year one to year I, the first period and the second conductor during the rest of the period from year I+1 to year NFINAL. This quantity, TMIN(I,NFINAL) is composed of: 1) FINMIN(I): Total present worth of the most economical conductor from year 1 to year I or equal to TPWMIN(1,I) in the two conductor study. In the n conductor case, n<2, FINMIN(I) would represent the total mininum cost obtained in the previous case the (n-1) case study for a total of I years. Costs in the second period are represented by; 2) TPWMIN(I+1),NFINAL) which constitutes the cost of the most economic conductor to be used in the second period, or from year I+1 to year NFINAL; (3) PACO(NCDTS,I) stands for annuities paid on initial investment of the conductor being replaced. These annuities are based on return and depreciation. Since they have to be paid throughout the expected life of the installation their effect is a string of constant payments for the rest of the replaced conductor's amortization period. By means of the uspwf, the uniform series present worth factor, (see Appendix) these constant annuities can be converted to a single lump sum at the year of replacement which is finally discounted to present worth; (4) SALNET, the net salvage value of the conductor to be replaced. It is composed of the salvage value of the conductor, a function of its years in use, minus the cost incurred in removing the conductor. Being an inflow of capital SALNET is subtracted from TMIN(I,NFINAL).

As already stated, for each I ranging from NCDTS (number of conductors in first period) to N-1, NFINAL takes all values (integers) in the closed interval (I+1,N). After doing all these calculations for all values of I the following arrangement is obtained (in the conductor study):

TMIN(1,2)

TMIN(1,3) TMIN(2,3)

TMIN(1,4) TMIN(2,4) TMIN(3,4)

TMIN(1,5) TMIN(2,5) TMIN(3,5) TMIN(4,5)

. . . .

. . . .

TMIN(1,N) TMIN(2,N) TMIN(3,N) TMIN(4,n). . TMIN(N-1,N)

Figure 10. Replacement cost representation.

From this diagram it is observed that for every NFINAL there are (NFINAL-1) possible partitions. For the n replacement case there would be (NFINAL -n) partitions for each NFINAL.

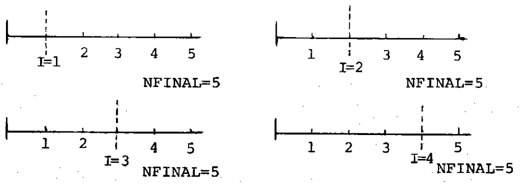

Figure 11. Partitions of a time interval.

Minimization is then performed for each NFINAL over all values that I can take. An optimum combination for each NFINAL is found. The number of years in the first period are denoted by NNL(KNCDTS, NFINAL)=I optimum where KNCDTS is the total number of conductors in the study, that is, including replacement and past installations. The optimum conductor in the second period is then by definition NN(I 1, NFINAL). These figures are computed for all NFINAL in (KNCDTS,N). Next a list of the best two (n) conductor combination (including replacements) is printed for each NFINAL with their respective total costs and year of replacement. Comparison with other alternatives (generally with the 1 conductor case without replacement if we are dealing with two conductors, or with the two conductor case if we are dealing with three conductor combinations and so on) has still to be made. This would be done by just comparing the cost of installation for each year with the results of the other cases already studied. In order to avoid this procedure the program automatically compares new results with those obtained in the latter case. For example, suppose that we just obtained the best combinations for a three conductor (two replacement) study. For any year n, the program compares the total cost of our best choice for three conductors with the cost of an installation if the best two conductors were used. If it turns out to be more economical it will be stated so, if not it will tell you that the best combination corresponds to the two conductor case. Note that comparisons need to be made with the latest case only. If for a period of n years a two conductor installation was not economically feasible it is logical to assume and this is indeed the case that three conductors will neither be. On the other hand, if the two conductor case was an acceptable installation, more economical than the single conductor case for the same number of years, there exists the possibility for the three conductor case to be one also.

In the case that all the best choices of KNCDTS combinations resulted to be higher in cost for every year from NCDTS to N than those of the previous case, the KNCDTS-1 case, the listing of the comparatives results is skipped and termination occurs. In case of savings occurring in any of the years under study, the program will go the the KNCDTS 1 conductor case.

The values to be used in some of the computations are now taken from results obtained in the previous case, For example, TMIN(I,NFINAL) will be composed of the best choice of conductors in the KNCDTS conductor case for I years and the most economic conductor from year I+1 to NFINAL.

CHAPTER IV

RESULTS

A Sample Case

A case study with the following characteristics has been included.

Initial Current - 30 Amperes, CK=8%

The sample case presents a typical study with a salvage value characteristic corresponding to a shaping exponent of 1/2. Inflation effects are ignored.

A list of the data is obtained from the program, Table 1. The next Table (No. 2) indicates by column from left to right the starting year, the conductor used, final year and its effective current, energy and demand losses in that year, fixed charges, total annual cost (sum of the last two components), present worth up to final year with and without salvage value included. Table 3 is next with a list of optimum conductors without replacement for any number of years $\epsilon(1,N)$. Results for the best two conductor combination appear in Table 4. The program then compares these results with the ones obtained for the one conductor case without replacement. Since it is economical in some years to make the replacement a list of comparative results is obtained.

LIST OF DATA

NUMBER OF YEARS UNDER STUDY = 60 INITIAL CURRENT= 30. RATE =0.080
NUMBER OF CONDUCTORS = 33 CONDUCTOR COST($/LB) =0.70
INSTALLATION COST($/LB) =0.40 KWHR COST =0.02 KW-DEMAND COST =35.0
LOSS FACTOR =0.25 INTEREST RATE =0.07 CAPITAL RECOV. FACTOR =0.07123
TAXES INS. ETC =0.07877 AMORTIZATION PERIOD = 60
INFLATION ON CONDUCTOR =0.00 ON LABOR =0.00 ON ENERGY =0.00
ON DEMAND =0.00 K1 =1.00 K2 =0.80 SHAPE =0.50 USABLE =1.00
OLD CONDUCTOR =# 0 PW OF SUCH CD. IN PU =0.000 YEARS OF USE = 0

CONDUCTOR	A.W.G. Or ACSR(MCM)	RESISTANCE(O/M)	WEIGHT(LBS/M)	CURRENT CAPACITY(AMPS)
1	6.00	3.5600	191.00	100.00
2	5.00	2.8200	241.00	120.00
3	4.00	2.2400	304.00	140.00
4	3.00	1.7800	384.00	160.00
5	2.00	1.4100	484.00	180.00
6	1.00	1.1200	610.00	200.00
7	1.01 → 1/0	0.8880	769.00	230.00
8	2.01 → 2/0	0.7060	970.00	270.00
9	3.01 → 3/0	0.5600	1223.00	300.00
10	4.01 → 4/0	0.4450	1542.00	340.00
11	226.80	0.3500	1936.00	460.00
12	300.00	0.3110	2178.00	490.00
13	336.40	0.2780	2442.00	530.00
14	397.50	0.2350	2885.00	590.00

TABLE 1. Data for Sample System.

CONDUCTOR	ACSR(MCM)	RESISTANCE(O/M)	WEIGHT(LBS/M)	CURRENT CAPACITY(AMPS)
15	477.00	0.1960	3462.00	670.00
16	500.00	0.1870	4122.00	690.00
17	556.50	0.1680	4039.00	730.00
18	605.50	0.1550	4109.00	750.00
19	636.00	0.1480	4319.00	770.00
20	666.60	0.1410	4527.00	800.00
21	715.50	0.1320	4859.00	830.00
22	795.00	0.1190	5399.00	900.00
23	874.50	0.1080	5940.00	950.00
24	900.00	0.1040	6112.00	970.00
25	954.00	0.0982	6479.00	1010.00
26	1033.50	0.0909	7019.00	1060.00
27	1113.00	0.0844	7544.00	1110.00
28	1192.50	0.0788	8082.00	1160.00
29	1272.00	0.0737	8621.00	1200.00
30	1351.00	0.0695	9160.00	1250.00
31	1431.00	0.0656	9699.00	1300.00
32	1510.50	0.0622	10237.00	1340.00
33	1590.00	0.0591	10777.00	1380.00

TABLE 1. (Continued).

FROM	CD	YR	CURREN	AC.LOSS	AC.PURCH	AC.TOTAL	P.WORTH	TOTAL.PW	TPW/SALVA
1	1	1	30.	652.	95.	747.	698.	698.	1086.
1	1	2	32.	761.	95.	855.	747.	1445.	1810.
1	1	3	35.	887.	95.	982.	801.	2246.	2590.
1	1	4	38.	1035.	95.	1129.	862.	3108.	3431.
1	1	5	41.	1207.	95.	1302.	928.	4036.	4340.
1	1	6	44.	1408.	95.	1503.	1001.	5037.	5323.
1	1	7	48.	1642.	95.	1737.	1082.	6119.	6398.
1	1	8	51.	1916.	95.	2010.	1170.	7289.	7542.
1	1	9	56.	2234.	95.	2329.	1267.	8556.	8793.
1	1	10	60.	2606.	95.	2701.	1373.	9928.	10152.
1	1	11	65.	3040.	95.	3134.	1489.	11417.	11628.
1	1	12	70.	3546.	95.	3640.	1616.	13034.	13232.
1	1	13	76.	4136.	95.	4230.	1755.	14789.	14975.
1	1	14	82.	4824.	95.	4918.	1907.	16696.	16872.
1	1	15	88.	5626.	95.	5721.	2074.	18770.	18935.
1	1	16	95.	6563.	95.	6657.	2255.	21025.	21180.
1	1	17	103.	7655.	95.	7749.	2453.	23478.	23624.
1	1	18	111.	8928.	95.	9023.	2670.	26148.	26285.
1	1	19	120.	10414.	95.	10509.	2906.	29053.	29182.
1	1	20	129.	12147.	95.	12241.	3163.	32217.	32338.
1	1	21	140.	14168.	95.	14263.	3445.	35661.	35776.
1	1	22	151.	16526.	95.	16620.	3751.	39413.	39520.
1	1	23	163.	19276.	95.	19370.	4086.	43499.	43600.
1	1	24	176.	22483.	95.	22578.	4451.	47950.	48045.
1	1	25	190.	26224.	95.	26319.	4849.	52799.	52889.
1	1	26	205.	30588.	95.	30682.	5283.	58083.	58167.
1	1	27	222.	35678.	95.	35772.	5757.	63840.	63918.
1	1	28	240.	41614.	95.	41709.	6273.	70113.	70187.
1	1	29	259.	48539.	95.	48634.	6836.	76949.	77018.
1	1	30	280.	56616.	95.	56711.	7450.	84399.	84464.

TABLE 2. Annual Cost Figures.

FROM	CD	YR	CURREN	AC.LOSS	AC.PURCH	AC.TOTAL	P.WORTH	TOTAL.PW	TPW/SALVA
1	1	31	302.	66037.	95.	66131.	8119.	92518.	92579.
1	1	32	326.	77025.	95.	77120.	8849.	101367.	101424.
1	1	33	352.	89842.	95.	89937.	9644.	111011.	111065.
1	1	34	380.	104792.	95.	104887.	10512.	121523.	121574.
1	1	35	411.	122230.	95.	122324.	11457.	132980.	133028.
1	1	36	444.	142569.	95.	142663.	12488.	145469.	145513.
1	1	37	479.	166292.	95.	166386.	13612.	159081.	159122.
1	1	38	517.	193963.	95.	194057.	14837.	173918.	173957.
1	1	39	559.	226238.	95.	226333.	16173.	190090.	190127.
1	1	40	603.	263884.	95.	263979.	17629.	207719.	207753.
1	1	41	652.	307795.	95.	307889.	19216.	226935.	226967.
1	1	42	704.	359011.	95.	359106.	20946.	247882.	247911.
1	1	43	760.	418751.	95.	418846.	22833.	270714.	270742.
1	1	44	821.	488431.	95.	488526.	24889.	295603.	295629.
1	1	45	850.	523551.	95.	523645.	24933.	320536.	320560.
1	1	46	850.	523551.	95.	523645.	23302.	343838.	343860.
1	1	47	850.	523551.	95.	523645.	21777.	365615.	365636.
1	1	48	850.	523551.	95.	523645.	20353.	385968.	385987.
1	1	49	850.	523551.	95.	523645.	19021.	404989.	405006.
1	1	50	850.	523551.	95.	523645.	17777.	422766.	422782.
1	1	51	850.	523551.	95.	523645.	16614.	439380.	439394.
1	1	52	850.	523551.	95.	523645.	15527.	454907.	454919.
1	1	53	850.	523551.	95.	523645.	14511.	469418.	469429.
1	1	54	850.	523551.	95.	523645.	13562.	482980.	482990.
1	1	55	850.	523551.	95.	523645.	12675.	495654.	495663.
1	1	56	850.	523551.	95.	523645.	11845.	507500.	507507.
1	1	57	850.	523551.	95.	523645.	11071.	518570.	518577.
1	1	58	850.	523551.	95.	523645.	10346.	528916.	528922.
1	1	59	850.	523551.	95.	523645.	9669.	538586.	538590.
1	1	60	850.	523551.	95.	523645.	9037.	547623.	547626.

TABLE 2. (Continued).

FROM	CD	YR	CURREN	AC.LOSS	AC.PURCH	AC.TOTAL	P.WORTH	TOTAL.PW	TPW/SALVA
1	10	1	30.	82.	763.	845.	790.	790.	3922.
1	10	2	32.	95.	763.	858.	750.	1539.	4466.
1	10	3	35.	111.	763.	874.	714.	2253.	5024.
1	10	4	38.	129.	763.	893.	681.	2934.	5540.
1	10	5	41.	151.	763.	914.	652.	3586.	6037.
1	10	6	44.	176.	763.	939.	626.	4212.	6518.
1	10	7	48.	205.	763.	969.	603.	4815.	6984.
1	10	8	51.	239.	763.	1003.	584.	5398.	7439.
1	10	9	56.	279.	763.	1043.	567.	5965.	7885.
1	10	10	60.	326.	763.	1089.	554.	6519.	8325.
1	10	11	65.	380.	763.	1143.	543.	7062.	8761.
1	10	12	70.	443.	763.	1206.	536.	7598.	9196.
1	10	13	76.	517.	763.	1280.	531.	8129.	9633.
1	10	14	82.	603.	763.	1366.	530.	8659.	10073.
1	10	15	88.	703.	763.	1467.	532.	9191.	10521.
1	10	16	95.	820.	763.	1584.	536.	9727.	10979.
1	10	17	103.	957.	763.	1720.	545.	10272.	11449.
1	10	18	111.	1116.	763.	1879.	556.	10828.	11935.
1	10	19	120.	1302.	763.	2065.	571.	11399.	12440.
1	10	20	129.	1519.	763.	2282.	590.	11988.	12968.
1	10	21	140.	1771.	763.	2534.	612.	12600.	13522.
1	10	22	151.	2066.	763.	2829.	639.	13239.	14105.
1	10	23	163.	2409.	763.	3173.	669.	13908.	14723.
1	10	24	176.	2810.	763.	3574.	705.	14613.	15378.
1	10	25	190.	3278.	763.	4041.	745.	15357.	16077.
1	10	26	205.	3823.	763.	4587.	790.	16147.	16824.
1	10	27	222.	4460.	763.	5223.	841.	16988.	17624.
1	10	28	240.	5202.	763.	5965.	897.	17885.	18482.
1	10	29	259.	6067.	763.	6831.	960.	18845.	19406.
1	10	30	280.	7077.	763.	7840.	1030.	19875.	20402.

TABLE 2. (Continued).

FROM	CD	YR	CURREN	AC.LOSS	AC.PURCH	AC.TOTAL	P.WORTH	TOTAL.PW	TPW/SALVA
1	10	31	302.	8255.	763.	9018.	1107.	20982.	21477.
1	10	32	326.	9628.	763.	10391.	1192.	22174.	22639.
1	10	33	352.	11230.	763.	11994.	1286.	23461.	23897.
1	10	34	380.	13099.	763.	13862.	1389.	24850.	25259.
1	10	35	411.	15279.	763.	16042.	1503.	26352.	26736.
1	10	36	444.	17821.	763.	18584.	1627.	27979.	28339.
1	10	37	479.	20786.	763.	21550.	1763.	29742.	30079.
1	10	38	517.	24245.	763.	25009.	1912.	31654.	31970.
1	10	39	559.	28280.	763.	29043.	2075.	33730.	34025.
1	10	40	603.	32986.	763.	33749.	2254.	35983.	36259.
1	10	41	652.	38474.	763.	39238.	2449.	38432.	38690.
1	10	42	704.	44876.	763.	45640.	2662.	41094.	41335.
1	10	43	760.	52344.	763.	53107.	2895.	43989.	44213.
1	10	44	821.	61054.	763.	61817.	3149.	47139.	47347.
1	10	45	850.	65444.	763.	66207.	3152.	50291.	50484.
1	10	46	850.	65444.	763.	66207.	2946.	53237.	53416.
1	10	47	850.	65444.	763.	66207.	2753.	55991.	56156.
1	10	48	850.	65444.	763.	66207.	2573.	58564.	58716.
1	10	49	850.	65444.	763.	66207.	2405.	60969.	61109.
1	10	50	850.	65444.	763.	66207.	2248.	63217.	63344.
1	10	51	850.	65444.	763.	66207.	2101.	65317.	65433.
1	10	52	850.	65444.	763.	66207.	1963.	67280.	67385.
1	10	53	850.	65444.	763.	66207.	1835.	69115.	69208.
1	10	54	850.	65444.	763.	66207.	1715.	70830.	70912.
1	10	55	850.	65444.	763.	66207.	1603.	72432.	72504.
1	10	56	850.	65444.	763.	66207.	1498.	73930.	73991.
1	10	57	850.	65444.	763.	66207.	1400.	75330.	75381.
1	10	58	850.	65444.	763.	66207.	1308.	76638.	76680.
1	10	59	850.	65444.	763.	66207.	1223.	77860.	77894.
1	10	60	850.	65444.	763.	66207.	1143.	79003.	79028.

TABLE 2. (Continued)

FROM	CD	YR	CURREN	AC.LOSS	AC.PURCH	AC.TOTAL	P.WORTH	TOTAL.PW	TPW/SALVA
1	20	1	30.	26.	2241.	2267.	2118.	2118.	11315.
1	20	2	32.	30.	2241.	2271.	1984.	4102.	12752.
1	20	3	35.	35.	2241.	2276.	1858.	5960.	14095.
1	20	4	38.	41.	2241.	2282.	1741.	7701.	15353.
1	20	5	41.	48.	2241.	2289.	1632.	9332.	16530.
1	20	6	44.	56.	2241.	2297.	1530.	10863.	17633.
1	20	7	48.	65.	2241.	2306.	1436.	12299.	18668.
1	20	8	51.	76.	2241.	2317.	1348.	13647.	19638.
1	20	9	56.	88.	2241.	2329.	1267.	14914.	20550.
1	20	10	60.	103.	2241.	2344.	1192.	16106.	21408.
1	20	11	65.	120.	2241.	2361.	1122.	17228.	22215.
1	20	12	70.	140.	2241.	2381.	1057.	18285.	22977.
1	20	13	76.	164.	2241.	2405.	998.	19283.	23677.
1	20	14	82.	191.	2241.	2432.	943.	20226.	24378.
1	20	15	88.	223.	2241.	2464.	893.	21119.	25025.
1	20	16	95.	260.	2241.	2501.	847.	21966.	25640.
1	20	17	103.	303.	2241.	2544.	805.	22771.	26228.
1	20	18	111.	354.	2241.	2594.	768.	23539.	26790.
1	20	19	120.	412.	2241.	2653.	734.	24273.	27330.
1	20	20	129.	481.	2241.	2722.	703.	24976.	27852.
1	20	21	140.	561.	2241.	2802.	677.	25653.	28357.
1	20	22	151.	655.	2241.	2895.	654.	26306.	28850.
1	20	23	163.	763.	2241.	3004.	634.	26940.	29332.
1	20	24	176.	890.	2241.	3131.	617.	27557.	29806.
1	20	25	190.	1039.	2241.	3280.	604.	28162.	30275.
1	20	26	205.	1211.	2241.	3452.	594.	28756.	30743.
1	20	27	222.	1413.	2241.	3654.	588.	29344.	31211.
1	20	28	240.	1648.	2241.	3889.	585.	29929.	31694.
1	20	29	259.	1922.	2241.	4163.	585.	30514.	32163.
1	20	30	280.	2242.	2241.	4483.	589.	31103.	32651.

TABLE 2. (Continued).

FROM	CD	YR	CURREN	AC.LOSS	AC.PURCH	AC.TOTAL	P.WORTH	TOTAL.PW	TPW/SALVA
1	20	31	302.	2616.	2241.	4856.	596.	31700.	33153.
1	20	32	326.	3051.	2241.	5292.	607.	32307.	33671.
1	20	33	352.	3558.	2241.	5799.	622.	32929.	34209.
1	20	34	380.	4150.	2241.	6391.	641.	33569.	34770.
1	20	35	411.	4841.	2241.	7082.	663.	34232.	35359.
1	20	36	444.	5647.	2241.	7888.	690.	34923.	35979.
1	20	37	479.	6586.	2241.	8827.	722.	35645.	36634.
1	20	38	517.	7682.	2241.	9923.	759.	36404.	37329.
1	20	39	559.	8961.	2241.	11201.	800.	37204.	38070.
1	20	40	603.	10452.	2241.	12692.	848.	38052.	38861.
1	20	41	652.	12191.	2241.	14432.	901.	38952.	39708.
1	20	42	704.	14219.	2241.	16460.	960.	39913.	40618.
1	20	43	760.	16585.	2241.	18826.	1026.	40939.	41596.
1	20	44	821.	19345.	2241.	21586.	1100.	42039.	42650.
1	20	45	850.	20736.	2241.	22977.	1094.	43133.	43700.
1	20	46	850.	20736.	2241.	22977.	1022.	44155.	44681.
1	20	47	850.	20736.	2241.	22977.	956.	45111.	45596.
1	20	48	850.	20736.	2241.	22977.	893.	46004.	46451.
1	20	49	850.	20736.	2241.	22977.	835.	46838.	47249.
1	20	50	850.	20736.	2241.	22977.	780.	47618.	47993.
1	20	51	850.	20736.	2241.	22977.	729.	48347.	48687.
1	20	52	850.	20736.	2241.	22977.	681.	49029.	49335.
1	20	53	850.	20736.	2241.	22977.	637.	49665.	49939.
1	20	54	850.	20736.	2241.	22977.	595.	50260.	50502.
1	20	55	850.	20736.	2241.	22977.	556.	50817.	51026.
1	20	56	850.	20736.	2241.	22977.	520.	51336.	51516.
1	20	57	850.	20736.	2241.	22977.	486.	51822.	51973.
1	20	58	850.	20736.	2241.	22977.	454.	52276.	52400.
1	20	59	850.	20736.	2241.	22977.	424.	52700.	52799.
1	20	60	850.	20736.	2241.	22977.	397.	53097.	53172.

TABLE 2. (Continued).

FROM	CD	YR	CURREN	AC.LOSS	AC.PURCH	AC.TOTAL	P.WORTH	TOTAL.PW	TPW/SALVA
1	30	1	30.	13.	4534.	4547.	4249.	4249.	22858.
1	30	2	32.	15.	4534.	4549.	3973.	8223.	25725.
1	30	3	35.	17.	4534.	4552.	3715.	11938.	28400.
1	30	4	38.	20.	4534.	4554.	3475.	15413.	30896.
1	30	5	41.	24.	4534.	4558.	3250.	18662.	33227.
1	30	6	44.	27.	4534.	4562.	3040.	21702.	35402.
1	30	7	48.	32.	4534.	4566.	2844.	24546.	37433.
1	30	8	51.	37.	4534.	4572.	2661.	27206.	39329.
1	30	9	56.	44.	4534.	4578.	2490.	29696.	41100.
1	30	10	60.	51.	4534.	4585.	2331.	32027.	42755.
1	30	11	65.	59.	4534.	4594.	2182.	34210.	44301.
1	30	12	70.	69.	4534.	4603.	2044.	36254.	45747.
1	30	13	76.	81.	4534.	4615.	1915.	38169.	47099.
1	30	14	82.	94.	4534.	4628.	1795.	39964.	48365.
1	30	15	88.	110.	4534.	4644.	1683.	41647.	49550.
1	30	16	95.	128.	4534.	4662.	1579.	43226.	50660.
1	30	17	103.	149.	4534.	4684.	1483.	44709.	51702.
1	30	18	111.	174.	4534.	4708.	1393.	46102.	52680.
1	30	19	120.	203.	4534.	4738.	1310.	47412.	53599.
1	30	20	129.	237.	4534.	4771.	1233.	48645.	54464.
1	30	21	140.	277.	4534.	4811.	1162.	49807.	55279.
1	30	22	151.	323.	4534.	4857.	1096.	50903.	56049.
1	30	23	163.	376.	4534.	4911.	1036.	51939.	56778.
1	30	24	176.	439.	4534.	4973.	980.	52919.	57469.
1	30	25	190.	512.	4534.	5046.	930.	53849.	58126.
1	30	26	205.	597.	4534.	5131.	884.	54733.	58753.
1	30	27	222.	697.	4534.	5231.	842.	55574.	59352.
1	30	28	240.	812.	4534.	5347.	804.	56379.	59929.
1	30	29	259.	948.	4534.	5482.	771.	57149.	60484.
1	30	30	280.	1105.	4534.	5639.	741.	57890.	61022.

TABLE 2. (Continued).

FROM	CD	YR	CURREN	AC.LCSS	AC.FURCH	AC.TOTAL	P.WORTH	TOTAL.PW	TPW/SALVA
1	30	31	302.	1289.	4534.	5823.	715.	58605.	61546.
1	30	32	326.	1504.	4534.	6038.	693.	59298.	62059.
1	30	33	352.	1754.	4534.	6288.	674.	59972.	62563.
1	30	34	380.	2046.	4534.	6580.	659.	60631.	63062.
1	30	35	411.	2386.	4534.	6920.	648.	61280.	63559.
1	30	36	444.	2783.	4534.	7317.	641.	61920.	64056.
1	30	37	479.	3246.	4534.	7781.	637.	62557.	64558.
1	30	38	517.	3767.	4534.	8321.	636.	63193.	65066.
1	30	39	559.	4417.	4534.	8951.	640.	63832.	65585.
1	30	40	603.	5152.	4534.	9686.	647.	64479.	66117.
1	30	41	652.	6009.	4534.	10543.	658.	65137.	66667.
1	30	42	704.	7009.	4534.	11543.	673.	65811.	67237.
1	30	43	760.	8175.	4534.	12709.	693.	66503.	67833.
1	30	44	821.	9535.	4534.	14070.	717.	67220.	68457.
1	30	45	850.	10221.	4534.	14755.	703.	67923.	69071.
1	30	46	850.	10221.	4534.	14755.	657.	68579.	69643.
1	30	47	850.	10221.	4534.	14755.	614.	69193.	70176.
1	30	48	850.	10221.	4534.	14755.	573.	69766.	70672.
1	30	49	850.	10221.	4534.	14755.	536.	70302.	71133.
1	30	50	850.	10221.	4534.	14755.	501.	70803.	71561.
1	30	51	850.	10221.	4534.	14755.	468.	71271.	71959.
1	30	52	850.	10221.	4534.	14755.	438.	71709.	72329.
1	30	53	850.	10221.	4534.	14755.	409.	72118.	72671.
1	30	54	850.	10221.	4534.	14755.	382.	72500.	72988.
1	30	55	850.	10221.	4534.	14755.	357.	72857.	73281.
1	30	56	850.	10221.	4534.	14755.	334.	73191.	73554.
1	30	57	850.	10221.	4534.	14755.	312.	73503.	73808.
1	30	58	850.	10221.	4534.	14755.	292.	73794.	74045.
1	30	59	850.	10221.	4534.	14755.	272.	74066.	74266.
1	30	60	850.	10221.	4534.	14755.	255.	74321.	74473.

TABLE 2. (Continued).

FROM	CD	YR	CURREN	AC.LOSS	AC.PURCH	AC.TOTAL	P.WORTH	TOTAL.PW	TPW/SALVA
1	33	1	30.	11.	5335.	5345.	4996.	4996.	26889.
1	33	2	32.	13.	5335.	5347.	4670.	9666.	30258.
1	33	3	35.	15.	5335.	5349.	4367.	14033.	33400.
1	33	4	38.	17.	5335.	5352.	4083.	18116.	36333.
1	33	5	41.	20.	5335.	5355.	3818.	21934.	39069.
1	33	6	44.	23.	5335.	5358.	3570.	25504.	41622.
1	33	7	48.	27.	5335.	5362.	3339.	28843.	44005.
1	33	8	51.	32.	5335.	5366.	3123.	31966.	46229.
1	33	9	56.	37.	5335.	5372.	2922.	34888.	48305.
1	33	10	60.	43.	5335.	5378.	2734.	37622.	50243.
1	33	11	65.	50.	5335.	5385.	2558.	40180.	52054.
1	33	12	70.	59.	5335.	5393.	2395.	42575.	53745.
1	33	13	76.	69.	5335.	5403.	2242.	44817.	55325.
1	33	14	82.	80.	5335.	5415.	2100.	46917.	56802.
1	33	15	88.	93.	5335.	5428.	1967.	48885.	58183.
1	33	16	95.	109.	5335.	5444.	1844.	50728.	59475.
1	33	17	103.	127.	5335.	5462.	1729.	52457.	60685.
1	33	18	111.	148.	5335.	5483.	1622.	54080.	61819.
1	33	19	120.	173.	5335.	5507.	1523.	55603.	62882.
1	33	20	129.	202.	5335.	5536.	1431.	57033.	63879.
1	33	21	140.	235.	5335.	5570.	1345.	58378.	64817.
1	33	22	151.	274.	5335.	5609.	1266.	59644.	65699.
1	33	23	163.	320.	5335.	5655.	1193.	60837.	66530.
1	33	24	176.	373.	5335.	5708.	1125.	61963.	67315.
1	33	25	190.	435.	5335.	5770.	1063.	63026.	68058.
1	33	26	205.	508.	5335.	5842.	1006.	64032.	68761.
1	33	27	222.	592.	5335.	5927.	954.	64986.	69431.
1	33	28	240.	691.	5335.	6025.	906.	65892.	70068.
1	33	29	259.	806.	5335.	6140.	863.	66755.	70679.
1	33	30	280.	940.	5335.	6274.	824.	67579.	71254.

TABLE 2. (Continued).

FROM	CD	YR	CURREN	AC.LOSS	AC.PURCH	AC.TOTAL	P.WORTH	TOTAL.PW	TPW/SALVA
1	33	31	302.	1096.	5335.	6431.	790.	68369.	71829.
1	33	32	326.	1279.	5335.	6613.	759.	69127.	72376.
1	33	33	352.	1491.	5335.	6826.	732.	69859.	72908.
1	33	34	380.	1740.	5335.	7074.	709.	70568.	73428.
1	33	35	411.	2029.	5335.	7364.	690.	71258.	73939.
1	33	36	444.	2367.	5335.	7701.	674.	71932.	74445.
1	33	37	479.	2761.	5335.	8095.	662.	72594.	74949.
1	33	38	517.	3220.	5335.	8555.	654.	73248.	75452.
1	33	39	559.	3756.	5335.	9090.	650.	73898.	75960.
1	33	40	603.	4381.	5335.	9715.	649.	74547.	76474.
1	33	41	652.	5110.	5335.	10444.	652.	75199.	76998.
1	33	42	704.	5960.	5335.	11295.	659.	75857.	77536.
1	33	43	760.	6952.	5335.	12286.	670.	76527.	78091.
1	33	44	821.	8109.	5335.	13443.	685.	77212.	78667.
1	33	45	850.	8692.	5335.	14026.	668.	77880.	79230.
1	33	46	850.	8692.	5335.	14026.	624.	78504.	79755.
1	33	47	850.	8692.	5335.	14026.	583.	79087.	80244.
1	33	48	850.	8692.	5335.	14026.	545.	79632.	80697.
1	33	49	850.	8692.	5335.	14026.	509.	80142.	81119.
1	33	50	850.	8692.	5335.	14026.	476.	80618.	81510.
1	33	51	850.	8692.	5335.	14026.	445.	81063.	81873.
1	33	52	850.	8692.	5335.	14026.	416.	81479.	82208.
1	33	53	850.	8692.	5335.	14026.	389.	81867.	82518.
1	33	54	850.	8692.	5335.	14026.	363.	82231.	82805.
1	33	55	850.	8692.	5335.	14026.	339.	82570.	83070.
1	33	56	850.	8692.	5335.	14026.	317.	82887.	83315.
1	33	57	850.	8692.	5335.	14026.	297.	83184.	83543.
1	33	58	850.	8692.	5335.	14026.	277.	83461.	83756.
1	33	59	850.	8692.	5335.	14026.	259.	83720.	83955.
1	33	60	850.	8692.	5335.	14026.	242.	83962.	84141.

TABLE 2. (Continued).

LIST OF OPTIMUM CONDUCTORS W/O REPLACEMENTS FROM YEAR 1 TO YEAR X

CASE # 1 (NO REPLACEMENTS)

YEAR X	CURRENT	CONDUCTOR #	ACSR(MCM)	TOTAL COST(P.W)
1	30.	2	5.00	594.30
2	32.	3	4.00	1073.64
3	35.	4	3.00	1497.93
4	38.	4	3.00	2037.71
5	41.	5	2.00	2427.34
6	44.	5	2.00	2958.58
7	48.	5	2.00	3512.85
8	51.	6	1.00	3918.52
9	56.	6	1.00	4465.11
10	60.	6	1.00	5035.39
11	65.	6	1.00	5633.19
12	70.	7	1.01	6087.21
13	76.	7	1.01	6673.23
14	82.	7	1.01	7287.48
15	88.	7	1.01	7934.12
16	95.	7	1.01	8617.56
17	103.	8	2.01	9160.81
18	111.	8	2.01	9826.73
19	120.	8	2.01	10530.56
20	129.	8	2.01	11277.15
21	140.	8	2.01	12071.70

TABLE 3. Optimum Conductors w/o Replacement.

YEAR X	CURRENT	CONDUCTOR #	ACSR(MCM)	TOTAL COST(P.W)
22	151.	9	3.01	12731.58
23	163.	9	3.01	13498.90
24	176.	9	3.01	14315.49
25	190.	9	3.01	15187.09
26	205.	9	3.01	16119.88
27	222.	10	4.01	16987.60
28	240.	10	4.01	17884.77
29	259.	10	4.01	18844.91
30	280.	10	4.01	19874.88
31	302.	10	4.01	20982.04
32	326.	11	226.80	21967.73
33	352.	11	226.80	23017.68
34	380.	11	226.80	24146.25
35	411.	11	226.80	25361.57
36	444.	11	226.80	26672.41
37	479.	12	300.00	27930.46
38	517.	13	336.40	29431.95
39	559.	14	397.50	31408.63
40	603.	15	477.00	34213.26
41	652.	15	477.00	35377.86
42	704.	18	605.50	38098.93
43	760.	19	636.00	40077.96
44	821.	21	715.50	43522.64
45	850.	22	795.00	47032.42
46	850.	22	795.00	47930.11
47	850.	22	795.00	48769.07

TABLE 3. (Continued)

YEAR X	CURRENT	CONDUCTOR #	ACSR(MCM)	TOTAL COST(P.W)
48	850.	22	795.00	49553.15
49	850.	22	795.00	50285.93
50	850.	22	795.00	50970.78
51	850.	22	795.00	51610.82
52	850.	22	795.00	52208.98
53	850.	22	795.00	52768.02
54	850.	22	795.00	53290.48
55	850.	22	795.00	53778.77
56	850.	22	795.00	54235.11
57	850.	22	795.00	54661.59
58	850.	22	795.00	55060.18
59	850.	22	795.00	55432.69
60	850.	22	795.00	55780.83

TABLE 3. (Continued).

COST FIGURES FOR THE BEST 2 CONDUCTOR COMBINATION WITH 1 REPLACEMENTS

TABLE INDICATES # OF YEARS IN THE FIRST PERIOD,THE YEAR OF REPLACEMENT AND THE CONDUCTOR TO BE USED FROM THEN UP TO THE LAST YEAR.

YEARS IN 1 PERIOD	RPLMENT YEAR	LAST YR	CDT#	ACSR(MCM)	TOTAL COST PW
1	2	2	2	5.00	1714.40
1	2	3	3	4.00	2211.95
1	2	4	4	3.00	2639.21
1	2	5	5	2.00	3045.92
1	2	6	5	2.00	3577.16
1	2	7	5	2.00	4131.42
1	2	8	6	1.00	4528.46
1	2	9	6	1.00	5075.04
1	2	10	6	1.00	5645.33
3	4	11	7	1.01	6216.16
1	2	12	7	1.01	6663.32
1	2	13	7	1.01	7249.34
6	7	14	8	2.01	7830.52
6	7	15	8	2.01	8408.96
6	7	16	8	2.01	9012.45
9	10	17	9	3.01	9489.89
9	10	18	9	3.01	10084.54
9	10	19	9	3.01	10704.89
12	13	20	10	4.01	11274.52
10	11	21	10	4.01	11831.00
10	11	22	10	4.01	12469.55

TABLE 4. Best Two Conductor Combinations.

YEARS IN 1 PERIOD	RPLMENT YEAR	LAST YR	CDT#	ACSR(MCM)	TOTAL COST PW
14	15	23	11	226.80	13025.81
13	14	24	11	226.80	13636.29
13	14	25	11	226.80	14287.89
15	16	26	12	300.00	14939.68
14	15	27	12	300.00	15578.87
14	15	28	12	300.00	16287.80
14	15	29	13	336.40	16941.54
14	15	30	13	336.40	17681.13
15	16	31	14	397.50	18334.04
15	16	32	14	397.50	19081.31
19	20	33	18	605.50	19662.69
19	20	34	18	605.50	20323.79
19	20	35	18	605.50	21012.76
19	20	36	18	605.50	21734.17
19	20	37	18	605.50	22492.88
19	20	38	18	605.50	23294.08
19	20	39	18	605.50	24143.27
19	20	40	20	666.60	24964.80
19	20	41	20	666.60	25865.51
20	21	42	21	715.50	26755.05
23	24	43	24	900.00	27537.76
23	24	44	24	900.00	28418.85
24	25	45	25	954.00	29287.46
23	24	46	25	954.00	30049.40
24	25	47	26	1033.5)	30749.85
24	25	48	26	1033.50	31404.48
24	25	49	27	1113.00	31961.82
24	25	50	27	1113.00	32509.97
24	25	51	27	1113.00	33022.25
25	26	52	28	1192.50	33489.61
25	26	53	28	1192.50	33921.62

TABLE 4. (Continued)

YEARS IN 1 PERIOD	RPLMENT YEAR	LAST YR	CDT#	ACSR(MCM)	TOTAL COST PW
25	26	54	28	1192.50	34325.36
25	26	55	28	1192.50	34702.70
25	26	56	29	1272.00	35020.31
25	26	57	29	1272.00	35339.67
25	26	58	29	1272.00	35638.14
25	26	59	29	1272.00	35917.08
25	26	60	29	1272.00	36177.77

TABLE 4. (Continued).

Table 5. Addition of another replacement is considered and the same process is repeated successively until no more savings are produced by adding up a new replacement. Table 8 is of no practical use since combinations obtained by considering small number of replacements, Table 6 results in consistently lower costs for all years under study. From Table 6, it is seen that after year (51) all replacements are scheduled at the same year and with the same conductor. In this case we see that after a large enough number of years replacement policy for the first years of the project remains constant. Table 6 shows that for sixty years replacement should occur at year (37), with the first period being composed of the best two conductor for a period of (36) years. By looking for this number of final years in the two conductor case, Table 4, the rest of the replacement schedule is derived. It shows that the best two conductors for (36) years consists of a replacement at year (20) and the best single conductor up to the preceeding year (Table 3). The following schedule is obtained.

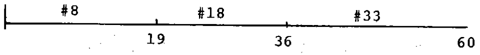

Figure 12. **Replacement Schedule. Sample case. (Three conductor study)**

COMPARATIVE RESULTS FOR THE CASE STUDY OF 2 CONDUCTORS / 1 REPLACEMENTS

TABLE SHOWS ECONOMIC CHOICE WITH RESPECT TO PREVIOUS CASE.

NUMBER OF YEARS	MOST ECONOMIC CASE CONDUCTOR STUDY NUMBER	TOTAL COST
2	1	1073.64
3	1	1497.93
4	1	2037.71
5	1	2427.34
6	1	2958.58
7	1	3512.85
8	1	3918.52
9	1	4465.11
10	1	5035.39
11	1	5633.19
12	1	6067.21
13	1	6673.23
14	1	7287.48
15	1	7934.12
16	1	8617.56
17	1	9160.81
18	1	9826.73

TABLE 5. Comparative Results. (Two Conductor Case)

NUMBER OF YEARS	MOST ECONOMIC CASE CONDUCTOR STUDY NUMBER	TOTAL COST
19	1	10530.56
20	2	11274.52
21	2	11831.00
22	2	12469.55
23	2	13025.81
24	2	13636.29
25	2	14237.89
26	2	14939.68
27	2	15578.87
28	2	16237.80
29	2	16941.54
30	2	17681.13
31	2	18334.04
32	2	19081.31
33	2	19662.69
34	2	20323.79
35	2	21012.76
36	2	21734.17
37	2	22492.88
38	2	23294.08
39	2	24143.27
40	2	24964.80
41	2	25865.51
42	2	26755.05
43	2	27537.76
44	2	28418.85

TABLE 5. (Continued).

NUMBER OF YEARS	MOST ECONOMIC CASE CONDUCTOR STUDY NUMBER	TOTAL COST
45	2	29237.46
46	2	30049.40
47	2	30749.85
48	2	31404.48
49	2	31961.82
50	2	32509.97
51	2	33022.25
52	2	33489.61
53	2	33921.62
54	2	34325.36
55	2	34702.70
56	2	35020.31
57	2	35339.67
58	2	35638.14
59	2	35917.08
60	2	36177.77

TABLE 5. (Continued).

COST FIGURES FOR THE BEST 3 CONDUCTOR COMBINATION WITH 2 REPLACEMENTS

TABLE INDICATES # OF YEARS IN THE FIRST PERIOD,THE YEAR OF REPLACEMENT AND THE CONDUCTOR TO BE USED FROM THEN UP TO THE LAST YEAR.

YEARS IN 1 PERIOD	RPLMENT YEAR	LAST YR	CDT#	ACSR(MCM)	TOTAL COST PW
2	3	3	2	5.00	2843.07
2	3	4	3	4.00	3362.11
2	3	5	4	3.00	3794.90
2	3	6	5	2.00	4192.81
2	3	7	5	2.00	4747.08
2	3	8	6	1.00	5143.76
2	3	9	6	1.00	5690.35
2	3	10	6	1.00	6260.64
3	4	11	7	1.01	6782.93
2	3	12	7	1.01	7253.18
2	3	13	7	1.01	7839.20
6	7	14	8	2.01	8444.43
6	7	15	8	2.01	9022.87
2	3	16	8	2.01	9579.45
9	10	17	9	3.01	10094.89
9	10	18	9	3.01	10689.53
9	10	19	9	3.01	11309.89
12	13	20	10	4.01	11845.41
10	11	21	10	4.01	12436.28
10	11	22	10	4.01	13074.82

TABLE 6. Best Three Conductor Combinations.

YEARS IN 1 PERIOD	RPLMENT YEAR	LAST YR	CDT#	ACSR(MCM)	TOTAL COST PW
15	16	23	11	226.80	13698.82
13	14	24	11	226.80	14207.49
13	14	25	11	226.80	14859.10
13	14	26	11	226.80	15541.95
13	14	27	12	300.00	16161.80
16	17	28	13	336.40	16835.04
19	20	29	14	397.50	17406.95
19	20	30	14	397.50	18085.51
24	25	31	15	477.00	18790.37
22	23	32	18	605.50	19197.36
22	23	33	18	605.50	19834.94
22	23	34	18	605.50	20496.05
22	23	35	18	605.50	21185.01
22	23	36	18	605.50	21906.42
25	26	37	20	666.60	22603.88
28	29	38	22	795.00	23352.21
27	28	39	22	795.00	24034.62
27	28	40	24	900.00	24671.16
27	28	41	24	900.00	25421.18
27	28	42	24	900.00	26209.41
27	28	43	25	954.00	26980.57
29	30	44	27	1113.00	27720.40
28	29	45	27	1113.00	28479.71
30	31	46	28	1192.50	29154.50
30	31	47	29	1272.00	29742.34
30	31	48	29	1272.00	30329.46
36	37	49	32	1510.50	30841.93
35	36	50	32	1510.50	31319.43
36	37	51	33	1590.00	31732.73
36	37	52	33	1590.00	32148.63
36	37	53	33	1590.00	32537.31

TABLE 6. (Continued).

YEARS IN 1 PERIOD	RPLMENT YEAR	LAST YR	CDT#	ACSR(MCM)	TOTAL COST PW
36	37	54	33	1590.00	32900.57
36	37	55	33	1590.00	33240.07
36	37	56	33	1590.00	33557.36
36	37	57	33	1590.00	33853.88
36	37	58	33	1590.00	34131.01
36	37	59	33	1590.00	34390.01
36	37	60	33	1590.00	34632.07

TABLE 6. (Continued).

COMPARATIVE RESULTS FOR THE CASE STUDY OF 3 CONDUCTORS / 2 REPLACEMENTS

TABLE SHOWS ECONOMIC CHOICE WITH RESPECT TO PREVIOUS CASE.

NUMBER OF YEARS	MOST ECONOMIC CASE CONDUCTOR STUDY NUMBER	TOTAL COST
3	2	2211.95
4	2	2639.21
5	2	3045.92
6	2	3577.16
7	2	4131.42
8	2	4528.46
9	2	5075.04
10	2	5645.33
11	2	6216.16
12	2	6663.32
13	2	7249.34
14	2	7830.52
15	2	8408.96
16	2	9012.45
17	2	9489.89
18	2	10084.54
19	2	10704.89

TABLE 7. Comparative Results. (Three Conductor Case)

NUMBER OF YEARS	MOST ECONOMIC CASE CONDUCTOR STUDY NUMBER	TOTAL COST
20	2	11274.52
21	2	11831.00
22	2	12469.55
23	2	13025.81
24	2	13636.29
25	2	14287.89
26	2	14939.68
27	2	15578.87
28	2	16287.80
29	2	16941.54
30	2	17681.13
31	2	18334.04
32	2	19081.31
33	2	19662.69
34	2	20323.79
35	2	21012.76
36	2	21734.17
37	2	22492.88
38	2	23294.08
39	3	24034.62
40	3	24671.16
41	3	25421.18
42	3	26209.41
43	3	26980.57
44	3	27720.40
45	3	28479.71

TABLE 7. (Continued).

NUMBER OF YEARS	MOST ECONOMIC CASE CONDUCTOR STUDY NUMBER	TOTAL COST
46	3	29154.50
47	3	29742.34
48	3	30329.46
49	3	30841.93
50	3	31319.43
51	3	31732.73
52	3	32148.63
53	3	32537.31
54	3	32900.57
55	3	33240.07
56	3	33557.36
57	3	33853.88
58	3	34131.01
59	3	34390.01
60	3	34632.07

TABLE 7. (Continued).

COST FIGURES FOR THE BEST 4 CONDUCTOR COMBINATION WITH 3 REPLACEMENTS

TABLE INDICATES # OF YEARS IN THE FIRST PERIOD.THE YEAR OF REPLACEMENT AND THE CONDUCTOR TO BE USED FROM THEN UP TO THE LAST YEAR.

YEARS IN 1 PERIOD	RPLMENT YEAR	LAST YR	CDT#	ACSR(MCM)	TOTAL COST PW
3	4	4	3	4.00	3882.28
3	4	5	4	3.00	4376.33
3	4	6	5	2.00	4809.11
3	4	7	5	2.00	5363.38
3	4	8	6	1.00	5768.15
3	4	9	6	1.00	6314.74
3	4	10	6	1.00	6885.03
3	4	11	7	1.01	7298.82
3	4	12	7	1.01	7860.52
3	4	13	7	1.01	8446.54
6	7	14	8	2.01	9055.46
4	5	15	8	2.01	9614.97
3	4	16	8	2.01	10142.60
9	10	17	9	3.01	10705.29
9	10	18	9	3.01	11299.93
9	10	19	9	3.01	11920.29
12	13	20	10	4.01	12430.11
12	13	21	10	4.01	13042.18
12	13	22	10	4.01	13680.72
16	17	23	11	226.80	14298.53

TABLE 8. Best Four Conductor Combinations.

YEARS IN 1 PERIOD	RPLMENT YEAR	LAST YR	CDT#	ACSR(MCM)	TOTAL COST PW
13	14	24	11	226.80	14792.49
13	14	25	11	226.80	15444.09
13	14	26	11	226.80	16126.95
13	14	27	12	300.00	16746.80
16	17	28	13	336.40	17422.13
19	20	29	14	397.50	18011.94
19	20	30	14	397.50	18690.50
24	25	31	15	477.00	19361.57
22	23	32	18	605.50	19802.64
22	23	33	18	605.50	20440.22
22	23	34	18	605.50	21101.32
22	23	35	18	605.50	21790.29
26	27	36	20	666.60	22491.95
25	26	37	20	666.60	23175.09
26	27	38	21	715.50	23905.05
26	27	39	22	795.00	24579.46
27	28	40	24	900.00	25259.51
26	27	41	24	900.00	25998.62
34	35	42	27	1113.00	26686.40
35	36	43	28	1192.50	27374.34
35	36	44	29	1272.00	28058.89
35	36	45	29	1272.00	28778.15
35	36	46	30	1351.00	29389.06
35	36	47	31	1431.00	29946.40
35	36	48	31	1431.00	30507.97
36	37	49	32	1510.50	30997.43
35	36	50	32	1510.50	31473.80
36	37	51	33	1590.00	31888.22
36	37	52	33	1590.00	32304.12
36	37	53	33	1590.00	32692.81
36	37	54	33	1590.00	33056.07

TABLE 8. (Continued).

YEARS IN 1 PERIOD	RPLMENT YEAR	LAST YR	CDT#	ACSR(MCM)	TOTAL COST PW
36	37	55	33	1590.00	33395.57
36	37	56	33	1590.00	33712.85
36	37	57	33	1590.00	34009.38
36	37	58	33	1590.00	34286.51
36	37	59	33	1590.00	34545.51
36	37	60	33	1590.00	34787.56

TABLE 8. (Continued).

YEAR	RATE OF CURRENT GROWTH		
	4 %	8 %	13 %
1	30	30	30
2	31.2	32.4	33.9
3	32.5	35	38.3
4	33.8	37.8	43.3
5	35.1	40.8	48.9
6	36.5	44	55.2
7	38	47.6	62.5
8	39.5	51.4	70.6
9	41.1	55.5	79.8
10	42.7	60	90.1
11	44.4	64.8	101.9
12	46.2	70	115.1
13	48	75.6	130
14	50	81.6	147
15	52	88.1	166
16	54	95.2	187.6
17	56.2	102.8	212
18	58.4	111	239.6
19	60.8	119.9	270.7
20	63.2	129.5	305.9
21	65.7	139.8	345.7
22	68.36	151	390.7
23	71	163.1	441.4
24	74	176.1	498.8
25	76.9	190.2	563.6
26	80	205.5	636.9
27	83.2	221.9	719.7
28	86.5	240	813.3

Table 9. Effective Current (Amperes)

YEAR	4 %	8 %	13 %
29	90	258.8	850
30	93.6	269.5	850
31	97.3	301.8	850
32	101.2	326	850
33	105.2	352.1	850
34	109.4	380.2	850
35	113.8	410.7	850
36	118.4	443.6	850
37	123.1	479	850
38	128	517.4	850
39	133.2	558.8	850
40	138.5	603.5	850
41	144	651.7	850
42	150	703.9	850
43	155.8	760.2	850
44	162	821	850
45	168.5	850	850
46	175.2	850	850
47	182.2	850	850
48	189.5	850	850
49	197.1	850	850
50	205	850	850
51	213.2	850	850
52	221.7	850	850
53	230.6	850	850
54	239.8	850	850
55	249.4	850	850
56	259.4	850	850
57	269.8	850	850
58	280.6	850	850
59	291.8	850	850
60	303.5	850	850

Table 9. (continuation)

Before making any final conclusions it may be necessary to look at the results found if only two conductors were used for sixty years. From Table 4 it is found that this corresponds to conductor (29) from year (26) to year sixty and in the first period the best choice of a single conductor for a period of (25) years, Table 3.

Figure 13. Replacement Scheduled. Sample case. (Two conductor case)

<u>Ideal Case</u>

When a conductor is replaced, its salvage value is strongly dependent on its past history. Strains put on a conductor by weather, overloads, maintenance and some other factors contributes to the unpredictability of the salvage value estimation. This, so called ideal case pertains to the condition where the unamortized value of the conductor at any year of replacement coincides with the salvage value of the conductor at that year. If the basic reasoning is followed in estimating the cost of a replacement installation annuities on the investment of the original installation are extended over the life of the second installation, at least until the original investment has been completely amortized. As it was explained in a previous section this series of uniform costs in the future can be represented by means of discounting factors by a single lump sum at the time of replacement. This constitutes a positive cost at the time of replacement. By the definition of the ideal case, the salvage value at this year will be equal to the last quantity. Since the salvage value is a negative cost it will exactly nullify the effects of the unamortized cost. Since this equality holds for all years under study, the calculations of the unamortized cost and the estimation of the salvage value of the conductor becomes completely unnecessary. In program language this is translated to making the control variable USABLE equal to zero as well as the proportionality factor for the salvage value CVALUE(K)=K1=0. This will make the annuities on the old installation after its replacement and its salvage value equal to zero, thus producing the desired effect. It should be mentioned, however, that removeal cost of the conductor at the time of replacement is always included. The following schedule for the same system described in the sample case, was obtained.

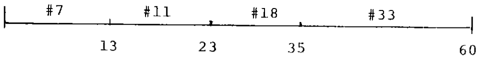

Figure 14. Replacement Schedule. Ideal Case.

Further results of this case, and the different rates of current growth are listed in Table 10.

<u>Non-reusable Conductor</u>

For several reasons, it is possible to have a conductor installed in a line even though its salvage value will be zero at the year of replacement. For a growing load it is almost certain that a replacement should occur long before the physical life of the conductor is over. Since its salvage value is zero, the undepreciated capital still has to be depreciated over the life of the new installation. This is done in the program by making K1=CVALUE=0, and USABLE=1. Another way of representing these conditions will be by appropriately choosing the value of the parameter shape. See Figure 15 (shape = 10). By choosing a fast decaying exponential function for the salvage value curve the zero salvage value assumption can be readily approximated.

GROWTH RATE OF CURRENT	IDEAL CASE.	FOUR CONDUCTORS (3 REPLACEMENTS)				THREE CONDUCTORS (2 REPLACEMENTS)			2 CONDUCTS. (1 REPL.)		1 Cd.
4 %	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	1-16	17-32	33-47	48-60	1-24	25-45	46-60	1-27	28-60	1-60
	CONDUCTOR	6	9	12	18	7	11	18	7	13	10
	COST $/mi	14181 *				14188			14412		17109
8 %	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	1-13	14-23	24-35	36-60	1-19	20-35	36-60	1-25	26-60	1-60
	CONDUCTOR	7	11	18	33	8	18	33	9	29	22
	COST $/mi	33331 *				33689			35823		55780
13 %	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	1-6	7-13	14-22	23-60	1-12	13-22	23-60	1-18	19-60	1-60
	CONDUCTOR	6	10	18	33	8	18	33	10	33	24
	COST $/mi	58817 *				58858			61104		84470

(* denotes optimum policy)

TABLE 10. Results for Ideal case.

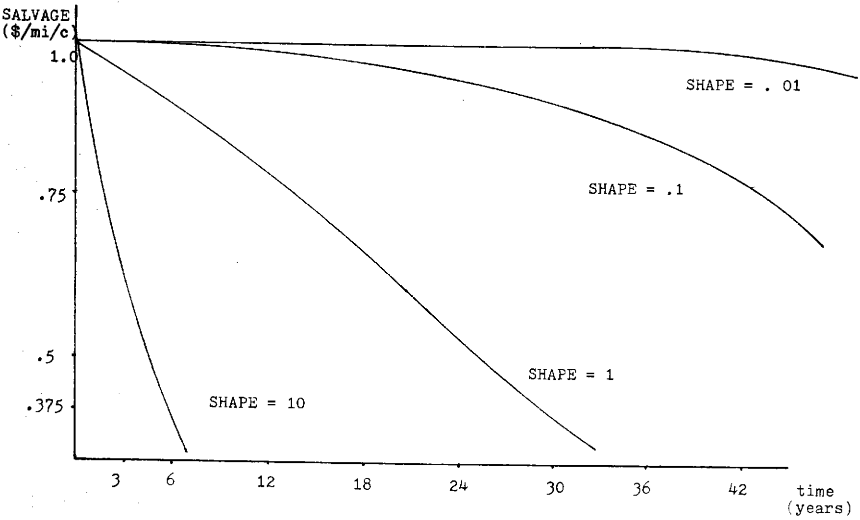

FIGURE 15. Salvage value curves.

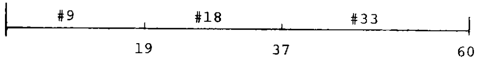

Figure 16. Replacement Schedule. Scrap conductor.

Figure 16, represents the results obtained for this type of installation using the basic parameters of the sample model. By straight reasoning it is seen that by eliminating the costs reducing effects of the salvage value the overall costs of the installations, in comparison with other cases, is increased.

The number of replacements is generally decreased due to increases in revenue requirement produced by extending the recovery charges of old conductors to the annual costs of the new installations. This will obviously tend to offset the savings produced by installing a larger conductor as the current increases. A new installation will be characterized not only by reduced annuities on energy and demand losses but will possess a higher annuity on investment cost than that normally produced by a non-zero salvage value conductor. Table 11 shows results obtained for a similar case but different rates of current growth.

GROWTH RATE OF CURRENT	SALVAGE VALUE=0	FOUR CONDUCTORS (3 REPLACEMENTS)				THREE CONDUCTORS (2 REPLACEMENTS)			2 CONDUCTS. (1 REPL.)		1 Cd.
4 %	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	-	-	-	-	1-27	28-49	50-60	1-29	30-60	1-60
	CONDUCTOR	-	-	-	-	7	11	18	7	13	10
	COST $/mi	-				14840			14421 *		17109
8 %	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	1-11	12-23	24-37	38-60	1-19	20-37	38-60	1-25	26-60	1-60
	CONDUCTOR	6	10	18	33	9	18	33	9	29	22
	COST $/mi	36603				35693 *			36508		55780
13 %	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	-	-	-	-	1-9	10-20	21-60	1-18	19-60	1-60
	CONDUCTOR	-	-	-	-	6	13	33	10	33	24
	COST $/mi	-				62557			62547 *		84470

(* denotes optimum policy)

TABLE 11. Result for SALVAGE = 0 case.

Salvage Value Modeling

Figures 16 and 17 present some of the different salvage value approximations that can be achieved by changing the exponential coefficient of the salvage value equation. This is equivalent in the program to assigning different values to the variable SHAPE. Small values of SHAPE will tend to make the salvage value equal to a prescribed value throughout the life of the conductor. The larger this constant value the smaller the number of replacements that will be permissible. The inverse is also true, that the smaller the constant, the larger the number of replacements that are permitted. The equation for the salvage value, (see Appendix), presented in the program defines a non-increasing type of function. If there happens to be a case where the salvage value is expected to exceed the original cost of the conductor at the time of replacement a more suitable equation should be defined by the user. In any case, the one stated in the program will fit most practical cases.

The salvage value of the conductor cost is assumed to be proportional to the original cost of the conductor itself. Installation costs are excluded. The proportionality coefficient CVALUE(K), is a function of the conductor in question and provides a mean of dealing with

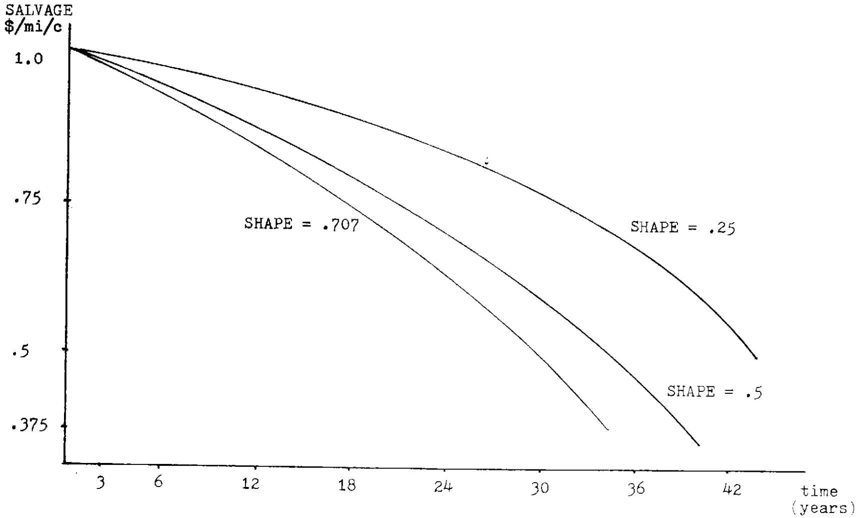

FIGURE 17. Salvage value curves.

GROWTH RATE OF CURRENT	SALVAGE VALUE ≠0	FOUR CONDUCTORS (3 REPLACEMENTS)				THREE CONDUCTORS (2 REPLACEMENTS)			2 CONDUCTS. (1 REPL.)		1 Cd.
8 % SHAPE= 10	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	1-1	2-19	20-37	38-60	1-19	20-37	38-60	1-25	26-60	1-60
	CONDUCTOR	1	8	18	33	8	18	33	9	29	22
	COST $/mi	36251				35678 *			36508		55780
8 % SHAPE= 1/2	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	1-10	11-22	23-36	37-60	1-19	20-36	37-60	1-25	26-60	1-60
	CONDUCTOR	6	10	18	33	8	18	33	9	29	22
	COST $/mi	34787				34632 *			36177		55780
13 % SHAPE= 1/2	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	1-5	6-13	14-23	24-60	1-10	11-20	21-60	1-18	19-60	1-60
	CONDUCTOR	5	9	18	33	7	14	33	10	33	24
	COST $/mi	61181				60631 *			61773		84470

(* denotes optimum policy)

TABLE 12. Results for SALVAGE VALUE ≠ 0 case.

different salvage value behavior for each conductor. Associated with the salvage value is the removal cost of the conductor since the first cannot be obtained without the realization of the second. It is assumed to be proportional to the installation cost of the conductor alone. A coefficient of proportionality, as a function of the conductor CREMOV(K), is provided also. Inflation effects can be included when desired.

Constant Load

More as a check to the structure of the program than anything else, a run was made where the load current was assumed constant for the length of the period under study. The results were consistent with Kelvin's Law. The optimum conductor was that for which the difference between the annual costs of losses and annual cost of investment was a minimum. Since a conductor cannot be in service forever the year of replacement will be that in which the physical status of the installation requires it.

Increasing, Annually compounded load

In most actual cases, the load in any given area is effectively increasing each year or at least is a non-decreasing function of time. Independent of the shape of the load cycle in a given year, the total losses produced by energy transportation can be represented by an effective current in that year. According to how fast this effective current is predicted to increase every year an appropriate rate of growth for an annually compounded current can be found. The faster the load increases the larger this number should be. As in any physical system, the load cannot keep growing forever, in a given line, since eventually it will exceed the capacity of the larger conductor available. Even with bundle installations, they are designed to carry up to a maximum load. In distribution lines, especially in residential areas, the load density which is proportional to the area population will eventually level off primarily due to space limitations. In view of the results obtained, in order to obtain any relevant solutions the period of study should be extended a few years over that in which the load becomes more or less stable.

By increasing the current rate it was seen that replacements occur at an earlier date than with a lower rate. Since the higher the rate the faster it reaches the limiting value of the current, the sooner it becomes economically feasible to install the larger conductors.

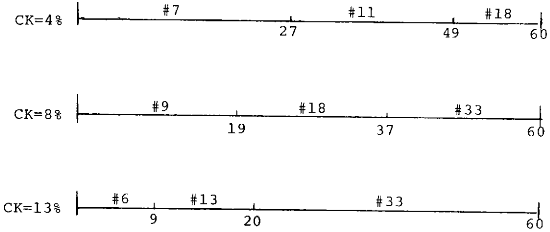

Figure 18. Effect of change in the rate of current growth. (Zero Salvage Value)

Interest and Inflation Rates

This section will summarize some of the effects in optimum replacement policy observed to be caused by using relatively extreme values of interest rate.

It is important to note that changes in interest rate are clearly reflected in the calculation of the capital recovery factor. Costs charged to insurance, taxes and similar terms may be influenced somehow by variations in interest rate. It is then necessary to make the appropriate adjustments in these quantities before proceeding to the actual computations.

An interest rate of 3% was considered with all other parameters in the study being similar to those in the sample case. A new capital recovery factor was calculated assuming equal amortization period. Annuities on taxes, insurance, operation and maintenance expenses remained unchanged during the study. The magnitude of the energy and demand cost increases rapidly causing a larger conductor to be installed sooner in order to reduce energy losses. Just how early this is depends on how much the savings in energy costs are upset by the increases in investment costs. The corresponding decrease in capital recovery factor, due to the lower interest rate, while not affecting the energy component it effectively reduces the fixed charges annuities thus allowing larger conductors to be present earlier in the schedule. Table 13 shows the results obtained by using a 3% and a 12% interest rate.

By increasing the interest rate, relative contributions of costs in the future are greatly reduced. The corresponding increase in capital recovery factor enhances the proportion of total annual cost due to investment annuities. A consequence of the above, is to have smaller conductors installed so that energy losses would more or less balance the annuities on investment.

Inflation rates and their overall effects on replacement policy were also studied. As previosuly described, the program allows for four different types of inflation

INTEREST RATE.	CK=8% SHAPE=1/2	FOUR CONDUCTORS (3 REPLACEMENTS)				THREE CONDUCTORS (2 REPLACEMENTS)			2 CONDUCTS. (1 REPL.)		1 Cd.
3 %	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	1-1	2-18	19-33	34-60	1-17	18-33	34-60	1-28	29-60	1-60
	CONDUCTOR	2	9	18	33	9	18	33	11	33	26
	COST $/mi	111627				111010 *			112773		169153
12 %	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	1-12	13-24	25-37	38-60	1-14	15-31	32-60	1-21	22-60	1-60
	CONDUCTOR	6	10	18	32	6	12	28	8	22	22
	COST $/mi	13277 *				13324			13955		32665

(* denotes optimum policy)

TABLE 13. Results for Interest Rate case.

rates, on energy, demand, labor and conducting material.

Table 14 shows the results obtained by assuming a similar inflation rate for all four components. No definite conclusions can be made since costs in investment and energy losses are both inflated at the same rate. In order to see the definite effect of each of these factors separately, a run with only the energy and demand costs inflated and then another one with the investment costs inflated was made.

With inflation rates on the energy and demand components the overall effect is an increase in the annuities of these components. Consequently larger conductors are admitted earlier in the replacement schedule. Since the energy and demand losses, in the given conditions, constitute most of the annual cost a way of reducing them is to introduce larger conductors earlier in the study so as to reduce the I^2R losses. How large these conductors should be and how soon should they be put in the line depends on what effect these decisions have on the total cost.

Inflation effects on labor and material costs only strongly contrast with those in the previous case. The weighing factors are now reflected on the investment costs producing a total annual cost which is highly depen-

RATE OF INFLATION	SHAPE=1/2 CK=8%	FOUR CONDUCTORS (3 REPLACEMENTS)				THREE CONDUCTORS (2 REPLACEMENTS)			2 CONDUCTS. (1 REPL.)		1 Cd.
4 % LABOR MATER. ENERGY DEMAND	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	-	-	-	-	1-1	2-23	24-60	1-23	24-60	1-60
	CONDUCTOR	-	-	-	-	2	10	33	10	33	29
	COST $/mi	-				109225			108603 *		126046
4 % LABOR MATER.	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	-	-	-	-	1-1	2-21	22-60	1-21	22-60	1-60
	CONDUCTOR	-	-	-	-	1	18	22	8	22	22
	COST $/mi	-				51701			50994 *		57281
4 % ENERGY DEMAND	PERIOD	1	2	3	4	1	2	3	1	2	1
	YEARS	1-8	9-18	19-28	29-60	1-15	16-28	29-60	1-22	23-60	1-60
	CONDUCTOR	6	10	18	33	8	18	33	10	33	29
	COST $/mi	82715				82328 *			83191		123649

(* denotes optimum policy)

TABLE 14. Results for Inflation case.

dent on the type of installation. Consequently, the choosing of a small conductor will be favored.

CHAPTER V

AVAILABLE OPTIONS

Dealing with Existing Conductor Installations

A frequent situation will be that of installations already in existence prior to the study. So far, it has been assumed that the project under study is in the design stage. The extension of the ideas developed in this thesis to systems with installations already in service can be shown to be of practical and economic advantage.

Three parameters are introduced which will sufficiently describe this condition in the program. OLDCDT (old conductor) represents the appropriate number that identifies the conductor of the existing installation. NYRSUP (number of years up) stands for the number of years the installation has been in service. This parameter is needed to calculate the salvage value. CWORTH is defined as the ratio of the present worth of the old installation over the cost of a similar installation today. In order to account for the fact that the conductor is installed before any replacements are introduced, computations made for all intervals of time starting at the beginning of the study, that is M=1, have to be made using the values related to the existing conductor only. In this matter, the conductor in question is forced to appear in all possible strategies and before any replacement. This is the desired effect since the existing conductor should certainly appear as the initial installation in any proposed schedule. What the program has executed at this point, is a search for the optimum replacement policy given that conductor X is in the line. Note that X may be replaced by any other conductor of interest, in order to observe the effects that changing initial conductor has an optimum replacement policy.

By proper modifications, it is also possible to force a given conductor in any of the replacement periods. This can be done in order to study changes in replacement policy caused by introducing certain conductors in the intermediate periods of the replacement schedule.

Bundled and Mixed Installations

In many cases, specifically transmission lines, the utilization of bundle conductors becomes a major consideration. Naturally whenever load growth is involved the potential for replacements is always present. The question rises on the possibility of introducing bundle replacements to single line installations.

A method of dealing with all these cases besides the regular one of single line conductors being replaced by similar installations, is presented in a way that the whole set of alternatives is treated at the same time.

Corona losses are assumed to be negligibly small in comparison with regular line losses. Nonetheless they can be included if desired by the user. This may be done by adding a term to the energy loss equation in order to account for the corona losses.

The basic idea in the incorporation of bundling and mixed replacements into the program is based on treating the bundle conductors as if they were another type of conductor with their own specific resistances, weights and current carrying capacities. Consequently, the dimension of the vectors R(NCON), W(NCON), CURCAP (NCON) has to be doubled. That is, NCON (number of conductors in study) is doubled. Since bundled conductors are assumed to be formed among conductors of the same size, the net effect of an *n-bundle* conductor is to decrease the resistance by a factor of 1/n and increase the weight and the capacity to the line by n.

These operations are easily introduced in the program. By extending the size of the matrix defined in Figure 6, more specifically by doubling it, the hardware and structural costs incurred when changing from a small conductor to a larger one or from a single conductor line to bundle installations can be stored in a systematic way. A method of implementing this idea into the program would be to aggregate a term to TMIN(I, NFINAL), essentially the adequate entry of the structural costs matrix, EXTCOS(I,J) where I represents the old conductor and J the new one being installed. More concisely, for the two conductor case, when the first replacement is introduced, this term becomes:

$$\text{EXTCOS(I,J)=EXTCOS}(\underbrace{\text{NN(1,I)}}_{\text{I}},\underbrace{\text{NN(IPLUS1,NFINAL)}}_{\text{J}}) \qquad (24)$$

Where I and J represent the best installations respectively in the two intervals of time defined by (1,I) and (I+1,NFINAL). When two or more replacements are introduced the corresponding entry becomes:

$$\text{EXTCOS(I,J)=EXTCOS}(\underbrace{\text{NN(NNL(NCDTS,I)+1,I)}}_{\text{I}},\underbrace{\text{NN(IPLUS1,NFINAL)}}_{\text{J}}) \qquad (25)$$

NNL(NCDTS,I+1) denotes the starting year for a replacement in the previous case, the n-1 conductor case for a total of I years. The letter n stands for the total number of conductors in the study. So, for two or more replacements, $n \geq 3$.

CHAPTER VI

CONCLUSION

A point to stress in this thesis is in regard to the inherent flexibility with which the program is designed.

Conductors to be used in the study may be determined according to existent stock, storage capabilities and any other limitations presented by the user.

Inflationary rates are free to be chosen by the user. Although the program is designed with a built-in expression of the yearly load in terms of its compound rate of growth, it can be replaced by another one or by just reading in the expected load as a part of the data. In dealing with the salvage value, figure 16 & 17 shows a family of curves, representing this parameter that can be obtained with different modeling factors SHAPE. If the user prefers to use his own expression he may do so without affecting the rest of the program.

In order to obtain any reliable results, the period under study should be made long enough so that events far enough in the future would have no repercussions on short term policies obtained for the first few years. The criterion for choosing where far enough should be depends mostly on the load variations during the period of study. This was determined according to results obtained for the different cases studied. Results obtained for the 4%, 8%, 13% rates of current growth, show that the sooner the load approached a limiting value, between certain tolerances, the shorter the period under study would have to be in order to obtain relevant results.

Even when the results obtained may not be definite in as far as its realization over the period under study is concerned, they constitute the best possible strategy to follow in order to minimize revenue requirements.

If some of the economic factors used in the study exceed certain expected tolerances before the year of a replacement, a new study should be done at that time that will accomodate the unexpected changes.

In any case, the policy found for a given number of years is a result of the original data and the solution to the optimization problem given those initial conditions.

A general approach to bundling installations and their replacement as well as to single conductors with bundled installations is devised. A solution which incorporates the diversity of costs between different installation structures is given, with the appropriate modifications to the structure of the program in order to encompass all these cases.

By proper utilization of these results, storage space as well as production cost can be considerably improved for any given utility company.

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APPENDIX

Kelvin's Law Equation

For a fixed current the annual cost of a conductor installation is given by:

$$AC(R) = K_1 I^2 R + K_2/R \qquad \text{(A-1)}$$

Annual Energy Cost   Annual Investment Cost

where K_1 and K_2 are appropriate proportionality constants.

$$\frac{dAC(R)}{dr} = K_1 I^2 - K_2/R^2 \qquad \text{(A-2)}$$

Setting the derivative equal to zero and noting that the second derivative is positive. The minimum R that will minimize this equation is:

$$R = \frac{K^2}{I^2 K_1} \qquad \text{(A-3)}$$

Note that the minimum occurs at the point where the slope of the annual energy curve equals the negative slope of the annual investment curve, Figure A-1.

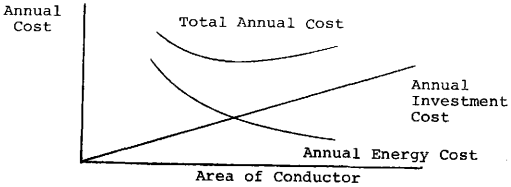

Figure A-1

Annual costs of a conductor installation

For this equation to hold, the linear variation on investment must originate at zero. A necessary condition is that energy costs must be inversely proportional and investment cost directly proportional to the area of the conductor.

Cost Equations

The total annual cost of a conductor installation may be given by:

$$AC(R,N)=AI(R,N)+AEC(R,N)+ADC(R,N) \qquad (A-4)$$

where,

AC(R,N): Total annual cost of conductor R at year N.

AI(R,N): Annual investment cost of conductor R at year N.

AEC(R,N): Annual energy cost of conductor R at year N.

ADC(R,N): Annual demand cost of conductor R at year N.

AI(R,N) = n(weight)(cost of conductor + cost to install)(capital recovery factor + annual percentage of insurance, taxes and maintenance cost) (A-5)

AEC(R,N) = n(hours in year(resistance)(current at year N)^2 (loss factor)(cost of kw-hr.)/1000. (A-6)

ADC(R,N) = n(resistance)(current at year N)^2 (cost of demand losses)/1000. (A-7)

$$\text{Total Cost (Pst. Worth)} = AC(R,n)/(1+i)^n - \text{SALVAGE } (R_{n-1}) (R_n - R_{n-1})/(1+i)^{n-1} \qquad (A-8)$$

where

$$\delta(R_n - R_{n-1}) = \begin{cases} 0 \text{ if } & R_n = R_{n-1} \\ 1 \text{ if } & R_n \neq R_{n-1} \end{cases} \quad \text{(A-9)}$$

R_n : Conductor in service at year n.

SALVAGE(R_{n-1}): (Salvage value of the conductor at year n-1) - (Unamortized value of same conductor) - (cost to remove). (A-10)

Load Approximation

$$I(n) \doteq I_0 \ (L+CK)^n \quad \text{(A-11)}$$

I_0: Initial current

n : Year of interest

I(n): Current at that year

$$I(n) = K \quad \text{iff} \quad i(n)>K \quad \text{(A-12)}$$

where K is the maximum value the current can take.

Salvage Value Equation

$$f(x) = \begin{cases} CC(K) \ \exp((SHAPE)X/(X-APE)) \text{ if } X>APE \\ 0 \text{ otherwise} \end{cases} \quad \text{(A-13)}$$

where

CC(K): Cost of conductor K

f(x): Salvage value of coductor K after X years of use

SHAPE: Modeling parameter

APE: Amortization period

Discrete Interest Formulas

Time value of money considerations are essential in most relevant economic studies. Costs occurring at different stages in the time scale can only be related to one another by appropriate discounting of compounding factors. Factors of this type encountered in the solution of the problem will be briefly explained and summarized.

The concept of rate of interest or cost of money is the fundamental idea behind the existence of the so called compounding and discounting factors and some others derived of these which are frequently used in economic analysis.

Rate of interest is defined as the minimum acceptable interest paid to the suppliers of capital for the right to invest their money in a given installation.

SPPWF, which stands for single payment present worth factor, represents the discounting factor. Given a sum of money in the future, S, its present value today, is given by:

$$P = S \frac{1}{(1+i)^n} \qquad \text{(A-14)}$$

where n = year in the future

i = interest rate

SPCAF, single payment compound amount factor, given a present sum P, what will be its future worth S at the end of n periods.

$$S = P(1+i)^n \qquad \text{(A-15)}$$

CRF, capital recovery factor produces the future series of end-of-period payments that will just recover a present sum P over n periods with compound interest i.

$$R = P \left(\frac{i(1+i)^n}{(1-i)^n-1}\right) \qquad \text{(A-16)}$$

USPWF, uniform series present worth factor, produces the present worth of a series of end-of-period payments R for n periods at compound interest i.

$$P = R \left(\frac{(1+i)^n-1}{k(1+i)^n}\right) \qquad \text{(A-17)}$$

```
//$OPTIONS
      INTEGER OLDCDT,CDTCAP(40),APE
      REAL K1,K2,NYLEFT
      DIMENSION R(40),W(40),ACL(40,80),PAC(40,80),TAC(40,80),PW(40,80),
     *TPW(40,80),CURREN(80),SPPWF(80),CONDUC(40),TPWMIN(80,80),
     *PACO(10,80),NCOUNT(80),VALUE(40,80),REMOVE(40,80),SALVAG(40,80),
     *NN(80,80),FINMIN(80),TMIN(80,80),NNL(10,80),NC(10,80),TTMIN(80),
     *CREMOV(40),CVALUE(40),TPWWSA(40,80),PACCRF(40,80),CURCAP(40),USPWF
     *(80)
      READ,CURENO,N,CK,AI,CCOND,CINST,CRF,CKWHRL,CKWL,NCON,FL,TOMI,APE
C
C K1=COEFFICIENT OF SALVAGE VALUE
C K2=COEFICCIENT OF REMOVAL COST
C SHAPE=MODELING EXPONENT OF THE SALVAGE VALUE CURVE
C
      READ,K1,K2,SHAPE
      READ,CINFL1,CINFL2,CINFL3,CINFL4
      READ,(R(I),W(I),I=1,NCON)
      READ,(CONDUC(I),I=1,NCON)
      READ,(CURCAP(K),K=1,NCON)
C
C  IF AN OLD CONDUCTOR IS IN THE LINE PRIOR TO INSTALLATION
C OLDCDT=ASSIGNED NUMBER OF SUCH CONDUCTOR IN PROGRAM
C CWORTH=PST.WORTH OF SUCH CONDUCTER IN P.U. OF ORIGINAL COST
C  NYRSUP=# OF YEARS ITS BEEN UP
C
      READ,OLDCDT,CWORTH,NYRSUP
C CONTROL INDECES
      READ,NPRINT, LSABLE, LDATA
C
```

TABLE 15. List of Program.

```
      IF(LDATA.EQ.0)GO TO 451
      WRITE(6,444)
  444 FORMAT('1',29X,'LIST OF DATA')
      WRITE(6,445)N,CURENO,CK,NCON,CCOND,CINST,CKWHRL,CKWL,FL,AI,CRF,
     *TCMI,APE,CINFL1,CINFL2,CINFL3,CINFL4,K1,K2,SHAPE,USABLE,OLDCDT,CWO
     *RTH,NYRSUP
  445 FORMAT('-','NUMBER OF YEARS UNDER STUDY =',I3,3X,'INITIAL CURRENT=
     *',F5.0,3X,'RATE =',F5.3/' ','NUMBER OF CONDUCTORS =',I3,3X,'CONDUC
     *TOR COST($/LB) =',F4.2/' ','INSTALLATION COST($/LB) =',F4.2,3X,'KW
     *HR COST =',F4.2,3X,'KW-DEMAND COST =',F4.2/' ','LOSS FACTOR =',F4.
     *2,3X,'INTEREST RATE =',F4.2,3X,'CAPITAL RECOV. FACTOR =',F7.5/' ',
     *'TAXES INS. ETC =',F7.5,3X,'AMORTIZATION PERIOD =',I3/' ','INFLATI
     *ON ON CONDUCTOR =',F4.2,3X,'ON LABOR =',F4.2,3X,'ON ENERGY =',F4.2
     */' ','ON DEMAND =',F4.2,3X,'K1 =',F4.2,3X,'K2 =',F4.2,3X,'SHAPE ='
     *,F4.2,3X,'USABLE =',F4.2/' ','OLD CONDUCTOR =#',I3,3X,'PW OF SUCH
     *CD. IN PU =',F5.3,3X,'YEARS OF USE =',I3)
      WRITE(6,447)
  447 FORMAT('-','CONDUCTOR ACSR(MCM) RESISTANCE(O/M) WEIGHT(LBS/M) CURR
     *ENT CAPACITY(AMPS)')
      DO 448 K=1,NCON
  448 WRITE(6,449)K,CONDUC(K),R(K),W(K),CURCAP(K)
  449 FORMAT(' ',I5,6X,F7.2,6X,F7.4,7X,F8.2,10X,F8.2)
  451 CONTINUE
      FXCOST=CRF+TCMI
      NIMUSI = N-1
   12 DO 15I=1,N
      SPPWF(I)=1.0/(1.+AI)**(I)
      USPWF(I)=((1.+AI)**I-1.)/(AI*(1.+AI)**I)
      IF(I.EQ.1)GO TO 22
      CURREN(I)=CURENO*(1.+CK)**(I-1)
```

TABLE 15. (Continued).

```
      IF(CURREN(I).GT.850.)CURREN(I)=850.
      GO TO 15
22    CURREN(I)=CURENC
      USPWF(77)=0.
15    CONTINUE
      DO 18 K=1,NCON
      CVALUE(K)=K1
      CREMOV(K)=K2
      DO 18 I=1,N
      REMOVE(K,I)=3.0*CREMOV(K)*CINST*W(K)*(1.+CINFL2)**I
      IF(I.GE.APE)GO TO 80
C
C VALUE(K,I) IS EXPRESSED AS A PORTION OF INVESTMENT ON CONDUCTOR ONLY.
C
      EQUIS=(SHAPE*I)/(I-APE)
      IF(EQUIS.LE.-25.)GO TO 80
      VALUE(K,I)=CVALUE(K)*EXP(EQUIS)*3.0*W(K)*CCOND
      GO TO 19
80    VALUE(K,I)=0.0
19    AKWHRL=3.0*8760.0*FL*CKWHRL*R(K)*(CURREN(I))**2/1000.0
      AKWHRL=AKWHRL*(1+CINFL3)**I
      AKWL=(3.0*R(K)*CKWL*(CURREN(I))**2)/1000.0
      AKWL=AKWL*(1.+CINFL4)**I
      ACL(K,I)=AKWHRL+AKWL
      PAC(K,I)=3.*W(K)*(CCOND*(1.+CINFL1)**(I)+CINST*(1.+CINFL2)**I)*FXC
     *CST
      PACCRF(K,I)=3.*W(K)*(CCOND*(1.+CINFL1)**I+CINST*(1.+CINFL2)**I)*CR
     *F*USABLE
      IF(K.NE.CLDCOT)GO TO 18
      IF(I.NE.1)GO TO 18
      PAC(K,I)=PAC(K,I)*CWORTH
```

TABLE 15. (Continued).

```
      PACCRF(K,I)=PACCRF(K,I)*CWORTH
   18 CONTINUE
      DO 77 M=1,N
      IF(M.GT.NPRINT)GO TO 21
   21 DO 16 K=1,NCCN
      WRITE(6,301)
  301 FORMAT('1','FROM CD YR CURREN AC.LOSS AC.PURCH AC.TOTAL P.WORTH TO
     *TAL.PW TPW/SALVA')
      CDTCAP(K)=0
      DO 16 I=M,N
      NUSE=I-M+1
      NAPE=APE-NUSE
      IF(NAPE.LE.0)NAPE=77
      PW(K,I)=SPPWF(I)*(PAC(K,M)+ACL(K,I))
      IF(I.EQ.M)GO TO 33
      NK=I-1
      TPW(K,I)=PW(K,I)+TPW(K,NK)
      TPWWSA(K,I)=TPW(K,I)+PACCRF(K,M)*USPWF(NAPE)*SPPWF(I)-(VALUE(K,NUS
     *E)*(1.+CINFL1)**I-REMOVE(K,I))*SPPWF(I)
      GO TO 116
   33 TPW(K,I)=PW(K,I)
      TPWWSA(K,I)=TPW(K,I)+PACCRF(K,M)*USPWF(NAPE)*SPPWF(I)-(VALUE(K,NUS
     *E)*(1.+CINFL1)**I-REMOVE(K,I))*SPPWF(I)
  116 CONTINUE
      TAC(K,I)=PAC(K,M)+ACL(K,I)
      IF(M.GT.NPRINT)GO TO 16
      WRITE(6,201)M,K,I,CURREN(I),ACL(K,I),PAC(K,M),TAC(K,I),PW(K,I),TPW
     *(K,I),TPWWSA(K,I)
  201 FORMAT(' ',I3,2X,I2,I3,2X,F5.0,F8.0,2X,F6.0,1X,F9.0,F8.0,F9.0,F10.
     *0)
```

TABLE 15. (Continued).

```
   16 CONTINUE
      IF(M.NE.1)GO TO 17
      WRITE(6,102)
  102 FORMAT('1',40X,'LIST OF OPTIMUM CONDUCTORS W/O REPLACEMENTS FROM Y
     *EAR 1 TO YEAR X'/'-',60X,'CASE # 1 (NO REPLACEMENTS)'/'0',30X,'YEA
     *R  X',2X,'CURRENT(AMPS)',2X,'CONDUCTOR #  ACSR(MCM)',6X,'TOTAL COS
     *T $/MILE (PST.WORTH)')
      NCAP=0
   17 DO 25 I=M,N
      K=1
      IF(OLDCDT.NE.0.AND.M.EQ.1)GO TO 37
  471 CONTINUE
      IF(K.GT.NCON)GO TO 162
      IF(CDTCAP(K).EQ.1)GO TO 473
      IF(CURCAP(K).GE.CURREN(I))GO TO 470
      CDTCAP(K)=1
  473 K=K+1
      NCAP=NCAP+1
      GO TO 471
  470 KPLUS1=K+1
      TPWMIN(M,I)=TPW(K,I)
      TPWMI=TPWWSA(K,I)
      NN(M,I)=K
      IF(KPLUS1.GT.NCON)GO TO 67
      GO TO 39
   37 NN(M,I)=OLDCDT
      TPWMIN(M,I)=TPW(OLDCDT,I)
      GO TO 27
   39 DO 28 K=KPLUS1,NCON
      IF(CURCAP(K).LT.CURREN(I))GO TO 82
      IF(TPWWSA(K,I).GE.TPWMI)GO TO 28
```

TABLE 15. (Continued).

```
           TPWMIN(M,I)=TPW(K,I)
           NN(M,I)=K
           TPWMI=TPWWSA(K,I)
           GO TO 28
      82   NCAP=NCAP+1
           CCTCAP(K)=1
      28   CONTINUE
           IF(NCAP.EQ.NCON)GO TO 162
      67   CONTINUE
           IF(M.NE.1)GO TO 25
      27   WRITE(6,101)I,CURREN(I),NN(M,I),CONDUC(NN(M,I)),TPWMIN(M,I)
     101   FORMAT('0',30X,I4,6X,F9.2,8X,I2,8X,F7.2,15X,F12.2)
      25   CONTINUE
      77   CONTINUE
           NCDTS=1
           FINMIN(N)=TPWMIN(1,N)
      89   DO 91 I= NCDTS,NIMUSI
           IPLUSI=I+1
           IF(NCDTS.EQ.1)GO TO 99
           SALNET=(VALUE(NN(NNL(NCDTS,I)+1,I),I-NNL(NCDTS,I))*(1.+CINFL1)**(I
          *)-REMOVE(NN(NNL(NCDTS,I)+1,I),I))*SPPWF(I)
           GO TO 48
      99   FINMIN(I)=TPWMIN(1,I)
           L=I+NYRSUP
           SALNET=(VALUE(NN(1,I),L)*(1.+CINFL1)**(L)-REMOVE(NN(1,I),I))*SPPWF
          *(I)
           PACC(NCDTS,I)=PACCRF(NN(1,I),I)
      48   DO 91 NFINAL=IPLUSI,N
           NYLEFT=APE-(I+NYRSUP)
           IF(NCDTS.NE.1)NYLEFT=APE-(I-NNL(NCDTS,I))
```

TABLE 15. (Continued).

```
      IF(NYLEFT.LE.0)NYLEFT=77
      TMIN(I,NFINAL)=FINMIN(I)+TPWMIN(IPLUS1,NFINAL)+PACO(NCDTS,I)*SPPWF
     *(I)*USPWF(NYLEFT)
      TMIN(I,NFINAL)=TMIN(I,NFINAL)-SALNET
   91 CONTINUE
      KNCDTS=NCDTS+1
      IF(KNCDTS.GE.6)GO TO 73
      WRITE(6,160)KNCDTS,NCDTS
  160 FORMAT('1','COST FIGURES FOR THE BEST ',I2,' CONDUCTOR COMBINATION
     * WITH ',I2,' REPLACEMENTS'/'-','TABLE INDICATES # OF YEARS IN THE
     *FIRST PERIOD,THE YEAR OF REPLACEMENT '/' ','AND THE CONDUCTOR TO B
     *E USED FROM THEN UP TO THE LAST YEAR.')
      WRITE(6,150)
  150 FORMAT('0','YEARS IN 1 PERIOD  RPLMENT YEAR  LAST YR  CDT#  ACSR(M
     *CM)  TOTAL COST PW')
      DO 92 NFINAL=KNCDTS,N
      I=NCDTS
      TTMIN(NFINAL)=TMIN(I,NFINAL)
      NNL(KNCDTS,NFINAL)=I
      IPLUS1=I+1
      NC(KNCDTS,NFINAL)=NN(IPLUS1,NFINAL)
      MFINAL=NFINAL-1
      DO 93 I=NCDTS,MFINAL
      IF(TMIN(I,NFINAL).GE.TTMIN(NFINAL)) GO TO 93
      TTMIN(NFINAL)=TMIN(I,NFINAL)
      NNL(KNCDTS,NFINAL)=I
      IPLUS1=I+1
      NC(KNCDTS,NFINAL)=NN(IPLUS1,NFINAL)
   93 CONTINUE
   92 WRITE(6,151)NNL(KNCDTS,NFINAL),IPLUS1,NFINAL,NC(KNCDTS,NFINAL),CON
     *DUC(NC(KNCDTS,NFINAL)),TTMIN(NFINAL)
  151 FORMAT(' ',8X,I2,14X,I2,9X,I2,6X,I2,4X,F7.2,3X,F12.2)
```

TABLE 15. (Continued.)

```
      DO 122 NFINAL=KNCDTS,N
  122 PACO(KNCDTS,NFINAL)=PACCRF(NN(NNL(KNCDTS,NFINAL)+1,NFINAL),NFINAL)
      WRITE(6,190)KNCDTS,NCDTS
  190 FORMAT('1','COMPARATIVE RESULTS FOR THE CASE STUDY OF ',I2,' CONDU
     *CTORS /',I2,' REPLACEMENTS'/'0','TABLE SHOWS ECONOMIC CHOICE WITH
     *RESPECT TO PREVIOUS CASE.'/'-',10X,'NUMBER OF YEARS    MOST ECONOM
     *IC CASE     TOTAL COST'/' ',17X,'CONDUCTOR STUDY NUMBER'//)
      NTPWMI=0
      DO 140 NFINAL=KNCDTS,N
      TMINI=TTMIN(NFINAL)
      IF(FINMIN(NFINAL).GE.TMINI)GO TO 111
      NTPWMI=NTPWMI+1
      WRITE(6,132)NFINAL,NCDTS,FINMIN(NFINAL)
  132 FORMAT(' ',17X,I2,18X,I2,F10.2)
      FINMIN(NFINAL)=TMINI
      IF(NTPWMI.EQ.(N-KNCDTS+1)) GO TO 161
      GO TO 140
  111 FINMIN(NFINAL)=TMINI
      WRITE(6,131)NFINAL,KNCDTS,FINMIN(NFINAL)
  131 FORMAT(' ',17X,I2,18X,I2,F10.2)
  140 CONTINUE
      NCDTS=NCDTS+1
      GO TO 89
  161 WRITE(6,71)N
   71 FORMAT('-','IT IS NOT WORTH TO ADD ANY MORE CONDUCTORS IN A ',I2,'
     *YEARS OR LESS')
      GO TO 73
  162 WRITE(6,72)I
   72 FORMAT('-','CURRENT AT YEAR ',I2,' EXCEEDS CURRENT CARRYING CAPACI
     *TY OF ALL CONDUCTORS.')
   73 STOP
      END
```

TABLE 15. (Continued).

VITA

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