A TECHNIQUE FOR ALLOCATING LOSSES IN LARGE

INTERCONNECTED ELECTRIC SYSTEMS

APPROVED:

W C Duesterhoeft

H H Woodson

A TECHNIQUE FOR ALLOCATING LOSSES IN LARGE INTERCONNECTED ELECTRIC SYSTEMS

by

Eugene Gordon Preston, B.S.E.E.

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Abstract

A method of determining the distribution of power flows through an electric power system and the loss of power in each circuit for any single transaction occurring simultaneously with a multitude of other transactions is presented in this thesis. An important accounting criteria met by the technique of this paper is that the sum of all transaction flows and losses produces precisely the same flows and losses as a load flow solution.

Table of Contents

Chapter I

Introduction

The electric utilities are presently dissatisfied with the way losses are being assigned to individual power transactions when those transactions cause displacements of power remote from the contracting utilities [5]*. These displacements are a result of the recent necessity of pooling the energy production of interconnected utilities [2, 4, 6, 7, 8, 9, 10]. This paper presents a solution to the problem of identifying the transmission flows and losses occurring in the network. The technique produces a unique answer for each transaction.

The solution technique begins with a solved load flow base case to establish the voltage profile of the network. A special matrix equation is built and solved for each transaction. For any one transaction, the transmission circuit powers are found to determine the loss in each circuit. As in the load flow, bus powers are balanced, and network flows are identified. The sum of losses and flows for all transactions will precisely agree with the load flow.

The method is straightforward and works well on large networks. Examples utilizing a 1178 bus system and a 16 bus system are included in the Appendix.

*For numbered references see Bibliography on page 90

Chapter II

Current Electric Utility Practices

The topic addressed by this thesis is identification of the sources of losses that occur in an electric power transmission network. However, a discussion of the physical facilities and historical evolution of most utilities is appropriate before delving into the mathematics of the technique.

The physical system of an average utility consists of generation, transmission, and local distribution facilities. The transmission network is usually arranged so that any one circuit can be opened without affecting the generation from any plant or service to any distribution substation. An important point here is that multiple paths exist for the power to flow from a power plant to any substation. If these multiple paths did not exist, the analysis presented in this thesis would be greatly simplified, and the problem would probably have been solved long ago.

The continuous task of the production or generation division within a utility is to increase or decrease the level of power output of the plants that are on line to satisfy three power requirements. Customer load within a utility's service area, losses on circuits within the area, and sales or purchases to other utilities must all sum to the power production or generation level.

Of the three factors needed to determine generation, only the power flowing through transmission circuits that tie to other utilities is known. The power production dispatcher adjusts the generation power until the sum of power through all tie circuits equals the desired interchange power. The load and losses are automatically met without knowledge of their exact magnitude. All these quantities are constantly changing with time, so the generation must also be constantly adjusted.

A utility uses generation power from its own plants to cover losses within its metered or control area. Until recently, the losses were usually the result of the utility's own generation and loads since most utilities had located their power plants close to their loads. In this case, very little circulating power appeared in the utility's neighboring transmission systems. Transmission ties between utilities were allowed to "float" and were designed to increase the reliability of each area in case local generation had a forced outage [1]. In recent years, the development of a national grid [10] for the purpose of wheeling economic energy over greater distances [3] has resulted in transactions between utilities that have significantly altered the power flows on transmission circuits on a local level [6]. These flows will thereby impact the local generation requirement in each utility by altering the losses within the control area.

The losses accounted for by a utility may not be directly related to its own operation.

If these losses were easy to identify, then an equitable compensation agreement would probably be in effect today for all affected parties. Currently, two methods are being utilized to compensate for losses. The "Contract Path" method has the buying and selling utilities find a path of connected utilities that will agree to wheel the power for the two parties. Each intermediate utility has some charge for the service [10]. Various paths are reviewed to find the one with the lowest overall wheeling cost. The problem with this technique is that the contract flows through the network do not align very well with the electrical flows. Load flow solutions modeling the transaction usually show that all the utilities in the network are affected to some degree. The Contract Path method allows some utilities to charge for a service that is only partially provided while other utilities receive no compensation at all.

Another more sophisticated method utilized by some power pools for compensation among the members of the pool involves the analytical determination of incremental losses for each utility for each transaction [1, 2, 4, 6, 8]. Since the nonlinearity of the losses is recognized, the transactions must be handled in the reverse order of occurrence. This procedure can produce an embarrassingly large increase in loss for a transaction if the order of occurrence moves it from last on the list one day to first on the list the next day. If the order were based on some other criteria than "first come first serve", then some utilities would feel cheated by the technique that allowed some to take advantage of the peculiarity of the calculation procedure. Recognition of the nonlinearity in the calculation of losses therefore does not guarantee the success of a technique.

A technique not requiring ordering of transactions will be developed in the next two chapters. It will produce a unique solution for each transaction for a given load flow. Certain important scientific and accounting conditions will be satisfied that have been overlooked in other papers. The technique will have no more difficulty of implementation than a load flow model.

Chapter III

The Solution Requirements

The loss evaluation technique described in this thesis will begin by using as a basis for describing the network what is known in the electric utility industry as a "load flow". The load flow will be used to define one of the boundary conditions of our problem. The load flow will be assumed to be the best estimate available for the description of the state of the transmission system. In a real time application the load flow would need to be frequently updated. From the load flow, the total loss and power flow for each circuit is obtained.

The objective is to break the losses down so they can be identified circuit by circuit for each transaction. The load flow models the total network nicely but produces unsatisfactory incremental losses if transactions are solved as separate load flow cases and then compared. The solution of all transactions by this load flow comparison technique will produce loss sums that are grossly different from a load flow solution modeling them all simultaneously. Therefore the new technique must, as its first and most important characteristic, have the loss components and power flows identified in a manner such that the sum of all transactions will give the base case load flow quantities.

Another important requirement that is easily overlooked but is significant is the balance of power at each bus for each transaction. The sum of powers into a bus must be zero, and the sum of power into each end of a circuit must be the circuit loss. This law of physics is met in the load flow solution and should be met for transaction flows also. If a transaction is defined as a subset of generation and load within the network, then the total transaction generation power must equal the sum of transaction loads and losses. Since the loss a transaction causes is unknown before the problem is solved, an iterative procedure will be required to adjust either the transaction load or generation to obtain the power balance.

A third feature that is not a strict requirement but only a desirable result is to have the distribution of power through the network for a given transaction be in good agreement with a comparison of two load flow solutions, one solution being the base case and the other having the transaction removed from the base case. Since the load flow is nonlinear, precisely the same distribution should not be expected. The objective here will be to minimize the difference. The 16 bus example in the Appendix includes the distributions using both the load flow comparison and the method developed in this thesis.

Chapter IV

Formulation of Analytical Tools

The requirements on the preceding pages must now be formally met using the precise terminology of mathematics. The first requirement stated that the sum of losses would agree with the load flow. The summation property can be met with a linear set of equations. The most desirable form is shown below by equation 1.

$$[P] = [W][V] \qquad (1)$$

The column vector of bus powers equals some unknown square matrix [W] times the column vector of bus voltages. Matrix [W] is defined so that insertion of the base case load flow bus voltages will yield the load flow bus powers. Any other set of [P] representing a transaction could be used to find a set of [V]. From these voltages, the circuit currents, powers, and losses could somehow be determined. If the form shown in equation 1 is not used to meet the summation property, then the analysis is severly complicated. This paper will proceed with the linear form of equation 1 since it is considered by the author as being the most productive path to follow at the present time in the development of the other equations needed to allocate the losses associated with wheeling energy. Nonlinear forms are beyond the scope of this thesis.

Now the losses for any single circuit must be formulated. Let the current from transaction 1 be I_1, from transaction 2 be I_2, etc. until all components of current in the one subject transmission line are identified. Equation 2 shows that the sum of all transaction currents for the circuit is the same as the base case current I_b.

$$I_b = I_1+I_2+I_3+\ldots \tag{2}$$

The real power base case loss for the circuit is:

$$P_{Lb} = Re(ZI_bI_b^*) = I_bI_b^*Re(Z) \tag{3}$$

Z is the circuit impedance.

Substituting equation 2 into 3 will expand and identify the loss each transaction current contributes toward the total circuit loss as shown in equation 4.

$$\begin{aligned} P_{Lb} = (&I_1I_1^*+I_1I_2^*+I_1I_3^*+\ldots \\ &+I_2I_1^*+I_2I_2^*+I_2I_3^*+\ldots \\ &+I_3I_1^*+I_3I_2^*+I_3I_3^*+\ldots \\ &+\ldots \qquad\qquad +\ldots))Re(Z) \end{aligned} \tag{4}$$

The complex nature of separating the loss components can be seen in equation 4 since inner product terms exist between each current. The scheme utilized in this thesis defines the loss assigned to transaction current I_1 as the real part of the sum of terms in the first row, the loss due to I_2 as the second row, and so on for each current. Cross terms such as $I_1 I_2^*$ and $I_2 I_1^*$ produce real power loss components of equal value that are equally shared between the two transactions. Using this definition results in an interesting simplification of equation 4.

Factoring out the first current term from each row shows that each transaction current is effectively multiplied times the conjugate of the base case current as shown in equation 5.

$$\begin{aligned} P_{Lb} = \mathrm{Re}(&I_1(I_1^*+I_2^*+I_3^*+\ldots) \\ &+I_2(I_1^*+I_2^*+I_3^*+\ldots) \\ &+I_3(I_1^*+I_2^*+I_3^*+\ldots) \\ &+..(.. \qquad\qquad\qquad))\mathrm{Re}(Z) \end{aligned}$$

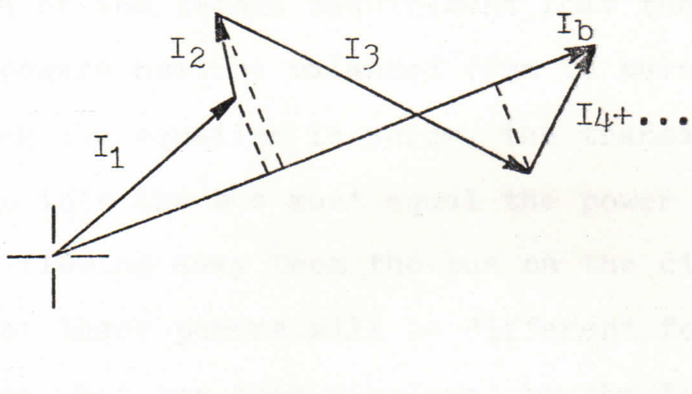
or

$$P_{Lb} = \mathrm{Re}(I_1 I_b^*+I_2 I_b^*+I_3 I_b^*+\ldots)\mathrm{Re}(Z) \qquad (5)$$

The application of the Re expressions as they appear in equation 5 is important for accounting and conceptual reasons. A single Re could have been performed on the entire expression since $\mathrm{Re}(I_b I_b^* Z)$ and $I_b I_b^* \mathrm{Re}(Z)$ will produce the same real number. $I_b I_b^*$ is always a real number and can be factored out of the Re argument without changing the answer. A transaction loss caused by current I_1 could be calculated either as $\mathrm{Re}(I_1 I_b^* Z)$ or as $\mathrm{Re}(I_1 I_b^*)\mathrm{Re}(Z)$. These two equations do not produce the same result because $I_1 I_b^*$ will usually be a complex number. If this complex quantity is multiplied times the complex number Z, the reactive part of the impedance will contribute toward the transaction current real power loss. This contribution is unrealistic since the circuit loss in the real world is caused only by the circuit resistance. If R is the circuit resistance and is obtained by Re(Z), then the logical definition of transaction loss for transaction current I_1 is $R\,Re(I_1 I_b^*)$. This form is the same as equation 5.

Figure 1 shows conceptually how several complex transaction currents contribute toward the base case current. The transaction losses are assigned in proportion to the projection of each transaction current with respect to the base case current.

Fig. 1.--Transaction currents in a circuit

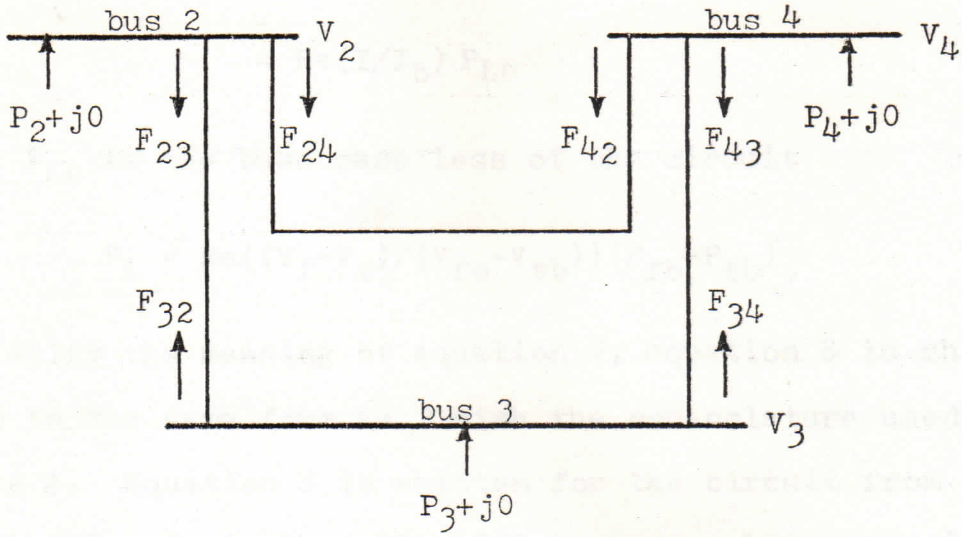


Equation 5 can be interpreted in a slightly different form to give more physical meaning to the definition selected to simplify equation 4. The term $Re(Z)(I_b^*)$ is the portion of the voltage drop across the circuit that relates to the loss of real power. When a current I_1 is forced through this potential difference, real power is lost or gained depending on the direction of the current and the voltage difference. If the load flow base case potentials are viewed as a topographic map, then the losses due to transaction currents are found by calculating the work required to force these currents through the network profile. Although this profile is a function of the simultaneous combination of all transactions, its shape is frozen for the purpose of identifying the losses.

Equation 5 allows the loss of each transaction to be identified uniquely for the circuit if each of the transaction currents I_1, I_2, I_3, etc., are known. Equation 1 must be designed with a [W] matrix that will produce currents consistent with the losses of equation 5.

This connection between equations 1 and 5 is found through the use of the second requirement that the bus real and imaginary powers must be balanced (sum to zero) at each bus. Describing the equation in words, the transaction power from generation into the bus must equal the power to the load plus the power flowing away from the bus on the circuits. The magnitude of these powers will be different for the transaction than what has been displayed by the load flow solution. Figure 2 and equation 6 illustrate the bus power balance. The reactive power from load and generation is set to zero for the transaction although it may be nonzero in the base case load flow solution.

Fig. 2.--A three bus example



Summing the powers around bus 3:

$$P_3 + j0 = F_{32} + F_{34} \tag{6}$$

Equation 6 is close to the desired form of equation 1. The circuit flows in equation 6 must be written in a manner consistent with equation 5. Since equation 5 is in terms of currents and equation 1 in terms of voltages, a conversion of equation 5 is performed to get it into the desired voltage form as shown in equation 7. Equation 7 is written in a form applicable to any of the three circuits shown in figure 2. Base case values have an additional b subscript. P_L is a circuit loss, subscripts f and t mean from and to buses respectively, and the transaction current in the circuit is I. The base case current is I_b. The real part of the circuit Z is shown as R.

$$P_L = Re(I\ I_b^*)\ R$$

$$= Re(I\ I_b I_b^*/I_b)\ R$$

$$= Re(I/I_b)\ P_{Lb}$$

where P_{Lb} is the base case loss of the circuit

$$P_L = Re((V_f-V_t)/(V_{fb}-V_{tb}))(F_{fb}+F_{tb}) \tag{7}$$

To clarify the meaning of equation 7, equation 8 is shown below in the same form as 7 with the nomenclature used in figure 2. Equation 8 is written for the circuit from bus 3 to bus 2. Again, the subscript b means a base case load flow quantity and is not a function of the transaction.

$$P_{L32} = Re((V_3-V_2)/(V_{3b}-V_{2b}))(F_{32b}+F_{23b}) \tag{8}$$

Equation 8 shows the loss in the circuit from bus 3 to bus 2 for the transaction but does not indicate what the transaction flows F_{23} and F_{32} are. If the loss of the circuit in the base case is described by equation 9, then the same relation must be true for the transaction powers as shown by equation 10. Then observing that equation 8 contains the proper terms to relate the base case flows to the transaction flows and still be consistent with all the equations that have been developed up to this point, equation 11 can be written by observation. Equation 11 is very close to the desired power and voltage relationship of equation 1.

$$P_{L32b} = F_{32b} + F_{23b} \tag{9}$$

$$P_{L32} = F_{32} + F_{23} \tag{10}$$

$$F_{32} = \mathrm{Re}((V_3-V_2)/(V_{3b}-V_{2b}))\, F_{32b} \tag{11}$$

The form of equation 11 can be applied to the other circuit connected to bus 3 to find the transaction flow F_{34}. Combining these two flows will show in detailed form the expansion of equation 6. This equation is shown below in equation 12.

$$\begin{aligned} P_3+j0 = {} & \mathrm{Re}((V_3-V_2)/(V_{3b}-V_{2b}))\, F_{32b} \\ & +\mathrm{Re}((V_3-V_4)/(V_{3b}-V_{4b}))\, F_{34b} \end{aligned} \tag{12}$$

At first glance equation 12 looks like the desired link between equations 1 and 5. However, inserting values for all quantities except V_3 will reveal that an infinite number of solutions still exist for the value of V_3. In order for equation 12 to be of any use, the Re expression must be dropped. This means that reactive flows will exist, but will sum to zero to meet the requirement of j0 shown on the left hand side of the equation. Equation 13 is the magic power balance equation needed in the [W] matrix. It is linear in terms of power and voltage.

$$\begin{aligned} P_3+j0 = {} & ((V_3-V_2)/(V_{3b}-V_{2b}))\, F_{32b} \\ & +((V_3-V_4)/(V_{3b}-V_{4b}))\, F_{34b} \end{aligned} \tag{13}$$

Repeating equation 13 for buses 2 and 4, collecting the voltage terms, and writing the three equations in matrix notation completes the derivation of [W] in equation 1. This expansion of equation 1 for the circuit in figure 2 is shown below in equation 14.

$$\begin{bmatrix} P_2+j0 \\ P_3+j0 \\ P_4+j0 \end{bmatrix} = \begin{bmatrix} \frac{F_{23b}}{V_{2b}-V_{3b}} + \frac{F_{24b}}{V_{2b}-V_{4b}} & \frac{-F_{23b}}{V_{2b}-V_{3b}} & \frac{-F_{24b}}{V_{2b}-V_{4b}} \\ \frac{-F_{32b}}{V_{3b}-V_{2b}} & \frac{F_{32b}}{V_{3b}-V_{2b}} + \frac{F_{34b}}{V_{3b}-V_{4b}} & \frac{-F_{34b}}{V_{3b}-V_{4b}} \\ \frac{-F_{42b}}{V_{4b}-V_{2b}} & \frac{-F_{43b}}{V_{4b}-V_{3b}} & \frac{F_{42b}}{V_{4b}-V_{2b}} + \frac{F_{43b}}{V_{4b}-V_{3b}} \end{bmatrix} \begin{bmatrix} V_2 \\ V_3 \\ V_4 \end{bmatrix} \quad (14)$$

One more item concerning equation 14 needs addressing. The matrix will be singular if all the voltages are left as variables. To circumvent this problem, one of the buses must have its voltage specified as a constant. The author has chosen to use the network swing bus and its voltage as the reference in equation 14. If the power array is entered as all zeroes, the network will have the voltage magnitude and angle of the system swing bus at every bus in the network. If the bus powers of the base case are entered and equation 14 is solved, the base case voltages will result. Any other set of P vectors will yield a set of V vectors that can be used with equation 11 to find the distribution of power flows in the network.

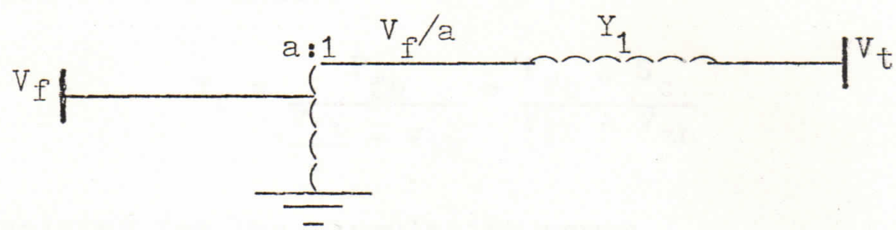
A balance between the generation power sources and the load power sinks must be obtained to prevent the reference bus from having a P different from the desired value. The load or generation at one bus or several buses must be adjusted to achieve the desired results. An iterative procedure can be used to find the proper load, generation, and loss to meet the power balance requirement for the network. Since the losses are considerably smaller than the load or generation in a reasonable electric power system, the iterative procedure will converge very quickly. Two or three iterations are typical for any size of network.

Once the V vector has been found for a given P vector, the power flows everywhere in the network and losses of each circuit can be found easily. The losses occurring within each metered area are obtained simply by summing individual circuit losses within each area. Power flows at ties or utility interconnection points are easily determined.

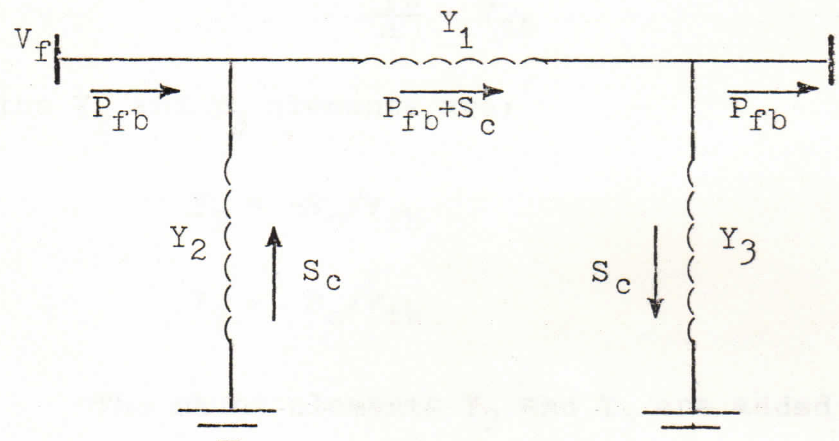
The flows and losses of any two transactions can be combined and solved as one transaction. The sums of the results of any combination of transactions produces valid flow and loss answers. The reason these linear processes are possible is because the voltage profile of the network has been frozen allowing linear equations to describe the currents necessary to deliver the power from the generation sources to load sinks. The solution is similiar to the familiar short circuit calculations used by the electric utility industry. The main difference here is the objective of power matching for each bus, circuit, and entire network.

The initial computer runs during the early development of this thesis indicated the need for an autotransformer model. The relatively large voltage difference between the high and low side of the transformers were producing terms in the matrix that were not related to power. The voltage difference made the autotransformers appear to have a very high impedance to the flow of power in almost all cases except the base case. Figure 3 below shows the physical and equivalent models of the autotransformer.

Fig. 3.--Autotransformer model



or as a pi equivalent



The Y_1 term is not the impedance of the transformer, but rather the term that would be entered into the [W] matrix if the tap setting a, is unity. For reasons of simplification, the autotransformer will be considered as lossless and have no phase shifting capability. A complex circulating power S_c is introduced to allow the pi equivalent to have V_f and V_t be greatly different in voltage magnitude. The terms Y_1, Y_2, and Y_3 are derived in equations 15 through 18 in a form that can be directly inserted into [W]. Equation 15 is written by inspection using equation 14 as a guide.

$$Y_1 = \frac{P_{fb}}{\frac{V_{fb}}{a} - V_{tb}} = \frac{P_{fb} + S_c}{V_{fb} - V_{tb}} \qquad (15)$$

then solving for the circulating power

$$S_c = P_{fb}\left(\frac{V_{fb} - V_{tb}}{\frac{V_{fb}}{a} - V_{tb}} - 1\right) \qquad (16)$$

then the Y_2 and Y_3 elements are:

$$Y_2 = -S_c/V_{fb} \qquad (17)$$

$$Y_3 = S_c/V_{tb} \qquad (18)$$

The shunt elements Y_2 and Y_3 are added only to the diagonal of [W]. Element Y_1 is entered like any other circuit into [W] although its value is calculated from equation 15. This model of the autotransformer has solved one problem and created a set of new ones.

Implementation of the model as shown by equations 15 through 18 will result in a moderately small power mismatch at the unregulated or "from" bus shown in figure 3 for transactions other than the base case. This problem can be corrected by modifying equation 18 as shown below in equation 19.

$$Y_3 = (S_c/V_{fb})(V_f/V_t) \tag{19}$$

Now the shunt element Y_3 is a function of the transaction rather than being a constant. Test cases run by the author have shown that the linearity property of summing transaction solutions to produce other valid transactions no longer holds true if equation 19 is used.

Another problem with the autotransformer model is the injection of complex power into the network and its effect on the distribution of real power flows in the network. The inclusion of reactive powers in [P] will require additional analytical work to guarantee meaningful results.

With these weaknesses in mind, the author has elected to incorporate the autotransformer model into the large network program, and accept for the present time the small mismatch using equation 18. The 1178 bus example in the appendix uses this model. The 16 bus example treats the two autotransformers as ordinary circuits to demonstrate the other properties of bus power matching and linearity of transaction solutions more clearly.

Chapter V

Conclusions

An algorithm has been developed in this thesis that allows utilities operating in a pool environment to separate the power flows and losses each is causing in the network. The need for this accounting procedure was outlined in chapter II. The desired characteristics sought were described in chapter III, and the technique was developed in chapter IV. This linear approach is easy to implement in a computer program but is probably more difficult to set up in a real time environment. Since a certain degree of arbitrariness is allowed in setting up a problem and solution of the sort in this thesis, the author recommends the following work be continued on this topic.

1. Develop better models for the autotransformer and phase shifting transformer.
2. Exploit the reactive power into each bus for the objective of obtaining flow distributions that are closer to those obtained by running load flow cases with and without the transaction.
3. Develop a nonlinear loss assignment for each circuit that is more compatible with utility desires, or show that nonlinear allocations cannot meet all the power criteria described in chapter III.
4. Develop a power matrix equivalent that would allow the losses between pools to be calculated.

Appendix A

Definitions and Symbols

a - A real number representing the per unit tap setting of an autotransformer.

Contract Path - An agreement with several electrically interconnected utilities for the purpose of handling the accounting of wheeling power.

F_{fb} - A real number base case power flow into a circuit on the "from" end.

F_{tb} - A real number base case power flow into a circuit on the "to" end.

F_{32} - The real number transaction power flow from bus 3 to bus 2 and measured at bus 3. Other circuit flows are subscripted according to the bus numbers used in the network.

F_{32b} - The base case value of F_{32}.

I_b - A complex number base case circuit current. Only the series impedance and bus voltages are used to find this quantity.

I_b^* - The complex conjugate of I_b.

I_1 - A complex number current in the circuit for transaction 1. Other transaction currents are similiarly subscripted.

Load Flow - A solution to the nonlinear set of equations describing an electric power transmission network.

[P] - A column vector of real number bus powers representing a transaction.

P_{fb} - A real number base case power flow into an autotransformer on the adjustable tap side.

P_L - A real number transaction case circuit power loss.

P_{Lb} - A real number base case circuit power loss.

Pooling - The centralized planning and control of a group of locally interconnected utilities for the purpose of increasing the reliability and reducing the cost of power production and transmission expenses to the members.

P_3 - A real number representing a transaction power into bus 3. Other bus powers are subscripted similiarly in accordance with the numbering scheme used in the base case load flow. The set of all bus powers for a transaction is the [P] vector.

R - The real number part of the complex number Z.

S_c - A constant complex number circulating power in the autotransformer model.

Transaction - In this thesis, a set of bus powers that algebraically sum to the portion of network loss caused by the circuit flows those bus powers create. For the electric utility industry, a contracted interchange power metered on the tie circuits between connected utilities.

[V] - A column vector of complex number bus voltages for a transaction.

V_f - A complex number transaction voltage at the "from" bus end of a circuit.

V_{fb} - The base case version of V_f.

V_t - A complex number transaction voltage at the "to" bus end of a circuit.

V_{tb} - The base case version of V_t.

[W] - A sparse nonsymmetrical square matrix of complex numbers developed in chapter IV.

Wheeling - The exchange of power between utilities for mutual benefit. The term is used more frequently for exchange power between pools and within interconnected systems not yet matured to a pool coordination status. The power will be in effect for a period of time making it an energy contract also.

Y_1 - A constant complex number series circuit element for an autotransformer that is put into the [W] matrix.

Y_2 - A constant complex number shunt circuit element for an autotransformer model that is added to the diagonal of [W] on the row representing the variable tap side of the autotransformer.

Y_3 - A variable complex number shunt circuit element for an autotransformer that is added to the diagonal of [W] on the row representing the opposite side of the autotransformer from the variable tap side.

Z - A complex number circuit series impedance.

Appendix B

Large Network Example

The 1178 bus example has resulted from work performed for the Power Interchange Effects Task Force of the Texas Interconnected System Planning Subcommittee. Tables B-1 and B-2 have been prepared to summarize the results of the study since the data base and computer program source code are too lengthy to include in this thesis. A map of the Texas Interconnected System is shown in figure B-1.

Table B-1 shows 14 transactions (one per line) and the loss in megawatts caused in each of the 12 control areas for each transaction. The generation sources are from jointly owned plants and the loads are scaled within the receiving area for each transaction from those appearing in the load flow base case.

Two loss impacts are of large enough magnitude to warrant relief to those utilities carrying the additional loss. The DPL and TESC lignite generation cause considerable loss in the TPL area, and the COA portion of power from the Fayette plant causes loss within the LCRA area. In both of these cases the joint generation projects are remote from the areas receiving the power.

SUMMARY OF MW LOSS CAUSED BY TRANSACTION POWER FLOWS FOR THE 1981 SUMMER PEAK

GENERATION DESCRIPTION	LOAD	TPL	DPL	TESC	HLP	CPS	WTU	LCRA	CPL	COA	TMPP	STEC	MIG	TOTAL
2351.4 MW-TPL LIGNITE	TPL	44.7	3.9	4.8	0.1	0.1	-0.2	0.5	-0.5	0.1	1.0	0.1	0.	54.6
360.5 MW-COMMANCHE PEAK	TPL	1.2	-0.2	2.2	0.	0.	-0.1	0.	-0.1	0.	0.1	0.	0.	3.1
1056.9 MW-DPL LIGNITE	DPL	23.3	9.2	2.9	0.2	0.1	0.4	0.1	0.5	-0.1	0.6	0.2	0.	37.3
252.4 MW-COMMANCHE PEAK	DPL	2.5	1.6	1.5	0.	0.	0.1	0.	0.1	0.	0.1	0.	0.	5.8
1670.9 MW-TESCO LIGNITE	TESC	38.7	4.2	18.2	-0.1	0.4	3.5	1.1	2.2	0.	1.3	0.2	0.	69.8
360.5 MW-COMMANCHE PEAK	TESC	3.0	0.1	5.3	0.	0.1	0.7	0.2	0.4	0.	0.2	0.	0.	10.1
385.0 MW-S TEX PROJ	HLP	-0.6	0.	0.	3.1	0.4	0.1	0.4	0.7	0.2	-0.2	0.	0.	4.0
350.0 MW-S TEX PROJ	CPS	0.7	0.	0.1	0.6	3.2	-0.2	0.6	0.7	0.7	0.2	0.3	0.	7.0
315.0 MW-S TEX PROJ	CPL	0.5	0.	0.	0.4	1.5	-0.1	0.3	10.6	0.4	0.2	0.4	-0.1	14.0
200.0 MW-S TEX PROJ	COA	1.1	0.	0.	0.6	1.2	0.1	3.2	0.5	2.5	0.2	-0.1	0.	9.1
555.7 MW-FAYETTE	COA	2.7	0.1	0.	0.2	1.1	-0.4	12.2	0.3	7.5	0.2	0.	0.	23.9
200.7 MW-SAN MIGUEL	TMPP	3.2	0.	0.	0.7	-0.8	0.4	1.1	0.4	0.	2.8	0.1	0.8	8.7
108.2 MW-COMMANCHE PEAK	TMPP	1.2	-0.1	0.8	0.	0.	0.	0.	0.	0.	1.3	0.	0.	3.4
200.7 MW-SAN MIGUEL	STEC	0.	0.	0.	0.	-0.2	0.	-0.1	-1.2	-0.1	0.	5.4	0.6	4.4

Table B-1

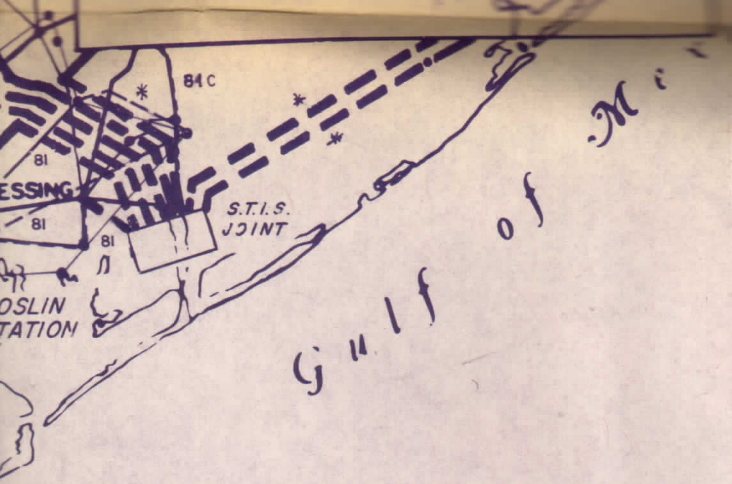
Table B-2 shows the total generation of each utility as a transaction for all areas except MIG. It was omitted since no load appeared within the area in the base case load flow. The bottom line shows the base case load flow solution loss within each area.

Notice that the sum of all transaction losses of a column doesn't sum precisely to the base case loss of an area. This is due to the manner in which the loads were adjusted to obtain a power balance for each transaction. If the loads had been held constant and the generation adjusted, the same problem would have occurred. Comparing the right hand column with the bottom row of table B-2 shows that an adjustment should be made to the net interchange of each area in the base case load flow to compensate for the losses incurred by the simultaneous set of transactions. Resolving the load flow with this adjustment and performing the interchange adjustment in the real world at the same time will satisfy the accounting criteria and will allow the sum of all transaction losses to agree with the load flow base case. If the losses are calculated at a later time rather than in real time, this problem will be a continuous headache of the accounting personnel. The small error will probably be spread among all the utilities by some arbitrary agreement. The best operating environment would be the continuous compensation for losses in real time by making small interchange adjustments.

TOTAL MW LOSS CAUSED BY THE OPERATION OF ALL LOAD AND GENERATION IN EACH AREA

GENERATION DESCRIPTION	LOAD	TPL	DPL	TESC	HLP	CPS	WTU	LCRA	CPL	COA	TMPP	STEC	MIG	TOTAL
6637.5 MW-ALL TPL	TPL	95.8	4.0	11.0	0.6	0.3	1.2	1.9	0.7	0.1	4.8	0.3	0.	120.8
2910.3 MW-ALL DPL	DPL	27.0	21.7	4.1	0.2	0.1	0.4	0.	0.4	0.	0.6	0.2	0.	54.6
4613.4 MW-ALL TESCO	TESC	43.5	4.5	43.8	0.	0.4	4.1	1.2	2.2	0.	1.5	0.2	0.	101.5
11221.4 MW-ALL HLP	HLP	-0.7	0.2	-0.2	104.8	0.6	-0.1	0.4	1.4	0.2	-0.2	-0.1	0.	106.3
2365.1 MW-ALL CPS	CPS	0.8	0.1	-0.1	0.5	21.1	-0.2	0.8	1.3	0.7	0.2	0.3	0.	25.5
940.9 MW-ALL WTU	WTU	-0.8	0.	1.2	-0.1	0.2	26.6	1.4	0.6	0.1	-0.2	0.	0.	28.9
1268.6 MW-ALL LCRA	LCRA	0.6	0.1	0.	0.	1.4	-0.3	21.1	0.2	1.7	0.1	-0.2	0.	24.7
2732.1 MW-ALL CPL	CPL	0.8	0.2	-0.2	0.4	2.2	-0.3	0.8	69.2	0.4	0.2	2.7	0.	76.4
928.1 MW-ALL COA	COA	3.8	0.1	-0.1	0.8	2.3	-0.5	15.8	0.8	10.9	0.5	-0.1	0.	34.3
1324.1 MW-ALL TMPP	TMPP	16.5	0.2	0.4	-0.3	-0.3	0.9	1.8	1.1	0.3	24.3	0.2	0.8	45.9
310.3 MW-ALL STECMEC	STEC	0.	0.	0.	0.	-0.4	0.	-0.1	-1.3	-0.1	0.	8.2	0.6	6.9
35251.9 MW-TIS BASE CASE		189.2	31.4	60.3	107.3	27.7	32.2	45.7	77.4	14.4	32.9	9.8	1.5	629.7

Table B-2



MAJOR TRANSMISSION NETWORK
F INTERCONNECTED SYSTEMS IN TEXAS
PROPOSED 1978-1987 ADDITIONS

(FOR SYSTEM PLANNING PURPOSES ONLY)

FEBRUARY 17, 1978

Fig. B-1

Appendix C

Small Network Example

The 16 bus network shown in figure C-1 has been designed to test the losses allocation technique under adverse conditions. The network has large reactive flows, lossy circuits, and large voltage gradients. The computer program listing in appendix D was used to prepare all the reports shown in appendix C. The input data and base case load flow solution are shown in tables C-1 and C-2.

The three transaction cases shown in tables C-4, C-5, and C-6 can be summed to verify they produce the base case flows and losses shown in table C-3. Tables C-7, C-8, and C-9 are load flow solutions modeling the transactions shown in tables C-4, C-5, and C-6 respectively.

A 16 Bus Example Network

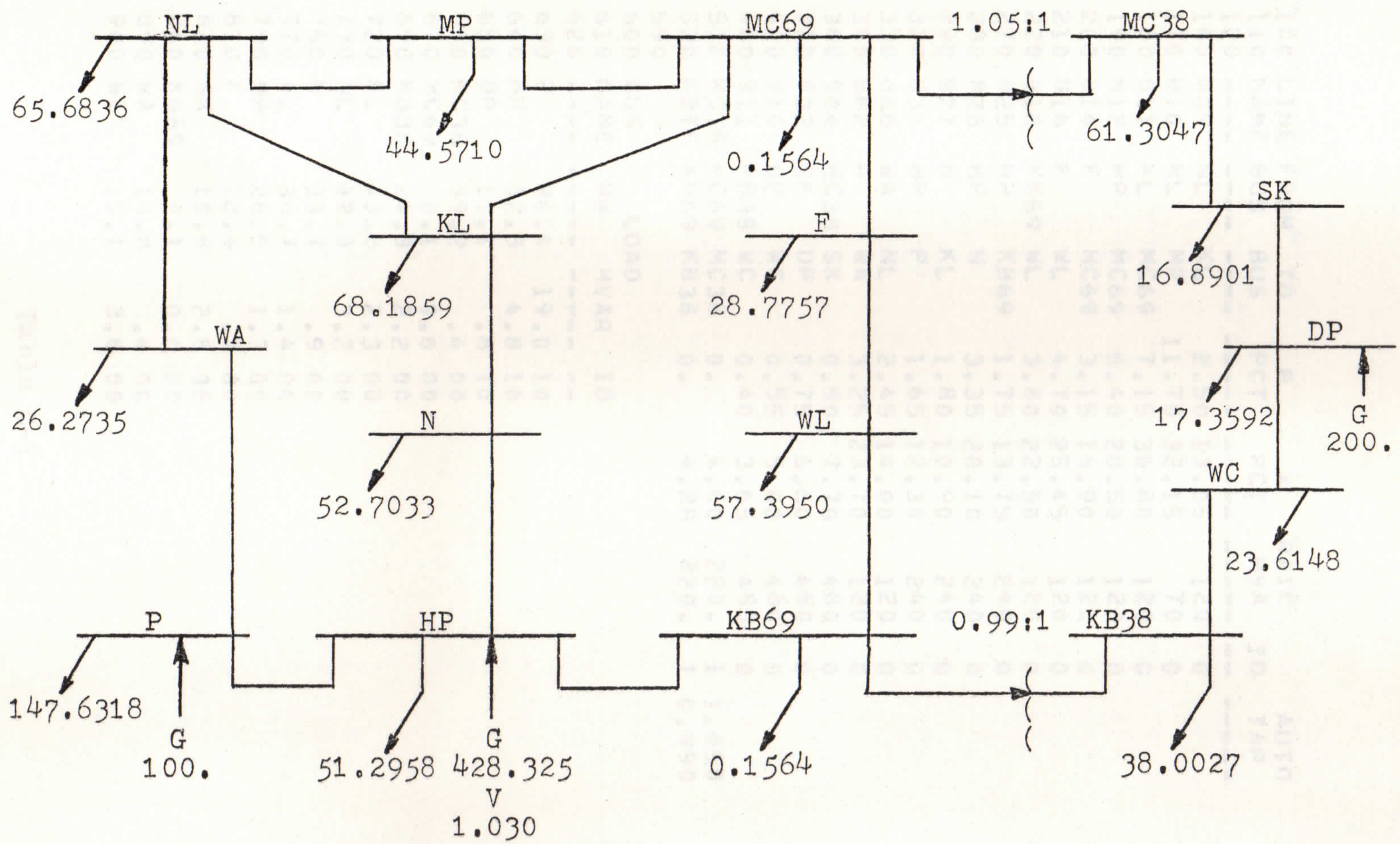


Figure C-1

Input Data for 16 Bus Example

```
100 LINE FROM  TO     R      X     RATE       AUTO
110 NAME BUS   BUS   PCT    PCT    MVA   ID   TAP
120 ---- ----  ----  -----  -----  ----  --   -----
160 809  NL    KL     2.50  13.05   120  0
170 810  NL    MP    11.70  32.15    70  0
180 811  KL    MC69   7.15  36.80   120  0
190 812  MP    MC69   5.40  28.50   120  0
200 814  F     MC69   3.15  16.90   120  0
210 816  F     WL     4.70  25.45   120  0
220 818  KB69  WL     3.80  22.50   120  0
270 825  HP    KB69   1.75  13.75   240  0
280 826  HP    N      3.35  20.10   240  0
290 827  N     KL     1.80  10.90   240  0
320 831  HP    P      1.65  12.30   240  0
330 866  WA    NL     2.45  14.00   120  0
340 862  P     WA     3.25  23.70   120  0
360 904  MC38  SK     0.90   7.70   480  0
370 902  SK    DP     0.75   6.60   480  0
400 910  DP    WC     0.55   5.00   480  0
460 911  KB38  WC     0.40   3.65   480  0
510 MCTF MC69  MC38   0.     4.60  220.  1  1.050
520 KBTF KB69  KB38   0.     4.28  220.  1  0.990
590
600 BUS       LOAD
610 NAME  MW     MVAR  ID
620 ---- -----  ----- --
630 P     94.4  19.0  10
640 HP    32.8   4.8  10
650 DP    11.1    .8  10
660 MC38  39.2    .4  00
670 MC69   0.1   0.0  00
690 KB38  24.3   2.2  00
720 KL    43.6   2.3  00
730 NL    42.0   3.2  00
750 N     33.7    .9  00
770 WL    36.7   1.4  00
790 MP    28.5   1.3  00
810 F     18.4    .7  00
820 SK    10.8   2.8  00
840 KB69   0.1   0.0  00
890 WA    16.8    .4  00
900 WC    15.1   3.6  00
```

Table C-1

Base Case Load Flow Output

COMMAND NUMBER ? 4

X--------BUS DATA--------X----------LINE FLOWS-------------X

FROM				TO	CKT	MW	MVAR	PCT	AUTO
DP	VOLT	0.921	-6.1	SK	902	140.	59.	34.	
	GEN	200.	50.	WC	910	43.	-11.	10.	
	LOAD	17.	2.						
F	VOLT	0.861	-23.0	MC69	814	-11.	-2.	11.	
	GEN	0.	0.	WL	816	-18.	0.	17.	
	LOAD	29.	2.						
HP	VOLT	1.030	0.0	KB69	825	100.	65.	48.	
	GEN	428.	225.	N	826	148.	72.	66.	
	LOAD	51.	11.	P	831	129.	76.	61.	
KB38	VOLT	0.932	-8.1	WC	911	-19.	20.	6.	
	GEN	0.	0.	KB69	KBTF	-19.	-25.	15.	
	LOAD	38.	5.						
KB69	VOLT	0.934	-7.5	WL	818	78.	21.	72.	
	GEN	0.	0.	HP	825	-98.	-47.	48.	
	LOAD	0.	0.	KB38	KBTF	19.	26.	16.	0.990
KL	VOLT	0.847	-24.4	NL	809	26.	5.	27.	
	GEN	0.	0.	MC69	811	-10.	-3.	10.	
	LOAD	68.	5.	N	827	-85.	-8.	42.	
MC38	VOLT	0.837	-19.5	SK	904	-119.	-18.	30.	
	GEN	0.	0.	MC69	MCTF	58.	18.	33.	
	LOAD	61.	1.						
MC69	VOLT	0.869	-21.7	KL	811	10.	3.	10.	
	GEN	0.	0.	MP	812	37.	10.	36.	
	LOAD	0.	0.	F	814	11.	2.	11.	
				MC38	MCTF	-58.	-15.	31.	1.050
MP	VOLT	0.823	-29.6	NL	810	-9.	1.	16.	
	GEN	0.	0.	MC69	812	-36.	-4.	36.	
	LOAD	45.	3.						
N	VOLT	0.882	-17.4	HP	826	-139.	-21.	66.	
	GEN	0.	0.	KL	827	86.	19.	42.	
	LOAD	53.	2.						

Table C-2

NL	VOLT	0.832	-27.1	KL	809	-26.	-4.	27.
	GEN	0.	0.	MP	810	9.	-1.	16.
	LOAD	66.	7.	WA	866	-49.	-2.	49.
P	VOLT	0.929	-8.8	HP	831	-126.	-50.	61.
	GEN	100.	20.	WA	862	78.	27.	74.
	LOAD	148.	43.					
SK	VOLT	0.873	-12.4	MC38	904	121.	34.	30.
	GEN	0.	0.	DP	902	-138.	-41.	34.
	LOAD	17.	6.					
WA	VOLT	0.854	-21.7	NL	866	49.	7.	49.
	GEN	0.	0.	P	862	-76.	-8.	74.
	LOAD	26.	1.					
WC	VOLT	0.925	-7.6	DP	910	-43.	12.	10.
	GEN	0.	0.	KB38	911	19.	-20.	6.
	LOAD	24.	8.					
WL	VOLT	0.871	-19.5	F	816	18.	1.	17.
	GEN	0.	0.	KB69	818	-76.	-4.	72.
	LOAD	57.	3.					

COMMAND NUMBER ? 1

END OF JOB

Table C-2 cont.

Base Case Condition

GENERATOR NAME ? ALL

SYS MW MISMATCH AND MW LOSS 2.8324830E+01 2.8324830E+01
SYS MW MISMATCH AND MW LOSS 0. 2.8324830E+01

MISMATCH AT EACH BUS

P	-0.0000
HP	-0.0188
DP	0.0000
MC38	0.0000
MC69	-0.0000
KB38	0.0000
KL	-0.0000
NL	-0.0000
N	-0.0000
WL	0.0000
MP	-0.0000
F	0.0000
SK	-0.0000
KB69	-0.0000
WA	-0.0000
WC	-0.0000

CIRCUIT FLOWS AND LOSSES

809	NL	KL	-26.2320	26.4867	0.2547
810	NL	MP	9.1098	-8.9686	0.1412
811	KL	MC69	-10.1536	10.2638	0.1102
812	MP	MC69	-35.6024	36.6265	1.0241
814	F	MC69	-10.8019	10.8532	0.0514
816	F	WL	-17.9738	18.1789	0.2051
818	KB69	WL	78.4430	-75.5739	2.8691
825	HP	KB69	100.0922	-97.7398	2.3525
826	HP	N	147.5401	-139.0289	8.5112
827	N	KL	86.3256	-84.5190	1.8066
831	HP	P	129.3966	-125.8826	3.5141
866	WA	NL	49.3980	-48.5614	0.8366
862	P	WA	78.2507	-75.6714	2.5793
904	MC38	SK	-119.2047	121.0759	1.8712
902	SK	DP	-137.9660	140.0032	2.0372
910	DP	WC	42.6375	-42.5124	0.1251
911	KB38	WC	-18.8623	18.8976	0.0353
MCTF	MC69	MC38	-57.8999	57.8999	0.0000
KBTF	KB69	KB38	19.1404	-19.1404	0.0000

Table C-3

DP Generation

GENERATOR NAME ? DP

SYS MW MISMATCH AND MW LOSS	5.3045858E+00	5.3045858E+00
SYS MW MISMATCH AND MW LOSS	-2.7463311E-01	5.0299526E+00
SYS MW MISMATCH AND MW LOSS	1.4218450E-02	5.0441711E+00
SYS MW MISMATCH AND MW LOSS	-7.3611736E-04	5.0434350E+00

MISMATCH AT EACH BUS

P	-0.0000
HP	0.0007
DP	-0.0000
MC38	-0.0000
MC69	-0.0000
KB38	-0.0000
KL	-0.0000
NL	0.0000
N	-0.0000
WL	0.0000
MP	0.0000
F	0.0000
SK	0.0000
KB69	-0.0000
WA	0.0000
WC	0.0000

CIRCUIT FLOWS AND LOSSES

809	NL	KL	-10.3721	10.4728	0.1007
810	NL	MP	-13.2671	13.0615	-0.2056
811	KL	MC69	-27.6003	27.8999	0.2996
812	MP	MC69	-25.4749	26.2077	0.7328
814	F	MC69	-6.9909	7.0241	0.0332
816	F	WL	-1.0234	1.0351	0.0117
818	KB69	WL	17.6662	-17.0201	0.6461
825	HP	KB69	-76.1454	74.3558	-1.7896
826	HP	N	17.5960	-16.5810	1.0151
827	N	KL	1.9026	-1.8628	0.0398
831	HP	P	44.2623	-43.0603	1.2021
866	WA	NL	-5.4379	5.3458	-0.0921
862	P	WA	1.9436	-1.8795	0.0641
904	MC38	SK	-78.2491	79.4774	1.2283
902	SK	DP	-84.1815	85.4245	1.2430
910	DP	WC	109.7408	-109.4188	0.3220
911	KB38	WC	-102.6496	102.8419	0.1923
MCTF	MC69	MC38	-61.1753	61.1753	0.0000
KBTF	KB69	KB38	-92.0655	92.0655	-0.0000

Table C-4

HP Generation

GENERATOR NAME ? HP

SYS MW MISMATCH AND MW LOSS	2.2174583E+01	2.2174583E+01
SYS MW MISMATCH AND MW LOSS	-1.1480398E+00	2.1026543E+01
SYS MW MISMATCH AND MW LOSS	5.9437275E-02	2.1085980E+01
SYS MW MISMATCH AND MW LOSS	-3.0770302E-03	2.1082903E+01
SYS MW MISMATCH AND MW LOSS	1.5902519E-04	2.1083062E+01

MISMATCH AT EACH BUS

P	-0.0000
HP	-0.0001
DP	0.0000
MC38	-0.0000
MC69	0.0000
KB38	0.0000
KL	-0.0000
NL	0.0000
N	-0.0000
WL	-0.0000
MP	-0.0000
F	0.0000
SK	-0.0000
KB69	-0.0000
WA	-0.0000
WC	-0.0000

CIRCUIT FLOWS AND LOSSES

809	NL	KL	-21.9265	22.1393	0.2129
810	NL	MP	15.0559	-14.8226	0.2333
811	KL	MC69	12.3150	-12.4486	-0.1337
812	MP	MC69	-11.1065	11.4260	0.3195
814	F	MC69	-1.5266	1.5339	0.0073
816	F	WL	-15.2136	15.3871	0.1736
818	KB69	WL	50.6283	-48.7765	1.8518
825	HP	KB69	147.1715	-143.7126	3.4590
826	HP	N	112.8772	-106.3656	6.5116
827	N	KL	75.7056	-74.1212	1.5844
831	HP	P	138.4162	-134.6572	3.7590
866	WA	NL	31.8806	-31.3407	0.5399
852	P	WA	48.7728	-47.1651	1.6077
904	MC38	SK	-36.2661	36.8354	0.5693
902	SK	DP	-46.6611	47.3501	0.6890
910	DP	WC	-57.4489	57.2803	-0.1685
911	KB38	WC	70.8854	-71.0182	-0.1328
MCTF	MC69	MC38	-0.6022	0.6022	0.0000
KBTF	KB69	KB38	92.9933	-92.9933	0.0000

Table C-5

P Generation

GENERATOR NAME ? P

SYS MW MISMATCH AND MW LOSS	2.3111415E+00	2.3111415E+00
SYS MW MISMATCH AND MW LOSS	-1.1965448E-01	2.1914870E+00
SYS MW MISMATCH AND MW LOSS	6.1951280E-03	2.1976821E+00
SYS MW MISMATCH AND MW LOSS	-3.2088161E-04	2.1973612E+00

MISMATCH AT EACH BUS

P	-0.0000
HP	0.0003
DP	0.0000
MC38	-0.0000
MC69	0.0000
KB38	-0.0000
KL	-0.0000
NL	0.0000
N	-0.0000
WL	-0.0000
MP	-0.0000
F	0.0000
SK	0.0000
KB69	0.0000
WA	-0.0000
WC	-0.0000

CIRCUIT FLOWS AND LOSSES

809	NL	KL	6.0675	-6.1264	-0.0589
810	NL	MP	7.3203	-7.2069	0.1134
811	KL	MC69	5.1312	-5.1869	-0.0557
812	MP	MC69	0.9795	-1.0077	-0.0282
814	F	MC69	-2.2843	2.2952	0.0109
816	F	WL	-1.7362	1.7560	0.0198
818	KB69	WL	10.1462	-9.7751	0.3711
825	HP	KB69	29.0593	-28.3763	0.6830
826	HP	N	17.0617	-16.0775	0.9842
827	N	KL	8.7139	-8.5315	0.1824
831	HP	P	-53.2883	51.8411	-1.4472
866	WA	NL	22.9538	-22.5650	0.3887
862	P	WA	27.5321	-26.6246	0.9075
904	MC38	SK	-4.6878	4.7614	0.0736
902	SK	DP	-7.1212	7.2264	0.1052
910	DP	WC	-9.6518	9.6234	-0.0283
911	KB38	WC	12.8987	-12.9228	-0.0242
MCTF	MC69	MC38	3.8776	-3.8776	0.0000
KBTF	KB69	KB38	18.2083	-18.2083	0.0000

Table C-6

Load Flow for DP Generation

GENERATOR NAME ? ALL

SYS MW MISMATCH AND MW LOSS 4.8409184E+00 4.8409184E+00
SYS MW MISMATCH AND MW LOSS 0. 4.8409184E+00

MISMATCH AT EACH BUS

P	0.0000
HP	0.0026
DP	0.0000
MC38	-0.0000
MC69	0.0000
KB38	-0.0000
KL	-0.0000
NL	0.0000
N	0.0000
WL	-0.0000
MP	0.0000
F	0.0000
SK	-0.0000
KB69	0.0000
WA	-0.0000
WC	0.0000

CIRCUIT FLOWS AND LOSSES

809	NL	KL	-11.0146	11.0491	0.0345
810	NL	MP	-13.9306	14.1583	0.2277
811	KL	MC69	-29.0859	29.6873	0.6014
812	MP	MC69	-26.8929	27.2703	0.3774
814	F	MC69	-8.1962	8.2219	0.0257
816	F	WL	-0.0254	0.0318	0.0063
818	KB69	WL	16.5280	-16.4303	0.0977
825	HP	KB69	-70.3156	71.1413	0.8257
826	HP	N	16.5983	-16.5049	0.0935
827	N	KL	1.4468	-1.4449	0.0019
831	HP	P	43.9022	-43.5206	0.3817
866	WA	NL	-6.1681	6.1784	0.0104
862	P	WA	1.3400	-1.3386	0.0014
904	MC38	SK	-82.7398	83.3774	0.6377
902	SK	DP	-88.2032	88.8046	0.6014
910	DP	WC	106.2356	-105.6747	0.5610
911	KB38	WC	-98.5719	98.9276	0.3557
MCTF	MC69	MC38	-65.2241	65.2241	0.0000
KBTF	KB69	KB38	-87.7140	87.7140	0.0000

Table C-7

Load Flow for HP Generation

GENERATOR NAME ? ALL

SYS MW MISMATCH AND MW LOSS 1.6106452E+01 1.6106452E+01
SYS MW MISMATCH AND MW LOSS 0. 1.6106452E+01

MISMATCH AT EACH BUS

P	-0.0000
HP	-0.0114
DP	0.0000
MC38	0.0000
MC69	0.0000
KB38	-0.0000
KL	0.0000
NL	0.0000
N	0.0000
WL	-0.0000
MP	-0.0000
F	0.0000
SK	-0.0000
KB69	0.0000
WA	-0.0000
WC	0.0000

CIRCUIT FLOWS AND LOSSES

809	NL	KL	-20.9314	21.0594	0.1280
810	NL	MP	15.2563	-14.9364	0.3200
811	KL	MC69	13.3369	-13.1893	0.1475
812	MP	MC69	-10.5328	10.6104	0.0777
814	F	MC69	-1.9585	1.9663	0.0079
816	F	WL	-14.4848	14.6090	0.1242
818	KB69	WL	48.4230	-47.4062	1.0169
825	HP	KB69	142.5953	-138.5895	4.0059
826	HP	N	108.6700	-104.5922	4.0778
827	N	KL	74.4761	-73.3597	1.1164
831	HP	P	135.5292	-132.3514	3.1778
866	WA	NL	32.1491	-31.8584	0.2907
862	P	WA	47.9903	-47.1625	0.8279
904	MC38	SK	-34.5081	34.6548	0.1467
902	SK	DP	-44.3062	44.5032	0.1970
910	DP	WC	-54.4227	54.6328	0.2101
911	KB38	WC	68.3613	-68.1270	0.2342
MCTF	MC69	MC38	0.5232	-0.5232	0.0000
KBTF	KB69	KB38	90.0771	-90.0771	0.0000

Table C-8

Load Flow for P Generation

```
GENERATOR NAME   ? ALL

SYS MW MISMATCH AND MW LOSS   1.2235164E+00   1.2235164E+00
SYS MW MISMATCH AND MW LOSS   0.              1.2235164E+00

MISMATCH AT EACH BUS
P       0.0000
HP      0.0002
DP     -0.0000
MC38    0.0000
MC69    0.0000
KB38   -0.0000
KL     -0.0000
NL      0.0000
N       0.0000
WL     -0.0000
MP     -0.0000
F       0.0000
SK     -0.0000
KB69    0.0000
WA     -0.0000
WC      0.0000

CIRCUIT FLOWS AND LOSSES
809   NL   KL       6.4759    -6.4660    0.0099
810   NL   MP       7.3325    -7.2702    0.0623
811   KL   MC69     5.2468    -5.2246    0.0222
812   MP   MC69     0.9029    -0.8997    0.0032
814   F    MC69    -2.9032     2.9117    0.0084
816   F    WL      -1.2076     1.2158    0.0082
818   KB69 WL       9.4523    -9.4151    0.0372
825   HP   KB69    28.9539   -28.7897    0.1642
826   HP   N       16.1458   -16.0634    0.0824
827   N    KL       8.5344    -8.5216    0.0128
831   HP   P      -51.2041    51.6168    0.4127
866   WA   NL      23.3165   -23.1918    0.1247
862   P    WA      27.2930   -27.0699    0.2231
904   MC38 SK      -5.5676     5.5787    0.0111
902   SK   DP      -7.9915     8.0053    0.0137
910   DP   WC     -10.4852    10.4982    0.0130
911   KB38 WC      13.8861   -13.8718    0.0143
MCTF  MC69 MC38     3.1903    -3.1903    0.0000
KBTF  KB69 KB38    19.3150   -19.3150    0.0000
```

Table C-9

Appendix D

Program Source Listing

```
* POWER SYSTEM LOADFLOW PROGRAM - USING ZBUS SOLUTION
*
      DIMENSION NCR(10),NML(51),NMF(51),NMT(51),NMB(36),TAP(51),
&                RAT(51),IDL(51),PL(36),IB(35),IC(35),
&                QL(36),IDBG(36),IDBT(36),JDL(51)
&       ,PF(50),P2(50),P(35)
      COMPLEX ZL(51),ZB(35,36),G(35),TF(35),LD(35),ZA(35),AS(35),
&           A(35),V(35),VO(35),ZD,S,LF,W(35,36)
      EQUIVALENCE (ZB,W)
      FILENAME DATA
      DATA IS,NCR,J,N,IBC,PT,QT,ZB,IALL
&          /11*"    ",0,1,1,0.,0.,1260*(0.,0.),"ALL "/
      ZB(1,1)=(.0002,0.)
      ML=50; MB=35
      DO 65 I=1,MB
      IB(I)=0
      G(I)=(0.,0.)
   65 TF(I)=(0.,0.)
      PRINT,"DATA FILE NAME  "
      READ,DATA
      READ(DATA,15)LN
   15 FORMAT(A1//)
      PRINT 1
    1 FORMAT(1H )
      DO 4 I=1,10
      PRINT 2
    2 FORMAT(1H+,"REMOVE CIRCUIT    ")
      READ 3,NCR(I)
    3 FORMAT(A4)
      IF(NCR(I).EQ.IS) GO TO 6
    4 CONTINUE
* READ LINE DATA BUT SKIP REMOVED CIRCUITS
    6 J=J+1
      READ(DATA,7)LN,NML(J),NMF(J),NMT(J),ZL(J),RAT(J),IDL(J),TAP(J)
      IF(TAP(J).EQ.0.) TAP(J)=1.0
      TAP(J)=1./TAP(J)
    7 FORMAT(I3,3(1X,A4),3F6.0,I3,F6.3)
* CONVERT Z TO PER UNIT ON A 1 MVA BASE
      ZL(J)=ZL(J)/10000.
      IF(NML(J).EQ.IS) GOTO 9
      IF(J.LE.ML) GOTO 8
      PRINT,"EXCESSIVE NUMBER OF CIRCUITS";STOP
    8 DO 10 I=1,10
      IF(NCR(I).NE.NML(J)) GO TO 10
      NCR(I)=IS ; J=J-1 ; GO TO 6
   10 CONTINUE
      GO TO 6
```

```
* CHECK TO SEE THAT ALL REMOVED CIRCUITS WERE REMOVED
  9 NL=J-1
    DO 11 I=1,10
    IF(NCR(I).EQ.IS) GO TO 11
    PRINT 12,NCR(I) ; STOP
 12 FORMAT(" REMOVED CIRCUIT ",A4," WAS NOT FOUND")
 11 CONTINUE
* CONTINUE REQUESTS FOR DATA
    PRINT,"SYS MW MVAR LOAD "
    READ,SYSL,SYSX
    PRINT,"SWING GENERATOR  "
    READ 3,NM
    PRINT 57
 57 FORMAT(1H+,"BUS VOLTAGE (PU) ")
    READ,VSG
    PRINT 1
    READ(DATA,15)LN
* READ BUS DATA BUT OMIT BUSES WITH NO CIRCUITS
    J=0
 17 J=J+1
    READ(DATA,13,END=14) LN,NMB(J),PL(J),QL(J),IDBG(J),IDBT(J)
 13 FORMAT(I3,1X,A4,2F6.0,1X,2I1)
    IF(J.LE.MB) GOTO 5
    PRINT,"EXCESSIVE NUMBER OF BUSES":STOP
  5 DO 16 I=1,NL
    IF(NMB(J).EQ.NMF(I)) GO TO 18
    IF(NMB(J).EQ.NMT(I)) GO TO 18
 16 CONTINUE
    J=J-1 ; GO TO 17
 18 PT=PT+PL(J)
    QT=QT+QL(J)
    IF(NM.EQ.NMB(J)) IDBG(J)=2
    IF(IDBG(J).EQ.0) GOTO 17
    IF(NM.NE.NMB(J)) GO TO 19
    IB(J)=1 : A(J)=CMPLX(VSG*5000.,0.) ; GOTO 17
 19 PRINT 20,NMB(J)
 20 FORMAT(1H+,A4," MW MVAR GEN ")
    READ,G(J) ; GOTO 17
* ADJUST LOADS, INITIALIZE A, AND READ TIE FLOW VALUES
 14 NB=J-1
    PRINT 1
    DO 30 I=1,NB
    PL(I)=PL(I)*SYSL/PT ; QL(I)=QL(I)*SYSX/QT
     LD(I)=CMPLX(PL(I),QL(I))
     IF(IDBT(I).EQ.0) GOTO 21
     PRINT 22,NMB(I)
  22 FORMAT(1H+,A4," MW MVAR TIE ")
     READ,TF(I)
  21 IF(IDBG(I).EQ.2) GOTO 30
     S=(G(I)-TF(I)-LD(I))
     A(I)=CONJG(S)
  30 CONTINUE
```

```
* NUMBER BUSES BY LOOKING FOR LINE CONNECTIONS
    DO 27 K=2,NB
    DO 23 I=1,NL
    IF(IDL(I).EQ.2)  GO TO 23
    IF(NM.EQ.NMF(I)) GO TO 24
    IF(NM.NE.NMT(I))   GO TO 23
    NM1=NMF(I) ; GO TO 26
 24 NM1=NMT(I)
 26 DO 25 J=1,NB
    IF(NM1.NE.NMB(J)) GO TO 25
    IF(IB(J).GT.0) GO TO 23
    N=N+1
    IB(J)=N
    IF(N-NB) 23,28,28
 25 CONTINUE
 23 CONTINUE
    DO 29 I=1,NB
    IF(IB(I).NE.K) GO TO 29
    NM=NMB(I) ; GO TO 27
 29 CONTINUE
    PRINT,"ISOLATED BUS(S)";STOP
 27 CONTINUE
    STOP
*CHANGE BUS NAMES TO BUS NUMBERS LISTED IN TABLE IB
 28 DO 31 I=1,NL
    DO 32 J=1,NB
    IF(NMF(I).NE.NMB(J)) GO TO 32
    NMF(I)=IB(J) ; GO TO 33
 32 CONTINUE
    GOTO 67
 33 DO 34 J=1,NB
    IF(NMT(I).NE.NMB(J)) GO TO 34
    NMT(I)=IB(J) ; GO TO 31
 34 CONTINUE
 67 PRINT 68,NML(I);STOP
 68 FORMAT(" ILLEGAL BUS NAME; CIRCUIT ",A4)
 31 CONTINUE
* MAKE THE TO BUS NUMBER GREATER IN THE LINE DATA
    DO 41 I=1,NL
    JDL(I)=NMF(I)*10+IDL(I)
    IF(NMF(I).LT.NMT(I)) GOTO 41
    J=NMF(I)
    NMF(I)=NMT(I)
    NMT(I)=J
 41 CONTINUE
* CREATE TABLE IC, THE REVERSE OF TABLE IB
    DO 50 I=1,NB
    DO 51 J=1,NB
    IF(I.NE.IB(J)) GO TO 51
    IC(I)=J ; GO TO 50
 51 CONTINUE
    STOP
 50 CONTINUE
```

```
* SEARCH THROUGH LINE TABLES SELECTING LINES FOR ZBUS
    N=2
    DO 36 NF=1,NB
    DO 35 I=1,NL
    IF(NMF(I).NE.NF) GO TO 35
    IF(IDL(I).EQ.2) GO TO 35
    NT=NMT(I) ; M=N-1
    IF(NT.LT.N) GO TO 37
* ADD BRANCHES TO  ZBUS MATRIX
    DO 38 J=1,M
    ZB(J,N)=ZB(J,NF)
 38 ZB(N,J)=ZB(J,N)
    ZB(N,N)=ZL(I)+ZB(NF,NF)
    N=N+1 ; GO TO 35
* ADD LINKS TO ZBUS MATRIX
 37 DO 39 J=1,M
 39 ZA(J)=ZB(J,NT)-ZB(J,NF)
    ZD=ZL(I)+ZA(NT)-ZA(NF)
    ZD=1./ZD
    DO 40 J=1,M
    DO 40 K=J,M
    ZB(J,K)=ZB(J,K)-ZD*ZA(J)*ZA(K)
 40 ZB(K,J)=ZB(J,K)
 35 CONTINUE
 36 CONTINUE
* ITERATE UNTIL BUS POWERS AND VOLTAGES ARE SATISFIED
 73 M=1
    DO 42 I=1,100
    DO 43 J=1,NB
    AS(J)=0.
    ZD=(0.,0.)
    DO 44 K=1,NB
 44 ZD=ZD+ZB(IB(J),IB(K))*A(K)
 43 V(J)=ZD
    IF(M.EQ.NB) GO TO 45
    ITER=I;M=1
* SUM UP SHUNT FLOWS FOR AUTO AND STORE IN AS
    DO 116 J=1,NL
    IF(TAP(J).EQ.1..OR.IDL(J).NE.1) GOTO 116
    IF(JDL(J)/10.EQ.NMF(J)) GOTO 121
    NF=IC(NMT(J));NT=IC(NMF(J));GO TO 122
121 NF=IC(NMF(J)); NT=IC(NMT(J))
122 T1=1.+TAP(J); T2=1.-TAP(J)
    AS(NF)=AS(NF)+CONJG((V(NF)*T1-V(NT))*T2/ZL(J))*V(NF)
    AS(NT)=AS(NT)+CONJG(-T2*V(NF)/ZL(J))*V(NT)
116 CONTINUE
    M=1
    DO 46 J=1,NB
    IF(IDBG(J).EQ.2) GOTO 47
    ZD=(G(J)+AS(J)-TF(J)-LD(J))
    S=ZD-V(J)*CONJG(A(J))
    D=CABS(S)
```

```
      IF(D.LT..01) M=M+1
      A(J)=.5*(A(J)+CONJG(ZD/V(J)))
      GO TO 46
   47 A(J)=CMPLX(VSG,0.)*A(J)/V(J)
   46 CONTINUE
   42 CONTINUE
      PRINT,"CASE DID NOT CONVERGE"
   45 PRINT 49,ITER
   49 FORMAT(" TOTAL ITERATIONS =",I3)
      I=IC(1)
      G(I)=V(I)*CONJG(A(I)-5000.*V(I))
      G(I)=G(I)+LD(I)+TF(I)-AS(I)
      IF(IBC.EQ.2) GOTO 60
* MODIFY TF VARIABLE FOR CONTINGENCY CASES
      IBC=2
      DO 54 I=1,NB
      IF(IDBT(I).NE.1) GOTO 54
      S=(0.,0.)
      DO 55 J=1,NL
      IF(IDL(J).NE.2) GOTO 55
      IF(NMF(J).EQ.IB(I)) GOTO 63
      IF(NMT(J).NE.IB(I)) GOTO 55
      K=IC(NMF(J)) ; GOTO 64
   63 K=IC(NMT(J))
   64 S=S+V(I)*CONJG((V(I)-V(K))/ZL(J))
   55 CONTINUE
      TF(I)=TF(I)-S
      A(I)=A(I)+CONJG(S/V(I))
   54 CONTINUE
* ADD EQUIVALENT CIRCUITS TO ORIGINAL ZBUS
      DO 56 I=1,NL
      IF(IDL(I).NE.2) GOTO 56
      NF=NMF(I)
      NT=NMT(I)
      DO 61 J=1,NB
   61 ZA(J)=ZB(J,NT)-ZB(J,NF)
      ZD=ZL(I)+ZA(NT)-ZA(NF)
      ZD=1./ZD
      DO 59 J=1,NB
      DO 59 K=J,NB
      ZB(J,K)=ZB(J,K)-ZD*ZA(J)*ZA(K)
   59 ZB(K,J)=ZB(J,K)
   56 CONTINUE
* PRINT LISTING OF DECISIONS AVAILABLE
      PRINT 1
      PRINT,"LIST OF COMMANDS:"
      PRINT," 1 = END OF JOB"
      PRINT," 2 = CONTINGENCY"
      PRINT," 3 = CKT SUMMARY"
      PRINT," 4 = FULL REPORT"
      PRINT," 5 = RUN ZIPFLOW"
```

```
      PRINT," 6 = ADJUST GENR"
      PRINT," 7 = RESTORE CKT"
      PRINT," 8 = CHANGE TAPS"
      PRINT," 9 = LOSS ASSIGN"
* DECIDE WHAT STEP IS TO BE PERFORMED NEXT
 60 PRINT 1
      PRINT,"COMMAND NUMBER     "; READ,IBR
      IF(IBR.LT.1.OR.IBR.GT.9) GOTO 60
      GOTO (69,70,71,72,48,107,109,133,207),IBR
 69 PRINT,"END OF JOB"; CALL EXIT
* PREPARE AND EXECUTE CONTINGENCY
 70 PRINT,"REMOVE CIRCUIT     "; READ 3,NM
      DO 62 I=1,NL
      IF(IDL(I).EQ.9) GOTO 62
      IF(NML(I).NE.NM) GOTO 62
      M=I ; GOTO 53
 62 CONTINUE
      PRINT,"CIRCUIT NOT FOUND"; GOTO 60
* MODIFY ZBUS BY REMOVING REQUESTED CIRCUIT
 53 DO 66 J=1,NB
 66 ZA(J)=ZB(J,NMT(M))-ZB(J,NMF(M))
      ZD=ZA(NMT(M))-ZA(NMF(M))-ZL(M)
      IF(CABS(ZD)/CABS(ZL(M)).GT..0000001) GOTO 52
      PRINT,"ILLEGAL CIRCUIT REMOVAL"; GOTO 60
 52 IDL(M)=9 ; ZD=1./ZD
      DO 58 J=1,NB
      DO 58 K=J,NB
      ZB(J,K)=ZB(J,K)-ZD*ZA(J)*ZA(K)
 58 ZB(K,J)=ZB(J,K)
      GOTO 73
* PRINT CIRCUIT SUMMARY OUTPUT
 71 PRINT,"PERCENT LIMIT     "; READ,PCL
      PRINT," CKT  PCT"
      DO 74 I=1,NL
      IF(IDL(I).EQ.2.OR.IDL(I).EQ.9) GOTO 74
      IF(JDL(I)/10.EQ.NMF(I)) GOTO 123
      J=IC(NMT(I)) ; K=IC(NMF(I))
      GOTO 124
 123 J=IC(NMF(I)); K=IC(NMT(I))
 124 S=(V(J)*TAP(I)-V(K))/ZL(I)
      IF(TAP(I).GT.1.) S=S*TAP(I)
      PCT=100.*CABS(S)/RAT(I)
      IF(PCL.GT.PCT) GOTO 74
      PRINT 75,NML(I),PCT
 75 FORMAT(2X,A4,F4.0)
 74 CONTINUE
      GOTO 60
* PRINT DETAILED OUTPUT REPORT OF BUS AND CIRCUIT VALUES
 72 PRINT,"X--------BUS DATA--------X-----------LINE FLOWS-----
    +  --------X"
      PRINT," FROM                              TO  CKT    MW   MVAR
    +  PCT  AUTO"
```

```
* ARRANGE BUS NAMES IN ALPHABETICAL ORDER
      NM1=0
      DO 76 LN=1,NB
       NM2=31000000000
      DO 136 II=1,NB
      IF(NMB(II).LE.NM1) GOTO 136
       IF(NM2.LT.NMB(II)) GOTO 136
       I=II ; NM2=NMB(I)
 136  CONTINUE
      NM1=NMB(I)
      VB=CABS(V(I)) ; N=0
      ANG=AIMAG(V(I))/REAL(V(I))
      ANG=57.29578*ATAN(ANG)
      S=TF(I)
      IF(IDBT(I).NE.1) GOTO 77
* SUM UP NET INTERCHANGE
      DO 78 J=1,NL
      IF(IDL(J).NE.2) GOTO 78
      IF(NMF(J).EQ.IB(I)) GOTO 79
      IF(NMT(J).NE.IB(I)) GOTO 78
      K=IC(NMF(J)) ; GOTO 80
 79   K=IC(NMT(J))
 80   S=S+V(I)*CONJG((V(I)-V(K))/ZL(J))
 78   CONTINUE
 77   CONTINUE
 81   DO 82 J=1,NL
      DATA="      "
      IF(IDL(J).EQ.2.OR.IDL(J).EQ.9) GOTO 82
      IF(NMF(J).EQ.IB(I)) GOTO 83
      IF(NMT(J).NE.IB(I)) GOTO 82
      K=IC(NMF(J)) ; GOTO 84
 83   K=IC(NMT(J))
 84   IF(IC(JDL(J)/10).EQ.I) GOTO 125
      ZD=(V(I)-V(K)*TAP(J))/ZL(J)
      GOTO 126
 125  ZD=TAP(J)*(V(I)*TAP(J)-V(K))/ZL(J)
      T1=1./TAP(J) ; IF(T1.EQ.1.) GOTO 126
      ENCODE(NCR,127) T1
 127  FORMAT(F6.3)
      DECODE(NCR,128) DATA
 128  FORMAT(A6)
 126  LF=V(I)*CONJG(ZD)
      PCT=100.*CABS(ZD)/RAT(J)
      N=N+1
      IF(N.EQ.1) PRINT 85,NMB(I),VB,ANG,NMB(K),NML(J),LF,PCT,DATA
      IF(N.EQ.2) PRINT 86,G(I),NMB(K),NML(J),LF,PCT,DATA
      IF(N.EQ.3) PRINT 87,LD(I),NMB(K),NML(J),LF,PCT,DATA
      IF(N.EQ.4.AND.S.NE.(0.,0.)) PRINT 88,S,NMB(K),NML(J),LF,PCT
     + ,DATA
      IF(N.EQ.4.AND.S.EQ.(0.,0.)) PRINT 89,NMB(K),NML(J),LF,PCT
     + ,DATA
      IF(N.GT.4) PRINT 89,NMB(K),NML(J),LF,PCT,DATA
 82   CONTINUE
```

```
 96 N=N+1
    IF(N.GT.4) GOTO 76
    GOTO(76,93,94,95),N
 93 PRINT 90,G(I) ; GOTO 96
 94 PRINT 91,LD(I) ; GOTO 96
 95 IF(S.NE.(0.,0.)) PRINT 92,S
 76 CONTINUE
 85 FORMAT(/2X,A4," VOLT",F6.3,F6.1,3X,A4,1X,A4,2F6.0,F4.0,A6)
 86 FORMAT(7X," GEN",2F6.0,3X,A4,1X,A4,2F6.0,F4.0,A6)
 87 FORMAT(7X,"LOAD",2F6.0,3X,A4,1X,A4,2F6.0,F4.0,A6)
 88 FORMAT(7X," TIE",2F6.0,3X,A4,1X,A4,2F6.0,F4.0,A6)
 89 FORMAT(26X,A4,1X,A4,2F6.0,F4.0,A6)
 90 FORMAT(7X," GEN",2F6.0)
 91 FORMAT(7X,"LOAD",2F6.0)
 92 FORMAT(7X," TIE",2F6.0)
    GOTO 60
*  BEGIN EXECUTION OF THE ZIPFLOW ROUTINE
 48 DO 98 I=1,NL
   IF(IDL(I).GE.2) GO TO 98
   NF=NMF(I)
   NT=NMT(I)
   DO 99 J=1,NB
 99 VO(IC(J))=ZB(J,NF)-ZB(J,NT)
   ZD=1./ZL(I)
   NF=IC(NF) ; NT=IC(NT)
   LF=CMPLX(1.,0.)-(VO(NF)-VO(NT))*ZD
   SEP=CABS(LF)
   IF(SEP.GT..001) GO TO 100
   PRINT 101,NML(I)
 101 FORMAT("0OPEN CKT ",A4," - SYSTEM SEPARATION")
   GO TO 98
 100 IF(IC(JDL(I)/10).EQ.NF) GOTO 129
     S=(V(NF)-V(NT)*TAP(I))*ZD/LF
     GOTO 130
 129 S=(V(NF)*TAP(I)-V(NT))*ZD/LF
 130 IF(TAP(I).GT.1.) S=S*TAP(I)
   DO 102 J=1,NB
 102 VO(J)=VO(J)*S
   K=0
   DO 103 J=1,NL
   NF=IC(NMF(J))
   NT=IC(NMT(J))
   IF(J.EQ.I) GO TO 103
   IF(IDL(J).GE.2) GO TO 103
   PCT=0.
   IF(RAT(J).GT.0.) PCT=100./RAT(J)
     IF(IC(JDL(I)/10).EQ.NF) GOTO 131
     S=V(NF)+VO(NF)-TAP(J)*V(NT)-VO(NT)
     GOTO 132
 131 S=TAP(J)*V(NF)+VO(NF)-V(NT)-VO(NT)
 132 IF(TAP(J).GT.1.) S=S*TAP(J)
     PCT=CABS(S/ZL(J))*PCT
```

```
    IF(PCT.LT.90.) GOTO 103
    IF(K.EQ.0) PRINT 104,NML(I)
 104 FORMAT("0OPEN CKT ",A4," - OVERLOAD CKTS")
    K=1
    PRINT 105,NML(J),PCT
 105 FORMAT(1X,A4,F6.0," PERCENT")
 103 CONTINUE
    IF(K.EQ.0) PRINT 106,NML(I)
 106 FORMAT("0OPEN CKT ",A4," - NO PROBLEMS")
 98 CONTINUE
    GO TO 60
* ADJUST INTERNAL GENERATION WHILE HOLDING NET TIE FLOW CONSTANT
 107 DO 108 I=1,NB
    IF(IDBG(I).NE.1) GOTO 108
    PRINT 20,NMB(I)
    READ,G(I)
 108 CONTINUE
    GOTO 73
* RESTORE FULL TRANSMISSION ZBUS
 109 DO 120 LN=1,NL
    IF(IDL(LN).NE.9) GOTO 120
    DO 117 KZ=1,NB
 117 ZA(KZ)=ZB(KZ,NMT(LN))-ZB(KZ,NMF(LN))
    ZD=ZA(NMT(LN))-ZA(NMF(LN))+ZL(LN)
    ZD=1./ZD
    DO 119 J=1,NB
    DO 119 K=J,NB
    ZB(J,K)=ZB(J,K)-ZD*ZA(J)*ZA(K)
 119 ZB(K,J)=ZB(J,K)
    IDL(LN)=JDL(LN)-JDL(LN)/10*10
 120 CONTINUE
    GOTO 73
* CHANGE TAP SETTINGS FOR AUTOS
 133 DO 135 I=1,NL
    IF(IDL(I).NE.1) GOTO 135
    PRINT 134,NML(I)
 134 FORMAT(1H+,"TAP FOR ",A4)
    READ,T1
    TAP(I)=1./T1
 135 CONTINUE
    GOTO 73
*
* BEGIN EXECUTION OF THE LOSSES ALGORITHEM
*
 207 NB1=NB+1
* IDENTIFY THE REFERENCE BUS IRB
    IRB=IC(1)
* STORE W IN THE 1ST REC AND ZB IN THE 2ND REC
    WRITE("WSAVE")((ZB(I,J),I=1,NB),J=1,NB)
    WRITE("WSAVE")((ZB(I,J),I=1,NB),J=1,NB)
    REWIND"WSAVE"
```

```
* STORE BASE CASE VOLTAGES IN VO
    DO 208 I=1,NB
    VO(I)=V(I)
* CLEAR THE W MATRIX
    DO 208 J=1,NB
 208 W(I,J)=0.
    DO 209 L=1,NL
* CONVERT INTERNAL FROM AND TO BUS NUMBERS TO ORIGINAL NUMBERS
* APPEARING IN ORDER OF INPUT DATA
    NF=IC(NMF(L))
    NT=IC(NMT(L))
* RESTORE ORIGINAL FROM-TO ORDER IF REVERSED
    IF(IC(JDL(L)/10).EQ.NF) GOTO 236
    NF=IC(NMT(L))
    NT=IC(NMF(L))
* CALCULATE THE BASE CASE FROM AND TO POWERS FOR EACH CIRCUIT
 236 PF(L)=VO(NF)*CONJG((VO(NF)*TAP(L)-VO(NT))/ZL(L))*TAP(L)
    P2(L)=VO(NT)*CONJG((VO(NT)-VO(NF))/ZL(L))
* ASSUME A LOSSLESS AUTOTRANSFORMER MODEL
    IF(IDL(L).EQ.1) P2(L)=-PF(L)
    ZD=PF(L)/(VO(NF)-VO(NT))
* INSERT TERMS INTO THE W MATRIX
    W(NF,NT)=W(NF,NT)-ZD
    W(NF,NF)=W(NF,NF)+ZD
    IF(IDL(L).NE.1) ZD=P2(L)/(VO(NT)-VO(NF))
    W(NT,NF)=W(NT,NF)-ZD
    W(NT,NT)=W(NT,NT)+ZD
 209 CONTINUE
* SHORT THE REG BUS TO GND
    W(IRB,IRB)=W(IRB,IRB)+1.E5
* STORE W FOR FUTURE ITERATIONS DURING CONVERGENCE
    WRITE("WSAVE") ((W(I,J),I=1,NB),J=1,NB)
 235 PRINT 245
 245 FORMAT("1GENERATOR NAME    ")
    READ 3,LGM
    J=0
    IF(LGM.EQ.IALL) GOTO 211
    IF(LGM.NE.IS) GOTO 237
* RESTORE ORIG ZB AND BASE V AND RETURN TO PROG CONTROL
    DO 234 I=1,NB
 234 V(I)=VO(I)
    READ("WSAVE")((ZB(I,J),I=1,NB),J=1,NB)
    REWIND"WSAVE"
    GOTO 60
 237 DO 210 I=1,NB
    J=I
    IF(LGM.EQ.NMB(I)) GOTO 211
 210 CONTINUE
    PRINT,"CANNOT FIND THAT GENERATOR"
    GOTO 235
 211 LGM=J
```

```
      REWIND"WSAVE"
      PLOLD=0.
  212 PLOSS=0.
* BUILD TRANSACTION POWER VECTOR
* ONLY TRANSACTIONS OF POWER FROM GENERATORS TO LOAD IS MODELED
      DO 213 I=1,NB
      IF(LGM.EQ.0) P(I)=-PL(I)+REAL(G(I))
      IF(LGM.EQ.0) GOTO 213
      P(I)=-PL(I)*(REAL(G(LGM))-PLOLD)/SYSL
  213 CONTINUE
      IF(LGM.GT.0) P(LGM)=P(LGM)+G(LGM)
      DO 214 I=1,NB
  214 W(I,NB1)=P(I)
* SOLVE W USING THE GAUSS-JORDAN TECHNIQUE
      DO 218 K=1,NB
      ZD=W(K,K)
      DO 216 J=K,NB1
  216 W(K,J)=W(K,J)/ZD
      DO 218 I=1,NB
      IF(I.EQ.K) GOTO 218
      S=W(I,K)
      DO 217 J=1,NB1
  217 W(I,J)=W(I,J)-W(K,J)*S
  218 CONTINUE
      DO 220 I=1,NB
  220 V(I)=W(I,NB1)+VO(IRB)
* CALCULATE THE PROJECTION OF CURRENT ON THE BASE CASE CURRENT
* FOR EACH CIRCUIT
      DO 221 L=1,NL
      NF=IC(NMF(L))
      NT=IC(NMT(L))
      IF(IC(JDL(L)/10).EQ.NF) GOTO 238
      NF=IC(NMT(L))
      NT=IC(NMF(L))
  238 FACT=(V(NF)-V(NT))/(VO(NF)-VO(NT))
      PLOSS=PLOSS+FACT*(PF(L)+P2(L))
      P(NF)=P(NF)-FACT*PF(L)
  221 P(NT)=P(NT)-FACT*P2(L)
      ERR=PLOSS-PLOLD
      PRINT,"SYS MW MISMATCH AND MW LOSS",ERR,PLOSS
      PLOLD=PLOSS
* RESTORE ORIGINAL W FOR NEXT ITERATION
      READ("WSAVE")((W(I,J),I=1,NB),J=1,NB)
      REWIND "WSAVE"
      IF(ABS(ERR).GE..001) GOTO 212
      PRINT," "
      PRINT,"MISMATCH AT EACH BUS"
      DO 222 I=1,NB
  222 PRINT 223,NMB(I),P(I)
  223 FORMAT(1X,A4,F10.4)
```

```
      PRINT," "
      PRINT,"CIRCUIT FLOWS AND LOSSES"
      DO 232 L=1,NL
      NF=IC(NMF(L))
      NT=IC(NMT(L))
      IF(IC(JDL(L)/10).EQ.NF) GOTO 239
      NF=IC(NMT(L))
      NT=IC(NMF(L))
  239 FACT=(V(NF)-V(NT))/(VO(NF)-VO(NT))
      FLO1=PF(L)*FACT
      FLO2=P2(L)*FACT
      PLOSS=FLO1+FLO2
  232 PRINT 233,NML(L),NMB(NF),NMB(NT),FLO1,FLO2,PLOSS
  233 FORMAT(3(1X,A4),3F10.4)
      PRINT," "
      GOTO 235
      END
```

```
      PRINT," "
      PRINT,"CIRCUIT FLOWS AND LOSSES"
      DO 232 L=1,NL
      NF=IC(NMF(L))
      NT=IC(NMT(L))
      IF(IC(JDL(L)/10).EQ.NF) GOTO 239
      NF=IC(NMT(L))
      NT=IC(NMF(L))
  239 FACT=(V(NF)-V(NT))/(VO(NF)-VO(NT))
      FLO1=PF(L)*FACT
      FLO2=P2(L)*FACT
      PLOSS=FLO1+FLO2
  232 PRINT 233,NML(L),NMB(NF),NMB(NT),FLO1,FLO2,PLOSS
  233 FORMAT(3(1X,A4),3F10.4)
      PRINT," "
      GOTO 235
      END
```

Appendix E

Wheeling Power Task Force Letters

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Vita

Eugene Gordon Preston was born in Dallas, Texas, on August 25, 1947, the son of Helen Gordon Preston and Robert Eugene Preston. After graduating from Hooks High School in 1965, he entered the University of Texas at Arlington. He received the degree of Bachelor of Science in Electrical Engineering in May, 1970. He has since been employed by the City of Austin Electric Department. In 1974 he obtained a Professional Engineer's Certificate in the State of Texas. In 1974 he entered the Graduate School of The University of Texas at Austin.

Permanent address: 4710 Fawn Run
Austin, Texas 78735

This thesis was typed by Eugene G. Preston