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ABSTRACT

Title of Thesis: A STUDY ON EFFECTS OF WEIGHTING MATRICES IN POWER SYSTEM STATE ESTIMATION

Yanshi Wang, Master of Science in Electrical Engineering, 1990

Thesis directed by: Dr. W. Hubbi, Associate Professor

The effects of weighting matrices that may be used in the Weighted Least Squares (WLS) method when applied to the problem of Power System State Estimation (PSSE) are studied. These weighting matrices include the one usually used in the literature and the one used in the utility PSSE programs.

The performances of these weighting matrices are compared using the Monte Carlo simulation technique.

To test the performances of the weighting matrices, a PSSE program is developed, different performance indices for state comparison are defined, and many cases are studied.

Results show that the weighting matrix usually used in literature, $\frac{1}{\sigma^2}$, and a proposed weighting matrix, $\frac{1}{\sigma}$, give comparable results and are the best of those tested. The weighting matrix used in the utility industry programs offers little or no improvement.

A STUDY OF THE EFFECTS OF WEIGHTING
MATRICES IN POWER SYSTEM STATE ESTIMATION

by

Yanshi Wang

Thesis submitted to the Faculty of the Graduate School of
the New Jersey Institute of Technology
in partial fulfillment of the requirements for the degree of
Master of Science in Electrical Engineering

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To My

Father, Mother

and

Brother

for all their support, faith and patience

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Contents

1	INTRODUCTION	1
1.1	Power System State Estimation	2
1.2	Weighted Least Squares Method Applied to PSSE	4
1.3	Minimizing the Relative Errors	7
1.4	Measurement Accuracy	9
1.5	The Usually Used Weighting Matrix	10
1.6	The Practically Used Weighting Matrix	12
1.7	Possible Weighting Matrices	13
1.8	Thesis outline	15
2	PLAN FOR WEIGHTING MATRICES STUDIES	16
2.1	Introduction	16
2.2	Indices Used for State Comparison	17
2.3	Simulated Measurements Generation	20
2.4	Number of Cases	22
2.5	Explanation of the Program Used	24
3	STUDY CONDUCTED ON EFFECTS OF WEIGHTING MATRICES	28

3.1	Analysis of the Values of Performance Indices Using Different Weighting Matrices	29
3.2	Using FJM PSSE program	36
3.3	Measurement Error Amplification	38
3.4	Testing Effects of Weighting Matrices Using the IEEE 30-bus Test System	41
3.5	Conclusions	44

APPENDICES

A	The IEEE 14-bus and IEEE 30-bus Test Systems and Their Input Data with Explanation Notes	45
A.1	The IEEE 14-bus Test System and IEEE 30-bus Test System	46
A.2	Explanation of the Input Data Files for the IEEE 14-bus and IEEE 30-bus Systems	48
A.3	Input Data of the IEEE 14-bus Test System	48
A.4	Input Data of the IEEE 30-bus Test System	51
B	Generation of Normally Distributed Numbers	57
B.1	Mean	58
B.2	Variance	58
B.3	The Central Limit Theorem	58
B.4	Generation of Normally Distributed Numbers	59
B.5	References	59
C	Listing of Main Program and Some of the Subroutines Used	60

D Values of the Performance Indices	109
SELECTED BIBLIOGRAPHY	126

List of Figures

2.1	Flow chart of the main program	26
3.1	Values of performance indices JCT and AJCT obtained using different weighting matrices. Instrumentation configuration 14-A is used with a CRIT = 0.005. FJM PSSE program is used.	39
3.2	Values of performance indices JCT and AJCT obtained using different weighting matrices. Instrumentation configuration 14-B is used with a CRIT = 0.005. FJM PSSE program is used.	40
3.3	Values of performance indices JCT and AJCT obtained using different weighting matrices. Instrumentation configuration 14-A is used with a CRIT = 0.005. FJM PSSE program is used when errors introduced to measurements are amplified.	44
3.4	Values of performance indices JCT and AJCT obtained using different weighting matrices. Instrumentation configuration 14-B is used with a CRIT = 0.005. FJM PSSE program is used when errors introduced to measurements are amplified.	45
A.1	The single-line diagram of IEEE 14-bus test system.	46
A.2	The single-line diagram of IEEE 30-bus test system.	47

List of Tables

2.1	Values of performance indices obtained using different simulated case numbers and different seeds. Measurement set 14-A is used. weighting matrix used is W1	23
3.1	Normalized values of performance indices with those obtained using W1 as a reference. Data used to obtain the values in this table are in Table D.1.	31
3.2	Normalized values of performance indices with those obtained using W1 as a reference. Data used to obtain the values in this table are in Table D.3.	31
3.3	Normalized values of performance indices with those obtained using W1 as a reference. Data used to obtain the values in this table are in Table D.1 and Table D.2.	33
3.4	Normalized values of performance indices with those obtained using W1 as a reference. Data used to obtain the values in this table are in Table D.3 and Table D.4.	33
3.5	Normalized values of performance indices. Data used to obtain the values in this table are in Table D.2.	34

3.6	Normalized values of performance indices. Data used to obtain the values in this table are in Table D.4.	34
3.7	Normalized values of performance indices with those obtained using W1 as a reference. Data used to obtain the values in this table are in Table D.1 or D.2.	35
3.8	Normalized values of performance indices with those obtained using W1 as a reference. Data used to obtain the values in this table are in Table D.3 or D.4.	35
D.1	Values of performance indices obtained using different weighting matrices. Instrumentation configuration 14-A is used with a CRIT = 0.005. The number of cases is 20, <i>i.e.</i> , 20 values are used to obtain one entry in this table.	112
D.2	Values of performance indices obtained using different weighting matrices. Instrumentation configuration 14-A is used with a CRIT = 0.005. The number of cases is 20, <i>i.e.</i> , 20 values are used to obtain one entry in this table.	113
D.3	Values of performance indices obtained using different weighting matrices. Instrumentation configuration 14-B is used with a CRIT = 0.005. The number of cases is 60, <i>i.e.</i> , 60 values are used to obtain one entry in this table.	114
D.4	Values of performance indices obtained using different weighting matrices. Instrumentation configuration 14-B is used with a CRIT = 0.005. The number of cases is 60, <i>i.e.</i> , 60 values are used to obtain one entry in this table.	115

D.5	Values of the largest mismatches between calculated and true system variables and other corresponding values obtained using different weighting matrices. Instrumentation configurations 14-A and 14-B are used with a CRIT = 0.005. The number of cases for configurations 14-A and 14-B are 20 and 60, respectively.	116
D.6	Values of performance indices obtained using different weighting matrices. Instrumentation configuration 14-C, 14-D, 14-E, 14-F AND 14-G are used with a CRIT = 0.005. The number of cases is 20, <i>i.e.</i> , 20 values are used to obtain one entry in this table.	117
D.7	Values of performance indices obtained using different weighting matrices. FJM PSSE program is used. Instrumentation configuration 14-A is used with a CRIT = 0.005. The number of cases is 20, <i>i.e.</i> , 20 values are used to obtain one entry in this table.	118
D.8	Values of performance indices obtained using different weighting matrices. FJM PSSE program is used. Instrumentation configuration 14-B is used with a CRIT = 0.005. The number of cases is 60, <i>i.e.</i> , 60 values are used to obtain one entry in this table.	119
D.9	Values of the largest mismatches between calculated and true system variables and other corresponding values obtained using different weighting matrices. Instrumentation configurations 14-A and 14-B are 20 and 60, respectively.	120

D.10	Values of performance indices obtained using different weighting matrices. FJM PSSE program is used when measurement errors amplified. Instrumentation configuration 14-A is used with a CRIT = 0.005. 20 values are used to obtain one entry in this table.	121
D.11	Values of performance indices obtained using different weighting matrices. FJM PSSE program is used when measurement errors amplified. Instrumentation configuration 14-B is used with a CRIT = 0.005. 60 values are used to obtain one entry in this table.	122
D.12	Values of the largest mismatches between calculated and true system variables and other corresponding values obtained using different weighting matrices. Instrumentation configurations 14-A and 14-B are used with a CRIT = 0.005. The number of cases for configurations 14-A and 14-B are 20 and 60, respectively.	123
D.13	Values of performance indices obtained using different weighting matrices. FJM PSSE program is used with a CRIT = 0.005. 10 values are used to obtain one entry in this table.	124

Chapter 1

INTRODUCTION

In electric power systems, on-line control centers are used to monitor the system to insure a reliable and optimal operation. A typical on-line control center is equipped with a supervisory control and data acquisition (SCADA) system. The central computer of the SCADA system scans the remote terminal units (RTUs) to collect real-time data from the system. These data are processed by the power system state estimation (PSSE) program to provide a best estimate of the state of the system to be used in various application programs.

The objective of this thesis is to study the effects of different weighting matrices on the overall performance of PSSE. The question of the quality of the state estimation is discussed and different performance indices are defined.

In section 1.1, PSSE is studied. The Weighted Least Squares (WLS) method applied to power system state estimation, together with its mathematical formulation, is introduced in section 1.2. How minimizing the sum of squared relative errors (SSRE) is related to the weighting matrix is presented in section 1.3. Measurement accuracy is discussed in section 1.4. Section 1.5 introduces the weighting matrix which is usually used in the literature. Section 1.6 introduces the weighting matrix

used by industry. Possible weighting matrices to test are discussed in section 1.7. In section 1.8, the rest of the thesis is outlined.

1.1 Power System State Estimation

This section is descriptive and is taken from [1 – 8].

The information transmitted to the control center is raw information, it is inaccurate due to one or more of the following:

- Power transducer and instrument transformer errors,
- A/D (Analog to Digital) conversion errors,
- Analog or digital data transmission errors,
- Delayed measurements that reflect a prior system state,
- Damaged meters.

The information transmitted to the control center do not form the complete data base of the system because of the following:

- Meters and communication equipment are expensive, so it is necessary to reduce the number of meters as much as possible.
- Some variables, like voltage angles, are difficult and almost impossible to measure economically.
- The unavailable measurements can be calculated using mathematical models.

Because the available measurements are contaminated by errors and because the data are not complete, power system state estimation (PSSE) programs are used to process the available measurements to provide the control personnel with a complete, reliable and accurate data base of the system under control. The data transmitted from RTUs are processed based on a mathematical model which assumes the existence of random errors, bad data, modeling errors, and parameter errors. The system variables are calculated (or estimated) using that model.

PSSE then is a data processing algorithm for converting redundant meter readings and other available information, such as the mathematical model of the system, past behavior of the system variables (known as pseudomeasurements), etc., into an estimate of the state variables.

The state variables of an electric power system are usually defined as voltage magnitudes and phase angles at all network buses. These are sufficient to characterize the system. Once the state is obtained, all the remaining system variables which are known functions of the state variables can be calculated.

Normally PSSE includes the following basic operations:

- Modelling of the system,
- Prefiltering raw data,
- State estimation,
- Detection of bad data,
- Identification of bad data,
- Removal of bad data.

The output of the PSSE program is not the true state of the system. Besides the measurement errors mentioned above, the reasons for the existences of this discrepancy are the following:

- Error in the mathematical model,
- Inaccuracy of system parameters,
- Use of pesudomeasurements.

The following methods are suggested in the literature to solve PSSE problem:

- Weighted Least Squares Method,
- Fast Decoupled Solution Method,
- Independent Equations Method,
- Line-flow Only Method.

1.2 Weighted Least Squares Method Applied to PSSE

This section follows the symbol conventions below, unless otherwise stated; boldface uppercase symbols denote matrix quantities and boldface lowercase ones denote vectors.

In the WLS method [1 – 4], the static model of an electrical system (or network) is given by its admittance matrix. All measurements (and other information) are modeled in terms of

$$\mathbf{m} = \mathbf{f}(\mathbf{x}) + \epsilon \quad (1.1)$$

where \mathbf{m} is a vector of measurements, \mathbf{x} is the state vector of the static structure model, and $\mathbf{f}(\mathbf{x})$ is a nonlinear function of \mathbf{x} which is determined by the admittance matrix and Kirchhoff's laws, relating the real-time measurements to the state vector of the system. To take into account the errors in the measurements, the error vector ϵ is introduced in the above model.

The estimated state of the system is defined as the value of \mathbf{x} which minimizes the performance index

$$J(\mathbf{x}) = [\mathbf{m} - \mathbf{f}(\mathbf{x})]^T \mathbf{W} [\mathbf{m} - \mathbf{f}(\mathbf{x})] \quad (1.2)$$

where the superscripts (T) indicate the transposition of a matrix. \mathbf{W} is a diagonal weighting matrix and it will be discussed in detail later.

In order to estimate \mathbf{x} , an initial value \mathbf{x}_0 is assumed and a Taylor expansion approximates it near this point:

$$\mathbf{f}(\mathbf{x}) = \mathbf{f}(\mathbf{x}_0) + \mathbf{f}_x(\mathbf{x}_0)\Delta\mathbf{x} + \mathbf{f}_{xx}(\mathbf{x}_0)\frac{\Delta\mathbf{x}^2}{2} + \dots$$

Disregarding higher than linear terms, we have

$$\mathbf{f}(\mathbf{x}) = \mathbf{f}(\mathbf{x}_0) + \mathbf{f}_x(\mathbf{x}_0)\Delta\mathbf{x}$$

where $\mathbf{f}_x(\mathbf{x}_0)$ indicates the Jacobian (derivative with respect to \mathbf{x} at point \mathbf{x}_0).

Substituting $\mathbf{f}(\mathbf{x}) = \mathbf{f}(\mathbf{x}_0) + \mathbf{f}_x(\mathbf{x}_0)\Delta\mathbf{x}$ into equation (1.2) and letting $\Delta\mathbf{m} = \mathbf{m} - \mathbf{f}(\mathbf{x}_0)$ yields

$$J(\mathbf{x}) = [\Delta\mathbf{m} - \mathbf{f}_x(\mathbf{x}_0)\Delta\mathbf{x}]^T \mathbf{W} [\Delta\mathbf{m} - \mathbf{f}_x(\mathbf{x}_0)\Delta\mathbf{x}]$$

$$\begin{aligned}
&= [(\Delta \mathbf{m})^T - (\Delta \mathbf{x})^T \mathbf{f}_x(\mathbf{x}_0)^T] \mathbf{W} [\Delta \mathbf{m} - \mathbf{f}_x(\mathbf{x}_0) \Delta \mathbf{x}] \\
&= (\Delta \mathbf{m})^T \mathbf{W} \Delta \mathbf{m} - (\Delta \mathbf{m})^T \mathbf{W} \mathbf{f}_x(\mathbf{x}_0) \Delta \mathbf{x} - (\Delta \mathbf{x})^T \mathbf{f}_x(\mathbf{x}_0)^T \mathbf{W} \Delta \mathbf{m} + \\
&\quad (\Delta \mathbf{x})^T \mathbf{f}_x(\mathbf{x}_0)^T \mathbf{W} \mathbf{f}_x(\mathbf{x}_0) \Delta \mathbf{x}
\end{aligned}$$

Since $J(\mathbf{x})$ is a scalar, $(\Delta \mathbf{m})^T \mathbf{W} \Delta \mathbf{m}$, $(\Delta \mathbf{m})^T \mathbf{W} \mathbf{f}_x(\mathbf{x}_0) \Delta \mathbf{x}$, $(\Delta \mathbf{x})^T \mathbf{f}_x(\mathbf{x}_0)^T \mathbf{W} \Delta \mathbf{m}$, and $(\Delta \mathbf{x})^T \mathbf{f}_x(\mathbf{x}_0)^T \mathbf{W} \mathbf{f}_x(\mathbf{x}_0) \Delta \mathbf{x}$ are all scalars. It is known that the transpose of any scalar equals its own value, thus $(\Delta \mathbf{m})^T \mathbf{W} \mathbf{f}_x(\mathbf{x}_0) \Delta \mathbf{x}$ and $(\Delta \mathbf{x})^T \mathbf{f}_x(\mathbf{x}_0)^T \mathbf{W} \Delta \mathbf{m}$ are equal. And since \mathbf{W} is a diagonal matrix, $\mathbf{W}^T = \mathbf{W}$

$$J(\mathbf{x}) = (\Delta \mathbf{m})^T \mathbf{W} \Delta \mathbf{m} - 2(\Delta \mathbf{x})^T \mathbf{f}_x(\mathbf{x}_0)^T \mathbf{W} \Delta \mathbf{m} + (\Delta \mathbf{x})^T \mathbf{f}_x(\mathbf{x}_0)^T \mathbf{W} \mathbf{f}_x(\mathbf{x}_0) \Delta \mathbf{x} \quad (1.3)$$

The estimate of the state vector \mathbf{x} is obtained by minimizing the performance index

$$\frac{\partial J}{\partial \mathbf{x}} = 0$$

The differentiation of the second term of the equation (1.3) yields

$$\frac{\partial [(\Delta \mathbf{x})^T \mathbf{f}_x(\mathbf{x}_0)^T \mathbf{W} \Delta \mathbf{m}]}{\partial \mathbf{x}} = \mathbf{f}_x(\mathbf{x}_0)^T \mathbf{W} \Delta \mathbf{m}$$

And since $(\Delta \mathbf{m})^T \mathbf{W} \Delta \mathbf{m}$ does not depend on \mathbf{x} , the condition for a minimum is

$$-2\mathbf{f}_x(\mathbf{x}_0)^T \mathbf{W} \Delta \mathbf{m} + 2\mathbf{f}_x(\mathbf{x}_0)^T \mathbf{W} \mathbf{f}_x(\mathbf{x}_0) \Delta \mathbf{x} = 0$$

or

$$\mathbf{G}(\mathbf{x}_0) \Delta \mathbf{x} = \mathbf{J}^T \mathbf{W} [\mathbf{m} - \mathbf{f}(\mathbf{x}_0)] \quad (1.4)$$

where $\mathbf{J} = \mathbf{f}_x(\mathbf{x}_0)$ is the Jacobian matrix, $\mathbf{G}(\mathbf{x}_0) = \mathbf{J}^T \mathbf{W} \mathbf{J}$ is the gain matrix and $\Delta \mathbf{m} = \mathbf{m} - \mathbf{f}(\mathbf{x}_0)$, $\Delta \mathbf{x} = \mathbf{x}_1 - \mathbf{x}_0$.

This is a set of linear equations, in which the solution is based on the initial guess \mathbf{x}_0 . To compute \mathbf{x} to a certain accuracy, equation (1.4) can be rewritten as

$$\mathbf{G}(\mathbf{x}_k)\Delta\mathbf{x}_k = \mathbf{J}^T\mathbf{W}[\mathbf{m} - \mathbf{f}(\mathbf{x}_k)] \quad (1.5)$$

$$\Delta\mathbf{x}_k = \mathbf{x}_{k+1} - \mathbf{x}_k \quad (1.6)$$

In the above iterative equations, $k = 0, 1, 2, \dots$ until the required convergence is achieved.

1.3 Minimizing the Relative Errors

Equation (1.5) is obtained by minimizing the performance index J given by equation (1.2), *i.e.*, minimizing the SSE.

Although minimizing the SSE is widely used, it has a disadvantage. It is possible that the difference between an estimated value and its true value is considerably larger than the true value itself if the true value is small, *i.e.*, the percentage errors of some estimated values could be large. If we minimize SSRE, this disadvantage can be overcome.

Minimizing SSRE also has its own disadvantage. For a large quantity, even if the relative error is minimized, the difference between the estimated and true could be significant. When this quantity is a power flow in a tie line connecting two utilities, if the power exchange is not correctly estimated, one utility would lose revenue; when this quantity is at a dangerously high level, it could create security problems.

In any case, if it is desired that the estimate of the state variables is obtained by minimizing SSRE, then the performance index to be minimized is J' , where $J' = \left[1 - \frac{\mathbf{f}(\mathbf{x})}{\mathbf{m}}\right]^T \mathbf{W} \left[1 - \frac{\mathbf{f}(\mathbf{x})}{\mathbf{m}}\right]$. Following the same procedure outlined in the former

section, the final iterative equation can be obtained as

$$\mathbf{J}^T \mathbf{W}' \mathbf{J} \Delta \mathbf{x}_k = \mathbf{J}^T \mathbf{W}' [m - f(\mathbf{x}_k)] \quad (1.7)$$

where $\Delta \mathbf{x}_k = \mathbf{x}_{k+1} - \mathbf{x}_k$, each element of \mathbf{W}' is the corresponding element of the matrix \mathbf{W} divided by the square of the corresponding measurement.

Thus the iterative equations resulting from minimizing SSE and minimizing SSRE are the same but the two weighting matrices are different. Therefore, the problem of minimizing J or J' is reduced to the problem of selecting a different weighting matrix.

Before talking about weighting matrices, one thing that needs to be noticed is that the two iterative equations mentioned above result from minimizing sum of squared differences (absolute differences or relative differences). What would the iterative equation be if the sum of absolute differences (sum of absolute errors or sum of absolute relative errors) is to be minimized? Will an iterative equation for this case exist?

From the mathematical point of view, the derivative of a non-continuous function does not exist; thus the derivative of $\sum |m - f(x)|$ or $\sum \left| 1 - \frac{f(x)}{m} \right|$ does not exist; this creates a problem in getting an iterative equation. However, in engineering, ways are usually found to overcome mathematical difficulties by introducing approximations and assumptions.

In fact, there have been attempts to improve the robustness of the estimator using nonquadratic objective functions [9 – 11]. More recently, at the IEEE/PES 1990 Summer Meeting, the weighted least absolute value (WLAV) estimator was proposed for PSSE [12]. Solving the PSSE problem using WLAV can be shown

to be equivalent to a linear programming problem and hence can be solved using the well-known Simplex method [13,14]. In this thesis, studies of the effects of weighting matrices are conducted based on the WLS method; the WLAV method will not be further discussed.

1.4 Measurement Accuracy

Whenever measurements are made, errors are made. Each measurement in a PSSE program contains errors. In an electric power system, both analog and digital meters are used. As stated in section 1.1, the accuracy of these meters is influenced by transducers and instrument transformers. In a digital meter, the accuracy is also influenced by A/D conversion.

The accuracy of most analog meters is specified in per cent of full-scale deflection. The following example is taken from [15]:

Assume that a voltage is measured on the 50-V d-c scale, that a reading of "10" is obtained, and that the rated accuracy is ± 3 percent of full-scale. The full-scale value is 50 V; therefore the absolute accuracy is ± 1.5 V (50×3 percent). The 10-V reading could thus indicate an actual value of anywhere between 8.5 and 11.5 V.

The accuracy of a digital meter is closely related to its resolution; it is usually expressed as

$$\pm(\%reading + counts)$$

Thus it is necessary to determine what each count represents on each scale to determine the measurement accuracy. The following example is also taken from [15]:

Suppose in a digital volt meter, the accuracy of the 1-V range for d-c voltage measurements is rated as 1 percent \pm 1 count. (In this case, the 1 percent applies to the reading.) The resolution for the 1-V d-c range is 1 mV (the extreme right-hand digit equals 1 mV). As a result, if the display is 0.987, the true voltage is within 1 percent of the reading (within 9.87 mV) \pm 1 mV. This produces an area of uncertainty of about 22 mV (almost 11 mV above or below the display reading). Further detailed analysis of measurement accuracy can be found in [15] and [16].

No matter what the sources of errors, they can be classified into two broad categories: errors proportional to the quantity being measured, and fixed errors. These are given the symbol $ERR \times M$ and $FERR$, respectively, where M denotes the measurements. Different meters have different accuracies; therefore when measuring a certain quantity, different ERR s and $FERR$ s are introduced if different meters are used. It is for that reason measurements used in PSSE should not be treated equally; a measurement obtained from a more accurate meter should be given more weight. It is reasonable to choose as an estimate the values of state variables which best fit the observations where the fit is weighted by the accuracy of the measurement. Weighting matrices are used to carry out that task.

1.5 The Usually Used Weighting Matrix

In the literature, it is suggested that the weighting matrix be a diagonal matrix as

$$\mathbf{W}^{-1} = \text{diag}[\sigma_i^2] \quad (1.8)$$

where σ_i is the standard deviation of noise on the i th measurement. This \mathbf{W} will be referred to in this thesis as the “usually used” weighting matrix, \mathbf{WU} .

What is the standard deviation of a measurement? From the statistics point of view, standard deviation of a single measurement does not exist. In statistics, if one quantity is measured n times, measurements M_1, M_2, \dots and M_n are obtained. M_{mean} is the mean of these measurements, the standard deviation of which is defined in terms of the squares of the deviation from the mean (or average) by

$$\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (M_i - M_{mean})^2}$$

So, when a quantity is estimated from repeated, independent determinations, standard deviation provides analytical means of the uncertainty of the final result.

Virtually all engineering measurements one might encounter will have normal distribution. The standard deviation (σ) tells that any individual measurement (may be a next measurement) in a sample or set has a 68.3 % probability of lying within $\pm\sigma$ of the sample mean, a 95.5 % probability of being within $\pm 2 \sigma$, a 99.7 % probability of being within $\pm 3 \sigma$, and so on [17].

Therefore, in the two examples of the last section, since the true values are always between 8.5 and 11.5 V and between 0.99787 (0.987 + 0.01087) and 0.97613 (0.987 - 0.01087) mV, the uncertainty ranges can be regarded as from -3σ to 3σ . It is assumed in this thesis that the maximum error of a measurement is 3σ ; thus σ can be calculated if the maximum error is known.

In PSSE, standard deviation of a measurement is not the standard deviation stated in statistics because in the dynamic power system each measurement set represents a snapshot of the system that will never occur again. The characteristics of a meter determine the bounds of $ERR \times M$ and $FERR$. The sum of absolute values of those is taken as the standard deviation of a measurement in PSSE.

From the above discussion, the weighting matrix which is usually used in the literature is actually a diagonal matrix \mathbf{W} , where

$$W(i, i) = \frac{1}{(|(ERR \times M)_i| + |FERR_i|)^2} \quad (1.9)$$

M_i , $(ERR \times M)_i$, $FERR_i$ indicate i th measurement value, percentage error, and fixed error of i th measurement, respectively.

It should be noted that equation (1.9) is valid only when measurement errors do not correlate. If measurement errors correlate, the weighting matrix is not a diagonal matrix, it is the inverse covariance matrix of the noise in the measurements [5]. In the study conducted in this thesis, it is assumed that the errors do not correlate and thus the weighting matrices studied are all diagonal matrices.

It should be also noted that a weighting factor pertaining to a certain measurement is given according to the accuracy of that measurement, but the importance of a measurement is determined not only by its accuracy but also by its location. Thus increasing the accuracy of different measurements may not have the same effect on the estimated state.

1.6 The Practically Used Weighting Matrix

The weighting matrix used by the utility industry will be referred to as \mathbf{WP} .

In order to avoid calculating the weighting matrix whenever measurements are changed, the weighting matrix \mathbf{WP} used by utility programs takes into account only the FERRs of the measurements. The FERRs of the measurements are proportional to the expected upper bounds of the measurements. For example, suppose the FERR bound of a 4-digit volt meter is ± 1 count, if the range is 1 V, the FERR

bound of the measurement is ± 1 mV; if the reading is 1 kV, the FERR bound of the measurement is ± 1 V. This means that the larger the upper bounds of the measurements the larger the FERRs. Therefore, in utility programs the weighting matrix \mathbf{WP} gives weights according to the expected upper bounds of measurements: the larger the expected upper bounds, the less the associated weights. The upper bounds of a line power flow are usually taken as the rating of the line.

The practically used weighting matrix is a diagonal matrix \mathbf{W} , where

$$W(i, i) = \frac{1}{EUBOUND_i} \quad (1.10)$$

$EUBOUND_i$ stands for the expected upper bound of i th system measurement error.

The practically used weighting matrix is different from that usually used in the literature. The reason is thought to be the following:

1. Some meters in power systems are several decades old, so their accuracies are impossible to know economically.
2. If in real life \mathbf{WU} is used, then it has to be recalculated when measurements change, *i.e.*, the weighting matrix has to be recalculated. This lengthens the computation time.

1.7 Possible Weighting Matrices

In the former section, it is said that the usually used weighting matrix is expressed by equation (1.9). How about a weighting matrix \mathbf{W} , with $W(i, i) = \frac{1}{|(ERR \times M)_i| + |FERR_i|}$? This weighting matrix gives the more accurate measurements more weight, as it is supposed to be.

It can be observed also that a small measured value has a larger relative error but smaller absolute error and hence greater weight (in **WU**) despite the larger relative error. To give the larger measurements (which have smaller relative errors) greater weight, one can try multiplying each diagonal element of **WU** by its corresponding measurement M_i or its corresponding measurement squared, M_i^2 .

From the discussion in section 1.3, it is shown that if each element of the weighting matrix (**WU**) is divided by the corresponding measurements, then the resulting iterative equation minimizes the SSRE instead of the used SSE.

Based on the observation made above, the following weighting matrices are tested:

$$\begin{aligned}
W1(i, i) &= 1 \\
W2(i, i) &= \frac{1}{|(ERR \times M)_i| + |FERR_i|} \\
WU(i, i) &= \frac{1}{(|(ERR \times M)_i| + |FERR_i|)^2} \\
WP(i, i) &= \frac{1}{EUBOUND_i} \\
W4(i, i) &= \frac{1}{(|(ERR \times M)_i| + |FERR_i|)^2} \times |M_i| \\
W5(i, i) &= \frac{1}{(|(ERR \times M)_i| + |FERR_i|)^2} \times M_i^2 \\
W6(i, i) &= \frac{1}{|(ERR \times M)_i| + |FERR_i|} \times |M_i| \\
W7(i, i) &= \frac{1}{|(ERR \times M)_i| + |FERR_i|} \times M_i^2 \\
W8(i, i) &= \frac{1}{|(ERR \times M)_i| + |FERR_i|} \times \frac{1}{M_i^2} \\
W9(i, i) &= \frac{1}{(|(ERR \times M)_i| + |FERR_i|)^2} \times \frac{1}{M_i^2}
\end{aligned}$$

$$W10(i, i) = \frac{1}{|(ERR_i \times M)_i| + |FERR_i|} \times \frac{1}{|M_i|}$$

$$W11(i, i) = \frac{1}{(|(ERR \times M)_i| + |FERR_i|)^2} \times \frac{1}{|M_i|}$$

Actually the possible matrices are not limited to these, but in this thesis we have attempted to find out the best weighting matrix among them. Studies using these weighting matrices are described and conducted in the next two chapters.

1.8 Thesis outline

The main goal of this thesis is to find the optimal weighting matrix to be used in the WLS method, and to compare the performances of the usually used one, the practically used one, and the unit one. In Chapter 2, preparation for these studies is done by defining performance indices to be used for state comparison, and by determining the number of cases needed to simulate. Also in Chapter 2 the programs used to conduct these studies are explained.

Chapter 3 is devoted to studying the effect of weighting matrices using the IEEE 14-bus test system and the IEEE 30-bus test system. The effects of using different weighting matrices are tested under different conditions and the best weighting matrices are selected. Also, the effects of weighting matrices **WU** and **WP**, unity weighting matrix **W1**, and the best of the rest of those defined in the previous section are compared. At the end of this chapter, the conclusions of the thesis study are given.

Chapter 2

PLAN FOR WEIGHTING MATRICES STUDIES

2.1 Introduction

In the studies in this thesis, all true values are assumed to be known. Simulated measurements are generated based upon them. However, in real life systems, the true quantities are unknown and obtaining an estimate of them is the objective of state estimation.

To find the effects of the different weighting matrices, the IEEE 14-bus test system and the IEEE 30-bus test system are used. The IEEE 14-bus test system is used to develop and debug the program and conduct studies. Also the IEEE 30-bus test system is used to conduct some studies. The obtained results are in Appendix D and the analysis of these results appear in Chapter 3. This chapter explains the approach adopted for the studies to be conducted.

Before conducting studies on the effect of the different weighting matrices, several things must be made clear, these are:

- What indices to be used to judge the qualities of the states obtained using

different weighting matrices?

- How to generate simulated measurements?
- How many different cases are needed to be simulated for a given instrumentation configuration of a certain system before a decision can be made about which weighting matrix is best? This is necessary because Monte Carlo type simulation will be used.

All of the above items are discussed in turn in section 2.2 to section 2.4. Also, in section 2.5, the program used to conduct studies is explained.

2.2 Indices Used for State Comparison

In the foregoing chapter, possible weighting matrices were mentioned. The best weighting matrix, of course, is the one that gives the best state estimate in a competitive solution time. The question of what constitute a “best state estimate” is open to discussion and perhaps further research. In this thesis, four sets of indices are used for state comparison and these are defined in the following:

- Index set one

$$JCT = \sum_i (C_i - T_i)^2 \times 100$$

$$JCM = \sum_i (C_i - M_i)^2 \times 100$$

$$JMT = \sum_i (M_i - T_i)^2 \times 100$$

where C, M and T denote calculated, measured and true values, respectively. The summation index i is from 1 to NM, the number of measurements actually used.

JCT and JCM indicate how close the calculated (or estimated) state is to the true one and to the measured one respectively. JMT indicates the level of error in the measurements with respect to the true values, useful for comparison purposes.

The use of this set of indices for comparison purposes comes to mind first because state estimation programs usually aim at minimizing the weighted sum of the squared residuals (*i.e.* JCM). This set of indices takes into account only those variables whose corresponding measurements are taken. In order to consider the fitness of all the system variables, it is necessary to use index set two:

- Index set two

$$AJCT = \sum_i |C_i - T_i|$$

$$AJMT = \sum_i |M_i - T_i|$$

$$AJCM = \sum_i |C_i - M_i|$$

where summation index i is from 1 to NMM, the maximum possible number of measurements that could be obtained.

In real systems only JCM can be obtained as the others involve either true values or unavailable “measured” values.

The above two sets of indices are all absolute quantities. The reason that only absolute quantities are used is that in a electric power system there are buses and lines that have no load or very light load. (This is true for both the IEEE 14-bus test system and the IEEE 30-bus test system that are used in this thesis.) Under this situation, relative quantities are very large and therefore useless. The disadvantage of using only absolute quantities is that they will not give us any indication of how significant the differences (or squared differences) between C and T, M and T, and

C and M are relative to C, M or T values. One way to overcome this disadvantage is to introduce the following index set three:

- Index set three

$$PJCT = \frac{\sum_i |C_i - T_i|}{\sum_i |T_i|}$$

$$PJMT = \frac{\sum_i |M_i - T_i|}{\sum_i |T_i|}$$

$$PJCT = \frac{\sum_i |C_i - M_i|}{\sum_i |M_i|}$$

where summation index i is from 1 to NMM, the maximum possible number of measurements that could be obtained.

- Index set four

$$CTX = MAX |C_i - T_i|$$

$$MTX = MAX |M_i - T_i|$$

$$CMX = MAX |C_i - M_i|$$

where index i is from 1 to NMM, the maximum possible number of measurements that could be obtained. and their corresponding relative values

$$CTRX = \frac{|C_i - T_i|}{|C_i|}$$

$$MTRX = \frac{|M_i - T_i|}{|M_i|}$$

$$CMRX = \frac{|C_i - M_i|}{|C_i|}$$

This set of indices is used because it is possible that most elements of one estimated state are very close to their corresponding true values or to their corresponding measured values, while large differences may exist between one or two estimated

elements and their corresponding true ones and/or their corresponding measured values. It is necessary therefore, to examine the largest difference between these corresponding values. Indices CTRX, MTRX and CMRX give the relative values of these corresponding largest differences. It can be noticed that the element that has the largest difference is not necessarily the one that has the largest relative difference.

Since many cases were simulated in the study, the maximum, average and standard deviation of all the above indices were used as the actual indices when comparing the states.

2.3 Simulated Measurements Generation

In the studies in this thesis, the true values of all system variables are assumed; measurements are simulated by adding random errors to these true values. Of course, in real systems not all possible measurements are taken. And if there are no errors in the measured values, then only K measurements are needed where K is the number of state variables. But because of the existence of errors, more measurements are used. The ratio of the number of used measurements to K is called measurement redundancy or redundancy. This ratio is about 2 in real systems. A redundancy of 2 will be used throughout this thesis.

For the IEEE 14-bus test system, the number of state variables is 27 and therefore 54 simulated measurements are selected randomly from the available simulated measurements. Many instrumentation configurations are used for the 14-bus system studies. Two of them are studied in detail, instrumentation configuration 14-A and 14-B, defined as follows:

- Instrumentation configuration set 14-A:

$P_{1-14} : 10100011000000$

$Q_{1-14} : 10100011000000$

$V_{1-14} : 10100011000000$

$PL_{1-40} : 1011011011010001011011000001011011011100$

$QL_{1-40} : 1011011011010001011011000001011011011100$

- Instrumentation configuration set 14-B:

$P_{1-14} : 00100100110000$

$Q_{1-14} : 00100100110000$

$V_{1-14} : 00100100110000$

$PL_{1-40} : 1010111000101101100101010010111000110011$

$QL_{1-40} : 1010111000101101100101010010111000110011$

where P is nodal real power, Q is nodal reactive power, V is nodal voltage, PL is real power flow, and QL is reactive power flow.

Each position in the above strings corresponds to a possible measurement. If the measurement is used, then a nonzero occupies that position; if it is not used a “0” occupies its corresponding position. Later on, when it is necessary to use meters of different accuracies, the accuracy of the measurement can be indicated in a string similar to the above.

Meters are classified into four categories according to their accuracies. Therefore, if a measurement is used and it is of category 2, then a “2” would appear on its corresponding position in the above measurements’ strings.

For nodal real and reactive power injections and flows, the maximum ERR of the four categories are 3 %, 6 %, 9 % and 12 %, respectively. The corresponding FERRs are 0.0035 , 2×0.0035 , 3×0.0035 and 4×0.0035 , respectively. For voltage measurements, the maximum ERRs of the four categories are 0.45 %, 0.9 %, 1.35 % and 1.8 %, respectively. The corresponding FERRs are 0.003 , 2×0.003 , 3×0.003 and 4×0.003 , respectively. These errors are exaggerated to amplify the differences between the different methods to be used.

Simulated measurements are generated according to

$$M_i = ERR_i \times T_i \pm FERR_i$$

where M and T denote simulated measurements and true values, respectively. ERR_i is assumed to be normally distributed with a 3σ of maximum ERR. $FERR_i$ is assumed constant but its sign is chosen at random. How this is implemented in the program is described in section 2.5.

2.4 Number of Cases

In this thesis the Monte Carlo simulation technique is used; therefore, a large number of cases need to be studied. How many cases are enough? To answer that question, a large number of cases are studied and the values of performance indices are examined as the number of cases is increased.

A “case” is determined by the measured values obtained by the assumed instrumentation configuration. Practically, a case is determined by a “seed” that is used

to generate ERR_i and the sign of $FERR_i$.

The studies conducted here use instrumentation configuration 14-A of IEEE 14-bus system without weighting matrix. The objective is to determine the number of cases above which the values of indices are considered stable.

Table 2.1 contains the values of performance indices JCT, JCTSIG, AJCT and AJCTSIG. These are obtained using different numbers of cases generated using the seeds shown. From Table 2.1, it is seen that the differences in the values of a performance index depend on the seeds used, but these differences become smaller as the number of cases become larger.

<i>number of cases</i>	<i>seed</i>	<i>JCTAVE</i>	<i>JCTSIG</i>	<i>AJCTAVE</i>	<i>AJCTSIG</i>
20	43	0.5324	0.4728	1.0794	0.1437
20	1043	0.6381	0.4301	1.1061	0.1907
20	2043	0.7536	0.6967	1.1332	0.2237
30	43	0.5269	0.4810	1.0941	0.1638
30	1043	0.6826	0.4189	1.1361	0.2268
30	2043	0.6549	0.5896	1.1589	0.2028
40	43	0.6677	0.6977	1.1038	0.1770
40	1043	0.7492	0.5649	1.1659	0.2438
40	2043	0.7008	0.6934	1.1421	0.2483
100	43	0.6685	0.6379	1.1244	0.2118
100	1043	0.6617	0.5662	1.1410	0.2380
100	2043	0.6766	0.6174	1.1370	0.2347

Table 2.1: Values of performance indices obtained using different simulated case numbers and different seeds. Measurement set 14-A is used. weighting matrix used is $W1$.

The usefulness of Table 2.1 is that it determines if the conclusions to be made about the relative effectiveness of using different weighting matrices are valid or not. For example, if 20 cases are used to calculate JCTAVE using weighting matrices W_x

and W_y , and the difference between these JCTAVEs is close to the corresponding difference shown in Table 2.1, then using W_x or W_y will not result in a statistically significant difference between the resulting JCTAVEs.

The number of cases needed may vary if a different system is studied; it may also vary if different instrumentation configurations of the same system are used. Based on many experiments leading to tables similar to Table 2.1, it is judged that 20 cases are sufficient and that number of cases is used frequently. However in this thesis 60 cases are also studied to make sure of the validity of the arrived at conclusions.

2.5 Explanation of the Program Used

To study the effects of weighting matrices, a PSSE program is developed and used. The program includes subroutines: 'SYSDATA', 'MG', 'NRAN', 'WMG', 'EJACO', 'PQLCAL', 'EDELTA', 'TEST', 'PI', 'STAM', 'PQCAL', 'CLF', 'DELTA', 'TRAN', 'XRR', 'INVERM', 'FACTO', 'JACOB', 'TESTPO', 'UTION', 'FRANK' and 'RANDOM'. The first 10 subroutines, together with the main program, are presented in Appendix C. The rest of the subroutines are not listed because they can be found in [18 – 19].

Figure 2.1 shows the flow chart of the program used. The following explanatory notes are numbered to correspond with the block numbers in the flow chart they pertain to:

(1): System parameters along with other data are read (by calling subroutine 'SYSDATA'). The input data files for the IEEE 14-bus test system and the IEEE 30-bus test system are shown in Appendix A. The nodes of both systems were

renamed so that the PV nodes are numbered last.

(2): Load flow calculation is performed to establish the true values of state variables. Subroutine 'FRANK' is called to do this job. In the studies in this thesis, the state obtained from this load flow run is assumed to be the true state.

(3): The true state is used to calculate the true values of all system variables: real and reactive power injections, flows, and nodal voltages. The subroutines used for that purpose are 'PQCAL', 'PQLCAL' and 'CLF'.

(5): Random errors are added to the true system variables to simulate measurements.

In the program, blocks (3) and (5) are done in a subroutine called 'MG', to simulate one measurement, it does following operations:

- Determine the true value of i th system variable.
- Depending on the i th meter category, the standard deviation of the proportional error, σ_i , and the fixed error $FEER_i$ for the i th measurement are determined. NRAN, a subroutine to generate normally distributed random number NDR, is used to give random proportional error, $(ERR \times M)_i$ of the i th measurement, using a standard deviation σ_i .
- Let NDR_i be bounded as desired. If NDR_i is greater than $3 \times \sigma_i$, then $NDR_i = 3 \times \sigma_i$; if NDR is less than $-3 \times \sigma_i$, then $NDR_i = -3 \times \sigma_i$.
- Let the i th measurement equals true value plus a percentage error $(ERR \times M)_i$, where ERR_i is $NDR_i \times T$, T is the true value.
- Generate a uniformly distributed random number RAN_i to decide whether

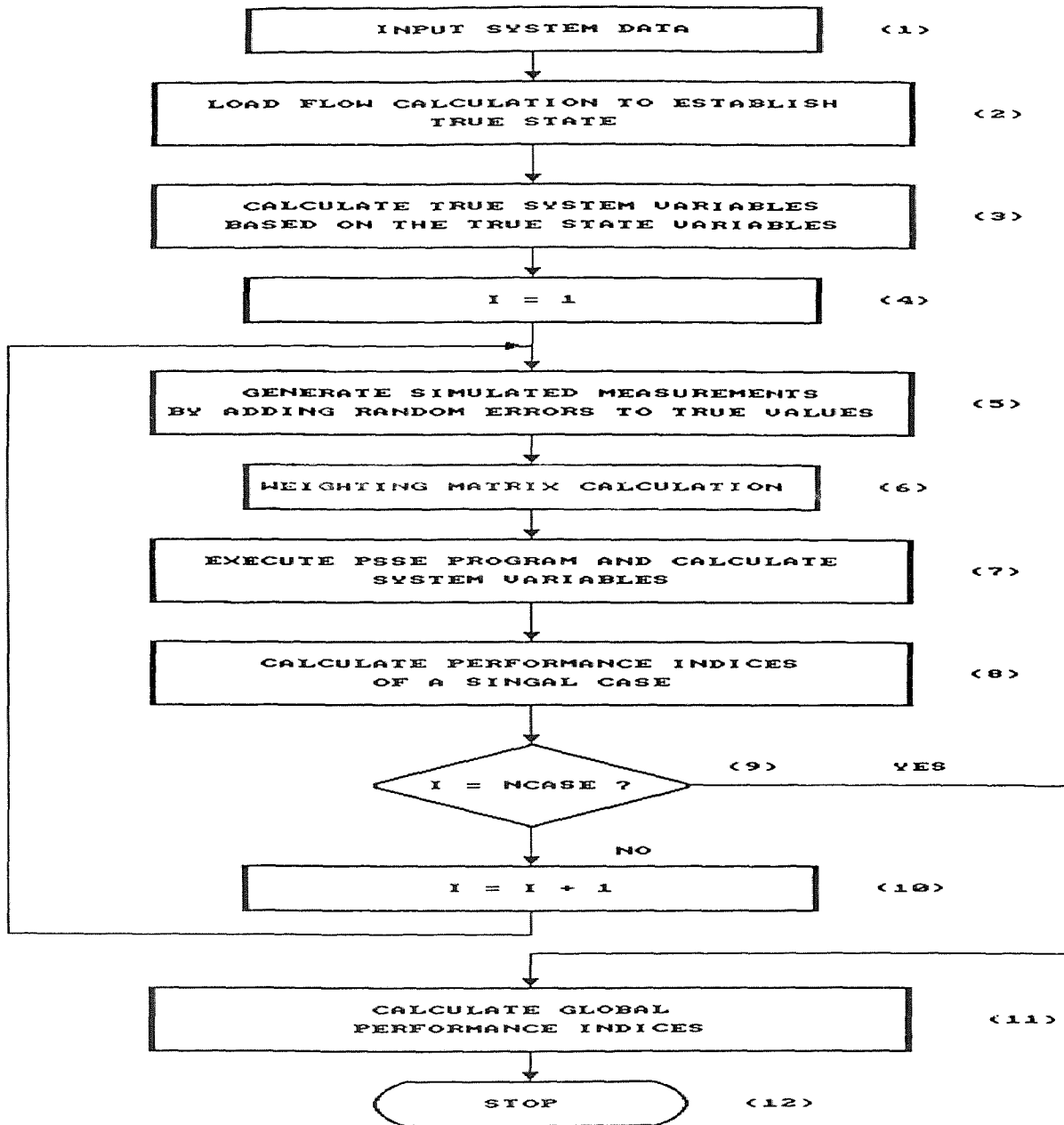


Figure 2.1: Flow chart of the main program

$FEER_i$ should be added to or subtracted from the i th measurement. If RAN_i is greater than zero, $FEER_i$ is added to i th measurement.

Section 2.3 has explained the logic behind it.

(6): This block calculates the weighting matrix. In this thesis 12 different weighting matrices are tested and compared.

(7): Subroutines 'PQCAL', 'PQLCAL' and 'CLF' are called to calculate system variables after the state is estimated.

(11): Call Subroutine 'STAM' to calculate the maximum, average and standard deviation of the values of each kind of performance index.

Chapter 3

STUDY CONDUCTED ON EFFECTS OF WEIGHTING MATRICES

This chapter contains the analyses of the results obtained when different weighting matrices are used under various conditions.

This chapter consists of five sections. Section 3.1 contains the analysis of the calculated values of the performance indices obtained using the different weighting matrices proposed in section 1.7. Based on the analysis, some weighting matrices are eliminated and excluded from further studies. Beginning from section 3.2, all studies are conducted on the selected weighting matrices. Through these studies, performances of weighting matrices are compared. Section 3.2 studies the effect of weighting matrices using Fixed Jacobian Method (FJM) PSSE program. Section 3.3 studies the effect of weighting matrices when measurement errors are amplified. Studies conducted on the 30-bus system are presented in section 3.4. Section 3.5 is the summary of the thesis.

3.1 Analysis of the Values of Performance Indices Using Different Weighting Matrices

This section contains the analysis of the values of various performance indices obtained using different weighting matrices. These values are in Appendix D, Table D.1 through Table D.5. The conditions under which the values are obtained are stated below:

1. The seed used is set to 2043 at the beginning of the program
2. The convergence criterion is 0.005
3. The measurements are simulated as explained in section 2.4
4. The number of simulated cases is either twenty or sixty

The reason for choosing the convergence criterion to be 0.005 is that if this value is reduced, the computing time will be increased considerably while the improvement in the estimated states is insignificant. The study for the convergence criterion for PSSE can be found in [20].

The studies in this chapter, unless otherwise stated, are performed under the above conditions.

For instrumentation configuration 14-A, when weighting matrices **W8** and **W9** are used, the PSSE program diverges. This did not happen when instrumentation configuration 14-B was used. The reason for divergence is thought to be the very large amplification of $W(i, i)$ if measurement i is very small. The solution to this problem is to use combined weighting matrices: for small measurements, minimizing SSE; for large measurements, minimizing SSRE; so that division by small values

of measurements is avoided. In Chapter 1, section 3, it is pointed out that for large measurements minimizing SSE is better while for small measurements minimizing SSRE is better; therefore using the combined weighting matrix is not a good solution.

Under instrumentation configuration 14-B, the number of iterations needed when weighting matrix **W8** is used is 6.9, and when weighting matrix **W9** is used, the number is 7.2667. When all the other weighting matrices are used, the number of iterations needed is 3 no matter what instrumentation configuration is chosen except when **W11** is used, the needed number of iterations is 4 when instrumentation configuration 14-A is used.

To select the promising matrices for further studies, values of performance indices obtained using different weighting matrices are analysed.

From the results in Appendix D, it can be found that the estimated states obtained using weighting matrices **W2**, **WU** and **W4** are closer to the true state than that obtained using **W1**. This is because:

- The major performance indices JCTAVEs and AJCTAVEs obtained using **W2**, **WU** and **W4** are all better than that obtained using **W1**. JCTAVE indicates how close the estimated values (whose corresponding measurements are available) is to the true ones, while AJCTAVE indicates the fitness of all the estimated system variables to the true ones. A better state estimate method usually results lower JCTAVE and AJCTAVE values.
- When **W2**, **WU** and **W4** are used, the largest mismatches between calculated values and true ones are less than that resulting from using **W1**.

Table 3.1 and 3.2 give the values calculated by dividing performance indices JCTMAX, JCTAVE, JCTSIG, AJCTMAX, AJCTAVE and AJCTSIG obtained using weighting matrices W_2 , W_U and W_4 by that obtained using weighting matrix W_1 under instrumentation configuration 14-A and instrumentation configuration 14-B, respectively.

Weighting matrices W_2 , W_U and W_4 are selected for further studies.

<i>normalized indices</i>	W_2	W_U	W_4
$JCTMAX_{W_i}/JCTMAX_{W_1}$	22.03%	10.33%	19.07%
$JCTAVE_{W_i}/JCTAVE_{W_1}$	30.02%	20.73%	33.73%
$JCTSIG_{W_i}/JCTSIG_{W_1}$	21.34%	7.99%	15.73%
$AJCTMAX_{W_i}/AJCTMAX_{W_1}$	68.16%	63.51%	86.91%
$AJCTAVE_{W_i}/AJCTAVE_{W_1}$	74.01%	69.24%	85.82%
$AJCTSIG_{W_i}/AJCTSIG_{W_1}$	52.88%	41.26%	74.79%

Table 3.1: Normalized values of performance indices with those obtained using W_1 as a reference. Data used to obtain the values in this table are in Table D.1.

<i>normalized indices</i>	W_2	W_U	W_4
$JCTMAX_{W_i}/JCTMAX_{W_1}$	79.11%	91.96%	92.52%
$JCTAVE_{W_i}/JCTMAX_{W_1}$	73.79%	69.38%	82.85%
$JCTSIG_{W_i}/JCTSIG_{W_1}$	90.34%	101.20%	114.86%
$AJCTMAX_{W_i}/AJCTMAX_{W_1}$	80.50%	80.76%	85.69%
$AJCTAVE_{W_i}/AJCTAVE_{W_1}$	79.94%	76.53%	82.59%
$AJCTSIG_{W_i}/AJCTSIG_{W_1}$	52.88%	77.15%	85.08%

Table 3.2: Normalized values of performance indices with those obtained using W_1 as a reference. Data used to obtain the values in this table are in Table D.3.

For weighting matrices W_P , according to the way by which the measurements are simulated and also according to the way by which the weights are given, the

performance of **WP** can be better than that of **W1** or worse than that of **W1**. The reasons are the following:

- **W1** gives each simulated measurement the same weight despite the fact that each simulated measurement is of different accuracy.
- **WP** gives the larger weight to the simulated measurements which have lower expected upper bounds. And the simulated measurements that have lower expected upper bounds may or may not be more accurate than those simulated measurements that have higher expected upper bounds. **WP** is used in practice since generally speaking measurements with larger expected upper bounds have less accuracy.

The results in Appendix D support the above observations. Since **WP** is the practically used one, it will be used in the later studies to compare with other weighting matrices.

Also from results in Appendix D, it can be seen that using **W5**, **W7**, **W8** and **W9** are inappropriate. The reasons are:

- The performances of weighting matrices **W5**, **W7**, **W8** and **W9** are much worse than that of unit weighting matrix **W1**.

Indices JCTAVEs and AJCTAVEs obtained using **W5**, **W7**, **W8** and **W9** are all worse than that obtained using **W1**. Table 3.3 and 3.4 give the values calculated by dividing performance indices JCTMAX, JCTAVE, JCTSIG, AJCTMAX, AJCTAVE and AJCTSIG obtained using weighting matrices **W5**, **W7**, **W8** and **W9** by that obtained using weighting matrix **W1** under instrumentation configuration

<i>normalized indices</i>	<i>W5</i>	<i>W7</i>
$JCTMAX_{W_i}/JCTMAX_{W_1}$	1.0484	3.4520
$JCTAVE_{W_i}/JCTAVE_{W_1}$	2.1255	5.7370
$JCTSIG_{W_i}/JCTSIG_{W_1}$	0.9706	3.7597
$AJCTMAX_{W_i}/AJCTMAX_{W_1}$	2.3644	5.0393
$AJCTAVE_{W_i}/AJCTAVE_{W_1}$	2.0868	3.3480
$AJCTSIG_{W_i}/AJCTSIG_{W_1}$	2.9419	7.0331

Table 3.3: Normalized values of performance indices with those obtained using **W1** as a reference. Data used to obtain the values in this table are in Table D.1 and Table D.2.

<i>normalized indices</i>	<i>W5</i>	<i>W7</i>	<i>W8</i>	<i>W9</i>
$JCTMAX_{W_i}/JCTMAX_{W_1}$	8.1677	36.2659	28.9730	59.5717
$JCTAVE_{W_i}/JCTAVE_{W_1}$	6.8476	17.1342	15.6061	30.4753
$JCTSIG_{W_i}/JCTSIG_{W_1}$	1.3291	44.8679	43.2838	92.0706
$AJCTMAX_{W_i}/AJCTMAX_{W_1}$	2.5223	4.9264	3.5186	60.0234
$AJCTAVE_{W_i}/AJCTAVE_{W_1}$	1.9436	3.1868	2.7673	4.6466
$AJCTSIG_{W_i}/AJCTSIG_{W_1}$	4.2908	9.2597	6.4759	69.0142

Table 3.4: Normalized values of performance indices with those obtained using **W1** as a reference. Data used to obtain the values in this table are in Table D.3 and Table D.4.

14-A and instrumentation configuration 14-B, respectively. Also, when **W5**, **W7**, **W8** and **W9** are used, the largest mismatches between calculated values and true ones are larger than that resulting from using **W1**, which can be seen from Table D.5 in Appendix D.

- When **W5**, **W7**, **W8** and **W9** are used, the distances between estimated values and true ones are much greater than that between measurements and true ones. This can be seen from Table 3.5 and Table 3.6.

<i>normalized indices</i>	<i>W5</i>	<i>W7</i>
(JCTMAX-JMTMAX)/JMTMAX	-0.2988	1.3087
(JCTAVE-JMTAVE)/JMTAVE	0.1528	2.1115
(JCTSIG-JMTSIG)/JMTSIG	-0.3278	1.6038
(AJCTMAX-AJMTMAX)/AJMTMAX	3.0051	7.5359
(AJCTAVE-AJMTAVE)/AJMTAVE	2.2412	4.2000
(AJCTSIG-AJMTSIG)/AJMTSIG	8.9261	22.7300

Table 3.5: Normalized values of performance indices. Data used to obtain the values in this table are in Table D.2.

<i>normalized indices</i>	<i>W5</i>	<i>W7</i>	<i>W8</i>	<i>W9</i>
(JCTMAX-JMTMAX)/JMTMAX	3.5650	19.2691	15.1931	32.2948
(JCTAVE-JMTAVE)/JMTAVE	2.4196	7.5566	6.7935	14.2190
(JCTSIG-JMTSIG)/JMTSIG	6.6574	24.8495	23.9368	52.0441
(AJCTMAX-AJMTMAX)/AJMTMAX	2.4363	5.7118	3.7937	57.7863
(AJCTAVE-AJMTAVE)/AJMTAVE	1.1507	2.5265	2.0623	4.1419
(AJCTSIG-AJMTSIG)/AJMTSIG	10.6215	24.0793	16.5396	6.3686

Table 3.6: Normalized values of performance indices. Data used to obtain the values in this table are in Table D.4.

It is known that the distances between estimated values and true ones may be greater than those between measurements and true ones. But if the distances between estimated values and true ones several times greater than those between measurements and true ones, the method of estimate is not suitable, actually is useless.

- Weighting matrices **W8** and **W9** can not be used under certain instrumentation configurations. And using **W8** or **W9** needs more solution time, since more iterations are needed.

Since **W5**, **W7**, **W8** and **W9** are proved to be inappropriate. They are no longer used in the later studies.

Table 3.7 and 3.8 are created using the data in Table D.1, D.2, D.3 and D.4. Table 3.7 and 3.8 give the values calculated by dividing performance indices JCTMAX, JCTAVE, JCTSIG, AJCTMAX, AJCTAVE and AJCTSIG obtained using weighting matrices **W6**, **W10** and **W11** by that obtained using weighting matrix **W1** under instrumentation configuration 14-A and instrumentation configuration 14-B, respectively.

<i>normalized indices</i>	<i>W6</i>	<i>W10</i>	<i>W11</i>
$JCTMAX_{W_i}/JCTMAX_{W_1}$	0.4716	0.9532	0.5850
$JCTAVE_{W_i}/JCTMAX_{W_1}$	0.6515	1.2170	0.9465
$JCTSIG_{W_i}/JCTSIG_{W_1}$	0.4508	1.0112	0.7400
$AJCTMAX_{W_i}/AJCTMAX_{W_1}$	1.1975	1.1455	1.1106
$AJCTAVE_{W_i}/AJCTAVE_{W_1}$	1.1413	1.0985	1.0125
$AJCTSIG_{W_i}/AJCTSIG_{W_1}$	1.2204	1.2496	0.9432

Table 3.7: Normalized values of performance indices with those obtained using **W1** as a reference. Data used to obtain the values in this table are in Table D.1 or D.2.

<i>normalized indices</i>	<i>W6</i>	<i>W10</i>	<i>W11</i>
$JCTMAX_{W_i}/JCTMAX_{W_1}$	1.1853	1.9179	2.6922
$JCTAVE_{W_i}/JCTMAX_{W_1}$	1.0946	1.5938	2.4405
$JCTSIG_{W_i}/JCTSIG_{W_1}$	1.4399	2.3123	4.1772
$AJCTMAX_{W_i}/AJCTMAX_{W_1}$	1.1652	1.2907	1.2907
$AJCTAVE_{W_i}/AJCTAVE_{W_1}$	1.0004	1.1886	1.2720
$AJCTSIG_{W_i}/AJCTSIG_{W_1}$	1.4721	1.6219	1.6469

Table 3.8: Normalized values of performance indices with those obtained using **W1** as a reference. Data used to obtain the values in this table are in Table D.3 or D.4.

Because the values in Table 3.4 corresponding to **W11** are the values obtained using one more iteration than the others, and the largest mismatch between calculated values and true ones obtained using **W11** is 0.1304, more than 70 % larger than that obtained using **W1**, **W11** is no longer used since its is worse than without weighting matrix.

For the same reason that the performance of **W10** is not better than without weighting matrix, weighting matrix **W11** is also no longer used in the later studies.

For instrumentation configurations 14-A and 14-B, the promising weighting matrices are **W2**, **WU**, **W4** and **W6**. This conclusion is valid since many other instrumentation configurations are used to test. The results of some are presented in Table D.6 in Appendix D. These results support the conclusion.

Based on the above analysis, the following weighting matrices: **W1**, **W2**, **WU**, **WP**, **W4** and **W6** are selected for further studies. **W1** and **WP** are selected for comparison purpose.

Practically, FJM PSSE programs are widely used; thus results in the next two sections are obtained using a FJM PSSE program.

3.2 Using FJM PSSE program

The Jacobian matrix of (1.5) gives the linearized relationship between small changes in voltage angles and magnitudes, $\Delta\delta$ and $\Delta\mathbf{V}_k$, small changes in real and reactive power injections, $\Delta\mathbf{PN}_k$ and $\Delta\mathbf{QN}_k$, and real and reactive power flows $\Delta\mathbf{PL}_k$ and $\Delta\mathbf{QL}_k$.

Ordinarily, equation (1.5) is solved by computing the residuals, multiplying by the inverse of the Jacobian to obtain the corrections, computing new residuals, etc.

To accelerate the solution speed, the standard technique is to reuse the Jacobian matrix of one iteration for several successive cycles without recomputing it. The process is continued until the problem is solved or the decrease in rate of improvements indicates that the Jacobian should be recalculated at the new operating point [21].

In the studies in this section, the Jacobian matrix calculated at the first iteration is kept and reused until the solution is achieved. Usually, using the FJM method will increase the number of needed iterations but this is not necessarily the case. The weighting matrices tested using FJM PSSE program are **W1**, **W2**, **WU**, **WP**, **W4** and **W6**. Testing results are in Tables D.7, D8 and D.9 in Appendix D.

From the testing results, following the same analysis in the last section, it can be concluded that using appropriate weighting matrices is better than not using any weighting matrix. When weighting matrices **W2**, **WU**, **W4** and **W6** are used, the values of performance indices JCTs and AJCTs obtained are better than that obtained using unit weighting matrix **W1**, which can be seen from Fig. 3.1. Values of JCTs obtained using weighting matrices **W2** and **WU** are 0.5408 and 0.6817, respectively; while the value of JCT obtained using **W1** is 1.0154. The differences between the former two JCTs and the last JCT are much larger than those which may be caused by the changing of seeds used to generate different simulated cases, that is to say, using **W2** and **WU** will usually get better better results than using **W1**. When instrumentation configuration 14-A is used, The largest differences between calculated values and true values obtained using **W2**, **WU**, **W4**, **W6** and **WP** are smaller than that obtained using **W1**.

Also from the testing results, it can be seen that when weighting matrices **W2**, **WU**, **W4** and **W6** are used, the values of performance indices JCTs and AJCTs obtained are better than that obtained using unit weighting matrix **W1**, which can be seen from Fig. 3.2. But the conclusion can not be drawn that using weighting matrices **W2**, **WU**, **W4** and **W6** will always get better values of performance indices JCTs and AJCTs than using unit weighting matrix **W1**, since the differences are small, and the change of seeds, which are used to generate simulated cases, may cause such differences. Also, the largest differences between calculated values and true values obtained using **W2**, **WU**, **W4**, **W6** and **WP** are smaller than that obtained using **W1**.

In order to enlarge the differences between the performances between different weighting matrices, in the studies in the next section, random errors used to generate simulated measurements are amplified.

3.3 Measurement Error Amplification

In this section, the ERRs and FERRs of each kind of meter are amplified three times. The results of the studies are in Tables D.10 through Table D.12 in Appendix D.

Analysing the testing results using the similar method used before, it can be found that the conclusions made in the last section is still valid in here and when errors are amplified the values of performance indices obtained using different weighting matrices are also amplified, which is expected. And the differences between values of performance indices JCTs and AJCTs obtained using different weighting

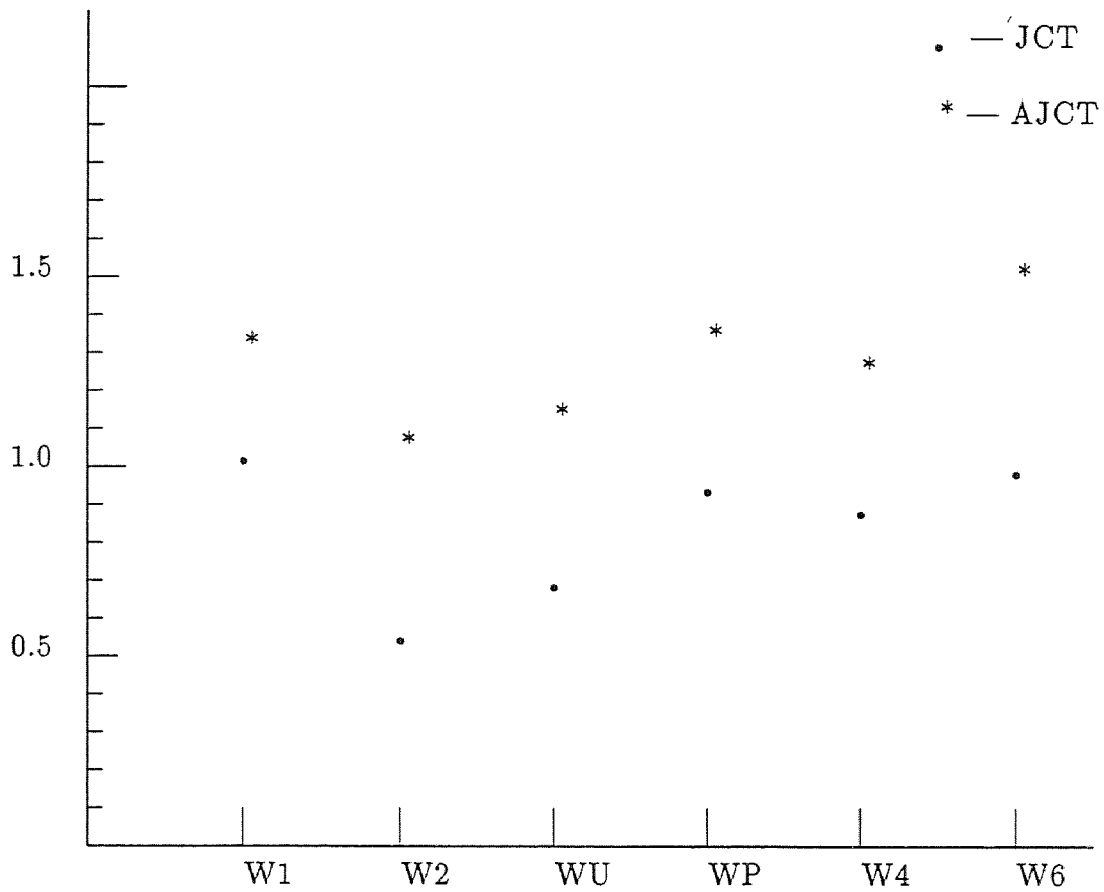


Figure 3.1: Values of performance indices JCT and AJCT obtained using different weighting matrices. Instrumentation configuration 14-A is used with a CRIT = 0.005. FJM PSSE program is used.

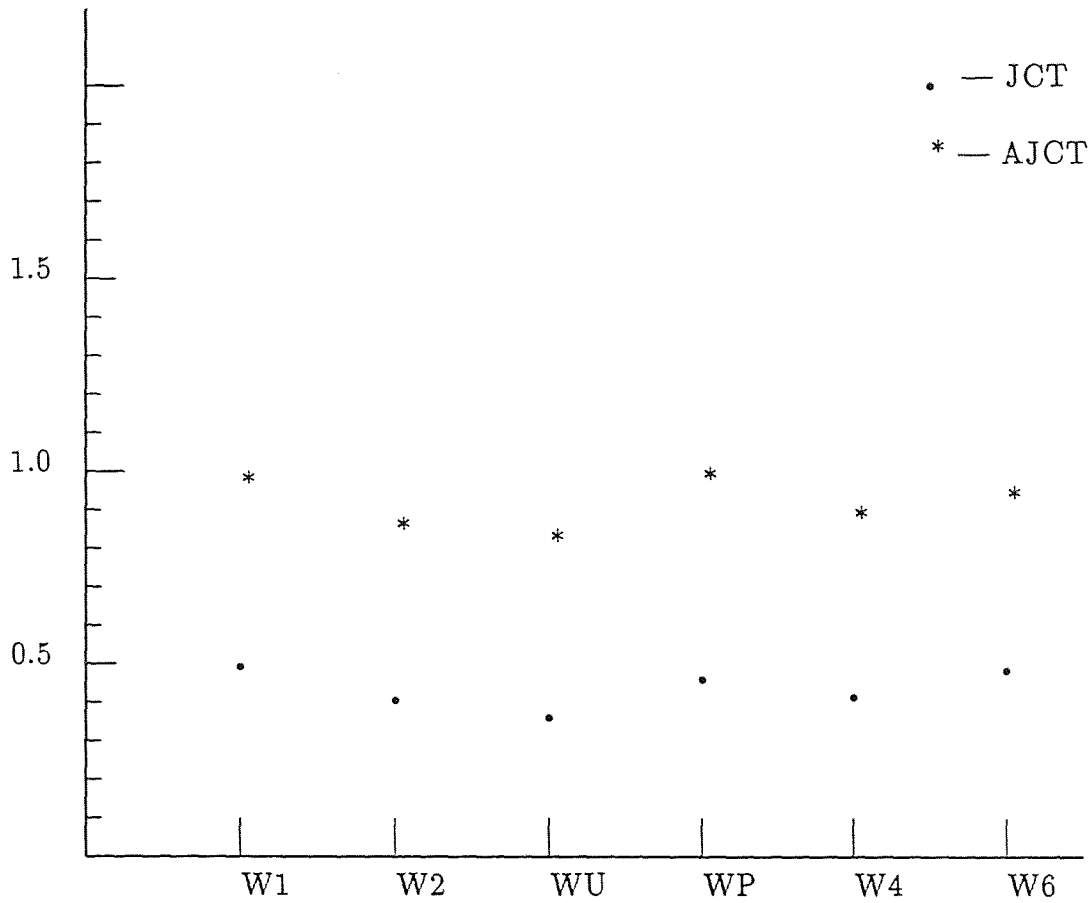


Figure 3.2: Values of performance indices JCT and AJCT obtained using different weighting matrices. Instrumentation configuration 14-B is used with a CRIT = 0.005. FJM PSSE program is used.

matrices are enlarged too, which can be seen from Fig.3.3 and Fig. 3.4. Fig. 3.3 and Fig. 3.4 give the values of performance indices JCTs and AJCTs obtained using different weighting matrices.

From the study in this section and the studies in former sections, it can be concluded that weighting matrices **W2**, **WU** are the best. And the decision of which one of **W2**, **WU** and **W4** is best can not drawn.

To verify the studies that have been done so far and also to test the weighting matrices's behaviors in a larger system, the studies in the next section is conducted on the IEEE 30-bus test system.

3.4 Testing Effects of Weighting Matrices Using the IEEE 30-bus Test System

In this section, an instrumentation configuration of 30-bus system is chosen to do the studies. It is defined as:

$$P_{1-30} : 021031001204120021000410020031$$

$$Q_{1-30} : 021031001204120021000410020031$$

$$V_{1-30} : 021031001204120021000410020031$$

$$PL_{1-82} : 30102004020000214030020300103021040010310$$

$$04001100201020400201000320010030200101000$$

$$QL_{1-82} : 30102004020000214030020300103021040010310$$

$$04001100201020400201000320010030200101000$$

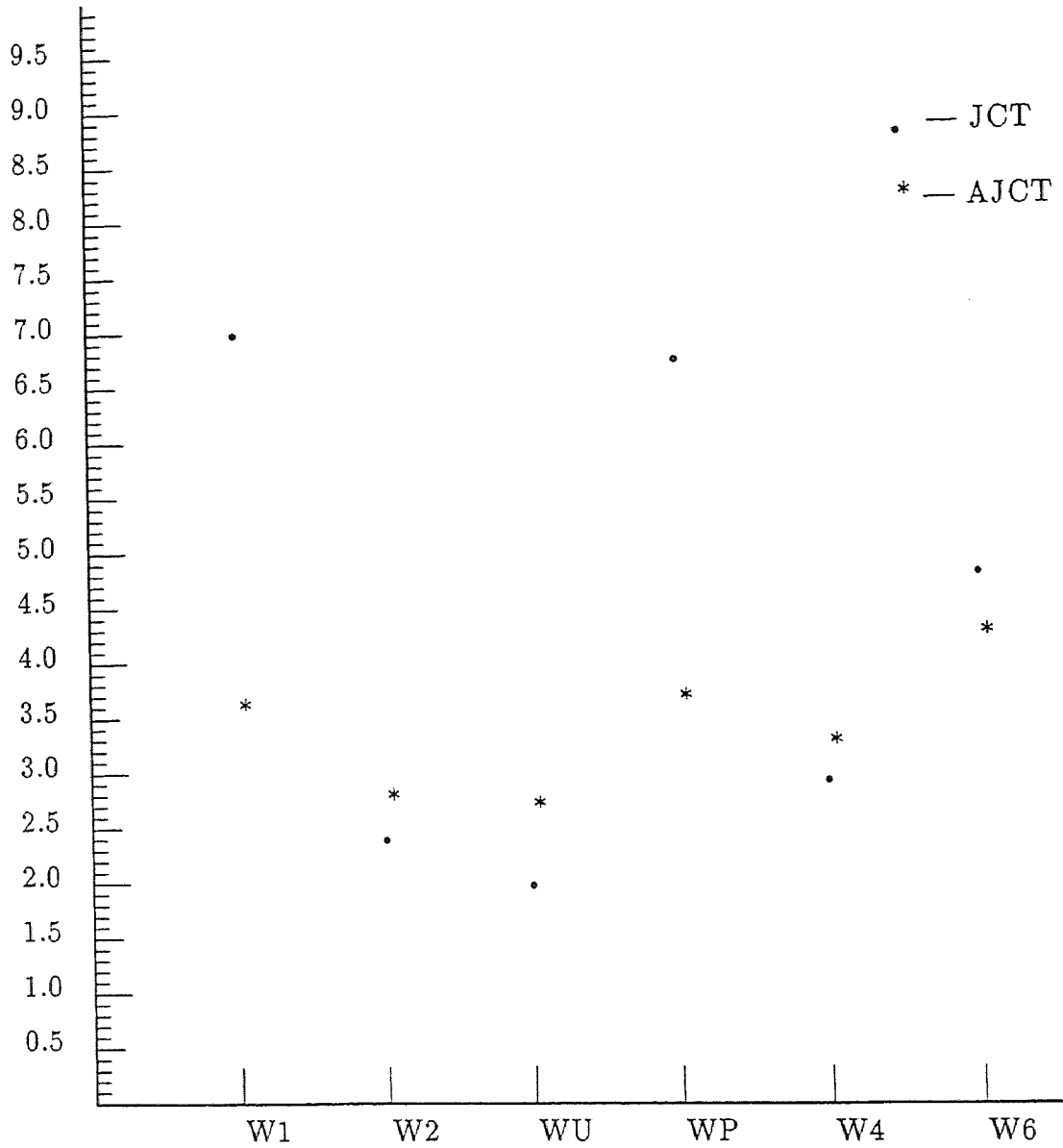


Figure 3.3: Values of performance indices JCT and AJCT obtained using different weighting matrices. Instrumentation configuration 14-A is used with a CRIT = 0.005. FJM PSSE program is used when errors introduced to measurements are amplified.

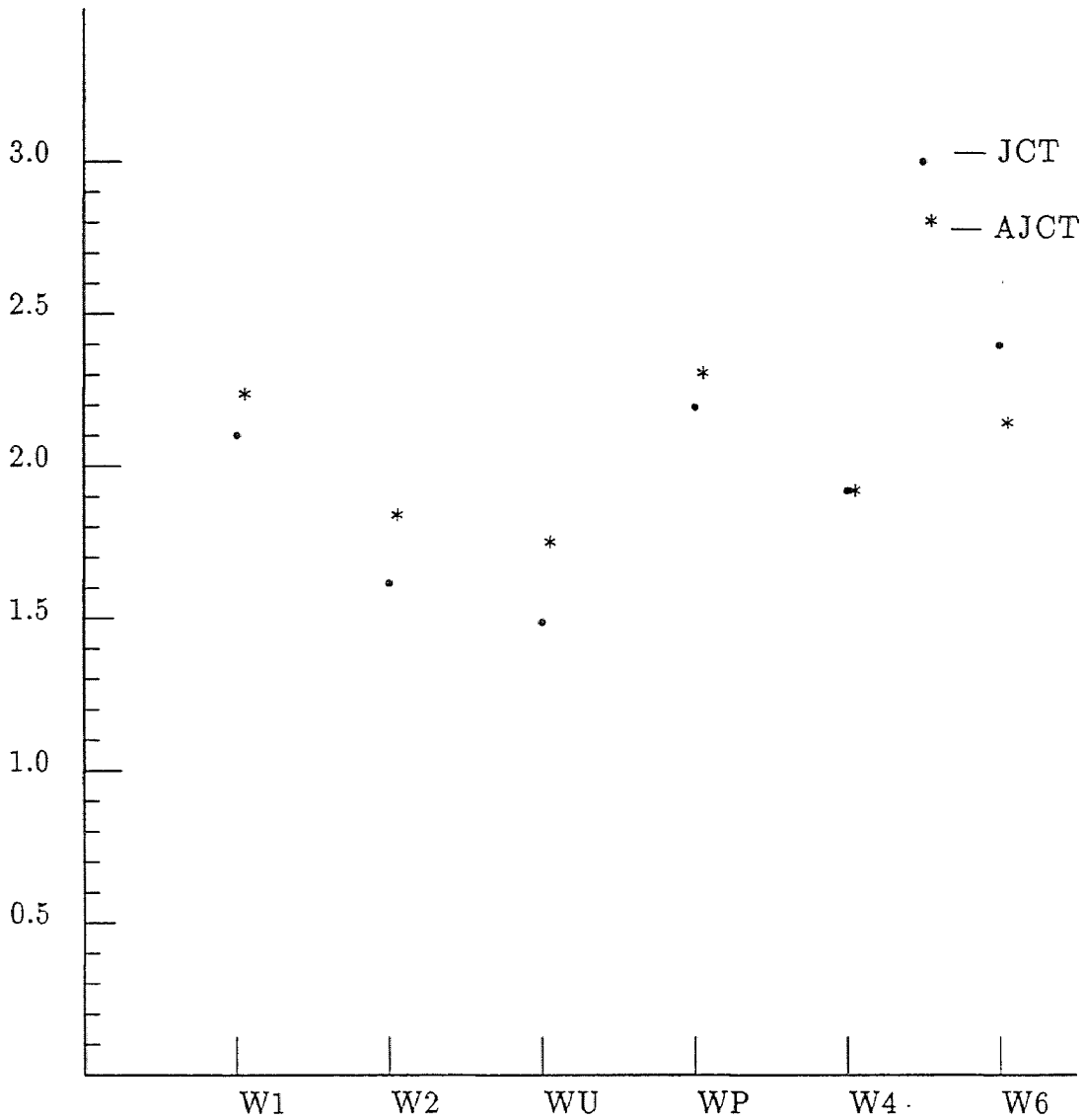


Figure 3.4: Values of performance indices JCT and AJCT obtained using different weighting matrices. Instrumentation configuration 14-B is used with a CRIT = 0.005. FJM PSSE program is used when errors introduced to measurements are amplified.

Where P is nodal real power, Q is nodal reactive power, V is nodal voltage, PL is real power flow, and QL is reactive power flow.

Testing results are in Table D.13 in Appendix D, it can be seen that weighting matrices $W2$ and WU are the best. The conclusion which can be drawn here is similar to the conclusions that have been drawn for the 14-bus system.

3.5 Conclusions

In this thesis, the effects of different weighting matrices on the estimated state of a power system were studied. Different measurement configurations, different weighting matrices and different performance criteria were used, as were the IEEE 14-bus test system and the IEEE 30-bus test system. Among all the weighting matrices which are proposed in chapter 1, $W2$ and WU are most effective. Also, there are no statistically significant differences between the results using weighting matrices $W2$ and WU .

Based on the studies in this thesis, the practically used weighting matrix WP behaved similarly to $W1$ (the unit matrix). The reasons are explained in section 3.2. However, in real systems, the measurements which have higher expected upper bounds are, in general, less accurate; so using weighting matrix WP is expected to give better results than $W1$. Also, using WP can reduce the solution time by considering only FEERs of the measurements; this is the major advantage WP has over $W2$ and $W3$.

Appendix A

The IEEE 14-bus and IEEE 30-bus Test Systems and Their Input Data with Explanation Notes

A.1 The IEEE 14-bus Test System and IEEE 30-bus Test System

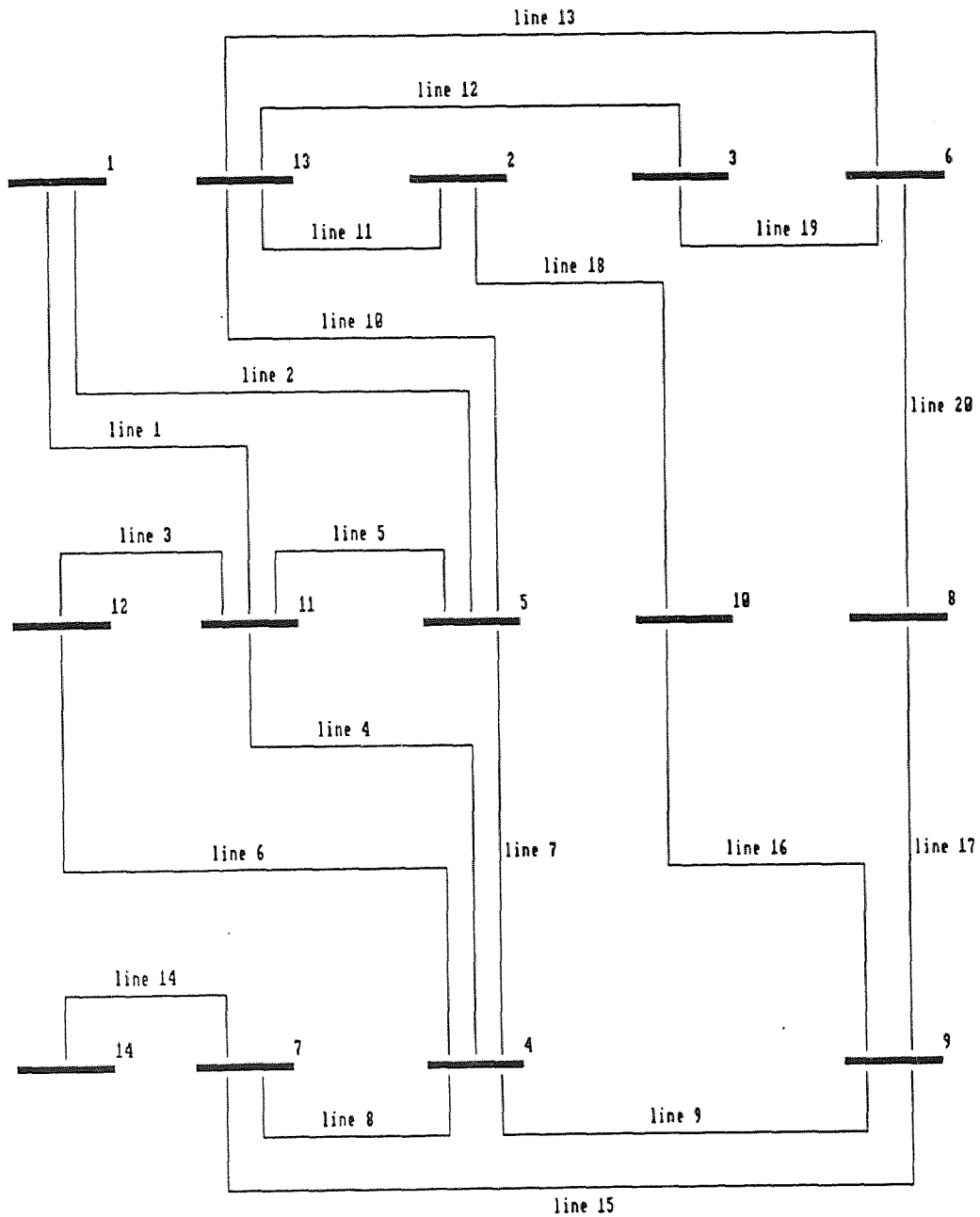


Figure A.1: The single-line diagram of IEEE 14-bus test system.

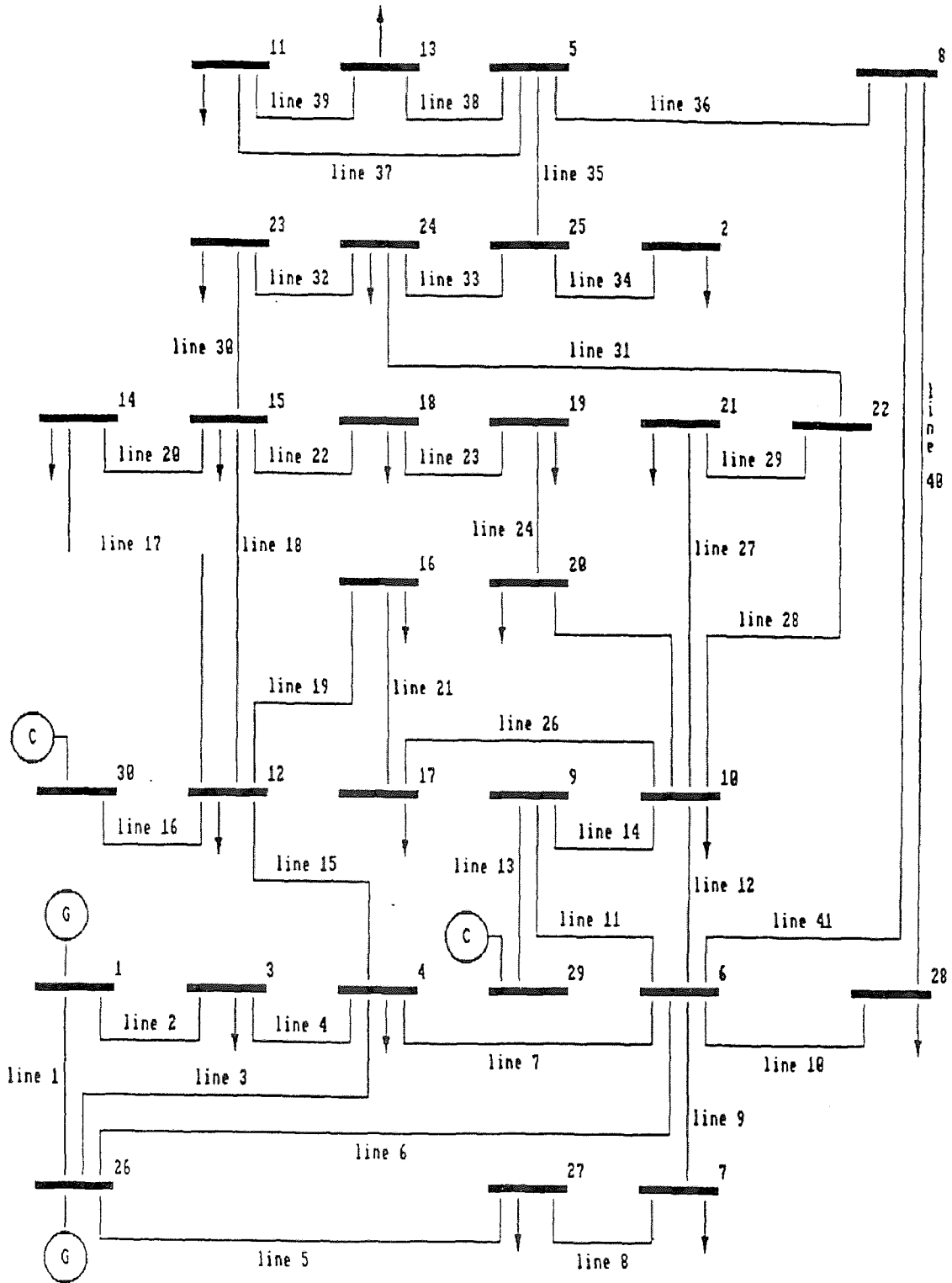


Figure A.2: The single-line diagram of IEEE 30-bus test system.

A.2 Explanation of the Input Data Files for the IEEE 14-bus and IEEE 30-bus Test Systems

The structure of the input data files of IEEE 14-bus and 30-bus are similar. The following is an explanation of the input data file for the IEEE 14-bus system.

1. Network parameters: the first 40 records:
 - column 1: the bus number at which the line starts
 - column 2: the bus number at which the line is terminated
 - column 3 and 4: the real and imaginary components of the network admittance matrix
2. Specified complex power injections: the next 14 records:
 - column 1: bus numbers
 - column 2: specified complex power, assumed positive for a load condition
3. MTOBO: the next 40 records:
 - column 1: counter number
 - column 2: bus number from which the assumed power flows
 - column 3: bus number into which the assumed power flows
 - column 4: the line number through which the power flows
4. network parameters: the next 20 records: each record contains two complex parameters separated by a comma (FORTRAN complex data input format)
 - The first parameters are the line charging shunt admittances and are read into YC array.
 - The second parameters are the series line impedances which are read into ZLINE array.
5. specified voltage: the next 4 records.

A.3 Input Data of the IEEE 14-bus Test System

The following shows the structure of the input data for the IEEE 14-bus test system, which was used in the program which studies effects of weighting matrices.

```
1 1 6.02503 -19.44705
1 5 -1.02590 4.23498
1 11 -4.99913 15.26309
2 2 3.83591 -8.49701
2 10 -1.88088 4.40294
2 13 -1.95503 4.09407
3 3 4.01499 -5.42794
3 6 -2.48903 2.25198
```


3	13	-1.52597	3.17596
4	4	10.51299	-38.66307
4	5	-6.84098	21.57854
4	7	0.00000	4.88951
4	9	0.00000	1.86900
4	11	-1.68603	5.11584
4	12	-1.98598	5.06882
5	5	9.56801	-34.92735
5	11	-1.70114	5.19393
5	13	0.00000	3.96794
6	6	6.72495	-10.66969
6	8	-1.13699	2.31496
6	13	-3.09893	6.10275
7	7	0.00000	-19.54900
7	9	0.00000	9.09008
7	14	0.00000	5.67698
8	8	2.56100	-5.34402
8	9	-1.42401	3.02905
9	9	5.32606	-24.47247
9	10	-3.90205	10.36540
10	10	5.78293	-14.76834
11	11	9.52132	-30.27066
11	12	-1.13502	4.78186
12	12	3.12099	-9.81148
13	13	6.57992	-17.34073
14	14	0.00000	-5.67698
1,(0.0,0.0)			
2,(0.035,0.018)			
3,(.061,.016)			
4,(.478,-0.039)			
5,(0.076,0.016)			
6,(0.135,0.058)			
7,(0.0,0.0)			
8,(0.149,0.05)			
9,(0.295,0.166)			
10,(0.09,0.058)			
11,(-0.183,-0.2434)			
12,(0.942,-0.03988)			
13,(.112,-0.46956)			
14,(0.0,-0.28348)			
1	1	11	1
2	11	1	1
3	1	5	2
4	5	1	2
5	11	12	3
6	12	11	3
7	11	4	4
8	4	11	4

9 11 5 5
 10 5 11 5
 11 12 4 6
 12 4 12 6
 13 4 5 7
 14 5 4 7
 15 4 7 8
 16 7 4 8
 17 4 9 9
 18 9 4 9
 19 5 13 10
 20 13 5 10
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 22 2 13 11
 23 13 3 12
 24 3 13 12
 25 13 6 13
 26 6 13 13
 27 7 14 14
 28 14 7 14
 29 7 9 15
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1.010
1.070
1.090

A.4 Input Data of the IEEE 30-bus Test System

The structure of the input data (for the program), for the IEEE 30-bus test system follows. The structure is similar to that of the 14-bus test system, which is explained in Appendix A, section 1.

1	1	6.46838	-20.69594
1	3	-1.24374	5.09602
1	26	-5.22464	15.64672
2	2	1.21653	-1.81714
2	25	-1.21653	1.81714
3	3	9.43918	-28.60225
3	4	-8.19545	23.53085
4	4	16.31409	-55.50935
4	6	-6.41312	22.31120
4	12	0.00000	4.19126
4	26	-1.70553	5.19738
5	5	3.65228	-9.46044
5	8	0.00000	2.60873
5	11	-0.99553	1.88101
5	13	-0.68746	1.29397
5	25	-1.96929	3.76021
6	6	22.34161	-82.77054
6	7	-3.59021	11.02612
6	8	-4.36284	15.46356
6	9	0.00000	4.91584
6	10	0.00000	1.85610
6	26	-1.68614	5.11648
6	28	-6.28931	22.01256
7	7	6.54423	-18.45668
7	27	-2.95402	7.44927
8	8	5.80682	-22.61293
8	28	-1.44398	4.54081
9	9	0.00000	-18.70628
9	10	0.00000	9.09091
9	29	0.00000	4.80769
10	10	13.46205	-41.76373

10	17	-3.95604	10.31745
10	20	-1.78483	3.98536
10	21	-5.10186	10.98072
10	22	-2.61932	5.40077
11	11	1.90759	-3.60436
11	13	-0.91205	1.72336
12	12	6.57396	-24.42416
12	14	-1.52657	3.17343
12	15	-3.09540	6.09728
12	16	-1.95200	4.10436
12	30	0.00000	7.14286
13	13	1.59951	-3.01733
14	14	4.01752	-5.42430
14	15	-2.49095	2.25087
15	15	9.36240	-16.01563
15	18	-1.80770	3.69142
15	23	-1.96835	3.97606
16	16	3.83461	-8.49787
16	17	-1.88261	4.39351
17	17	5.83865	-14.71097
18	18	4.88338	-9.91018
18	19	-3.07569	6.21876
19	19	8.95804	-17.98346
19	20	-5.88235	11.76471
20	20	7.66718	-15.75006
21	21	21.87650	-45.10843
21	22	-16.77464	34.12772
22	22	21.93448	-43.48286
22	24	-2.54054	3.95440
23	23	3.42975	-6.96530
23	24	-1.46141	2.98924
24	24	5.31184	-9.27426
24	25	-1.30989	2.28762
25	25	4.49571	-7.86498
26	26	9.75228	-30.64862
26	27	-1.13596	4.77248
27	27	4.08998	-12.19064
28	28	7.73328	-26.52745
29	29	0.00000	-4.80769
30	30	0.00000	-7.14286
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 27, (-0.942, 0.18429)
 28, (-0.30, 0.15430)
 29, (-0.0, 0.28699)
 30, (-0.0, 0.22034)

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(0.0,0.0),(0.2198,0.4153)
(0.0,0.0),(0.3202,0.6027)
(0.0,0.0),(0.2399,0.4533)
(0.0,0.0214),(0.0636,0.2000)

(0.0,0.065),(0.0169,0.0599)

1.045

1.0100

1.0100

1.082

1.071

Appendix B

Generation of Normally Distributed Numbers

This appendix explains how to generate normally distributed numbers.

B.1 Mean

The *expected value* or *mean* of an RV x is by definition the integral

$$E\{x\} = \int_{-\infty}^{\infty} x f(x) dx \quad (\text{B.1})$$

This number will also be denoted by η_x or η . If x is uniform in the interval (x_1, x_2) then $f(x) = 1/(x_2 - x_1)$ in the interval. Hence

$$E\{x\} = \frac{1}{x_2 - x_1} \int_{-\infty}^{\infty} x dx \quad (\text{B.2})$$

It can be noted that if the vertical line $x = a$ is an axis of symmetry of $f(x)$, then $E\{x\} = a$; in particular, if $f(-x) = f(x)$, then $E\{x\} = 0$.

B.2 Variance

The *variance* of an RV x is by definition the integral

$$\sigma^2 = \int_{-\infty}^{\infty} (x - \eta)^2 f(x) dx \quad (\text{B.3})$$

where $\eta = E\{x\}$. The positive constant σ , denoted also by σ_x , is called the *standard deviation* of x .

From the definition it follows that σ^2 is the mean of RV $(x - \eta)^2$. Thus

$$\begin{aligned} \sigma^2 &= E\{(x - \eta)^2\} \\ &= E\{x^2 - 2x\eta + \eta^2\} \\ &= E\{x^2\} - 2\eta E\{x\} + \eta^2 \end{aligned} \quad (\text{B.4})$$

Hence

$$\sigma^2 = E\{x^2\} - E^2\{x\} \quad (\text{B.5})$$

If x is uniform in the interval $(-1, 1)$, then $\eta = 0$ and

$$\sigma^2 = E\{x^2\} = \frac{1}{2} \int_{-1}^1 x^2 dx \quad (\text{B.6})$$

B.3 The Central Limit Theorem

The central limit theorem states that if the RVs x_i are independent, then under general conditions, the density $f(x)$ of their sum

$$x = x_1 + x_2 + x_3 + \cdots + x_n \quad (\text{B.7})$$

properly normalized, tends to a normal curve as $n \rightarrow \infty$. In other words, if n is sufficiently large, then $f(x) \simeq \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$.

B.4 Generation of Normally Distributed Numbers

If $x_1, x_2, x_3, \dots, x_n$ are uniform in the interval $(-1,1)$, $x = x_1 + x_2 + x_3 + \dots + x_n$, then

$$\begin{aligned} \sigma^2 &= E\{x^2\} \\ &= \frac{1}{2} \int_{-1}^1 x_1^2 dx + \frac{1}{2} \int_{-1}^1 x_2^2 dx + \frac{1}{2} \int_{-1}^1 x_3^2 dx + \dots + \frac{1}{2} \int_{-1}^1 x_n^2 dx \\ &= \frac{n}{3} \end{aligned} \tag{B.8}$$

From the above introduction, it can be seen that if $x_1, x_2, x_3, \dots, x_n$ are uniform in the interval $(-1,1)$ and $x = x_1 + x_2 + x_3 + \dots + x_n$, then normally distributed number x' can be created according to

$$x' = \sigma \sqrt{\frac{n}{3}} x \tag{B.9}$$

where σ should be specified before generate normally distributed random numbers. n is the number of uniformly distributed random numbers used, the larger the n , the better the result.

B.5 References

- G. Richard, *Normal Random*, CACM, 6 (1963), 444.
- A. Papoulis, *Probability, Random Variables, and Stochastic Processes*, Second Edition, 1984.

Appendix C

Listing of Main Program and Some of the Subroutines Used

```

MAIN PROGRAM

C THIS PROGRAM IS USED TO TEST THE EFFECTS OF DIFFERENT WEIGHTING MATRICES.
C THE PROGRAM MAINLY CONSISTS OF THREE PARTS: PART ONE IS TO SIMULATE
C MEASUREMENTS, PART TWO EXECUTES PSSE PROGRAM AND PART THREE CALCULATE
C PERFORMANCE INDICES FOR STATE COMPARISON.

INTEGER FJM,WMN,IR,DFM,BUS

REAL CTMAX,MTMAX,CMMAX
REAL CTAVE,MTAVE,CMAVE
REAL CTSIG,MTSIG,CMSIG
REAL CTXMAX,MTXMAX,CMXMAX
REAL CTRXMAX,MTRXMAX,CMRXMAX

C THIS STATEMENT IS FOR THE 14-BUS SYSTEM
PARAMETER(NB=14,NLINES=20,NT=40,NNBB=28,NM=54,NMM=122,
1NNBB1=27,NB1=13,NL=9,K1=10,K2=11,DFM=22,BUS=14,
1ERR1=0.0015,ERR2=0.01,FERR1=0.003,FERR2=0.0035)

C THIS STATEMENT IS FOR THE 30-BUS SYSTEM
C PARAMETER(NB=30,NLINES=41,NT=82,NNBB=60,NM=118,NMM=254,
C 1NNBB1=59,NB1=29,NL=24,K1=25,K2=26,DFM=53,BUS=30,
C 1ERR1=0.0015,ERR2=0.01,FERR1=0.003,FERR2=0.0035)

PARAMETER(CRIT=0.005,KMAX=100,NUDR=100,
1NCASE=60)

COMPLEX YC(NLINES),ZLINE(NLINES),ST(NT),SP,E(NB)
DIMENSION MTOBO(NT,4),FM(DFM,DFM),VSP(NB),CONN(NNBB)
REAL PSP(NB),QSP(NB),V(NB),D(NB),P(NB),Q(NB),
1PNM(NB),QNM(NB),VT(NB),DT(NB)
REAL PLM(NT),QLM(NT),PLT(NT),QLT(NT)
REAL JK11(NB,NB),JK12(NB,NB),JK21(NB,NB),
1JK22(NB,NB),G(NB,NB),B(NB,NB)
REAL JK31(NT,NB),JK32(NT,NB)
REAL JK41(NT,NB),JK42(NT,NB)
REAL JK51(NB,NB),JK52(NB,NB)
REAL JKEM(NMM,NNBB),IM(NNBB1,NNBB1),NY(NLINES)

REAL CONM(NMM),CON1(NNBB1),CON2(NNBB1),ESTIM(NNBB1,NNBB1)
REAL PLC(NT),QLC(NT),PNC(NB),QNC(NB)
REAL VM(NB),ZM(NMM),WMM(NMM,NMM)
REAL NDR

REAL JCT(NCASE),JMT(NCASE),JCM(NCASE)

```

```

REAL AJCT(NCASE),AJMT(NCASE),AJCM(NCASE)

REAL SUT(NCASE),SUM(NCASE),SUC(NCASE)

REAL CTX(NCASE),MTX(NCASE),CMX(NCASE)

REAL CTRX(NCASE),MTRX(NCASE),CMRX(NCASE)

REAL PJCT(NCASE),PJMT(NCASE),PJCM(NCASE)

INTEGER AM(NMM),AM1(NMM),CTI(NCASE),MTI(NCASE),CMI(NCASE)

C DFM: DIMENSION OF FM MATRIX, EQUAL TO THE NUMBER OF UNKNOWNNS IN
C THE LOAD FLOW PROGRAM, DFM = NB + NL -1

REAL CON(NM),JKE(NM,NNBB1),JKET(NNBB1,NM)
REAL AESTIM(NNBB1,NM),WM(NM,NM)

DATA WMN/12/
DATA VT(1),DT(1)/1.06,0.0/
DATA SIG/0.01/
DATA NR,FJM,MFJM/1,0,0/

C*****
C THESE DATA STATEMENTS ARE FOR 14-BUS SYSTEM, THEY GIVE
C THE EXPECTED UPPER BOUNDS OF MEASUREMENTS.
C*****

DATA (AM1(I),I=1,14)/1,1,1,1,1,1,2,1,1,1,1,1,1,2/
DATA (AM1(I),I=15,28)/1,1,1,1,1,1,2,1,1,1,1,1,1,2/
DATA (AM1(I),I=29,68)/1,1,2,2,2,2,2,2,2,2,2,2,1,1,2,2,2,2,2,2,
12,2,2,2,1,1,2,2,2,2,1,1,2,2,2,2,1,1,2,2/
DATA (AM1(I),I=69,108)/1,1,2,2,2,2,2,2,2,2,2,2,2,1,1,2,2,2,2,2,2,
12,2,2,2,1,1,2,2,2,2,1,1,2,2,2,2,1,1,2,2/
DATA (AM1(I),I=109,122)/1,1,1,1,1,1,1,2,1,1,1,1,1,1,2/

C***** 14-A *****
C THIS IS INSTRUMENTATION CONFIGURATION 14-A FOR 14-BUS SYSTEM.
C FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
C AVAILIABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILIABLE
C MEASUREMENTS.
C*****
C
C DATA (AM(I),I=1,14)/4,0,2,0,0,0,1,3,0,0,0,0,0,0/
C DATA (AM(I),I=15,28)/4,0,2,0,0,0,1,3,0,0,0,0,0,0/
C DATA (AM(I),I=29,68)/1,0,1,4,0,1,2,0,1,1,0,1,0,0,0,3,0,3,1,0,
C 11,4,0,0,0,0,0,4,0,1,1,0,1,4,0,2,1,2,0,0/
C DATA (AM(I),I=69,108)/1,0,1,4,0,1,2,0,1,1,0,1,0,0,0,3,0,3,1,0,

```

C 11,4,0,0,0,0,0,4,0,1,1,0,1,4,0,2,1,2,0,0/
C DATA (AM(I),I=109,122)/4,0,2,0,0,0,1,3,0,0,0,0,0,0/
C*****

C***** 14-A *****
C THIS IS INSTRUMENTATION CONFIGURATION 14-A FOR 14-BUS SYSTEM.
C FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
C AVAILIABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILIABLE
C MEASUREMENTS.
C*****
C
C THESE DATA STATEMENTS ARE FOR 14-BUS SYSTEM
C DATA (AM(I),I=1,14)/0,0,1,0,0,4,0,0,1,2,0,0,0,0/
C DATA (AM(I),I=15,28)/0,0,1,0,0,4,0,0,1,2,0,0,0,0/
C DATA (AM(I),I=29,68)/1,0,3,0,1,2,1,0,0,0,4,0,1,1,0,3,3,0,0,1,
C 10,1,0,2,0,0,1,0,1,2,1,0,0,0,2,1,0,0,1,4/
C DATA (AM(I),I=69,108)/1,0,3,0,1,2,1,0,0,0,4,0,1,1,0,3,3,0,0,1,
C 10,1,0,2,0,0,1,0,1,2,1,0,0,0,2,1,0,0,1,4/
C DATA (AM(I),I=109,122)/0,0,1,0,0,4,0,0,1,2,0,0,0,0/
C*****

C***** 14-C *****
C THIS IS INSTRUMENTATION CONFIGURATION 14-C FOR 14-BUS SYSTEM.
C FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
C AVAILIABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILIABLE
C MEASUREMENTS.
C*****
C
C THESE DATA STATEMENTS ARE FOR 14-BUS SYSTEM
C DATA (AM(I),I=1,14)/1,0,0,0,4,1,0,1,2,0,0,0,1,0/
C DATA (AM(I),I=15,28)/1,0,0,0,4,1,0,1,2,0,0,0,1,0/
C DATA (AM(I),I=29,68)/0,3,0,1,0,0,2,1,0,0,0,4,0,1,0,1,0,0,0,3,
C 11,0,0,0,1,3,0,1,0,1,0,1,0,0,4,1,0,2,0,1/
C DATA (AM(I),I=69,108)/0,3,0,1,0,0,2,1,0,0,0,4,0,1,0,1,0,0,0,3,
C 11,0,0,0,1,3,0,1,0,1,0,1,0,0,4,1,0,2,0,1/
C DATA (AM(I),I=109,122)/1,0,0,0,4,1,0,1,2,0,0,0,1,0/
C*****

C***** 14-D *****
C THIS IS INSTRUMENTATION CONFIGURATION 14-D FOR 14-BUS SYSTEM.
C FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
C AVAILIABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILIABLE
C MEASUREMENTS.
C*****
C
C THESE DATA STATEMENTS ARE FOR 14-BUS SYSTEM
C DATA (AM(I),I=1,14)/0,0,0,1,0,0,3,0,0,0,2,0,0,1/
C DATA (AM(I),I=15,28)/0,0,0,1,0,0,3,0,0,0,2,0,0,1/
C*****

```

C      DATA (AM(I),I=29,68)/4,0,2,0,1,2,0,0,1,1,0,3,0,0,2,4,1,0,0,0,
C      12,0,1,0,2,0,3,0,0,1,1,0,1,0,3,0,2,0,4,1/
C      DATA (AM(I),I=69,108)/4,0,2,0,1,2,0,0,1,1,0,3,0,0,2,4,1,0,0,0,
C      12,0,1,0,2,0,3,0,0,1,1,0,1,0,3,0,2,0,4,1/
C      DATA (AM(I),I=109,122)/0,0,0,1,0,0,3,0,0,0,2,0,0,1/
C*****

```

```

C***** 14-E *****
C      THIS IS INSTRUMENTATION CONFIGURATION 14-E FOR 14-BUS SYSTEM.
C      FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
C      AVAILIABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILIABLE
C      MEASUREMENTS.
C*****
C
C      THESE DATA STATEMENTS ARE FOR 14-BUS SYSTEM
C      DATA (AM(I),I=1,14)/1,0,2,0,3,0,0,4,0,0,0,2,0,1/
C      DATA (AM(I),I=15,28)/1,0,2,0,3,0,0,4,0,0,0,2,0,1/
C      DATA (AM(I),I=29,68)/0,2,0,0,4,1,0,2,0,0,0,3,0,1,2,0,4,0,3,0,
C      11,1,0,0,2,2,3,0,0,4,0,0,0,0,3,0,0,2,1,0/
C      DATA (AM(I),I=69,108)/0,2,0,0,4,1,0,2,0,0,0,3,0,1,2,0,4,0,3,0,
C      11,1,0,0,2,2,3,0,0,4,0,0,0,0,3,0,0,2,1,0/
C      DATA (AM(I),I=109,122)/1,0,2,0,3,0,0,4,0,0,0,2,0,1/
C*****

```

```

C***** 14-F *****
C      THIS IS INSTRUMENTATION CONFIGURATION 14-A FOR 14-BUS SYSTEM.
C      FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
C      AVAILIABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILIABLE
C      MEASUREMENTS.
C*****
C
C      DATA (AM(I),I=1,14)/3,0,0,2,3,1,0,1,0,4,0,2,0,1/
C      DATA (AM(I),I=15,28)/3,0,0,2,3,1,0,1,0,4,0,2,0,1/
C      DATA (AM(I),I=29,68)/0,0,2,0,0,0,3,0,1,1,0,0,0,4,0,0,1,0,0,0,
C      10,3,0,2,2,0,0,1,0,4,0,3,1,0,0,2,0,0,1,0/
C      DATA (AM(I),I=69,108)/0,0,2,0,0,0,3,0,1,1,0,0,0,4,0,0,1,0,0,0,
C      10,3,0,2,2,0,0,1,0,4,0,3,1,0,0,2,0,0,1,0/
C      DATA (AM(I),I=109,122)/3,0,0,2,3,1,0,1,0,4,0,2,0,1/
C*****

```

```

C***** 14-G *****
C      THIS IS INSTRUMENTATION CONFIGURATION 14-G FOR 14-BUS SYSTEM.
C      FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
C      AVAILIABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILIABLE
C      MEASUREMENTS.
C*****
C
C      THESE DATA STATEMENTS ARE FOR 14-BUS SYSTEM

```



```

C DATA (AM(I),I=1,14)/0,0,2,0,3,0,0,4,0,1,1,0,0,2/
C DATA (AM(I),I=15,28)/0,0,2,0,3,0,0,4,0,1,1,0,0,2/
C DATA (AM(I),I=29,68)/0,1,1,0,3,2,0,0,0,4,1,0,0,2,1,0,3,2,0,0,
C 12,0,3,0,0,4,0,0,2,0,0,1,0,1,0,4,0,0,1,0/
C DATA (AM(I),I=69,108)/0,1,1,0,3,2,0,0,0,4,1,0,0,2,1,0,3,2,0,0,
C 12,0,3,0,0,4,0,0,2,0,0,1,0,1,0,4,0,0,1,0/
C DATA (AM(I),I=109,122)/0,0,2,0,3,0,0,4,0,1,1,0,0,2/
C*****

```

```

C***** 30-A *****
C THIS IS INSTRUMENTATION CONFIGURATION 30-A FOR 14-BUS SYSTEM.
C FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
C AVAILIABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILIABLE
C MEASUREMENTS.

```

```

C*****
C
C DATA (AM(I),I=1,30)/0,2,1,0,3,1,0,0,1,2,0,4,1,2,0,0,2,1,0,0,
C 10,4,1,0,0,2,0,0,3,1/
C
C DATA (AM(I),I=31,60)/0,2,1,0,3,1,0,0,1,2,0,4,1,2,0,0,2,1,0,0,
C 10,4,1,0,0,2,0,0,3,1/
C
C DATA (AM(I),I=61,101)/3,0,1,0,2,0,0,4,0,2,0,0,0,0,2,1,4,0,3,0,
C 10,2,0,3,0,0,1,0,3,0,2,1,0,4,0,0,1,0,3,1,0/
C DATA (AM(I),I=102,142)/0,4,0,0,1,1,0,0,2,0,1,0,2,0,4,0,0,2,0,1,
C 10,0,0,3,2,0,0,1,0,0,3,0,2,0,0,1,0,1,0,0,0/
C
C DATA (AM(I),I=143,183)/3,0,1,0,2,0,0,4,0,2,0,0,0,0,2,1,4,0,3,0,
C 10,2,0,3,0,0,1,0,3,0,2,1,0,4,0,0,1,0,3,1,0/
C DATA (AM(I),I=184,224)/0,4,0,0,1,1,0,0,2,0,1,0,2,0,4,0,0,2,0,1,
C 10,0,0,3,2,0,0,1,0,0,3,0,2,0,0,1,0,1,0,0,0/
C
C DATA (AM(I),I=225,254)/0,2,1,0,3,1,0,0,1,2,0,4,1,2,0,0,2,1,0,0,
C 10,4,1,0,0,2,0,0,3,1/
C*****

```

DOUBLE PRECISION RAN

```

OPEN(15,FILE='W14B.DAT',STATUS='OLD')
C OPEN(15,FILE='W30.DAT',STATUS='OLD')
OPEN(50,FILE='P1.DAT',STATUS='NEW')

```

C THIS READS IN THE SYSTEM DATA FROM DATA FILE

```

CALL SYSDATA(NB,NLINES,G,B,NT,K1,MTOBO,PSP,QSP,VSP,SP,
1YC,ZLINE,K2)

```

10 CONTINUE

```

DO 20 I = 1,NB
VT(I) = VT(1)
DT(I) = DT(1)
20 CONTINUE

IF(K1.EQ.NB)GO TO 40
DO 30 I=K2,NB
VT(I) = VSP(I)
30 CONTINUE
40 CONTINUE

C LOAD FLOW CALCULATION TO ESTABLISH THE TRUE VALUES OF STATE
C VARIABLES.
CALL FRANK(NB,NL,NNBB,K1,KMAX,CRIT,P,PSP,Q,QSP,VT,
1DT,CONN,G,B,JK11,JK12,JK21,JK22,FM,DFM,FJM,MFJM,NR,1)

C IR IS A SEED TO GENERATE RANDOM NUMBERS.
IR=2043

C DIFFERENT CASES ARE SIMULATED TO TEST THE PERFORMANCES OF
C DIFFERENT WEIGHTING MATRICES

DO 1000 KKK=1,NCASE

IF (KKK.GT.1) GO TO 1112

C PRINT OUT THE INFORMATION OF WHICH MEASUREMENTS ARE
C AVAILIABLE AND WHAT ARE THE ACCURACY CATEGORY OF
C THE AVAILABLE MEASUREMENTS.

WRITE(50,960)(AM(I),I=1,NB)
960 FORMAT(' P(I):',14I1)
WRITE(50,961)(AM(I+NB),I=1,NB)
961 FORMAT(' Q(I):',14I1)

WRITE(50,965)(AM(I+NNBB),I=1,NT)
965 FORMAT(' PL(I):',40I1)
WRITE(50,966)(AM(I+NNBB+NT),I=1,NT)
966 FORMAT(' QL(I):',40I1)
WRITE(50,967)(AM(I+NNBB+NT+NT),I=1,NB)
967 FORMAT(' V(I):',14I1)

1112 CONTINUE

WRITE(50,*)

```

```

C   THIS GENERATES SIMULATED MEASUREMENTS OF A SYSTEM
    CALL MG(AM,NUDR,VM,VT,DT,E,MTOBO,NT,NB,ST,
1ZLINE,YC,NLINES,PLM,QLM,PLT,QLT,PNM,QNM,P,Q,NDR,NMM,NNBB,
1ERR1,ERR2,FERR1,FERR2,IR)

C   THIS CALCULATE THE WEIGHTING MATRIX WMM
    CALL WMG(AM,AM1,WMM,NMM,PNM,QNM,PLM,QLM,VM,NB,NNBB,NT,
1ERR1,ERR2,FERR1,FERR2,WMN)

C   THIS GIVES INITIAL VALUES FOR PSSE

340 DO 60 I = 1,NB
    V(I) = 1.0
    60 D(I) = 0.0
    70 CONTINUE

    DO 85 I = 1, NLINES
    NY(I)=AIMAG(YC(I))
    85 CONTINUE

C   MAIN PROGRAM OF PSSE BEGINS HERE
C   K IS A ITERATION NUMBER INDEX

    K=0
    90 CONTINUE

C   THIS CALCULATES PNC AND QNC FROM CURRENT VALUES OF V AND D
    CALL PQCAL(PNC,QNC,V,D,B,G,NB)

C   THIS CALCULATES PLC AND QLC FROM CURRENT VALUES OF V AND D
    CALL PQLCAL(PLC,QLC,V,D,B,G,NB,MTOBO,E,ST,ZLINE,YC,NLINES,NT)

C   THIS CALCULATES THE DIFFERENCES BETWEEN MEASUREMENTS AND
C   CALCULATED VALUES
    CALL EDELTA(PNM,QNM,PLM,QLM,VM,PNC,QNC,PLC,QLC,V,CONM,
1NMM,NB,NT)

C   WHEN FIXED JACOBIAN METHOD IS USED, THE FOLLOWING STATEMENT
C   SHOULD BE USED.
C   IF (K.GT.0.0) GO TO 3333

C   CALCULATING THE JACOBIAN MATRIX FOR STATE ESTIMATION (JKE)
    CALL EJACOB(JK11,JK12,JK21,JK22,JK31,JK32,JK41,JK42,JK51,JK52,
1JKEM,PNC,QNC,V,D,NB,NT,B,G,NNBB,NMM,MTOBO,NY,NLINES,PNM,QNM,
2PLM,QLM,VM)

3333 CONTINUE

```

```

      III=1
      DO 200 I=1,NMM
      IF (am(I).EQ.0) GO TO 200
      DO 212 J=2,NNBB
      JKE(III,J-1)=JKEM(I,J)
212  CONTINUE
      CON(III)=CONM(I)
      WM(III,III)=WMM(I,I)
      III=III+1
200  CONTINUE

C     WHEN FIXED JACOBIAN METHOD IS USED, THE FOLLOWING STATEMENT
C     SHOULD BE USED.
C     IF (K.GT.0) GO TO 3334

C     FINDING THE TRANSPOSE MATRIX OF JKE--JKET
      CALL TRAN(JKET,NNBB1,NM,JKE)

3334 CONTINUE

C     CALCULATING THE RESULT OF JKET*WM
      CALL XRR(JKET,NNBB1,NM,WM,NM,AESTIM)

C     CALCULATING THE RESULT OF AESTIM*JKE
      CALL XRR(AESTIM,NNBB1,NM,JKE,nnbb1,ESTIM)

C     CALCULATING THE RESULT OF AESTIM*CON
      CALL XRR(AESTIM,NNBB1,NM,CON,1,CON1)

C     CALCULATING THE INVERSE MATRIX OF ESTIM
      CALL INVERM(IM,ESTIM,NNBB1)

C     CALCULATING THE RESULT OF IM*CON1
      CALL XRR(IM,NNBB1,NNBB1,CON1,1,CON2)

      DO 100 I=2,NB
      D(I)=D(I)+CON2(I-1)
100  CONTINUE
      DO 105 I=1,NB
      V(I)=V(I)+V(I)*CON2(I+NB1)
105  CONTINUE

C     THIS TEST THE PROGRAM IS CONVERGED OR DIVERGED OR
C     NOT BOTH
      CALL TEST(CON2,ITEST,NB,CRIT)
      IF(ITEST.EQ.1.OR.ITEST.EQ.2)GO TO 110

      K=K+1

```

```

        IF (K.LT.KMAX) GO TO 90
        WRITE(6,*) 'K=KMAX'

110 CONTINUE
        WRITE(6,*) 'ITEST=', ITEST

C      THIS CALCULATES THE PERFORMANCE INDICES OF THE CASE SIMULATED
        CALL PI(P,Q,PLT,QLT,VT,PNM,QNM,PLM,QLM,VM,PNC,QNC,PLC,QLC,V,
1JCT,JMT,JCM,AJCT,AJMT,AJCM,WMM,AM,NB,NT,NCASE,NMM,NNBB,KKK,SUT,
1SUM,SUC,CTX,MTX,CMX,CTRX,MTRX,CMRX,CTI,MTI,CMI,PJCT,PJCM)

        WRITE(50,1010)
1010 FORMAT(5X,'JCT100',5X,'JMT100',5X,'JCM100',5X,'K' /
1      5X,'-----',5X,'-----',5X,'-----',5X,'-')

        WRITE(50,1020) JCT(KKK)*100,JMT(KKK)*100,JCM(KKK)*100,K
1020 FORMAT(4X,F7.4,4X,F7.4,4X,F7.4,4X,I2)

        WRITE(50,*)
        WRITE(50,1015)
1015 FORMAT(5X,'AJCT',5X,'AJMT',5X,'AJCM' /
1      5X,'-----',5X,'-----',5X,'-----')

        WRITE(50,1025) AJCT(KKK),AJMT(KKK),AJCM(KKK)
1025 FORMAT(4X,F8.4,4X,F8.4,4X,F8.4)

        WRITE(50,*)

        WRITE(50,1030)
1030 FORMAT(5X,'SUT',8X,'SUM',8X,'SUC' /
1      5X,'----',8X,'----',8X,'----')

        WRITE(50,1040) SUT(KKK),SUM(KKK),SUC(KKK)
1040 FORMAT(2X,F10.4,X,F10.4,X,F10.4)

        WRITE(50,*)
1113 continue

        WRITE(50,1050)
1050 FORMAT(5X,'CTX',3X,'CTRX',5X,'CTI',5X,'MTX',3X,
1'MTRX',3X,'MTI',5X,'CMX',3X,'CMRX',3X,'CMI' /
1      5X,'-----',3X,'----',5X,'----',5X,'-----',3X,
1'----',3X,'----',5X,'-----',3X,'----',3X,'----')

        WRITE(50,1060) CTX(KKK),CTRX(KKK),CTI(KKK),MTX(KKK),
1MTRX(KKK),MTI(KKK),CMX(KKK),CMRX(KKK),CMI(KKK)

```

```

1060 FORMAT(X,F10.4,f10.4,X,I3,X,F9.4,X,f8.4,X,I3,2X,
1F10.4,3X,f7.4,X,I3)

WRITE(50,*)

IF (KKK.GT.1) GO TO 1111

WRITE(50,1055)
1055 FORMAT(5X,'PJCT100',5X,'PJMT100',5X,'PJCM100'/
1      5X,'-----',5X,'-----',5X,'-----')

WRITE(50,1065)PJCT(KKK)*100,PJMT(KKK)*100,PJCM(KKK)*100
1065 FORMAT(X,F10.4,2X,F10.4,2X,F10.4)

WRITE(50,*)

WRITE(50,1070)
1070 FORMAT(4X,' I',X,'      P',X,'      PNM',X,'      PNC',
12X,' I',X,'      Q',X,'      QNM',X,'      QNC'/
1      4X,'---',X,'-----',X,'-----',X,'-----',
12X,'---',X,'-----',X,'-----',X,'-----')

WRITE(50,1075)(I,P(I),PNM(I),PNC(I),
1I+NB,Q(I),QNM(I),QNC(I), I=1,NB)
1075 FORMAT(4X,I3,X,F8.5,X,F8.5,X,F8.5,2X,I3,X,F8.5,X,F8.5,X,F8.5)

WRITE(50,*)
WRITE(50,1085)
1085 FORMAT(4X,' I',X,'      PLT',X,'      PLM',X,'      PLC',
12X,' I',X,'      QLT',X,'      QLM',X,'      QLC'/
1      4X,'---',X,'-----',X,'-----',X,'-----',
12X,'---',X,'-----',X,'-----',X,'-----')

WRITE(50,1090)(I+NNBB,PLT(I),PLM(I),PLC(I),
1I+NNBB+NT,QLT(I),QLM(I),QLC(I), I=1,NT)
1090 FORMAT(4X,I3,X,F8.5,X,F8.5,X,F8.5,2X,I3,X,F8.5,X,F8.5,X,F8.5)

WRITE(50,*)
WRITE(50,1095)
1095 FORMAT(4X,' I',X,'      VT',X,'      VM',X,'      V'/
1      4X,'---',X,'-----',X,'-----',X,'-----')

WRITE(50,1080)(I+NNBB+NT+NT,VT(I),VM(I),V(I),DT(I),I=1,NB)

1080 FORMAT(4X,I3,X,F8.5,X,F8.5,X,F8.5,X,F8.5)

```

1111 CONTINUE

WRITE(50,*)KKK,' ', 'K=',K,' ITEST=', ITEST
1000 CONTINUE

C THIS GIVES AVERAGE, STANDARD DEVIATION AND MAX OF JCT
CALL STAM(JCT, NCASE, CTAVE, CTSIG, CTMAX)
C THIS GIVES AVERAGE, STANDARD DEVIATION AND MAX OF JMT
CALL STAM(JMT, NCASE, MTAVE, MTSIG, MTMAX)
C THIS GIVES AVERAGE, STANDARD DEVIATION AND MAX OF JCM
CALL STAM(JCM, NCASE, CMAVE, CMSIG, CMMAX)

C THIS GIVES AVERAGE, STANDARD DEVIATION AND MAX OF AJCT
CALL STAM(AJCT, NCASE, ACTAVE, ACTSIG, ACTMAX)
C THIS GIVES AVERAGE, STANDARD DEVIATION AND MAX OF AJMT
CALL STAM(AJMT, NCASE, AMTAVE, AMTSIG, AMTMAX)
C THIS GIVES AVERAGE, STANDARD DEVIATION AND MAX OF AJCM
CALL STAM(AJCM, NCASE, ACMAVE, ACMSIG, ACMMAX)

C THIS GIVES AVERAGE, STANDARD DEVIATION AND MAX OF PJCT
CALL STAM(PJCT, NCASE, PJCTAVE, PJCTSIG, PJCTMAX)
C THIS GIVES AVERAGE, STANDARD DEVIATION AND MAX OF PJMT
CALL STAM(PJMT, NCASE, PJMTAVE, PJMTSIG, PJMTMAX)
C THIS GIVES AVERAGE, STANDARD DEVIATION AND MAX OF PJCM
CALL STAM(PJCM, NCASE, PJCMAVE, PJCMSIG, PJCMMAX)

C THIS GIVES AVERAGE, STANDARD DEVIATION AND MAX OF CTX
CALL STAM(CTX, NCASE, CTXAVE, CTXSIG, CTXMAX)
C THIS GIVES AVERAGE, STANDARD DEVIATION AND MAX OF MTX
CALL STAM(MTX, NCASE, MTXAVE, MTXSIG, MTXMAX)
C THIS GIVES AVERAGE, STANDARD DEVIATION AND MAX OF CMX
CALL STAM(CMX, NCASE, CMXAVE, CMXSIG, CMXMAX)

WRITE(50,900)
900 FORMAT(5X, 'JCTMAX', 5X, 'JMTMAX', 5X, 'JCMMAX' /
1 5X, '-----', 5X, '-----', 5X, '-----')

WRITE(50,910)CTMAX*100,MTMAX*100,CMMAX*100
910 FORMAT(X,F10.4,X,F10.4,X,F10.4)

WRITE(50,*)

WRITE(50,920)
920 FORMAT(5X, 'JCTAVE', 5X, 'JMTAVE', 5X, 'JCMAVE' /
1 5X, '-----', 5X, '-----', 5X, '-----')

WRITE(50,930)CTAVE*100,MTAVE*100,CMAVE*100

```

930 FORMAT(X,F10.4,2X,F10.4,F10.4)

      WRITE(50,*)

      WRITE(50,940)
940  FORMAT(5X,'JCTSIG',5X,'JMTSIG',5X,'JCMSIG'/
1     5X,'-----',5X,'-----',5X,'-----')

      WRITE(50,950)CTSIG*100,MTSIG*100,CMSIG*100
950  FORMAT(4X,F7.4,4X,F7.4,4X,F7.4)

      WRITE(50,*)

      WRITE(50,905)
905  FORMAT(5X,'AJCTMAX',5X,'AJMTMAX',5X,'AJCMAX')/
1     5X,'-----',5X,'-----',5X,'-----')

      WRITE(50,915)ACTMAX,AMTMAX,ACMAX
915  FORMAT(3X,F10.4,X,F10.4,3X,F10.4)

      WRITE(50,*)

      WRITE(50,925)
925  FORMAT(5X,'AJCTAVE',5X,'AJMTAVE',5X,'AJCAVE')/
1     5X,'-----',5X,'-----',5X,'-----')

      WRITE(50,935)ACTAVE,AMTAVE,ACAVE
935  FORMAT(2X,F10.4,2X,F10.4,3X,F10.4)

      WRITE(50,*)
      WRITE(50,945)
945  FORMAT(5X,'AJCTSIG',5X,'AJMTSIG',5X,'AJCMSIG')/
1     5X,'-----',5X,'-----',5X,'-----')

      WRITE(50,955)ACTSIG,AMTSIG,ACMSIG
955  FORMAT(5X,F7.4,4X,F7.4,6X,F7.4)

      WRITE(50,*)

      WRITE(50,1160)
1160 FORMAT(5X,'CTXMAX',5X,'MTXMAX',5X,'CMXMAX')/
1     5X,'-----',5X,'-----',5X,'-----')

      WRITE(50,1170)CTXMAX,MTXMAX,CMXMAX
1170 FORMAT(X,F10.4,X,F10.4,X,F10.4)

      WRITE(50,*)

```



```

WRITE(50,1180)
1180 FORMAT(5X,'CTXAVE',5X,'MTXAVE',5X,'CMXAVE'/
1      5X,'-----',5X,'-----',5X,'-----')

WRITE(50,1190)CTXAVE,MTXAVE,CMXAVE
1190 FORMAT(4X,F7.4,4X,F7.4,3X,F8.4)

WRITE(50,*)

WRITE(50,2240)
2240 FORMAT(5X,'CTXSIG',5X,'MTXSIG',5X,'CMXSIG'/
1      5X,'-----',5X,'-----',5X,'-----')

WRITE(50,2250)CTXSIG,MTXSIG,CMXSIG
2250 FORMAT(4X,F8.4,4X,F7.4,4X,F8.4)
WRITE(50,*)

WRITE(50,*)

WRITE(50,1165)
1165 FORMAT(5X,'PJCTMAX',5X,'PJMTMAX',5X,'PJCMMAX'/
1      5X,'-----',5X,'-----',5X,'-----')

WRITE(50,1175)PJCTMAX*100,PJMTMAX*100,PJCMMAX*100
1175 FORMAT(X,F10.4,2X,F10.4,X,F10.4)

WRITE(50,*)

WRITE(50,1185)
1185 FORMAT(5X,'PJCTAVE',5X,'PJMTAVE',5X,'PJCMAVE'/
1      5X,'-----',5X,'-----',5X,'-----')

WRITE(50,1195)PJCTAVE*100,PJMTAVE*100,PJCMAVE*100
1195 FORMAT(4X,F7.4,5X,F7.4,3X,F8.4)

WRITE(50,*)

WRITE(50,2245)
2245 FORMAT(5X,'PJCTSIG',5X,'PJMTSIG',5X,'PJCMSIG'/
1      5X,'-----',5X,'-----',5X,'-----')

WRITE(50,2255)PJCTSIG*100,PJMTSIG*100,PJCMSIG*100
2255 FORMAT(4X,F7.4,5X,F7.4,4X,F7.4)
WRITE(50,*)

999 STOP
END

```

```

C*****
      SUBROUTINE SYSDATA(NB,NLINES,G,B,NT,K1,MTOBO,PSP,QSP,VSP,SP,
      1YC,ZLINE,K2)
C*****
C
C   THIS SUBROUTINE READS IN THE SYSTEM PARAMETERS AND OTHER DATA
C
C   PARAMETER PASSED:
C       K1 = NUMBER OF LOAD BUS + 1
C       K2 = NUMBER OF LOAD BUS + 2, NEEDED TO READ SPECIFIED VOLTAGES
C       NB = NUMBER OF BUSES
C       NLINE = NUMBER OF LINES
C
C   PARAMETER RETURNED:
C       G = ADMITTANCE
C       B = SUSCEPTANCE
C       NT = 2 X NLINES
C       MTOBO = ARRAY OF: #, FROM_BUS, TO_BUS, LINE #
C       PSP = ARRAY OF SPECIFIED NODAL REAL POWER INJECTIONS
C       QSP = ARRAY OF SPECIFIED NODAL REACTIVE POWER INJECTIONS
C       SP = ARRAY OF COMPLEX NODAL POWER INJECTIONS
C       YC = ARRAY OF LINE CHANGING ADMITTANCES
C       ZLINE = ARRAY OF LINE IMPEDANCES
C
C   CALLED BY:
C       MAIN PROGRAM
C
C   CALLS:
C       NONE
C
C*****

      REAL G(NB,NB),B(NB,NB),PSP(NB),QSP(NB),VSP(NB)

      COMPLEX SP,YC(NLINES),ZLINE(NLINES)

      INTEGER MTOBO(NT,4),K2

C   READING LINE ADMITTANCE

      DO 5 I=1,NB
      DO 5 J=1,NB
      B(I,J)=0.0
5  G(I,J)=0.0
      LN=NB+NLINES
      DO 10 K=1,LN
      READ(15,*) I,J,G(I,J),B(I,J)

```

```
G(J,I)=G(I,J)
B(J,I)=B(I,J)
10 CONTINUE
```

```
C   READING BUS DATA
```

```
DO 15 I=1,NB
READ(15,*)J,SP
PSP(J)=-REAL(SP)
QSP(J)=-AIMAG(SP)
15 CONTINUE
```

```
DO 4 I = 1,NT
READ(15,*)(MTOBD(I,J),J=1,4)
4 CONTINUE
READ(15,*)(YC(I),ZLINE(I),I=1,NLINES)
DO 20 I=K2,NB
READ(15,*)VSP(I)
20 CONTINUE
```

```
RETURN
END
```

```

C*****
      SUBROUTINE MG(AM,NUDR,VM,VT,DT,E,MTOBO,NT,NB,ST,ZLINE,YC,NLINES,
      1PLM,QLM,PLT,QLT,PNM,QNM,P,Q,NDR,NMM,NNBB,ERR1,ERR2,FERR1,FERR2,IR)
C*****
C
C   THIS SUBROUTINE IS USED TO GENERATE ALL THE SIMULATED SYSTEM
C   VARIABLES WHICH ARE SIMULATED MEASUREMENTS.
C
C   PARAMETERS PASSED:
C     AM = ARRAY OF INDICES SPECIFY WHETHER CORRESPONDING MEASUREMENTS
C         ARE AVAILIABLE OR NOT AND SPECIFY THEIR ACCURACY CATEGORIES
C     NUDR = NUMBER OF UNIFORMLY DISTRIBUTED RANDOM NUMBERS USED TO
C           GENERATE NORMALLY DISTRIBUTED RANDOM NUMBERS
C     VT = ARRAY OF TRUE MAGNITUDES OF NODAL VOLTAGES
C     DT = ARRAY OF TRUE ANGLES OF NODAL VOLTAGES
C     E = ARRAY OF NODAL VOLTAGES
C     MTOBO = ARRAY OF: #, FROM_BUS, TO_BUS, LINE #
C     NT = 2 X NLINES
C     NB = NUMBER OF BUSES
C     ST = ARRAY OF COMPLEX LINE FLOWS
C     ZLINE = ARRAY OF LINE IMPEDANCES
C     YC = ARRAY OF LINE ADMITTANCES
C     NLINES = NUMBER OF LINES
C     PLT = ARRAY OF TRUE REAL POWER FLOWS
C     QLT = ARRAY OF TRUE REACTIVE POWER FLOWS
C     P = ARRAY OF TRUE NODAL REAL POWER INJECTIONS
C     Q = ARRAY OF TRUE NODAL REACTIVE POWER INJECTIONS
C     NMM = NUMBER OF SYSTEM VARIABLES (= NNBB + 2 X NT + NB)
C     NNBB = 2 X NB
C     ERR1 = ERROR PROPORTIONAL TO MEASUREMENTS FOR VOLTAGE MEASUREMENTS
C     ERR2 = ERROR PROPORTIONAL TO MEASUREMENTS FOR OTHER MEASUREMENTS
C     FERR1 = FIXED ERROR FOR VOLTAGE MEASUREMENTS
C     FERR2 = FIXED ERROR OTHER MEASUREMENTS
C     IR = A SEED USED TO GENERATE RANDOM NUMBERS
C
C   PARAMETERS RETURNED:
C     PNM = ARRAY OF SIMULATED NODAL REAL POWER INJECTIONS
C     QNM = ARRAY OF SIMULATED NODAL REACTIVE POWER INJECTIONS
C     PLM = ARRAY OF SIMULATED REAL POWER POWER FLOWS
C     QLM = ARRAY OF SIMULATED REACTIVE POWER FLOWS
C     VM = ARRAY OF SIMULATED MAGNITUDES OF NODAL VOLTAGES
C
C   CALLED BY:
C     MAIN PROGRAM
C
C   CALLS:
C     SUBROUTINE NRAN

```

```

C          SUBROUTINE RANDOM
C          SUBROUTINE CLF
C
C*****
      REAL VM(NB),VT(NB),DT(NB),PLM(NB),QLM(NB),PNM(NB),QNM(NB),
      1PLT(NLINES),QLT(NLINES),P(NB),Q(NB),NDR

      COMPLEX E(NB),ST(NT),ZLINE(NLINES),YC(NLINES)

      INTEGER MTOBO(NT,4),AM(NMM),IR

      DO 201 I = 1, NB

      IF (AM(I+NNBB+NT+NT).EQ.0) THEN
      SIG=ERR1
      FERR=FERR1
      ELSE IF (AM(I+NNBB+NT+NT).EQ.1) THEN
      SIG=ERR1
      FERR=FERR1
      ELSE IF (AM(I+NNBB+NT+NT).EQ.2) THEN
      SIG=2*ERR1
      FERR=2*FERR1
      ELSE IF (AM(I+NNBB+NT+NT).EQ.3) THEN
      SIG=3*ERR1
      FERR=3*FERR1
      ELSE
      SIG=4*ERR1
      FERR=4*FERR1
      ENDIF

      CALL NRAN(NUDR,NDR,SIG,IR)
      IF(NDR.GT.(3*SIG))THEN NDR=3*SIG
      IF(NDR.LT.(-3*SIG))THEN NDR=-3*SIG
      VM(I) = VT(I)*(1 + NDR)

      CALL RANDOM(IR,RAN)
      IF(RAN.GT.(0.0)) THEN
      VM(I) = VM(I) + FERR
      ELSE
      VM(I) = VM(I) - FERR
      ENDIF

201 CONTINUE

      DO 8 I = 1,NB
      AA = VT(I)*COS(DT(I))
      BB = VT(I)*SIN(DT(I))

```

```

      E(I) = CMPLX(AA,BB)
8  CONTINUE

      CALL CLF(MTOBO,NT,E,NB,ST,ZLINE,YC,NLINES)

C  LINE FLOW MEASUREMENTS GENERATION

      DO 20 I = 1, NT

      IF (AM(I+NNBB).EQ.0) THEN
      SIG=ERR2
      FERR=FERR2
      ELSE IF (AM(I+NNBB).EQ.1) THEN
      SIG=ERR2
      FERR=FERR2
      ELSE IF (AM(I+NNBB).EQ.2) THEN
      SIG=2*ERR2
      FERR=2*FERR2
      ELSE IF (AM(I+NNBB).EQ.3) THEN
      SIG=3*ERR2
      FERR=3*FERR2
      ELSE
      SIG=4*ERR2
      FERR=4*FERR2
      ENDIF

      CALL NRAN(NUDR,NDR,SIG,IR)
      IF (NDR.GT.(3*SIG)) THEN NDR=3*SIG
      IF (NDR.LT.(-3*SIG)) THEN NDR=-3*SIG
      PLT(I)=REAL(ST(I))
      PLM(I) = REAL(ST(I))*(1 + NDR)

      CALL RANDOM(IR,RAN)
      IF(RAN.GT.(0.0)) THEN
      PLM(I) = PLM(I) + FERR
      ELSE
      PLM(I) = PLM(I) - FERR
      ENDIF

      IF (AM(I+NNBB+NT).EQ.0) THEN
      SIG=ERR2
      FERR=FERR2
      ELSE IF (AM(I+NNBB+NT).EQ.1) THEN
      SIG=ERR2
      FERR=FERR2
      ELSE IF (AM(I+NNBB+NT).EQ.2) THEN
      SIG=2*ERR2
      FERR=2*FERR2

```

```

ELSE IF (AM(I+NNBB+NT).EQ.3) THEN
SIG=3*ERR2
FERR=3*FERR3
ELSE IF (AM(I+NNBB+NT).EQ.4) THEN
SIG=4*ERR2
FERR=4*FERR2
ENDIF

```

```

CALL NRAN(NUDR,NDR,SIG,IR)
IF (NDR.GT.(3*SIG)) THEN NDR=3*SIG
IF (NDR.LT.(-3*SIG)) THEN NDR=-3*SIG
QLT(I) = AIMAG(ST(I))
QLM(I) = AIMAG(ST(I))*(1 + NDR)

```

```

CALL RANDOM(IR,RAN)
IF(RAN.GT.(0.0)) THEN
QLM(I) = QLM(I) + FERR
ELSE
QLM(I) = QLM(I) - FERR
ENDIF

```

20 CONTINUE

C NODAL MEASUREMENTS GENERATION

```

DO 22 I = 1, NB

IF (AM(I).EQ.0) THEN
SIG=ERR2
FERR=FERR2
ELSE IF (AM(I).EQ.1) THEN
SIG=ERR2
FERR=FERR2
ELSE IF (AM(I).EQ.2) THEN
SIG=2*ERR2
FERR=2*FERR2
ELSE IF (AM(I).EQ.3) THEN
SIG=3*ERR2
FERR=3*FERR2
ELSE IF (AM(I).EQ.4) THEN
SIG=4*ERR2
FERR=4*FERR2
ENDIF

```

```

CALL NRAN(NUDR,NDR,SIG,IR)
IF (NDR.GT.(3*SIG)) THEN NDR=3*SIG
IF (NDR.LT.(-3*SIG)) THEN NDR=-3*SIG
PNM(I) = P(I)*(1 + NDR)

```

```
CALL RANDOM(IR,RAN)
IF(RAN.GT.(0.0)) THEN
PNM(I) = PNM(I) + FERR
ELSE
PNM(I) = PNM(I) - FERR
ENDIF
```

```
IF (AM(I+NB).EQ.0) THEN
SIG=ERR2
FERR=FERR2
ELSE IF (AM(I+NB).EQ.1) THEN
SIG=ERR2
FERR=FERR2
ELSE IF (AM(I+NB).EQ.2) THEN
SIG=2*ERR2
FERR=2*FERR2
ELSE IF (AM(I+NB).EQ.3) THEN
SIG=3*ERR2
FERR=3*FERR2
ELSE IF (AM(I+NB).EQ.4) THEN
SIG=4*ERR2
FERR=4*FERR2
ENDIF
```

```
CALL NRAN(NUDR,NDR,SIG,IR)
IF (NDR.GT.(3*SIG)) THEN NDR=3*SIG
IF (NDR.LT.(-3*SIG))THEN NDR=-3*SIG
QNM(I) = Q(I)*(1 + NDR)
```

```
CALL RANDOM(IR,RAN)
IF(RAN.GT.(0.0)) THEN
QNM(I) = QNM(I) + FERR
ELSE
QNM(I) = QNM(I) - FERR
ENDIF
```

22 CONTINUE

```
RETURN
END
```



```

C*****
      SUBROUTINE NRAN(NUDR,NDR,SIG,IR)
C*****
C
C
C   THIS SUBROUTINE IS USED TO CREAT NORMALLY DISTRIBUTED
C   NUMBERS USING UNIFORMLY DISTRIBUTED NUMBERS BASED ON
C   THE CENTRAL LIMITATION THEORY
C
C
C   PARAMETERS PASSED:
C     NUDR = NO. OF NORMALLY DISTRIBUTED RANDOM NUMBER
C           INTEND TO GENERATE
C     SIG = STANDARD DEVIATION OF THE NORMALLY DISTRIBUTED
C           RANDOM NUMBERS CREATED. THIS VALUE SHOULD BE
C           SPECIFIED AT THE BEGINNING OF THE SUBROUTINE
C     IR = A SEED USED TO PRODUCE UNIFORMLY DISTRIBUTED
C          RANDOM NUMBERS
C
C
C   PARAMETER RETURNED:
C     NDR = NORMALLY DISTRIBUTED RANDOM NUMBER
C
C   CALLED BY:
C     SUBROUTINE MG
C
C   CALLS:
C     SUBROUTINE RANDOM
C
C*****

      REAL NDR,RAN,SIG

      INTEGER NUDR,IR

      SUM=0.0

      DO 10 I=1,NUDR
      CALL RANDOM(IR,RAN)
      SUM=SUM+RAN
10 CONTINUE

      NDR=SUM*SIG*SQRT(3./NUDR)

      RETURN
      END

```



```

C*****
      SUBROUTINE WMG(AM,AM1,WMM,NMM,PNM,QNM,PLM,QLM,VM,NB,NNBB,NT,
      1ERR1,ERR2,FERR1,FERR2,WMN)
C*****
C
C   THIS SUBROUTINE IS USED TO PRODUCE THE WEIGHTING MATRIX.
C   THE SUBROUTINE SHOWN HERE IS TO CREAT WEIGHTING MATRIX  $\mathbf{WU}$ .
C
C   PARAMETERS PASSED:
C     AM = ARRAY OF INDICES SPECIFYING WHETHER CORRESPONDING MEASUREMENTS
C         ARE AVAILABLE OR NOT AND SPECIFY THEIR ACCURACY CATEGORIES
C     NMM = NUMBER OF SYSTEM VARIABLES (= NNBB + 2 X NT + NB)
C     PNM = ARRAY OF SIMULATED NODAL REAL POWER INJECTIONS
C     QNM = ARRAY OF SIMULATED NODAL REACTIVE POWER INJECTIONS
C     PLM = ARRAY OF SIMULATED REAL POWER POWER FLOWS
C     QLM = ARRAY OF SIMULATED REACTIVE POWER FLOWS
C     VM = ARRAY OF SIMULATED MAGNITUDES OF NODAL VOLTAGES
C     NB = NUMBER OF BUSES
C     NNBB = 2 X NB
C     NT = 2 X NLINES
C     ERR1 = ERROR PROPORTIONAL TO MEASUREMENTS FOR VOLTAGE MEASUREMENTS
C     ERR2 = ERROR PROPORTIONAL TO MEASUREMENTS FOR OTHER MEASUREMENTS
C     FERR1 = FIXED ERROR FOR VOLTAGE MEASUREMENTS
C     FERR2 = FIXED ERROR OTHER MEASUREMENTS
C
C   PARAMETERS RETURNED:
C     WMG = WEIGHTING MATRIX USED IN PSSE
C
C   CALLED BY:
C     MAIN PROGRAM
C
C   CALLS:
C     NONE
C
C*****

      REAL WMM(NMM,NMM),PNM(NB),QNM(NB),PLM(NT),QLM(NT),VM(NB)

      INTEGER AM(NMM),AM1(NMM),WMN

      DO 800 I=1,NMM
      DO 800 J=1,NMM
      WMM(I,J)=0.0
800 CONTINUE

      IF (WMN.EQ.1) GO TO 100

```

```

IF (WMN.EQ.12) GO TO 500

DO 32 I=1,NB
IF (AM(I).EQ.0) THEN
ERR=ERR2
FERR=FERR2
ELSE IF (AM(I).EQ.1) THEN
ERR=ERR2
FERR=FERR2
ELSE IF (AM(I).EQ.2) THEN
ERR=2*ERR2
FERR=2*FERR2
ELSE IF (AM(I).EQ.3) THEN
ERR=3*ERR2
FERR=3*FERR2
ELSE IF (AM(I).EQ.4) THEN
ERR=4*ERR2
FERR=4*FERR2
ENDIF

C=(1/(ABS(PNM(I))*ERR+FERR))
CC=(ABS(PNM(I)))

IF (WMN.EQ.2) THEN
WMM(I,I)=C
ELSE IF (WMN.EQ.3) THEN
WMM(I,I)=C*C
ELSE IF (WMN.EQ.4) THEN
WMM(I,I)=C*C*CC
ELSE IF (WMN.EQ.5) THEN
WMM(I,I)=C*C*CC*CC
ELSE IF (WMN.EQ.6) THEN
WMM(I,I)=C*CC
ELSE IF (WMN.EQ.7) THEN
WMM(I,I)=C*CC*CC
ELSE IF (WMN.EQ.8) THEN
WMM(I,I)=C/(CC*CC)
ELSE IF (WMN.EQ.9) THEN
WMM(I,I)=C*C/(CC*CC)
ELSE IF (WMN.EQ.10) THEN
WMM(I,I)=C/CC
ELSE
WMM(I,I)=C*C/CC
ENDIF

IF (AM(I+NB).EQ.0) THEN
ERR=ERR2

```

```

FERR=FERR2
ELSE IF (AM(I+NB).EQ.1) THEN
ERR=ERR2
FERR=FERR2
ELSE IF (AM(I+NB).EQ.2) THEN
ERR=2*ERR2
FERR=2*FERR2
ELSE IF (AM(I+NB).EQ.3) THEN
ERR=3*ERR2
FERR=3*FERR2
ELSE
ERR=4*ERR2
FERR=4*FERR2
ENDIF

```

```

D=(1/(ABS(QNM(I))*ERR+FERR))
DD=(ABS(QNM(I)))

```

```

IF (WMN.EQ.2) THEN
WMM(I+NB,I+NB)=D
ELSE IF (WMN.EQ.3) THEN
WMM(I+NB,I+NB)=D*D
ELSE IF (WMN.EQ.4) THEN
WMM(I+NB,I+NB)=D*D*DD
ELSE IF (WMN.EQ.5) THEN
WMM(I+NB,I+NB)=D*D*DD*DD
ELSE IF (WMN.EQ.6) THEN
WMM(I+NB,I+NB)=D*DD
ELSE IF (WMN.EQ.7) THEN
WMM(I+NB,I+NB)=D*DD*DD
ELSE IF (WMN.EQ.8) THEN
WMM(I+NB,I+NB)=D/(DD*DD)
ELSE IF (WMN.EQ.9) THEN
WMM(I+NB,I+NB)=D*D/(DD*DD)
ELSE IF (WMN.EQ.10) THEN
WMM(I+NB,I+NB)=D/DD
ELSE
WMM(I+NB,I+NB)=D*D/DD
ENDIF

```

32 CONTINUE

```

DO 34 I=1,NT

```

```

IF (AM(I+NNBB).EQ.0) THEN
ERR=ERR2
FERR=FERR2
ELSE IF (AM(I+NNBB).EQ.1) THEN

```

```

ERR=ERR2
FERR=FERR2
ELSE IF (AM(I+NNBB).EQ.2) THEN
ERR=2*ERR2
FERR=2*FERR2
ELSE IF (AM(I+NNBB).EQ.3) THEN
ERR=3*ERR2
FERR=3*FERR2
ELSE
ERR=4*ERR2
FERR=4*FERR2
ENDIF

```

```

E=(1/(ABS(PLM(I))*ERR+FERR))
EE=(ABS(PLM(I)))

```

```

IF (WMN.EQ.2) THEN
WMM(I+NNBB,I+NNBB)=E
ELSE IF (WMN.EQ.3) THEN
WMM(I+NNBB,I+NNBB)=E*E
ELSE IF (WMN.EQ.4) THEN
WMM(I+NNBB,I+NNBB)=E*E*EE
ELSE IF (WMN.EQ.5) THEN
WMM(I+NNBB,I+NNBB)=E*E*EE*EE
ELSE IF (WMN.EQ.6) THEN
WMM(I+NNBB,I+NNBB)=E*EE
ELSE IF (WMN.EQ.7) THEN
WMM(I+NNBB,I+NNBB)=E*EE*EE
ELSE IF (WMN.EQ.8) THEN
WMM(I+NNBB,I+NNBB)=E/(EE*EE)
ELSE IF (WMN.EQ.9) THEN
WMM(I+NNBB,I+NNBB)=E*E/(EE*EE)
ELSE IF (WMN.EQ.10) THEN
WMM(I+NNBB,I+NNBB)=E/EE
ELSE
WMM(I+NNBB,I+NNBB)=E*E/EE
ENDIF

```

```

IF (AM(I+NNBB+NT).EQ.0) THEN
ERR=ERR2
FERR=FERR2
ELSE IF (AM(I+NNBB+NT).EQ.1) THEN
ERR=ERR2
FERR=FERR2
ELSE IF (AM(I+NNBB+NT).EQ.2) THEN
ERR=2*ERR2
FERR=2*FERR2
ELSE IF (AM(I+NNBB+NT).EQ.3) THEN

```

```

ERR=3*ERR2
FERR=3*FERR2
ELSE
ERR=4*ERR2
FERR=4*FERR2
ENDIF

```

```

A=(1/(ABS(QLM(I))*ERR+FERR))
AA=(ABS(QLM(I)))

```

```

IF (WMN.EQ.2) THEN
WMM(I+NNBB+NT,I+NNBB+NT)=A
ELSE IF (WMN.EQ.3) THEN
WMM(I+NNBB+NT,I+NNBB+NT)=A*A
ELSE IF (WMN.EQ.4) THEN
WMM(I+NNBB+NT,I+NNBB+NT)=A*A*AA
ELSE IF (WMN.EQ.5) THEN
WMM(I+NNBB+NT,I+NNBB+NT)=A*A*AA*AA
ELSE IF (WMN.EQ.6) THEN
WMM(I+NNBB+NT,I+NNBB+NT)=A*AA
ELSE IF (WMN.EQ.7) THEN
WMM(I+NNBB+NT,I+NNBB+NT)=A*AA*AA
ELSE IF (WMN.EQ.8) THEN
WMM(I+NNBB+NT,I+NNBB+NT)=A/(AA*AA)
ELSE IF (WMN.EQ.9) THEN
WMM(I+NNBB+NT,I+NNBB+NT)=A*A/(AA*AA)
ELSE IF (WMN.EQ.10) THEN
WMM(I+NNBB+NT,I+NNBB+NT)=A/AA
ELSE
WMM(I+NNBB+NT,I+NNBB+NT)=A*A/AA
ENDIF

```

34 CONTINUE

```

DO 36 I=1,NB

```

```

IF (AM(I+NNBB+NT+NT).EQ.0) THEN
ERR=ERR1
FERR=FERR1
ELSE IF (AM(I+NNBB+NT+NT).EQ.1) THEN
ERR=ERR1
FERR=FERR1
ELSE IF (AM(I+NNBB+NT+NT).EQ.2) THEN
ERR=2*ERR1
FERR=2*FERR1
ELSE IF (AM(I+NNBB+NT+NT).EQ.3) THEN
ERR=3*ERR1
FERR=3*FERR1

```

```

ELSE
ERR=4*ERR1
FERR=4*FERR1
ENDIF

B=(1/(ABS(VM(I))*ERR+FERR))
BB=(ABS(VM(I)))

IF (WMM.EQ.2) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B
ELSE IF (WMM.EQ.3) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B*B
ELSE IF (WMM.EQ.4) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B*B*BB
ELSE IF (WMM.EQ.5) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B*B*BB*BB
ELSE IF (WMM.EQ.6) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B*BB
ELSE IF (WMM.EQ.7) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B*BB*BB
ELSE IF (WMM.EQ.8) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B/(BB*BB)
ELSE IF (WMM.EQ.9) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B*B/(BB*BB)
ELSE IF (WMM.EQ.10) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B/BB
ELSE
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B*B/BB
ENDIF

36 CONTINUE

DO 210 I=1,NMM
WMM(I,I)=WMM(I,I)*0.001
210 CONTINUE
GO TO 999

500 DO 560 I =1,NMM
IF (AM(I).EQ.0) GO TO 550
IF (AM1(I).EQ.1) THEN
WMM(I,I)=1
ELSE
WMM(I,I)=2
ENDIF
GO TO 560
550 WMM(I,I)=1
560 CONTINUE

```


GO TO 999

100 DO 209 I=1,NMM
WMM(I,I)=1.
209 CONTINUE

999 RETURN
END

```

C*****
      SUBROUTINE EJACOB(JK11,JK12,JK21,JK22,JK31,JK32,JK41,JK42,JK51,
      1JK52,JKEM,PNC,QNC,V,D,NB,NT,B,G,NNBB,NMM,MTOBO,NY,NLINES,PNM,QNM,
      2PLM,QLM,VM)
C*****
C
C      THIS SUBROUTINE CALCULATES JACOBIAN MATRIX.
C      PNC AND QNC ARE NEEDED TO CALCULATE THE DIAGONAL
C      ELEMENTS OF SUBEJACOBIANS. THE OUTPUT IS JKEM.
C
C      PARAMETERS PASSED:
C          PNC = ARRAY OF CALCULATED NODAL REAL POWER INJECTIONS
C          QNC = ARRAY OF CALCULATED NODAL REACTIVE POWER INJECTIONS
C          V = ARRAY OF MAGNITUDE OF NODAL VOLTAGES
C          D = ARRAY OF ANGLE OF NODAL VOLTAGE ANGLES
C          NB = NUMBER OF BUSES
C          NT = 2 X NLINES
C          B = SUSCEPTANCES
C          G = ADMITTANCES
C          NNBB = 2 X NB
C          NMM = NUMBER OF SYSTEM VARIABLES (= NNBB + 2 X NT + NB)
C          MTOBO = ARRAY OF: #, FROM_BUS, TO_BUS, LINE #
C          NY = SHUNT ADMITTANCE
C          NLINES = NUMBER OF LINES
C
C      PARAMETERS RETURNED:
C          JKEM = JACOBIAN MATRIX FOR STATE ESTIMATION
C
C      CALLED BY:
C          MAIN PROGRAM
C
C      CALLS:
C          NONE
C
C*****

      REAL JK11(NB,NB),JK12(NB,NB),JK21(NB,NB),JK22(NB,NB)
      REAL JK31(NT,NB),JK32(NT,NB),JK41(NT,NB),JK42(NT,NB),
      1JK51(NB,NB),JK52(NB,NB),NY(NLINES)
      REAL JKEM(NMM,NNBB),PNC(NB),QNC(NB),V(NB),D(NB),B(NB,NB),G(NB,NB)

      INTEGER MTOBO(NT,4)

C      GENERATING JK11,JK12,JK21,JK22,JK31,JK32,JK41,JK42,
C      JK51 AND JK52

```

```

DO 10 I=1,NB
DO 20 J=1,NB
IF (I.EQ.J) GOTO 20
IF (G(I,J).EQ.0.0.AND.B(I,J).EQ.0.0) GO TO 20
DIJ=D(I)-D(J)
SINDIJ=SIN(DIJ)
COSDIJ=COS(DIJ)
JK11(I,J)=V(I)*V(J)*(G(I,J)*SINDIJ-B(I,J)*COSDIJ)
JK12(I,J)=V(I)*V(J)*(G(I,J)*COSDIJ+B(I,J)*SINDIJ)
JK21(I,J)=-JK12(I,J)
JK22(I,J)=JK11(I,J)
20 CONTINUE
10 CONTINUE

DO 30 I=1,NB
JK11(I,I)=(-V(I)*V(I)*B(I,I)-QNC(I))
JK12(I,I)=(V(I)*V(I)*G(I,I)+PNC(I))
JK21(I,I)=(-V(I)*V(I)*G(I,I)+PNC(I))
JK22(I,I)=(-V(I)*V(I)*B(I,I)+QNC(I))
30 CONTINUE

DO 40 II=1,NT
KK=MTOBO(II,1)
I=MTOBO(II,2)
J=MTOBO(II,3)
L=MTOBO(II,4)
DIJ=D(I)-D(J)
SINDIJ=SIN(DIJ)
COSDIJ=COS(DIJ)

JK31(KK,I)=V(I)*V(J)*(-G(I,J)*SINDIJ+B(I,J)*COSDIJ)
JK31(KK,J)=-JK31(KK,I)

JK32(KK,I)=V(I)*V(J)*(G(I,J)*COSDIJ+B(I,J)*SINDIJ)
JK32(KK,J)=JK32(KK,I)
JK32(KK,I)=JK32(KK,I)-2*V(I)*V(I)*G(I,J)

JK41(KK,I)=V(I)*V(J)*(B(I,J)*SINDIJ+G(I,J)*COSDIJ)
JK41(KK,J)=-JK41(KK,I)

JK42(KK,I)=-V(I)*V(J)*(B(I,J)*COSDIJ-G(I,J)*SINDIJ)
JK42(KK,J)=JK42(KK,I)
JK42(KK,I)=JK42(KK,I)+2*V(I)*V(I)*B(I,J)
JK42(KK,I)=JK42(KK,I)-2*V(I)*V(I)*NY(L)

40 CONTINUE

DO 50 I=1,NB

```

```

        JK52(I,I)=V(I)
50 CONTINUE

C      CREATING JKEM MATRIX USING JK11,JK12,JK21,JK22,
C      JK31,JK32,JK41,JK42,JK51 AND JK52

        DO 60 I=1,NB
        DO 60 J=1,NB
        JKEM(I,J)=JK11(I,J)
60 CONTINUE

        DO 70 I=1,NB
        DO 70 J=1,NB
        JKEM(I,J+NB)=JK12(I,J)
70 CONTINUE

        DO 80 I=1,NB
        DO 80 J=1,NB
        JKEM(I+NB,J)=JK21(I,J)
80 CONTINUE

        DO 90 I=1,NB
        DO 90 J=1,NB
        JKEM(I+NB,J+NB)=JK22(I,J)
90 CONTINUE

        DO 100 I=1,NT
        DO 100 J=1,NB
        JKEM(I+NB+NB,J)=JK31(I,J)
100 CONTINUE

        DO 110 I=1,NT
        DO 110 J=1,NB
        JKEM(I+NB+NB,J+NB)=JK32(I,J)
110 CONTINUE

        DO 120 I=1,NT
        DO 120 J=1,NB
        JKEM(I+NB+NB+NT,J)=JK41(I,J)
120 CONTINUE

        DO 130 I=1,NT
        DO 130 J=1,NB
        JKEM(I+NB+NB+NT,J+NB)=JK42(I,J)
130 CONTINUE

        DO 140 I=1,NB
        DO 140 J=1,NB

```

```
JKEM(I+NB+NB+NT+NT,J)=JK51(I,J)
140 CONTINUE

DO 150 I=1,NB
DO 150 J=1,NB
JKEM(I+NB+NB+NT+NT,J+NB)=JK52(I,J)
150 CONTINUE

999 RETURN
END
```

```

C*****
      SUBROUTINE PQLCAL(PLC,QLC,V,D,B,G,NB,MTOBO,E,ST,ZLINE,
      1YC,NLINES,NT)
C*****
C      THIS SUBROUTINE CALCULATES THE COMPLEX LINE FLOWS AT EACH END
C      OF EACH LINE
C
C      PARAMETER PASSED:
C          V = ARRAY OF MAGNITUDE OF NODAL VOLTAGES
C          D = ARRAY OF ANGLE OF NODAL VOLTAGE ANGLES
C          B = SUSCEPTANCES
C          G = ADMITTANCES
C          NB = NUMBER OF BUSES
C          MTOBO = ARRAY OF: #, FROM_BUS, TO_BUS, LINE #
C          E = ARRAY OF COMPLEX NODAL VOLTAGES
C          ST = ARRAY OF COMPLEX LINE FLOWS (FOR EACH END OF EACH LINE)
C          ZLINE = ARRAY OF LINE IMPEDANCES
C          YC = ARRAY OF LINE CHARGING ADMITTANCES
C          NLINE = NUMBER OF LINES
C          NT = 2 X NLINES
C
C      PARAMETER RETURNED:
C          PLC = ARRAY OF CALCULATED REAL POWER FLOWS
C          QLC = ARRAY OF CALCULATED REACTIVE POWER FLOWS
C
C      CALLED BY:
C          MAIN PROGRAM
C
C      CALLS:
C          SUBROUTINE CLF
C*****

```

```

      REAL PLC(NT),QLC(NT),V(NB),D(NB),G(NB,NB),B(NB,NB)

```

```

      COMPLEX E(NB),ST(NT),ZLINE(NLINES),YC(NLINES)

```

```

      DO 10 I = 1,NB
      AA = V(I)*COS(D(I))
      BB = V(I)*SIN(D(I))
      E(I) = CMLX(AA,BB)
10 CONTINUE

```

```

      CALL CLF(MTOBO,NT,E,NB,ST,ZLINE,YC,NLINES)

```

C LINE FLOW CALCULATION USING CURRENT V AND D VALUES

```
DO 20 I = 1,NT  
PLC(I) = REAL(ST(I))  
QLC(I) = AIMAG(ST(I))  
20 CONTINUE
```

```
RETURN  
END
```

```

C*****
      SUBROUTINE EDELTA(PNM,QNM,PLM,QLM,VM,PNC,QNC,PLC,QLC,V,CONM,
      1NMM,NB,NT)
C*****
C
C   THIS SUBROUTINE CALCULATES THE DIFFERENCES BETWEEN CALCULATED
C   VALUES AND MEASUREMENTS
C
C   PARAMETER PASSED:
C       PNM = ARRAY OF SIMULATED NODAL REAL POWER INJECTIONS
C       QNM = ARRAY OF SIMULATED NODAL REACTIVE POWER INJECTIONS
C       PLM = ARRAY OF SIMULATED REAL POWER POWER FLOWS
C       QLM = ARRAY OF SIMULATED REACTIVE POWER FLOWS
C       VM = ARRAY OF SIMULATED MAGNITUDES OF NODAL VOLTAGES
C       PNC = ARRAY OF CALCULATED NODAL REAL POWER INJECTIONS
C       QNC = ARRAY OF CALCULATED NODAL REAL POWER INJECTIONS
C       PLC = ARRAY OF CALCULATED REAL POWER POWER FLOWS
C       QLC = ARRAY OF CALCULATED REAL POWER POWER FLOWS
C       V = ARRAY OF CALCULATED MAGNITUDE OF NODAL VOLTAGES
C       NMM = NUMBER OF SYSTEM VARIABLES (= NNBB + 2 X NT + NB)
C       NB = NUMBER OF BUSES
C       NT = NUMBER OF LINES
C
C   PARAMETERS RETURNED:
C       CONM = ARRAY OF DIFFERENCES BETWEEN CALCULATED VALUES AND
C             MEASUREMENTS
C   CALLED BY:
C       MAIN PROGRAM
C
C   CALLS:
C       NONE
C
C*****

      REAL PNM(NB),QNM(NB),PLM(NT),QLM(NT),VM(NB)
      REAL PNC(NB),QNC(NB),PLC(NT),QLC(NT),V(NB),CONM(NMM)

      DO 10 I=1,NB
      CONM(I) = PNM(I) - PNC(I)
      CONM(I + NB) = QNM(I) - QNC(I)
10 CONTINUE

      DO 20 I=1,NT
      CONM(I+NB+NB)=PLM(I)-PLC(I)
      CONM(I+NB+NB+NT)=QLM(I)-QLC(I)
20 CONTINUE

```



```
DO 30 I=1,NB
  CONM(I+NB+NB+NT+NT)=VM(I)-V(I)
30 CONTINUE

RETURN
END
```

```

C*****
      SUBROUTINE TEST(CON2, ITEST, NB, CRIT)
C*****
C
C
C      THIS SUBROUTINE IS USED TO TEST IF THE PROGRAM HAS
C      CONVERGED, DIVERGED OR NOT BOTH BY CALCULATING THE
C      DIFFERENCES BETWEEN COMPLEX
C      VOLTAGES OBTAINED FROM TWO CONSECUTIVE ITERATIONS.
C
C      PARAMETERS PASSED:
C          CON2 = ARRAY OF DIFFERENCES BETWEEN MEASUREMENTS AND
C                CALCULATED VALUES
C          NB = NUMBER OF BUSES
C          CRIT = CONVERGENCE CRITERION
C
C      PARAMETER RETURNED:
C          ITEST = INDEX OF STATUS (CONVERGE, DIVERGE OR NOT BOTH)
C
C      CALLED BY:
C          MAIN PROGRAM
C
C      CALLS:
C          NONE
C*****

      DIMENSION CON2(2*NB-1)

      DO 5 I=1,2*NB-1
      IF(ABS(CON2(I)).GT.10.)GO TO 20
5  CONTINUE

      DO 10 I=1,2*NB-1
      IF(ABS(CON2(I)).GT.CRIT)GO TO 30
10 CONTINUE

      ITEST=1

      GO TO 50

20  ITEST=2

      GO TO 50

30  ITEST=0

```

50 RETURN
END

```

C*****
C      SUBROUTINE PI(P,Q,PLT,QLT,VT,PNM,QNM,PLM,QLM,VM,PNC,QNC,PLC,QLC,
C      1V,JCT,JMT,JCM,AJCT,AJMT,AJCM,WMM,AM,NB,NT,NCASE,NMM,NNBB,KKK,SUT,
C      1SUM,SUC,CTX,MTX,CMX,CTRX,MTRX,CMRX,CTI,MTI,CMI,PJCT,PJMT,PJCM)
C*****
C
C      THIS SUBROUTINE CALCULATES PERFORMANCE INDICES OF EACH SINGLE CASE
C
C      PARAMETERS PASSED:
C          P = ARRAY OF TRUE NODAL REAL POWER INJECTIONS
C          Q = ARRAY OF TRUE NODAL REACTIVE POWER INJECTIONS
C          PLT = ARRAY OF TRUE REAL POWER FLOWS
C          QLT = ARRAY OF TRUE REACTIVE POWER FLOWS
C          VT = ARRAY OF TRUE MAGNITUDES OF NODAL VOLTAGES
C          PNM = ARRAY OF SIMULATED NODAL REAL POWER INJECTIONS
C          QNM = ARRAY OF SIMULATED NODAL REACTIVE POWER INJECTIONS
C          PLM = ARRAY OF SIMULATED REAL POWER POWER FLOWS
C          QLM = ARRAY OF SIMULATED REACTIVE POWER FLOWS
C          VM = ARRAY OF SIMULATED MAGNITUDES OF NODAL VOLTAGES
C          VM = ARRAY OF SIMULATED MAGNITUDES OF NODAL VOLTAGES
C          PNC = ARRAY OF CALCULATED NODAL REAL POWER INJECTIONS
C          QNC = ARRAY OF CALCULATED NODAL REAL POWER INJECTIONS
C          PLC = ARRAY OF CALCULATED REAL POWER POWER FLOWS
C          QLC = ARRAY OF CALCULATED REAL POWER POWER FLOWS
C          V = ARRAY OF CALCULATED MAGNITUDE OF NODAL VOLTAGES
C          WMM = WEIGHTING MATRIX
C          AM = ARRAY OF INDICES SPECIFY WHETHER CORRESPONDING MEASUREMENTS
C              ARE AVAILIABLE OR NOT AND SPECIFY THEIR ACCURACY CATEGORIES
C          NB = NUMBER OF BUSES
C          NT = 2 X NLINES
C          NCASE = NUMBER OF SIMULATED CASES
C          NMM = NUMBER OF SYSTEM VARIABLES (= NNBB + 2 X NT + NB)
C          NNBB = 2 X NB
C          KKK = CASE NUMBER
C
C      PARAMETERS RETURNED:
C          JCT = SUM OF DIFFERENCES BETWEEN CALCULATED AND TRUE VALUES
C              WHOSE CORRESPONDING MEASUREMENTS ARE AVAILIABLE SQUARED
C          JMT = SUM OF DIFFERENCES BETWEEN AVAILIABLE MEASUREMENTS AND
C              TRUE VALUES SQUARED
C          JCM = SUM OF DIFFERENCES BETWEEN CALCULATED VALUES AND
C              AVAILIABLE MEASUREMENTS SQUARED
C          AJCT = SUM OF ABSOLUTE DIFFERENCES BETWEEN CALCULATED AND
C              TRUE VALUES
C          AJMT = SUM OF ABSOLUTE DIFFERENCES BETWEEN MEASUREMENTS AND
C              TRUE VALUES
C          AJCM = SUM OF ABSOLUTE DIFFERENCES BETWEEN CALCULATED VALUES

```

```

C          AND MEASUREMENTS
C          SUT = SUM OF ABSOLUTE TRUES VALUES
C          SUM = SUM OF ABSOLUTE MEASUREMENTS
C          SUC = SUM OF ABSOLUTE CALCULATED VALUES
C          CTX = MAXIMUM DIFFERENCE BETWEEN CALCULATED AND TRUE VALUES
C          MTX = MAXIMUM DIFFERENCE BETWEEN MEASUREMENTS AND TRUE VALUES
C          CMX = MAXIMUM DIFFERENCE BETWEEN CALCULATED VALUES AND MEASUREMENTS
C          CTRX = RELATIVE DIFFERENCE BETWEEN CALCULATED AND TRUE VALUES
C                   FOR CTX
C          MTRX = RELATIVE DIFFERENCE BETWEEN MEASUREMENTS AND TRUE VALUES
C                   FOR MTX
C          CMRX = RELATIVE DIFFERENCE BETWEEN CALCULATED VALUES AND
C                   MEASUREMENTS FOR CMX
C          CTI = INDEX TO TELL WHERE CTX OCCURS
C          MTI = INDEX TO TELL WHERE MTX OCCURS
C          CMI = INDEX TO TELL WHERE CMX OCCURS
C          PJCT = AJCT/SUT
C          PJMT = AJMT/SUM
C          PJCM = AJCM/SUC

```

```

C
C CALLED BY:
C     MAIN PROGRAM
C

```

```

C CALLS:
C     NONE
C

```

C*****

```

INTEGER AM(NMM),CTI(NCASE),MTI(NCASE),CMI(NCASE)

```

```

REAL WMM(NMM)
REAL P(NB),Q(NB),PLT(NB),QLT(NB),VT(NB)
REAL PNM(NB),QNM(NB),PLM(NB),QLM(NB),VM(NB)
REAL PNC(NB),QNC(NB),PLC(NB),QLC(NB),V(NB)

```

```

REAL JCT(NCASE)
REAL JMT(NCASE)
REAL JCM(NCASE)

```

```

REAL AJCT(NCASE)
REAL AJMT(NCASE)
REAL AJCM(NCASE)
REAL PJCT(KKK),PJCM(KKK),PJMT(KKK)

```

```

REAL SUT(NCASE),SUM(NCASE),SUC(NCASE)
REAL CTX(NCASE),MTX(NCASE),CMX(NCASE)
REAL CTRX(NCASE),MTRX(NCASE),CMRX(NCASE)

```

```

CTX(KKK)=0.0
MTX(KKK)=0.0
CMX(KKK)=0.0

CTRX(KKK)=0.0
MTRX(KKK)=0.0
CMRX(KKK)=0.0

CTI(KKK)=0.0
MTI(KKK)=0.0
CMI(KKK)=0.0

DO 10 I=1,NB
IF (ABS(PNC(I)-P(I)).GT.CTX(KKK)) THEN
CTX(KKK)=ABS(PNC(I)-P(I))
CTRX(KKK)=ABS((PNC(I)-P(I))/PNC(I))
CTI(KKK)=I
ELSE
CTX(KKK)=CTX(KKK)
CTRX(KKK)=CTRX(KKK)
CTI(KKK)=CTI(KKK)
ENDIF
IF (ABS(PNM(I)-P(I)).GT.MTX(KKK)) THEN
MTX(KKK)=ABS(PNM(I)-P(I))
MTRX(KKK)=ABS((PNM(I)-P(I))/PNM(I))
MTI(KKK)=I
ELSE
MTX(KKK)=MTX(KKK)
MTI(KKK)=MTI(KKK)
ENDIF
IF (ABS(PNC(I)-PNM(I)).GT.CMX(KKK)) THEN
CMX(KKK)=ABS(PNC(I)-PNM(I))
CMRX(KKK)=ABS((PNC(I)-PNM(I))/PNC(I))
CMI(KKK)=I
ELSE
CMX(KKK)=CMX(KKK)
CMRX(KKK)=CMRX(KKK)
CMI(KKK)=CMI(KKK)
ENDIF

SUT(KKK)=SUT(KKK)+ABS(P(I))
SUM(KKK)=SUM(KKK)+ABS(PNM(I))
SUC(KKK)=SUC(KKK)+ABS(PNC(I))

AJCT(KKK)=AJCT(KKK)+ABS(PNC(I)-P(I))
AJMT(KKK)=AJMT(KKK)+ABS(PNM(I)-P(I))
AJCM(KKK)=AJCM(KKK)+ABS(PNC(I)-PNM(I))

```

```

IF (AM(I).EQ.0) GO TO 10
JCT(KKK)=JCT(KKK)+(PNC(I)-P(I))*(PNC(I)-P(I))
JMT(KKK)=JMT(KKK)+(PNM(I)-P(I))*(PNM(I)-P(I))
JCM(KKK)=JCM(KKK)+(PNC(I)-PNM(I))*(PNC(I)-PNM(I))
10 CONTINUE

DO 20 I=1,NB
IF (ABS(QNC(I)-Q(I)).GT.CTX(KKK)) THEN
CTX(KKK)=ABS(QNC(I)-Q(I))
CTRX(KKK)=ABS((QNC(I)-Q(I))/QNC(I))
CTI(KKK)=I+NB
ELSE
CTX(KKK)=CTX(KKK)
CTRX(KKK)=CTRX(KKK)
CTI(KKK)=CTI(KKK)
ENDIF
IF (ABS(QNM(I)-Q(I)).GT.MTX(KKK)) THEN
MTX(KKK)=ABS(QNM(I)-Q(I))
MTRX(KKK)=ABS((QNM(I)-Q(I))/QNM(I))
MTI(KKK)=I+NB
ELSE
MTX(KKK)=MTX(KKK)
MTRX(KKK)=MTRX(KKK)
MTI(KKK)=MTI(KKK)
ENDIF
IF (ABS(QNC(I)-QNM(I)).GT.CMX(KKK)) THEN
CMX(KKK)=ABS(QNC(I)-QNM(I))
CMRX(KKK)=ABS((QNC(I)-QNM(I))/QNC(I))
CMI(KKK)=I+NB
ELSE
CMX(KKK)=CMX(KKK)
CMRX(KKK)=CMRX(KKK)
CMI(KKK)=CMI(KKK)
ENDIF

SUT(KKK)=SUT(KKK)+ABS(Q(I))
SUM(KKK)=SUM(KKK)+ABS(QNM(I))
SUC(KKK)=SUC(KKK)+ABS(QNC(I))

AJCT(KKK)=AJCT(KKK)+ABS(QNC(I)-Q(I))
AJMT(KKK)=AJMT(KKK)+ABS(QNM(I)-Q(I))
AJCM(KKK)=AJCM(KKK)+ABS(QNC(I)-QNM(I))

IF (AM(I+NB).EQ.0) GO TO 20
JCT(KKK)=JCT(KKK)+(QNC(I)-Q(I))*(QNC(I)-Q(I))
JMT(KKK)=JMT(KKK)+(QNM(I)-Q(I))*(QNM(I)-Q(I))
JCM(KKK)=JCM(KKK)+(QNC(I)-QNM(I))*(QNC(I)-QNM(I))
20 CONTINUE

```

```

DO 30 I=1,NT
IF (ABS(PLC(I)-PLT(I)).GT.CTX(KKK)) THEN
CTX(KKK)=ABS(PLC(I)-PLT(I))
CTRX(KKK)=ABS((PLC(I)-PLT(I))/PLC(I))
CTI(KKK)=I+NNBB
ELSE
CTX(KKK)=CTX(KKK)
CTRX(KKK)=CTRX(KKK)
CTI(KKK)=CTI(KKK)
ENDIF
IF (ABS(PLM(I)-PLT(I)).GT.MTX(KKK)) THEN
MTX(KKK)=ABS(PLM(I)-PLT(I))
MTRX(KKK)=ABS((PLM(I)-PLT(I))/PLM(I))
MTI(KKK)=I+NNBB
ELSE
MTX(KKK)=MTX(KKK)
MTRX(KKK)=MTRX(KKK)
MTI(KKK)=MTI(KKK)
ENDIF
IF (ABS(PLC(I)-PLM(I)).GT.CMX(KKK)) THEN
CMX(KKK)=ABS(PLC(I)-PLM(I))
CMRX(KKK)=ABS((PLC(I)-PLM(I))/PLC(I))
CMI(KKK)=I+NNBB
ELSE
CMX(KKK)=CMX(KKK)
CMRX(KKK)=CMRX(KKK)
CMI(KKK)=CMI(KKK)
ENDIF

SUT(KKK)=SUT(KKK)+ABS(PLT(I))
SUM(KKK)=SUM(KKK)+ABS(PLM(I))
SUC(KKK)=SUC(KKK)+ABS(PLC(I))

AJCT(KKK)=AJCT(KKK)+ABS(PLC(I)-PLT(I))
AJMT(KKK)=AJMT(KKK)+ABS(PLM(I)-PLT(I))
AJCM(KKK)=AJCM(KKK)+ABS(PLC(I)-PLM(I))

IF (AM(I+NNBB).EQ.0) GO TO 30
JCT(KKK)=JCT(KKK)+(PLC(I)-PLT(I))*(PLC(I)-PLT(I))
JMT(KKK)=JMT(KKK)+(PLM(I)-PLT(I))*(PLM(I)-PLT(I))
JCM(KKK)=JCM(KKK)+(PLC(I)-PLM(I))*(PLC(I)-PLM(I))
30 CONTINUE

DO 40 I=1,NT
IF (ABS(QLC(I)-QLT(I)).GT.CTX(KKK)) THEN
CTX(KKK)=ABS(QLC(I)-QLT(I))
CTRX(KKK)=ABS((QLC(I)-QLT(I))/QLC(I))

```



```

CTI(KKK)=I+NNBB+NT
ELSE
CTX(KKK)=CTX(KKK)
CTRX(KKK)=CTRX(KKK)
CTI(KKK)=CTI(KKK)
ENDIF
IF (ABS(QLM(I)-QLT(I)).GT.MTX(KKK)) THEN
MTX(KKK)=ABS(QLM(I)-QLT(I))
MTRX(KKK)=ABS((QLM(I)-QLT(I))/QLM(I))
MTI(KKK)=I+NNBB+NT
ELSE
MTX(KKK)=MTX(KKK)
MTRX(KKK)=MTRX(KKK)
MTI(KKK)=MTI(KKK)
ENDIF
IF (ABS(QLC(I)-QLM(I)).GT.CMX(KKK)) THEN
CMX(KKK)=ABS(QLC(I)-QLM(I))
CMRX(KKK)=ABS((QLC(I)-QLM(I))/QLC(I))
CMI(KKK)=I+NNBB+NT
ELSE
CMX(KKK)=CMX(KKK)
CMRX(KKK)=CMRX(KKK)
CMI(KKK)=CMI(KKK)
ENDIF

SUT(KKK)=SUT(KKK)+ABS(QLT(I))
SUM(KKK)=SUM(KKK)+ABS(QLM(I))
SUC(KKK)=SUC(KKK)+ABS(QLC(I))

AJCT(KKK)=AJCT(KKK)+ABS(QLC(I)-QLT(I))
AJMT(KKK)=AJMT(KKK)+ABS(QLM(I)-QLT(I))
AJCM(KKK)=AJCM(KKK)+ABS(QLC(I)-QLM(I))

IF (AM(I+NNBB+NT).EQ.0) GO TO 40
JCT(KKK)=JCT(KKK)+(QLC(I)-QLT(I))*(QLC(I)-QLT(I))
JMT(KKK)=JMT(KKK)+(QLM(I)-QLT(I))*(QLM(I)-QLT(I))
JCM(KKK)=JCM(KKK)+(QLC(I)-QLM(I))*(QLC(I)-QLM(I))
40 CONTINUE

DO 50 I=1,NB
IF (ABS(V(I)-VT(I)).GT.CTX(KKK)) THEN
CTX(KKK)=ABS(V(I)-VT(I))
CTRX(KKK)=ABS((V(I)-VT(I))/V(I))
CTI(KKK)=I+NNBB+NT+NT
ELSE
CTX(KKK)=CTX(KKK)
CTRX(KKK)=CTRX(KKK)
CTI(KKK)=CTI(KKK)

```

```

ENDIF
IF (ABS(VM(I)-VT(I)).GT.MTX(KKK)) THEN
MTX(KKK)=ABS(VM(I)-VT(I))
MTRX(KKK)=ABS((VM(I)-VT(I))/VM(I))
MTI(KKK)=I+NNBB+NT+NT
ELSE
MTX(KKK)=MTX(KKK)
MTRX(KKK)=MTRX(KKK)
MTI(KKK)=MTI(KKK)
ENDIF
IF (ABS(V(I)-VM(I)).GT.CMX(KKK)) THEN
CMX(KKK)=ABS(V(I)-VM(I))
CMRX(KKK)=ABS((V(I)-VM(I))/V(I))
CMI(KKK)=I+NNBB+NT+NT
ELSE
CMX(KKK)=CMX(KKK)
CMRX(KKK)=CMRX(KKK)
CMI(KKK)=CMI(KKK)
ENDIF

SUT(KKK)=SUT(KKK)+ABS(VT(I))
SUM(KKK)=SUM(KKK)+ABS(VM(I))
SUC(KKK)=SUC(KKK)+ABS(V(I))

AJCT(KKK)=AJCT(KKK)+ABS(V(I)-VT(I))
AJMT(KKK)=AJMT(KKK)+ABS(VM(I)-VT(I))
AJCM(KKK)=AJCM(KKK)+ABS(V(I)-VM(I))

IF (AM(I+NNBB+NT+NT).EQ.0) GO TO 50
JCT(KKK)=JCT(KKK)+(V(I)-VT(I))*(V(I)-VT(I))
JMT(KKK)=JMT(KKK)+(VM(I)-VT(I))*(VM(I)-VT(I))
JCM(KKK)=JCM(KKK)+(V(I)-VM(I))*(V(I)-VM(I))
50 CONTINUE

PJCT(KKK)=AJCT(KKK)/SUT(KKK)
PJMT(KKK)=AJMT(KKK)/SUM(KKK)
PJCM(KKK)=AJCM(KKK)/SUM(KKK)

RETURN
END

```

```

C*****
      SUBROUTINE STAM(A,N,AVE,SIG,MAX)
C*****
C
C   THIS SUBROUTINE CALCULATES MAXIMUM, AVERAGE VALUE AND
C   STANDARD DEVIATION FOR THE ELEMENTS OF ARRAY A.
C
C   PARAMETERS PASSED:
C     A = ARRAY OF "N" NUMBER OF ELEMENTS
C     N = NUMBER OF ELEMENTS IN ARRAY "A"
C
C   PARAMETERS RETURNED:
C     AVE = AVERAGE OF "N" ELEMENTS IN ARRAY "A"
C     SIG = STANDARD DEVIATION OF ELEMENTS IN ARRAY "A"
C     MAX = MAXIMUM OF "N" ELEMENTS IN ARRAY "A"
C
C   CALLED BY:
C     MAIN PROGRAM
C
C   CALLS:
C     NONE
C
C*****

      DIMENSION A(N)

      REAL MAX

      SUM = 0.0

      DO 10 I = 1,N
      SUM = SUM + A(I)
10 CONTINUE

      AVE = SUM/N
      SIG = 0.0

      DO 20 I=1,N
      SIG = SIG + (A(I) - AVE)*(A(I) - AVE)
20 CONTINUE

      SIG = SQRT(SIG/(N-1))

      MAX=0.0

      DO 30 I=1,N
      IF (MAX.GT.A(I)) GO TO 30

```

```
MAX=A(I)  
30 CONTINUE
```

```
RETURN  
END
```

Appendix D

Values of the Performance Indices

This appendix contains the values of performances indices obtained using different weighting matrices under various conditions.

Table D.1 and D.2 give the maxima, the average values and the standard deviations of the different set of performance indices obtained using different weighting matrices. For example, one set of 20 values of the performance index JCT is obtained by solving 20 cases using **W1**. The maximum of those 20 values appear in the first row labeled JCTMAX, the average of those 20 values appear in the second row labeled JCTAVE, and the standard deviation of those 20 values appear in the third row labeled JCTSIG. Instrumentation configuration 14-A is used to get these two tables. Each entry in those two tables is obtained using of 20 values, *i.e.*, 20 cases are simulated. Both tables are grouped according to the index sets mentioned in section 2.1.

Tables D.3 and D.4 are similar to Tables D.1 and D.2 except that instrumentation configuration 14-B is used and 60 cases are simulated.

Table D.5 gives the largest mismatches between calculated values and true ones when different weighting matrices are used. The instrumentation configurations used are 14-A and 14-B. Table D.5 also gives the corresponding relative values for the mismatches using calculated values as references, the corresponding true values, the corresponding calculated values, the index of system variables that have the largest mismatches, and the case in which the largest mismatches occur. For example, the first row tells that when instrumentation configuration 14-A is used, if using weighting matrix **W1**, the largest mismatch calculated value and true one is 0.1549, this mismatch divided by the calculated value is 1.9415, the true value is -0.07613, the calculated value is 0.0809, the system variable has the largest mismatch

is PN_5 , and the largest mismatch occurs in case 17.

The values in Table D.6 is the values of performance indices obtained using different weighting matrices. Different instrumentation configurations are used.

Tables D.7 and D.8 contain the maxima, the average values and the standard deviations of different performance indices obtained using different weighting matrices when FJM PSSE program is used. Table D.7 contains the results when instrumentation configuration 14-A is used while Table D.8 contains the result when instrumentation configuration 14-B is chosen.

Table D.9 gives the largest mismatches between calculated values and true ones when different weighting matrices are used. The instrumentation configurations used are 14-A and 14-B. Table D.9 also gives the corresponding relative values for the mismatches using calculated values as references, the corresponding true values, the corresponding calculated values, the index of system variables that have the largest mismatches, and the case in which the largest mismatches occur.

Tables D.10 and D.11 contain the maxima, the average values and the standard deviations of different performance indices obtained using different weighting matrices when errors introduced to measurements are amplified. They are still obtained using FJM PSSE program. Table D.10 contains the results when instrumentation configuration 14-A is used while Table D.11 contains the result when instrumentation configuration 14-B is chosen.

Table D.12 gives the largest mismatches between calculated values and true ones when different weighting matrices are used. The instrumentation configurations used are 14-A and 14-B. Table D.5 also gives the corresponding relative values for the mismatches using calculated values as references, the corresponding true

values, the corresponding calculated values, the index of system variables that have the largest mismatches, and the case in which the largest mismatches occur.

Table D.13 contains the maxima, the average values and the standard deviations of different performance indices obtained using different weighting matrices and the IEEE 30 bus test system.

<i>indices</i>	<i>W1</i>	<i>W2</i>	<i>WU</i>	<i>WP</i>	<i>W4</i>
JCTMAX	2.8297	0.6233	0.2922	2.6287	0.5396
JCTAVE	0.7536	0.2262	0.1562	0.7111	0.2519
JCTSIG	0.6967	0.1487	0.0557	0.6347	0.1096
JMTMAX	4.2309	4.2309	4.2309	4.2309	4.2309
JMTAVE	1.3895	1.3895	1.3895	1.3895	1.3895
JMTSIG	1.0060	1.0060	1.0060	1.0060	1.0060
JCMMAX	1.3821	2.3308	3.3124	1.4101	2.9936
JCMAVE	0.6339	0.9115	1.2023	0.6457	1.1949
JCMSIG	0.3483	0.5817	0.7958	0.3565	0.7446
AJCTMAX	1.5284	1.0418	0.9708	1.5187	1.3283
AJCTAVE	1.1332	0.8387	0.7846	1.1413	0.9725
AJCTSIG	0.2237	0.1183	0.0923	0.2302	0.1673
AJMTMAX	0.9023	0.9023	0.9023	0.9023	0.9023
AJMTAVE	0.7296	0.7296	0.7296	0.7296	0.7296
AJMTSIG	0.0663	0.0663	0.0663	0.0663	0.0663
AJCMMAX	1.4746	1.1936	1.1746	1.5278	1.4753
AJCMAVE	1.1776	1.0157	1.0095	1.1987	1.1500
AJCMSIG	0.1818	0.1053	0.1035	0.1947	0.1526
CTXMAX	0.1549	0.1167	0.1068	0.1305	0.0984
CTRX	0.2449	0.1964	0.1828	0.2145	0.2652
MTXMAX	0.1934	0.1934	0.1934	0.1934	0.1934
MTRX	0.0768	0.0768	0.0768	0.0768	0.0768
CMXMAX	0.1464	0.1428	0.1738	0.1219	0.1644
CMRX	0.2315	0.0601	0.0741	0.2005	0.0698
PJCTMAX	4.0496	2.7602	2.5720	4.0237	3.5193
PJCTAVE	3.0024	2.2221	2.0788	3.0239	2.5767
PJCTSIG	0.5926	0.3134	0.2447	0.6098	0.4432
PJMTMAX	2.3906	2.3906	2.3906	2.3906	2.3906
PJMTAVE	1.9331	1.9331	1.9331	1.9331	1.9331
PJMTSIG	0.1757	0.1757	0.1757	0.1757	0.1757
PJCMMAX	3.9091	3.1530	3.1030	4.0114	3.9356
PJCMAVE	3.1163	2.6878	2.6714	3.1719	3.0434
PJCMSIG	0.4819	0.2787	0.2744	0.5124	0.4066

Table D.1: Values of performance indices obtained using different weighting matrices. Instrumentation configuration 14-A is used with a CRIT = 0.005. The number of cases is 20, i.e., 20 values are used to obtain one entry in this table.

<i>indices</i>	<i>W5</i>	<i>W6</i>	<i>W7</i>	<i>W10</i>	<i>W11</i>
JCTMAX	2.9666	1.3345	9.7680	2.6973	1.6554
JCTAVE	1.6018	0.4910	4.3234	0.9171	0.7133
JCTSIG	0.6762	0.3141	2.6194	0.7045	0.5156
JMTMAX	4.2309	4.2309	4.2309	4.2309	4.2309
JMTAVE	1.3895	1.3895	1.3895	1.3895	1.3895
JMTSIG	1.0060	1.0060	1.0060	1.0060	1.0060
JCMMAX	4.1404	1.9608	9.5209	8.7033	9.0805
JCMAVE	2.4513	0.9350	4.5139	1.8169	1.8998
JCMSIG	1.1078	0.4837	2.7176	1.8795	1.8953
AJCTMAX	3.6138	1.8202	7.7020	1.7508	1.6974
AJCTAVE	2.3648	1.2933	3.7939	1.2448	1.1474
AJCTSIG	0.6581	0.2730	1.5733	0.2773	0.2110
AJMTMAX	0.9023	0.9023	0.9023	0.9023	0.9023
AJMTAVE	0.7296	0.7296	0.7296	0.7296	0.7296
AJMTSIG	0.0663	0.0663	0.0663	0.0663	0.0663
AJCMMAX	3.7851	1.8645	7.6093	1.7116	1.6527
AJCMAVE	2.4521	1.3952	3.7909	1.3605	1.3106
AJCMSIG	0.6909	0.2356	1.5745	0.2518	0.1926
CTXMAX	0.3319	0.1386	0.9443	0.2050	0.2009
CTR	0.8940	0.2249	1.0162	0.3003	0.2961
MTXMAX	0.1934	0.1934	0.1934	0.1934	0.1934
MTR	0.0768	0.0768	0.0768	0.0768	0.0768
CMXMAX	0.3282	0.1371	0.9480	0.2752	0.2806
CMR	0.8842	0.3922	1.0202	0.1227	0.1253
PJCTMAX	9.5747	4.8491	20.4064	4.6389	4.4973
PJCTAVE	6.2655	3.4265	10.0519	3.2981	3.0400
PJCTSIG	1.7436	0.7233	4.1685	0.7347	0.5592
PJMTMAX	2.3906	2.3906	2.3906	2.3906	2.3906
PJMTAVE	1.9331	1.9331	1.9331	1.9331	1.9331
PJMTSIG	0.1757	0.1757	0.1757	0.1757	0.1757
PJCMMAX	9.9822	4.8954	20.1296	4.5371	4.3812
PJCMAVE	6.4881	3.6920	10.0302	3.6007	3.4683
PJCMSIG	1.8236	0.6229	4.1597	0.6684	0.5098

Table D.2: Values of performance indices obtained using different weighting matrices. Instrumentation configuration 14-A is used with a CRIT = 0.005. The number of cases is 20, *i.e.*, 20 values are used to obtain one entry in this table.

<i>indices</i>	<i>W1</i>	<i>W2</i>	<i>WU</i>	<i>WP</i>	<i>W4</i>
JCTMAX	0.4156	0.3288	0.3822	0.4728	0.3845
JCTAVE	0.2041	0.1506	0.1416	0.2141	0.1691
JCTSIG	0.0666	0.0602	0.0674	0.0741	0.0765
JMTMAX	0.7436	0.7436	0.7436	0.7436	0.7436
JMTAVE	0.4087	0.4087	0.4087	0.4087	0.4087
JMTSIG	0.1156	0.1156	0.1156	0.1156	0.1156
JCMMAX	0.4929	0.5600	0.7188	0.5033	0.8185
JCMAVE	0.2056	0.2307	0.2817	0.2108	0.3070
JCMSIG	0.0821	0.0902	0.1066	0.0849	0.1183
AJCTMAX	0.9748	0.7847	0.7873	0.9809	0.8353
AJCTAVE	0.6894	0.5511	0.5276	0.7056	0.5694
AJCTSIG	0.1059	0.0783	0.0817	0.1096	0.0951
AJMTMAX	0.7155	0.7155	0.7155	0.7155	0.7155
AJMTAVE	0.6230	0.6230	0.6230	0.6230	0.6230
AJMTSIG	0.0391	0.0391	0.0391	0.0391	0.0391
AJCMMAX	1.0116	0.8956	0.9298	1.0387	0.9648
AJCMAVE	0.7609	0.6800	0.6759	0.7753	0.7066
AJCMSIG	0.1019	0.0782	0.0786	0.1055	0.0908
CTXMAX	0.0765	0.0675	0.0640	0.0727	0.0656
CTRX	0.2950	0.2695	0.2591	0.2844	0.2640
MTXMAX	0.0531	0.0531	0.0531	0.0531	0.0531
MTRX	0.0749	0.0749	0.0749	0.0749	0.0749
CMXMAX	0.0788	0.0805	0.0831	0.0854	0.0828
CMRX	0.3035	0.0355	0.0367	0.0357	0.0366
PJCTMAX	2.5828	2.0790	2.0858	2.5989	2.2132
PJCTAVE	1.8266	1.4602	1.3980	1.8694	1.5087
PJCTSIG	0.2806	0.2075	0.2166	0.2903	0.2520
PJMTMAX	1.8958	1.8958	1.8958	1.8958	1.8958
PJMTAVE	1.6505	1.6505	1.6505	1.6505	1.6505
PJMTSIG	1.1036	0.1036	0.1036	0.1036	1.1036
PJCMMAX	2.6780	2.3731	2.4637	2.7497	2.5566
PJCMAVE	2.0146	1.8004	1.7894	2.0527	1.8706
PJCMSIG	0.2696	0.2067	0.2080	0.2791	0.2403

Table D.3: Values of performance indices obtained using different weighting matrices. Instrumentation configuration 14-B is used with a CRIT = 0.005. The number of cases is 60, i.e., 60 values are used to obtain one entry in this table.

<i>indices</i>	<i>W5</i>	<i>W6</i>	<i>W7</i>	<i>W8</i>	<i>W9</i>	<i>W10</i>	<i>W11</i>
JCTMAX	3.3945	0.4926	15.0721	12.0412	24.7580	0.7971	1.1189
JCTAVE	1.3976	0.2234	3.4971	3.1852	6.2200	0.3253	0.4983
JCTSIG	0.8852	0.0959	2.9882	2.8827	6.1319	0.1540	0.2782
JMTMAX	0.7436	0.7436	0.7436	0.7436	0.7436	0.7436	0.7436
JMTAVE	0.4087	0.4087	0.4087	0.4087	0.4087	0.4087	0.4087
JMTSIG	0.1156	0.1156	0.1156	0.1156	0.1156	0.1156	0.1156
JCMMAX	3.8167	0.7870	15.1937	12.7867	25.9064	0.9323	1.7669
JCMAVE	1.4322	0.2916	3.4489	3.3884	6.5236	0.4337	0.6799
JCMSIG	0.8460	0.1329	2.9950	3.0585	6.3961	0.1782	0.3449
AJCTMAX	2.4587	1.1358	4.8023	3.4299	58.5018	1.2582	1.2582
AJCTAVE	1.3399	0.6897	2.1970	1.9078	3.2034	0.8194	0.8769
AJCTSIG	0.4544	0.1559	0.9806	0.6858	7.3086	0.1717	0.1742
AJMTMAX	0.7155	0.7155	0.7155	0.7155	0.7155	0.7155	0.7155
AJMTAVE	0.6230	0.6230	0.6230	0.6230	0.6230	0.6230	0.6230
AJMTSIG	0.0391	0.0391	0.0391	0.0391	0.0391	0.0391	0.0391
AJCMMAX	2.5404	1.2608	4.8287	3.5012	58.4821	1.2958	1.3515
AJCMAVE	1.4146	0.7966	2.2228	1.9458	3.2412	0.9068	0.9752
AJCMSIG	0.4576	0.1594	0.9725	0.6959	7.3009	0.1623	0.1738
CTXMAX	0.1864	0.0716	0.4873	0.4537	16.1954	0.0946	0.1304
TRX	0.4345	0.2813	0.6677	0.7127	0.9833	0.0424	0.4162
MTXMAX	0.0531	0.0531	0.0531	0.0531	0.0531	0.0531	0.0531
MTRX	0.0749	0.0749	0.0749	0.0749	0.0749	0.0749	0.0749
CMXMAX	0.1849	0.0780	0.4897	0.4516	16.1894	0.1222	0.1446
CMRX	0.9414	0.0344	0.6710	0.7093	0.9830	0.0548	0.0654
PJCTMAX	6.5144	3.0094	12.7236	9.0875	155.0248	3.3194	3.3337
PJCTAVE	3.5500	1.8274	5.8210	5.0546	8.4874	2.1711	2.3233
PJCTSIG	1.2039	0.4130	2.5982	1.8170	19.3642	0.4550	0.4615
PJMTMAX	1.8958	1.8958	1.8958	1.8958	1.8958	1.8958	1.8958
PJMTAVE	1.6505	1.6505	1.6505	1.6505	1.6505	1.6505	1.6505
PJMTSIG	0.1036	0.1036	0.1036	0.1036	0.1036	0.1036	0.1036
PJCMMAX	6.7250	3.3333	12.7661	9.2582	155.0441	3.4236	3.5855
PJCMAVE	3.7455	2.1091	5.8852	5.1518	8.5845	2.4009	2.5821
PJCMSIG	1.2123	0.4220	0.5755	1.8430	19.3565	0.4302	0.4612

Table D.4: Values of performance indices obtained using different weighting matrices. Instrumentation configuration 14-B is used with a CRIT = 0.005. The number of cases is 60, i.e., 60 values are used to obtain one entry in this table.

<i>I.C.</i>	<i>W</i>	<i>CTXMAX</i>	<i>CTRXMAX</i>	<i>TRUE V.</i>	<i>CAL. V.</i>	<i>CTI</i>	<i>CASE</i>
14-A	W1	0.1549	0.2449	-0.47763	-0.6325	4	17
	W2	0.1167	0.1964	-0.47763	-0.5941	4	17
	WU	0.1068	0.1828	-0.47763	-0.5842	4	17
	W4	0.0884	0.2652	0.46943	0.3710	2	27
	W5	0.3319	0.8940	0.03935	0.3712	6	18
	W6	0.1386	0.2249	-0.47763	-0.6163	4	17
	W7	0.9443	1.0162	-0.01509	0.9292	19	16
	W8	diver	diver	diver	diver	diver	diver
	W9	diver	diver	diver	diver	diver	diver
	W10	0.2050	0.3003	-0.47763	-0.6826	4	17
	W11	0.2009	0.2961	-0.47763	-0.6785	4	17
	WP	0.1305	0.2145	-0.47763	-0.6084	4	17
14-B	W1	0.0765	0.2950	0.18293	0.2393	11	10
	W2	0.0675	0.2695	0.18293	0.2505	11	10
	W3	0.0640	0.2591	0.18293	0.2470	11	10
	W4	0.0656	0.2640	0.18293	0.2485	11	10
	W5	0.1864	0.4345	0.24254	0.4290	25	21
	W6	0.0716	0.2813	0.18293	0.2545	11	10
	W7	0.4873	0.6677	0.25254	0.7298	25	19
	W8	0.4537	0.7127	0.18293	0.6366	11	38
	W9	16.1954	0.9833	0.27462	16.4705	70	7
	W10	0.0946	0.0424	2.32573	2.2311	1	23
	W11	0.1304	0.4162	0.18293	0.3133	11	19
	WP	0.0727	0.2844	0.18293	0.2556	11	10

Table D.5: Values of the largest mismatches between calculated and true system variables and other corresponding values obtained using different weighting matrices. Instrumentation configurations 14-A and 14-B are used with a CRIT = 0.005. The number of cases for configurations 14-A and 14-B are 20 and 60, respectively.

<i>indices</i>	<i>W</i>	<i>14-C</i>	<i>14-D</i>	<i>14-E</i>	<i>14-F</i>	<i>14-G</i>
JCTAVE	W1	0.2767	0.4419	0.3446	0.7921	0.2322
	W2	0.1896	0.1539	0.2837	0.6632	0.1498
	W3	0.1763	0.1346	0.2773	0.5434	0.1351
	W4	0.2209	0.1707	0.3931	0.7948	0.2250
	W5	0.6926	0.7761	2.2197	3.9549	3.4637
	W6	0.2644	0.3977	0.4843	0.9073	0.3136
	W7	2.8036	1.7473	4.1567	6.9260	k=kmax
	W8	diverg	0.7015	4.1095	4.9817	diverg
	W9	diverg	0.8793	6.7685	6.7268	diverg
	W10	0.2577	0.5447	0.5623	1.2668	0.4191
	W11	0.5693	0.7034	0.7136	3.8502	0.4776
	WP	0.2688	0.3721	0.3460	0.7498	0.2345
AJCTAVE	W1	0.7070	0.8441	1.0496	0.9662	0.7379
	W2	0.5942	0.5905	0.9567	0.8582	0.5861
	W3	0.5796	0.5676	0.9492	0.8184	0.5538
	W4	0.6288	0.6336	1.1249	0.9949	0.6687
	W5	0.9730	1.0887	2.0350	1.9019	1.6380
	W6	0.6936	0.7635	1.2083	1.1019	0.7846
	W7	1.4542	1.5109	2.4297	2.3682	k=kmax
	W8	diverg	1.2689	2.6548	1.9079	diverg
	W9	diverg	1.3442	3.0344	2.0884	diverg
	W10	0.7194	0.9930	1.3166	1.1164	0.9643
	W11	0.8006	1.0573	1.4127	1.4542	0.9873
	WP	0.7016	0.7883	1.0413	0.9359	0.7362

Table D.6: Values of performance indices obtained using different weighting matrices. Instrumentation configuration 14-C, 14-D, 14-E, 14-F AND 14-G are used with a CRIT = 0.005. The number of cases is 20, *i.e.*, 20 values are used to obtain one entry in this table.

<i>indices</i>	$W1$	$W2$	WU	WP	$W4$	$W6$
JCTMAX	2.8736	1.0919	0.9455	2.2628	1.3215	2.1756
JCTAVE	1.0154	0.5408	0.6817	0.9313	0.8729	0.9780
JCTSIG	0.6489	0.2018	0.2117	0.5691	0.3102	0.4618
JMTMAX	4.2309	4.2309	4.2309	4.2309	4.2309	4.2309
JMTAVE	1.3895	1.3895	1.3895	1.3895	1.3895	1.3895
JMTSIG	1.0060	1.0060	1.0060	1.0060	1.0060	1.0060
JCMMAX	1.7454	3.1849	4.8732	1.6568	5.2236	3.5469
JCMAVE	0.9617	1.2757	1.7948	0.8891	1.9541	1.5686
JCMSIG	0.3809	0.7515	1.1673	0.3734	1.3457	0.8159
AJCTMAX	1.8031	1.4153	1.4877	1.7361	1.4606	2.0244
AJCTAVE	1.2942	1.0322	1.1069	1.3138	1.2289	1.4728
AJCTSIG	0.2268	0.1712	0.1923	0.2459	0.1679	0.2499
AJMTMAX	0.9023	0.9023	0.9023	0.9023	0.9023	0.9023
AJMTAVE	0.7296	0.7296	0.7296	0.7296	0.7296	0.7296
AJMTSIG	0.0663	0.0663	0.0663	0.0663	0.0663	0.0663
AJCMMAX	1.6184	1.5174	1.7199	1.7248	1.5980	1.8997
AJCMAVE	1.3311	1.1801	1.2866	1.3593	1.3522	1.5497
AJCMSIG	0.1801	0.1333	0.1719	0.2148	0.1380	0.2106
CTXMAX	0.1570	0.1104	0.0917	0.1341	0.1049	0.1407
CTRX	1.9415	0.1877	0.1611	0.2192	3.6493	2.1789
MTXMAX	0.1934	0.1934	0.1934	0.1934	0.1934	0.1934
MTRX	0.0768	0.0768	0.0768	0.0768	0.0768	0.0768
CMXMAX	0.1554	0.1630	0.2022	0.1256	0.2127	0.1698
CMRX	1.9216	0.0692	0.0873	0.2050	0.0922	0.0723
PJCTMAX	4.7773	3.7500	3.9415	4.5999	3.8698	5.3637
PJCTAVE	3.4289	2.7348	2.9326	3.4808	3.2561	3.9023
PJCTSIG	0.6009	0.4537	0.5096	0.6514	0.4449	0.6621
PJMTMAX	2.3906	2.3906	2.3906	2.3906	2.3906	2.3906
PJMTAVE	1.9331	1.9331	1.9331	1.9331	1.9331	1.9331
PJMTSIG	0.1757	0.1757	0.1757	0.1757	0.1757	0.1757
PJCMMAX	4.2901	4.0084	4.5434	4.5436	4.2433	4.9929
PJCMAVE	3.5226	3.1230	3.4043	3.5967	3.5782	4.1008
PJCMSIG	0.4776	0.3532	0.4524	0.5648	0.3658	0.5574

Table D.7: Values of performance indices obtained using different weighting matrices. FJM PSSE program is used. Instrumentation configuration 14-A is used with a CRIT = 0.005. The number of cases is 20, *i.e.*, 20 values are used to obtain one entry in this table.

<i>indices</i>	<i>W1</i>	<i>W2</i>	<i>WU</i>	<i>WP</i>	<i>W4</i>	<i>W6</i>
JCTMAX	0.8746	0.8946	0.8966	0.8324	0.9702	1.0104
JCTAVE	0.4929	0.4048	0.3619	0.4795	0.4154	0.4825
JCTSIG	0.1680	0.1538	0.1443	0.1512	0.1556	0.1700
JMTMAX	0.7436	0.7436	0.7436	0.7436	0.7436	0.7436
JMTAVE	0.4087	0.4087	0.4087	0.4087	0.4087	0.4087
JMTSIG	0.1156	0.1156	0.1156	0.1156	0.1156	0.1156
JCMMAX	0.7927	0.7889	0.8528	0.7887	0.9198	0.9039
JCMAVE	0.4977	0.4872	0.5045	0.4789	0.5584	0.5571
JCMSIG	0.0968	0.0969	0.1113	0.1005	0.1242	0.1148
AJCTMAX	1.1894	1.0302	1.0319	1.2006	1.1047	1.1750
AJCTAVE	0.9401	0.8192	0.7903	0.9510	0.8511	0.9016
AJCTSIG	0.1259	0.1009	0.1092	0.1247	0.1175	0.1170
AJMTMAX	0.7155	0.7155	0.7155	0.7155	0.7155	0.7155
AJMTAVE	0.6230	0.6230	0.6230	0.6230	0.6230	0.6230
AJMTSIG	0.0391	0.0391	0.0391	0.0391	0.0391	0.0391
AJCMMAX	1.2604	1.1225	1.1522	1.2421	1.2152	1.2663
AJCMAVE	1.0082	0.9382	0.9349	1.0135	0.9849	1.0069
AJCMSIG	0.1018	0.0856	0.0907	0.1007	0.0962	0.1075
CTXMAX	0.1111	0.1076	0.1025	0.1078	0.1054	0.1094
CTR _X	0.3779	0.0485	0.3519	0.3708	0.0475	0.0494
MTXMAX	0.0531	0.0531	0.0531	0.0531	0.0531	0.0531
MTR _X	0.0749	0.0749	0.0749	0.0749	0.0749	0.0749
CMXMAX	0.1272	0.1275	0.1219	0.1185	0.1253	0.1302
CMR _X	0.0571	0.0575	0.0548	0.0530	0.0564	0.0586
PJCTMAX	3.1514	2.7294	2.7340	3.1809	2.9270	3.1131
PJCTAVE	2.4908	2.1703	2.0950	2.5196	2.2550	2.3888
PJCTSIG	0.3335	0.2674	0.2893	0.3304	0.3114	0.3101
PJMTMAX	1.8958	1.8958	1.8958	1.8958	1.8958	1.8958
PJMTAVE	1.6505	1.6505	1.6505	1.6505	1.6505	1.6505
PJMTSIG	0.1036	0.1036	0.1036	0.1036	0.1036	0.1036
PJCMMAX	3.3375	2.9723	3.0502	3.2889	3.2170	3.3540
PJCMAVE	2.6694	2.4838	2.4752	2.6834	2.6074	2.6659
PJCMSIG	0.2700	0.2265	0.2401	0.2671	0.2546	0.2844

Table D.8: Values of performance indices obtained using different weighting matrices. FJM PSSE program is used. Instrumentation configuration 14-B is used with a CRIT = 0.005. The number of cases is 60, *i.e.*, 60 values are used to obtain one entry in this table.

<i>I.C.</i>	<i>W</i>	<i>CTXMAX</i>	<i>CTRXMAX</i>	<i>TRUE V.</i>	<i>CAL. V.</i>	<i>CTI</i>	<i>CASE</i>
14-A	W1	0.1570	1.9415	-0.07613	0.0809	5	17
	W2	0.1104	0.1877	-0.47763	-0.5882	4	17
	WU	0.0917	0.1611	-0.47763	-0.5692	4	17
	W4	0.1049	3.6493	-0.07613	0.0287	5	19
	W6	0.1407	2.1789	-0.07613	-0.0646	5	17
	WP	0.1341	0.2192	-0.47763	-0.6118	4	17
14-B	W1	0.1111	0.3779	0.18293	0.2940	11	10
	W2	0.1076	0.0485	2.32573	2.2186	1	45
	W3	0.1025	0.3591	0.18293	0.2854	11	10
	W4	0.1054	0.0475	2.32573	2.2189	1	45
	W6	0.1094	0.0494	2.32573	2.2146	1	45
	WP	0.1078	0.3708	0.18293	0.2907	11	10

Table D.9: Values of the largest mismatches between calculated and true system variables and other corresponding values obtained using different weighting matrices. Instrumentation configurations 14-A and 14-B are used with a CRIT = 0.005. The number of cases for configurations 14-A and 14-B are 20 and 60, respectively.

<i>indices</i>	<i>W1</i>	<i>W2</i>	<i>WU</i>	<i>WP</i>	<i>W4</i>	<i>W6</i>
JCTMAX	22.3889	5.3164	2.9428	22.5452	4.7156	9.7336
JCTAVE	6.9688	2.3870	1.9672	6.6753	2.8871	4.7389
JCTSIG	5.7844	1.1563	0.5762	5.5291	0.9447	2.2857
JMTMAX	38.0778	38.0778	38.0778	38.0778	38.0778	38.0778
JMTAVE	12.5051	12.5051	12.5051	12.5051	12.5051	12.5051
JMTSIG	9.0542	9.0542	9.0542	9.0542	9.0542	9.0542
JCMMAX	12.9158	22.7126	31.9924	12.9037	31.4749	21.3962
JCMAVE	6.1033	8.6326	11.4103	6.0998	11.8366	9.2832
JCMSIG	3.2196	5.6857	7.8152	3.2516	8.0279	5.1966
AJCTMAX	4.7822	3.4419	3.4155	4.7611	3.8963	5.5427
AJCTAVE	3.4775	2.6530	2.5691	3.5192	3.1083	4.0743
AJCTSIG	0.6738	0.3887	0.3886	0.7067	0.5312	0.8206
AJMTMAX	2.7068	2.7068	2.7068	2.7068	2.7068	2.7068
AJMTAVE	2.1889	2.1889	2.1889	2.1889	2.1889	2.1889
AJMTSIG	0.1990	0.1990	0.1990	0.1990	0.1990	0.1990
AJCMMAX	4.4492	3.9422	4.1365	4.7841	4.6498	5.7346
AJCMAVE	3.6142	3.1374	3.1663	3.6865	3.5749	4.3535
AJCMSIG	0.5453	0.3475	0.3938	0.6077	0.5176	0.7147
CTXMAX	0.4630	0.3348	0.2759	0.3946	0.3143	0.4127
CTR _X	0.4922	0.4121	0.3662	0.4524	2.0263	0.4636
MTXMAX	0.5802	0.5802	0.5802	0.5802	0.5802	0.5802
MTR _X	0.1997	0.1997	0.1997	0.1997	0.1997	0.1997
CMXMAX	0.4494	0.4461	0.5361	0.3691	0.5313	0.4093
CMR _X	1.1886	0.1814	0.2262	0.4231	0.2237	0.1639
PJCTMAX	12.6704	9.1193	9.0493	12.6146	10.3234	14.6856
PJCTAVE	9.2136	7.0293	6.8070	9.3241	8.2354	10.7950
PJCTSIG	1.7853	1.0298	1.0296	1.8725	1.4075	2.1741
PJMTMAX	7.1717	7.1717	7.1717	7.1717	7.1717	7.1717
PJMTAVE	5.7994	5.7994	5.7994	5.7994	5.7994	5.7994
PJMTSIG	0.5272	0.5272	0.5272	0.5272	0.5272	0.5272
PJCMMAX	11.8024	10.3336	10.8430	12.4338	11.9672	14.9638
PJCMAVE	9.5320	8.2739	8.3487	9.7187	9.4282	11.4801
PJCMSIG	1.4434	0.9188	1.0334	1.5731	1.3736	1.8742

Table D.10: Values of performance indices obtained using different weighting matrices. FJM PSSE program is used when measurement errors are amplified. Instrumentation configuration 14-A is used with a CRIT = 0.005. 20 values are used to obtain one entry in this table.

<i>variables</i>	<i>W1</i>	<i>W2</i>	<i>WU</i>	<i>WP</i>	<i>W4</i>	<i>W6</i>
JCTMAX	3.9411	4.0247	4.4097	3.8703	4.6928	6.3127
JCTAVE	2.1020	1.6170	1.4893	2.1952	1.9208	2.3969
JCTSIG	0.7160	0.6896	0.7544	0.6775	0.8748	1.1045
JMTMAX	6.6923	6.6923	6.6923	6.6923	6.6923	6.6923
JMTAVE	3.6786	3.6786	3.6786	3.6786	3.6786	3.6786
JMTSIG	1.0400	1.0400	1.0400	1.0400	1.0400	1.0400
JCMMAX	4.5424	5.0107	6.5769	4.8117	7.0572	5.8253
JCMAVE	2.1306	2.3541	2.7745	2.1847	3.1582	2.9652
JCMSIG	0.7488	0.8273	0.9832	0.7613	1.1584	1.0899
AJCTMAX	3.0991	2.5178	2.4577	3.1130	2.5788	3.1688
AJCTAVE	2.1840	1.7853	1.6967	2.2521	1.8656	2.0887
AJCTSIG	0.3372	0.2631	0.2875	0.3362	0.3261	0.3739
AJMTMAX	2.1466	2.1466	2.1466	2.1466	2.1466	2.1466
AJMTAVE	1.8689	1.8689	1.8689	1.8689	1.8689	1.8689
AJMTSIG	0.1173	0.1173	0.1173	0.1173	0.1173	0.1173
AJCMMAX	3.0950	2.6862	2.8154	3.1560	3.0142	3.4288
AJCMAVE	2.4060	2.1760	2.1649	2.4494	2.2972	2.4244
AJCMSIG	0.2906	0.2285	0.2417	0.2907	0.2841	0.3526
CTXMAX	0.2623	0.2390	0.2313	0.2514	0.2339	0.2474
CTRX	0.5891	0.5665	0.5583	0.5788	0.5612	0.5749
MTXMAX	0.1594	0.1594	0.1594	0.1594	0.1594	0.1594
MTRX	0.2644	0.2644	0.2644	0.2644	0.2644	0.2644
CMXMAX	0.2737	0.2872	0.2880	0.2580	0.2926	0.2897
CMRX	0.1282	0.1369	0.1373	0.5940	0.1398	0.1367
PJCTMAX	8.2111	6.6710	6.5118	8.2480	6.8326	8.3958
PJCTAVE	5.7864	4.7303	4.4955	5.9671	4.9430	5.5341
PJCTSIG	0.8935	0.6970	0.7618	0.8908	0.8639	0.9907
PJMTMAX	5.6875	5.6875	5.6875	5.6875	5.6875	5.6875
PJMTAVE	4.9516	4.9516	4.9516	4.9516	4.9516	4.9516
PJMTSIG	0.3109	0.3109	0.3109	0.3109	0.3109	0.3109
PJCMMAX	8.1675	7.1067	7.4485	8.3286	7.9745	9.0714
PJCMAVE	6.3558	5.7476	5.7182	6.4702	6.0678	6.4036
PJCMSIG	0.7699	0.6020	0.6354	0.7695	0.7475	0.9263

Table D.11: Values of performance indices obtained using different weighting matrices. FJM PSSE program is used when measurement errors are amplified. Instrumentation configuration 14-B is used with a CRIT = 0.005. 60 values are used to obtain one entry in this table.

<i>I.C.</i>	<i>W</i>	<i>CTXMAX</i>	<i>CTRXMAX</i>	<i>TRUE V.</i>	<i>CAL. V.</i>	<i>CTI</i>	<i>CASE</i>
14-A	W1	0.4630	0.4922	-0.47763	-0.9407	4	17
	W2	0.3348	0.4121	-0.47763	-0.8124	4	17
	WU	0.2759	0.3662	-0.47763	-0.7534	4	17
	W4	0.3134	2.0263	0.46943	0.1551	27	2
	W6	0.4127	0.4636	-0.07613	-0.8902	4	17
	WP	0.3946	0.4524	-0.47763	-0.8722	4	17
14-B	W1	0.2632	0.5891	0.18293	0.4453	11	10
	W2	0.2390	0.5665	0.18293	0.4219	11	10
	W3	0.2313	0.5583	0.18293	0.4143	11	10
	W4	0.2339	0.5612	0.18293	0.4168	11	10
	W6	0.2474	0.5749	0.18293	0.4303	11	10
	WP	0.2514	0.5788	0.18293	0.4343	11	10

Table D.12: Values of the largest mismatches between calculated and true system variables and other corresponding values obtained using different weighting matrices. Instrumentation configurations 14-A and 14-B are used with a CRIT = 0.005. The number of cases for configurations 14-A and 14-B are 20 and 60, respectively.

<i>indices</i>	<i>W1</i>	<i>W2</i>	<i>WU</i>	<i>WP</i>	<i>W4</i>
JCTMAX	1.3086	1.2393	1.2833	1.1151	1.4951
JCTAVE	0.8678	0.6454	0.7015	0.7556	0.9035
JCTSIG	0.2335	0.2827	0.3708	0.1936	0.2574
JMTMAX	1.6890	1.6890	1.6890	1.6890	1.6890
JMTAVE	1.1960	1.1960	1.1960	1.1960	1.1960
JMTSIG	0.2998	0.2998	0.2998	0.2998	0.2998
JCMMAX	1.0611	2.2991	2.5760	1.0284	1.4559
JCMAVE	0.6037	0.8418	1.1901	0.5728	1.0499
JCMSIG	0.1843	0.6500	0.7488	0.1867	0.2175
AJCTMAX	2.1105	1.7985	1.8802	1.9987	2.4851
AJCTAVE	1.8454	1.5512	1.5571	1.7359	2.0869
AJCTSIG	0.2445	0.1973	0.2500	0.2199	0.3500
AJMTMAX	1.5492	1.5492	1.5492	1.5492	1.5492
AJMTAVE	1.4000	1.4000	1.4000	1.4000	1.4000
AJMTSIG	0.0798	0.0798	0.0798	0.0798	0.0798
AJCMMAX	2.3230	2.2055	2.2855	2.1308	2.6288
AJCMAVE	1.9180	1.7449	1.8291	1.8356	2.2754
AJCMSIG	0.2491	0.2489	0.2912	0.2270	0.3348
CTXMAX	0.1350	0.0819	0.1434	0.1173	0.1717
CTRX	2.2885	0.8332	0.8974	2.8399	1.7947
MTXMAX	0.0802	0.0802	0.0802	0.0802	0.0802
MTRX	0.1188	0.1188	0.1188	0.1188	0.1188
CMXMAX	0.1312	0.0869	0.1469	0.2370	0.1678
CMRX	2.2231	0.0586	0.9194	1.4378	1.7544
PJCTMAX	3.0406	2.5911	2.7088	2.8795	3.5803
PJCTAVE	2.6587	2.2348	2.2433	2.5009	3.0067
PJCTSIG	0.3522	0.2843	0.3601	0.3168	0.5042
PJMTMAX	2.2320	2.2320	2.2320	2.2320	2.2320
PJMTAVE	2.0170	2.0170	2.0170	2.0170	2.0170
PJMTSIG	0.1150	0.1150	0.1150	0.1150	0.1150
PJCMMAX	3.3417	3.1635	3.2782	3.0651	3.7815
PJCMAVE	2.7555	2.5069	2.6278	2.6372	3.2690
PJCMSIG	0.3588	0.3577	0.4180	0.3271	0.4824

Table D.13: Values of performance indices obtained using different weighting matrices. FJM PSSE program is used with a CRIT = 0.005. 10 values are used to obtain one entry in this table.

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