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CIRCUIT BREAKER OPERATION AND POTENTIAL FAILURE
MODES DURING AN EARTHQUAKE: A
PRELIMINARY INVESTIGATION

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ABSTRACT

This study addresses the effect of a strong-motion earthquake on circuit breaker operation. It focuses on the loss of offsite power (LOSP) transient caused by a strong-motion earthquake at the Zion Nuclear Power Plant. This report also describes the operator action necessary to prevent core melt if the above circuit breaker failure modes occur simultaneously on three 4.16 KV buses. Numerous circuit breakers important to plant safety, such as circuit breakers to diesel generators and engineered safety systems, (ESS), must open and/or close during this transient while strong motion is occurring.

Potential seismically-induced circuit-breaker failure modes were uncovered while the study was conducted. These failure modes include:

- circuit breaker fails to close
- circuit breaker trips inadvertently
- circuit breaker fails to reclose after trip

The causes of these failure modes include:

- Relay chatter causes the circuit breaker to trip
- Relay chatter causes anti-pumping relays to seal-in which prevents automatic closure of circuit breakers
- Manual switches and test switches transferring open causing control power not to be available
- Load sequencer failures

Nearly 500 electrical drawings were examined to address the effects of earthquakes on circuit breaker operation. Due to the complexity of the problem, this study is not intended to be definitive but serves as a focusing tool for further work.

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FOREWORD

This report arose as a result of the internal review of the Zion seismic PRA performed as part of the Seismic Safety Margins Research Program (SSMRP). The report specifically deals with electrical control systems reliability validation. During a strong-motion earthquake at a nuclear power plant, numerous circuit breakers, important to plant safety, are expected to open and/or close while strong motion is occurring. This report studies (1) the operation of circuit breakers and (2) potential electrical component failure modes at the Zion Plant during a major seismic event.

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1.0 INTRODUCTION

The Seismic Safety Margins Research Program (SSMRP) is a multiyear, multiphase program whose overall objective is to develop improved methods for seismic safety assessment of nuclear power plants, using a probabilistic computational procedure[1,2]. The program is being carried out at Lawrence Livermore National Laboratory (LLNL) and is sponsored by the U. S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research. Phase I of the SSMRP was successfully completed in January 1981. The program has developed and demonstrated a probabilistic computational procedure for the seismic risk assessment of nuclear power plants. The methodology is implemented by three computer programs:

- HAZARD - assesses the seismic hazard at a given site
- SMACS - computes in-structure and subsystem seismic responses
- SEISIM - calculates, component and system failure probabilities and radioactive release probabilities.

The practicality of this model was demonstrated by computing release probabilities for Unit 1 of the Zion Nuclear Power Plant which is located north of Chicago, Illinois, References 1 and 2.

The SSMRP assumed that circuit breakers would fail open circuit or trip as the result of mechanical failure modes such as

- jarring the release trip mechanism
- physically removing the breaker from the cubicle resulting in an open circuit.

The SSMRP assumed that relay chatter would not affect circuit breaker operation. Control circuits for circuit breakers, in general, contain numerous trip contacts that could cause trip of breakers if chattering of these contacts occurred.

As shown in Table 1.1, the relay chatter mode has a much lower median fragility (i.e., the median spectral acceleration at which the breaker fails) than the circuit breaker trip mode*. Also the standard deviation is much larger for the chatter mode than for the circuit breaker trip mode. As shown in Table 1.2, a lower median fragility and a higher Beta (standard deviation of the log of fragility) of the chatter mode results in a much higher probability of failure than for the trip mode.

This report focuses on the loss of offsite power (LOSP) transient caused by a strong motion earthquake at the Zion plant. Numerous circuit breakers important to plant safety, such as circuit breakers to diesel generators and engineered safety systems, (ESS), must open and/or close during this transient while strong motion is occurring. This report addresses the effect of relay chatter on circuit breaker operation. Also, it appears that other seismically-induced electrical component failures affect circuit breaker operation and should be addressed in this study. These failures include:

- manual switches and test switches in control circuits transferring open
- load sequencer (i.e., timer) failures.

Operator action necessary to ameliorate the effect of circuit breaker failures (such as manual circuit breaker operation) is also discussed.

* Fragility curves are probability distributions that describe the probability of failure as a function of a critical response parameter.

Table 1.1
Fragility Data for Circuit Breakers (Cover, 1983)

Circuit Breaker Failure Mode	Median Fragility Spectral Acceleration (g)	Beta
• Breaker Trip	9.583	.818
• Relay Chatter	2.588	1.510

Table 1.2
Probability Data for Relay Chatter and Breaker Trip

Earthquake Level in Bedrock (g)	Peak Ground Acceleration Range (g)	Probability of Earthquake Per Year	Probability of Relay Chatter Given Earthquake Level*	Probability of Circuit Breaker Trip Given Earthquake Level*
.06-.1	0.0918-0.27	5.4×10^{-4}	.095	7.9×10^{-8}
.1- .2	0.174-0.489	2.7×10^{-4}	.15	3.1×10^{-5}
.2- .32	0.258-0.651	1.3×10^{-5}	.26	3.2×10^{-4}
.32-.42	0.493-1.19	1.6×10^{-6}	.33	1.7×10^{-3}
.42-.53	0.42-1.561	4.2×10^{-7}	.37	4.1×10^{-3}
.53-.69	0.665-1.76	1.6×10^{-7}	.42	9.2×10^{-3}

*Response location: motor control center, auxiliary building

2.0 SEQUENCE OF EVENTS FOLLOWING STRONG MOTION

As described in reference 3, failure of offsite power is dominated by failure of ceramic insulators. A review of insulator failures in six major earthquakes, ranging from 0.11g to 0.4g peak ground acceleration, resulted in a median capacity (based on a log-normal distribution), A , for ceramic insulators of .2g with a β of 0.4. Table 2.1 shows the probability of failure of one ceramic insulator as a function of earthquake level. As described in the Zion FSAR [4], there are six 345 KV transmission lines which serve Zion as a source of offsite power. Examining Table 2.1, we see that the conditional probability of losing offsite power due to ceramic insulator failure is high and will be the accident initiator considered in this study.

For Zion Unit-1, there are a total of three 4.16 KV engineered safety system buses, Bus 147, Bus 148 and Bus 149. These buses contain loads critical to plant safety. Fig. 2.1 displays loads that are attached to the 147 and 148 bus. Bus 147 contains the swing diesel that is shared by both units. The diesel swings to the bus in which power is lost first, bus 147 for Unit 1 or bus 247 for Unit 2.

2.1 Assumptions

Figure 2.2 shows the expected sequence of events following LOSP. Prior to LOSP, we assume that the plant is at full power. At time equals zero seconds (i.e., $t = 0$), strong motion greater than .1g starts. At some finite time later, Δt , LOSP occurs due to ceramic insulator failures in the switchyard. Ceramic insulator failures occur instantaneously, i.e., $\Delta t = 0$. In the discussion that follows, no further failures occur. In Section 4.0, we will consider additional failures that could result from the earthquake. At the Zion site, strong motion can occur for as long as 20 seconds. Additional shaking of buildings, such as the auxiliary building where the motor control centers are located, can occur for as long as 60 seconds when a strong motion earthquake occurs.

2.2 Reapplication of Power and Engineered Safety Systems (ESS) Loads

Again referring to Fig. 2.2, an undervoltage signal generates a trip signal for all ESS breakers. For bus 147 shown in Fig. 2.1, breakers to the service water pump 18 and component cooling water pump 00 trip since these loads are required for normal operation. The FSAR states that within 10 seconds, $t=10$ sec, the diesel should run at synchronous speed. At this time, the diesel generator breaker should close and the load sequencers should start. The load sequencers are timers with rotating cam shafts that close contacts to ESS circuit breakers as the shaft rotates. Figure 2.2 shows the closing sequence for ESS loads on buses 147, 148 and 149. The sequence is shown for a safe shutdown (SD) sequence which is produced by an undervoltage signal on the ESS buses.

2.3 Further Assumptions

We assume that a loss of coolant accident (LOCA) does not occur. A LOCA produces a safety injection signal (SIS). An SIS starts the following loads at Zion (listed in order of time at which their respective circuit breakers are closed by the load sequencers):

- safety injection pump
- residual heat removal pump
- containment spray pumps
- service water pumps
- containment cooling fans

Though the SIS sequence is important, we will assume in this report that it does not occur while strong motion is occurring. This report will consider only the safe shutdown sequence following LOSP.

Table 2.1

Ceramic Insulator Failure as a Function of Earthquake Level (g)

Earthquake Level, Bedrock (g)	Probability of Earthquake Per Year	Probability of Ceramic Insulator Failure Given Earthquake
.06-.1	5.4×10^{-4}	.27
.1 -.2	2.7×10^{-4}	.79
.2 -.32	1.3×10^{-5}	1.0
.32-.42	1.6×10^{-6}	1.0
.42-.53	4.2×10^{-7}	1.0
.53-.69	1.6×10^{-7}	1.0

Figure 2.2 Possible Sequence of Events Following a Strong-Motion Earthquake

3.0 DETAILS OF CIRCUIT BREAKER OPERATION

In this section we discuss the fundamentals of circuit breaker operation. For purposes of example, we focus our attention on the operation of two circuit breakers critical to plant safety:

- service water pump 1B circuit breaker
- diesel generator 1A circuit breaker.

Both of these electrical components are attached to bus 14B (see Fig. 2.1).

The service water system is a vital system required for both normal and emergency operation. The diesel generator 1A is required for reapplication of power following LOSP. Both circuit breakers are ITE circuit breakers using a typical X-Y breaker scheme, the details of which are discussed in Appendix-A. In Section 3.1, we discuss this scheme in terms of an example by describing the control circuitry associated with the circuit breaker of service water pump 1B. In Section 3.2, we discuss manual operation of the circuit breaker at the motor control center. In Sections 3.2, 3.4 and 3.5, we discuss the following circuit breaker operations which are critical to plant safety:

- tripping of service water pump circuit breaker following LOSP
- closure of diesel generator 1A breaker
- reclosure of service water pump 1B circuit breaker following trip.

3.1 X-Y Circuit Breaker Scheme

Figure 3.1 shows the control circuit to the circuit breaker of service water pump 1B. For ease of locating relays and contacts, we use a grid locating the row and column. We use the designators to locate the lettered row and numbered column; e.g., [D-4] represents location Row D and Column 4.

The circuit left of the dashed line in Fig. 3.1 is the closing circuit; to the right, is the tripping circuit. The lower left-hand corner of this drawing shows the X-relay, [Q-4], called the closing relay; and the Y relay, [Q-5], called the anti-pumping relay. The trip coil, TC, [Q-9] opens the breaker on a trip signal if the breaker is in the closed position. Also shown in the lower left-hand corner are numerous relay and auxiliary contacts.

The basic modes of circuit breaker operation involving these relays and contacts are described below:

- charging the closing spring
- closure of the circuit breaker by electrical control
- recharging the closing spring
- trip of the circuit breaker by electrical control.

3.1.1 Charging the Closing Spring

The circuit breaker is enclosed in a cabinet on wheels. When the circuit breaker is racked into its cubicle, the LS/b contacts, [N-3] and [O-6], are closed (LS denotes limit switch which follows the spring position). The LS/b contacts are open when the spring is fully wound, otherwise the LS/b contacts are closed. The LS/a contacts follow the opposite position of the LS/b contacts. If DC control power is available, the motor [P-3] will wind the spring causing the LS/b contacts to open and the LS/a contacts to close.

Fig. 3.1 Circuit Breaker to Service
Water Pump 1B

3.1.2 Closure of the Circuit Breaker by Electrical Control

The 52/b contacts [P-4], Fig. 3.1, (52 is the device number denoting circuit breaker) are closed since the breaker is open (the 52b contacts are open (closed) when the breaker is closed (open)). Also the Y/b contacts are closed since the anti-pumping relay, Y, is de-energized.

When the closing relay X is energized, the relay releases a latch that causes the closing spring to discharge and the breaker closes. The X-relay can be energized by the operator manually closing the control switch in the control room causing the CS/C contacts, [C-4], to close. Since all other contacts located in the current path in column 4 are closed, the X-relay [Q-4] becomes energized.

Automatic reclosure of the circuit breaker following LOSP is accomplished by the R6 relay contacts closing, [F-5] and/or [F-6]. Operation of the R6 relay is discussed in Section 3.5. The other current path located in row 1 is not available since the M427X contacts [H-1] are open when the 4.16KV bus voltage is lost. Details are discussed in Section 3.3.

When the closing spring discharges, the LS/b contacts [O-6] close, causing the Y-relay to energize and to seal itself in via the Y/a contacts [N-5]. The Y/b contacts [N-4] open thereby preventing automatic reclosure against a faulted circuit. If this anti-pumping feature did not exist, the breaker could destroy itself by cycling from the closed to the open position continuously.

3.1.3 Recharging the Closing Spring

After the closing spring discharges, the LS/b contacts [N-3] and [O-6] close and the motor, [P-3], starts winding the closing spring. It takes approximately 30 seconds to wind the spring. During this time, the circuit breaker cannot close since the LS/a contacts, [O-4], are open. Also, it is

important to note that the Y relay will remain energized if control power is available or becomes available while the motor is winding the spring. During this time, the LS/b, [D-6], remains closed providing a current path to the Y relay [Q-5]. As described in section 3.1.2, the X relay [Q-4] cannot be energized while the Y relay is energized since the Y/b, [N-4], contacts are open. What this implies is that the circuit breaker cannot be closed by an electrical signal (produced either automatically or manually) as long as the Y relay remains energized.

3.1.4 Trip of the Circuit Breaker by Electrical Control

The tripping circuit in Fig. 3.1 consists of numerous protective relay contacts. When these contacts close, they energize the trip coil, provided that the breaker is closed. (When the breaker is closed, 52/a, [P-9], is closed). These contacts are numbered according to the following scheme: the first number denotes the type of switchgear; for example, 4 denotes 4.16 KV switchgear; 1 denotes 345 KV switchgear. The second and third numbers represent the type of protective relay. The circuit in figure 3.1 has the following protective relay contacts.

- 27, undervoltage relay contacts [L-15]
- 50, instantaneous over current relay contacts, [M-20], [M-23], and [M-26].
- 51, AC time over current relay [M-20] and [M-23].

An example of the above scheme, 427 X1, [L-15] represents the contacts to undervoltage relay X1, which energizes when undervoltage on bus 148 occurs. The 427 X1 contacts close, which causes the breaker to service water pump 1B (a 4.16 KV load) to trip.

The circuit breaker can be tripped in the control room by placing the control switch on the trip position. In this case, the CS/T contacts, [B-12], close, and trip coil, [Q-9] energizes which causes the breaker to trip.

3.2 Manual Operation of the Circuit Breaker

All circuit breakers can be operated manually at the motor control center. The closing spring can be manually wound by a front-mounted handle. The breaker can be closed by pressing the close button or tripped by pressing the trip button. Both buttons are mounted on the front face of the circuit breaker.

3.3 Tripping of the Service Water Pump Following LOSP

LOSP results in undervoltage on all 4.16 KV and 480 V buses. Contacts 427 X1, [L-15], in Fig. 3.1 close, thereby energizing the trip coil, causing the breaker to trip. We now address the signal initiation logic which causes these contacts to close.

Undervoltage on bus 148 causes the undervoltage, UV contacts to close (see Fig. 3.2). Relay 427 X1 energizes and seals in via the 1-2 contacts. Auxiliary 7-8 contacts close. The 7-8 contacts are the 427 X1 contacts in the service water circuit breaker control circuit (see righthand side of Fig. 3.2 and Fig. 3.1, [M-15]).

Another breaker that will trip is the breaker to the component cooling pump OD. All the other breakers to ESS loads are normally open and do not trip. *These loads include (see righthand side of Fig. 3.2)*

- Auxiliary feedwater pump 1B
- Safety injection pump 1B
- Residual heat removal pump 1B

**Fig. 3.2 Undervoltage Relays
For ESS Bus 148**

3.4 Closure of Diesel Generator 1A Circuit Breaker

Figure 3.3 shows the control circuit to the Diesel Generator 1A Feed Breakers. Automatic closure of the circuit breaker require that the following sets of contacts close

<u>Contacts</u>	<u>Location</u>	<u>Description</u>
148-M/b	[A-6]	Incomplete sequence relay bus 143
486 - 148M	[D-4]	Interlock relay bus 143
148 - R/b	[E-4]	Incomplete sequence relay bus 241
486 DG1A	[G-4]	Interlock relay bus 241
DGX1A	[I-4]	Undervoltage relay

All contacts listed above close upon LOSP except 486 DG1A. The contacts, 486 DG1A, close when the diesel 1A runs at synchronous speed. When the diesel supplies power to the bus, the DGX1A contacts will open since voltage to bus 148 is restored.

Figure 3.4 shows the initiation logic for the relay DGX1A. This relay de-energizes when the 27 contacts open causing contacts DGX1A to open. The 27 contacts open when voltage to bus 148 is restored.

3.5 Reclosure of Service Water Pump 1B Circuit Breaker

Automatic reclosure of circuit breaker pump 1B, requires closure of contacts R6, [F-5] or [F-6], in the circuit shown in Fig. 3.1.

We now discuss the initiation logic which causes the R6 contacts to close. Figure 3.5 shows the circuit which energizes the timer motor T-SD/81-1. The contacts which must close for energizing are indicated by arrows. When the LOSP occurs, the following sets of contacts close

- 427 X 1/148
- M427/T18

where M denotes contacts to an agastat relay which is a timing relay. Contacts SIX6/A remain closed since we assume (as was stated in Section 2.3) that a safety injection signal, SIS, is not produced. If an SIS is generated, then the SIX6/A contacts open and timer motor T-SI/18-1 in Fig. 3.5 energizes. In this case a safeguards sequence is produced, as opposed to a safe shutdown sequence. When the breaker to diesel generator 1A closes, contacts G1A/a close, the timer motor starts, (also known as a load sequencer), and the contacts close sequentially in time as shown in the lower half of Fig. 3.6 (the timing sequence for all three 4.16 KV buses is shown in Fig. 2.2). As shown in Fig. 3.6, the 2A-2B contacts on cam No. 2 close in five seconds after the timer is energized. As shown in Fig. 3.7, when the 2A-2B contacts close, relay R6 is energized and the R6, 18-1 contacts, [F-5] close (Fig. 3.1). The other set of parallel contacts in Fig. 3.1, R6, 18-2, [E-6], close by a redundant timer.

* The upper half of the circuit in Fig. 3.6 shows the safeguards sequence when a SIS is produced.

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Figure 3.4 Initiation Logic for Relay D6X-1A

Figure 3.5 Initiation Logic
for Relay R-6 Part 1

Figure 3.6 Load Sequencer Timer Development

4.0 CIRCUIT BREAKER FAILURE MODES

In this section, we describe potential failure modes of circuit breakers that can cause loss of AC power to ESS loads. These failure modes include

- circuit breaker fails to close
- circuit breaker fails to reclose after trip

These failure modes apply to both the ESS circuit breakers and the diesel generator breaker. We also describe potential operator action that can ameliorate the effect of these failure modes for the diesel generator.

4.1 Diesel Generator Circuit Breaker Failure Modes

The diesel generator breaker can fail to close if any of the test switches in Fig. 3.3 transfer open. In this case control power is not available and the operator must manually close the breaker at the motor control center.

The next failure mode we wish to discuss is the diesel generator breaker tripping after closure because the ESS loads are not tripped. The ESS loads will not trip if an undervoltage signal is not generated. Failure to produce an undervoltage signal can result from the switches (shown in Fig. 3.2) transferring open prior to LOSEP.

In the event an undervoltage signal does not trip the circuit breakers to the ESS loads, the operator must perform the following steps to restore AC power to the ESS loads

- open the breakers to the ESS loads
- close the diesel generator breaker at the motor control center
- close the breakers to the ESS loads.

The operator can accomplish circuit breaker operation either by (1) manipulating control switches in the control room or (2) at the motor control center by manually winding the closing spring.

The next two failure modes to be discussed involve the chattering of relay contacts that cause the Y-relay to seal in and prevent automatic reclosure of the circuit breaker.

As shown in Fig. 2.2, the diesel generator circuit breaker should close approximately 10 seconds following LOSP. At this time, the DGX1A [1-4] contacts shown in Fig. 3.3 should close. However, if any of the following contacts chatter open:

- Y/b [N-4]
- LS/a [0-4]
- 52/b [0-4]

and, simultaneously, if any of the following contacts chatter close

- Y/a [N-5]
- LS/b [0-6]

then the Y relay could seal in and prevent automatic closure of the breaker.

Another way the Y relay can seal in is if a trip signal is received within 30 seconds after closure of the breaker. A trip signal can be caused by chattering of the trip contacts. During this 30 second time interval, the motor is winding the spring and the LS/b contacts, [0-6], Fig. 3.3, are closed. The DG-1A circuit breaker would be commanded to close after trip since contacts DGX1A close on undervoltage. However, during this time, relay Y would seal in preventing relay X to energize.

In the two cases in which relay Y seals in, the operator must open the test switches to cause relay Y to drop out and then he must close the control switch in the control room.

It must be pointed out that for Y to seal in, control power must be available, which implies that the first failure mode described above, test switches transferring open, did not occur since this mode causes control power to be unavailable.

Since these failure modes are mutually exclusive, logic models (such as fault trees), may have to contain complemented events if the probability of successful operation of the electrical components do not have probability near unity (which is true at high earthquake levels).

4.2 Engineered Safety Systems (ESS) Circuit Breaker Failure Modes

First, we discuss the fails-to-close mode for ESS circuit breakers. As described in Section 3.4, to start the load sequencer following LOSP requires that the diesel generator, DG, breaker close. Hence, if the DG breaker does not close, all ESS circuit breakers will not close automatically. Also, if both load sequencers fail, then the ESS loads will not be loaded automatically.

Also, the simultaneous chattering of contacts (as described for the diesel generator breaker) could cause relay Y to seal in, preventing automatic closure of the circuit breaker.

Now we discuss the fails-to-reclose after trip mode. The control circuit to the service water pump circuit breaker, Fig. 3.1, is different from the control circuit to the diesel generator circuit breaker, Fig. 3.3. After the service water pump circuit breaker closes, control power remains available and the Y relay remains sealed in. This is not the case with the diesel generator breaker which contains the DGX1A contacts [1-4]. When the diesel generator

circuit breaker closes, the DGX1A contacts open and control power is not available. What this statement implies is that any trip of an ESS breaker from the closed position will prevent automatic reclosure of the breaker.

An ESS breaker could trip due to the following reasons

- chattering of the trip contacts
- trip of the diesel generator breaker (causes undervoltage).

It is important to note however, that the operator can close any ESS breaker by first placing the control switch in the reset position and then placing the switch in the close position. Placing the control switch in the reset position causes a momentary open circuit, which causes the relay Y to drop out.

5.0 CONCLUSIONS

This report addressed the loss of offsite power transient caused by a strong motion earthquake at the Zion plant. Possible failure modes for circuit breakers considering relay chatter include

- chatter of relay trip contacts causing circuit breaker trip
- anti-pumping relay sealing in and preventing automatic reclosure of the circuit breaker.

Also the control circuits and the signal actuation system necessary for operation of the circuit breakers were examined and the following potential failure modes were addressed.

- switches transferring open, resulting in (1) failure to produce an undervoltage signal and (2) failure to initiate an operating sequence that opens and close circuit breakers critical to plant safety.
- test switches transferring open in the control circuit to the breaker of the diesel generator causing the breaker to fail to close when needed.
- load sequencer failures

The failure modes described above can cause total loss of AC power if these modes occurred simultaneously on all three 4.16 KV buses. Operator action is necessary to restore AC power and the ESS loads.

5.1 Recommendations for Future Work

Currently, shaker-table test data are not available for circuit breakers. It is important to note that merely testing the internals of the

breaker is insufficient. As described in the body of this report, the control circuits and signal initiation system are important to circuit breaker operation. In other words, the entire system must be tested to obtain meaningful fragility data--not merely the circuit breaker itself. As with other components, a difficulty that arises when using generic fragility data for electrical components is that failure can be sensitive to the spatial (i.e., X-Y-Z) orientation of the component.

Also the effects of chattering seal-in contacts are potentially important--other systems such as the reactor protection system should be examined for the effect of relay chatter and electrical component failures.

Another issue considered in the study is operator action following an earthquake. It is clear that if the failure modes described in this report occurred, operator action including proper diagnosis is necessary to prevent core melt. A detailed human factors study could be fruitful in determining how much credit can be taken for the operator. Needless to say--operators were very innovative operating circuit breakers at the Browns Ferry fire. However, the additional stress on the operator should be considered when a strong motion earthquake occurs.

Depending upon the results of the future work recommended, it might be fruitful to modify the existing Phase II fault trees and recalculate seismic risk to determine the impact of relay chatter and other electrical failure modes discussed in this report.

6.0 REFERENCES

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Appendix A
Description of 4 KV switch Gear Operation.

- A - A standard drawout compartment consists of provision for three breaker positions, namely: Connected, Test and Disconnected.
- B - This design is for a four position compartment which includes two test positions without moving the breaker from the normal test position. These two test positions are identified as "Local Test" and "Remote Test".
- C - "Local Test" is obtained by the normal movement of the breaker to test position. (See Paragraph E)
- D - "Remote Test" is obtained by moving the breaker to test position and pulling the test selector.
- E - After the mechanism has been latched for "Remote Test", it may be returned to "Local Test" by depressing the release lever (SC 3). The release from "Remote Test" is automatic if the breaker is moved out of test position.
- F - The following tabulation lists the four positions and the condition of associated devices:

Device	Condition of Device in each Breaker Position			
	Connected	Local Test	Remote Test	Disconnected
Main Contacts	Connected	Disconnected	Disconnected	Disconnected
Control Cont.	Connected	Connected	Connected	Disconnected
MCC Switches	Operable	Non-Operable	Operable	Non-Operable
TSC Switches	Not Controlled	Operated	Not Operated	Not Operated

TSC

CONTACTS	SYMBOL	BREAKER POSITION			
		OPEN	REMOTE TEST	LOCAL TEST	WITH-DRAWN
10-11-03 11-03	LT			X	
11-03	RTO	X	X		X
20-11-04 11-06	LT			X	
11-06	RTO	X	X		X

BREAKER POSITION SWITCH

TCS

CONTACTS	SYMBOL	POSITION		
		TRIP	NORMAL	CLOSE
10-11-02	C			X
40-11-03	T	X		

LOCAL TEST CONTROL SWITCH

REVISIONS									
A	4-10-72	15	FOR SUBSTITUTION 4224, 2-22-72						

DRAWN F. MOB
CHECKED J. H. S.
ENGINEER

D-C ELECTRICAL OPERATING SEQUENCE

With the circuit breaker open, the closing springs uncharged, and the control power source energized, and motor disconnect switch closed, operation occurs as follows:

- 1 - Immediately upon the availability of control power, the spring charging motor (motor) is energized, which in turn charges the closing springs. When the closing springs are charged, limit switch contacts "LSb" are opened, and limit switch contact "LSa" is closed.
- 2 - Operation of the Close Control switch energizes the latch release coil (X) through the circuit breaker auxiliary switch "b" contact, the normally-closed lockout relay contact "Yb", and the limit switch contact "LSa". The latch release coil (X) releases the closing latch. The springs then discharge to close the circuit breaker.
- 3 - When the springs discharge, limit switch contacts "LSb" close, and limit switch contact "LSa" opens.
- 4 - When limit switch contact "LSb" in the motor circuit closes, the spring charging motor is energized, which in turn re-charges the closing springs.
- 5 - When the circuit breaker closes, all auxiliary switch "b" contacts open and all auxiliary switch "a" contacts close.
- 6 - When limit switch contacts "LSb" close, the lockout relay coil (Y) is energized and opens lockout relay contact "Yb", which de-energizes the latch release coil (X). Lockout relay contact "Ya" closes, which seals-in the lockout relay coil (Y) as long as the "Close" contact is maintained. The purpose of the lockout relay coil (Y) is to prevent pumping of the closing mechanism when closing against a faulted circuit.
- 7 - After the breaker has closed and when the "Close" switch is released by the operator, the lockout relay coil (Y) is de-energized. This allows the normally-closed lockout relay contact "Yb" to close, and the normally-open lockout relay contact "Ya" to open.
- 8 - The circuit breaker can be tripped by operation of the Trip Control switch, which energizes the circuit breaker trip coil (TC) through the auxiliary switch "a" contact.

LEGEND:

- a - Auxiliary switch contact closed when breaker is closed
- b - Auxiliary switch contact open when breaker is closed
- LC - Latch check switch contact closed when breaker operating mechanism is reset.
- LS - Limit switch contact open when springs are discharged, closed when springs are charged.
- LSb - Limit switch contact closed when springs are discharged, open when springs are charged.
- X - Closing latch release coil
- Y - Control relay lockout coil
- Ya - Normally open control relay contact
- Yb - Normally closed control relay contact
- TC - Trip Coil

DATE	18-10-71	LEGEND & NOTES - 4KV SWITCHGEAR		
VIC	18-10-71		SCHMATIC DIAGRAM	Dwg. No. 22E-2-4840 1/58 PAGE: 7
DESIGN	4-10-71		ZION STATION	
<i>James J. Kelly</i>		COMMONWEALTH EDISON CO CHICAGO, ILLINOIS		

SCALE 1/8" = 1"