A study of the effects of weighting matrices in power system state estimation

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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

1990
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To My

Father, Mother

and

Brother

for all their support, faith and patience
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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,

- Prefilting 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 pseudomeasurements.

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
\[ m = f(x) + \epsilon \]  \hspace{1cm} (1.1)

where \( m \) is a vector of measurements, \( x \) is the state vector of the static structure model, and \( f(x) \) is a nonlinear function of \( x \) 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 \( \epsilon \) is introduced in the above model.

The estimated state of the system is defined as the value of \( x \) which minimizes the performance index

\[
J(x) = [m - f(x)]^T W [m - f(x)]
\]  \hspace{1cm} (1.2)

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

In order to estimate \( x \), an initial value \( x_0 \) is assumed and a Taylor expansion approximates it near this point:

\[
f(x) = f(x_0) + f_x(x_0) \Delta x + f_{xx}(x_0) \frac{\Delta x^2}{2} + \ldots
\]

Disregarding higher than linear terms, we have

\[
f(x) = f(x_0) + f_x(x_0) \Delta x
\]

where \( f_x(x_0) \) indicates the Jacobian (derivative with respective to \( x \) at point \( x_0 \)).

Substituting \( f(x) = f(x_0) + f_x(x_0) \Delta x \) into equation (1.2) and letting \( \Delta m = m - f(x_0) \) yields

\[
J(x) = [\Delta m - f_x(x_0) \Delta x]^T W [\Delta m - f_x(x_0) \Delta x]
\]
Since $J(x)$ is a scalar, $(\Delta m)^T W \Delta m$, $(\Delta m)^T W f_x(x_0) \Delta x$, $(\Delta x)^T f_x(x_0) W \Delta m$, and $(\Delta x)^T f_x(x_0) W f_x(x_0) \Delta x$ are all scalars. It is known that the transpose of any scalar equals its own value, thus $(\Delta m)^T W f_x(x_0) \Delta x$ and $(\Delta x)^T f_x(x_0) W \Delta m$ are equal. And since $W$ is a diagonal matrix, $W^T = W$

\[ J(x) = (\Delta m)^T W \Delta m - 2(\Delta x)^T f_x(x_0) W \Delta m + (\Delta x)^T f_x(x_0) W f_x(x_0) \Delta x \]  

The estimate of the state vector $x$ is obtained by minimizing the performance index

\[ \frac{\partial J}{\partial x} = 0 \]

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

\[ \frac{\partial [(\Delta x)^T f_x(x_0)^T W \Delta m]}{\partial x} = f_x(x_0)^T W \Delta m \]

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

\[ -2f_x(x_0)^T W \Delta m + 2f_x(x_0)^T W f_x(x_0) \Delta x = 0 \]

or

\[ G(x_0) \Delta x = J^T W [m - f(x_0)] \]  

where $J = f_x(x_0)$ is the Jacobian matrix, $G(x_0) = J^T W J$ is the gain matrix and $\Delta m = m - f(x_0)$, $\Delta x = x_1 - x_0$.  

This is a set of linear equations, in which the solution is based on the initial guess $x_0$. To compute $x$ to a certain accuracy, equation (1.4) can be rewritten as

$$G(x_k) \Delta x_k = J^T W [m - f(x_k)] \quad (1.5)$$

$$\Delta x_k = x_{k+1} - x_k \quad (1.6)$$

In the above iterative equations, $k = 0, 1, 2, ...$ 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

$$J' = \left[1 - \frac{f(x)}{m}\right]^T W \left[1 - \frac{f(x)}{m}\right].$$

Following the same procedure outlined in the former
section, the final iterative equation can be obtained as

$$J^T W' J \Delta x_k = J^T W' [m - f(x_k)]$$  \hspace{1cm} (1.7)

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

Thus the iterative equations resulting from minimizing $\text{SSE}$ and minimizing $\text{SSRE}$ 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 $\sum |1 - \frac{f(x)}{m}|$ 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 x 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

$$\pm(\% \text{reading} + \text{counts})$$

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]:

9
Suppose in a digital volt meter, the accuracy of the 1-V range for d-c voltage measurements is rated as 1 percent ± 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) ± 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 × M and FERR, respectively, where M denotes the measurements. Different meters have different accuracies; therefore when measuring a certain quantity, different ERRs and FERRs 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

$$W^{-1} = diag[\sigma_i^2]$$

(1.8)

where \(\sigma_i\) is the standard deviation of noise on the ith measurement. This W will be referred to in this thesis as the "usually used" weighting matrix, 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 \( M_1, M_2, \ldots, M_n \) are obtained. \( M_{\text{mean}} \) 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

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

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 (\( \sigma \)) 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 \(-3 \sigma\) to \(3 \sigma\). It is assumed in this thesis that the maximum error of a measurement is \( 3 \sigma \); thus \( \sigma \) 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 \( \text{ERR} \times M \) and \( \text{FERR} \). 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 $W$, where

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

Equation (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 $WP$.

In order to avoid calculating the weighting matrix whenever measurements are changed, the weighting matrix $WP$ 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 $\pm 1$ 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 \( WP \) 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 \( W \), where

\[
W(i,i) = \frac{1}{EUBOUND_i}
\]

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 \( WU \) 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 \( W \), with \( W(i,i) = \frac{1}{|ERR_xM_i| + |FERR_i|} \)? 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:

\[
W1(i,i) = 1
\]

\[
W2(i,i) = \frac{1}{|(ERR \times M)_i| + |ERR_i|}
\]

\[
WU(i,i) = \frac{1}{(|(ERR \times M)_i| + |ERR_i|)^2}
\]

\[
WP(i,i) = \frac{1}{EUBOUND_i}
\]

\[
W4(i,i) = \frac{1}{(|(ERR \times M)_i| + |ERR_i|)^2} \times |M_i|
\]

\[
W5(i,i) = \frac{1}{(|(ERR \times M)_i| + |ERR_i|)^2} \times M_i^2
\]

\[
W6(i,i) = \frac{1}{|(ERR \times M)_i| + |ERR_i|} \times |M_i|
\]

\[
W7(i,i) = \frac{1}{|(ERR \times M)_i| + |ERR_i|} \times M_i^2
\]

\[
W8(i,i) = \frac{1}{|(ERR \times M)_i| + |ERR_i|} \times \frac{1}{M_i^2}
\]

\[
W9(i,i) = \frac{1}{(|(ERR \times M)_i| + |ERR_i|)^2} \times \frac{1}{M_i^2}
\]
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 \( W_U \) and \( W_P \), unity weighting matrix \( W_1 \), 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

\[
P_{JCT} = \frac{\sum_i |C_i - T_i|}{\sum_i |T_i|}
\]
\[
P_{JMT} = \frac{\sum_i |M_i - T_i|}{\sum_i |T_i|}
\]
\[
P_{JCT} = \frac{\sum_i |C_i - M_i|}{\sum_i |M_i|}
\]

where summation index \( i \) is from 1 to \( N_{MM} \), the maximum possible number of measurements that could be obtained.

- Index set four

\[
C_{TX} = MAX \ |C_i - T_i|
\]
\[
M_{TX} = MAX \ |M_i - T_i|
\]
\[
C_{MX} = MAX \ |C_i - M_i|
\]

where index \( i \) is from 1 to \( N_{MM} \), the maximum possible number of measurements that could be obtained. and their corresponding relative values

\[
C_{TRX} = \frac{|C_i - T_i|}{|C_i|}
\]
\[
M_{TRX} = \frac{|M_i - T_i|}{|M_i|}
\]
\[
C_{MRX} = \frac{|C_i - M_i|}{|C_i|}
\]

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:

\[ P_{1-14} : 10100011000000 \]
\[ Q_{1-14} : 10100011000000 \]
\[ V_{1-14} : 10100011000000 \]
\[ PL_{1-40} : 101101101101000101101100 \]
\[ QL_{1-40} : 101101101101000101101100 \]

• Instrumentation configuration set 14-B:

\[ P_{1-14} : 00100100110000 \]
\[ Q_{1-14} : 00100100110000 \]
\[ V_{1-14} : 00100100110000 \]
\[ PL_{1-40} : 101011100010110110010101001011100 \]
\[ QL_{1-40} : 101011100010110110010101001011100 \]

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 $0.0035$, $2 \times 0.0035$, $3 \times 0.0035$ and $4 \times 0.0035$, 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, $2 \times 0.003$, $3 \times 0.003$ and $4 \times 0.003$, 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 $3\sigma$ 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 \( \text{ERR}_i \) and the sign of \( \text{FERR}_i \).

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.

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

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 \( W_1 \).

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', 'NTRAN', 'WMG', 'EJACO', 'PQLCAL', 'EDELA', '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
(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 ith system variable.

- Depending on the ith meter category, the standard deviation of the proportional error, $\sigma_i$, and the fixed error $FEER_i$ for the ith measurement are determined. NRAN, a subroutine to generate normally distributed random number $NDR_i$, is used to give random proportional error, $(ERR \times M)_i$ of the ith measurement, using a standard deviation $\sigma_i$.

- 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 $NDR_i$ is less than $-3 \times \sigma_i$, then $NDR_i = -3 \times \sigma_i$.

- Let the ith 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 ith measurement. If RAN_i is greater than zero, FEER_i is added to ith 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 \( W_8 \) is used is 6.9, and when weighting matrix \( W_9 \) 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 \( W_{11} \) 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 \( W_2, W_U \) and \( W_4 \) are closer to the true state than that obtained using \( W_1 \). This is because:

- The major performance indices JCTAVEs and AJCTAVEs obtained using \( W_2, W_U \) and \( W_4 \) are all better than that obtained using \( W_1 \). 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 \( W_2, W_U \) and \( W_4 \) are used, the largest mismatches between calculated values and true ones are less than that resulting from using \( W_1 \).
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.

<table>
<thead>
<tr>
<th>normalized indices</th>
<th>$W_2$</th>
<th>$W_U$</th>
<th>$W_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$JCTMAX_{w_1}/JCTMAX_{w_1}$</td>
<td>22.03%</td>
<td>10.33%</td>
<td>19.07%</td>
</tr>
<tr>
<td>$JCTAVE_{w_1}/JCTAVE_{w_1}$</td>
<td>30.02%</td>
<td>20.73%</td>
<td>33.73%</td>
</tr>
<tr>
<td>$JCTSIG_{w_1}/JCTSIG_{w_1}$</td>
<td>21.34%</td>
<td>7.99%</td>
<td>15.73%</td>
</tr>
<tr>
<td>$AJCTMAX_{w_1}/AJCTMAX_{w_1}$</td>
<td>68.16%</td>
<td>63.51%</td>
<td>86.91%</td>
</tr>
<tr>
<td>$AJCTAVE_{w_1}/AJCTAVE_{w_1}$</td>
<td>74.01%</td>
<td>69.24%</td>
<td>85.82%</td>
</tr>
<tr>
<td>$AJCTSIG_{w_1}/AJCTSIG_{w_1}$</td>
<td>52.88%</td>
<td>41.26%</td>
<td>74.79%</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>normalized indices</th>
<th>$W_2$</th>
<th>$W_U$</th>
<th>$W_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$JCTMAX_{w_1}/JCTMAX_{w_1}$</td>
<td>79.11%</td>
<td>91.96%</td>
<td>92.52%</td>
</tr>
<tr>
<td>$JCTAVE_{w_1}/JCTAVE_{w_1}$</td>
<td>73.79%</td>
<td>69.38%</td>
<td>82.85%</td>
</tr>
<tr>
<td>$JCTSIG_{w_1}/JCTSIG_{w_1}$</td>
<td>90.34%</td>
<td>101.20%</td>
<td>114.86%</td>
</tr>
<tr>
<td>$AJCTMAX_{w_1}/AJCTMAX_{w_1}$</td>
<td>80.50%</td>
<td>80.76%</td>
<td>85.69%</td>
</tr>
<tr>
<td>$AJCTAVE_{w_1}/AJCTAVE_{w_1}$</td>
<td>79.94%</td>
<td>76.53%</td>
<td>82.59%</td>
</tr>
<tr>
<td>$AJCTSIG_{w_1}/AJCTSIG_{w_1}$</td>
<td>52.88%</td>
<td>77.15%</td>
<td>85.08%</td>
</tr>
</tbody>
</table>

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.
Table 3.3: 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 and Table D.2.

<table>
<thead>
<tr>
<th>normalized indices</th>
<th>$W_5$</th>
<th>$W_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$JCTMAX_{W_1}/JCTMAX_{W_1}$</td>
<td>1.0484</td>
<td>3.4520</td>
</tr>
<tr>
<td>$JCTAVE_{W_1}/JCTAVE_{W_1}$</td>
<td>2.1255</td>
<td>5.7370</td>
</tr>
<tr>
<td>$JCTSIG_{W_1}/JCTSIG_{W_1}$</td>
<td>0.9706</td>
<td>3.7597</td>
</tr>
<tr>
<td>$AJCTMAX_{W_1}/AJCTMAX_{W_1}$</td>
<td>2.3644</td>
<td>5.0393</td>
</tr>
<tr>
<td>$AJCTAVE_{W_1}/AJCTAVE_{W_1}$</td>
<td>2.0868</td>
<td>3.3480</td>
</tr>
<tr>
<td>$AJCTSIG_{W_1}/AJCTSIG_{W_1}$</td>
<td>2.9419</td>
<td>7.0331</td>
</tr>
</tbody>
</table>

Table 3.4: 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 and Table D.4.

<table>
<thead>
<tr>
<th>normalized indices</th>
<th>$W_5$</th>
<th>$W_7$</th>
<th>$W_8$</th>
<th>$W_9$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$JCTMAX_{W_1}/JCTMAX_{W_1}$</td>
<td>8.1677</td>
<td>36.2659</td>
<td>28.9730</td>
<td>59.5717</td>
</tr>
<tr>
<td>$JCTAVE_{W_1}/JCTMAX_{W_1}$</td>
<td>6.8476</td>
<td>17.1342</td>
<td>15.6061</td>
<td>30.4753</td>
</tr>
<tr>
<td>$JCTSIG_{W_1}/JCTSIG_{W_1}$</td>
<td>1.3291</td>
<td>44.8679</td>
<td>43.2838</td>
<td>92.0706</td>
</tr>
<tr>
<td>$AJCTMAX_{W_1}/AJCTMAX_{W_1}$</td>
<td>2.5223</td>
<td>4.9264</td>
<td>3.5186</td>
<td>60.0234</td>
</tr>
<tr>
<td>$AJCTAVE_{W_1}/AJCTAVE_{W_1}$</td>
<td>1.9436</td>
<td>3.1868</td>
<td>2.7673</td>
<td>4.6466</td>
</tr>
<tr>
<td>$AJCTSIG_{W_1}/AJCTSIG_{W_1}$</td>
<td>4.2908</td>
<td>9.2597</td>
<td>6.4759</td>
<td>69.0142</td>
</tr>
</tbody>
</table>

14-A and instrumentation configuration 14-B, respectively. Also, when $W_5$, $W_7$, $W_8$ and $W_9$ are used, the largest mismatches between calculated values and true ones are larger than that resulting from using $W_1$, which can be seen from Table D.5 in Appendix D.

- When $W_5$, $W_7$, $W_8$ and $W_9$ 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.
Table 3.5: Normalized values of performance indices. Data used to obtain the values in this table are in Table D.2.

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

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

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

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 $W_8$ and $W_9$ can not be used under certain instrumentation configurations. And using $W_8$ or $W_9$ needs more solution time, since more iterations are needed.
Since \textbf{W5}, \textbf{W7}, \textbf{W8} and \textbf{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 \textbf{W6}, \textbf{W10} and \textbf{W11} by that obtained using weighting matrix \textbf{W1} under instrumentation configuration 14-A and instrumentation configuration 14-B, respectively.

<table>
<thead>
<tr>
<th>normalized indices</th>
<th>\textbf{W6}</th>
<th>\textbf{W10}</th>
<th>\textbf{W11}</th>
</tr>
</thead>
<tbody>
<tr>
<td>JCTMAX_{W_i}/JCTMAX_{W_1}</td>
<td>0.4716</td>
<td>0.9532</td>
<td>0.5850</td>
</tr>
<tr>
<td>JCTAVE_{W_i}/JCTMAX_{W_1}</td>
<td>0.6515</td>
<td>1.2170</td>
<td>0.9465</td>
</tr>
<tr>
<td>JCTSIG_{W_i}/JCTSIG_{W_1}</td>
<td>0.4508</td>
<td>1.0112</td>
<td>0.7400</td>
</tr>
<tr>
<td>AJCTMAX_{W_i}/AJCTMAX_{W_1}</td>
<td>1.1975</td>
<td>1.1455</td>
<td>1.1106</td>
</tr>
<tr>
<td>AJCTAVE_{W_i}/AJCTAVE_{W_1}</td>
<td>1.1413</td>
<td>1.0985</td>
<td>1.0125</td>
</tr>
<tr>
<td>AJCTSIG_{W_i}/AJCTSIG_{W_1}</td>
<td>1.2204</td>
<td>1.2496</td>
<td>0.9432</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>normalized indices</th>
<th>\textbf{W6}</th>
<th>\textbf{W10}</th>
<th>\textbf{W11}</th>
</tr>
</thead>
<tbody>
<tr>
<td>JCTMAX_{W_i}/JCTMAX_{W_1}</td>
<td>1.1853</td>
<td>1.9179</td>
<td>2.6922</td>
</tr>
<tr>
<td>JCTAVE_{W_i}/JCTMAX_{W_1}</td>
<td>1.0946</td>
<td>1.5938</td>
<td>2.4405</td>
</tr>
<tr>
<td>JCTSIG_{W_i}/JCTSIG_{W_1}</td>
<td>1.4399</td>
<td>2.3123</td>
<td>4.1772</td>
</tr>
<tr>
<td>AJCTMAX_{W_i}/AJCTMAX_{W_1}</td>
<td>1.1652</td>
<td>1.2907</td>
<td>1.2907</td>
</tr>
<tr>
<td>AJCTAVE_{W_i}/AJCTAVE_{W_1}</td>
<td>1.0004</td>
<td>1.1886</td>
<td>1.2720</td>
</tr>
<tr>
<td>AJCTSIG_{W_i}/AJCTSIG_{W_1}</td>
<td>1.4721</td>
<td>1.6219</td>
<td>1.6469</td>
</tr>
</tbody>
</table>

Table 3.8: Normalized values of performance indices with those obtained using \textbf{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 \( \Delta V_k \), small changes in real and reactive power injections, \( \Delta P N_k \) and \( \Delta Q N_k \), and real and reactive power flows \( \Delta P L_k \) and \( \Delta Q L_k \).

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 $W_1$, $W_2$, $W_U$, $W_P$, $W_4$ and $W_6$. 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 $W_2$, $W_U$, $W_4$ and $W_6$ are used, the values of performance indices JCTs and AJCTs obtained are better than that obtained using unit weighting matrix $W_1$, which can be seen from Fig. 3.1. Values of JCTs obtained using weighting matrices $W_2$ and $W_U$ are 0.5408 and 0.6817, respectively; while the value of JCT obtained using $W_1$ 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 $W_2$ and $W_U$ will usually get better better results than using $W_1$. When instrumentation configuration 14-A is used, The largest differences between calculated values and true values obtained using $W_2$, $W_U$, $W_4$, $W_6$ and $W_P$ are smaller than that obtained using $W_1$. 

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Also from the testing results, it can be seen that when weighting matrices $W_2$, $W_U$, $W_4$ and $W_6$ are used, the values of performance indices $JCTs$ and $AJCTs$ obtained are better than that obtained using unit weighting matrix $W_1$, which can be seen from Fig. 3.2. But the conclusion cannot be drawn that using weighting matrices $W_2$, $W_U$, $W_4$ and $W_6$ will always get better values of performance indices $JCTs$ and $AJCTs$ than using unit weighting matrix $W_1$, 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 $W_2$, $W_U$, $W_4$, $W_6$ and $W_P$ are smaller than that obtained using $W_1$.

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 \( W_2, W_U \) are the best. And the decision of which one of \( W_2, W_U \) and \( W_4 \) is best cannot be drawn.

To verify the studies that have been done so far and also to test the weighting matrices’ 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:

\[
P_{1-30} : 021031001204120021000410020031
\]

\[
Q_{1-30} : 021031001204120021000410020031
\]

\[
V_{1-30} : 021031001204120021000410020031
\]

\[
PL_{1-82} : 3010200402000214030020300103021040010310
\]
\[
04001100201020400201000320010030200101000
\]

\[
QL_{1-82} : 3010200402000214030020300103021040010310
\]
\[
04001100201020400201000320010030200101000
\]
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 $W_2$ and $W_U$ 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, $W_2$ and $W_U$ are most effective. Also, there are no statistically significant differences between the results using weighting matrices $W_2$ and $W_U$.

Based on the studies in this thesis, the practically used weighting matrix $W_P$ behaved similarly to $W_1$ (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 $W_P$ is expected to give better results than $W_1$. Also, using $W_P$ can reduce the solution time by considering only FEERs of the measurements; this is the major advantage $W_P$ has over $W_2$ and $W_3$. 
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
<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
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</tr>
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</tr>
<tr>
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<td>-10.66969</td>
</tr>
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</tr>
<tr>
<td>6</td>
<td>13</td>
<td>-3.09893</td>
<td>6.10275</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>0.00000</td>
<td>-19.54900</td>
</tr>
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<td>9</td>
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<td>10</td>
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<td>10.36540</td>
</tr>
<tr>
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<td>10</td>
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</tr>
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<td>4.78186</td>
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</tr>
<tr>
<td>14</td>
<td>14</td>
<td>0.00000</td>
<td>-5.67698</td>
</tr>
</tbody>
</table>

1, (0.0, 0.0)
2, (0.035, 0.018)
3, (.061, .016)
4, (.478, -.039)
5, (.076, .016)
6, (.135, .058)
7, (0.0, .0)
8, (0.149, .05)
9, (.295, .166)
10, (0.09, .058)
11, (-.183, -.2434)
12, (.942, -.03988)
13, (.112, -.46956)
14, (.0, -.28348)

1 1 1 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
50
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  6.54223 -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  9.09991
9 29  0.00000  4.80769
10 10 13.46205 -41.76373
```
<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
<th>z</th>
</tr>
</thead>
<tbody>
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<td>-3.95604</td>
</tr>
<tr>
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<td>20</td>
<td>-1.78483</td>
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<tr>
<td>10</td>
<td>21</td>
<td>-5.10186</td>
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<tr>
<td>10</td>
<td>22</td>
<td>-2.61932</td>
</tr>
<tr>
<td>11</td>
<td>11</td>
<td>1.90759</td>
</tr>
<tr>
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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

$$E\{x\} = \int_{-\infty}^{\infty} zf(z) \, dz$$  \hspace{1cm} (B.1)

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

$$E\{x\} = \frac{1}{x_2 - x_1} \int_{-\infty}^{\infty} z \, dz$$  \hspace{1cm} (B.2)

It can be noted that if the vertical line $z = a$ is an axis of symmetry of $f(z)$, 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

$$\sigma^2 = \int_{-\infty}^{\infty} (z - \eta)^2 f(z) \, dz$$  \hspace{1cm} (B.3)

where $\eta = E\{x\}$. The positive constant $\sigma$, denoted also by $\sigma_x$, is called the standard deviation of $x$. From the definition it follows that $\sigma^2$ is the mean of RV $(x - \eta)^2$. Thus

$$\sigma^2 = E\{(x - \eta)^2\} = E\{x^2 - 2x\eta + \eta^2\} = E\{x^2\} - 2\eta E\{x\} + \eta^2$$  \hspace{1cm} (B.4)

Hence

$$\sigma^2 = E\{x^2\} - E^2\{x\}$$  \hspace{1cm} (B.5)

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

$$\sigma^2 = E\{x^2\} = \frac{1}{2} \int_{-1}^{1} z^2 \, dz$$  \hspace{1cm} (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

$$x = x_1 + x_2 + x_3 + \cdots + x_n$$  \hspace{1cm} (B.7)
properly normalized, tends to a normal curve as \( n \to \infty \). In other words, if \( n \) is sufficiently large, then \( f(z) \approx \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(z-\eta)^2}{2\sigma^2}} \).

### B.4 Generation of Normally Distributed Numbers

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

\[
\sigma^2 = E(x^2) = \frac{1}{2} \int_{-1}^{1} x_1^2 dx + \frac{1}{2} \int_{-1}^{1} x_2^2 dx + \frac{1}{2} \int_{-1}^{1} x_3^2 dx + \cdots + \frac{1}{2} \int_{-1}^{1} x_n^2 dx = \frac{n}{3} \tag{B.8}
\]

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

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

where \( \sigma \) 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

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 CTSG,MTSG,CMSIG
REAL CTRMAX,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,BB1=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
PARAMETER(NB=30,NLINES=41,NT=82,NNBB=60,NM=118,NMM=254,
1NNBB1=59,BB1=29,NL=24,K1=25,K2=26,DFM=53,BUS=30,
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,NT),JK32(NT,NT)
REAL JK41(NT,NT),JK42(NT,NT)
REAL JK51(NB,NB),JK52(NB,NB)
REAL JKEM(NMM,NNBB),IM(NNBB1,NNBB1),NT(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)

DFM: DIMENSION OF FM MATRIX, EQUAL TO THE NUMBER OF UNKNOWNS IN
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)/1.08, 0.0/
DATA SIG/0.01/
DATA NR, FJM, MFJM/1, 0, 0/

C************************************************************
THESE DATA STATEMENTS ARE FOR 14-BUS SYSTEM, THEY GIVE
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, 2, 2,
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DATA (AM1(I), I=69, 108)/1, 1, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 2/
DATA (AM1(I), I=109, 122)/1, 1, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 2/

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

DATA (AM1(I), I=1, 14)/4, 0, 2, 0, 0, 0, 1, 3, 0, 0, 0, 0, 0, 0/
DATA (AM1(I), I=15, 28)/4, 0, 2, 0, 0, 0, 1, 3, 0, 0, 0, 0, 0, 0/
DATA (AM1(I), I=29, 68)/1, 0, 1, 4, 0, 1, 2, 0, 1, 1, 0, 1, 0, 0, 0, 3, 0, 3, 1, 0,
11, 4, 0, 0, 0, 0, 4, 0, 1, 1, 0, 1, 4, 0, 2, 1, 2, 0, 0/
DATA (AM1(I), I=69, 108)/1, 0, 1, 4, 0, 1, 2, 0, 1, 1, 0, 1, 0, 0, 0, 3, 0, 3, 1, 0,
THESE DATA STATEMENTS ARE FOR 14-BUS SYSTEM
DATA (AM(I),I=1,14)/1,0,0,0,4,1,0,1,2,0,0,0,1,0/
DATA (AM(I),I=15,28)/1,0,0,0,4,1,0,1,2,0,0,0,1,0/
DATA (AM(I),I=29,68)/0,3,0,1,0,0,2,1,0,0,0,4,0,1,0,1,0,0,0,3,11,0,0,0,1,3,0,1,0,1,0,0,4,1,0,2,0,1/
DATA (AM(I),I=69,108)/0,3,0,1,0,0,2,1,0,0,0,4,0,1,0,1,0,0,0,3,11,0,0,0,1,3,0,1,0,1,0,0,4,1,0,2,0,1/
DATA (AM(I),I=109,122)/1,0,0,0,4,1,0,1,2,0,0,0,1,0/
C**********************************************************************
C*********************** 14-C  *******************************************
THIS IS INSTRUMENTATION CONFIGURATION 14-C FOR 14-BUS SYSTEM.
FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
AVAILABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILABLE
MEASUREMENTS.
C**********************************************************************
C THESE DATA STATEMENTS ARE FOR 14-BUS SYSTEM
DATA (AM(I),I=1,14)/1,0,0,0,4,1,0,1,2,0,0,0,1,0/
DATA (AM(I),I=15,28)/1,0,0,0,4,1,0,1,2,0,0,0,1,0/
DATA (AM(I),I=29,68)/0,3,0,1,0,0,2,1,0,0,0,4,0,1,0,1,0,0,0,3,11,0,0,0,1,3,0,1,0,1,0,0,4,1,0,2,0,1/
DATA (AM(I),I=69,108)/0,3,0,1,0,0,2,1,0,0,0,4,0,1,0,1,0,0,0,3,11,0,0,0,1,3,0,1,0,1,0,0,4,1,0,2,0,1/
DATA (AM(I),I=109,122)/1,0,0,0,4,1,0,1,2,0,0,0,1,0/
C**********************************************************************
C********************#### 14-D  *******************************************
THIS IS INSTRUMENTATION CONFIGURATION 14-D FOR 14-BUS SYSTEM.
FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
AVAILABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILABLE
MEASUREMENTS.
C**********************************************************************
C THESE DATA STATEMENTS ARE FOR 14-BUS SYSTEM
DATA (AM(I),I=1,14)/1,0,0,0,4,1,0,1,2,0,0,0,1,0/
DATA (AM(I),I=15,28)/1,0,0,0,4,1,0,1,2,0,0,0,1,0/
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)/0,0,0,1,0,0,3,0,0,0,2,0,1/
C*********************************************************************
C************************ 14-E ***********************************
THIS IS INSTRUMENTATION CONFIGURATION 14-E FOR 14-BUS SYSTEM.
FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
AVAILABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILABLE
MEASUREMENTS.
C*********************************************************************
THESE DATA STATEMENTS ARE FOR 14-BUS SYSTEM
DATA (AM(I),I=1,14)/1,0,2,0,3,0,0,4,0,0,0,2,0,1/
DATA (AM(I),I=15,28)/1,0,2,0,3,0,0,4,0,0,0,2,0,1/
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,
11,1,0,0,2,2,3,0,0,4,0,0,0,0,3,0,0,0,2,1,0/
DATA (AM(I),I=69,108)/0,2,0,0,4,1,0,2,0,0,3,0,1,2,0,4,0,3,0,
11,1,0,0,2,2,3,0,0,4,0,0,0,3,0,0,0,2,1,0/
DATA (AM(I),I=109,122)/1,0,2,0,3,0,0,4,0,0,0,2,0,1/
C*********************************************************************
C************************ 14-F ***********************************
THIS IS INSTRUMENTATION CONFIGURATION 14-F FOR 14-BUS SYSTEM.
FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
AVAILABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILABLE
MEASUREMENTS.
C*********************************************************************
DATA (AM(I),I=1,14)/3,0,0,2,3,1,0,1,0,4,0,2,0,1/
DATA (AM(I),I=15,28)/3,0,0,2,3,1,0,1,0,4,0,2,0,1/
DATA (AM(I),I=29,68)/0,0,2,0,0,3,0,1,1,0,0,0,0,0,1,0,0,0,
10,3,0,2,0,2,0,1,0,0,4,0,3,1,0,0,2,0,0,1,0/
DATA (AM(I),I=69,108)/0,0,2,0,0,3,0,1,1,0,0,0,0,4,0,0,1,0,0,0,
10,3,0,2,0,2,0,1,0,0,4,0,3,1,0,0,2,0,0,1,0/
DATA (AM(I),I=109,122)/3,0,0,2,3,1,0,1,0,4,0,2,0,1/
C*********************************************************************
C************************ 14-G ***********************************
THIS IS INSTRUMENTATION CONFIGURATION 14-G FOR 14-BUS SYSTEM.
FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE
AVAILABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILABLE
MEASUREMENTS.
C*********************************************************************
THESE DATA STATEMENTS ARE FOR 14-BUS SYSTEM
THIS IS INSTRUMENTATION CONFIGURATION 30-A FOR 14-BUS SYSTEM.
FOLLOWING DATA STATEMENTS SPECIFY WHICH MEASUREMENTS ARE AVAILABLE AND SPECIFY THE ACCURACY CATEGORY OF EACH AVAILABLE MEASUREMENTS.

DOUBLE PRECISION RAN

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

THIS READS IN THE SYSTEM DATA FROM DATA FILE

CALL SYSDATA(NB,NLINES,G,B,NT,K1,MTOBO,PSPASP,VSP,SP,YC,ZLINE,N2)

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

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

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

• DIFFERENT CASES ARE SIMULATED TO TEST THE PERFORMANCES OF
  DIFFERENT WEIGHTING MATRICES
DO 1000 KKK=1,NCASE
  IF (KKK.GT.1) GO TO 1112
  • PRINT OUT THE INFORMATION OF WHICH MEASUREMENTS ARE
    AVAILABLE AND WHAT ARE THE ACCURACY CATEGORY OF
    THE AVAILABLE MEASUREMENTS.
  WRITE(50,960)(AM(I),I=1,NB)
  960 FORMAT(’PI:',14I1)
  WRITE(50,961)(AM(I+NB),I=1,NB)
  961 FORMAT(’QI:',14I1)
  WRITE(50,965)(AM(I+NNBB),I=1,NT)
  965 FORMAT(’PLI:',40I1)
  WRITE(50,966)(AM(I+NNBB+NT),I=1,NT)
  966 FORMAT(’QLI:',40I1)
  WRITE(50,967)(AM(I+NNBB+NT+NT),I=1,NB)
  967 FORMAT(’VI:',14I1)
1112 CONTINUE

WRITE(50,*)

66
THIS GENERATES SIMULATED MEASUREMENTS OF A SYSTEM
CALL MG(AM,NUDR,VM,VT,DT,E,MTBO,NT,NB,ST,
  1ZLINE,YC,NLINES,PLM,QLM,PLT,QLT,PNM,QNM,P,Q,NUD,NNM,NNBB,
  1ERR1,ERR2,FERR1,FERR2,IR)

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

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(PC(I))
85 CONTINUE

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

K=0
90 CONTINUE

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

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

THIS CALCULATES THE DIFFERENCES BETWEEN MEASUREMENTS AND
CALCULATED VALUES
CALL EDELTA(PNMANM,PLM,OLM,VM,PNCANC,PLC,OLC,V,CONM,
  1NMM,NB,NT)

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

CALCULATING THE JACOBIAN MATRIX FOR STATE ESTIMATION (JKE)
CALL EJACOB(JK11,K12,JK21,JK22,JK31,JK32,JK41,JK42,JK51,JK52,
  1JKE,NPNC,QNC,V,D,NB,NT,B,G,NNBE,NNM,MTBO,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

• WHEN FIXED JACOBIAN METHOD IS USED, THE FOLLOWING STATEMENT
• SHOULD BE USED.
• 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, nmbb1, 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,*)'I TEST=' , ITEST

This calculates the performance indices of the case simulated
CALL PI(P,Q,PLT,QLT,VT,PM,PNM,QHM,PLM,QLM,VM,PNC,QNC,PLC,QLC,V,
JCT,JMT,JCM,AJCT,AJMT,AJCM,WMN,AM,NB,NT,NCASE,NMM,NNBB,KKK,SUT,
SUM,SUC,CTX,MTX,CMX,CTRX,MTRX,CMRX,CTI,MTI,CMI,PJCT,PJMT,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,----------,3X,
     1'------',3X,----------,3X,'------',3X,')

WRITE(50,1060)CTI(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,
       F10.4,5X,F7.4,X,I3)

WRITE(50,*)

IF (KKK.GT.1) GO TO 1111

WRITE(50,1055)
1055 FORMAT(5X,'PJCT100',5X,'PJMT100',5X,'PJCM100'/
       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'/
       4X,'---',X,'--------',X,'--------',X,'--------',
       12X,'---',X,'--------',X,'--------',X,'--------')

WRITE(50,1075)(I,P(I),PNM(I),PNC(I),
       11+NB,Q(I),QNM(I),QNC(I), I=1,NB)

WRITE(50,*)

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

WRITE(50,1090)(I+NNBE,PLT(I),PLM(I),PLC(I),
       11+NNBB+NT,QLT(I),QLM(I),QLC(I), I=1,NT)

WRITE(50,*)

WRITE(50,1095)
1095 FORMAT(4X,'I',X,'VT',X,'VM',X,'V'/
       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,I,F8.5,X,F8.5,X,F8.5)
CONTINUE

WRITE(50,*)KXX, ' ,K=', K, ' ITEST=', ITEST

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,'AJCMMAX/
1 5X,'-------',5X,'-------',5X,'-------')

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

WRITE(50,*)

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

WRITE(50,935)ACTAVE,AMTAVE,ACMAVE
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,'MTIMAX',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(50,1165)
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
SUBROUTINE SYSDATA(NB,NLINES,G,B,NT,K1,MTOBO,PSP,QSP,VSP,SP,
  YC,ZLINE,K2)

C**********************************************************************

THIS SUBROUTINE READS IN THE SYSTEM PARAMETERS AND OTHER DATA

PARAMETER PASSED:
  K1 = NUMBER OF LOAD BUS + 1
  K2 = NUMBER OF LOAD BUS + 2, NEEDED TO READ SPECIFIED VOLTAGES
  NB = NUMBER OF BUSES
  NLINES = NUMBER OF LINES

PARAMETER RETURNED:
  G = ADMITTANCE
  B = SUSCEPTANCE
  NT = 2 X NLINES
  MTOBO = ARRAY OF: #, FROM_BUS, TO_BUS, LINE #
  PSP = ARRAY OF SPECIFIED NODAL REAL POWER INJECTIONS
  QSP = ARRAY OF SPECIFIED NODAL REACTIVE POWER INJECTIONS
  SP = ARRAY OF COMPLEX NODAL POWER INJECTIONS
  YC = ARRAY OF LINE CHANGING ADMITTANCES
  ZLINE = ARRAY OF LINE IMPEDANCES

CALLED BY:
  MAIN PROGRAM

CALLS:
  NONE

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

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(*,*) 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, *) (MTDBU(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
SUBROUTINE MG(AM,NUDR,VM,VT,E,MTOBO,NT,NB,ST,ZLINE,YC,NLINES,
1PLM,QLM,PLT,QLT,PNM,QNM,P,Q,NDR,NMM,NNBB,ERR1,ERR2,FERR1,FERR2,IR)

THIS SUBROUTINE IS USED TO GENERATE ALL THE SIMULATED SYSTEM
VARIABLES WHICH ARE SIMULATED MEASUREMENTS.

PARAMETERS PASSED:

AM = ARRAY OF INDICES SPECIFY WHETHER CORRESPONDING MEASUREMENTS
ARE AVAILABLE OR NOT AND SPECIFY THEIR ACCURACY CATEGORIES
NUDR = NUMBER OF UNIFORMALLY DISTRIBUTED RANDOM NUMBERS USED TO
GENERATE NORMALLY DISTRIBUTED RANDOM NUMBERS
VT = ARRAY OF TRUE MAGNITUDES OF NODAL VOLTAGES
DT = ARRAY OF TRUE ANGLES OF NODAL VOLTAGES
E = ARRAY OF NODAL VOLTAGES
MTOBO = ARRAY OF: #, FROM_BUS, TO_BUS, LINE #
NT = 2 X NLINES
NB = NUMBER OF BUSES
ST = ARRAY OF COMPLEX LINE FLOWS
ZLINE = ARRAY OF LINE IMPEDANCES
YC = ARRAY OF LINE ADMITTANCES
NLINES = NUMBER OF LINES
PLT = ARRAY OF TRUE REAL POWER FLOWS
QLT = ARRAY OF TRUE REACTIVE POWER FLOWS
P = ARRAY OF TRUE NODAL REAL POWER INJECTIONS
Q = ARRAY OF TRUE NODAL REACTIVE POWER INJECTIONS
NMM = NUMBER OF SYSTEM VARIABLES (= NNBB + 2 X NT + NB)
NNBB = 2 X NB
ERR1 = ERROR PROPORTIONAL TO MEASUREMENTS FOR VOLTAGE MEASUREMENTS
ERR2 = ERROR PROPORTIONAL TO MEASUREMENTS FOR OTHER MEASUREMENTS
FERR1 = FIXED ERROR FOR VOLTAGE MEASUREMENTS
FERR2 = FIXED ERROR OTHER MEASUREMENTS
IR = A SEED USED TO GENERATE RANDOM NUMBERS

PARAMETERS RETURNED:

PNM = ARRAY OF SIMULATED NODAL REAL POWER INJECTIONS
QNM = ARRAY OF SIMULATED NODAL REACTIVE POWER INJECTIONS
PLM = ARRAY OF SIMULATED REAL POWER POWER FLOWS
QLM = ARRAY OF SIMULATED REACTIVE POWER FLOWS
VM = ARRAY OF SIMULATED MAGNITUDES OF NODAL VOLTAGES

CALLED BY:

MAIN PROGRAM

CALLS:

SUBROUTINE NRAN
SUBROUTINE RANDOM

SUBROUTINE CLF

REAL VM(NB), VT(NB), DT(NB), PLM(NB), QLM(NB), PNM(NB), QNM(NB), PLT(NLINES), QLT(NLINES), P(NB), Q(NB), NDR

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

INTEGER MT0BO(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,NE,ZLINE,SC,NT)

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*FERR2
ELSE
SIG=4*ERR2
FERR=4*FERR2
ENDIF
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
SUBROUTINE NRAN(NUDR,NDR,SIG,IR)

THIS SUBROUTINE IS USED TO CREATE NORMALLY DISTRIBUTED NUMBERS USING UNIFORMLY DISTRIBUTED NUMBERS BASED ON THE CENTRAL LIMITATION THEORY

PARAMETERS PASSED:
- NUDR = NO. OF NORMALLY DISTRIBUTED RANDOM NUMBER INTEND TO GENERATE
- SIG = STANDARD DEVIATION OF THE NORMALLY DISTRIBUTED RANDOM NUMBERS CREATED. THIS VALUE SHOULD BE SPECIFIED AT THE BEGINNING OF THE SUBROUTINE
- IR = A SEED USED TO PRODUCE UNIFORMLY DISTRIBUTED RANDOM NUMBERS

PARAMETER RETURNED:
- NDR = NORMALLY DISTRIBUTED RANDOM NUMBER

CALLED BY:
- SUBROUTINE MG

CALLS:
- SUBROUTINE RANDOM

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*SQR(3./NUDR)
RETURN
END
SUBROUTINE WMG(AM, AM1, WMM, NMM, PNM, QNM, PLM, QLM, VM, NB, NNBB, NT, ERR1, ERR2, FERR1, FERR2, WMN)

PARAMETERS PASSED:
AM = ARRAY OF INDICES SPECIFYING WHETHER CORRESPONDING MEASUREMENTS ARE AVAILABLE OR NOT AND SPECIFY THEIR ACCURACY CATEGORIES
NMM = NUMBER OF SYSTEM VARIABLES (= NNBB + 2 X NT + NB)
PNM = ARRAY OF SIMULATED NODAL REAL POWER INJECTIONS
QNM = ARRAY OF SIMULATED NODAL REACTIVE POWER INJECTIONS
PLM = ARRAY OF SIMULATED REAL POWER POWER FLOWS
QLM = ARRAY OF SIMULATED REACTIVE POWER FLOWS
VM = ARRAY OF SIMULATED MAGNITUDES OF NODAL VOLTAGES
NB = NUMBER OF BUSES
NNBB = 2 X NB
NT = 2 X NLINES
ERR1 = ERROR PROPORTIONAL TO MEASUREMENTS FOR VOLTAGE MEASUREMENTS
ERR2 = ERROR PROPORTIONAL TO MEASUREMENTS FOR OTHER MEASUREMENTS
FERR1 = FIXED ERROR FOR VOLTAGE MEASUREMENTS
FERR2 = FIXED ERROR OTHER MEASUREMENTS

PARAMETERS RETURNED:
WMM = WEIGHTING MATRIX USED IN PSSE

CALLED BY:
MAIN PROGRAM

CALLS:
NONE

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

34 CONTINUE
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/(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 IF (AM(I+NNBB+NT).EQ.4) THEN
ERR=4*ERR2
FERR=4*FERR2
ELSE IF (AM(I+NNBB+NT).EQ.5) THEN
ERR=5*ERR2
FERR=5*FERR2
ELSE IF (AM(I+NNBB+NT).EQ.6) THEN
ERR=6*ERR2
FERR=6*FERR2
ELSE IF (AM(I+NNBB+NT).EQ.7) THEN
ERR=7*ERR2
FERR=7*FERR2
ELSE IF (AM(I+NNBB+NT).EQ.8) THEN
ERR=8*ERR2
FERR=8*FERR2
ELSE IF (AM(I+NNBB+NT).EQ.9) THEN
ERR=9*ERR2
FERR=9*FERR2
ELSE IF (AM(I+NNBB+NT).EQ.10) THEN
ERR=10*ERR2
FERR=10*FERR2
ENDIF
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*A*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

87
ELSE
ERR=4*ERR1
FERR=4*FERR1
ENDIF

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

IF (WMN.EQ.2) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B
ELSE IF (WMN.EQ.3) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B*BB
ELSE IF (WMN.EQ.4) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B*BB*BB
ELSE IF (WMN.EQ.5) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B*BB*BB*BB
ELSE IF (WMN.EQ.6) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B*BB
ELSE IF (WMN.EQ.7) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B*BB*BB
ELSE IF (WMN.EQ.8) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B/(BB*BB)
ELSE IF (WMN.EQ.9) THEN
WMM(I+NNBB+NT+NT,I+NNBB+NT+NT)=B/(BB*BB)
ELSE IF (WMN.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*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 (AM(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
   WMK(I,I)=1.
209 CONTINUE

999 RETURN
END
SUBROUTINE EJACOB(JK11, JK12, JK21, JK22, JK31, JK32, JK41, JK42, JK51,
JK52, JKEM, PNC, QNC, V, D, NB, NT, B, G, NNBB, NMM, MTOBO, NY, NLMES, PN, QNM,
2PLM, QLM, VM)

THIS SUBROUTINE CALCULATES JACOBIAN MATRIX.

PNC AND QNC ARE NEEDED TO CALCULATE THE DIAGONAL
ELEMENTS OF SUBJACOBIANS. THE OUTPUT IS JKEM.

PARAMETERS PASSED:

PNC = ARRAY OF CALCULATED NODAL REAL POWER INJECTIONS
QNC = ARRAY OF CALCULATED NODAL REACTIVE POWER INJECTIONS
V = ARRAY OF MAGNITUDE OF NODAL VOLTAGES
D = ARRAY OF ANGLE OF NODAL VOLTAGE ANGLES
NB = NUMBER OF BUSES
NT = 2 X NLINES
B = SUSCEPTANCES
G = ADMITTANCES
NNBB = 2 X NB
NMM = NUMBER OF SYSTEM VARIABLES (= NNBB + 2 X NT + NB)
MTOBO = ARRAY OF: #, FROM_BUS, TO_BUS, LINE #
NY = SHUNT ADMITTANCE
NLINES = NUMBER OF LINES

PARAMETERS RETURNED:

JKEM = JACOBIAN MATRIX FOR STATE ESTIMATION

CALLED BY:
MAIN PROGRAM

CALLS:
NONE

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),
JK51(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)

GENERATING JK11, JK12, JK21, JK22, JK31, JK32, JK41, JK42,
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
KX=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,I)=-JK31(KK,I)
JK32(KK,I)=V(I)*V(J)*(G(I,J)*COSDIJ+B(I,J)*SINDIJ)
JK32(KK,I)=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,I)=-JK41(KK,I)
JK42(KK,I)=-(V(I)*V(J)*(-B(I,J)*COSDIJ+G(I,J)*SINDIJ)
JK42(KK,I)=JK42(KK,I)
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)=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
SUBROUTINE POLCAL(PLC, QLC, V, D, B, G, NB, MTOBO, E, ST, ZLINE, YC, NLINES, NT)

PARAMETER PASSED:
V = ARRAY OF MAGNITUDE OF NODAL VOLTAGES
D = ARRAY OF ANGLE OF NODAL VOLTAGE ANGLES
B = SUSCEPTANCES
G = ADMITTANCES
NB = NUMBER OF BUSES
MTOBO = ARRAY OF: #, FROM_BUS, TO_BUS, LINE #
E = ARRAY OF COMPLEX NODAL VOLTAGES
ST = ARRAY OF COMPLEX LINE FLOWS (FOR EACH END OF EACH LINE)
ZLINE = ARRAY OF LINE IMPEDANCES
YC = ARRAY OF LINE CHARGING ADMITTANCES
NLINE = NUMBER OF LINES
NT = 2 X NLINES

PARAMETER RETURNED:
PLC = ARRAY OF CALCULATED REAL POWER FLOWS
QLC = ARRAY OF CALCULATED REACTIVE POWER FLOWS

CALLED BY:
MAIN PROGRAM

CALLS:
SUBROUTINE CLF

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) = CMPLX(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
SUBROUTINE EDELTA(PNM, QNM, PLM, QLM, VM, PNC, QNC, PLC, QLC, V, CONM, 
NMM, NB, NT)

THIS SUBROUTINE CALCULATES THE DIFFERENCES BETWEEN CALCULATED 
VALUES AND MEASUREMENTS

PARAMETER PASSED:

PNM = ARRAY OF SIMULATED NODAL REAL POWER INJECTIONS
QNM = ARRAY OF SIMULATED NODAL REACTIVE POWER INJECTIONS
PLM = ARRAY OF SIMULATED REAL POWER POWER FLOWS
QLM = ARRAY OF SIMULATED REACTIVE POWER FLOWS
VM = ARRAY OF SIMULATED MAGNITUDES OF NODAL VOLTAGES
PNC = ARRAY OF CALCULATED NODAL REAL POWER INJECTIONS
QNC = ARRAY OF CALCULATED NODAL REAL POWER INJECTIONS
PLC = ARRAY OF CALCULATED REAL POWER POWER FLOWS
QLC = ARRAY OF CALCULATED REAL POWER POWER FLOWS
V = ARRAY OF CALCULATED MAGNITUDE OF NODAL VOLTAGES
NMM = NUMBER OF SYSTEM VARIABLES (= NNBB + 2 X NT + NB)
NB = NUMBER OF BUSES
NT = NUMBER OF LINES

PARAMETERS RETURNED:

CONM = ARRAY OF DIFFERENCES BETWEEN CALCULATED VALUES AND 
MEASUREMENTS

CALLED BY:

MAIN PROGRAM

CALLS:

NONE

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
SUBROUTINE TEST(CON2,I TEST,NB,CRIT)

THIS SUBROUTINE IS USED TO TEST IF THE PROGRAM HAS
CONVERGED, DIVERGED OR NOT BOTH BY CALCULATING THE
DIFFERENCES BETWEEN COMPLEX
VOLTAGES OBTAINED FROM TWO CONSECUTIVE ITERATIONS.

PARAMETERS PASSED:
CON2 = ARRAY OF DIFFERENCES BETWEEN MEASUREMENTS AND
       CALCULATED VALUES
NB = NUMBER OF BUSES
CRIT = CONVERGENCE CRITERION

PARAMETER RETURNED:
ITEST = INDEX OF STATUS (CONVERGE, DIVERGE OR NOT BOTH)

CALLED BY:
MAIN PROGRAM

CALLS:
NONE

DIMENSION CON2(2*NB-1)

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

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

  ITEST=1
  GO TO 50

  ITEST=2
  GO TO 50

  ITEST=0
50 RETURN
END
SUBROUTINE PI(P,Q,PLT,QLT,VT,PNM,QNM,PLM,QLM,VM,PBC,QNC,PLC,OLC,VM,JCT,JMT,JCM,AJCT,AJMT,AJCM,WMM,AM,NB,NT,NCASE,NMM,NNBB,KKK,SUT,JSUM,SUC,CTX,MTX,CMX,CTRX,MTRX,CMRX,CTI,MTI,CMI,PJCT,PJMT,PJCM)

THIS SUBROUTINE CALCULATES PERFORMANCE INDICES OF EACH SINGLE CASE

PARAMETERS PASSED:
P = ARRAY OF TRUE NODAL REAL POWER INJECTIONS
Q = ARRAY OF TRUE NODAL REACTIVE POWER INJECTIONS
PLT = ARRAY OF TRUE REAL POWER FLOWS
QLT = ARRAY OF TRUE REACTIVE POWER FLOWS
VT = ARRAY OF TRUE MAGNITUDES OF NODAL VOLTAGES
PNM = ARRAY OF SIMULATED NODAL REAL POWER INJECTIONS
QNM = ARRAY OF SIMULATED NODAL REACTIVE POWER INJECTIONS
PLM = ARRAY OF SIMULATED REAL POWER POWER FLOWS
QLM = ARRAY OF SIMULATED REACTIVE POWER FLOWS
VM = ARRAY OF SIMULATED MAGNITUDES OF NODAL VOLTAGES
AM = ARRAY OF INDICES SPECIFY WHETHER CORRESPONDING MEASUREMENTS ARE AVAILABLE OR NOT AND SPECIFY THEIR ACCURACY CATEGORIES
NB = NUMBER OF BUSES
NT = 2 X NLINES
NCASE = NUMBER OF SIMULATED CASES
NMM = NUMBER OF SYSTEM VARIABLES (= NNBB + 2 X NT + NB)
NNBB = 2 X NB
KKK = CASE NUMBER

PARAMETERS RETURNED:
JCT = SUM OF DIFFERENCES BETWEEN CALCULATED AND TRUE VALUES WHOSE CORRESPONDING MEASUREMENTS ARE AVAILABLE SQUARED
JMT = SUM OF DIFFERENCES BETWEEN AVAILABLE MEASUREMENTS AND TRUE VALUES SQUARED
JCM = SUM OF DIFFERENCES BETWEEN CALCULATED VALUES AND AVAILABLE MEASUREMENTS SQUARED
AJCT = SUM OF ABSOLUTE DIFFERENCES BETWEEN CALCULATED AND TRUE VALUES
AJMT = SUM OF ABSOLUTE DIFFERENCES BETWEEN MEASUREMENTS AND TRUE VALUES
AJCM = SUM OF ABSOLUTE DIFFERENCES BETWEEN CALCULATED VALUES
SUT = SUM OF ABSOLUTE TRUE VALUES
SUM = SUM OF ABSOLUTE MEASUREMENTS
SUC = SUM OF ABSOLUTE CALCULATED VALUES
CTX = MAXIMUM DIFFERENCE BETWEEN CALCULATED AND TRUE VALUES
MTX = MAXIMUM DIFFERENCE BETWEEN MEASUREMENTS AND TRUE VALUES
CMX = MAXIMUM DIFFERENCE BETWEEN CALCULATED VALUES AND MEASUREMENTS
CTR = RELATIVE DIFFERENCE BETWEEN CALCULATED AND TRUE VALUES
FOR CTX
MTR = RELATIVE DIFFERENCE BETWEEN MEASUREMENTS AND TRUE VALUES
FOR MTX
CMR = RELATIVE DIFFERENCE BETWEEN CALCULATED VALUES AND MEASUREMENTS
FOR CMX
CTI = INDEX TO TELL WHERE CTX OCCURS
MTI = INDEX TO TELL WHERE MTX OCCURS
CMI = INDEX TO TELL WHERE CMX OCCURS
PJCT = AJCT/SUT
PJMT = AJMT/SUM
PJCM = AJCM/SUC

CALLED BY:
MAIN PROGRAM

CALLS:
NONE

*******************************************************************************

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 CTR(NCASE),MTR(NCASE),CMR(NCASE)
DO 10 I=1,NB
IF (ABS(PNC(I)-P(I)).GT.CTI(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.MTI(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)
  MTRX(KKK)=MTRX(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
JCI(KKK)=JCI(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(ONC(I)-Q(I)).GT.CTI(KKK)) THEN
    CTX(KKK)=ABS(ONC(I)-Q(I))
    CTRX(KKK)=ABS((ONC(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(ONM(I)-Q(I)).GT.MTI(KKK)) THEN
    MTX(KKK)=ABS(ONM(I)-Q(I))
    MTRX(KKK)=ABS((ONM(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(ONC(I)-ONM(I)).GT.CMX(KKK)) THEN
    CMX(KKK)=ABS(ONC(I)-QNM(I))
    CMRX(KKK)=ABS((ONC(I)-QNM(I))/ONC(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(ONM(I))
  SUC(KKK)=SUC(KKK)+ABS(QNC(I))
  AJCI(KKK)=AJCI(KKK)+ABS(ONC(I)-Q(I))
  AJMT(KKK)=AJMT(KKK)+ABS(ONM(I)-Q(I))
  AJCM(KKK)=AJCM(KKK)+ABS(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(KEK)) THEN
      CMX(KEK)=ABS(PLC(I)-PLM(I))
      CMRX(KEK)=ABS((PLC(I)-PLM(I))/PLC(I))
      CMI(KEK)=I+NNBB
   ELSE
      CMX(KEK)=CMX(KEK)
      CMRX(KEK)=CMRX(KEK)
      CMI(KEK)=CMI(KEK)
   ENDIF
   SUTO(KK)=SUTO(KK)+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))
   ELSE
      CTX(KKK)=CTX(KKK)
      CTRX(KKK)=CTRX(KKK)
   ENDIF
40 CONTINUE
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)
50 CONTINUE
ENDIF
IF (ABS(VM(I)-VT(I)).GT.MTI(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)=CMI(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)/SUT(KKK)
PJCM(KKK)=AJCM(KKK)/SUM(KKK)
RETURN
END
C******************************************
SUBROUTINE STAM(A,N,AVE,SIG,MAX)
C*****************************************
THIS SUBROUTINE CALCULATES MAXIMUM, AVERAGE VALUE AND
STANDARD DEVIATION FOR THE ELEMENTS OF ARRAY A.
PARAMETERS PASSED:
A = ARRAY OF "N" NUMBER OF ELEMENTS
N = NUMBER OF ELEMENTS IN ARRAY "A"
PARAMETERS RETURNED:
AVE = AVERAGE OF "N" ELEMENTS IN ARRAY "A"
SIG = STANDARD DEVIATION OF ELEMENTS IN ARRAY "A"
MAX = MAXIMUM OF "N" ELEMENTS IN ARRAY "A"
CALLED BY:
MAIN PROGRAM
CALLS:
NONE
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
30 CONTINUE
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 $\text{PN}_5$, 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.
<table>
<thead>
<tr>
<th>indices</th>
<th>W1</th>
<th>W2</th>
<th>WU</th>
<th>WP</th>
<th>W4</th>
</tr>
</thead>
<tbody>
<tr>
<td>JCTMAX</td>
<td>2.8297</td>
<td>0.6233</td>
<td>0.2922</td>
<td>2.6287</td>
<td>0.5396</td>
</tr>
<tr>
<td>JCTAVE</td>
<td>0.7536</td>
<td>0.2262</td>
<td>0.1562</td>
<td>0.7111</td>
<td>0.2519</td>
</tr>
<tr>
<td>JCTSIG</td>
<td>0.6967</td>
<td>0.1487</td>
<td>0.0557</td>
<td>0.6347</td>
<td>0.1096</td>
</tr>
<tr>
<td>JMTMAX</td>
<td>4.2309</td>
<td>4.2309</td>
<td>4.2309</td>
<td>4.2309</td>
<td>4.2309</td>
</tr>
<tr>
<td>JMTAVE</td>
<td>1.3895</td>
<td>1.3895</td>
<td>1.3895</td>
<td>1.3895</td>
<td>1.3895</td>
</tr>
<tr>
<td>JMTSIG</td>
<td>1.0060</td>
<td>1.0060</td>
<td>1.0060</td>
<td>1.0060</td>
<td>1.0060</td>
</tr>
<tr>
<td>JCMMAX</td>
<td>1.3821</td>
<td>2.3308</td>
<td>3.3124</td>
<td>1.4101</td>
<td>2.9936</td>
</tr>
<tr>
<td>JCMAVE</td>
<td>0.6339</td>
<td>0.9115</td>
<td>1.2023</td>
<td>0.6457</td>
<td>1.1949</td>
</tr>
<tr>
<td>JCMSIG</td>
<td>0.3483</td>
<td>0.5817</td>
<td>0.7958</td>
<td>0.3565</td>
<td>0.7446</td>
</tr>
<tr>
<td>AJCTMAX</td>
<td>1.5284</td>
<td>1.0418</td>
<td>0.9708</td>
<td>1.5187</td>
<td>1.3283</td>
</tr>
<tr>
<td>AJCTAVE</td>
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<td>0.8387</td>
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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.
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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.
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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.
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.
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.
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.
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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.
<table>
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<th>( W_2 )</th>
<th>( W_U )</th>
<th>( W_P )</th>
<th>( W_4 )</th>
<th>( W_6 )</th>
</tr>
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<td>0.4154</td>
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</tr>
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<td>0.7436</td>
<td>0.7436</td>
<td>0.7436</td>
<td>0.7436</td>
<td>0.7436</td>
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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.
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<th>CAL. V.</th>
<th>CTI</th>
<th>CASE</th>
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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.
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.
<table>
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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.
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.

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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.
SELECTED BIBLIOGRAPHY


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[41] D. C. Yu and S. T. Chen, “Node Reordering and Matrix Partial Refactoriza-


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