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Engineering Economics of Alternative Energy Sources

Khalil Denno

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To my wife

BADIA

Who lighted for me the path and stressed
the far reaching contributions of this book to humanity

PREFACE

This text book presents a comprehensive picture for the economic aspects, feasibility and adaptability as well as modelling of alternative energy sources and their interconnections. The economic analysis for each mode of energy source is preceded by the introduction of the sources basic structural components and operational as well as fuel characteristics. Coverage of alternative energy sources in this book planned to be total and complete including: low temperature and high temperature fuel cells, rechargeable storage batteries (including the lead acid, Nickel-Cadmium, lithium and the Sodium-Sulphur batteries), the Redox Flow Cells energy system in compatibility with fuel cells and storage batteries, the MHD energy system using nonfossil renewable fuels, the solar energy system using direct thermal units and photovoltiac generators, the trind energy conversion system and its economic feasibility, various modes of tidal ocean wave energy converters, the geothermal energy conversion system, and finally, the ocean thermal energy converters including off-shore installation and cold water piping system.

Following the presentation of unit and system description for those modes of alternative energy sources, incremented energy costs curve or its equivalent will be presented, followed by the core introduction of the economic coordination equation for each possible system of operation of the particular mode, and by the presentation of the economic scheduling of generation. The aspect of economic scheduling of generation will be applied on several modes of system consumption such as localized dispersed system, interconnected load centers, and a totally central system.

Results of economic feasibility as well as future directions for adaptation to the nature of cyclic load demands will be presented with futuristic conclusive and indicative economic paths.

For the purpose of energy system design, a set of precalculated metrics representing linkage energy coefficients (known as the transmission loss coefficients) and the symmetric resistance elements (setting network design in the power reference frame) have been introduced in Chapters 1 and 2. To utilize those precalculated matrices as invariant frames, appropriate multiplying factors have been derived for every mode of renewable energy system throughout this book.

This book could be adopted by the following sectors:

1. Graduate students in the field of electrical engineering, mechanical engineering physics and operations research.
2. All engineering and professional societies.
3. Electric utilities worldwide.
4. Research organization worldwide.
5. Libraries worldwide.

THE AUTHOR

Khalil Denno, Ph.D., is a Distinguished Professor of Electrical Engineering at Newark College of Engineering, New Jersey Institute of Technology in Newark, New Jersey.

Dr. Denno received his B.S. degree from University of Bagdad, Iraq in 1955. He obtained his M.E.E. degree in 1959 from Rensselaer Polytechnic Institute of Troy, New York and his Ph.D. degree in 1967 from Iowa State University in Ames, Iowa. He joined the Newark College of Engineering of New Jersey Institute of Technology as Associate Professor in 1969, was promoted to the rank of Professor in 1973, and became Distinguished Professor in September 1987.

Dr. Denno is a Fellow of the Institution of Electrical Engineers (IEE), a senior member of the Institute of Electrical and Electronics Engineers (IEEE), a member of the American Nuclear Society, a member of the New York Academy of Sciences, a member of the American Society of Engineering Education, and a member of the Sigma Xi Society.

Dr. Denno has been honored in winning the 1982 Harlan Perlis Award for Excellence in Research, as well as with numerous listings in national and international honor societies and biographies.

Dr. Denno's main specialties are in the fields of Energy Conversion, Renewable Energy Sources, and Conventional Power System and Magnetohydrodynamics. He is a licensed Professional Engineer in New Jersey and Chartered Engineer in the U.K. He is the author of a book entitled *Power System Design and Applications for Alternative Energy Sources,* published by Prentice-Hall, Englewood Cliffs, New Jersey.

Dr. Denno has published 120 research papers in leading national and international journals covering the fields of magnetohydrodynamic power generation, fusion energy, lightning phenomenon, particle accelerators, conventional energy systems, characterization of cold plasma, and various modes of renewable energy sources.

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INTRODUCTION

Scope and objectives of this book are directed uniquely to deal comprehensively with the economics of various known forms of renewable energy sources, their system of operation as well as systems interconnection and their modeling. Presentation of subject matter targeted the aspects of system design using invariant basis of design which includes elements of sources linkage coefficients as well as elements of the symmetric resistance matrix which identify system design in the power flow reference frame.

Economic evaluation of system feasibility has been based on developing its incremental energy coast curve, optimal allocation of power generation, and total relative annual cost with respect to standard developed systems of centralized mode and then dispersed mode.

Renewable energy sources presented in this book includes: fuel cells, storage batteries, the redox flow cells, bioelectrochemical cells, magnetohydrodynamic generators using nonfossil fuel, solar energy converters, wind energy converters, ocean tidal energy converters, geothermal energy converters, and ocean thermal energy converters.

Besides the system design development presented, modeling of the system itself and its interconnection to other modes of renewable energy sources have been identified in every possible economic link-up.

The author would like to stress the total uniqueness of this book subject matter and its far reaching importance to the potential users in the area of selecting any mode of renewable sources of system as well as possible linkage to any other energy system or systems.

Chapter 1

SYNTHESIS OF ENERGY SYSTEMS
(Conventional and Renewable)

I. POWER SYSTEM IDENTIFICATION IN THE POWER FLOW REFERENCE FRAME[2,3,5,12,15]

Electrical energy systems are generally represented in a conventional form in terms of data related to actual generating sources, loads, and impedances of the interconnecting network. This is the first reference frame as called by Kron.[10] On the other hand, engineers in a single power area and multiarea power poll usually deal with real power of the generating sources and real energy exchange at area boundaries.

In situations where prompt and decisive action is needed in comparing several energy systems of different configurations under a unified constraint, it becomes necessary that those systems be expressed and identified in an overall power equivalent reference frame. Also, the calculation of economic scheduling of generation, which relates the generating capacity of individual plants to total generation based on coordinating incremental production costs and incremental transmission losses, is carried in the power flow reference frame (the sixth reference as called by Kron).[10]

Optimization of energy systems from an economic standpoint can proceed on the basis of arbitrary interconnecting networks in the power flow reference frame subject to certain constraints such as minimum losses, specified total generation, specified plant capacity, and total received load.

Determination of the optimum energy system network in the sixth or power flow reference frame can be followed by a series of transformations aimed at representing the optimum system in the actual or first reference frame. To compare and analyze from the start, several power system alternatives in the actual first reference frame require excessive computer time as well as large memory capacity to absorb all the data.

The foregoing points out the necessity to develop a criterion by which power system optimization in the power flow reference frame can be carried out using the [B] matrix, power source outputs within their maximum ranges, and fuel cost data. Such a criterion was developed earlier and treated successfully on small power systems.

Based on the solution obtained for the optimum [B] matrix, coupled with data from load flow calculations, a new path for designing the power network in the sixth or power flow reference frame will be developed and tested in this chapter.

II. OBJECTIVES OF SYSTEM SYNTHESIS[1,9,10]

Given several optimum energy system configurations to be established in a single area or multiarea mode, each system follows the conditions:

1. The system contains n equivalent generating renewable energy sources such as fuel cells, solar cells, OTEC plant, etc., as well as electromechanical plants, each has its own fuel cost curve as shown in Figure 1.1.
2. Each system operates optimally according to the coordination criteria relating incremental generation costs and incremental transmission losses costs, as expressed by Equation 1.1.

$$\frac{\partial F_i}{\partial P_i} + \lambda \frac{\partial P_L}{\partial P_i} = \lambda \qquad (1.1)$$

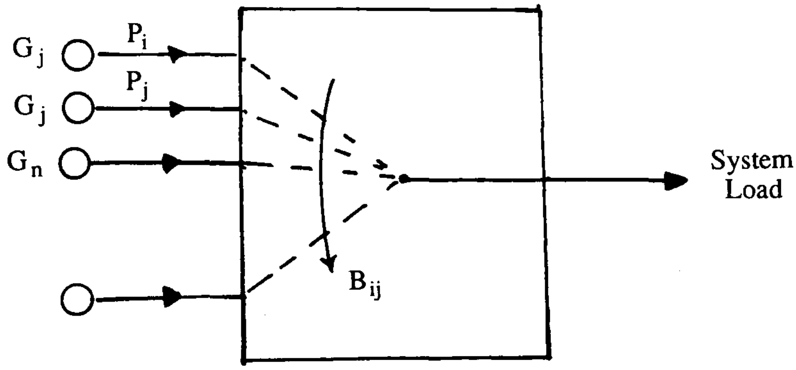

FIGURE 1.1 Power flow reference frame. (From Kron, G., Tensorial analysis of integrated transmission system, *IEEE*, 70, 1239—1246, 1951. With permission.)

where λ = incremental cost of received power in dollars per megawatt hour, known as Lagrange multiplier; P_i = capacity of plant i in megawatts (MW); and F_i = fuel cost of plant i in dollars per hour.

3. The [B] matrix for an optimum energy system[1,2,8,9] follows a solution expressed in terms of source output constrained by maximum range or capacity and fuel cost data as indicated in Equation 1.4. The latter is obtained from Equation 1.1, subject to the following constraint equations:

$$\phi\left(P_1, P_2 — P_n\right) = \sum_{i=1}^{N} P_i - P_r - P_L = 0 \tag{1.2}$$

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{M} P_i B_{ij} P_j \tag{1.3}$$

where P_L = total transmission losses in megawatts and P_r = given received power (load) in megawatts.

$$B_{ij} = \left[-F_{ii} F_{jj} P_i P_j = \lambda\left(F_{ii} - F_{ii} f_j\right) P_i + \left(\lambda F_{jj} - F_{jj} f_i\right) P_j + f_i + f_j - f_i - f_j - \lambda^2 \right]$$

$$\Big/ \left[2\lambda F_{jj} P_j^2 + 2\lambda F_{ii} P_i \left(2\lambda f_i - 2^2\right) P_i + \left(2\lambda f_j - 2\lambda^2\right) P \right] \tag{1.4}$$

4. The [B] matrix expressed above is an implicit function of all power sources as indicated in Equations 1.5 and 1.6.

$$P_j = f\left(P_i\right) \tag{1.5}$$

$$B_{ij} = g\left(P_i\right) \tag{1.6}$$

The problem centers on obtaining the optimum energy system representation in the power flow reference frame in terms of the symmetrical resistance matrix. The solution will be verified on two systems, namely:

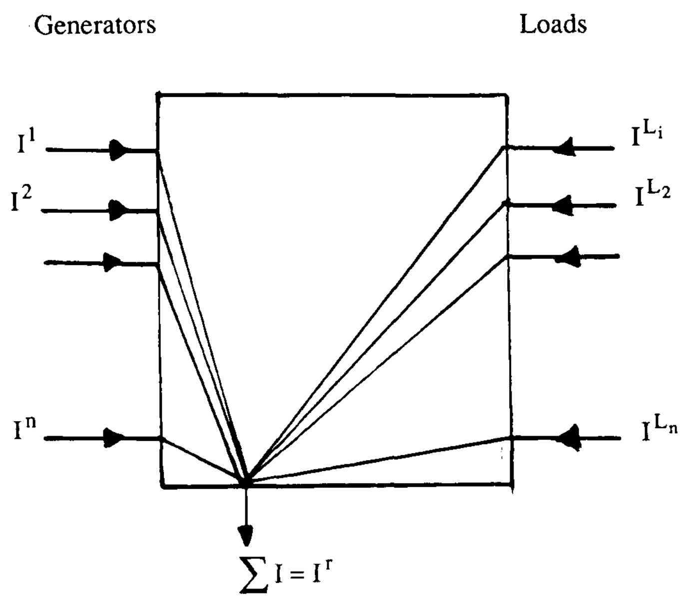

FIGURE 1.2 Measurement reference frame. (From Kron, G., Tensorial analysis of integrated transmission system, *IEEE*, 70, 1239—1246, 1951. With permission.)

1. A totally centralized system with electromechanical and electrochemical energy sources
2. A mixed dispersed-centralized system with electrochemical and electromechanical energy generating units

III. THE SIX BASIC REFERENCE FRAMES[1,8-10]

Energy system representation could be established in any of the following reference frames introduced by Kron.[10] Although the ultimate goal is the sixth frame in which the entire system is expressed in terms of power sources and power exchanges, a review of the preceding five references is presented below.

1. "Measurement" Reference Frame 1: system is expressed in terms of generating and load currents as shown in Figure 1.2
2. "Leakage" Reference Frame 2:[9] all individual load currents are replaced by a unified hypothetical load current as shown in Figure 1.3
3. "Through" Reference Frame 3:[9] the unified load current is replaced by an equivalent generator current as shown in Figure 1.4
4. "Time" Reference Frame 4: frame 3 is converted to a new time reference frame where each current possesses two components, one along its own generator terminal voltage I^D and the other at right angles to it I^Q. See Figure 1.5 where d, q, D, Q are the old and new time reference axes.
5. "Real" Power reference frame 5: derived from the new time reference frame, the real power of each generator is

$$P = I^D |E_o| \tag{1.7}$$

where I^D = generator real current in the new time reference frame and E_o = generator terminal voltage.

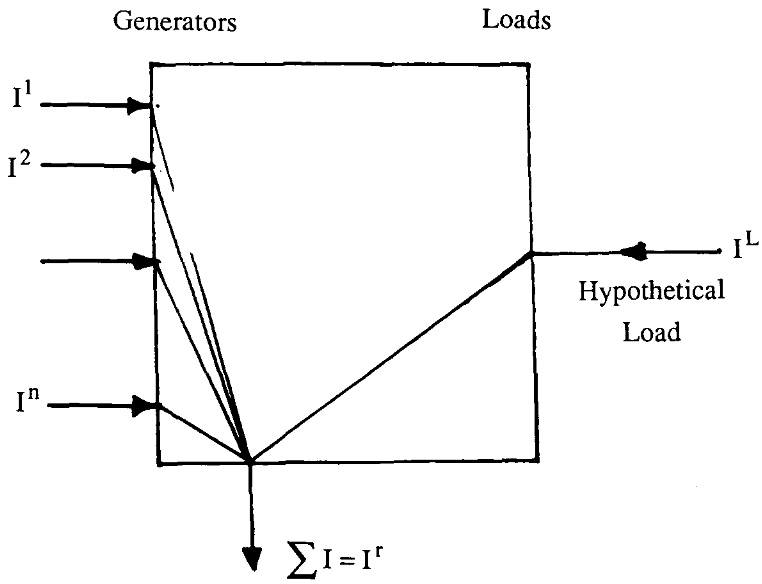

FIGURE 1.3 Leakage reference frame. (From Kron, G., Tensorial analysis of integrated transmission system, *IEEE*, 70, 1239—1246, 1951. With permission.)

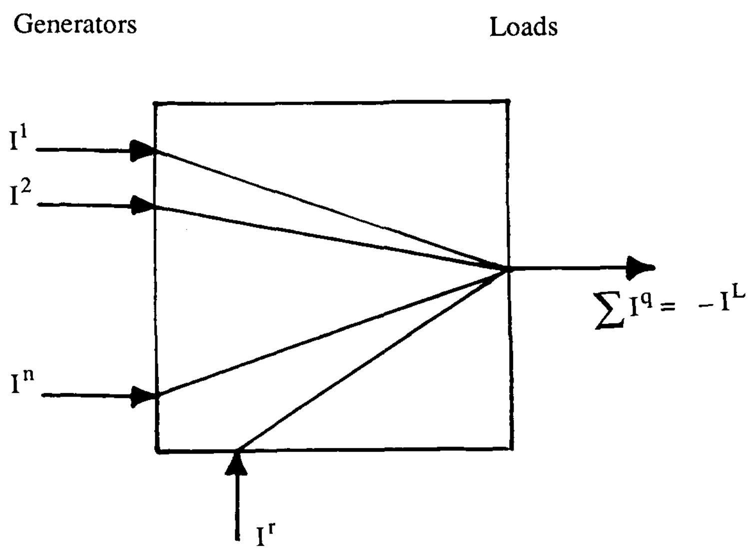

FIGURE 1.4 Through reference frame. (From Kron, G., Tensorial analysis of integrated transmission system, *IEEE*, 70, 1239—1246, 1951. With permission.)

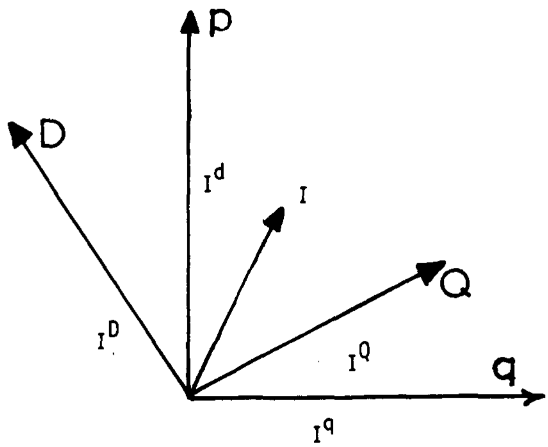

FIGURE 1.5 Time reference frame. (From Kron, G., Tensorial analysis of integrated transmission system, *IEEE*, 70, 1239—1246, 1951. With permission.)

$$\therefore I^D = \frac{1}{|E_o|} P \tag{1.8}$$

This reference frame is expressed in terms of the following diagonal matrix:

$$|C| = D\frac{1}{|E_o|} \tag{1.9}$$

6. "Power Flow" reference frame 6: all real powers are expressed in a frame involving power exchange among various equivalent generating sources as shown in Figure 1.1. The matrix of transformation to the power flow or sixth reference frame is known as the loss matrix with the following general terms:

$$B_{ij} = K_{ij}R_{ij} - H_{ij}\left(f_i - f_j\right) \tag{1.10}$$

Then the total transmission loss P_L is expressed as

$$P_L = \sum_{ij} P_i K_{ij} R_{ij} P_j - P_j H_{ij}\left(f_i - f_j\right) P_i \tag{1.11}$$

where

$$K_{ij} = \frac{1}{V_i V_j}\left(1 + S_i S_j\right)\cos\phi_{ij}\left(S_i - S_j\right)\sin\phi_{ij} \tag{1.12}$$

$$H_{ij} = \frac{1}{V_i V_j}\left(1 + S_i S_j\right)\sin\phi_{ij}\left(S_i - S_j\right)\cos\phi_{ij} \tag{1.13}$$

$$f_i = R_{Gi-Lk} l_k \tag{1.14}$$

$$f_j = R_{Gj-Lk} l_k \tag{1.15}$$

$$l_k = i_{LK} / i_L \tag{1.16}$$

and where l_k = the ratio of load current at bus k to total load current; $R_{Gi\text{-}Lk}$ = resistance between generator i and load k; $R_{Gj\text{-}Lk}$ = resistance between generator j and load k; R_{ij} = symmetric resistance in the sixth frame; $H_{ij}(f_i - f_j)$ could be neglected in a power system where ϕ_{ij} and $(S_i - S_j)$ are small, respectively. S_i = ratio of reactive to real power at bus i and ϕ_{ij} = phase angle between buses i and j, respectively. Equation 1.11 becomes:

$$P_L = \sum_i \sum_j P_i K_{ij} R_{ij} P_j \tag{1.17}$$

or

$$B_{ij} = K_{ij} R_{ij} \tag{1.18}$$

$$R_{ij} = K_{ij}^{-1}\ B_{ij} \tag{1.19}$$

IV. BASIS FOR ENERGY SYSTEM DESIGN IN THE POWER FLOW FRAME[1-15] *

The design criterion for an optimum energy system of an arbitrary interconnecting network subject to the constraints of minimum transmission losses, specified total received load, and specified plant capacity, is one of the objectives of this paper. Such a criterion is based on the calculation of the symmetrical resistance matrix in the power flow reference frame.

Also a knowledge of the resistance matrices of more than one interconnecting network could serve as the basis for identifying the nature and type of the power system, i.e., whether it be a centralized system, a dispersed system, or a mixed centralized-dispersed system as far as the locations of the power generating sources are concerned.

The solution of the [B] matrix in terms of energy generating sources within their capacity and fuel cost data was obtained and restated in equation 1.4 with the [K] matrix given in Equation 1.12.

Equation 1.18 can be expanded in matrix form and written as follows:

$$\begin{bmatrix} B_{11} & B_{12} & \cdots & B_{1n} \\ B_{21} & B_{22} & \cdots & B_{2n} \\ \vdots & & & \vdots \\ B_{n1} & B_{n2} & \cdots & B_{nn} \end{bmatrix} = \begin{bmatrix} (K_{11}R_{11}) & (K_{12}R_{12}) & \cdots & (K_{1n}R_{1n}) \\ (K_{21}R_{21}) & (K_{22}R_{22}) & \cdots & (K_{2n}R_{2n}) \\ \vdots & & & \vdots \\ (K_{n1}R_{n1}) & (K_{n2}R_{n2}) & \cdots & (K_{nn}R_{nn}) \end{bmatrix} \tag{1.20}$$

Therefore,

$$R_{11} = \frac{B_{11}}{K_{11}}$$

$$R_{12} = \frac{B_{12}}{B_{12}} \qquad \text{and so on}$$

$$R_{nn} = \frac{B_{nn}}{K_{nn}} \tag{1.21}$$

V. USING THE DIAGONAL [R] MATRICES IN COMPARISON OF ENERGY SYSTEM ALTERNATIVES[1-4,11] *

The overall [R] matrix can be expressed as below:

$$[R]=\begin{bmatrix} B_{11}/K_{11} & \cdots & B_{1n}/K_{1n} \\ B_{21}/K_{21} & \cdots & B_{2n}/K_{2n} \\ \vdots & & \vdots \\ B_{1n}/K_{1n} & & B_{nn}/K_{nn} \end{bmatrix} \tag{1.22}$$

The elements in the matrix of Equation 1.22 are the self-symmetrical resistances of the individual energy sources from a reference point and mutual symmetrical resistances among the individual sources, all represented in the energy flow frame. R_{11}, R_{22} — R_{nn} = the self-symmetrical resistances of energy source number 1 with respect to a reference point. R_{12}, R_{13} — R_{1n} = the mutual symmetrical resistances between source number 1 with respect to power source number 2.

Calculation of the [R] matrix elements requires the following procedure:

1. Load flow calculations to secure information for the [K] matrix, namely, voltage magnitude, phase angle, and real and reactive power of each bus-bar.
2. Complete establishment of the [B] matrices under all loadings for the presumed energy system.
3. Application of Equation 1.22 together with the procedure of calculating the [R] symmetric matrix which reflects an optimum energy system design in the energy flow reference frame and which was demonstrated for the two systems in the following section.

VI. CASE STUDY 1[1-15]

A. A centralized system of 32 equivalent power energy bus-bars with total peak received load of 23,000 MW.
B. A dispersed-centralized system of 123 equivalent bus-bars having the same total peak received load of 23,000 MW.

For the above two presumed systems, load flow calculations were carried on all loadings based on the Gauss-Seidel method on a program developed by the Public Service Electric and Gas Company (PSE&G) of New Jersey.

Also the [B] matrices for all loadings were obtained for the above mentioned two systems according to Equation 1.4.

By compiling elements from the [K] matrices with those of the [B] matrices for the two systems, elements of the [R] matrices are obtained by a simple computer program according to Equation 1.22, run on the RCA 70 machine, the capacity of which was quite adequate even for the large number of 123 bus-bars.

However, since the number of bus-bars in the centralized-dispersed system is 123, compared to 32 to the centralized system, a unified basis for comparison is obtained from extracting the diagonal elements from the full matrix and forming a new diagonal matrix.

As explained earlier, the elements of the new diagonal matrix have a great significance since they represent the symmetrical resistance of each energy source with respect to the system centroid or reference point, and hence can serve as a justified basis for comparing more than one optimum power network in the sixth reference frame.

A. LOAD FLOW CALCULATIONS[1-15]

Basic systematic procedure for the load flow calculations involves these steps:

1. Designating the slack or swing bus which is characterized as a large generating bus with a relatively high moment of inertia. For the swing bus, selected values for the voltage magnitude and phase angle are assumed, leaving real and reactive powers variables. Voltage controlled buses will have fixed voltage magnitude and real power while load buses will be assigned constant real and reactive powers.
2. Assignment of fixed tolerance and accelerating factors to insure rapid convergence of any change in voltage magnitude. Typical values for tolerance and accelerating factors are 0.001 and 1.6, respectively.
3. Through iteration technique, a set of voltage magnitudes and phase angles for voltage controlled buses and load buses are secured, according to the following equation. The process is repeated until the limit of tolerance is met.

$$E_p(\text{modified}) = \frac{1}{Y_{pp}}\left(\frac{P_p - jQ_p}{E_{p-\text{old}}} - \sum_{\substack{q=1 \\ P=q}}^{n} Y_{pq}E_q\right) \qquad (1.23)$$

   where E_p (modified) = the modified value for bus voltage; E_p^* (old) = the conjugate value for old bus voltage; Y_{pp} = the self bus admittance for bus p; P_p-jQ_p = the power at bus p; and $Y_{pq}E_q$ = the line admittance and bus voltage.
4. The bus phase angle is calculated according to the following equation:

$$\delta = \frac{\text{Im}\left(E_p\right)}{\text{Real}\left(E_p\right)} \qquad (1.24)$$

   where E_p = the bus voltage obtained earlier; and δ_p = the phase angle of bus p voltage where slack bus phase angle is the reference.
5. The reactive power for each bus is calculated as:

$$Q_p = -\,\text{Im}\left[Y_{pq}V_p + \sum_{\substack{q=1 \\ P=q}}^{n} V_{pq}V_qV_p^*\right] \qquad (1.25)$$

   where Q_p = the reactive power at bus p; V_p = the bus voltage; V_p^* = the conjugate of bus voltage; V_{pq} = the line voltage; Y_{pp} = the bus admittance and bus p; and Y_{pq} = the line admittance for line pq.
6. The bus current can be calculated from:

$$I_p = \frac{P_p - jQ_p}{E_q^*} \qquad (1.26)$$

   where I_p = the current at bus p; P_p - jQ_p = the power at bus p; E_p^* = the conjugate value of voltage at bus P; $P_p = jQ_p$ = the power at bus p; and Y_{pq}, E_q = the line admittance and bus voltage.

7. The transmission line loss can be calculated as:

$$P + jQ = \sum_{\substack{p=1 \\ p=q}}^{n} \sum_{\substack{q=1 \\ q=p}}^{n} \frac{I_{pq}^2}{Y_{pq}} \tag{1.27}$$

where P + jQ = the real and reactive power of line; I_{pq} = the line current for line p_q; and Y_{pq} = the line admittance for line p_q.

8. The line current can be calculated as:

$$I_{pq} = \left(E_p - E_q\right)Y_{pq} \tag{1.28}$$

where I_{pq} = the line current for line p_q; E_p, E_q = the bus voltage for bus p and q; and Y_{pq} = the line admittance for line p_q.

Load flow calculations were carried out using Gauss-Seidel method that is being used by most utility companies including PSE&G of New Jersey whose power grid system is used in this example. Also, we have to mention that Gauss-Seidel method is somehow preferred over Newton Raphson method, because it is characterized with fewer operations to complete any iteration process.

Handling capability of PSE&G load flow calculations program is basically Fortran IV. This Fortran IV computer program is written in the SAP language for the IBM-704 by the American Electric Power Corporation. The general features of the load flow program is described as follows.

This program can handle network assembly limit of 800 buses and 1200 lines. Within the 800 buses, all of the buses are either static capacitors or shunt reactors, and up to 300 buses can have voltage regulation. With a total of 1200 lines, up to 300 lines can be transformers with either the fixed taps or the tap changing under the load condition.

All input data will be reprinted as part of the final results. The load flow output also includes important summaries, such as the Area Power Interchange Summary which gives the actual iteration count of the solution, the tolerances and the acceleration factors, the total load and loss, the line charging, the generation, and the mismatch, all in megawatt (MW) and megavar (Mvar) units. Other summaries are the Tap-changing Summary, the Generator Summary, the Line over Load Summary, and the Summary of High and Low Voltage (above 1.05 per unit and below 0.95 per unit).

Load flow information secured by using the program of PSE&G of New Jersey conducted with respect to a peak load of around 23,000 MW on a PSE&G power grid system increasing over several stages by about 10,000 MW. Two modes of systems are considered in the calculation, one remaining centralized and the other is centralized-dispersed whereby the new additional generator bus-bars taking the bulk of the 10,000 MW increase to be supplied by on site assembly of fuel-cells electrochemical generators.

Description of generation expansion on a centralized mode is shown in Table 1.1.

Results of load flow calculations have been obtained for several levels of loadings from 60 to 100%. Shown in Tables 1.2 and 1.3 are those for centralized system, while Tables 1.4 and 1.5 are for mixed centralized-dispersed systems.

B. CALCULATION OF THE [B] MATRIX[1-15]

Elements of the transmission loss coefficient matrix under several levels of loadings were

TABLE 1.1
Generation Expansion Program

Year	Bus no.	Capacity (MW)	Type	Generation cost ($/kW)	Transmission cost ($/kW)
ΔG_1	450	533	N	250	65
	343	200	GT	100	10
	359	200	GT	100	10
	301	40	F4	160	30
	711	22	GT	100	10
	182	216	GT	100	10
	157	190	GT	100	10
ΔG_2	450	532	N	250	65
	391	200	GT	100	10
	285	270	F	160	20
	427	545	N	250	65
	693	60	F	180	10
	687	160	F	180	20
	157	126	F	180	20
ΔG_3	427	558	N	250	65
	391	400	F	160	30
	391	400	F	160	30
ΔG_4	183	400	F	160	20
ΔG_5	435	400	GT	100	10
	439	100	GT	100	10
ΔG_6	430	1100	N	300	20
	439	100	GT	100	10
	439	400	F	160	20
	195	1190	N	300	50
ΔG_7	430	1100	N	300	20
ΔG_8	438	1100	N	330	65
	439	400	F	160	20
ΔG_9	438	1100	N	330	65
	197	1200	N	300	40
	198	1300	PH		

Note: N = nuclear powerplant; GT = gas-turbine powerplant; F = steam-fossil powerplant; and PH = pumped-hydro powerplant.

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TABLE 1.2
New Off-Nominal Setting(s) for TCUL Transformers (70%)

Bus no. from	Bus no. to	PBI	Transformer tap
2	295	0	0.912000
179	180	0	0.975000
283	282	0	0.975000
286	288	0	0.944000
287	288	0	0.937000
298	299	0	0.975000
304	305	0	1.025000
309	336	0	1.019000
327	332	0	1.019000
328	332	0	1.006000
339	365	0	0.925000
378	426	0	0.981000
385	386	0	0.937000
390	391	0	1.019000
416	425	0	0.956000
701	702	0	1.025000

Note: Load flow calculations 70% loading for centralized system.

Table of Generator Data Sorted by Node Number

Node no.	Name	Generator voltage	Generator angle	Generator P (MW)	Generator Q (Mvar)
1	G001	1.0000	0.0000	427.8999	–461.3999
150	G150	1.0340	–1.7000	560.0000	0.0000
156	G156	1.0200	–18.5000	59.0000	38.7000
157	G157	1.0300	–3.4000	126.0000	0.5000
161	G161	1.0270	–5.6000	0.0000	0.0000
164	G164	1.0300	–5.7000	330.0000	–11.1000
172	G172	1.0300	4.5000	623.0000	2.0000
174	G174	1.0300	–3.7000	342.0000	–32.3000
182	G182	1.0350	–2.9000	0.0000	0.0000
183	G183	1.0360	–2.6000	335.0000	–300.0000
285	G285	1.0300	–6.8000	270.0000	–37.2000
291	G291	1.0300	–7.7000	580.0000	168.3000
301	G301	1.0000	–11.9000	40.0000	59.0000
315	G315	1.0080	–6.5000	0.0000	0.0000
316	G316	1.0090	–6.6000	0.0000	0.0000
327	G327	1.0290	–8.0000	27.0000	100.0000
332	G332	1.0140	–7.0000	0.0000	0.0000
336	G336	0.9820	–8.5000	0.0000	0.0000
339	G339	1.0160	–5.7000	976.0000	400.0000
343	G343	1.0340	–7.6000	0.0000	0.0000
357	G357	1.0130	–6.3000	535.0000	300.0000
359	G359	1.0320	–5.3000	0.0000	0.0000
365	G365	1.0360	–7.4000	61.0000	–80.0000
371	G371	1.0300	–2.4000	638.0000	128.2000
372	G372	1.0050	–6.2000	0.0000	0.0000
390	G390	1.0300	–5.8000	454.0000	181.0000
391	G391	1.0350	–4.1000	670.0000	320.0000
427	G427	1.0300	2.1000	1103.0000	31.0000
450	G450	1.0300	4.2000	1065.0000	–153.7000
685	G685	1.0000	–46.1000	131.0000	169.1000
687	G687	1.0000	–53.5000	160.0000	207.9000
693	G693	0.9540	–52.4000	0.0000	0.0000

TABLE 1.2 (continued)
Table of Load Data Sorted by Node Number

Node no.	Name	Load bus voltage	Load bus angle	Load P (MW)	Load Q (Mvar)	Sync. cond. Q (Mvar)
1	L001	1.0000	0.0000	0.0000	0.0000	0.000
2	L002	1.0110	–2.9000	0.0000	0.0000	0.000
16	L016	1.0220	–0.7000	0.0000	0.0000	0.000
96	L096	1.0170	–18.6000	0.0000	0.0000	0.000
125	L125	1.0080	–18.8000	0.0000	0.0000	0.000
126	L126	1.0290	–6.2000	0.0000	0.0000	0.000
150	L150	1.0340	–1.7000	163.0000	4.1000	0.000
151	L151	1.0040	–18.8000	22.4000	2.7000	0.000
152	L152	1.0030	–17.5000	14.3000	1.1000	0.000
153	L153	1.0120	–3.6000	47.0000	–8.1000	0.000
155	L155	1.0360	–2.6000	91.0000	13.8000	0.000
156	L156	1.0200	–18.5000	48.0000	7.6000	0.000
157	L157	1.0300	–3.4000	0.0000	0.0000	0.000
158	L158	1.0240	–7.1000	84.0000	12.9000	0.000
160	L160	1.0120	–18.1000	2.1000	0.4000	0.000
161	L161	1.0270	–5.6000	71.0000	3.5000	0.000
162	L162	1.0240	–8.5000	87.5000	15.0000	0.000
164	L164	1.0300	–5.7000	14.5000	–1.2000	0.000
167	L167	1.0260	–0.8000	12.4000	14.5000	0.000
168	L168	1.0260	1.9000	134.0000	18.6000	0.000
170	L170	1.0200	–9.2000	143.0000	33.2000	0.000
171	L171	1.0070	–18.9000	17.0000	11.8000	0.000
172	L172	1.0300	4.5000	26.0000	–2.7000	0.000
174	L174	1.0300	–3.7000	273.0000	48.1000	0.000
175	L175	1.0230	–7.9000	157.0000	35.6000	0.000
177	L177	0.9990	–16.6000	46.1000	2.0000	0.000
178	L178	1.0240	–8.5000	36.9000	1.9000	0.000
179	L179	1.0000	–11.1000	0.0000	0.0000	0.000
180	L180	1.0240	–8.6000	169.0000	44.5000	0.000
181	L181	1.0320	–3.3000	21.0000	12.6000	0.000
182	L182	1.0350	–2.9000	0.0000	0.0000	0.000
183	L183	1.0360	–2.6000	0.0000	0.0000	0.000
184	L184	1.0370	–2.5000	83.5000	4.8000	0.000
185	L185	1.0370	–2.4000	104.0000	32.2000	0.000
186	L186	1.0340	–1.9000	52.2000	8.4000	0.000
187	L187	1.0240	–3.3000	64.4000	7.4000	0.000
188	L188	1.0260	–7.4000	36.2000	–4.1000	0.000
189	L189	1.0270	–7.6000	36.6000	–1.5000	0.000
190	L190	1.0430	–4.3000	43.3000	9.1000	0.000
191	L191	1.0250	–8.4000	14.8000	3.3000	0.000
192	L192	0.9980	–17.5000	18.0000	4.6000	0.000
202	L202	1.0300	–5.7000	0.0000	0.0000	0.000
227	L227	1.0150	–1.3000	0.0000	0.0000	0.000
231	L231	1.0150	–7.0000	0.0000	0.0000	0.000
280	L280	1.0210	–5.0000	37.1000	11.8000	0.000
281	L281	1.0170	–6.8000	159.0000	26.3000	0.000
282	L282	1.0180	–9.5000	62.3000	23.1000	0.000
283	L283	1.0000	–10.7000	149.0000	51.5000	0.000
285	L285	1.0300	–6.8000	106.0000	42.0000	0.000
286	L286	1.0030	–6.9000	63.6000	59.0000	0.000
287	L287	1.0020	–6.3000	63.6000	59.0000	0.000
288	L288	1.0370	–5.6000	0.0000	0.0000	0.000
289	L289	0.9830	–8.2000	40.5000	7.4000	0.000
290	L290	1.0100	–9.7000	117.0000	90.3000	0.000
291	L291	1.0300	–7.7000	229.0000	74.2000	0.000

TABLE 1.2 (continued)
Table of Load Data Sorted by Node Number

Node no.	Name	Load bus voltage	Load bus angle	Load P (MW)	Load Q (Mvar)	Sync. cond. Q (Mvar)
295	L295	1.0580	–4.6000	0.0000	0.0000	0.000
296	L296	1.0320	–5.8000	154.0000	76.3000	0.000
297	L297	1.0280	–5.6000	0.0000	0.0000	0.000
298	L298	0.9990	–5.9000	0.0000	0.0000	0.000
299	L299	1.0060	–5.0000	178.5000	147.0000	0.000
301	L301	1.0000	–11.9000	115.0000	43.0000	0.000
303	L303	0.9890	–7.4000	0.0000	0.0000	0.000
304	L304	0.9970	–12.5000	170.0000	20.8000	0.000
305	L305	0.9810	–9.0000	0.0000	0.0000	0.000
306	L306	1.0200	–9.4000	125.0000	51.8000	0.000
308	L308	0.9960	–5.7000	0.0000	0.0000	0.000
309	L309	0.9970	–12.6000	93.8000	18.6000	0.000
311	L311	1.0070	–7.7000	0.0000	0.0000	0.000
312	L312	0.9820	–8.3000	33.6000	4.1000	0.000
313	L313	1.0030	–7.5000	72.8000	24.3000	0.000
314	L314	1.0020	–10.6000	145.0000	42.0000	0.000
315	L315	1.0080	–6.5000	0.0000	0.0000	0.000
316	L316	1.0090	–6.6000	0.0000	0.0000	0.000
327	L327	1.0290	–8.0000	102.0000	42.0000	0.000
328	L328	0.9980	–9.3000	227.0000	103.8000	0.000
332	L332	1.0140	–7.0000	0.0000	0.0000	0.000
333	L333	1.0010	–11.0000	237.0000	60.2000	0.000
334	L334	1.0020	–9.4000	49.0000	6.2000	0.000
336	L336	0.9820	–8.5000	180.0000	26.5000	0.000
337	L337	1.0230	–8.7000	37.8000	10.5000	0.000
339	L339	1.0160	–5.7000	0.0000	0.0000	0.000
340	L340	1.0310	–7.7000	86.8000	35.7000	0.000
343	L343	1.0340	–7.6000	29.0000	0.0000	0.000
345	L345	1.0250	–3.1000	76.3000	12.9000	0.000
347	L347	1.0180	–6.4000	95.2000	35.4000	0.000
349	L349	1.0030	–8.4000	40.5000	14.0000	0.000
351	L351	1.0250	–3.9000	139.0000	34.6000	0.000
352	L352	1.0290	–7.7000	40.0000	30.8000	0.000
353	L353	1.0200	–7.9000	115.0000	27.2000	0.000
354	L354	0.9960	–12.7000	124.0000	21.6000	0.000
357	L357	1.0130	–6.3000	185.0000	114.0000	0.000
359	L359	1.0320	–5.3000	0.0000	0.0000	0.000
360	L360	1.0280	–5.4000	39.2000	15.1000	0.000
362	L362	0.9990	–5.3000	25.2000	2.7000	0.000
365	L365	1.0360	–7.4000	272.0000	93.0000	0.000
366	L366	0.9960	–5.6000	85.4000	15.7000	0.000
368	L368	1.0090	–6.6000	39.2000	13.9000	0.000
371	L371	1.0300	–2.4000	0.0000	0.0000	0.000
372	L372	1.0050	–6.2000	0.0000	0.0000	0.000
373	L373	1.0130	–6.6000	145.5000	70.7000	0.000
375	L375	1.0330	–4.7000	19.6000	6.9000	0.000
376	L376	1.0280	–5.0000	19.6000	6.9000	0.000
377	L377	1.0070	–8.0000	65.8000	23.4000	0.000
378	L378	0.9960	–4.5000	0.0000	0.0000	0.000
379	L379	1.0200	–8.3000	44.1000	17.5000	0.000
380	L380	1.0040	–7.9000	149.0000	80.5000	0.000
381	L381	1.0230	–6.7000	38.5000	13.8000	0.000
382	L382	1.0320	–4.3000	0.0000	0.0000	0.000
383	L383	1.0050	–6.5000	37.8000	4.4000	0.000
385	L385	1.0020	–8.4000	0.0000	0.0000	0.000

TABLE 1.2 (continued)
Table of Load Data Sorted by Node Number

Node no.	Name	Load bus voltage	Load bus angle	Load P (MW)	Load Q (Mvar)	Sync. cond. Q (Mvar)
386	L386	1.0230	–8.8000	0.0000	0.0000	0.000
388	L388	1.0060	–10.6000	0.0000	0.0000	0.000
389	L389	1.0180	–9.5000	98.0000	28.6000	0.000
390	L390	1.0300	–5.8000	228.0000	50.0000	0.000
391	L391	1.0350	–4.1000	0.0000	0.0000	0.000
401	L401	1.0380	–5.5000	33.6000	10.8000	0.000
402	L402	1.0140	–7.3000	42.6000	14.7000	0.000
403	L403	1.0080	–6.3000	163.0000	52.4000	0.000
404	L404	1.0040	–8.3000	157.0000	33.6000	0.000
405	L405	1.0260	–8.7000	150.0000	2.1000	0.000
406	L406	1.0170	–8.6000	129.0000	41.4000	0.000
409	L409	0.9970	–5.8000	0.0000	0.0000	0.000
410	L410	1.0140	–7.2000	38.5000	18.4000	0.000
411	L411	1.0140	–7.3000	13.3000	2.1000	0.000
412	L412	1.0210	–9.3000	15.4000	2.8000	0.000
413	L413	1.0250	–8.9000	32.2000	9.8000	0.000
414	L414	1.0150	–8.5000	46.9000	15.0000	0.000
415	L415	1.0100	–9.6000	46.9000	15.0000	0.000
416	L416	1.0020	–4.4000	0.0000	0.0000	0.000
417	L417	1.0120	–4.4000	25.9000	7.2000	0.000
418	L418	1.0280	–4.6000	34.3000	13.8000	0.000
419	L419	1.0250	–6.7000	10.5000	3.9000	0.000
420	L420	1.0300	–5.0000	4.9000	1.0000	0.000
421	L421	1.0320	–4.5000	4.9000	1.0000	0.000
422	L422	1.0120	–6.3000	44.0000	12.8000	0.000
423	L423	1.0240	–6.1000	28.7000	9.2000	0.000
424	L424	1.0010	–10.7000	23.8000	3.4000	0.000
425	L425	1.0270	–3.2000	0.0000	0.0000	0.000
426	L426	1.0260	–1.2000	0.0000	0.0000	0.000
427	L427	1.0300	2.1000	0.0000	0.0000	0.000
428	L428	1.0300	2.4000	0.0000	0.0000	0.000
429	L429	0.9940	–5.5000	0.0000	0.0000	0.000
446	L446	0.9980	–5.9000	0.0000	0.0000	0.000
450	L450	1.0300	4.2000	0.0000	0.0000	0.000
501	L501	0.9820	–8.8000	0.0000	0.0000	0.000
518	L518	1.0040	–6.1000	0.0000	0.0000	0.000
683	L683	0.9860	–55.0000	101.0000	9.1000	0.000
685	L685	1.0000	–46.1000	173.0000	16.1000	0.000
687	L687	1.0000	–53.5000	51.8000	4.2000	0.000
690	L690	0.9460	–30.6000	0.0000	0.0000	0.000
693	L693	0.9540	–52.4000	197.0000	18.4000	0.000
695	L695	0.9840	–7.7000	70.4000	6.3000	0.000
698	L698	0.9740	–52.9000	0.0000	0.0000	0.000
701	L701	0.9960	–15.8000	0.0000	0.0000	0.000
702	L702	0.9800	–8.4000	136.5000	11.9000	0.000
711	L711	0.9410	–56.9000	168.0000	14.7000	0.000
717	L717	0.9960	–5.1000	0.0000	0.0000	0.000
926	L926	1.0260	–5.6000	0.0000	0.0000	0.000
929	L929	1.0320	–5.3000	0.0000	0.0000	0.000
946	L946	1.0240	–5.7000	0.0000	0.0000	0.000

TABLE 1.2 (continued)
Table of Generator Reactive Components and Reactive Characteristics

Node no.	Name	Generator reactive component	Generator reactive Char. - S
1	G001	0.0000	−1.0783
150	G150	0.0000	0.0000
156	G156	0.0000	0.6559
157	G157	0.0000	0.0040
161	G161	0.0000	0.0000
164	G164	0.0000	−0.0336
172	G172	0.0000	0.0032
174	G174	0.0000	−0.0944
182	G182	0.0000	0.0000
183	G183	0.0000	−0.8955
285	G285	0.0000	−0.1378
291	G291	0.0000	0.2902
301	G301	0.0000	1.4750
315	G315	0.0000	0.0000
316	G316	0.0000	0.0000
327	G327	0.0000	3.7037
332	G332	0.0000	0.0000
336	G336	0.0000	0.0000
339	G339	0.0000	0.4098
343	G343	0.0000	0.0000
357	G357	0.0000	0.5607
359	G359	0.0000	0.0000
365	G365	0.0000	−1.3115
371	G371	0.0000	0.2009
372	G372	0.0000	0.0000
390	G390	0.0000	0.3987
391	G391	0.0000	0.4776
427	G427	0.0000	0.0281
450	G450	0.0000	−0.1443
685	G685	0.0000	1.2908
687	G687	0.0000	1.2994
693	G693	0.0000	0.0000

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TABLE 1.3
New Off-Nominal Setting(s) for TCUL Transformers (100%)

Bus no. from	Bus no. to	PBI	Transformer tap
2	295	0	0.925000
179	180	0	0.994000
283	282	0	1.000000
286	288	0	0.944000
287	288	0	0.931000
298	299	0	0.962000
304	305	0	1.050000
309	336	0	1.037000
327	332	0	1.062000
328	332	0	1.044000

TABLE 1.3 (continued)
New Off-Nominal Setting(s) for TCUL Transformers (100%)

Bus no. from	Bus no. to	PBI	Transformer tap
339	365	0	1.000000
378	426	0	1.006000
385	386	0	1.000000
390	391	0	1.031000
416	425	0	0.969000
701	702	0	1.050000

Note: Load flow calculations 100% loading for centralized system.

Table of Generator Data Sorted by Node Number

Node no.	Name	Generator voltage	Generator angle	Generator P (MW)	Generator Q (Mvar)
1	G001	1.0000	0.0000	2546.3000	−183.8000
150	G150	1.0270	−19.9000	0.0000	0.0000
156	G156	1.0300	−28.8000	147.0000	50.7000
157	G157	1.0250	−11.4000	126.0000	50.4000
161	G161	1.0240	−14.6000	160.0000	64.0000
164	G164	1.0300	−21.1000	330.0000	90.9000
172	G172	1.0300	−14.0000	623.0000	35.6000
174	G174	1.0290	−19.5000	661.0000	264.0000
182	G182	1.0300	−19.3000	216.0000	−170.0000
183	G183	1.0310	−19.4000	400.0000	−200.0000
285	G285	1.0300	−22.2000	270.0000	122.1000
291	G291	1.0300	−27.4000	58.0000	312.7000
301	G301	1.0000	−28.6000	1.0000	99.8000
315	G315	1.0300	−14.5000	160.0000	181.6000
316	G316	1.0300	−14.4000	320.0000	54.7000
327	G327	1.0300	−21.6000	68.0000	27.2000
332	G332	1.0000	−20.3000	100.0000	−50.0000
336	G336	0.9850	−22.3000	20.0000	100.0000
339	G339	1.0270	−19.7000	1143.0000	457.2000
343	G343	1.0280	−23.0000	171.0000	68.4000
357	G357	1.0160	−20.1000	655.0000	500.0000
359	G359	1.0270	−16.4000	200.0000	200.0000
365	G365	1.0290	−23.1000	120.0000	200.0000
371	G371	1.0300	−16.0000	638.0000	170.9000
372	G372	1.0200	−17.7000	140.0000	62.5000
390	G390	1.0300	−15.1000	594.0000	128.4000
391	G391	1.0200	−14.2000	1000.0000	116.7000
427	G427	1.0300	−7.8000	1103.0000	328.0000
450	G450	1.0300	−3.3000	1065.0000	−77.4000
685	G685	1.0000	−63.8000	321.0000	204.7000
687	G687	1.0000	−81.2000	160.0000	107.3000
693	G693	1.0000	−79.7000	60.0000	271.0000

Table of Load Data Sorted by Node Number

Node no.	Name	Load bus voltage	Load bus angle	Load P (MW)	Load Q (Mvar)	Sync. cond. Q (Mvar)
1	L001	1.0000	0.0000	0.0000	0.0000	0.000
2	L002	0.9970	−10.5000	0.0000	0.0000	0.000

TABLE 1.3 (continued)
Table of Load Data Sorted by Node Number

Node no.	Name	Load bus voltage	Load bus angle	Load P (MW)	Load Q (Mvar)	Sync. cond. Q (Mvar)
16	L016	1.0130	–7.7000	0.0000	0.0000	0.000
96	L096	1.0250	–29.1000	0.0000	0.0000	0.000
125	L125	1.0110	–30.2000	0.0000	0.0000	0.000
126	L126	1.0260	–21.5000	0.0000	0.0000	0.000
150	L150	1.0270	–19.9000	233.4000	5.8000	0.000
151	L151	1.0070	–30.6000	32.0000	3.8000	0.000
152	L152	1.0040	–30.4000	20.5000	1.7000	0.000
153	L153	1.0090	–19.8000	67.2000	–11.6000	0.000
155	L155	1.0310	–19.5000	130.7000	19.8000	0.000
156	L156	1.0300	–28.8000	68.4000	10.9000	0.000
157	L157	1.0250	–11.4000	0.0000	0.0000	0.000
158	L158	1.0080	–22.1000	120.2000	18.4000	0.000
160	L160	1.0170	–29.7000	3.2000	0.6000	0.000
161	L161	1.0240	–14.6000	102.4000	5.4000	0.000
162	L162	1.0040	–23.5000	124.0000	21.5000	0.000
164	L164	1.0300	–21.1000	20.8000	–1.7000	0.000
167	L167	1.0210	–18.9000	177.3000	21.8000	0.000
168	L168	1.0240	–16.5000	191.5000	26.6000	0.000
170	L170	0.9960	–24.5000	204.0000	47.4000	0.000
171	L171	1.0110	–30.0000	24.2000	16.8000	0.000
172	L172	1.0300	–14.0000	37.2000	–3.8000	0.000
174	L174	1.0290	–19.5000	390.3999	68.9000	0.000
175	L175	1.0030	–22.9000	224.3000	50.8000	0.000
177	L177	0.9970	–30.2000	66.0000	2.9000	0.000
178	L178	1.0070	–23.7000	52.6000	2.7000	0.000
179	L179	0.9970	–25.5000	0.0000	0.0000	0.000
180	L180	1.0010	–23.3000	241.8000	63.8000	0.000
181	L181	1.0290	–19.4000	30.0000	18.0000	0.000
182	L182	1.0300	–19.3000	0.0000	0.0000	0.000
183	L183	1.0310	–19.4000	0.0000	0.0000	0.000
184	L184	1.0310	–19.6000	119.2000	6.8000	0.000
185	L185	1.0300	–19.8000	149.6000	46.0000	0.000
186	L186	1.0260	–20.3000	74.6000	12.5000	0.000
187	L187	1.0180	–18.4000	92.0000	10.6000	0.000
188	L188	1.0170	–22.9000	51.7000	–5.8000	0.000
189	L189	1.0170	–23.0000	52.4000	–2.2000	0.000
190	L190	1.0280	–14.5000	61.8000	12.9000	0.000
191	L191	1.0080	–23.6000	21.2000	4.7000	0.000
192	L192	0.9960	–30.7000	25.9000	6.5000	0.000
202	L202	1.0300	–21.1000	0.0000	0.0000	0.000
227	L227	1.0110	–5.4000	0.0000	0.0000	0.000
231	L231	1.0010	–20.3000	0.0000	0.0000	0.000
280	L280	1.0120	–15.0000	53.0000	16.9000	0.000
281	L281	1.0090	–18.8000	227.0000	37.6000	0.000
282	L282	0.9920	–25.1000	89.0000	33.0000	0.000
283	L283	0.9960	–28.2000	213.0000	73.5000	0.000
285	L285	1.0300	–22.2000	152.0000	60.0000	0.000
286	L286	1.0020	–20.4000	91.0000	84.5000	0.000
287	L287	1.0010	–19.7000	91.0000	84.5000	0.000
288	L288	1.0330	–17.0000	0.0000	0.0000	0.000
289	L289	0.9860	–21.9000	58.0000	10.7000	0.000
290	L290	0.9840	–25.4000	167.0000	129.0000	0.000
291	L291	1.0300	–27.4000	327.0000	10.6000	0.000
295	L295	1.0370	–14.7000	0.0000	0.0000	0.000

Table 1.3 (continued)
Table of Load Data Sorted by Node Number

Node no.	Name	Load bus voltage	Load bus angle	Load P (MW)	Load Q (Mvar)	Sync. cond. Q (Mvar)
296	L296	1.0140	–19.3000	217.0000	109.9000	0.000
297	L297	1.0160	–20.4000	0.0000	0.0000	0.000
298	L298	1.0020	–15.2000	0.0000	0.0000	0.000
299	L299	1.0030	–14.9000	255.0000	121.1000	0.000
301	L301	1.0000	–28.6000	168.0000	62.3000	0.000
303	L303	0.9790	–21.8000	0.0000	0.0000	0.000
304	L304	0.9980	–29.2000	242.0000	29.7000	0.000
305	L305	0.9660	–24.1000	0.0000	0.0000	0.000
306	L306	0.9940	–24.6000	179.0000	74.0000	0.000
308	L308	0.9930	–19.5000	0.0000	0.0000	0.000
309	L309	0.9990	–29.3000	134.0000	26.3000	0.000
311	L311	1.0060	–21.7000	0.0000	0.0000	0.000
312	L312	0.9840	–22.0000	48.0000	5.8000	0.000
313	L313	1.0010	–21.4000	104.0000	34.7000	0.000
314	L314	0.9970	–28.6000	207.0000	60.0000	0.000
315	L315	1.0300	–14.5000	0.0000	0.0000	0.000
316	L316	1.0300	–14.4000	0.0000	0.0000	0.000
327	L327	1.0300	–21.6000	146.0000	60.0000	0.000
328	L328	1.0000	–23.6000	299.0000	148.0000	0.000
332	L332	1.0000	–20.3000	0.0000	0.0000	0.000
333	L333	0.9950	–29.0000	338.0000	86.0000	0.000
334	L334	0.9990	–24.6000	70.0000	8.8000	0.000
336	L336	0.9850	–22.3000	257.0000	37.9000	0.000
337	L337	1.0070	–23.3000	54.0000	15.0000	0.000
339	L339	1.0270	–19.7000	0.0000	0.0000	0.000
340	L340	1.0260	–25.4000	124.0000	51.0000	0.000
343	L343	1.0280	–23.0000	0.1000	0.0000	0.000
345	L345	1.0230	–16.7000	109.0000	18.4000	0.000
347	L347	1.0240	–15.4000	136.0000	50.6000	0.000
349	L349	0.9940	–21.8000	58.0000	20.0000	0.000
351	L351	1.0190	–17.5000	199.0000	49.6000	0.000
352	L352	1.0280	–27.5000	57.0000	44.0000	0.000
353	L353	1.0130	–22.6000	165.0000	39.0000	0.000
354	L354	0.9960	–29.6000	177.0000	30.8000	0.000
357	L357	1.0160	–20.1000	265.0000	163.4000	0.000
359	L359	1.0270	–16.4000	0.0000	0.0000	0.000
360	L360	1.0170	–20.4000	56.0000	21.6000	0.000
362	L362	0.9970	–19.7000	36.0000	3.9000	0.000
365	L365	1.0290	–23.1000	389.0000	133.0000	0.000
366	L366	0.9940	–19.1000	122.0000	22.4000	0.000
368	L368	1.0290	–14.6000	56.0000	19.8000	0.000
371	L371	1.0300	–16.0000	0.0000	0.0000	0.000
372	L372	1.0200	–17.7000	0.0000	0.0000	0.000
373	L373	1.0230	–15.3000	208.0000	101.4000	0.000
375	L375	1.0230	–15.3000	28.0000	9.9000	0.000
376	L376	1.0220	–15.9000	28.0000	9.9000	0.000
377	L377	0.9990	–20.2000	94.0000	33.4000	0.000
378	L378	1.0000	–16.9000	0.0000	0.0000	0.000
379	L379	1.0080	–23.1000	63.0000	25.0000	0.000
380	L380	1.0010	–21.9000	213.0000	115.0000	0.000
381	L381	1.0240	–21.4000	55.0000	19.7000	0.000
382	L382	1.0230	–16.2000	0.0000	0.0000	0.000

Table 1.3 (continued)
Table of Load Data Sorted by Node Number

Node no.	Name	Load bus voltage	Load bus angle	Load P (MW)	Load Q (Mvar)	Sync. cond. Q (Mvar)
383	L383	1.0050	–17.6000	54.0000	6.3000	0.000
385	L385	0.9960	–21.9000	0.0000	0.0000	0.000
386	L386	0.9990	–23.7000	0.0000	0.0000	0.000
388	L388	1.0010	–28.9000	0.0000	0.0000	0.000
389	L389	0.9930	–25.1000	140.0000	41.0000	0.000
390	L390	1.0300	–15.1000	326.0000	71.3000	0.000
391	L391	1.0200	–14.2000	0.0000	0.0000	0.000
401	L401	1.0180	–18.2000	48.0000	15.5000	0.000
402	L402	1.0030	–19.8000	61.0000	21.0000	0.000
403	L403	1.0080	–19.5000	233.0000	74.9000	0.000
404	L404	0.9944	–21.6000	224.0000	48.0000	0.000
405	L405	1.0050	–23.0000	215.0000	3.0000	0.000
406	L406	1.0080	–23.7000	184.0000	59.1000	0.000
409	L409	0.9970	–19.3000	0.0000	0.0000	0.000
410	L410	1.0010	–20.3000	55.0000	26.0000	0.000
411	L411	1.0030	–20.0000	19.0000	3.0000	0.000
412	L412	0.9960	–24.3000	22.0000	4.0000	0.000
413	L413	1.0020	–23.5000	46.0000	14.0000	0.000
414	L414	0.9940	–23.0000	67.0000	21.5000	0.000
415	L415	0.9850	–25.3000	67.0000	21.5000	0.000
416	L416	0.9980	–14.1000	0.0000	0.0000	0.000
417	L417	1.0040	–14.3000	37.0000	10.3000	0.000
418	L418	1.0230	–20.0000	49.0000	19.8000	0.000
419	L419	1.0100	–21.7000	15.0000	5.6000	0.000
420	L420	1.0240	–15.9000	7.0000	1.4000	0.000
421	L421	1.0170	–15.1000	7.0000	1.4000	0.000
422	L422	1.0030	–17.8000	63.0000	18.3000	0.000
423	L423	1.0170	–17.6000	41.0000	13.1000	0.000
424	L424	0.9990	–26.7000	34.0000	4.8000	0.000
425	L425	1.0110	–12.0000	0.0000	0.0000	0.000
426	L426	1.0140	–11.9000	0.0000	0.0000	0.000
427	L427	1.0300	–7.8000	0.0000	0.0000	0.000
428	L428	1.0280	–6.7000	0.0000	0.0000	0.000
429	L429	0.9880	–18.1000	0.0000	0.0000	0.000
446	L446	1.0000	–19.1000	0.0000	0.0000	0.000
450	L450	1.0300	–3.3000	0.0000	0.0000	0.000
501	L501	0.9670	–23.8000	0.0000	0.0000	0.000
518	L518	1.0180	–17.8000	0.0000	0.0000	0.000
683	L683	0.9770	–83.0000	144.0000	13.0000	0.000
685	L685	1.0000	–63.8000	245.0000	23.0000	0.000
687	L687	1.0000	–81.2000	73.0000	6.0000	0.000
690	L690	0.9360	–49.1000	0.0000	0.0000	0.000
693	L693	1.0000	–79.7000	281.0000	26.0000	0.000
695	L695	0.9810	–21.1000	102.0000	9.0000	0.000
698	L698	1.0000	–80.3000	0.0000	0.0000	0.000
701	L701	1.0020	–31.1000	0.0000	0.0000	0.000
702	L702	0.9740	–21.9000	195.0000	17.0000	0.000
711	L711	0.8960	–83.3000	240.0000	21.0000	0.000
717	L717	0.9970	–18.0000	0.0000	0.0000	0.000
926	L926	1.0200	–17.8000	0.0000	0.0000	0.000
929	L929	1.0270	–16.4000	0.0000	0.0000	0.000
946	L946	1.0060	–16.8000	0.0000	0.0000	0.000

Table 1.3 (continued)
Table of Generator Reactive Components and Reactive Characteristics

Node no.	Name	Generator reactive component	Generator reactive Char. - S
1	G001	0.0000	–0.0722
150	G150	0.0000	–0.1172
156	G156	0.0000	0.3449
157	G157	0.0000	0.4000
161	G161	0.0000	0.4000
164	G164	0.0000	0.2755
172	G172	0.0000	0.0571
174	G174	0.0000	0.3994
182	G182	0.0000	–0.7870
183	G183	0.0000	–0.5000
285	G285	0.0000	0.4522
291	G291	0.0000	5.3914
301	G301	0.0000	–0.1172
315	G315	0.0000	1.1350
316	G316	0.0000	0.1709
327	G327	0.0000	0.4000
332	G332	0.0000	–0.5000
336	G336	0.0000	5.0000
339	G339	0.0000	0.4000
343	G343	0.0000	0.4000
357	G357	0.0000	0.7634
359	G359	0.0000	1.0000
365	G365	0.0000	1.6667
371	G371	0.0000	0.2679
372	G372	0.0000	0.4464
390	G390	0.0000	0.2162
391	G391	0.0000	0.1167
427	G427	0.0000	0.2974
450	G450	0.0000	–0.0727
685	G685	0.0000	0.6377
687	G687	0.0000	0.6706
693	G693	0.0000	4.5167

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TABLE 1.4
New Off-Nominal Setting(s) for TCUL Transformers (70%)

Bus no. from	Bus no. to	PBI	Transformer tap
2	295	0	0.906000
179	180	0	0.962000
283	282	0	0.969000
286	288	0	0.931000
287	288	0	0.931000
298	299	0	0.975000
304	305	0	1.012000
309	336	0	1.000000
327	332	0	1.019000
328	332	0	1.006000
339	365	0	0.925000

TABLE 1.4 (continued)
New Off-Nominal Setting(s) for TCUL Transformers (70%)

Bus no. from	Bus no. to	PBI	Transformer tap
378	426	0	0.956000
385	386	0	0.925000
390	391	0	1.006000
416	425	0	0.950000
701	702	0	0.981000

Note: Load flow calculations 70% loading for dispersed system.

Table of Generator Data Sorted by Node Number

Node no.	Name	Generator voltage	Generator angle	Generator P (MW)	Generator Q (Mvar)
1	G001	1.0000	0.0000	1164.2000	–642.2000
151	G151	1.0090	–11.1000	22.4000	0.0000
153	G153	1.0200	–5.9000	12.3000	0.0000
155	G155	1.0340	–5.6000	33.5000	0.0000
156	G156	1.0200	–11.3000	53.4000	32.5000
157	G157	1.0380	–4.1000	0.0000	0.6000
158	G158	1.0310	–6.7000	16.2000	0.0000
161	G161	1.0370	–5.2000	38.4000	0.0000
162	G162	1.0320	–6.4000	2.2000	0.0000
164	G164	1.0300	–2.8000	330.0000	–57.0000
167	G167	1.0270	–3.1000	32.4000	0.0000
168	G168	1.0270	0.1000	52.0000	0.0000
170	G170	1.0300	–6.6000	49.5000	0.0000
172	G172	1.0300	2.7000	630.7000	–4.1000
174	G174	1.0300	–5.8000	320.0000	–106.4000
175	G175	1.0310	–6.8000	54.6000	0.0000
177	G177	1.0030	–10.2000	26.1000	0.0000
178	G178	1.0320	–6.0000	10.5000	0.0000
180	G180	1.0340	–6.7000	70.7000	0.0000
181	G181	1.0320	–5.7000	21.0000	0.0000
182	G182	1.0350	–5.7000	0.0000	0.0000
183	G183	1.0350	–5.6000	0.0000	–300.0000
184	G184	1.0360	–5.5000	83.5000	0.0000
185	G185	1.0350	–5.5000	105.0000	0.0000
186	G186	1.0320	–5.2000	52.1000	0.0000
187	G187	1.0280	–3.2000	64.4000	0.0000
188	G188	1.0310	–4.3000	36.2000	0.0000
189	G189	1.0320	–4.6000	36.6000	0.0000
190	G190	1.0530	–4.5000	43.2000	0.0000
191	G191	1.0320	–5.8000	14.8000	0.0000
192	G192	1.0040	–10.4000	18.1000	0.0000
280	G280	1.0300	–5.4000	12.8000	0.0000
281	G281	1.0260	–5.9000	31.2000	0.0000
282	G282	1.0290	–7.0000	27.5000	0.0000
285	G285	1.0300	–5.9000	0.0000	–41.8000
291	G291	1.0300	–5.3000	588.0000	115.2000
296	G296	1.0400	–6.3000	26.8000	0.0000
299	G299	1.0150	–5.4000	30.8000	0.0000
301	G301	1.0000	–9.4000	173.0000	25.6000
304	G304	1.0010	–11.6000	33.2000	0.0000
306	G306	1.0310	–6.8000	91.1000	0.0000

TABLE 1.4 (continued)
Table of Generator Data Sorted by Node Number

Node no.	Name	Generator voltage	Generator angle	Generator P (MW)	Generator Q (Mvar)
309	G309	1.0010	−11.7000	40.0000	0.0000
312	G312	1.0100	−11.1000	15.8000	0.0000
313	G313	1.0050	−6.3000	26.8000	0.0000
314	G314	1.0050	−7.9000	46.4000	0.0000
315	G315	1.0120	−5.3000	0.0000	0.0000
316	G316	1.0120	−5.3000	0.0000	0.0000
327	G327	1.0300	−6.5000	24.0000	70.2000
328	G328	1.0040	−7.3000	3.5000	0.0000
332	G332	1.0220	−5.5000	0.0000	0.0000
334	G334	1.0040	−7.6000	8.9000	0.0000
336	G336	1.0080	−11.3000	0.0000	0.0000
339	G339	1.0240	−4.3000	860.0000	400.0000
340	G340	1.0330	−5.7000	1.3000	0.0000
343	G343	1.0380	−5.9000	61.0000	0.0000
345	G345	1.0260	−2.2000	40.6000	0.0000
347	G347	1.0220	−4.8000	34.8000	0.0000
349	G349	1.0090	−6.8000	1.3000	0.0000
351	G351	1.0290	−3.3000	50.5000	0.0000
352	G352	1.0290	−5.2000	65.0000	0.0000
353	G353	1.0290	−5.8000	52.6000	0.0000
354	G354	0.9980	−10.9000	6.3000	0.0000
357	G357	1.0150	−5.2000	562.8000	300.0000
359	G359	1.0420	−5.1000	0.0000	0.0000
360	G360	1.0320	−6.3000	6.4000	0.0000
362	G362	1.0120	−7.8000	18.7000	0.0000
365	G365	1.0390	−5.9000	112.0000	−80.0000
366	G366	1.0110	−8.5000	3.5000	0.0000
371	G371	1.0300	−1.5000	638.0000	81.0000
372	G372	1.0110	−6.1000	0.0000	0.0000
373	G373	1.0160	−5.2000	27.4000	0.0000
375	G375	1.0430	−4.7000	1.2000	0.0000
376	G376	1.0380	−5.0000	1.2000	0.0000
377	G377	1.0120	−6.2000	7.7000	0.0000
380	G380	1.0060	−6.5000	18.8000	0.0000
381	G381	1.0240	−5.7000	16.8000	0.0000
389	G389	1.0290	−6.9000	66.0000	0.0000
390	G390	1.0320	−4.2000	573.0000	181.0000
391	G391	1.0450	−4.3000	344.0000	320.0000
401	G401	1.0470	−6.0000	4.2000	0.0000
402	G402	1.0230	−6.1000	17.1000	0.0000
404	G404	1.0110	−6.8000	26.6000	0.0000
405	G405	1.0370	−6.3000	151.5000	0.0000
406	G406	1.0210	−6.7000	51.2000	0.0000
410	G410	1.0230	−5.8000	38.4000	0.0000
411	G411	1.0230	−6.0000	13.3000	0.0000
412	G412	1.0320	−6.7000	15.4000	0.0000
413	G413	1.0360	−6.4000	32.2000	0.0000
414	G414	1.0250	−6.3000	46.9000	0.0000
415	G415	1.0200	−7.0000	46.9000	0.0000
417	G417	1.0210	−4.8000	25.8000	0.0000
418	G418	1.0310	−6.0000	34.2000	0.0000
419	G419	1.0320	−6.6000	10.5000	0.0000
420	G420	1.0400	−4.9000	4.9000	0.0000
421	G421	1.0420	−4.5000	4.9000	0.0000
422	G422	1.0210	−5.7000	44.0000	0.0000