

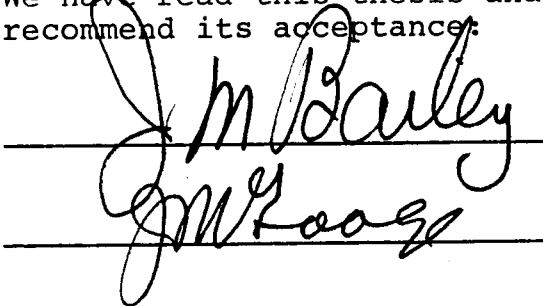
To the Graduate Council:

I am submitting herewith a thesis written by William Thomas McBride entitled "A Computer Assisted Wiring Program." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Electrical Engineering.



Thomas W. Reddoch
Major Professor

We have read this thesis and
recommend its acceptance.



Accepted for the Council:



Vice Chancellor
Graduate Studies and Research

Thesis
79
.M374
cop. 2

A COMPUTER ASSISTED WIRING PROGRAM

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

William Thomas McBride

August 1979

1397092

ACKNOWLEDGMENTS

The author is indeed grateful to the numerous individuals who made this study a reality. The initial suggestion by Mr. Claude Harvey III of the Tennessee Valley Authority provided the stimulus for this study.

The assistance of Mr. Gregory G. Mailen in the early stages enabled the author to formulate the problem. The author is grateful for all guidance and suggestions for improvements by Mr. Charles H. Pulse.

Very special recognition is given to Mr. Richard T. Wilson Jr. whose enthusiasm and programming expertise enabled the completion of this project.

The author also expresses his thanks to his advisor, Dr. Thomas W. Reddock, for his guidance and review of this report.

Lastly, special thanks go to my wife, Peggy, for her typing and editorial work.

ABSTRACT

The purpose of this study is to develop a computerized method for producing interconnection wiring drawings (IWD). The process of making IWD's manually is described along with the comparison of two algorithms that are used to calculate wiring paths. An algorithm is chosen for use in the computerized IWD production and the reasons for its selection are discussed.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
II. MANUAL PREPARATION OF INTERCONNECTION WIRING DRAWINGS	6
III. METHOD OF PRIORITY ORDERING	15
IV. METHOD OF SHORTEST DISTANCE	24
V. COMPARISON OF WIRING METHODS	31
VI. SUMMARY AND CONCLUSIONS	36
LIST OF REFERENCES	39
VITA	41

LIST OF FIGURES

FIGURE	PAGE
2.1. Equipment Arrangement Drawing	7
2.2. Equipment Installation Drawing	8
2.3. Control System Schematic Drawing	9
2.4. Wiring Examples	12
2.5. Manually Prepared IWD	14
3.1. X-Y Grid Coordinate	16
3.2. Equipment Drawing with Grid Overlay	17
3.3. Coding Form for Device Input	18
3.4. Coding Form for Schematic Input	20
3.5. Hierarchical Structure for Priority Ordering Wiring Algorithm	21
4.1. Start of a Tree	27
5.1. Wiring Run by Priority Ordering Algorithm . . .	32
5.2. Wiring Run by Branch and Bound Algorithm	33

CHAPTER I

INTRODUCTION

The making of electrical, instrument, and control interconnection wiring drawings is a large portion of the total electrical design effort that goes into the control system for a power generating station switchyard. Interconnection wiring drawings (IWD) are the representation of the actual physical tying (wiring) of the terminals together in the manner shown on the electrical schematic drawing and the electrical equipment arrangement drawing.

Following a long process in the design of the schematic and physical arrangement drawings, where delays often occur, IWD's are the last drawings made. The preparation of these interconnection drawings is as much a bookkeeping process as a design process. The intelligence of an electrical circuit is represented on the schematic drawing. Therefore, the engineering effort is put forth in the design of the higher level schematic drawings which show what is to be wired and how it is to operate electrically.

The preparation of IWD's becomes involved when designing for large and complex generating stations. To date, all of these drawings have been prepared manually. Manual design of the IWD's is very costly in terms of manhours expended, employee job satisfaction and accuracy of design.

This manual preparation consists of the engineer using a schematic, physical arrangement drawing and an equipment layout of the panel to be wired. The engineer must follow one wire at a time on the schematic in order to wire from terminal to terminal on the wiring drawing. This terminal to terminal wiring is a slow and tedious process on any system other than ones of the very simplest type. Before the IWD's can be used they must be checked for errors. Checking the IWD for accuracy requires the engineer to repeat the process of following the schematic one wire at a time in order to verify the correctness of the terminal to terminal wiring. Development of a computer program which assists in making IWD's could result in a reduction of manhours needed in preparation.

The quality of work performed by an employee is often a direct reflection of how satisfied he is in the type of work he is doing. Although the IWD's account for approximately 30 percent of the total electrical wiring effort, the engineering is essentially complete when the schematics and equipment drawings are established. Trying to motivate highly trained personnel to do a job that combines a design and accounting process frequently is a problem. A computer program that will produce wiring drawings and keep the engineer involvement to a minimum would be of great benefit.

The accuracy of the IWD depends on the thoroughness in which it is checked and the correctness of the schematic

drawing used in making the wiring drawing. The long lead time required to complete the IWD's necessitates that the design begin before all schematic drawings are complete. This means that any time a change is made on the schematic drawing, corresponding changes must be made on the IWD. Many times the schematic drawings are not finalized when the completion date for the wiring drawings is at hand. Delays of this type cause management to focus its concern and frustration on the IWD's. The need to complete the wiring drawings on schedule creates the necessity for a very fast check for accuracy and the opportunity for errors occur when checking these drawings very rapidly. By developing a computer program to assist in designing the IWD's, the drawings could be started much later in the design cycle than could a manual effort. The later starting date could enable the designer to have a complete group of schematic drawings to use. The scheduled completion date would be more easily met since the computer program would verify the wiring drawings for accuracy earlier than manually wired drawings.

One method of computer wiring is to use the criteria that all between-terminal wiring take the shortest distance possible. A branch and bound algorithm is used to calculate the shortest between-terminal wiring distance. The set of all wiring paths is broken up into increasingly small subsets by a procedure called branching. For each subset a lower

bound on the length of the path is calculated. Eventually, a subset is found that contains a single path whose length is less than or equal to some lower bound for every path. This single path is the one that connects the terminals in the shortest distance possible.

A second wiring algorithm is one that attempts to simulate the manual method of IWD's. This method makes use of all known and documented rules and procedures. First, the physical location of all terminals that are to be connected on a panel are established. The panel is then divided into left and right halves. All terminals that are to be wired in one division of the panel are connected together going in a top to bottom direction. The terminals in the other half of the panel are then connected together in a bottom to top direction. By establishing the priority in which the terminals are to be wired the algorithm can then apply the rules that govern the between-terminal connections.

As fossil-fired generating stations become larger, nuclear power stations become more complicated, manpower becomes more expensive and unmanageable and production schedules become more difficult to meet, it becomes necessary to search for a more advanced and economical method of making IWD's.¹ This study is about the development of two computer aided methods of designing IWD's and the subsequent selection

of the better method for application. The selected method was chosen for implementation by the Tennessee Valley Authority switchyard design section.

CHAPTER II

MANUAL PREPARATION OF INTERCONNECTION

WIRING DRAWINGS

The designer needs two items when beginning preparation of an IWD. First, he must have an equipment arrangement drawing. This drawing is a scaled representation of the front view of the panel or panels that the equipment to be wired is mounted on. (See Figure 2.1) Using the scaled equipment drawing as reference, the designer lays out the panel taking a view of the equipment that will most clearly show the terminals of the device. Figure 2.2 represents the view as seen by the installer who does the actual wiring of the equipment. All pieces of equipment (devices) and their terminals are represented on the panel layout.

The second item needed in preparation of the IWD's is a set of the appropriate schematic drawings. The logic of the circuit is taken from the schematic drawings which define the control systems. (See Figure 2.3) Following along on the schematic drawings, the designer connects the terminals of the devices that are now shown on the panel layout drawings. This process is very tedious and time consuming, which requires the designer to be careful to avoid mistakes.

Often on large projects with a condensed schedule of completion, several designers work on a given set of IWD's.

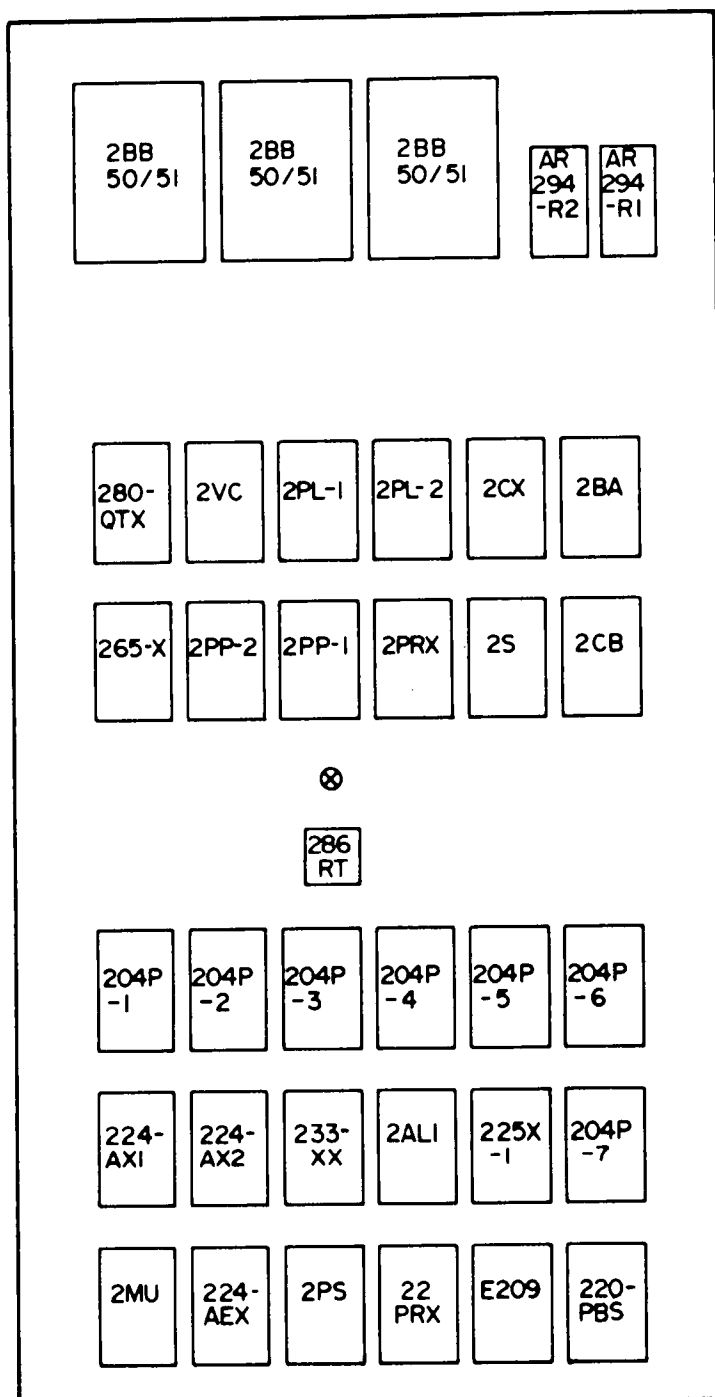
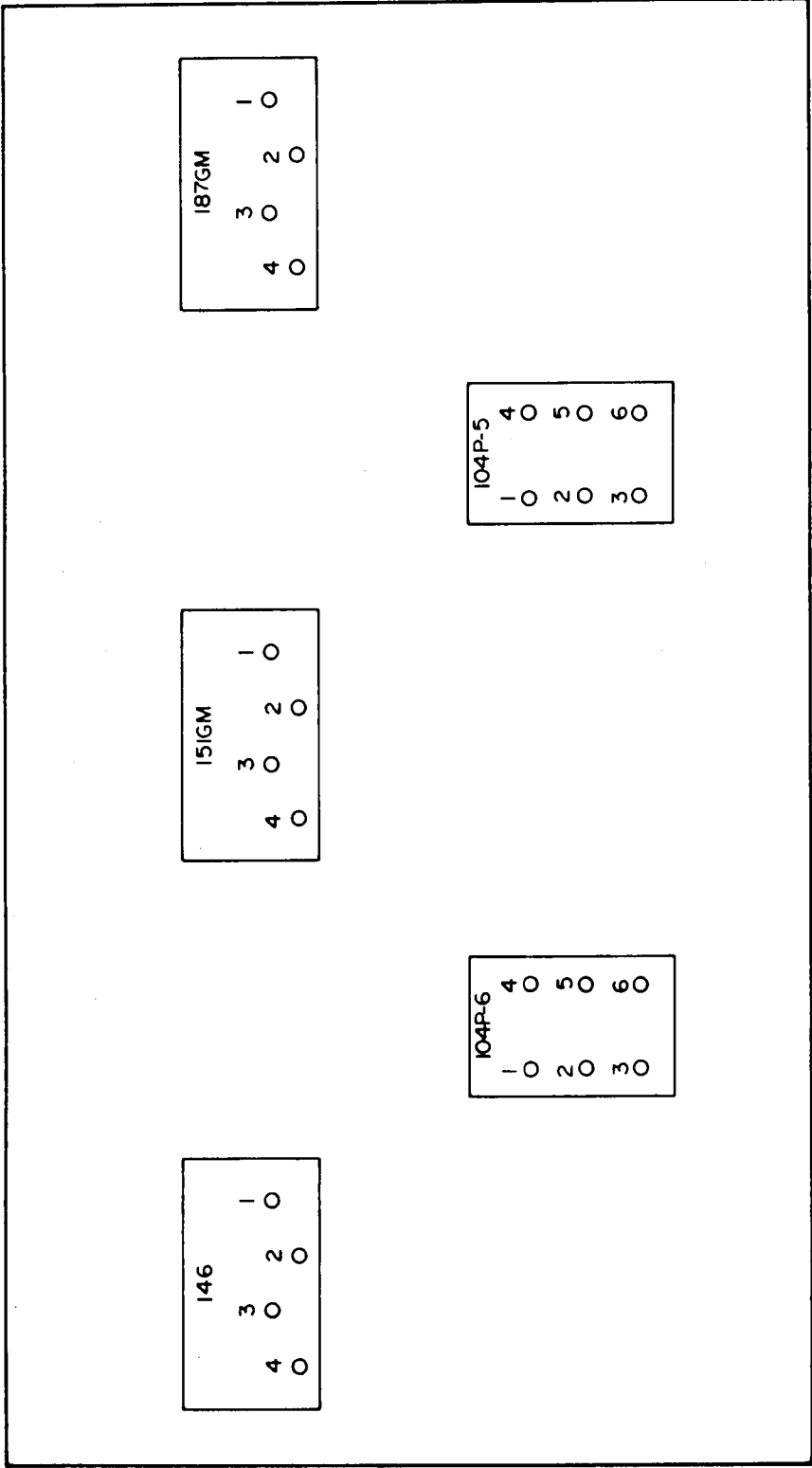


FIGURE 2.1

EQUIPMENT ARRANGEMENT DRAWING



(REAR VIEW)

FIGURE 2.2

EQUIPMENT INSTALLATION DRAWING

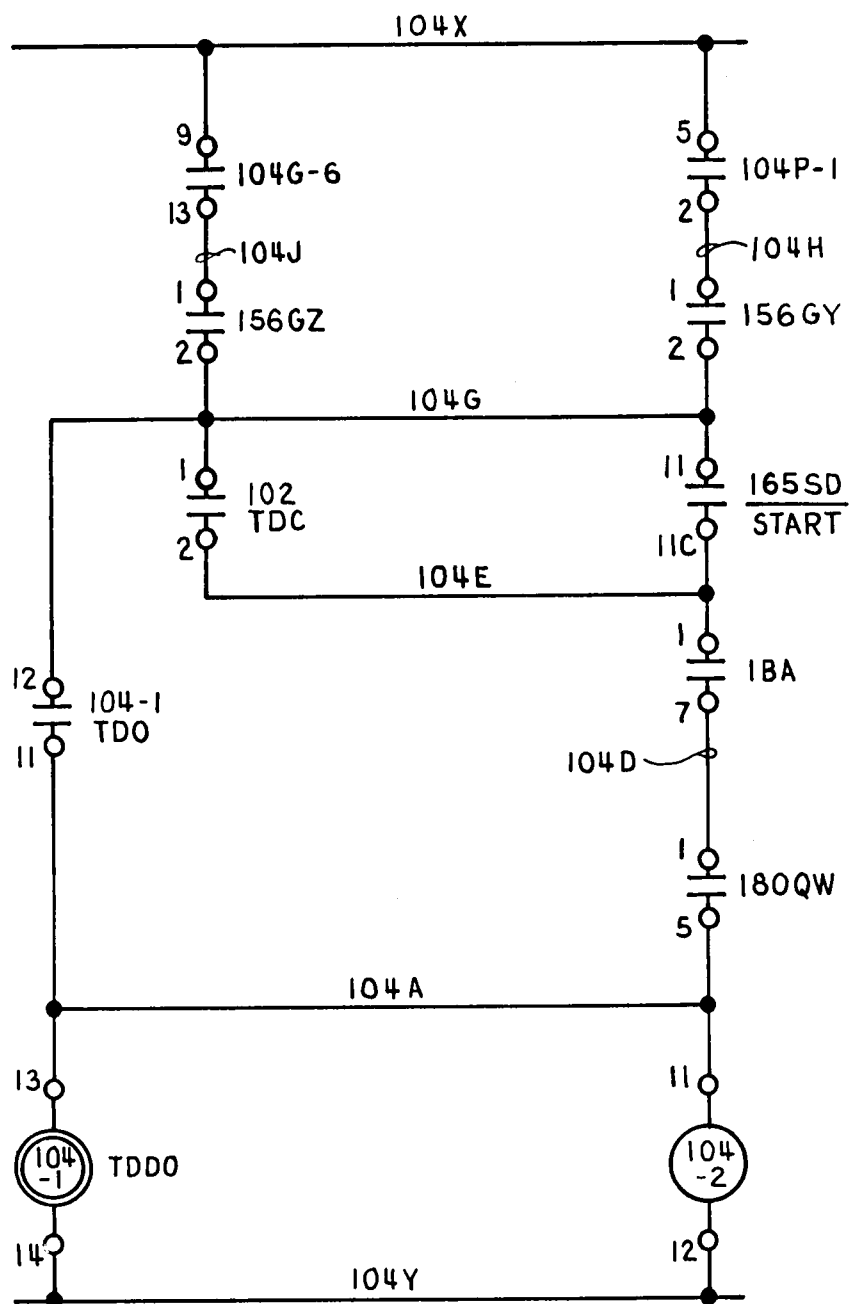


FIGURE 2.3

CONTROL SYSTEM SCHEMATIC DRAWING

This group effort requires close coordination; however, the division of work on the IWD's allows terminals to be omitted or wires to be misdirected. Only when the IWD's are complete and undergoing their final check are some of these errors found and corrected.

Although the chance for errors is more than just a possibility, a larger problem is the difference in the work of each individual wiring drawing designer. Each designer works with the same set of wiring rules, but individual interpretation of the rules can make each IWD different.

Detailed Requirements

The requirements listed below are based on established wiring practices and are used in the preparation of all IWD's done by the Tennessee Valley Authority.²

1. Every terminal of every device in a plant must have a completely unique identification.
2. All wire numbers (node names) must be unique to a plant.
3. All between-terminal wiring is to take the shortest distance possible.
4. Only two connections are to be wired per device terminal.
5. Indicating lamps should be the last devices to be connected in a circuit.

These rules are due to a combination of design requirements and actual wiring requirements.³ If the wiring designer had to apply one rule at a time the job of wiring

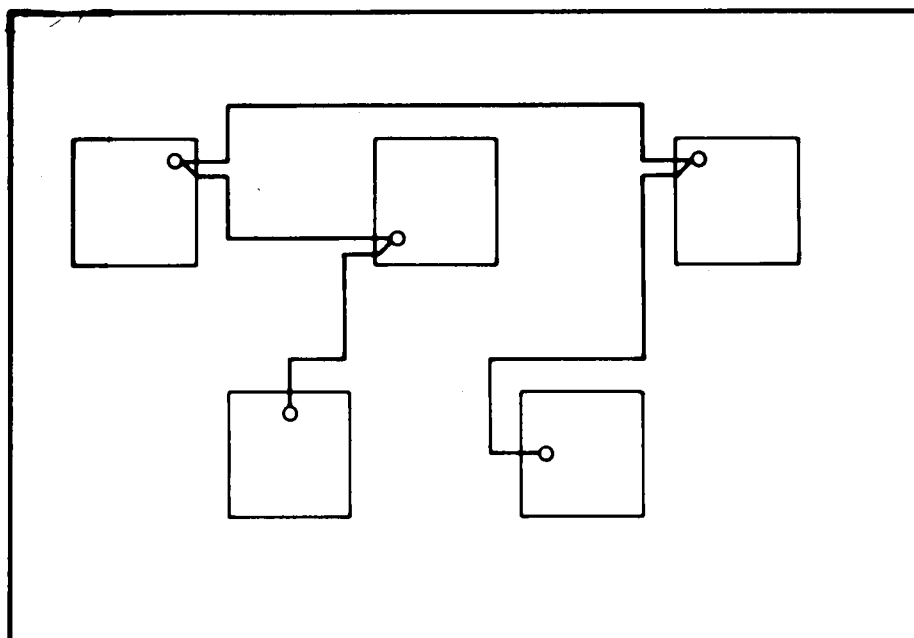
would be very simple. In practice, the designer must use a combination of the rules in deciding how to run each wire. The combining of the wiring rules is done in such a manner as to produce the optimum wire path from terminal to terminal.

Uniqueness must be maintained in designating wire numbers and device numbers in order to have correct connections. Otherwise, it would be impossible to decide if the wiring is correct as dictated by the schematic drawing.

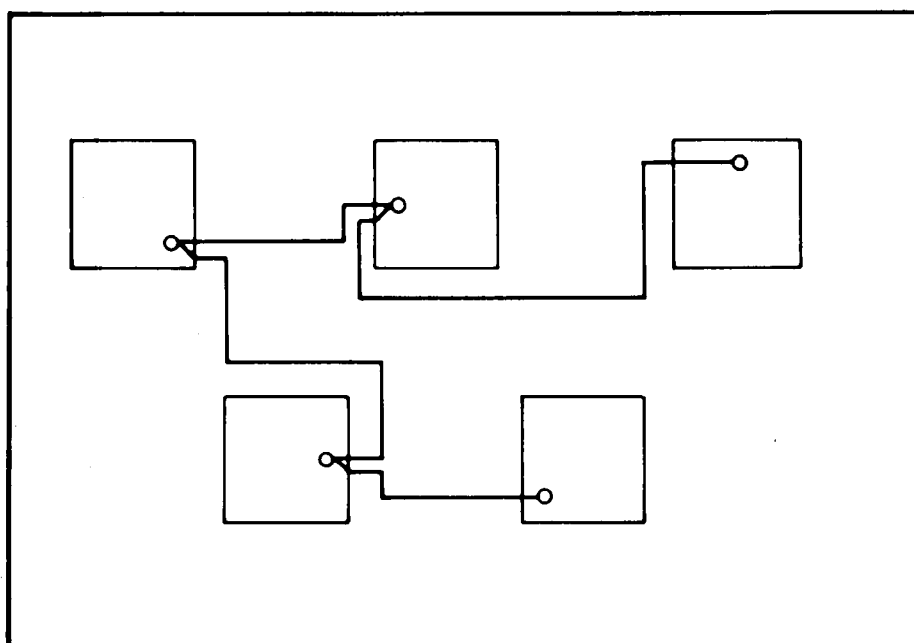
Figure 2.4A shows a panel with several terminals wired together. Tracing out a portion of the wiring will show that shorter distances could be found between terminals. As shown in Figure 2.4B, the wiring has been redone, this time taking the shortest distance between terminals. The advantage to the shortest distance approach is that on a large project less wire is used and a cost savings is realized.

In actual wiring, only two terminations are made to each terminal. This practice is followed for safety reasons because the connecting wires are crimped into O-ring terminals and then attached to the device that is being wired. Space limitation on the device terminal allows only two O-ring terminals to be tightened properly.

The termination of wires on indicating lamps must be made at the end of the circuit run. This requirement is due to the physical limitations of the lamp terminals. Lamp terminals are small and not strong; therefore, they are to be



A
RANDOMLY WIRED DEVICES



B
DEVICES WIRED IN MINIMUM DISTANCE

FIGURE 2.4
WIRING EXAMPLES

connected at the end of a circuit. This point of connection allows the remainder of the circuit to remain functional should the lamp connection become loose or broken.

A Manually Prepared Interconnection Drawing

Figure 2.5 shows an IWD that was prepared manually. It is noted from viewing the wired panel that the work required to make this drawing is time consuming and tedious and that the chance for error is present. The typical span of time required to produce this drawing is four months. The time and manhours required to produce an IWD represent substantial costs. The need for a new, improved method of making wiring drawings is evident.

Investigation Into The Feasibility of Computer Assisted Wiring

With a clear need for computer assisted aid in making IWD's established, a decision must be made as to how much change in the support drawings (schematic and equipment layout drawings) will be made to accommodate computer utilization. If the computer program is to help increase efficiency and reduce costs, the support drawings need to have minimal change. In developing the computer program, the major task is to select an algorithm that will successfully perform the IWD while closely following the established wiring practices.

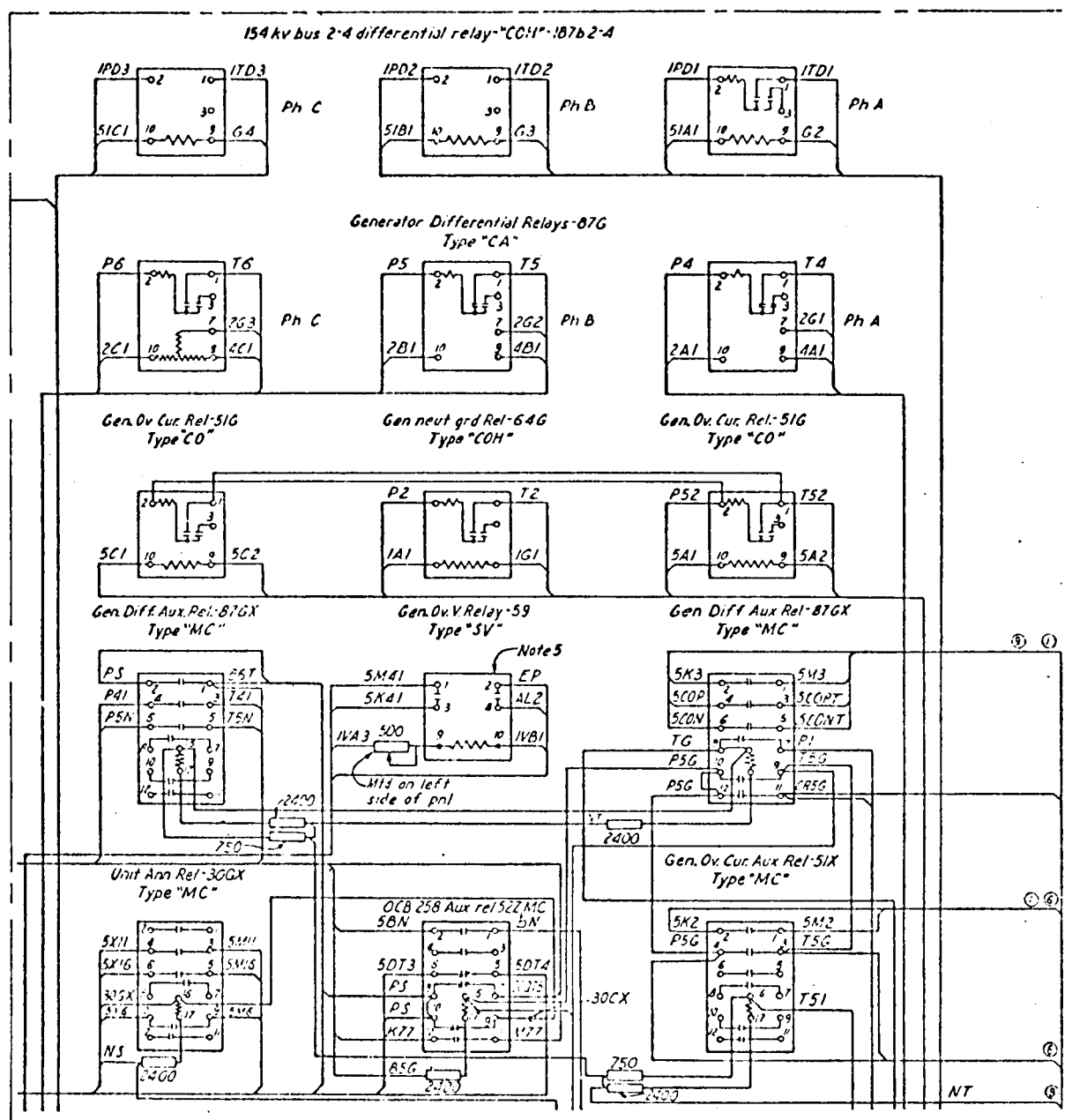


FIGURE 2.5

MANUALLY PREPARED IWD

CHAPTER III

METHOD OF PRIORITY ORDERING

Panel Equipment Location

The first task in developing a wiring algorithm is to make all information that will be needed readily available in a usable form. The exact physical location of the equipment on the panel to be wired is a necessity. One of the rules of good wiring practice dictates that between-terminal wiring be minimized, a X-Y grid coordinate system provides an excellent method to determine device locations. Figure 3.1 shows an example of a grid with X-Y coordinates. By applying the grid in an overlay fashion on the equipment layout drawing, each device on a panel has its physical location accurately described by the grid coordinates. A panel with a grid overlay is shown in Figure 3.2. The actual coding form for entering each device and its location is shown in Figure 3.3.

Panel Equipment Input

Each device used in the electrical circuits has an identification number given to it. This device identification number is unique to a project and allows each device and its terminals to be unique; thereby, not allowing one device and

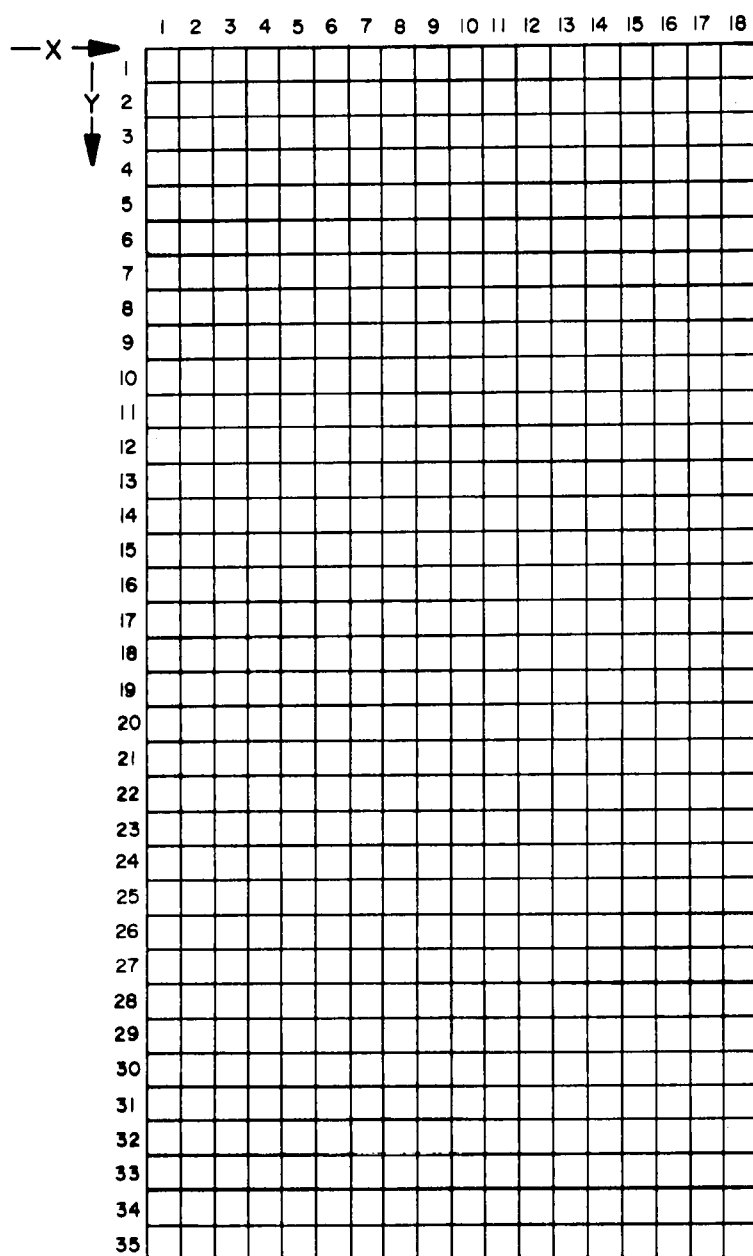


FIGURE 3.1
X-Y GRID COORDINATE

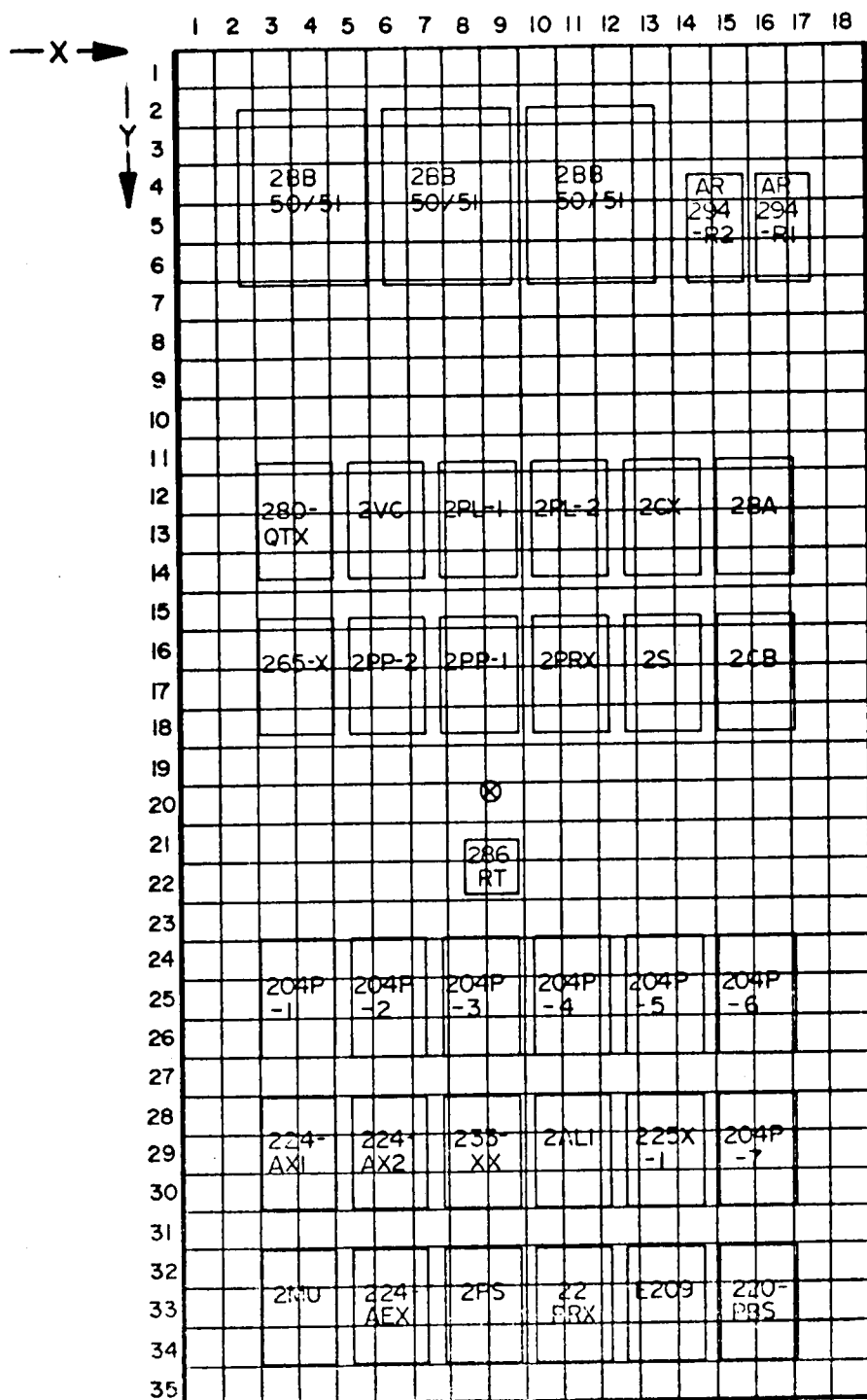


FIGURE 3.2

EQUIPMENT DRAWING WITH GRID OVERLAY

[illegible]

FIGURE 3.3
CODING FORM FOR DEVICE INPUT

its terminals to be confused with another device and its terminals.

The electrical schematics represent the devices and their functions. The schematics need to be put into a form that will enable a computer program to know how the devices are to be wired. Figure 3.4 shows the form that is used to input the schematics. All of the information that is needed to complete the coding form is found on the schematics. As stated in Chapter II, one of the objectives in developing a computer wiring program was to limit changes that would need to be made on the schematic drawings. By using the coding form already exhibited, no additional work or changes are necessary to the schematic drawings.

Priority Ordering Wiring Algorithm

Now that all the data necessary to wire a panel is assembled, a method for performing the actual wiring is needed. The devices and the information from the schematics can be arranged into a hierarchical structure as illustrated in Figure 3.5. This structure was devised to be used as the backbone of the priority ordering wiring algorithm (POA). The elements that make up each level in the structure are linked together by their logical ties with one another. For example, a terminal is tied to a node, a node ties terminals of devices together, and devices are located on a panel.

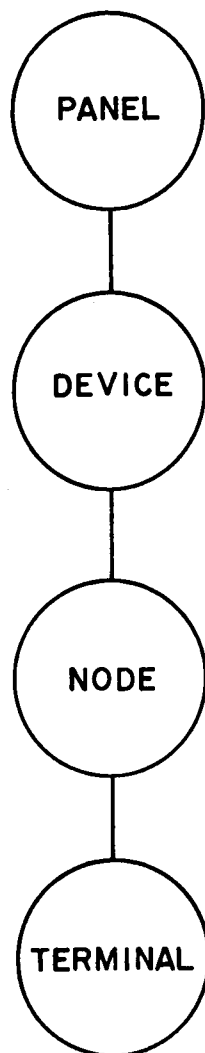


FIGURE 3.5

HIERARCHICAL STRUCTURE FOR PRIORITY ORDERING WIRING ALGORITHM

The POA is a method by which a node (wire number) and all the terminals that are directly associated with it are assembled in a particular order and assigned a priority in which they are to be wired. The POA consists of two operations:

1. All node associated terminals are put in an ordered form according to their position on the panel. This ordering of terminals is done with respect to each terminals' horizontal and vertical (Y,X) position on the panel.
2. The ordered position of each terminal on the panel establishes the priority in which the terminals are to be wired. The wiring begins at the terminal with the numerically lowest Y-X coordinate and continues sequentially until all of the terminals have been wired.

By arranging all of the devices on a panel in a numerically sequential Y-X order, each devices' location is now known with respect to all other devices. The Y-X ordering enables any devices' location on a panel to be found by merely scanning the ordered list.

Because of the hierarchial structure, all terminals for a specific node are grouped under that node name. The node name occurs only once but can have several terminals associated with it. The terminals associated with each node

are coded from the schematic drawing. Now that all terminal locations are known and all nodes have their associated terminals, the panel is now ready to be wired. The final step in the POA is to wire a panel. This is accomplished by calling for a sort of all the terminals under a node. All terminals under the node are now sorted by their Y-X location. The wiring sequence is now established when the node associated terminals have been located. The first terminal in the newly sorted node associated terminal list is defined as the starting point of the wiring. The next node associated terminal that is located establishes the next terminal to be wired or "TO" terminal. Therefore, the "TO" terminal would also have a "FROM" terminal which would be the previous terminal wired. Since actual panel wiring is a series of "TO" and "FROM" connections a wiring scheme has been established.

All terminals that are on the left half of the panel are wired top to bottom. The wiring on the right half of the panel begins with the terminals at the bottom and wired to the top. This wiring scheme is in keeping with the practice of all wiring originating or entering the left top side of a panel and exiting or stopping on the right side of the panel.

CHAPTER IV

METHOD OF SHORTEST DISTANCE

The problem of wiring the shortest distance between device terminals is easy to state: A node must wire every terminal under it once, at the same time keeping between-terminal wiring distances as short as possible.⁴ This procedure must not violate any of the detailed wiring requirements. The order in which the terminals are wired is determined by which $(n - 1)!$ possible paths is chosen. One or more of the paths will give a minimum distance.

The Branch and Bound Algorithm

The object in the well known branch and bound algorithm (BBA) is to break up the set of all wire paths into smaller and smaller subsets and to calculate for each of them a lower bound on the length of the best path therein.⁵ The bounds guide the grouping of the subsets and eventually identify the shortest path.⁶ The path is considered to be the shortest when a subset is found that contains a path whose distance is less than or equal to the lower bounds for all other subsets.

The subsets of paths are represented as the vertices of a tree and the process of grouping as a branching of the tree. The BBA is used as a systematic procedure to eliminate

the need to search through many possible solutions for a wiring path.

The paths from terminal to terminal form a matrix. The terminals are indexed by $i = 1, \dots, n$. The element in row i and column j of the matrix is the distance from terminal i to terminal j . For terminals that are to be wired, let

$$C = c(i,j)$$

which is defined as the original distance matrix. As the algorithm proceeds, the matrix C will undergo various transformations.

Lower Bounds

The minimum distance between terminals is the constraint that is used to construct the lower bounds of this problem. This lower bound is calculated by reducing the matrix C .

The process of subtracting the smallest element of a row from each element in the row is called reducing the row. A matrix with non-negative elements and at least one zero in each row and column is called a reduced matrix and is obtained by reducing rows and columns. If $Z(p)$ is the distance of a path p under a matrix before reduction, $Z_1(p)$ the distance under the matrix after reduction, and h the sum of the constants used in making the reduction, then

$$Z(p) = h + z_1(p).$$

Since a reduced matrix contains only nonnegative elements, h , constitutes a lower bound on the distance of p under the old matrix.

Branching

The splitting of the set of all paths into disjoint subsets is represented by the branching of a tree, as illustrated in Figure 4.1. The vertex containing all paths is self-explanatory. The vertex containing i, j represents all paths which include the terminal pair (i, j) . The vertex containing $\overline{i, j}$ represents all paths that do not include (i, j) . The branching continues at vertex (i, j) . The vertex containing $\overline{k, l}$ represents all paths that include (i, j) but not (k, l) , whereas vertex k, l represents all paths that include both (i, j) and (k, l) . If this branching process is carried far enough, some vertex will eventually represent a single path. At any stage of the branching process, the union of the sets represented by the terminal vertices is the set of all paths.

Computer Application of Branch and Bound Algorithm

In order to apply the BBA, the original distance matrix, C , must first be established. Since the elements of matrix C represent the actual physical distances between terminals that are to be wired, these distances are calculated by using the terminals' locations that were established in

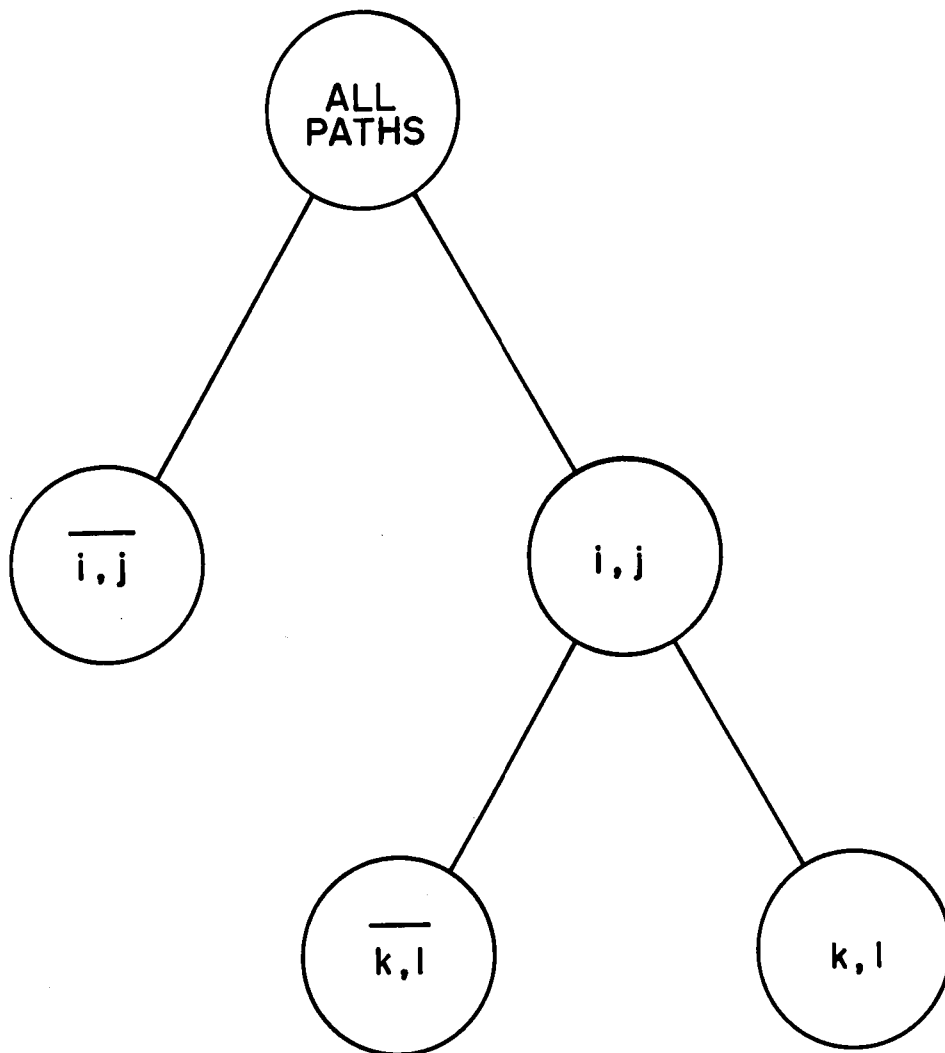


FIGURE 4.1
START OF A TREE

Chapter III. The matrix C can be constructed as

$$C = \begin{vmatrix} C_{11} & C_{12} & \dots & C_{1n} \\ C_{21} & C_{22} & \dots & C_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ C_{n1} & C_{n2} & \dots & C_{nn} \end{vmatrix}$$

where $c(i,j)$ represents the calculated between-terminal distance.

After establishing the matrix C the application of the algorithm can begin. Let X be the initial vertex which represents all paths and set $X = 1$. Let Z_0 represent the distance of the shortest path so far and set $Z_0 = \infty$. The original distance matrix C is reduced and the lower bound for the vertex X, $w(X)$ is found.

$$w(X) = \sum \text{reducing constants of } C$$

The next step in the algorithm is to choose a new vertex. In choosing a new vertex, the paths of X are split into a subset (Y) that is likely to include the best path of the vertex and another ($\bar{Y}$) that is unlikely to include it. The shortest paths to consider for Y are those involving an (i,j) for which $c(i,j) = 0$. Consequently, the paths that do not contain (i,j) are considered paths for $\bar{Y}$.

Since terminal i must be reached from some terminal, these paths must travel at least the distance of the smallest

element in row i , excluding $c(i,j)$. Likewise, terminal j must connect to some terminal, the paths must travel at least the distance of the smallest element in column j , excluding $c(i,j)$. Let $\theta(i,j)$ equal the sum of these two distances. The terminal distance pair (k,l) , for the next tree extension is chosen from the reduced matrix C such that

$$\theta(k,l) = \text{Max } \theta(i,j).$$

Vertex X is now extended into a subset Y . The lower bound for vertex Y is calculated as

$$w(Y) = w(X) + \theta(k,l).$$

Once again vertex X is extended into a subset Y . This Y branch is now the k,l vertex. Since the terminal distance pair is now committed to the wire path, row k and column l are no longer needed and are deleted from C . The terminal distance pair (k,l) is part of some connected path generated by the terminal distance pairs that have been committed to the paths of Y . Let the generated path start at terminal p and end at terminal m . The connecting of m to p is not allowed for it would create a subpath and no subpath can be part of a path. Therefore, set $c(m,p) = \infty$. Matrix C with row k and column l deleted, is reduced to find the lower bound for Y . Let h be the sum of the new reducing constants.

Consequently,

$$w(Y) = w(X) + h.$$

The process proceeds by branching, crossing out a row and column, blocking a subpath, reducing the distance matrix to set a lower bound and then repeating until the best path has a distance less than or equal to the lower bounds of all terminal vertices of the tree.

CHAPTER V

COMPARISON OF WIRING METHODS

In order to determine if either of the developed algorithms were better than producing IWD's manually, experimental wiring runs were conducted. A node with fifteen terminals was wired first manually and then by each of the wiring algorithms. Each of the terminals under the node was attached to a separate device. This arrangement allowed each wiring method to be tested thoroughly.

Results of Experimental Runs

The computer printout of the wiring run that used the Priority Ordering Algorithm for calculating wire paths is reproduced in Figure 5.1. The order in which each device's terminal was wired is read directly from the printout. Figure 5.2 illustrates the wiring order for the Branch and Bound Algorithm.

Table 1 shows the comparison of each wiring method tested. The wiring time for the POA and the BBA is actual computer CPU seconds required to search for the proper ordering of terminals. The calculated cost of the wire path was based on seventy cents for each CPU second used. The manual wiring time was the amount of time required by one designer to wire the node. The manual wire path cost was

PANEL WIRING INFORMATION SYSTEM
PANEL REWIRE NETWORK

8/01/79

NODE	DEVICE	TERM	FROM PANEL	FROM DEVICE	FROM TERM	TO PANEL	TO DEVICE	TO TERM
1AX	1B8-APH	04			X	R8010F	1B8-8PH	01
1AX	1B8-BPH	01	R8010F	1B8-APH	04	R8010F	1B8-CPH	02
1AX	1B8-CPH	02	R8010F	1B8-BPH	01	R8010F	1AL-2	01
1AX	1AL-2	01	R8010F	1B8-CPH	02	R8010F	1CX	04
1AX	1CX	04	R8010F	1AL-2	01	R8010F	1BA	01
1AX	1BA	01	R8010F	1CX	04	R8010F	1CB	03
1AX	1CB	03	R8010F	1BA	01	R8010F	104P-1	03
1AX	104P-1	03	R8010F	1CB	03	R8010F	104P-2	03
1AX	104P-2	03	R8010F	104P-1	03	R8010F	104P-3	03
1AX	104P-3	03	R8010F	104P-2	03	R8010F	1AL1	03
1AX	1AL1	03	R8010F	104P-3	03	R8010F	1MU	05
1AX	1MU	05	R8010F	1AL1	03	R8010F	E109	02
1AX	E109	02	R8010F	1MU	05	R8010F	E104G-2	01
1AX	E104G-2	01	R8010F	E109	02	R8010F	E104G-1	01
1AX	E104G-1	01	R8010F	E104G-2	01	R8010F		X
	SUBTOTAL	15						

FIGURE 5.1

WIRING RUN BY PRIORITY ORDERING ALGORITHM

8/01/79

PANEL WIRING INFORMATION SYSTEM
PANEL REMIRE NETWORK

PAGE

1

NODE	DEVICE	TERM	FROM PANEL	FROM DEVICE	FROM TERM	TO PANEL	TO DEVICE	TO TERM
1AX	188-APH	04			X	RB010F	188-BPH	01
1AX	188-BPH	01	RB010F	188-APH	04	RB010F	188-CPH	02
1AX	188-CPH	02	RB010F	188-BPH	01	RB010F	1AL-2	01
1AX	1AL-2	01	RB010F	188-CPH	02	RB010F	1CX	04
1AX	1CX	04	RB010F	1AL-2	01	RB010F	18A	01
1AX	18A	01	RB010F	1CX	04	RB010F	1CB	03
1AX	1CB	03	RB010F	18A	01	RB010F	104P-3	03
1AX	104P-3	03	RB010F	1CB	03	RB010F	104P-2	03
1AX	104P-2	03	RB010F	104P-3	03	RB010F	104P-1	03
1AX	104P-1	03	RB010F	104P-2	03	RB010F	1AL1	03
1AX	1AL1	03	RB010F	104P-1	03	RB010F	1MU	05
1AX	1MU	05	RB010F	1AL1	03	RB010F	E109	02
1AX	E109	02	RB010F	1MU	05	RB010F	E104G-1	01
1AX	E104G-1	01	RB010F	E109	02	RB010F	E104G-2	01
1AX	E104G-2	01	RB010F	E104G-1	01	RB010F		X
	SUBTOTAL	15						

FIGURE 5.2

WIRING RUN BY BRANCH AND BOUND ALGORITHM

TABLE 1
COMPARISON OF WIRING METHODS

Wiring Method	Wiring Time Required	Length of Wire Used	Wire Path Cost	Wire Cost	Total Cost of Run
Priority Ordering Algorithm	0.91 Sec.	34 Ft.	\$0.64	\$1.36	\$ 2.00
Branch and Bound Algorithm	10.89 Sec.	31.5 Ft.	\$7.62	\$1.26	\$ 8.88
Manual	35 Min.	34 Ft.	\$8.70	\$1.36	\$10.06

based on fifteen dollars per hour. The standard type of wire that is used in this application costs forty dollars per one thousand feet.

The results of Table 1 summarized critical parameters which must be considered in selecting the proper wiring method. The POA used much less computer time than the BBA, however, the BBA used less wire. Both algorithms cost less to wire than the manual wiring method. The manual method's wire path used the same amount of wire as the POA. Although the BBA used the least amount of wire, its total cost was greatly increased by the computer time required to calculate the wiring path. The low cost of calculating the wire path by the POA enabled the total cost of the run to be much less than the other two test methods. Thus, the POA was chosen as the least cost method.

It is surprising that the BBA required such a long time to determine the least cost path. If a more suitable technique could be devised for bounding the possible solutions, then the BBA might result in a lower total cost.

CHAPTER VI

SUMMARY AND CONCLUSIONS

A computer assisted wiring program for powerplants has been developed to replace manual preparation of interconnection wiring drawings. Two algorithms were chosen to try to simulate the established wiring methods. Consideration was given to the efficiency and cost of each method. The priority ordering algorithm (POA) was found to be the more desirable method for production of the IWD's.

The priority ordering wiring technique was chosen as the wiring algorithm for the following reasons:

1. Computer runs using each algorithm for calculating wiring paths were demonstrated. These runs showed that for a node with fifteen terminals associated with it, the branch and bound algorithm (BBA) required more time to calculate the wiring path than did the POA. The number of CPU seconds used directly related to cost. The BBA takes the shortest path in wiring thus uses less wire. The additional computer time used by the BBA must be compared with the cost of the wire saved. The price of the wire saved in the demonstration run by the BBA does not offset the difference in the cost of the computer time.

2. The BBA is a mathematical approach to selecting a wire path and is a more complicated method to apply. However, the POA is based on the geometry of the device locations and is simpler to use.

3. One basic requirement of the selected algorithm was the ability to shorten the production duration of the IWD. Although each algorithm allows design to start at a later date, the completion time for the BBA can never be predicted. The prolonged use of the computer due to the volume of transactions will cut down on other users if the program is run during prime computing time. This prolonged use would relegate the program to run at off-peak times, therefore, the exact time for completion of the wire run is not predictable. The speed of the POA allows it to be run at almost anytime with the results available almost immediately.

4. Knowing how the POA wires allows for prediction of the wire path. The BBA selects the shortest distance wire path and except in small cases the calculated wire path cannot be predicted. This ability to predict the wire path allows easier trouble shooting by the designer or installer.

The POA was the method chosen to calculate the wire paths for producing the IWD's. This algorithm was able to closely approximate the wiring practices that were in use and at the same time substantially shorten the duration required to produce the IWD. The cost of using the POA is substantially less than the BBA or the manually wired method.

Future studies might consider techniques to reduce the search time required for the BBA.

LIST OF REFERENCES

LIST OF REFERENCES

1. Thompson, N. W.: "A Computer System for Station Wiring," IEEE Paper T 72 576-7, July 14, 1972.
2. Tennessee Valley Authority: "Electrical Design Guide D. G.—E 15.2.1."
3. ANSI STANDARD Y 14.15-1966: "Electrical and Electronic Diagrams."
4. Ballou, Ronald H.: Business Logistics Management, Prentice-Hall International Series in Management, Englewood Cliffs, New Jersey, 1973.
5. Little, John D. C., Katta G. Murty, Dura W. Sweeney, Caroline Karel: "An Algorithm for the Traveling Salesman Problem," Operations Research Society of America, Vol. II, 1963.
6. Nicholson, T. A. J.: "Finding the Shortest Route Between Two Points in a Network," Computer Journal, Vol. 9, No. 3, November 1966.
7. Duerre, K. H. and J. R. Case: WIREX, a Fortran Computer Program for Producing Wire Lists, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, December 27, 1967.
8. Ringlee, R. J. and B. F. Wollenberg: "Overview of Optiminization Methods," Proc., IEEE, Course Text 76-CH 1107-2-PWR, Schenectady, N.Y., October 21, 1975.

VITA

William Thomas McBride was born in Chattanooga, Tennessee on January 13, 1947. He attended elementary school in that city and graduated in 1965 from Chattanooga Central High School.

In September 1965 he entered The University of Tennessee and received a Bachelor of Science degree in Electrical Engineering in March 1970. While attending The University of Tennessee, he was employed by The University of Tennessee's Computer Center.

He has been employed by the Tennessee Valley Authority since graduation and received the Master of Science degree in Electrical Engineering in August 1979.