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PRELIMINARY RELIABILITY ANALYSIS
OF THE PRIMARY ELECTRICAL POWER SYSTEM,
SYSTEM 11

O. B. Monteith

February 1968

AEC RESEARCH &
DEVELOPMENT REPORT

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SYSTEM 11

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February 1968

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SYSTEM 11

PRIMARY ELECTRICAL POWER

ABSTRACT

A preliminary reliability prediction for the FFTF Primary Electrical Power System is reported. The effect of lightning (or unknown) surges on system reliability is included and the system availability is determined. A calculation of expected unavailability of the FFTF caused by system outages is presented.

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PRELIMINARY RELIABILITY ANALYSIS OF THE PRIMARY ELECTRICAL POWER SYSTEM
SYSTEM 11

INTRODUCTION

This report is a preliminary reliability analysis of the Primary Electrical Power System as described in CSDD No. 11. Failure rates for the major components of the system were determined by consulting the listed references, and it is believed these failure rates are pessimistic. In this report, failure rates are expressed in failures per million hours, or failures $\times 10^{-6}$ per hour. An operating time of 1000 hours has been used in the reliability and availability calculations of the Primary Electrical System.

Two separate predictions of reliability are presented. The first is the system reliability based on data that does not include the effects of lightning surges (and surges from unknown causes). The second includes the outages resulting from surges. Under normal conditions, a surge causes an outage of something less than one-half second (30 cycles) which does not adversely affect conventional loads. However, because of the response and sensitivity of the control circuits employed on Hanford reactors, many surges cause the reactors to trip. Based on history at Hanford, a failure rate has been generated that represents the expected outages from surges.

RESULTS AND CONCLUSIONS

This preliminary reliability analysis determines predicted values for the reliability and availability of the Primary Electrical Power System, and estimates the unavailability of the FFTF as a result of electrical system outages.

The predicted reliability of the system for 1000 hours operation is $R(1000)=0.945$. Employing an optimistic outage rate for the Bonneville Power Administration source, the predicted system reliability is $R(1000)=0.99$.

The availability of the system is predicted to be $A_S = 0.99997+$.

The expected unavailability of the FFTF as a result of System 11 outages is predicted to be 0.140 hours per 1000 hours of operation.

A unique failure mode of the Electrical System is the momentary outages caused by lightning (or unknown) surges. These faults have a small effect on the system availability because the outage is less than one-half second. However, these surges may cause the reactor to scram which will add to the reactor unavailability. Including these momentary outages, the system reliability is predicted to be $R(1000) = .89403$, and the unavailability of the reactor is predicted to be 0.20 hours per 1000 hours operation.

SYSTEM OPERATIONAL REQUIREMENTS

SYSTEM FUNCTIONS AND BOUNDARIES

The Primary Electrical Power System provides the electrical power exigent to the entire FFTF complex. This primary power at 115 kV will be obtained from the Bonneville Power Administration through connections at the BPA Benton Switching Station. System 11 comprises two 115 kV transmission lines, two 115 kV/13.8 kV transformers, and ancilliary 115 kV equipment such as lightning arresters, disconnect switches and fuses. The two lines and transformers are designed as redundant power paths, thus, one line and one transformer can carry the full FFTF load. One of the transmission lines is a new facility to be constructed from the Benton Switching Station to the FFTF substation. The second 115 kV transmission line is an existing facility supplying power to the 300 Area from the Benton Switching Station, and connects to the South Richland Substation. System 11 does not include the secondary power equipment of System 12 at the FFTF substation, and it does not include the equipment at the Benton Switching Station, except the two feeder circuit breakers which have been included for this reliability prediction.

ANTICIPATED OPERATIONAL CONDITIONS

The Primary Electrical Power System interfaces the the following systems:

1. BPA 115 kV System at the Benton Switching Station.
2. 300 Area Substation.
3. South Richland Substation.
4. FFTF Building Electrical Power System (System 12).

Because of anticipated growth in the loads on the BPA system surrounding the South Richland Substation, this substation cannot be considered as a source for FFTF needs. Therefore, the connection to the BPA system is via the dual 115 kV transmission lines from the FFTF to the Benton Switching Station. A dual bus arrangement will be provided at the Benton Switching Station which will permit switching to any of three BPA interties through fast operating oil circuit breakers.

There are two types of outages associated with electrical utility systems. The sustained outage causing complete loss of power (or a reduced load capability known as a "brownout") can be provided for by emergency power generation facilities. The second outage type is a momentary disturbance lasting less than one-half second, and is the result of surges on the system. These surges may be due to lightning strikes on or near transmission lines, switching surges on the system, or insulation flashovers of various causes. This second outage type does not cause concern to the normal industrial load, but the existing Hanford production reactors have experienced scrams as a result of these surges. The generally accepted reason for these scrams is the sensitivity and response of the reactor control circuits. It is not known at this time if these control problems will obtain at the FFTF.

The planned operation of the Primary Electrical Power System is to divide the FFTF loads between the two 115/13.8 kV transformers, and to maintain this division of loads via the two transmission lines to the Benton Switching Station. There is provision for manual switching of either or both transformers to either transmission line, which will provide full power to the FFTF in event of an equipment failure on one line. In like manner, it will be possible to manually switch the loads to either transformer secondary, thus providing full power with one failed transformer. These failed conditions will require a controlled shutdown, or reduced power, of the reactor since full power reactor operation with only one source of primary power is not anticipated at this time.

MISSION PROFILES AND DUTY CYCLES

System 11 will be required to provide primary power continuously to the FFTF. However, the duty cycle of the reactor is such that approximately each two months, during refueling, two weeks are available for preventative maintenance on the system when one source of primary power will suffice.

EFFECTIVENESS GOALS

The effectiveness of the Primary Power System must be evaluated in relation to the safety of the reactor, and to the irradiation testing availability of the FFTF.

The first criterion requires an estimation of the chance that a failure in System 11 will cause an unsafe condition at the reactor. In actuality, the total loss of primary power as a single failure would not result in an unsafe condition. There are many rationales to justify the conclusion that a loss of primary power is not an unsafe condition. Some of these are: the safety circuits are fail-safe in design; the heat transport system will display a gradual decay of capacity as a result of mass inertia and convection processes; there are emergency power sources for lighting, safety circuits, and controlled shutdown; and operating procedures will require controlled shutdown of the reactor in event of specified emergency conditions. A measure of the effectiveness of the Primary Electrical Power System is the combined probability of the reliability and availability of the system. A preliminary goal for this effectiveness can be established by accepting the optimistic outage rate of BPA, which was estimated by Reference VII as two in 25 years with the mean time to restore the system for these incidents as 0.3 hr. Using these data, the combined probability of reliability and availability for 1000 hours is 0.99.

The second criterion for the effectiveness of System 11 involves a determination of the time lost in reactor irradiation testing as a result of outages in System 11. Most outages as a result of equipment failures will cause the reactor to scram. Momentary outages as a result of lightning and other surges may, or may not, cause the reactor to scram. Based on past experience with the Hanford production reactors, an arbitrary goal for the unavailability of the FFTF reactor, as a result of System 11 outages, is established as 0.1 hour per 1000 hours operation.

RELIABILITY ANALYSIS

RELIABILITY LOGIC DIAGRAM

The reliability logic diagram of the Primary Electrical Power System is shown in Figure 1. As indicated, the Bonneville Power Administration System source of power is represented by a logic block in series with redundant logic paths for successful power supply to the FFTF. The two redundant paths are identical and include the line circuit breaker at the Benton Switching Station, 5.4 miles of 115 kV line, a disconnect switch, three lightning arresters, three fused switches, and the 115 kV/13.8 kV power transformer.

FAILURE RATES

Bonneville Power Administration System

The failure rate of the BPA system is estimated from incidents reported on the Hanford 230 kV system during the period from May, 1951, to July, 1963. The data show six incidents that resulted in loss of primary power to the Hanford system, and 18 surges that resulted in scrams of one or more reactors. (It is noted that the surge incidents occurred during all months from April through December, but none were reported in January, February, and March.)

The system failure rate for incidents not including surges is:

$$\lambda_1 = 56 \text{ per million hours (Reference II)}$$

This failure rate closely agrees with that in AIEE paper 62-61, for public utility system failures from all causes excluding weather, which is given as $\lambda = 49$ per million hours (Reference I).

The mean time to restore the system for these six incidents is:

$$\tau_1 = .34 \text{ hours (Reference II)}$$

Redundant Transmission Paths

115 kV Circuit Breakers

(Reference I)

$$\lambda_2 = .98 \text{ per million hours}$$

$$\tau_2 = 3 \text{ hours}$$

5.4 miles 115 kV Transmission Line

(Reference I, IV, V)

$$\lambda_3 = 3.2 \text{ per million hours}$$

$$\tau_3 = 4 \text{ hours}$$

7

COMPONENT
NAME

XXXXXXXXXX
XXXXXXXXXX
N N

BLOCK NO.

QUANTITY

LEGEND

RELIABILITY BLOCK DIAGRAM
PRIMARY ELECTRICAL POWER SYSTEM

FIGURE 1

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115 kV Disconnect Switches

(Reference I)

$$\lambda_4 = .65 \text{ per million hours}$$

$$\tau_4 = 2 \text{ hours}$$

115 kV Lightning Arresters

(Reference IV, V)

$$\lambda_5 = .1 \text{ per million hours}$$

$$\tau_5 = 2 \text{ hours}$$

115 kV Fused Switch

(Reference IV, V)

$$\lambda_6 = .5 \text{ per million hours}$$

$$\tau_6 = 2 \text{ hours}$$

115/13.8 kV Transformer

(Reference I, V)

$$\lambda_7 = 2.35 \text{ per million hours}$$

$$\tau_7 = 168 \text{ hours}$$

RELIABILITY MODEL

The reliability model of the Primary Power System is:

$$R(t) = e^{-\lambda_1 t} \left(\frac{S_1 e^{S_2 t} - S_2 e^{S_1 t}}{S_1 - S_2} \right), \text{ Reference III,}$$

where λ_1 = failure rate of BPA system

$$S_1 = 1/2 \left[3\lambda_B + U_B - \sqrt{\lambda_B^2 + 6\lambda_B U_B + U_B^2} \right]$$

$$S_2 = 1/2 \left[3\lambda_B + U_B + \sqrt{\lambda_B^2 + 6\lambda_B U_B + U_B^2} \right]$$

$$\lambda_B = \sum_{n=2}^7 \lambda_n = \text{branch failure rate of blocks 2 through 7}$$

$$U_B = \frac{1}{\tau_B} = \text{branch restoration rate of blocks 2 through 7}$$

$$\tau_B = \frac{\lambda_2 \tau_2 + \lambda_3 \tau_3 + \lambda_4 \tau_4 + \lambda_5 \tau_5 + \lambda_6 \tau_6 + \lambda_7 \tau_7}{\sum_{n=2}^7 \lambda_n}$$

Substituting the appropriate values in the above expression yields a Primary Power System reliability for 1000 hours as:

$$R(1000) = .94554 \times .99999 = .94553$$

An optimistic estimate of BPA failure rates (Reference VII) which considers only the incidents for which no advance notice could be given, reduces the BPA failure rate to two outages in 25 years, or $\lambda_1 = 9.1$ per million hours. With this estimate, the BPA reliability for 1000 hours becomes approximately 0.99.

Effect of Surges on Reliability

Under normal conditions, surges on a power system cause an outage of less than one-half second (30 cycles) which does not adversely affect conventional loads. However, because of the sensitivity and response of the control circuits employed on Hanford reactors, many surges cause the reactors to scram. It is difficult at this point in time to predict the incidence and scope of the lightning surge problem for the FFTF reactor because: 1) the FFTF control parameter set points are not established, 2) historical data is based on early reactors with their unique controls, and 3) the 115 kV system of BPA presents a different characteristic with respect to lightning surges than does the 230 kV system that supplies the earlier Hanford reactors. As an illustration of the uncertainty in Item 3), it is known that the 115 kV system is not provided with complete overhead ground wires and counterpoise as is the 230 kV system, thus the 115 kV system is more vulnerable to direct lightning strokes.

To facilitate this preliminary reliability analysis, a representative incidence of surges that cause reactor scrams, based on the worst case of the Hanford reactors, has been determined. This outage condition is considered a hazard rate associated with the BPA system, and therefore, the failure rate of block 1 is increased by λ_L , the failure rate due to lightning. The worst case for reactor scrams from surges yields a failure rate of:

$$\lambda_L = 56 \text{ per million hours}$$

Including the effects of surges, the system reliability for 1000 hours is:

$$R(1000) = .89404 \times .99999 = .89403$$

AVAILABILITY MODEL

The system availability model is:

$$A_s = A_1 \times A_e$$

where A_1 = the availability of the BPA power system

A_e = the availability of the redundant paths.

$$A_1 = \frac{U_1}{\lambda_1 + U_1} = .99998$$

$$A_e = \frac{U_B^2 + 2\lambda_B U_B}{(\lambda_B + U_B)^2}$$

$$\lambda_B = 9.0 \times 10^{-6}$$

$$U_B = .0217$$

$$A_e = \frac{(.0217)^2 + (2 \times 9 \times 10^{-6} \times 0.0217)}{(.021709)^2} = .99999+$$

The availability of the Primary Electrical Power System then is:

$$A_s = .99998 \times .99999 = .99997+$$

Effects of Surges on Availability

The Primary Electrical System experiences an outage of less than one-half second due to surges, and their effect on system availability is negligible. However, there is a much longer downtime associated with the reactor when a trip or scram occurs. It is presently estimated that the reactor downtime (D) to recover from a trip will be one hour (Reference VIII). The expected proportion of downtime for 1000 hours of operation due to expected lightning surges then is:

$$\lambda_L D (1000) = .056 \text{ hours expected downtime per 1000 hours.}$$

This expected downtime of .056 hours per 1000 hours of operation of the reactor must be added when determining the unavailability of the reactor as a result of equipment failures.

EFFECTS OF PRIMARY ELECTRICAL POWER SYSTEM FAILURES ON REACTOR AVAILABILITY

For determining reactor unavailability, it is assumed that any failure of the Primary Electrical Power System will cause a reactor scram. The expected reactor downtime per 1000 hours operation due to failures in the power system, but not including effects of surges, is:

$$\sum_{i=1}^{13} \lambda_i D_i (1000) = .140 \text{ hours}$$

where D_i is the component repair time plus the one hour required for the reactor to recover from a trip except for the transformers where two hours for switching and trip recovery is assumed.

With respect to reactor availability, the reliability block diagram of the Primary Electrical Power System is represented by a series configuration of all elements. However, it is possible to operate the FFTF with a failure in one branch of the redundant paths. This operation is accomplished by manually operated switches to transfer all of the load to the remaining good path.

The total unavailability of the FFTF as a result of the Primary Power System is the sum of that caused by surges and that caused by equipment failures. This total predicted unavailability is .20 hours per 1000 hours.

ASSUMPTIONS

1. The Primary Electrical Power System is as described in CSDD No. 11, dated May 26, 1967. As specified in this CSDD, the following conditions obtain:
 - a. Two 115 kV transmission lines from the Benton Switching Station to the FFTF substation.
 - b. Each of the paths of power including the transformers shall have sufficient capacity to meet the load requirements of the FFTF.
2. For purposes of this analysis, the two primary power circuits including transformers will be considered identical. This assumption is not a serious departure from the actual case, and it makes the mathematics less complicated.
3. Lightning surge incidents on the BPA System which would cause the reactor to trip are considered to contribute to the reactor unavailability.
4. The Benton Switching Station is considered as the connecting point for power from BPA.
5. It is assumed that the equipment reliability function results from an exponential distribution of the times to failure.

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