Database of Seismic Parameters of Equipment in Substations

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ABSTRACT

This report documents a modular GIS-based risk/reliability modeling capability. This report identifies the needed parameters for a seismic vulnerability assessment of electric substation equipment and develops and documents a comprehensive procedure for compiling seismic performance parameters. The procedure addresses substation layout and substation components, photo taking, slack estimation, and parameter recording and documentation. Finally, this report conducts a pilot integration of data from a number of hypothetical substations resulting in a network performance assessment as an illustration of how data collected are used to conduct and System Earthquake Risk Assessment (SERA).

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1 Introduction

The PEER Lifelines Program is in progress of developing a practical analytical model/process for the seismic risk analysis of large electric transmission systems. The goal of this project is to develop and demonstrate a modular GIS-based risk/reliability modeling capability currently called SERA (for System Earthquake Risk Assessment). SERA has been and can be used to evaluate seismic risks to as-built lifeline systems with no seismic improvements or evaluate seismic risks to modified lifeline systems with physical and/or operational seismic improvements now included. This information can guide decision-makers as they assess then select seismic improvement programs that limit risks to their system to acceptable levels.

Electrical substations consist of many pieces of equipment that are vulnerable to earthquakes. Vulnerability depends on a variety of parameters including equipment type, voltage, manufacturer, seismic design criteria, installation and anchorage details, foundations and soil conditions, and connection to other equipment. In order to be able to make the most accurate and standardized estimates of potential losses in earthquakes and to set priorities for equipment upgrades and replacements, the most accurate database of the relevant seismic-performance parameters of substation equipment is needed. In this project, a comprehensive procedure for compiling seismic performance parameters is described.

A lot of attention is paid toward accuracy of results in developing and evaluating this SERA process. The rationale is that more accurate models can provide more accurate results. Utility personnel, while looking for accuracy, should understand that a SERA, as described in this paper, provides way of integrating the fragmented data and intuitions about a utility system with complex seismicity/attenuation and local effect models. Having done this, they may be better able to obtain a picture of the implications to an electric utility system of some future earthquake. With or without a SERA, as described in this paper, if the risk to a utility is perceived as too high, mitigation programs in response to the utility's earthquake hazard must be made. Therefore, a more realistic way to view a SERA is as a rational way to best assess the system performance in terms of the best information at hand rather than as a way to provide an accurate prediction of the utility's system performance to a future earthquake. This way of viewing a SERA should lead to a more appropriate appreciation for the results coming from such a study.

This report:

- Identifies the needed parameters for a seismic vulnerability assessment of electric substation equipment (**Chapter 2**)
- Develops and documents a comprehensive procedure for compiling seismic performance parameters. The procedure addresses substation layout and substation components, photo taking, slack estimation, and parameter recording and documentation (**Chapter 3**).
- Conducts a pilot integration of data from a number of hypothetical substations into a network performance model as an illustration of how data collected are used to conduct a System Earthquake Risk Assessment (SERA) (**Chapter 4**).

This project is unique in that it develops a generic data collection procedure for electric utility substations. The Report builds on experience from similar data collected at Southern California Edison facilities in the early and late 1990's.

2 Procedure for collecting Seismic Parameters of Substation Equipment

Models of the earthquake hazard and the electrical system must be developed when conducting a System Earthquake Risk Assessment (SERA). It was determined earlier during this PEER Task 413 that, for the purposes of this Report, the high voltage (220kV and up) transmission substation equipment will be the equipment represented in the electrical system model. This was decided because of the historic vulnerability of these classes of equipment, the impact of their failure on the system and the length of time it takes to restore them back to service. Table 2.1 shows the equipment that are modeled in a SERA along with the type of data that should be gathered for each equipment. Other equipment data that could have been collected are: telecommunication components, transmission towers, low voltage station control components, civil structures, lower voltage switchgear and lower voltage transformers.

The *electrical system model* does not have the classical engineer meaning such as a finite element model. In a SERA, the *electrical system model* is the sum of the descriptions of the equipment that make up the system. The information in each equipment description (See Table 2.1) includes: the equipment's presence, the type of equipment (column 1), for some equipment types certain aspects of the equipment's installation (column 3 & 5), the conductor slack between adjoining equipment (column 4) and each equipment's location within the substation and ultimately the electrical system (column 2). The three general categories of electrical equipment are Position (corresponding to switchrack positions), Bank (corresponding to transformer banks) and Misc. (everything else, e.g. equipment not in positions or banks). Information about the performance of each equipment during past earthquakes is contained in another data set.

There are 6 general types of station configurations, see Figure 2.1. A station switchyard may contain more than one configuration, e.g. breaker-and-one-half and double-bus-double-breaker. The current SERA can handle breaker-and-one-half, double-bus-double-breaker, and Single-bus configurations.

A critical step in any effort to model a utility system is the gathering of accurate site and component data. Each site is made up of components that are installed in a unique arrangement and separated with conductors having varying amounts of slack. Some data can be obtained in company inventory data sets (power transformer and circuit breaker types and positions), but the majority of the data needs to be collected in the field. Data available in the office may provide component type, location, electrical connectivity and cost (model and serial number for circuit breakers and transformers). The office copy of the dispatcher single line diagram will provide information on system connectivity and completeness of the system represented. Unfortunately, even for this basic information, the office data may not be up-to-date. Details such as equipment anchorage, component interaction (conductor sag and collateral damage potential) information, transformer radiator type and other installation information must be determined in the field along with actual system and component connectivity. Equipment other than disconnect switches, circuit breakers and transformers can be identified in electrical single line diagrams, but is it easier to document them while in the field. Except for transformers, anchorage has not been considered in the risk analysis, although the occasions of poor anchorage for any equipment should be noted for further evaluation. Except for transformers or transformer-like components (reactors, etc.), anchorage has not been an issue.

Data gathering should be systematic and information should be recorded, either with pen or pencil on a note pad or electronically on a Personnel Data Assistant. Station templates, if desired, can be developed from dispatcher single lines. Figure 2.2 “Blank Template of a Double Bus Double Breaker Position and Breaker and a Half Position” is a template for recording data of equipment in station switchyard positions. Figure 2.3 “Blank Template of a Transformer Bank” is a template for recording data of power transformer banks. Figure 5 ‘Blank Template of MISC Equipment” is a template for recording data of all other equipment. Generally, equipment types and slack (or available relative displacement capacity) need to be recorded. The order in which the component data is recorded and the location of the recording in the data file determine the component’s location in the electrical system. System or dispatcher single line diagrams may not include all equipment that are present. Generally only disconnect switches (gate), circuit breaker (box) and transformers are shown. The data gatherer must therefore add those components that are not included in these single line diagrams to the data recorder while in the field with special care given to connectivity.

Positions should be documented by first recording all equipment/components and slack in their serial order (moving north to south while recording the data on the west side of the position, for example). This is aided by following the template. Having traversed the position, the data recorder reviews the same position while moving in the opposite direction, e.g. noting anchorages or other observations and verifying slack (moving south to north on the east side of the position). Phasing should be consistent with the direction positions are documented, starting with lowest position number and progressing to the highest position number or with the system scheme if noted in the field. Phasing can usually be determined in the field, e.g. where there are single-phase transformers or line taps and their phases are identified. Based on inspection of the station one-line drawing templates are developed for each position. Developing templates in the office saves time and minimizes data recording in the field. Templates are not absolutely necessary for data collection as data can be taken "on the fly" in the field. In this case, as with templates, time will be saved if data is taken in a consistent manner and in the format of the assessment software to be used.

Position and Misc. equipment are documented by recording, first their proper acronym symbol, for example, CB is for circuit breakers, DS is for disconnect switches, etc. The equipment type is then recorded as a number that is consistent with that same equipment type in the performance data file and lastly, the equipment slack (with the next to be documented equipment) information is recorded. If the equipment is a 230kV disconnect switch with no seismic design (type) and has 6 inches of slack in each phase with the next component it will be recorded as DS1333 (see Chapter 3 for a detailed explanation).

There are more issues to consider for a transformer than for any other equipment. This is due to the many vulnerable components and appendages that are mounted on or near-by a transformer that can, upon failure, cause the transformer to malfunction.

Blank Bank templates should be brought to the substation. One template is used for each transformer tank. That is, one template is used for a three phase transformer bank and three templates are used for a bank made up of three single-phase transformers.

Surge Arresters (SA) can be mounted on either a transformer or civil structure. If the SA is mounted over the transformer, collateral damage to the transformer resulting from SA failure must be considered. To do this, visualize a pie with SA at center then visualize what portion of the pie represents the SA impacting the transformer. This portion relative to the whole circle is an estimate of the ratio of fail paths hitting transformer to total. Limited training can help the data gatherer include the pull effect of the conductor in this estimate.

Radiators are another type of attached component of the transformer that have failed in previous earthquakes. Transformer radiators that have failed in past earthquakes have generally not had any seismic or shipping bracing. After it has been determined that there is no seismic or shipping bracing/supports in the horizontal or vertical direction, the data gatherer must estimate radiator strength. He does this by first determining whether the radiators are manifold or directly attached to the transformer tank and how flexible (low frequency) the radiator is. Radiators directly attached to the transformer tank and radiators with frequencies below 3 Hz. should be considered most vulnerable.

Components in the MISC category are the components that cannot be assigned a unique position or Bank. Capacitors, reactors and potential transformers are included in this category. For these equipment, it is only necessary to identify the components station designation (e.g. ‘north bus potential transformer”), component type and slack. MISC equipment are recorded in the same manner as POSITION equipment.

There is no easy way to precisely measure flexible or rigid conductor slack (excess conductor). This is particularly true if the system is energized. Conductor slack can be estimated. Estimations can be greatly enhanced with the aid of templates. Appendix 1 – “Conductor Slack Template (15ft)” provides a flexible conductor slack estimation template for 15-ft equipment separation and two different equipment relative elevations (0 ft and 3 ft). Rigid bus can be estimated in a similar manner as flexible bus, which is by using templates. The data gatherer can estimate slack values, in a timely manner, using slack templates.

When practical, pictures of all components and notable details should be taken. Additional equipment documentation including station location and example photos should be developed. Station location of components can be documented via a station plot plan or photo from the air. Photos taken during data collection should include a panoramic photo(s) of the substation. A minimum of two photos (different angles) and anchorage detail should be taken for each transformer as well as two photos for each typical type of circuit breaker and disconnect switch (one to show the component and the other to show the anchorage).

Finally, a 30-40 minute digital video walk through of each substation should be developed. This video should trace the data-gathering route through the substation viewing each component during the walk through. An audio description of each component should be included.

Example data sets are described in Chapters 3 and 4. Station data, when formatted properly, can be entered directly into a computer program (e.g. SERA – as last used by Southern California Edison). Once in a SERA program, the system data will be integrated with each station's shaking amplitude (for each scenario) and the past earthquake performance of the components using a Monte Carlo simulation approach.

Table 2.1 – parameters to be gathered for each equipment[1] (220kV or greater).

Component	Location	Anch[2].	Slack[3]	other
Transformer (TR)	BANK	YES	YES	surge arrester, collateral damage, radiator strength
Circuit breaker (CB)	POSITION	NO, note[4]	YES	
Surge arrester (SA)	POSITION or BANK	NO	YES	component or structural mounted[5]
Disconnect switch (DS)	POSITION	NO	YES	structure elevation & angle mounted[6]
Coupling capacitor voltage transformer (CCVT)	POSITION	NO	YES	structure mounted, or suspended[6]
Current transformer (CT)	POSITION	NO	YES	
Potential transformer (PT)	MISC	NO	YES	structure mounted or suspended[6]
Wave trap (WT)	POSITION	NO	YES	structure mounted or suspended[6]
Capacitors (CAP)	MISC	NO	YES	
Reactors (RTR)	BANK	YES	YES	power only
Bus (BS)	MISC	NO	YES	rigid only
Post insulator (PI)	POSITION	NO	YES	
Motor disconnect switch (MDS)	POSITION	NO	YES	
Jack bus (JB)	MISC	NO	NO	post insulators only

1 – [when possible] Picture, Manufacturer, Serial #, Station ID
2 – if yes, estimate capacity, take picture and draw a sketch
3 – if yes, estimate slack for each phase
4 – take photo or sketch if seems deficient.
5 - same Performance Function (see Chapter 3)
6 – a different Performance Function for each configuration (see Chapter 3)

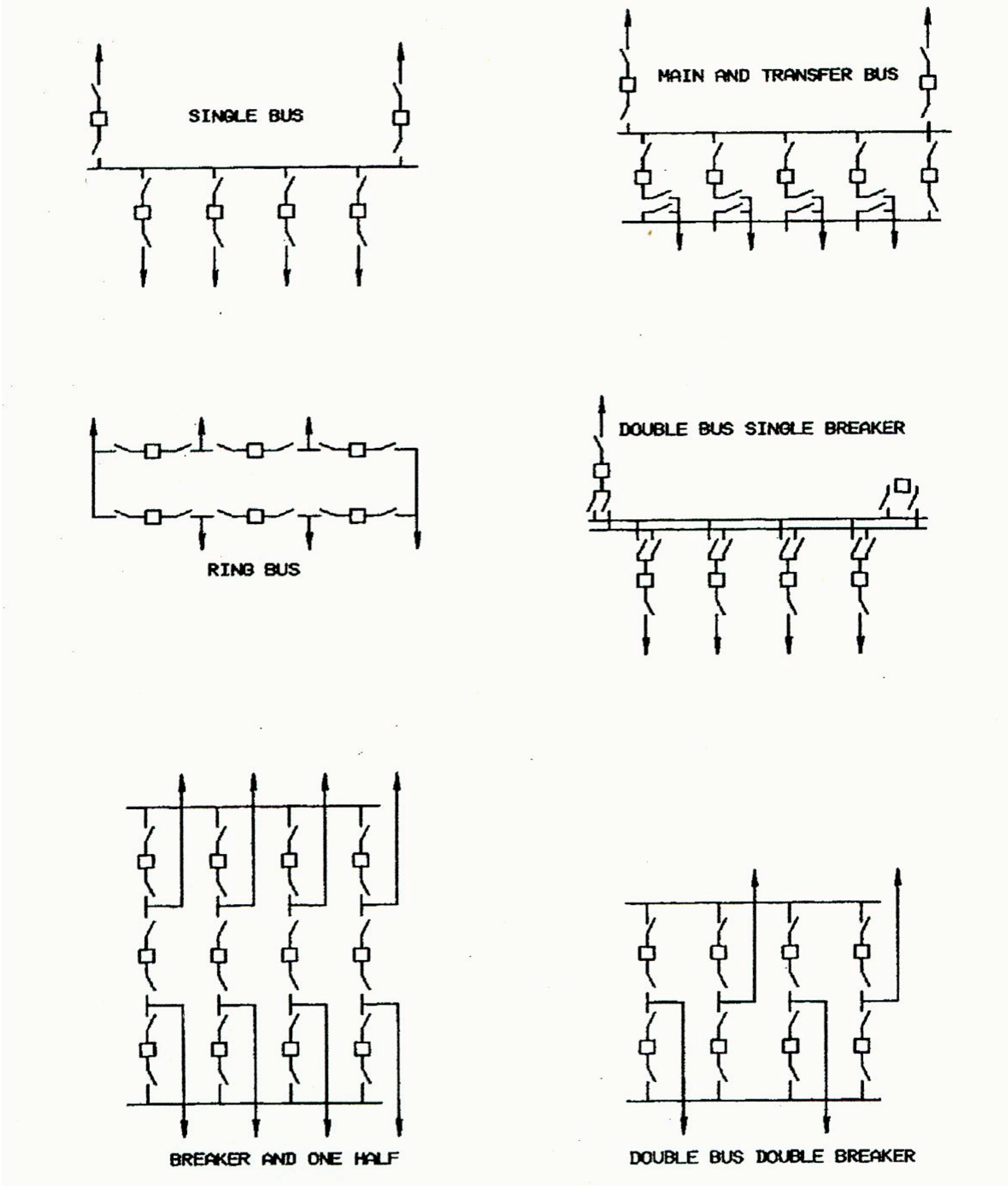

Figure 2.1 – Common One-line Schemes for Substations

_________________SUBSTATION (date______________________)

(Double Bus Double Breaker position)
#,POSITION,220,#_______;

P,CB_ *Station ID*,BS#___ ______,DS#__ ______,CB#___ ______,DS#__;

L,*line Destination*,CC#__ ____,WT#__ ____,DS#__ ______,DS#__ ______;

P,CB_ *Station ID*,DS#__ ______,CB#___ ______,DS#__ ______,BS#__;

(Breaker and a half Position)
#,POSITION,220,#________;

P,CB_*Station ID*,BS#___ ______,DS#__ ______,CB#___ ______,DS#__;

L, *line Destination*,CC#__ ____,WT#__ ____,DS#__ ______,DS#__ ______;

P,CB_ *Station ID*,DS#__ ______,CB#___ ______,DS#__;

L, *line Destination*,CC#__ ____,WT#__ ____,DS#__ ______,DS#__ ______;

P,CB_ *Station ID*,DS#__ ______,CB#___ ______,DS#__ ______,BS#__;

Figure 2.2 - Blank Template of a Double Bus Double Breaker Position and Breaker and a Half Position

Bank

Substation__________________ Date_____________________
Manuf______________________ Serial#______________________WT____________________
Bank____________#PH_____PH (if single)________Hi side________Lo side________
Anchorage Notes____
Radiator - EQ Bracing - None_______Vert______Horz______
Notes____
Surge Arrester notes____
High Side (X) – Trans Mount______Pole Mount______Frame Mount______Dist______
Low Site (X) - Trans Mount______Pole Mount______Frame Mount______Dist______
Tertiery SA ________________Jack Bus_____________________________________

Ratings
Transformer Anchorage _________Radiator Bracing 1-____2-____3-____4-____5-____
High Side Fail Path A-_____B-_____C-_____
Low Side Fail Path A-_____B-_____C-_____
High Side Slack w/SA A-_____B-_____C-_____w/Bush A-_____B-_____C-_____
Low Side Slack W/SA A-_____B-_____C-_____w/Bush A-_____B-_____C-_____
Tertiary Bush slack w/frame A-______B-______C-_____

Figure 2.3 - Blank Template of a Transformer Bank

MISC

Station ID, PT# __________
Line Destination, CP#__________
Line Destination, RE#__________

Figure 2.4 – Blank Template of Miscellaneous Equipment

3 Characteristics of the Database and defining the Contents of Each Data Field

Models of the earthquake hazard and the electrical system must be developed when conducting a System Earthquake Risk Assessment (SERA). It has been determined earlier during this PEER Task 413 that, for the purposes of this report, the high voltage (220kV and up) transmission substation equipment will be the equipment represented in the electrical system model. This chapter provides the characteristics of the database and defines the contents of each data field. The database consists of two files. The first file (Appendix 2) contains the data that reflects the author's best assessment of the performance (Performance Functions) of each component type during past earthquakes and the second file contains the data that describes each component in a hypothetical substation. An explanation of both data sets is given in this chapter. The example in Chapter 4 uses the two files presented in this chapter.

Performance Functions are used in a SERA analysis to provide the information needed for forecasting a component's performance during an earthquake. The type of function used is of a statistical nature and was first used because it allowed the easiest interpretation of experts' experience. The relationship is in the form of an asymmetric bell curve with a lower "g" cut-off.

In these performance functions, several failure modes can be considered. The performance functions are documented using two variables, the likelihood/history of failure and ground motion intensity.

Each failure mode is expressed as a continuous relationship of probability of failure vs. earthquake shaking intensity (peak ground acceleration in units of "g"). Estimates of failure outside of experience are extrapolated by means of "normal curve relationship" beyond experienced shaking intensity levels. Experience data on each component varies in terms of quantity and quality. Usually the more data there are (earthquakes, utilities, multiple locations, and shaking amplitudes and duration) the more confidence one can have with the resulting performance function. Table 3.1 shows the different means by which failure performance functions are determined along with Pros and Cons. No attempt has been made to rate the absolute or relative confidence of each component performance function or failure mode.

The determination of each performance function relationship curve is simple. First an acceleration is determined/judged for a 16% failure rate (16% fail and 84% don't fail). Next, the acceleration for a 50% failure rate (half fail and half don't fail) is determined/judged. Next, the acceleration for an 84% failure rate (84% fail and 16% don't fail) is determined/judged. Lastly, the acceleration for a zero failure rate is determined/judged. A bell shaped curve (not necessarily symmetrical) is used to connect the four acceleration amplitudes.

There are two types of failure modes, dependent and independent. For the transformer, each known failure mode is assumed independent of the others and has a set of parameters that are used to forecast the component's performance. For all other equipment, the failure modes are dependent. That is, at the first failure mode occurring, the balance of the failure modes is assumed to occur also (because of the ordering of the failure modes, the occurrence of a given failure mode automatically leads to the occurrence of the succeeding modes). For example, if the first failure mode does not occur, but the second does, then the second as well as the succeeding (3^{rd}, 4^{th}, etc) modes are assumed to occur. The performance function of transformers for certain failure modes are similar across all transformers and those are contained in the Performance Functions data file (e.g. porcelain failures). These failure modes are based on the transformer's type. Others parameters upon which failure modes are based and that are unique to each transformer are generally based on the transformer's installation details that are recorded in the substation component data file (e.g. anchorage and radiator details and strength). Performance function failure modes are listed in the order of severity, with the most severe failure modes listed first (e.g. (2 insulators fail, 1 insulator failures, contacts burn).

There is no provision for "common cause" types or causes of failure That is, at one extreme, the data may represent situations where all components failed at a certain location experiencing an acceleration level and at another location no components failed at the same acceleration level. In the current failure functions these two experiences would have been placed in the data and the performance averaged. Common causes that may arise that may bias a component to perform differently from one location to another are, installation practices, soil differences between substations, differences in earthquakes, and differences in equipment that aren't considered in this evaluation. There are cases in the data set where equipment types within an equipment class (e.g. disconnect switches and /or maker and mechanism or other significant differences are ambiguous. The implication of all this is that identical equipment may be represented differently and very different equipment may be represented as the same. It is the purpose of the current work by PEER on performance functions to sort out causes of failure that are not due to component vulnerabilities and include differences between components that are significant.

Table 3-2 provides a description of the data in the Component Performance Functions file. Table 3.2 provides an excerpt and accompanying explanation from the Component Performance Data Base file, Appendix 2. The line numbers on the left have been inserted to help in the referencing. Refer to the numbered lines when reading explanations of the file lines.

This report presents an inventory recording scheme that matches the actual physical installation. The substation single line diagram location and identification scheme is central to the data documentation. One beneficial byproduct of this approach is that it is intuitive to utility personnel that will be brought in to aid in the risk evaluation process. The data of a typical (large) bulk power switching station can be developed within a day or two on site.

The recording of a hypothetical "double breaker" and a "breaker and a half" position, transformer banks and Potential Transformer shown in Figure 3.1 is given with detailed explanation in Table 3.3. The line numbers on the left have been inserted to help in the referencing.

Table 3-1 – Methods to Determine Equipment Performance Functions

Method	**More detailed description**. *Component fragility is based on*:	Pros	Cons
Estimate	judgement with little or no experience data	1. much better than nothing 2. fills in data needs 3. inexpensive	1. low to high confidence, 2. may miss failure mode
Informed Estimates	Judgement with a lot of experience data, but data still has significant gaps	1. relatively accurate, 2. high user confidence, 3. mounting conditions are considered 4. relatively inexpensive	1. data doesn't exist for most equipment, 2. user may apply inappropriately 3. low math confidence
Statistics	statistics of components performances to many earthquakes of varying levels and installation details	1. accurate 2. high user and math confidence 3. mounting conditions considered 4. relatively inexpensive.	1. sufficient data doesn't exist for any equipment
Analysis	detailed analysis of component with various mountings to various motions	1. flexible, can evaluate to many loading and installation and mounting conditions 2. can be relatively inexpensive	1. model may be inaccurate or incomplete 2. low to high confidence
Shipping	loading that components undergo while being shipped	1. shipping loads may exceed earthquake loading 2. actual test of equipment 3. inexpensive 4. high confidence	1. some equipment may be disassembled and protection packaged for shipment, 2. there is little or no shaking data 3. problems duplicating installation and mounting conditions 4. loading not controllable 5. insufficient data for any one component to provide high math confidence, 6. component not taken to failure, underestimates fragility,

Table 3-1 – Methods to Determine Equipment Performance Functions (continued)

Qualification testing	qualification testing of component to IEEE 693 or other standard	1. lots of data exists (many components tested) and more being generated, 2. actual shaking of component and all failure modes considered. 3. high user confidence	1. inadequate low frequency content in table motion, 2. some equipment can't be tested, 3. problems duplicating installation and mounting conditions. 4. expensive, 5. insufficient data for any one component to provide high math confidence, 6. component not taken to failure, underestimates fragility,
Fragility testing	testing of one our more components to failure	1. component shaken to failure, 2. actual shaking of component, all failure modes considered, 3. high user confidence	1. inadequate low frequency content in motion, 2. some equipment can't be tested, 3. problems duplicating installation and mounting conditions, 4. very expensive 5. insufficient data for any one component to provide high math confidence 6. very little data exists

Table 3.2 – Explanation of Component Performance Function Data

```
 1   NEWEQUIP98.DAT 8/31/99
 2   DATA SET 1ST CARD - # TR, # LA, # CB, #CT, #DS, #CC, #PT, #PI, #WT, #PH
 3   COMPONENT FAILURE MODES
 4  1ST CARD - TYPE, #, DESCRIPTION, # FAIL MODES,SFREQ (HZ), STAU, SCREWT(HOURS)
 5   REMAINING - FAILURE MODE DESCRIPTION, $, MEAN G, - 1 SIG, + 1 SIG
 6          DURATION SUSEPTABILITY, LOWEST G/1000 FOR DAMAGE,
 7          FREQUENCY CPS, SSI VULNERABILITY, AND CREW TIME (DAYS)
 8     8  8 16 8  8  8  8  8  2  1
 9   TR  1 220kV TR 1 Phi                2    8  1.5   24
10       1 MAIN PORCELAIN BREAK            100  850  200  300   0  500  24         48
11       1 MAIN PORCLN GASKET LEAK   10  500  250  250   0  250  15         36
12   TR  2 220kV TR 3 Phi                6    8  1.5   24
13       3 MAIN PORCELAIN BREAKS     220  850  100  500   0  500  15         96
14       2 MAIN PORCELAIN BREAKS     160  850  200  400   0  350  15         72
15       1 MAIN PORCELAIN BREAK      100  850  300  300   0  200  15         48
16       3 MAIN PORCLN GASKET LEAKS  30  500  100  450   0  200  15         72
17       2 MAIN PORCLN GASKET LEAKS  20  500  200  350   0  200  15         54
18       1 MAIN PORCLN GASKET LEAK    10  500  300  250   0  200  15         36
19  CB  4 220KV GE ATB 4-6              3    4    1   72
20       2 PORCELAIN COLUMNS FAIL   250  350  150  150   2  100   5        80
21       1 PORCELAIN COLUMN FAILS   125  300  150  150   2  100   5        65
22       COLUMN BASE GASKET LEAK     30  250  150  100   2   75   5        30
```

<u>Explanation</u>

First 7 lines (1 – 7) are an explanation of the data to follow

line 1 - Data file name and last update

line 2 - list of components (explains that line 8 shows number of types for each component shown)

- TR - transformer; LA - lightening (surge) arrester
- CB - circuit breaker; CT - current transformer
- DS - disconnect switch; CA - Capacitors
- CC - coupling capacitor voltage transformer
- PT - potential transformer; PI - post insulator
- RE - reactor; WT - wave trap
- PH - pothead

line 4 - Explains what is shown in lines 9, 12, 19, …….

- TYPE – component type, see above
- # - sub component number
- Description – verbal picture of component
- # FAILURE MODES - number of failure modes
- SFREQ – frequency of the mode most responsible for conductor point movement (component swaying mode) For slack calculation.
- STAU – ratio of height of component to conductor lead to height to component center of gravity. For slack calculation.
- SCREWT(HOURS) – time for crew to repair damage due to insufficient slack in hours.

Line 5 - Explains what is shown in lines 10, 11, 13……..

- FAILURE MODE DESCRIPTION – verbal picture of failure

Table 3.2 – Explanation of Component Performance Function Data (con't)

$ - cost to repair failure
MEAN G – peak accel. in gals at which 50% of like components fail
- 1 SIG – gals off of mean at which 16% of like components fail
+ 1 SIG – gals plus mean at which 84% of like components fail

Line 6 continues from line 5
DURATION SUSEPTABILITY – total elastic = 1.0, plastic > 1.0
LOWEST G/1000 FOR DAMAGE – gal cutoff, below there is no damage

Line 7 continues from line 6
FREQUENCY CPS – major frequency of failure mode
SSI VULNERABILITY – factor showing additional susceptibility to damage due to soil structure interaction (not used)
Crew Time(hours) – crew time in hours for repairing failure mode damage

Line 8 number of components of each component type shown in line 2

line 9 through line 11 - performance data on first equipment

line 9 "TR" - equipment type
"1" - sub component number designation (type of transformer)
" 220KV TR 1 Phi" – equipment description (220kV" single phase transformer)
"2" - number of failure modes
"8" - component frequency when determining deflection in SAG calculations
"1.5" - participation factor. Ratio of conductor location motion to center of mass motion.
"24" - time (hours) for crew to repair interaction damage

line 10 through line 11 – (one line and set of parameters for each failure mode)
"1 MAIN PORCELAIN BREAK" - description of failure
"100" - cost to repair failure in thousands of dollars
"850" - mean failure rate in thousandths of g
"200" - minus one standard deviation in thousandths of g
"300" - plus one standard deviation in thousandths of g
"0" - duration susceptibility (0 = not susceptible)
"500" - lowest g for onset of failure mode in thousandths of g
"15" - predominant frequency for failure mode
"blank" - soil structure interaction vulnerability, not used
"24" - crew hours to repair

line 12 through line 18 – performance function for a three phase transformer.
Line 19 through line 22 – performance function for a live tank circuit breaker

New information can be added to the data file by simply editing the file making sure that when new equipment are added, line "8" is updated also.

Table 3.3 Explanation of Substation Component Parameter Data

```
0  @,Hypothetical Substation,3-16-02
1  #,POSITION,220,5;
2  P,5N-452N,BS1999,DS1333,CB01333,DS1;
3  L,Line 1-Bank 1A,DS1333,DS1333,CC1333;
4  P,5S-652S,DS1333,CB01333,DS1999,BS1;
5  #,POSITION,220,6;
6  P,6N-462N,BS1999,DS1333,CB01333,DS1;
7  L,Line 2-Sub B,DS1333,DS1333,CC1333,WT1SXX;
8  P,5T-562T,DS1333,CB01333,DS1;
9  L,Line 3-Sub A,DS1333,DS1333,SA1333;
10 P,4S-662S,DS1333,CB01333,DS1999,BS1;
11 #,BANK,1A,ID2,AN9,RAD4,RAD4;
12 A,DCSAH140,SABSH4;
13 B,DCSAH140,SABSH4;
14 C,DCSAH140,SABSH4;
15 #,MISC;
16 PTN1333,PTS1333;
```

Explanation

Line 0 - Generally, the "@" signals the substation whose data follows on the next line. The name of the Substation follows immediately after the "@". The substation name is followed by the date that the facility was investigated. Commas are used to separates all component information.

Lines 1 & 5 - After the line that starts with a "#,POSITION"…… information follows that describes the position components and station/system connectivity. The "#" signals that a new station function will be modeled. The switching positions models the circuit breakers and line taps. Also modeled are estimates of excess conductor between the components. After #POSITION is the position voltage in kilovolts and the position number.

Lines 2,4 & 6,8 &10 - If the line starts with a P, the second group of letters and numbers between commas describe the circuit breaker position, e.g. (see example line 2) 5N, or in dispatcher terminology 652 [6 – sub-position, 5 – position, 2 – sub-sub-position][1]. The balance of the line describes the components between the bus, BS and line tap and in the case of a breaker and a half position (Position 6), the line may also describe the components between two line taps. The components listed after a "P" are connected in series in the order of listing. The component ID number is the number in the third position, except in the case of a circuit breaker. In the case of the circuit breaker the ID number occupies the third and fourth position. The next three numbers represent slack (0 means no slack, 1 means 0+ to 2 inches of slack, 2 means 2+ inches to 4 inches of slack…….). If there is an "X" that means there was no component in that phase.

[1] Looking at Figure 3.1 the Position is made up of the lines and components connecting the Buses. The Positions are numbered 5 & 6. The sub-positions are the two or three clusters of disconnect switches and circuit breakers and are numbered 6, 5 & 4. 5 is often referred to as the “tie position” [sub-position]. The sub-sub-positions are the disconnect switches and circuit breakers themselves and are numbered 1, 2, &3 [the circuit breaker is always #2].

Table 3.3 Substation Component Parameter Data Gathering and Recording (con't)

Lines 3, 7 & 9 - If the line starts with an L, the line describes the line tap and its connections. The second group of letters and numbers describes the destination of the power transmission line. The balance of the line describes the components that are either suspended form the line tap or are connected to the line tap. For those components listed, the component ID (identification) number is in the third position. If the spaces 4 through 6 are "S" or "X" then the component is suspended on the line tap, when an "S" is present there is a component on that phase and when there is an "X" is present there is no component on that phase. If spaces 4 through 6 are numbers, these numbers represent slack. If there is an "X", that means there was no component in that phase.

Line 11 - #BANK - transformer bank The bank position models the transformer, surge arrester and its connectivity. After #BANK is the bank position number. ID precedes the number designation of the transformer. PH precedes the number of phases in the transformer. AN precedes the estimated mean strength of the anchorage in g units times 10. RAD precedes the estimated mean threshold of damage in g units times 10 of each radiator.

Lines 12, 13 & 14 describe each transformer's phase's tap connectivity. The first letter is the phase or an "S" for spare. Then might follow:

DCSAH123 - which stands for Down Comer Surge Arrester High (220KV on a 220KV TR), Type - 1, Sag (between down comer and surge arrester) - 2 and likelihood of collateral damage if SA fails - 3 (divided by 10 or 30%).
DCSAL123 - L stands for Low side (or 220KV on a 500KV TR) and the other numbers are as in above.
SABSH1 - Surge Arrester Bushing High side, sage between SA and bushing - 1.
SABSL1 - L stands for Low side
TERT1 - Tertiary bus slack is 1

Line 15 - #MISC - misc. positions. The MISC position models everything else.

Line 16 - describes the M:ISC equipment installations.
The first letters "PT" stands for Potential Transformer, N – north bus, 5 - ID number
6 - phase 1 slack (10 to 12 inches), 6 - phase 2 slack, and 6 - phase 3 slack

This data recording scheme is easily updated and can be field verified. The data identifies exactly where, in the substation, the data is representing and can be verified in the field by inspection and updated directly. This data set is also adaptable to the use of a PDA for data taking and verification.

4 Hypothetical Substation Example

This chapter presents an example of the current output of a SERA. Chapter 2 dealt with the details of data collected at a substation when conducting a SERA and Chapter 3 addressed the data sets that are necessary when documenting an electrical system and electrical component performance to past earthquakes. This Chapter integrates these two data sets into a SERA process and provides the reader with a sample output. It is important to distinguish between a SERA process, which is what the acronym suggests, i.e. System Earthquake Risk Assessment and SERA, the software. SERA the software conducts a SERA process. SERA, the software, was created and used at Southern California Edison and is free for the asking (from the author of this report), the potential user is cautioned however, in that considerable expertise is required in the use of SERA. SERA is not owned, managed, or licensed by Southern California Edison.

So far, in Chapters 2 and 3, we have addressed only aspects of an electrical system model. When a SERA is conducted, it is assumed that there is also a Hazard model and an electrical system to be evaluated. In this chapter, and for simplicity, the hazard will be assumed. The system will be a hypothetical electric system that contains issues of most real systems.

It was decided by PEER in conducting Project 413 that there existed a need to develop a hypothetical electrical system. Concerns about security and the current terrorist threats contributed to this. At the same time there existed a need for an electrical system to demonstrate technical tools for expressing system risk and for researchers to have a common system to compare results. The hypothetical layout was simplified geometrically by having a simple grid layout and a regular interconnection pattern. The system is large enough that motion attenuation is significant.

The first step in creating the hypothetical electrical system is to compile and document the attributes of equipment for all the substations of the hypothetical system. The transformer and Line capacities of the Hypothetical Electrical System are shown in Table 4.1. Table 4.2 shows the Hypothetical Systems substation geometrical layout. Figure 4.1 shows the hypothetical system single line diagram. Appendix 3 – System Physical Data is a data set documenting each substation and substation equipment. The attributes used to describe each equipment are shown in Chapter 2. The equipment performance functions were presented in Chapter 3 along with the documentation scheme used.

Transformer Capacities
All 500kV, 1000mva All 230kV in Substations A and B, 250mva All 230kV in Substations C and D, 150mva

Line Capacities
All 500kV, 4000 amp continuous All 230kV to Substations A and B, 1000 amp continuous All 230kV other, 500 amp continuous

Table 4.1 – Transformer and Line capacities in Hypothetical Electrical System

Substation	latitude	longitude
SA1/SAA1	36	122
SA4/SAA4	36	121
SB1	35.6	121.8
SB2	35.6	121.6
SB3	35.6	121.4
SB4	35.6	121.2
SC1	35.3	121.8
SC2	35.3	121.6
SC3	35.3	121.4
SC4	35.3	121.2
SD1	35	121.8
SD2	35	121.6
SD3	35	121.4
SD4	35	121.2

Table 4.2 – Substations Latitude and Longitude

Two system configurations were run. One system configuration, Conf-#1, consisted of all components having generous amounts of slack and only live tank circuit breakers were considered. Configuration #2, Conf-#2, had a live tank circuit breaker in Substation A1, 230kV yard at 412. In addition, Conf-#2 had insufficient slack in Substation A4 between Circuit breaker 412 and DS413. In both cases, substations A, B, C and D were shaken at .35g, .25g, .15g and .05g respectively. This represents a hypothetical earthquake north of the electrical system with the causative hypothetical fault running parallel to the system latitudes.

The results of a single run on SERA software to Conf-#1 are given in this report in Appendix 4 and 5. Appendix 4 shows the system function results of the single SERA run (see detailed explanation below) and Appendix 5 shows the component and system level results of the single SERA run (see detailed explanation below). The data of Appendix 4 and Appendix 5 are explained in Tables 4-3 and Table 4-4 respectively. The results in both Appendices are shown for each substation. Those that are intimately familiar with the system must make system operation interpretation. Load-flow analyses based on the results of the SERA runs could be made, however more information on system operation would be required. This information includes importance of various customers to utility and load and source profiles/potential at the time of earthquake and all times thereafter.

Both Appendices illustrate the disposition of the system after a single run on a single scenario. In order to use the evaluation with some confidence, as a minimum, multiple, at least 5 - 10, runs on the same earthquake should be conducted and reduced to a representative disposition. Conclusions about the system's performance to that one earthquake can be made. For example, approximate amounts of damage, to what types of components at what substations can be forecast for the earthquake used in the analyses. Also, after persons familiar with the operation of the system can review the system single-line with the open lines and transformation damage, assessments of system stability and of customer impact can be made. With this, the components that are needed for repair and the time to repair in order to return to desired levels of service can be estimated. This time to return to desired levels of service can be compared to previous set goals of system performance to see whether those goals will likely be achieved.

Mitigation programs can benefit from this information in that those components that consistently fail and block achievement of system goals can be identified and a rational for their replacement or a strategy for the mitigation of the effects of their failure can be developed. Where some specific component failures cannot be demonstrated but significant numbers of failures are shown to occur, estimates of repair times and spare part needs as well as vendor needs can be made. Generally hard position or bank strategies are necessary where there are certain lines or banks that must remain operational.

Table 4.3 Explanation of Appendix 4 data

```
1- TEST.OUT
2- ------------------------------------------------------------------------
3- *A1-AA1                   15.00 0.30 0.40  2.00
4-  POSITION 1, 220KV, IPOS =  3     7   0   0
5-  POSITION 2, 220KV, IPOS =  3     7   0  33
6- SUBSTATION B1 LOST TO A1-AA1
7-  POSITION 3, 220KV, IPOS =  3    33   0   0
8-  POSITION 4, 220KV, IPOS =  3     0   0   7
9-  POSITION 5, 220KV, IPOS =  5    40   7   1   0   0
10- BANK 1AA LOST TO A1-AA1
11-  POSITION 1, 500KV, IPOS =  5    49  14   1   7   0
12- BANK 1AA LOST TO A1-AA1
13- BANK 2AA LOST TO A1-AA1
14-  POSITION 2, 500KV, IPOS =  3    67  14  37
15- SOURCE 2 LOST TO A1-AA1
16-  POSITION 3, 500KV, IPOS =  5     9  14  46  21  18
17- SOURCE 1 LOST TO A1-AA1
18- SUBSTATION AA4 LOST TO A1-AA1

19- BANK 2AA  SA FAIL

20- BANK 2AA  SA FAIL

21- BANK 2AA  SA FAIL

22- ------------------------------------------------------------------------
23- *A4-AA4                   15.00 0.30 0.40  2.00
```

Each line has been given a number, e.g. lines 1 – 23 will be addressed.

Line 1 – name of data set
Line 2 & 22 – line of dashes to set off each substation evaluated
Line 3 & 23 – Following the "*" is the Substation name. The four numbers that follow provide; distance from fault in KM, mean peak acceleration in g, mean plus one standard deviation peak acceleration in g, and the site coefficient for site amplification information(in the current version

Table 4-1 Explanation of Appendix 4 data (continued)

of SERA, SCOEF is the UBC soil type designation).

Lines 4, 5, 7, & 8 - show that for 220kV switchyard positions 1, 2, 3 & 4 all have 3 sub-positions (switching or line tap) and the three following numbers show the crew hours needed for each sub-position to be returned to service. These positions are double breaker positions and consist of a disconnect, circuit breaker and another disconnect for sub-positions 1 and 3 and a line tap for sub-position 2.

Line 6 reports that substation B1 is lost to Substation A1-AA1. This can be deduced from reviewing Line 5 where sub-position 1 has damage that requires 7 crew hours and sub-position requires 33 crew hours to be returned to service. The line tap leading to Substation B1 from Substation A1-AA1 is therefore isolated. Restoration to an emergency level of service goal will likely take the route through sub-position 1 (if hours are the critical parameter).

Line 9 – shows that for 220kV switchyard position 5 has 5 sub-positions (switching or line tap) and the five following numbers show the crew hours needed for each sub-position to be returned to service. This position is a breaker and a half position and consists of a disconnect, circuit breaker, disconnect, for sub-positions 1, 3 and 5, a line tap for sub-positions 2 and 4.

Line 10 reports that Bank 1AA is lost to Substation A1-AA1. Note this would have been the result of damage to sub-position 2 or sub-positions 1 and 3 [or higher].

Lines 11 & 16 show that for 500kV switchyard positions 1 and 3 both have 5 sub-positions (switching or line tap) and the five following numbers show the crew hours needed for each sub-position to be returned to service. These positions are breaker and a half positions and consist of a disconnect switch, circuit breaker, disconnect switch, for sub-positions 1, 3 and 5, a line tap for sub-positions 2 and 4.

Lines 12, 13, 17 & 18 report losses to 500kV switchyard positions 1 and 3 and provide information that can be used to estimate the number of crew hours needed for their return to service.

Line 14 - show that 500kV switchyard positions 2 has 3 sub-positions (switching or line tap) and the three following numbers show the crew hours needed for each sub-position to be returned to service. This position is a double breaker position and consist of a disconnect switch, circuit breaker and another disconnect switch for sub-positions 1 and 3 and a line tap for sub-position 2.

Line 15 – reports that Source 2 is lost to Substation A1-AA1. Note this would have been the result of damage to sub-position 2 or sub-positions 1 and 3

Lines 19, 20 & 21 report that Surge arrester failure occurred on each of three phase transformer.

Table 4.4 Explanation of Appendix 5 Data

```
1- SITE                  D(KM)  M G  M+1  SCOEF
2- ---------------------------------------------------------------------------
3- *A1-AA1                     15.00 0.30 0.40  2.00  GEFF MN % RNUM
4- *F 1N-412 DS 1  CONTACTS BURN/A 220 1 PH- 2  315 400 0.20 0.18  4
5-  TEST FOR POSITION 1 FUNCTION AT 220kV --> , IPOS =  3     7   0   0
6- *F 2N-422 DS 1  CONTACTS BURN/A 220 2 PH- 3  315 400 0.20 0.10  6
7- *F 2S-622 DS 1  2 PORCELAIN COL 220 2 PH- 2  315 650 0.05 0.03  5
8-  TEST FOR POSITION 2 FUNCTION AT 220kV --> , IPOS =  3     7   0  33
9- SUBSTATION B1 LOST TO A1-AA1
10- *F 3N-432 DS 1  2 PORCELAIN COL 220 3 PH- 1  315 650 0.05 0.04  4
11-  TEST FOR POSITION 3 FUNCTION AT 220kV --> , IPOS =  3    33   0   0
12- *F 4S-642 DS 1  CONTACTS BURN/A 220 4 PH- 1  315 400 0.20 0.13  3
13-  TEST FOR POSITION 4 FUNCTION AT 220kV --> , IPOS =  3     0   0   7
14- *F 5N-452 DS 1  2 PORCELAIN COL 220 5 PH- 2  315 650 0.05 0.03  4
15- *F 5N-452 DS 1  CONTACTS BURN/A 220 5 PH- 3  315 400 0.20 0.17  6
16- *F BANK 1AA SA 1  FAILURE OF PORC 220 5 PH- 2  315 550 0.12 0.11  4
17-  TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5    40   7   1   0
0
18- BANK 1AA LOST TO A1-AA1
19- *F 1N-711 DS 6  2 PORCELAIN COL 500 1 PH- 1  315 550 0.06 0.02  4
20- *F BANK 1AA SA 5  FAILURE OF PORC 500 1 PH- 1  315 250 0.60 0.05  4
21- *F BANK 1AA SA 5  FAILURE OF PORC 500 1 PH- 2  315 250 0.60 0.29  4
22- *F BANK 2AA SA 5  FAILURE OF PORC 500 1 PH- 3  315 250 0.60 0.46  4
23-    1S-913 DS1333/DS/BS PH  1 3 allow   7.8 actual   7.9  4
24-    1S-913 DS1333/DS/BS PH  2 3 allow   7.8 actual   7.9  4
25-    1S-913 DS1333/DS/BS PH  3 3 allow   7.8 actual   7.9  4
26-  TEST FOR POSITION 1 FUNCTION AT 500kV --> , IPOS =  5    49  14   1   7
0
27- BANK 1AA LOST TO A1-AA1
28- BANK 2AA LOST TO A1-AA1
29- *F 2N-722 DS 6  CONTACTS BURN/A 500 2 PH- 2  315 350 0.41 0.32  4
30- *F 2N-722 DS 6  2 PORCELAIN COL 500 2 PH- 1  315 550 0.06 0.03  6
31- *F 2N-722 DS 6  CONTACTS BURN/A 500 2 PH- 3  315 350 0.41 0.32  6
32- *F SOURCE 2 SA 5  FAILURE OF PORC 500 2 PH- 1  315 250 0.60 0.28  5
33- *F SOURCE 2 SA 5  FAILURE OF PORC 500 2 PH- 2  315 250 0.60 0.25  5
34- *F 2S-922 DS 6  1 PORCELAIN COL 500 2 PH- 3  315 450 0.18 0.13  5
35-  TEST FOR POSITION 2 FUNCTION AT 500kV --> , IPOS =  3    67  14  37
36- SOURCE 2 LOST TO A1-AA1
37- *F 3N-732 DS 6  CONTACTS BURN/A 500 3 PH- 3  315 350 0.41 0.26  6
38- *F SOURCE 1 SA 5  FAILURE OF PORC 500 3 PH- 1  315 250 0.60 0.22  5
39- *F SOURCE 1 SA 5  FAILURE OF PORC 500 3 PH- 2  315 250 0.60 0.37  5
40- *F 3T-832 DS 6  1 PORCELAIN COL 500 3 PH- 3  315 450 0.18 0.13  3
41- *F 3T-832 DS 6  CONTACTS BURN/A 500 3 PH- 1  315 350 0.41 0.40  5
42- *F SUBSTATION AA4 SA 5  FAILURE OF PORC 500 3 PH- 1  315 250 0.60 0.21  5
43- *F SUBSTATION AA4 SA 5  FAILURE OF PORC 500 3 PH- 2  315 250 0.60 0.56  5
44- *F SUBSTATION AA4 SA 5  FAILURE OF PORC 500 3 PH- 3  315 250 0.60 0.46  5
45- *F 3S-932 DS 6  CONTACTS BURN/A 500 3 PH- 2  315 350 0.41 0.32  3
46- *F 3S-932 DS 6  CONTACTS BURN/A 500 3 PH- 1  315 350 0.41 0.21  5
47-  TEST FOR POSITION 3 FUNCTION AT 500kV --> , IPOS =  5     9  14  46  21
18
48- SOURCE 1 LOST TO A1-AA1
49- SUBSTATION AA4 LOST TO A1-AA1
50- *F BANK A  SA FAIL 500 2AA 315 250 0.603 0.131
51- *F BANK B  SA FAIL 500 2AA 315 250 0.603 0.509
52- *F BANK C  SA FAIL 500 2AA 315 250 0.603 0.306
53- *F PT 5 N COLUMN FAILURE  PH- 1  315 300 0.53 0.44
```

Table 4-2 Explanation of Appendix 5 Data (continued)

```
54- *F PT 5 N COLUMN FAILURE  PH- 3  315 300 0.53 0.00
55- *F PT 5 S COLUMN FAILURE  PH- 2  315 300 0.53 0.31
56- *F PT 5 S COLUMN FAILURE  PH- 3  315 300 0.53 0.18
57- ---------------------------------------------------------------------
58- *A4-AA4                    15.00 0.30 0.40  2.00  GEFF MN % RNUM
```

Each line has been given a number, e.g. lines 1 – 58 will be addressed.

Line 1 – Header
Line 2 and 57, see Line 2 & 22 above
Line 3 – see line 3 & 23 above
Line 4 – "*F" means that a failure has occurred
"1N-412" – sub-position identification
"DS 1" – type of component and component performance function number
"CONTACT BURN/A" – partial description of failure
"220" – volts of component in kilo volts
"1" – Position number
"PH – 2" – phase number
"315" – effective acceleration loading the component
"400" – mean failure acceleration
".20" – Monte Carlo switch, number between 0 and 1 and below which failure occurs
".18" – random number determined for this component and this failure mode
"4" – detailed location of component in sub-position
Lines 5, 8, 11, 13,17, 26, 35 & 47 – This is where the position is tested for functionality with respect to line continuity of current substation with other substations and switchrack to power transformers. See Line 6 explanation of Appendix 4 data output. The numbers, 3 for double breaker and 5 for breaker and a half positions represent crew hours needed to regain functionality of that sub-position.
Lines 6, 7, 10, 12, 14 – 16, 19 – 22, 29 – 34, & 37 – 46 see Line 4 explanation.
Line 9 – See explanation for Appendix 4 Line 6.
Line 18 – See explanation for Appendix 4 Line 10.
Lines 23 – 25 – this is the slack exceedance report, even though the conclusion is that there is no damage. If there had been damage an "*S" would have appeared at the start of the line.
"1S-913" sub-position where slack issue is located
"DS1333/DS/BS" – components involved and amount of reported slack. The inadequate slack is between a disconnect switch and a bus.
"PH 1" – identifies the phase as 1
"3" – field recorded sag
"allow 7.8" is the amount of slack available
"actual 7.9" is the amount of slack demand, in this case the demand is greater than the allowed, but the algorithm determined that there was no damage.
"4" – detailed location of component in sub-position

5 Summary and Conclusions

An electric utility system is made up of electrical components connected in a way that reflects needs at multiple previous times, and installed in a way that reflects electrical function during normal times over structural function during an earthquake. To conduct a SERA requires multiple disciplines; those of structural, seismological, earthquake and electrical professions. Even when the proper professional talent is assembled, the problem is complex, due to the complex nature of the system and lack of data. A means of assembling all the necessary ingredients of the SERA process is necessary. This report has attempted to bring order and standardization to the documentation of the electrical components that make up an electrical utility model for the SERA. This was done by suggesting what electrical system data is needed, how to collect it and document it. In addition, this report presents a tabulation of key electrical equipment performance during past earthquakes.

The SERA approach presented in this report is far more advanced than what is normally conducted by an electric utility. This SERA approach should only be conducted by a utility that knows it has a significant natural hazard risk and complexities in its system including size, spatial layout etc. such that some systematic means of integrating all this information is needed to aid in developing risk mitigation strategies.

This approach for a SERA is relatively new in implementation even though the Monte Carlo simulation approach has been in use for decades for other types of problems. More work needs to be done to improve component performance functions and to determine and describe the function of the utility system given a detailed understanding of system component damage. In addition, more work needs to be done in the integration process and problem set-up so that classical probabilistic SERAs which include probabilistic measures of results can be conducted.

Appendix 1: Conductor Slack Templates

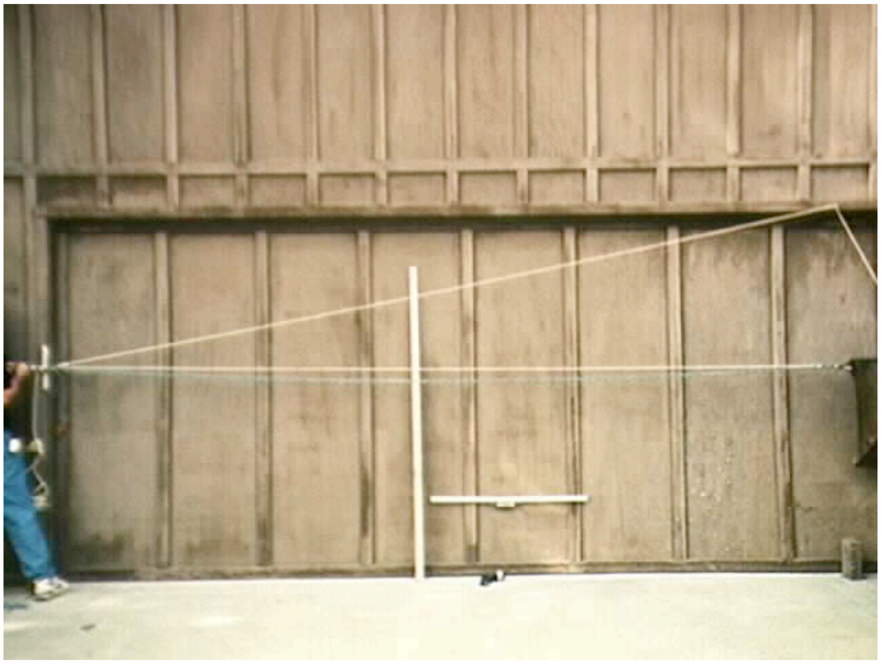

Figure A1.1 – Horizontal = 15, Vertical = 0, Slack = 0

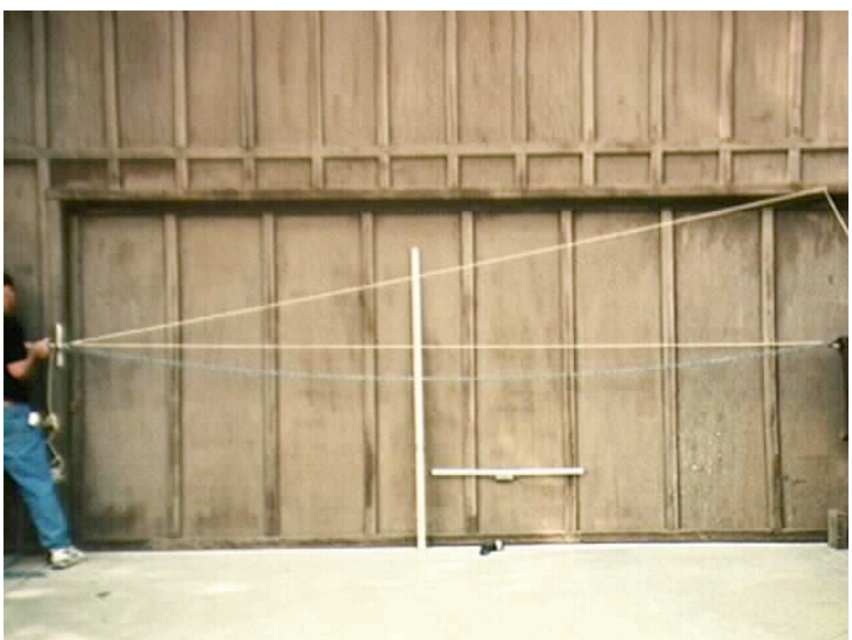

Figure A1.2 – Horizontal – 15, Vertical – 0, slack – 1 inch

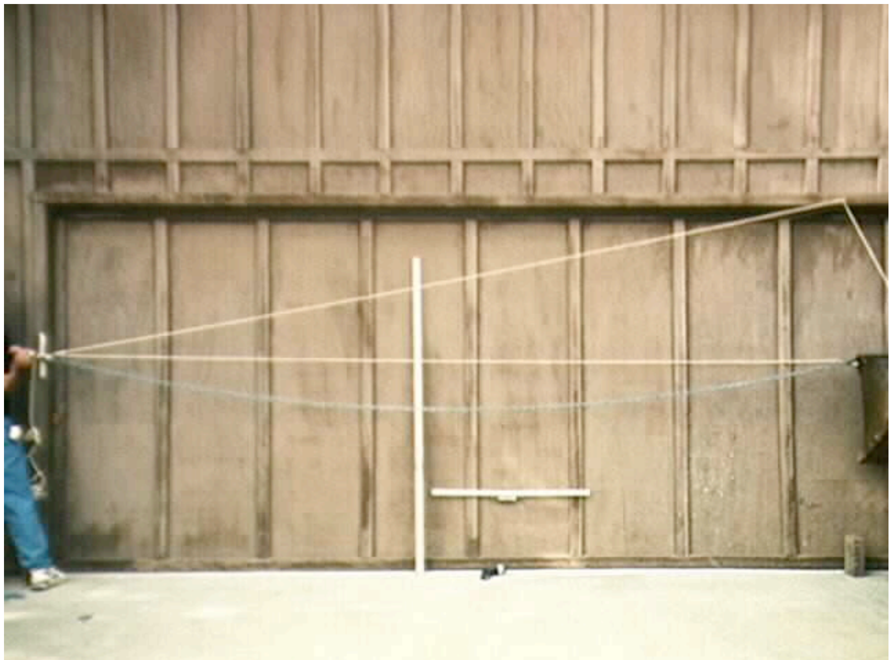

Figure A1.3 – Horizontal – 15, Vertical – 0, slack – 2 inches

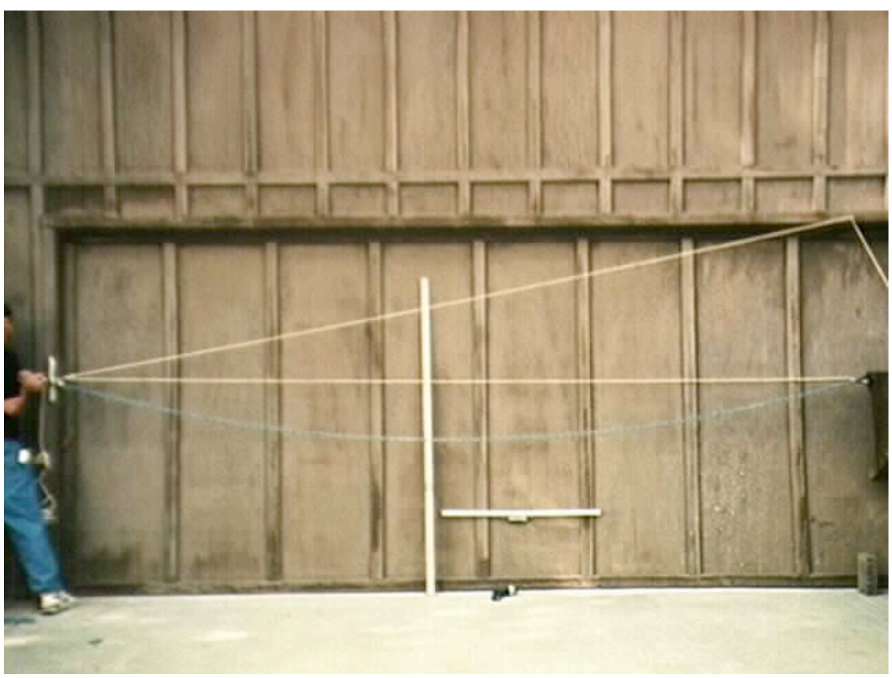

Figure A1.4 – Horizontal – 15, Vertical – 0, slack – 3 inches

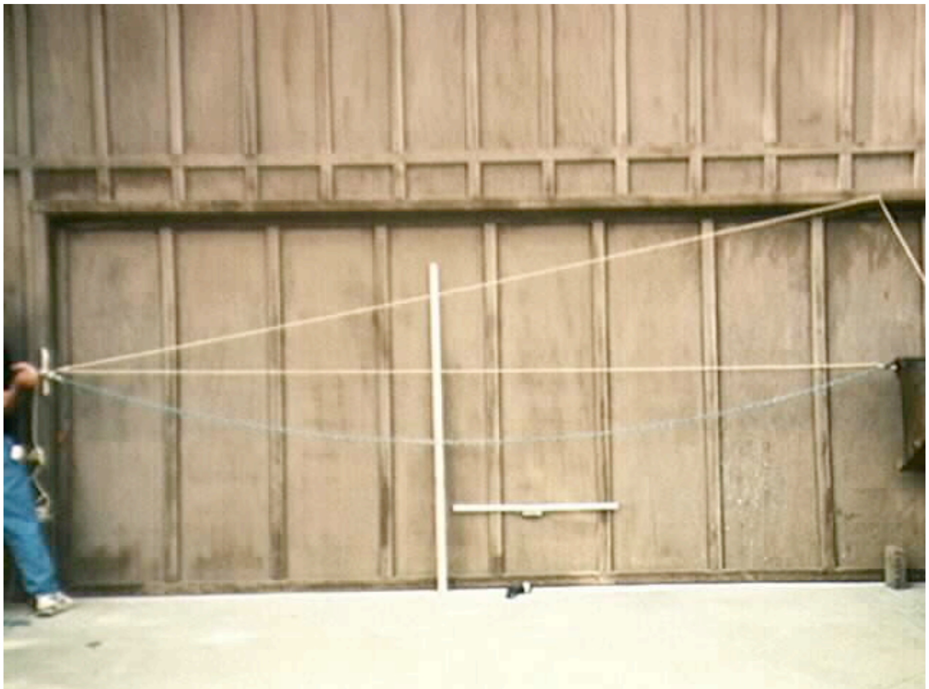

Figure A1.5 – Horizontal – 15, Vertical – 0, slack – 4 inches

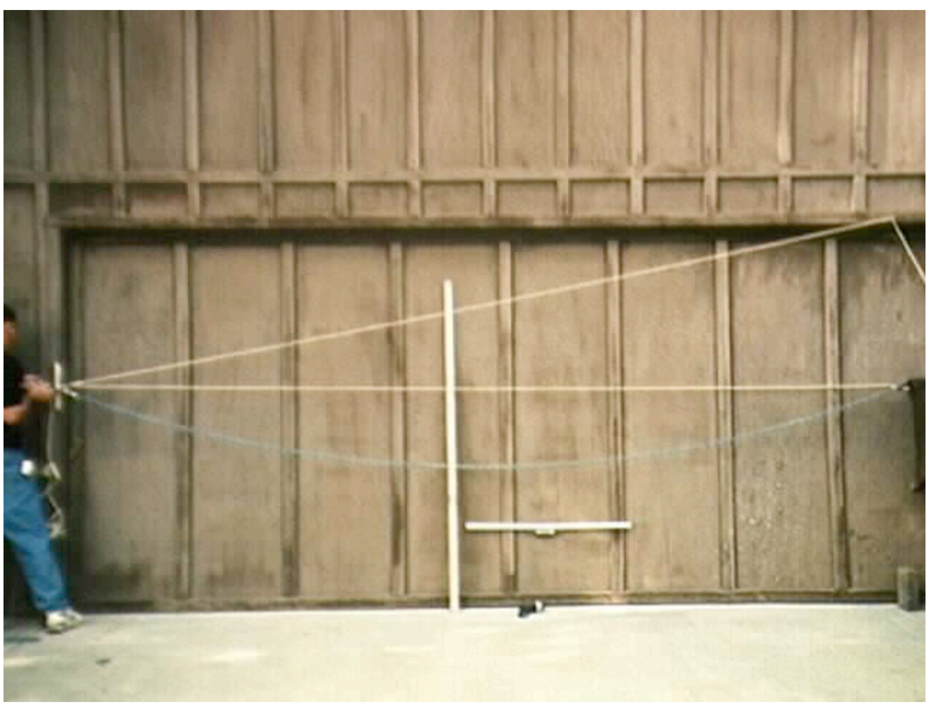

Figure A1.6 – Horizontal – 15, Vertical – 0, slack – 5 inches

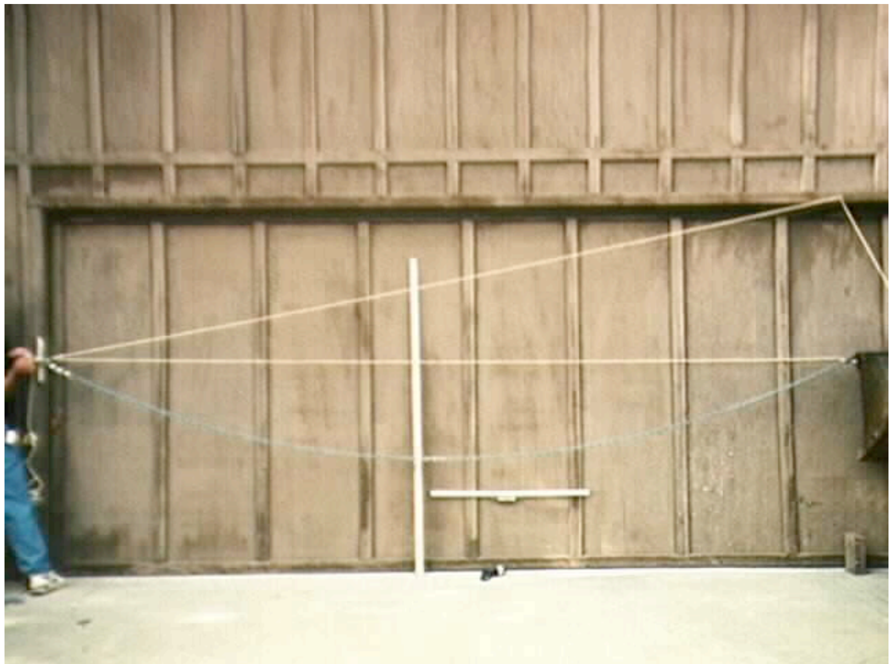

Figure A1.7 – Horizontal – 15, Vertical – 0, slack – 6 inches

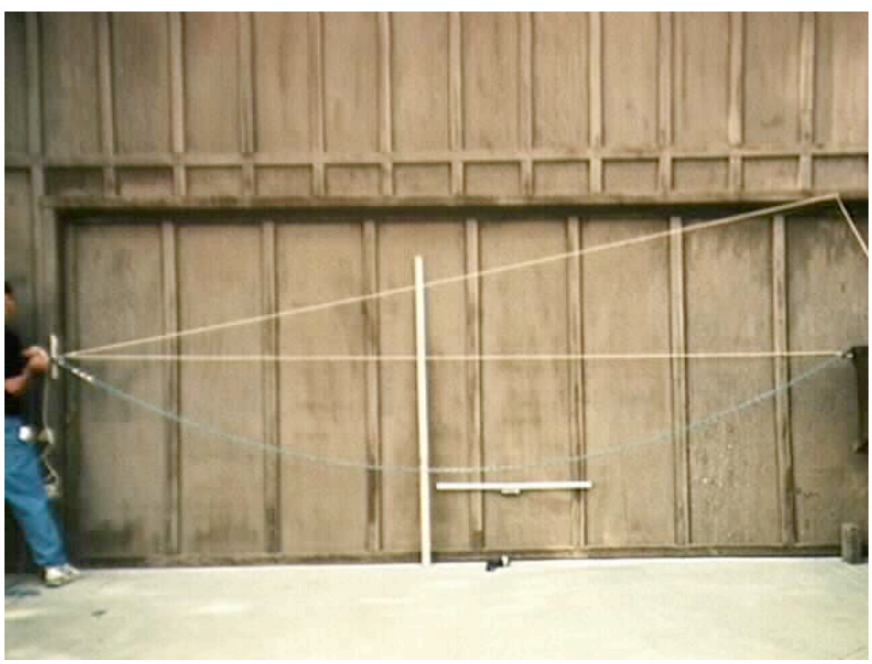

Figure A1.8 – Horizontal – 15, Vertical – 0, slack – 9 inches

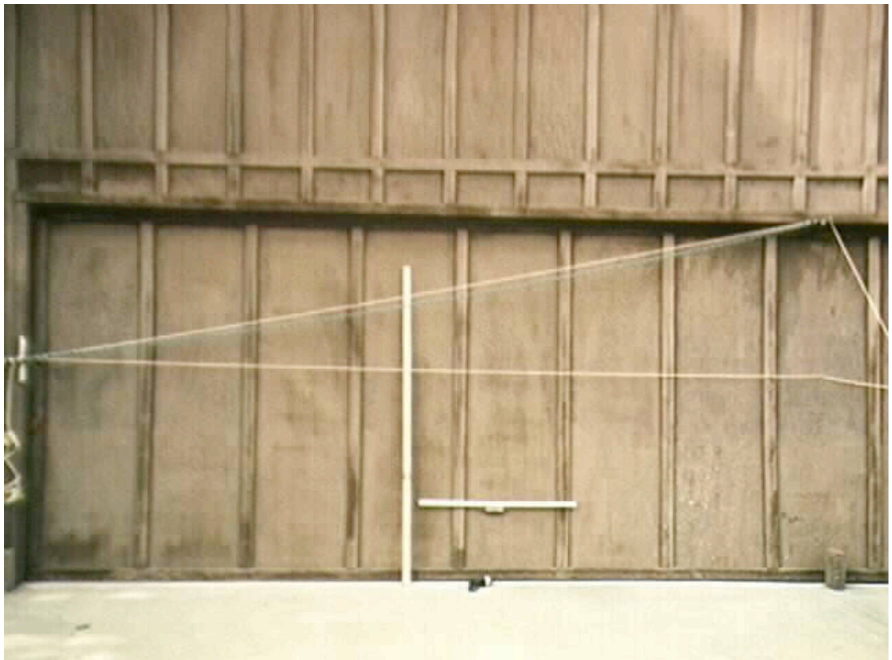

Figure A1.9 – Horizontal – ~15, Vertical – 3, slack – 0 inches

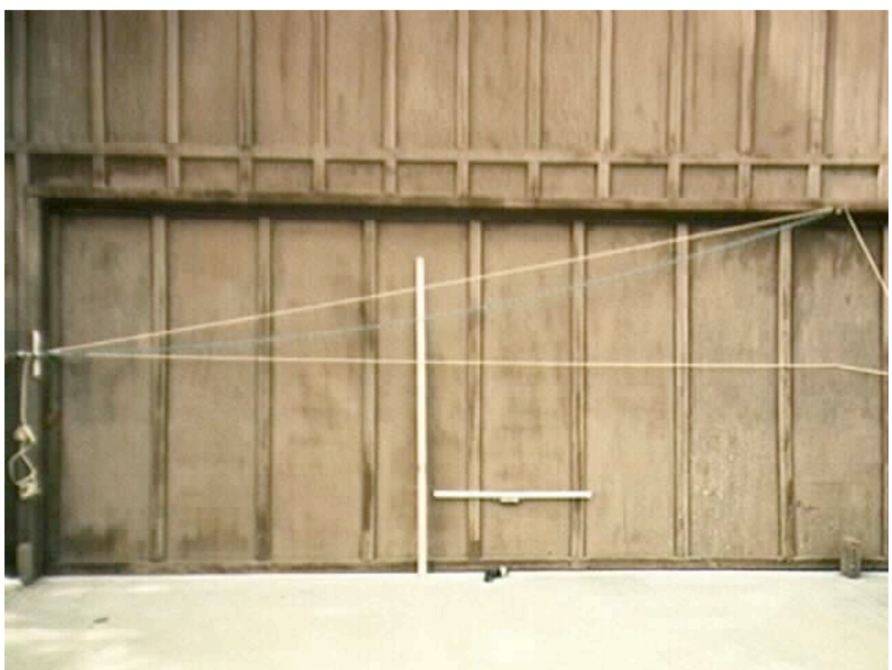

Figure A1.10 – Horizontal – ~15, Vertical – 3, slack – 1 inches

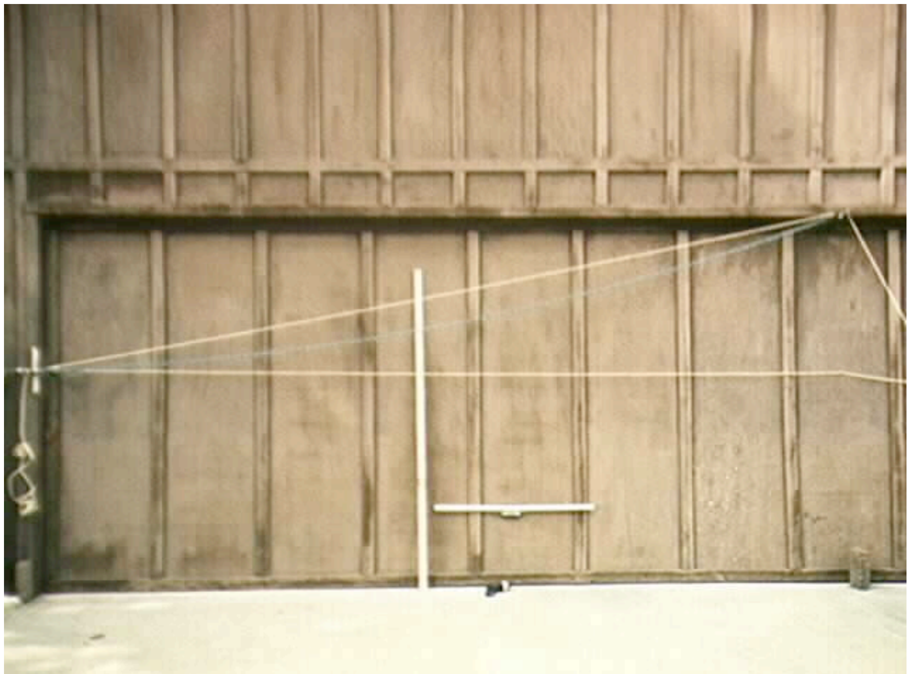

Figure A1.11 – Horizontal – ~15, Vertical – 3, slack – 2 inches

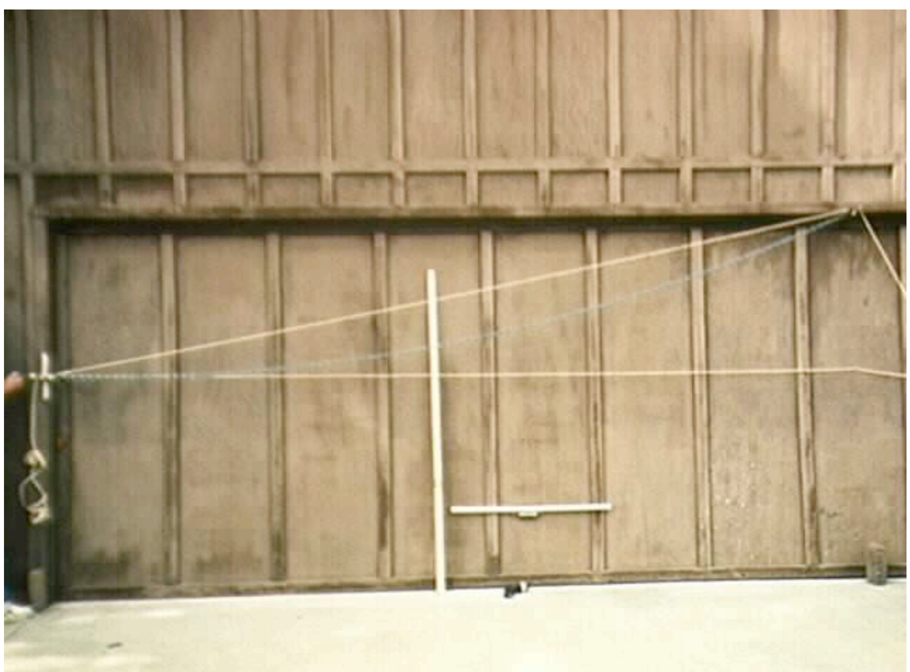

Figure A1.12 – Horizontal – ~15, Vertical – 3, slack – 3 inches

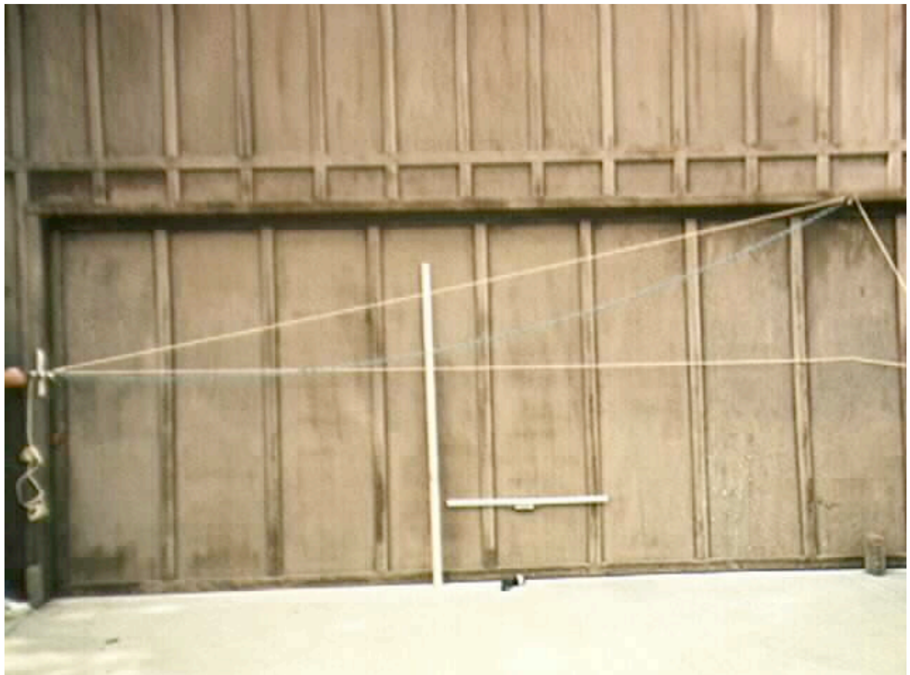

Figure A1.13 – Horizontal – ~15, Vertical – 3, slack – 4 inches

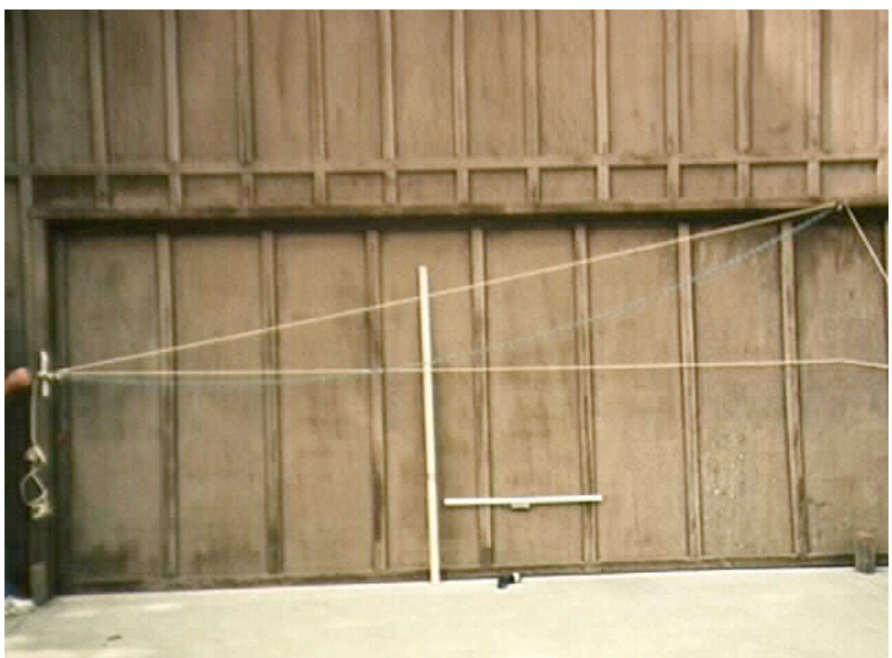

Figure A1.14 – Horizontal – ~15, Vertical – 3, slack – 5 inches

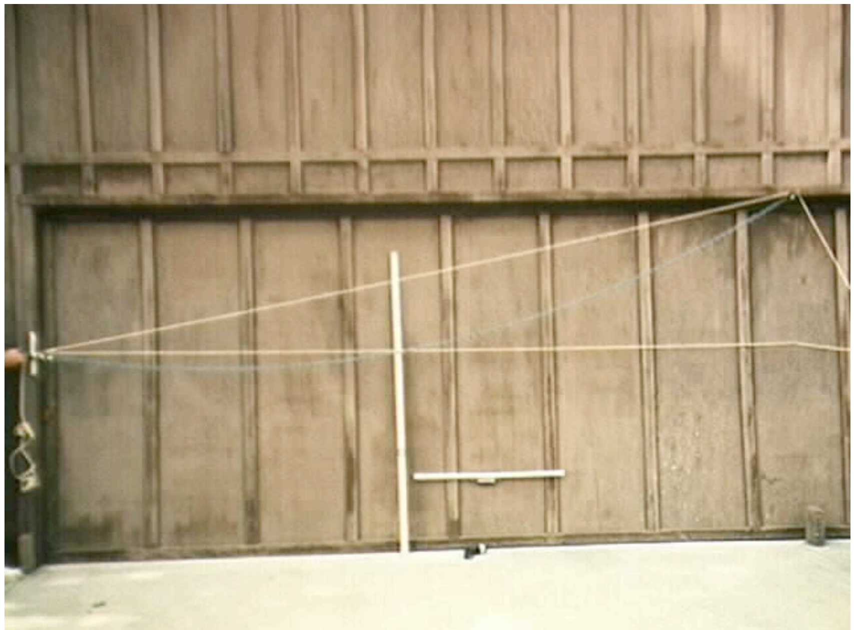

Figure A1.15 – Horizontal – ~15, Vertical – 3, slack – 6 inches

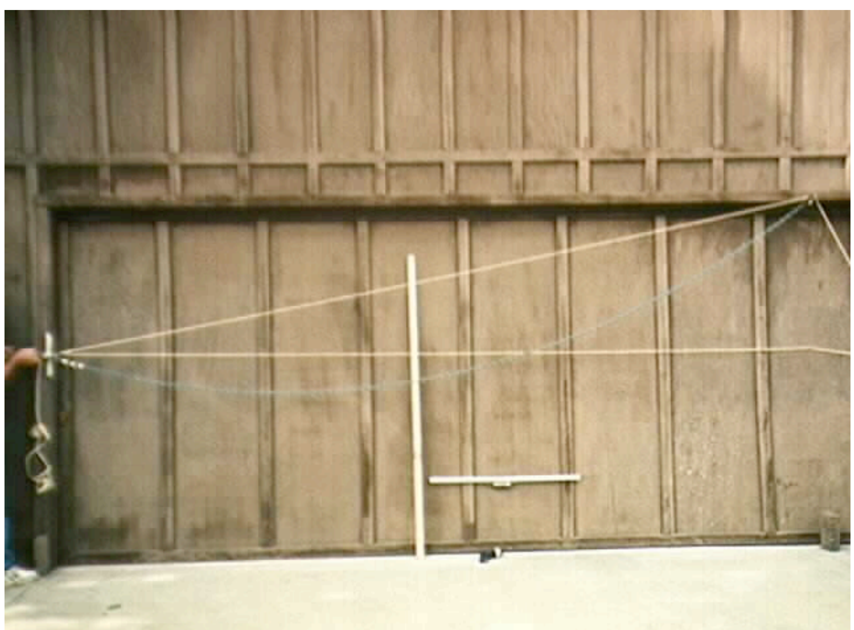

Figure A1.16 – Horizontal – ~15, Vertical – 3, slack – 9 inches

Appendix 2: Performance Function Database

```
EQUIP99.DAT 8/31/99
DATA SET 1ST CARD - # TR, # LA, # CB, #CT, #DS, #CC, #PT, #PI, #WT, #PH
COMPONENT
1ST CARD - TYPE, #, DESCRIPTION, # FAIL MODES,SFREQ (HZ),STAU,SCREWT(HOURS)
REMAINING - FAILURE MODE DESCRIPTION, $, MEAN G, - 1 SIG, + 1 SIG
           DURATION SUSEPTABILITY, LOWEST G/1000 FOR DAMAGE,
           FREQUENCY CPS, SSI VULNERABILITY, AND CREW TIME (HOURS)
  8  8 16 8  8  8  8  8  2  1
TR  1 220KV TR 1 Phi                  2    8  1.5   24
      1 MAIN BUSHING BREAK       100  850  200  300   0  500  15          48
      1 MAIN BUSHING GASKET LEAK  10  500  250  250   0  250  15          36
TR  2 220KV TR 3 Phi                  6    8  1.5   24
      3 MAIN BUSHING BREAKS      220  850  100  500   0  500  15          96
      2 MAIN BUSHING BREAKS      160  850  200  400   0  350  15          72
      1 MAIN BUSHING BREAK       100  850  300  300   0  200  15          48
      3 MAIN BUSHING GASKET LEAKS 30  500  100  450   0  200  15          72
      2 MAIN BUSHING GASKET LEAKS 20  500  200  350   0  200  15          54
      1 MAIN BUSHING GASKET LEAK  10  500  300  250   0  200  15          36
TR  3 220KV TR 1 Phi COMP BUSH        2    8  1.5   24
      1 MAIN BUSHING   BREAK     100 1200  200  300   0  500  15          48
      1 MAIN BUSHING GASKET LEAK  10 1000  250  250   0  250  15          36
TR  4 220KV TR 3 Phi COMP BUSH        6    8  1.5   24
      3 MAIN BUSHING BREAKS      220 1250  100  500   0  500  15          96
      2 MAIN BUSHING BREAKS      160 1250  200  400   0  350  15          72
      1 MAIN BUSHING BREAK       100 1250  300  300   0  200  15          48
      3 MAIN BUSHING GASKET LEAKS 30 1000  100  450   0  200  15          72
      2 MAIN BUSHING GASKET LEAKS 20 1000  200  350   0  200  15          54
      1 MAIN BUSHING GASKET LEAK  10 1000  300  250   0  200  15          36
TR  5 500KV TR 1 Phi                  2    8  1.5   24
      MAIN BUSHING BREAK         260  750  250  300   0  100  15          72
      MAIN BUSHING GASKET LEAK    10  450  250  250   0  100  15          54
TR  6 500KV TR 3 Phi                  6    8  1.5   24
      3 MAIN BUSHING BREAKS      780  650  100  500   0  100  15         144
      2 MAIN BUSHING BREAKS      530  650  200  400   0  100  15         108
      1 MAIN BUSHING BREAK       280  650  300  300   0  100  15          72
      3 MAIN BUSHING GASKET LEAKS 30  400  100  450   0  100  15         108
      2 MAIN BUSHING GASKET LEAKS 20  400  200  350   0  100  15          81
      1 MAIN BUSHING GASKET LEAK  10  400  250  250   0  100  15          54
TR  7 500KV TR 1 Phi COMP BUSH        2    8  1.5   24
      MAIN BUSHING BREAK         260 1250  250  300   0  100  15          72
      MAIN BUSHING GASKET LEAK    10 1000  250  250   0  100  15          54
TR  8 500KV TR 3 Phi COMP BUSH        6    8  1.5   24
      3 MAIN BUSHING BREAKS      780 1250  100  500   0  100  15         144
      2 MAIN BUSHING BREAKS      530 1250  200  400   0  100  15         108
      1 MAIN BUSHING BREAK       280 1250  300  300   0  100  15          72
      3 MAIN BUSHING GASKET LEAKS 30 1000  100  450   0  100  15         108
      2 MAIN BUSHING GASKET LEAKS 20 1000  200  350   0  100  15          81
      1 MAIN BUSHING GASKET LEAK  10 1000  250  250   0  100  15          54
SA  1 220KV SA LOW DESIGN             1    4  1.3    4
      FAILURE OF PORCLN COLUMN    20  550  200  200  .5  150   7           6
SA  2 220KV SA MED DESIGN             1    4  1.3    4
      FAILURE OF PORCLN COLUMN    20  650  200  200  .5  150   7           6
SA  3 220KV SA HIGH SEISMIC           1    4  1.3    4
```

		FAILURE OF PORCLN COLUMN	20	750	200	200	.5	150	7	6
SA	4	220KV SA COMP COL		1	4	1.3	4			
		FAILURE OF COMP COLUMN	20	1250	200	200	.5	150	7	6
SA	5	500KV SA LOW DESIGN		1	3	1.3	4			
		FAILURE OF PORCLN COLUMN	30	250	100	250	1	100	5	6
SA	6	500KV SA MED DESIGN		1	3	1.3	4			
		FAILURE OF PORCLN COLUMN	30	350	100	250	1	100	5	6
SA	7	500KV SA HIGH SEISMIC		1	3	1.3	4			
		FAILURE OF PORCLN COLUMN	30	450	100	250	1	100	5	6
SA	8	500KV SA COMP COL		1	3	1.3	4			
		FAILURE OF COMP COLUMN	30	1100	100	250	1	100	5	6
CB	1	220KV DEAD TANK SF-6		2	10	2	24			
		2 PORCELAIN COLUMNS FAIL	250	1200	200	400	0	400	20	40
		1 PORCELAIN COLUMN FAILS	125	1200	200	300	0	400	20	32
CB	2	220KV DEAD TANK OIL		2	10	2	24			
		2 PORCELAIN COLUMNS FAIL	250	1200	200	400	0	400	20	40
		1 PORCELAIN COLUMN FAILS	125	1200	200	300	0	400	20	32
CB	3	220KV SIEMANS LIVE TANK		2	3	1	72			
		2 PORCELAIN COLUMNS FAIL	250	700	200	400	.5	400	5	60
		1 PORCELAIN COLUMN FAILS	100	650	200	200	.5	400	5	40
CB	4	220KV GE ATB 4-6		3	4	1	72			
		2 PORCELAIN COLUMNS FAIL	250	350	150	150	2	100	5	80
		1 PORCELAIN COLUMN FAILS	125	300	150	150	2	100	5	65
		COLUMN BASE GASKET LEAK	30	250	150	100	2	75	5	30
CB	5	220KV GE ATB 7		2	3	1	72			
		2 PORCELAIN COLUMNS FAIL	250	200	75	200	2	40	5	80
		1 PORCELAIN COLUMN FAILS	125	150	75	150	2	40	5	65
CB	6	220KV GE ATB230 W/GKEEPER		3	3	1	72			
		2 PORCELAIN COLUMNS FAIL	250	450	150	150	1	200	5	80
		1 PORCELAIN COLUMN FAILS	125	400	150	150	1	200	5	65
		LOSE GAS PRESSURE	30	300	100	150	1	100	5	30
CB	7	220KV CIRCUIT SWITCHER		2	5	1.5	36			
		2 PORCELAIN COLUMNS FAIL	150	850	200	400	.5	400	5	60
		1 PORCELAIN COLUMN FAILS	100	800	250	250	.5	400	5	40
CB	8	230 BOGUS		2	10	2	24			
		2 PORCELAIN COLUMNS FAIL	65	1200	200	400	.5	400	7	1
		1 PORCELAIN COLUMN FAILS	65	1200	200	300	.5	400	7	1
CB	9	230 BOGUS		2	10	2	24			
		2 PORCELAIN COLUMNS FAIL	65	1200	200	400	.5	400	7	1
		1 PORCELAIN COLUMN FAILS	65	1200	200	300	.5	400	7	1
CB	10	500 kV DEAD TANK SF-6		2	8	2	36			
		2 PORCELAIN COLUMNS FAIL	85	1000	200	400	.5	400	7	60
		1 PORCELAIN COLUMN FAILS	85	1000	200	300	.5	400	7	40
CB	11	500KV MODERN SEISMIC PUFFER		2	3	1	72			
		2 PORCELAIN COLUMNS FAIL	40	1200	200	400	.5	400	7	60
		1 PORCELAIN COLUMN FAILS	40	1200	200	300	.5	400	7	45
CB	12	500KV WES PUFFER		2	3	1	72			
		2 PORCELAIN COLUMNS FAIL	40	1200	200	400	.5	400	7	90
		1 PORCELAIN COLUMN FAILS	40	1200	200	300	.5	400	7	65
CB	13	500KV GE ATB		3	2	1	72			
		2 PORCELAIN COLUMNS FAIL	500	350	200	200	1.5	100	5	90
		1 PORCELAIN COLUMN FAILS	350	300	150	200	1.5	100	5	65
		COLUMN BASE GASKET LEAK	250	250	100	100	1.5	100	5	30
CB	14	500KV COGENAL OLDER		1	1	1	72			
		COLLAPSE OF ALL COLUMNS	500	300	100	250	2	150	2	100
CB	15	500KV OTHER NON SEISMIC LT		3	2	1	72			
		2 PORCELAIN COLUMNS FAIL	500	350	200	200	1.5	100	5	90
		1 PORCELAIN COLUMN FAILS	350	300	150	200	1.5	100	5	65

		COLUMN BASE GASKET LEAK	250	250	100	100	1.5	100	5	30
CB	16	500KV CIRCUIT SWITCHER		2	5	1.5	36			
		2 PORCELAIN COLUMNS FAIL	350	750	200	400	.5	400	5	70
		1 PORCELAIN COLUMN FAILS	200	700	250	250	.5	400	5	50
CT	1	220KV CT LOW SEISMIC		1	5	1.5	36			
		PORCELAIN COLUMN FAILURE	20	400	200	400	1	250	7	24
CT	2	220KV CT MED SEISMIC		1	5	1.5	36			
		PORCELAIN COLUMN FAILURE	20	500	200	400	1	250	7	24
CT	3	220KV CT HIGH SEISMIC		1	5	1.5	36			
		PORCELAIN COLUMN FAILURE	20	600	200	400	1	250	7	24
CT	4	220KV CT COMPOSITE		1	5	1.5	36			
		COMPOSITE COLUMN FAILURE	20	1500	200	400	1	250	7	24
CT	5	500KV CT LOW SEISMIC		1	3.5	1.5	36			
		PORCELAIN COLUMN FAILURE	30	300	100	300	1	250	5	32
CT	6	500KV CT MED SEISMIC		1	3.5	1.5	36			
		PORCELAIN COLUMN FAILURE	30	450	150	200	1	250	5	32
CT	7	500KV CT HIGH SEISMIC		1	3.5	1.5	36			
		PORCELAIN COLUMN FAILURE	30	500	150	200	1	250	5	32
CT	8	500KV CT COMPOSITE		1	3.5	1.5	36			
		COMPOSITE COLUMN FAILURE	30	1500	200	200	1	250	5	32
DS	1	220KV DS LOW DESIGN		3	4	1.3	24			
		2 PORCELAIN COLUMNS FAIL	8	650	200	450	.5	300	7	32
		1 PORCELAIN COLUMN FAILS	5	600	200	450	.5	300	7	24
		CONTACTS BURN/ADJUSTMENT	2	400	100	300	.5	200	7	6
DS	2	220KV DS MEDIUM DESIGN		3	4	1.3	24			
		2 PORCELAIN COLUMNS FAIL	8	750	200	450	.5	300	7	32
		1 PORCELAIN COLUMN FAILS	5	700	200	450	.5	300	7	24
		CONTACTS BURN/ADJUSTMENT	2	500	50	300	.5	200	7	6
DS	3	220KV DS HIGH DESIGN		3	4	1.3	24			
		2 PORCELAIN COLUMNS FAIL	8	850	200	450	.5	300	7	32
		1 PORCELAIN COLUMN FAILS	5	800	200	450	.5	300	7	24
		CONTACTS BURN/ADJUSTMENT	2	700	50	300	.5	200	7	6
DS	4	220KV DS COMPOSITE DESIGN		3	4	1.3	24			
		2 COMPOSITE COLUMNS FAIL	8	1500	200	450	.5	300	7	32
		1 COMPOSITE COLUMN FAILS	5	1300	200	450	.5	300	7	24
		CONTACTS BURN/ADJUSTMENT	2	600	50	300	.5	200	7	6
DS	5	500KV DS LOW SEISMIC		3	3	1.3	36			
		2 PORCELAIN COLUMNS FAIL	10	450	200	300	1.5	100	5	48
		1 PORCELAIN COLUMN FAILS	8	350	150	300	1.5	100	5	36
		CONTACTS BURN/ADJUSTMENT	5	300	150	300	1.5	50	5	8
DS	6	500KV DS MED SEISMIC		3	3	1.3	36			
		2 PORCELAIN COLUMNS FAIL	10	550	150	300	1.5	100	5	48
		1 PORCELAIN COLUMN FAILS	8	450	150	300	1.5	100	5	36
		CONTACTS BURN/ADJUSTMENT	5	350	150	300	1.5	50	5	8
DS	7	500KV DS HIGH SEISMIC		3	3	1.3	36			
		2 PORCELAIN COLUMNS FAIL	10	650	150	300	1.5	100	5	48
		1 PORCELAIN COLUMN FAILS	8	550	150	300	1.5	100	5	36
		CONTACTS BURN/ADJUSTMENT	5	450	150	300	1.5	50	5	8
DS	8	500KV DS COMPOSITE		3	3	1.3	36			
		2 COMPOSITE COLUMNS FAIL	10	1500	150	300	1.5	100	5	48
		1 COMPOSITE COLUMN FAILS	8	1300	150	300	1.5	100	5	36
		CONTACTS BURN/ADJUSTMENT	5	550	150	300	1.5	50	5	8
CC	1	220KV CCVT LOW SEISMIC		1	4	1	24			
		COLUMN FAILURE	10	350	150	200	.5	250	4	12
CC	2	220KV CCVT MED SEISMIC		1	4	1	24			
		COLUMN FAILURE	10	450	150	200	.5	250	4	12
CC	3	220KV CCVT HIGH SEISMIC		1	4	1	24			
		COLUMN FAILURE	10	550	150	200	.5	250	4	12

CC	4	220KV CCVT COM SEISMIC		1	4	1	24			
		COLUMN FAILURE	10	1500	150	200	.5	250	4	12
CC	5	500KV CCVT LOW SEISMIC		1	4	1	24			
		COLUMN FAILURE	10	250	150	200	.5	250	4	16
CC	6	500KV CCVT MED SEISMIC		1	4	1	24			
		COLUMN FAILURE	10	350	150	200	.5	250	4	16
CC	7	500KV CCVT HIGH SEISMIC		1	4	1	24			
		COLUMN FAILURE	10	500	150	200	.5	250	4	16
CC	8	500KV CCVT COM SEISMIC		1	4	1	24			
		COLUMN FAILURE	10	1500	150	200	.5	250	4	16
PT	1	220KV PTRANS LOW SEIS		1	4	1	24			
		COLUMN FAILURE	15	400	150	200	.5	250	4	12
PT	2	220KV PTRANS MED SEIS		1	4	1	24			
		COLUMN FAILURE	15	500	150	200	.5	250	4	12
PT	3	220KV PTRANS HIGH SEIS		1	4	1	24			
		COLUMN FAILURE	15	600	150	200	.5	250	4	12
PT	4	220KV PTRANS COM SEIS		1	4	1	24			
		COLUMN FAILURE	15	1500	150	200	.5	250	4	12
PT	5	500KV PTRANS LOW SEIS		1	4	1	24			
		COLUMN FAILURE	15	300	150	200	.5	250	4	16
PT	6	500KV PTRANS MED SEIS		1	4	1	24			
		COLUMN FAILURE	15	400	150	200	.5	250	4	16
PT	7	500KV PTRANS HIGH SEIS		1	4	1	24			
		COLUMN FAILURE	15	500	150	200	.5	250	4	16
PT	8	500KV PTRANS COM SEIS		1	4	1	24			
		COLUMN FAILURE	15	1500	150	200	.5	250	4	16
PI	1	220KV POST INSUL LOW		1	6	1.4	12			
		COLUMN FAILURE	2	600	150	250	.5	250	4	4
PI	2	220KV POST INSUL MED		1	6	1.4	12			
		COLUMN FAILURE	2	700	150	250	.5	250	4	4
PI	3	220KV POST INSUL HIGH		1	6	1.4	12			
		COLUMN FAILURE	2	800	150	250	.5	250	4	4
PI	4	220KV POST INSUL COM		1	6	1.4	12			
		COLUMN FAILURE	2	1500	150	250	.5	250	4	4
PI	5	500KV POST INSUL LOW		1	6	1.4	12			
		COLUMN FAILURE	2	500	150	250	.5	250	4	6
PI	6	500KV POST INSUL MED		1	6	1.4	12			
		COLUMN FAILURE	2	600	150	250	.5	250	4	6
PI	7	500KV POST INSUL HIGH		1	6	1.4	12			
		COLUMN FAILURE	2	700	150	250	.5	250	4	6
PI	8	500KV POST INSUL COM		1	6	1.4	12			
		COLUMN FAILURE	2	1500	150	250	.5	250	4	6
BS	1	220KV BUS FOR SAG CALC		1	2	1.0	12			
		NO FAILURE	1	1000	1000	1000	1.	1000	4	6
BS	2	500KV BUS FOR SAG CALC		1	2	1.0	12			
		NO FAILURE	1	1000	1000	1000	1.	1000	4	8
PH	1	220KV POT HEAD		1	2	1.0	12			
		PORCELAIN FAILURE	1	1000	1000	1000	1.	1000	4	32
PH	2	500KV POT HEAD		1	2	1.0	12			
		PORCELAIN FAILURE	1	1000	1000	1000	1.	1000	4	48
WT	1	WAVE TRAP FOR SAG CALC		1	1	1.0	12			
		ATTACHMENT FAILURE	1	1000	100	500	1.	500	4	24

Appendix 3: Hypothetical Network Database

```
@,SUBSTATION A1/AA1,01/19/03
#,POSITION,220,1;
P,1N-412,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B1,DS31333,DS11333;
P,1S-612,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,2;
P,2N-422,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B1,DS31333,DS11333;
P,2S-622,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B2,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B2,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-452,BS1999,DS11333,CB01333,DS31;
L,BANK 1AA,DS31333;
#,POSITION,220,5;
L,BANK 2AA,DS11333;
P,5S-652,DS11333,CB01333,DS31999,BS1;
#,POSITION,500,1;
P,1N-711,BS6999,DS16;
L,BANK 1AA,DS16333,SA5333;
#,POSITION,500,1;
L,BANK 2AA,DS36333,SA5333;
P,1S-913,DS31333,BS6;
#,POSITION,500,2;
P,2N-722,BS6999,DS16333,CB10333,DS36;
L,SOURCE 2,DS36333,DS16333;
P,2S-922,DS16333,CB10333,DS36999,BS6;
#,POSITION,500,3;
P,3N-732,BS6999,DS16333,CB10333,DS36;
L,SOURCE 1,DS36333,DS16333;
P,3T-832,DS16333,CB10333,DS36;
L,SUBSTATION AA4,DS36333,DS16333;
P,3S-932,DS16333,CB10333,DS36999,BS6;
#,POSITION,220,1;
P,1N-412,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION B1,DS31333,DS11333;
P,1S-612,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,2;
P,2N-422,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B1,DS31333,DS11333;
P,2S-622,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B2,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,BANK,1AA,ID5,1,AN9,RAD9,RAD9;
A,DCSAH555,DCSAL155,SABSH5,SABSL5,TERT9;
#,BANK,1AA,ID5,1,AN9,RAD9,RAD9;
B,DCSAH555,DCSAL155,SABSH5,SABSL5,TERT9;
```

```
#,BANK,1AA,ID5,1,AN9,RAD9,RAD9;
C,DCSAH555,DCSAL155,SABSH5,SABSL5,TERT9;
#,BANK,2AA,ID5,1,AN9,RAD9,RAD9;
A,DCSAH555,DCSAL155,SABSH5,SABSL5,TERT9;
#,BANK,2AA,ID5,1,AN9,RAD9,RAD9;
B,DCSAH555,DCSAL155,SABSH5,SABSL5,TERT9;
#,BANK,2AA,ID5,1,AN9,RAD9,RAD9;
C,DCSAH555,DCSAL155,SABSH5,SABSL5,TERT9;
#,MISC;
P,PTN5666,PTS5666,PTN1555,PTS1555;


@,SUBSTATION A4/AA4,01/21/03
#,POSITION,500,2;
P,2N-722,BS6999,DS16333,CB10333,DS36;
L,SUBSTATION AA1,DS36333,DS16333;
P,2S-922,DS16333,CB10333,DS36999,BS6;
#,POSITION,500,3;
P,3N-732,BS6999,DS16333,CB10333,DS36;
L,SOURCE 3,DS36333,DS16333;
P,3S-932,DS16333,CB10333,DS36999,BS6;
#,POSITION,500,4;
P,4N-742,BS6999,DS16333,CB10333,DS36;
L,SOURCE 4,DS36333,DS16333;
P,4S-942,DS16333,CB10333,DS36999,BS6;
#,POSITION,500,5;
P,5N-751,BS6999,DS16;
L,BANK 1AA,DS16333,SA5333;
#,POSITION,500,5;
L,BANK 2AA,DS36333,SA5333;
P,5S-953,DS36333,BS6;
#,POSITION,220,1;
P,1N-412,BS1999,DS11333,CB01333,DS31;
L,BANK 1AA,DS31333;
#,POSITION,220,1;
L,BANK 2AA,DS1333;
P,1S-612,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,2;
P,2N-422,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B3,DS31333,DS11333;
P,2S-622,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B4,DS31333,DS11333;
P,3T-532,DS11333,CB01333,DS31;
L,SUBSTATION B3,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B4,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-452,BS1999,DS11333,CB01333,DS31;
L,BANK 1A,DS31333;
#,POSITION,220,5;
L,BANK 2A,DS11333;
P,5S-652,DS11333,CB01333,DS31999,BS1;
#,BANK,2AA,ID5,1,AN9,RAD9,RAD9;
```

```
A,DCSAH555,DCSAL155,SABSH5,SABSL5,TERT9;
#,BANK,2AA,ID5,1,AN9,RAD9,RAD9;
B,DCSAH555,DCSAL155,SABSH5,SABSL5,TERT9;
#,BANK,2AA,ID5,1,AN9,RAD9,RAD9;
C,DCSAH555,DCSAL155,SABSH5,SABSL5,TERT9;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,BANK,2A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN5666,PTS5666,PTN1555,PTS1555;


@,SUBSTATION B1,01/23/03
#,POSITION,220,1;
P,1N-412,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION A1,DS31333,DS11333;
P,1S-612,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,2;
P,2N-422,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION A1,DS31333,DS11333;
P,2S-622,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION C1,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B2,DS31333,DS11333;
P,4T-542,DS11333,CB01333,DS31;
L,SUBSTATION C2,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-452,BS1999,DS11333,CB01333,DS31;
L,BANK 1A,DS31333;
#,POSITION,220,5;
L,BANK 2A,DS11333;
P,5S-652,DS11333,CB01333,DS31999,BS1;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,BANK,2A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN1555,PTS1555;


@,SUBSTATION B2,01/23/03
#,POSITION,220,1;
P,1N-412,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION A1,DS31333,DS11333;
```

```
P,1T-512,DS11333,CB01333,DS31;
L,SUBSTATION B1,DS31333,DS11333;
P,1S-612,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,2;
P,2N-422,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION A1,DS31333,DS11333;
P,2S-622,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION C2,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION B3,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-452,BS1999,DS11333,CB01333,DS31;
L,BANK 1A,DS31333;
#,POSITION,220,5;
L,BANK 2A,DS11333;
P,5S-652,DS11333,CB01333,DS31999,BS1;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,BANK,2A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN1555,PTS1555;

@,SUBSTATION B3,01/23/03
#,POSITION,220,2;
P,2N-422,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION B2,DS31333,DS11333;
P,2S-622,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION A4,DS31333,DS11333;
P,3T-532,DS11333,CB01333,DS31;
L,SUBSTATION C3,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION A4,DS31333,DS11333;
P,4T-542,DS11333,CB01333,DS31;
L,SUBSTATION B4,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-452,BS1999,DS11333,CB01333,DS31;
L,BANK 1A,DS31333;
#,POSITION,220,5;
L,BANK 2A,DS11333;
P,5S-652,DS11333,CB01333,DS31999,BS1;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
```

```
C,DCSAH140,SABSH4;
#,BANK,2A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN1555,PTS1555;

@,SUBSTATION B4,01/23/03
#,POSITION,220,2;
P,2N-422,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION B3,DS31333,DS11333;
P,2S-622,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION A4,DS31333,DS11333;
P,3T-532,DS11333,CB01333,DS31;
L,SUBSTATION C3,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION A4,DS31333,DS11333;
P,4T-542,DS11333,CB01333,DS31;
L,SUBSTATION C4,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-452,BS1999,DS11333,CB01333,DS31;
L,BANK 1A,DS31333;
#,POSITION,220,5;
L,BANK 2A,DS11333;
P,5S-652,DS11333,CB01333,DS31999,BS1;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,BANK,2A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN1555,PTS1555;

@,SUBSTATION C1,01/23/03
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION D1,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B1,DS31333,DS11333;
P,4T-542,DS11333,CB01333,DS31;
L,SUBSTATION C2,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-451,BS1999,DS31;
L,BANK 1A,DS31333;
#,POSITION,220,5;
L,BANK 2A,DS11333;
```

```
P,5S-653,DS31999,BS1;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,BANK,2A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN1555,PTS1555;

@,SUBSTATION C2,01/23/03
#,POSITION,220,2;
P,2N-422,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION C1,DS31333,DS11333;
P,2T-522,DS11333,CB01333,DS31;
L,SUBSTATION D1,DS31333,DS11333;
P,2S-622,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B1,DS31333,DS11333;
P,3T-532,DS11333,CB01333,DS31;
L,SUBSTATION D2,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B2,DS31333,DS11333;
P,4T-542,DS11333,CB01333,DS31;
L,SUBSTATION C3,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-452,BS1999,DS11333,CB01333,DS31;
L,BANK 1A,DS31333;
#,POSITION,220,5;
L,BANK 2A,DS11333;
P,5S-652,DS11333,CB01333,DS31999,BS1;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,BANK,2A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN1555,PTS1555;

@,SUBSTATION C3,01/23/03
#,POSITION,220,2;
P,2N-422,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION C2,DS31333,DS11333;
P,2S-622,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B3,DS31333,DS11333;
P,3T-532,DS11333,CB01333,DS31;
L,SUBSTATION D3,DS31333,DS11333;
```

```
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B4,DS31333,DS11333;
P,4T-542,DS11333,CB01333,DS31;
L,SUBSTATION C4,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-452,BS1999,DS11333,CB01333,DS31;
L,BANK 1A,DS31333;
#,POSITION,220,5;
L,BANK 2A,DS11333;
P,5S-652,DS11333,CB01333,DS31999,BS1;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,BANK,2A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN1555,PTS1555;

@,SUBSTATION C4,01/23/03
#,POSITION,220,2;
P,2N-422,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION C3,DS31333,DS11333;
P,2S-622,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION B4,DS31333,DS11333;
P,3T-532,DS11333,CB01333,DS31;
L,SUBSTATION D4,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-451,BS1999,DS31;
L,BANK 1A,DS31333;
#,POSITION,220,5;
L,BANK 2A,DS11333;
P,5S-653,DS31999,BS1;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,BANK,2A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN1555,PTS1555;

@,SUBSTATION D1,01/23/03
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION C2,DS31333,DS11333;
P,3T-532,DS11333,CB01333,DS31;
L,SUBSTATION C1,DS31333,DS11333;
```

```
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION D2,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-451,BS1999,DS31;
L,BANK 1A,DS31333;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,BANK,2A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN1555,PTS1555;

@,SUBSTATION D2,01/23/03
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION D1,DS31333,DS11333;
P,3T-532,DS11333,CB01333,DS31;
L,SUBSTATION D3,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION C2,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-451,BS1999,DS31;
L,BANK 1A,DS31333;
#,POSITION,220,5;
L,BANK 2A,DS11333;
P,5S-653,DS31999,BS1;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,BANK,2A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN1555,PTS1555;

@,SUBSTATION D3,01/23/03
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION D2,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,DS31;
L,SUBSTATION C3,DS31333,DS11333;
P,4T-542,DS11333,CB01333,DS31;
L,SUBSTATION D4,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
```

```
#,POSITION,220,5;
P,5N-451,BS1999,DS31;
L,BANK 1A,DS31333;
#,POSITION,220,5;
L,BANK 2A,DS11333;
P,5S-653,DS31999,BS1;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN1555,PTS1555;

@,SUBSTATION D4,01/23/03
#,POSITION,220,3;
P,3N-432,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION D3,DS31333,DS11333;
P,3S-632,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,4;
P,4N-442,BS1999,DS11333,CB01333,D3S1;
L,SUBSTATION C4,DS31333,DS11333;
P,4S-642,DS11333,CB01333,DS31999,BS1;
#,POSITION,220,5;
P,5N-451,BS1999,DS31;
L,BANK 1A,DS31333;
#,BANK,1A,ID2,3,AN9,RAD4,RAD4;
A,DCSAH140,SABSH4;
B,DCSAH140,SABSH4;
C,DCSAH140,SABSH4;
#,MISC;
P,PTN1555,PTS1555;
```

Appendix 4: System Function Level Configuration 1 SERA Output

TEST.OUT

```
----------------------------------------------------------------------
*A1-AA1                    15.00 0.30 0.40  2.00
 POSITION 1, 220KV, IPOS =  3     7   0   0
 POSITION 2, 220KV, IPOS =  3     7   0  33
SUBSTATION B1 LOST TO A1-AA1
 POSITION 3, 220KV, IPOS =  3    33   0   0
 POSITION 4, 220KV, IPOS =  3     0   0   7
 POSITION 5, 220KV, IPOS =  5    40   7   1   0   0
BANK 1AA LOST TO A1-AA1
 POSITION 1, 500KV, IPOS =  5    49  14   1   7   0
BANK 1AA LOST TO A1-AA1
BANK 2AA LOST TO A1-AA1
 POSITION 2, 500KV, IPOS =  3    67  14  37
SOURCE 2 LOST TO A1-AA1
 POSITION 3, 500KV, IPOS =  5     9  14  46  21  18
SOURCE 1 LOST TO A1-AA1
SUBSTATION AA4 LOST TO A1-AA1
BANK 2AA  SA FAIL
BANK 2AA  SA FAIL
BANK 2AA  SA FAIL
----------------------------------------------------------------------
*A4-AA4                    15.00 0.30 0.40  2.00
 POSITION 2, 500KV, IPOS =  3    83  14  95
SUBSTATION AA1 LOST TO A4-AA4
 POSITION 3, 500KV, IPOS =  3    46   7  92
SOURCE 3 LOST TO A4-AA4
 POSITION 4, 500KV, IPOS =  3    46  21  64
SOURCE 4 LOST TO A4-AA4
 POSITION 5, 500KV, IPOS =  5    46  14   1   7  37
BANK 1AA LOST TO A4-AA4
BANK 2AA LOST TO A4-AA4
 POSITION 1, 220KV, IPOS =  5     7   0   1   0   0
BANK 1AA LOST TO A4-AA4
 POSITION 2, 220KV, IPOS =  3    47   0   7
SUBSTATION B3 LOST TO A4-AA4
 POSITION 3, 220KV, IPOS =  5    40   0  40   0   7
SUBSTATION B4 LOST TO A4-AA4
SUBSTATION B3 LOST TO A4-AA4
 POSITION 4, 220KV, IPOS =  3     0   0  40
 POSITION 5, 220KV, IPOS =  5    25   0   1   0  32
BANK 1A LOST TO A4-AA4
BANK 2A LOST TO A4-AA4
BANK 2AA  SA FAIL
BANK 2AA  SA FAIL
BANK 2AA  SA FAIL
BANK 1A  SA FAIL
----------------------------------------------------------------------
*B1                        30.00 0.20 0.25  2.00
----------------------------------------------------------------------
*B2                        30.00 0.20 0.25  2.00
 POSITION 1, 220KV, IPOS =  5     0   0   0   0   7
 POSITION 2, 220KV, IPOS =  3     7   0   7
SUBSTATION A1 LOST TO B2
 POSITION 3, 220KV, IPOS =  3     7   0   0
----------------------------------------------------------------------
```

```
*B3                         30.00 0.20 0.25  2.00
 POSITION 2, 220KV, IPOS =  3     0   0   7
-------------------------------------------------------------------------
*B4                         30.00 0.20 0.25  2.00
 POSITION 3, 220KV, IPOS =  5     0   0  14   0   0
 POSITION 4, 220KV, IPOS =  5     0   0   7   0   0
-------------------------------------------------------------------------
*C1                         45.00 0.10 0.15  2.00
-------------------------------------------------------------------------
*C2                         45.00 0.10 0.15  2.00
-------------------------------------------------------------------------
*C3                         45.00 0.10 0.15  2.00
-------------------------------------------------------------------------
*C4                         45.00 0.10 0.15  2.00
-------------------------------------------------------------------------
*D1                         60.00 0.05 0.10  2.00
-------------------------------------------------------------------------
*D2                         60.00 0.05 0.10  2.00
-------------------------------------------------------------------------
*D3                         60.00 0.05 0.10  2.00
-------------------------------------------------------------------------
*D4                         60.00 0.05 0.10  2.00
```

Appendix 5: Component Function Level Configuration #1 SERA Output

```
TESTD.OUT
 NOVEMBER 2003   <=======  DATE
 XXXXXXX     <=======  TIME
 HYPOTHETICAL SYSTEM SCENARIO
 SYSTEM.DAT
 NSITE ---->   14
 ----------------------------------------------------------------------
 FAULT  1 342. San And
 ATTENUATION -  HYPOTHETICAL
 ATTENUATION - HYPOTHETICAL
 NFP NRL ATT MMIN MSTP RT/DT BETA DEPTH ECIN COEF NYR SIGA SIGL BL    AL
   3   1   X X.00  .XX  .000 X.XX   X.X XX.0  X.0   0 .X0 .0X0  .XX0 -X.XX0
 NMAX  MMAX  PMAX  MMAX  PMAX  MMAX  PMAX
    1  X.XX  X.00
 FAULT SEGMENT COORDINATES
 PT LONG    LAT   PT LONG    LAT   PT LONG    LAT
  1 XX      YY     2 XX      YY     3 XX      YY
 FAULT LENGTH ------------->  XX KM
 MAGNITUDE OF EVENT ------->    7.00
 RUPTURE LENGTH ----------->  XX KM
 FOR SINGLE EVENT, EPICENTER IS XX.% ALONG THE FAULT
     FROM THE FAR (HIGH LONG. OR LAT) END
 SINGLE EVENT EPICENTER (LONG, LAT)     XX     YY
              NEAR END  (LONG, LAT)     XX     YY
              FAR  END  (LONG, LAT)     XX     YY

 **********************************************************************
      SITE                 D(KM)  M G  M+1  SCOEF
-----------------------------------------------------------------------
*A1-AA1                    15.00 0.30 0.40  2.00  GEFF MN % RNUM
*F 1N-412 DS 1  CONTACTS BURN/A 220 1 PH- 2  315 400 0.20 0.18  4
 TEST FOR POSITION 1 FUNCTION AT 220kV --> , IPOS =  3     7   0   0
*F 2N-422 DS 1  CONTACTS BURN/A 220 2 PH- 3  315 400 0.20 0.10  6
*F 2S-622 DS 1  2 PORCELAIN COL 220 2 PH- 2  315 650 0.05 0.03  5
 TEST FOR POSITION 2 FUNCTION AT 220kV --> , IPOS =  3     7   0  33
SUBSTATION B1 LOST TO A1-AA1
*F 3N-432 DS 1  2 PORCELAIN COL 220 3 PH- 1  315 650 0.05 0.04  4
 TEST FOR POSITION 3 FUNCTION AT 220kV --> , IPOS =  3    33   0   0
*F 4S-642 DS 1  CONTACTS BURN/A 220 4 PH- 1  315 400 0.20 0.13  3
 TEST FOR POSITION 4 FUNCTION AT 220kV --> , IPOS =  3     0   0   7
*F 5N-452 DS 1  2 PORCELAIN COL 220 5 PH- 2  315 650 0.05 0.03  4
*F 5N-452 DS 1  CONTACTS BURN/A 220 5 PH- 3  315 400 0.20 0.17  6
*F BANK 1AA SA 1  FAILURE OF PORC 220 5 PH- 2  315 550 0.12 0.11  4
 TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5    40   7   1   0   0
BANK 1AA LOST TO A1-AA1
*F 1N-711 DS 6  2 PORCELAIN COL 500 1 PH- 1  315 550 0.06 0.02  4
*F BANK 1AA SA 5  FAILURE OF PORC 500 1 PH- 1  315 250 0.60 0.05  4
*F BANK 1AA SA 5  FAILURE OF PORC 500 1 PH- 2  315 250 0.60 0.29  4
*F BANK 2AA SA 5  FAILURE OF PORC 500 1 PH- 3  315 250 0.60 0.46  4
   1S-913 DS1333/DS/BS PH  1 3 allow   7.8 actual   7.9  4
   1S-913 DS1333/DS/BS PH  2 3 allow   7.8 actual   7.9  4
   1S-913 DS1333/DS/BS PH  3 3 allow   7.8 actual   7.9  4
 TEST FOR POSITION 1 FUNCTION AT 500kV --> , IPOS =  5    49  14   1   7   0
BANK 1AA LOST TO A1-AA1
BANK 2AA LOST TO A1-AA1
*F 2N-722 DS 6  CONTACTS BURN/A 500 2 PH- 2  315 350 0.41 0.32  4
*F 2N-722 DS 6  2 PORCELAIN COL 500 2 PH- 1  315 550 0.06 0.03  6
*F 2N-722 DS 6  CONTACTS BURN/A 500 2 PH- 3  315 350 0.41 0.32  6
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*F SOURCE 2 SA 5  FAILURE OF PORC 500 2 PH- 1  315 250 0.60 0.28  5
*F SOURCE 2 SA 5  FAILURE OF PORC 500 2 PH- 2  315 250 0.60 0.25  5
*F 2S-922 DS 6  1 PORCELAIN COL 500 2 PH- 3  315 450 0.18 0.13  5
 TEST FOR POSITION 2 FUNCTION AT 500kV --> , IPOS =  3    67  14  37
SOURCE 2 LOST TO A1-AA1
*F 3N-732 DS 6  CONTACTS BURN/A 500 3 PH- 3  315 350 0.41 0.26  6
*F SOURCE 1 SA 5  FAILURE OF PORC 500 3 PH- 1  315 250 0.60 0.22  5
*F SOURCE 1 SA 5  FAILURE OF PORC 500 3 PH- 2  315 250 0.60 0.37  5
*F 3T-832 DS 6  1 PORCELAIN COL 500 3 PH- 3  315 450 0.18 0.13  3
*F 3T-832 DS 6  CONTACTS BURN/A 500 3 PH- 1  315 350 0.41 0.40  5
*F SUBSTATION AA4 SA 5  FAILURE OF PORC 500 3 PH- 1  315 250 0.60 0.21  5
*F SUBSTATION AA4 SA 5  FAILURE OF PORC 500 3 PH- 2  315 250 0.60 0.56  5
*F SUBSTATION AA4 SA 5  FAILURE OF PORC 500 3 PH- 3  315 250 0.60 0.46  5
*F 3S-932 DS 6  CONTACTS BURN/A 500 3 PH- 2  315 350 0.41 0.32  3
*F 3S-932 DS 6  CONTACTS BURN/A 500 3 PH- 1  315 350 0.41 0.21  5
 TEST FOR POSITION 3 FUNCTION AT 500kV --> , IPOS =  5     9  14  46  21  18
SOURCE 1 LOST TO A1-AA1
SUBSTATION AA4 LOST TO A1-AA1
*F BANK A  SA FAIL 500 2AA 315 250 0.603 0.131
*F BANK B  SA FAIL 500 2AA 315 250 0.603 0.509
*F BANK C  SA FAIL 500 2AA 315 250 0.603 0.306
*F PT 5 N COLUMN FAILURE  PH- 1  315 300 0.53 0.44
*F PT 5 N COLUMN FAILURE  PH- 3  315 300 0.53 0.00
*F PT 5 S COLUMN FAILURE  PH- 2  315 300 0.53 0.31
*F PT 5 S COLUMN FAILURE  PH- 3  315 300 0.53 0.18
--------------------------------------------------------------------------
*A4-AA4                    15.00 0.30 0.40  2.00  GEFF MN % RNUM
*F 2N-722 DS 6  1 PORCELAIN COL 500 2 PH- 3  315 450 0.18 0.14  4
*F 2N-722 DS 6  CONTACTS BURN/A 500 2 PH- 1  315 350 0.41 0.40  6
*F 2N-722 DS 6  1 PORCELAIN COL 500 2 PH- 2  315 450 0.18 0.15  6
*F SUBSTATION AA1 SA 5  FAILURE OF PORC 500 2 PH- 1  315 250 0.60 0.00  5
*F SUBSTATION AA1 SA 5  FAILURE OF PORC 500 2 PH- 3  315 250 0.60 0.18  5
*F 2S-922 DS 6  1 PORCELAIN COL 500 2 PH- 3  315 450 0.18 0.12  3
*F 2S-922 DS 6  CONTACTS BURN/A 500 2 PH- 1  315 350 0.41 0.19  5
*F 2S-922 DS 6  2 PORCELAIN COL 500 2 PH- 2  315 550 0.06 0.02  5
 TEST FOR POSITION 2 FUNCTION AT 500kV --> , IPOS =  3    83  14  95
SUBSTATION AA1 LOST TO A4-AA4
*F 3N-732 DS 6  CONTACTS BURN/A 500 3 PH- 2  315 350 0.41 0.21  4
*F 3N-732 DS 6  1 PORCELAIN COL 500 3 PH- 1  315 450 0.18 0.09  6
*F SOURCE 3 SA 5  FAILURE OF PORC 500 3 PH- 1  315 250 0.60 0.37  5
*F 3S-932 DS 6  CONTACTS BURN/A 500 3 PH- 1  315 350 0.41 0.34  3
*F 3S-932 DS 6  1 PORCELAIN COL 500 3 PH- 2  315 450 0.18 0.11  3
*F 3S-932 DS 6  CONTACTS BURN/A 500 3 PH- 1  315 350 0.41 0.22  5
*F 3S-932 DS 6  1 PORCELAIN COL 500 3 PH- 3  315 450 0.18 0.14  5
 TEST FOR POSITION 3 FUNCTION AT 500kV --> , IPOS =  3    46   7  92
SOURCE 3 LOST TO A4-AA4
*F 4N-742 DS 6  1 PORCELAIN COL 500 4 PH- 1  315 450 0.18 0.12  4
*F 4N-742 DS 6  CONTACTS BURN/A 500 4 PH- 3  315 350 0.41 0.36  4
*F SOURCE 4 SA 5  FAILURE OF PORC 500 4 PH- 1  315 250 0.60 0.34  5
*F SOURCE 4 SA 5  FAILURE OF PORC 500 4 PH- 2  315 250 0.60 0.27  5
*F SOURCE 4 SA 5  FAILURE OF PORC 500 4 PH- 3  315 250 0.60 0.13  5
*F 4S-942 DS 6  CONTACTS BURN/A 500 4 PH- 1  315 350 0.41 0.34  3
*F 4S-942 DS 6  CONTACTS BURN/A 500 4 PH- 2  315 350 0.41 0.25  3
*F 4S-942 DS 6  1 PORCELAIN COL 500 4 PH- 3  315 450 0.18 0.17  3
*F 4S-942 DS 6  CONTACTS BURN/A 500 4 PH- 2  315 350 0.41 0.32  5
 TEST FOR POSITION 4 FUNCTION AT 500kV --> , IPOS =  3    46  21  64
SOURCE 4 LOST TO A4-AA4
*F 5N-751 DS 6  CONTACTS BURN/A 500 5 PH- 2  315 350 0.41 0.39  4
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*F 5N-751 DS 6  1 PORCELAIN COL 500 5 PH- 3  315 450 0.18 0.15  4
*F BANK 1AA SA 5  FAILURE OF PORC 500 5 PH- 2  315 250 0.60 0.19  4
*F BANK 1AA SA 5  FAILURE OF PORC 500 5 PH- 3  315 250 0.60 0.34  4
*F BANK 2AA SA 5  FAILURE OF PORC 500 5 PH- 2  315 250 0.60 0.03  4
*F 5S-953 DS 6  1 PORCELAIN COL 500 5 PH- 3  315 450 0.18 0.13  3
   5S-953 DS6333/DS/BS PH  1 3 allow   7.8 actual   9.3  4
   5S-953 DS6333/DS/BS PH  2 3 allow   7.8 actual   9.3  4
   5S-953 DS6333/DS/BS PH  3 3 allow   7.8 actual   9.3  4
 TEST FOR POSITION 5 FUNCTION AT 500kV --> , IPOS =  5    46  14   1   7  37
BANK 1AA LOST TO A4-AA4
BANK 2AA LOST TO A4-AA4
*F 1N-412 DS 1  CONTACTS BURN/A 220 1 PH- 2  315 400 0.20 0.16  6
 TEST FOR POSITION 1 FUNCTION AT 220kV --> , IPOS =  5     7   0   1   0   0
BANK 1AA LOST TO A4-AA4
*F 2N-422 DS 1  CONTACTS BURN/A 220 2 PH- 1  315 400 0.20 0.19  4
*F 2N-422 DS 1  CONTACTS BURN/A 220 2 PH- 1  315 400 0.20 0.20  6
*F 2N-422 DS 1  2 PORCELAIN COL 220 2 PH- 2  315 650 0.05 0.03  6
*F 2S-622 DS 1  CONTACTS BURN/A 220 2 PH- 3  315 400 0.20 0.16  5
 TEST FOR POSITION 2 FUNCTION AT 220kV --> , IPOS =  3    47   0   7
SUBSTATION B3 LOST TO A4-AA4
*F 3N-432 DS 1  2 PORCELAIN COL 220 3 PH- 2  315 650 0.05 0.03  4
*F 3N-432 DS 1  CONTACTS BURN/A 220 3 PH- 3  315 400 0.20 0.14  6
*F 3T-532 DS 1  2 PORCELAIN COL 220 3 PH- 3  315 650 0.05 0.03  3
*F 3T-532 DS 1  CONTACTS BURN/A 220 3 PH- 2  315 400 0.20 0.20  5
*F 3S-632 DS 1  CONTACTS BURN/A 220 3 PH- 3  315 400 0.20 0.08  3
 TEST FOR POSITION 3 FUNCTION AT 220kV --> , IPOS =  5    40   0  40   0   7
SUBSTATION B4 LOST TO A4-AA4
SUBSTATION B3 LOST TO A4-AA4
*F 4S-642 DS 1  CONTACTS BURN/A 220 4 PH- 3  315 400 0.20 0.10  3
*F 4S-642 DS 1  2 PORCELAIN COL 220 4 PH- 3  315 650 0.05 0.03  5
 TEST FOR POSITION 4 FUNCTION AT 220kV --> , IPOS =  3     0   0  40
*F 5N-452 DS 1  1 PORCELAIN COL 220 5 PH- 2  315 600 0.08 0.06  4
*F 5S-652 DS 1  CONTACTS BURN/A 220 5 PH- 3  315 400 0.20 0.20  3
*F 5S-652 DS 1  1 PORCELAIN COL 220 5 PH- 3  315 600 0.08 0.06  5
 TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5    25   0   1   0  32
BANK 1A LOST TO A4-AA4
BANK 2A LOST TO A4-AA4
*F BANK A  SA FAIL 220 2AA 315 250 0.603 0.278
*F BANK B  SA FAIL 220 2AA 315 250 0.603 0.063
*F BANK C  SA FAIL 220 2AA 315 250 0.603 0.043
*F BANK C  SA FAIL 220 1A 315 550 0.120 0.031
*F PT 5 N COLUMN FAILURE  PH- 2  315 300 0.53 0.23
*F PT 1 N COLUMN FAILURE  PH- 1  315 400 0.29 0.08
*F PT 1 S COLUMN FAILURE  PH- 1  315 400 0.29 0.16
----------------------------------------------------------------------
*B1                         30.00 0.20 0.25  2.00  GEFF MN % RNUM
 TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5     0   0   1   0   0
*F BANK A  SA FAIL 220 1A 210 550 0.045 0.035
----------------------------------------------------------------------
*B2                         30.00 0.20 0.25  2.00  GEFF MN % RNUM
*F 1S-612 DS 1  CONTACTS BURN/A 220 1 PH- 1  210 400 0.03 0.02  3
 TEST FOR POSITION 1 FUNCTION AT 220kV --> , IPOS =  5     0   0   0   0   7
*F 2N-422 DS 1  CONTACTS BURN/A 220 2 PH- 2  210 400 0.03 0.01  6
*F 2S-622 DS 1  CONTACTS BURN/A 220 2 PH- 3  210 400 0.03 0.02  3
 TEST FOR POSITION 2 FUNCTION AT 220kV --> , IPOS =  3     7   0   7
SUBSTATION A1 LOST TO B2
*F 3N-432 DS 1  CONTACTS BURN/A 220 3 PH- 2  210 400 0.03 0.01  4
 TEST FOR POSITION 3 FUNCTION AT 220kV --> , IPOS =  3     7   0   0
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 TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5     0   0   1   0   0
----------------------------------------------------------------------
*B3                        30.00 0.20 0.25  2.00  GEFF MN % RNUM
*F 2S-622 DS 1  CONTACTS BURN/A 220 2 PH- 2  210 400 0.03 0.00  5
 TEST FOR POSITION 2 FUNCTION AT 220kV --> , IPOS =  3     0   0   7
 TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5     0   0   1   0   0
----------------------------------------------------------------------
*B4                        30.00 0.20 0.25  2.00  GEFF MN % RNUM
*F 3T-532 DS 1  CONTACTS BURN/A 220 3 PH- 1  210 400 0.03 0.02  3
*F 3T-532 DS 1  CONTACTS BURN/A 220 3 PH- 2  210 400 0.03 0.01  3
 TEST FOR POSITION 3 FUNCTION AT 220kV --> , IPOS =  5     0   0  14   0   0
*F 4T-542 DS 1  CONTACTS BURN/A 220 4 PH- 3  210 400 0.03 0.00  5
 TEST FOR POSITION 4 FUNCTION AT 220kV --> , IPOS =  5     0   0   7   0   0
 TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5     0   0   1   0   0
----------------------------------------------------------------------
*C1                        45.00 0.10 0.15  2.00  GEFF MN % RNUM
 TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5     0   0   1   0   0
----------------------------------------------------------------------
*C2                        45.00 0.10 0.15  2.00  GEFF MN % RNUM
 TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5     0   0   1   0   0
----------------------------------------------------------------------
*C3                        45.00 0.10 0.15  2.00  GEFF MN % RNUM
 TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5     0   0   1   0   0
----------------------------------------------------------------------
*C4                        45.00 0.10 0.15  2.00  GEFF MN % RNUM
 TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5     0   0   1   0   0
----------------------------------------------------------------------
*D1                        60.00 0.05 0.10  2.00  GEFF MN % RNUM
----------------------------------------------------------------------
*D2                        60.00 0.05 0.10  2.00  GEFF MN % RNUM
 TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5     0   0   1   0   0
----------------------------------------------------------------------
*D3                        60.00 0.05 0.10  2.00  GEFF MN % RNUM
 TEST FOR POSITION 5 FUNCTION AT 220kV --> , IPOS =  5     0   0   1   0   0
----------------------------------------------------------------------
*D4                        60.00 0.05 0.10  2.00  GEFF MN % RNUM
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