Spurious Operation Duration

Background:

Current Regulatory Framework

Section 3.5.1, "Criteria/Assumptions" of NEI 00-01, Rev. 2, provide fire-induced circuit failure evaluation criteria and assumptions. The criteria for circuit failures include a discussion on assumed duration of a fire-induced spurious operation. Section 3.5.1.1, "Circuit Failure Criteria," states:

> …For components classified as "required for hot shutdown," there is no limit on the duration of the hot short. It must be assumed to exist until an action is taken to mitigate its effects. …
>
> For components classified as "important to safe shutdown," the duration of a hot short may be limited to 20 minutes. (If the effect of the spurious operation involves a "sealing in" or "latching" mechanism, that is addressed separately from the duration of the spurious actuation,…[discussed elsewhere in NEI 00-01, Rev. 2])

The NRC staff's endorsement of NEI 00-01, Rev. 2, took an exception to the 20-minute criteria. Section 5.3, "Fire Protection of Safe-Shutdown Capabilities," of RG 1.189, states:

> …The eighth bullet [under the sub-heading "Circuit for 'important to safe shutdown' components" of Section 3.5.1.1 in NEI 00-01, Rev. 2] discusses limiting the duration of the hot short to 20 minutes; the NRC does not endorse this assumption for direct current circuits. …

Therefore, the current guidance is that all circuits for "required for hot shutdown" components and direct current (DC) circuits for "important to safe shutdown" components are assumed vulnerable to spurious operations that last for an infinite duration. Maximum spurious operation duration of 20-minutes can be applied to alternating current (AC) circuits for "important to safe shutdown" components.

Discussion

At the time NEI 00-01, Rev. 2 and the subsequent revision to RG 1.189 were being developed, there was no publically available data on the fire-induced spurious operation behavior of dc circuits. Based on limited proprietary utility testing (ADAMS Accession No. ML071200168), there were indications that the fire-induced circuit failure behavior of DC circuits may differ from AC circuits. Due to these apparent behavioral differences, the NRC sponsored a confirmatory testing project to evaluate DC circuit fire-induced failure modes which were ongoing at the time these guidance documents (NEI 00-01, Rev. 2 and RG 1.189, Rev. 2) were under development. Design differences between AC and DC circuits also suggested that the spurious operation duration for AC and DC circuits might differ. As such, the staff determined that it was not prudent to endorse the

20 minute criteria for DC circuits until additional supporting information could be collected, analyzed, and presented.

Supporting Information:

The NRC-sponsored testing is documented in NUREG/CR-7100, "Direct Current Electrical Shorting in Response to Exposure Fire (DESIREE-Fire): Test Results." Additional data analysis was conducted and documented in NUREG-2128, "Electrical Cable Test Results and Analysis during Fire Exposure (ELECTRA-Fire), A Consolidation of Three Major Fire-Induced Circuit and Cable Failure Experiments Performed Between 2001 and 2011." Both of these efforts were conducted under a cooperative research agreement (Memorandum of Understanding) between the US NRC-RES and the Electric Power Research Institute (EPRI).

Following the joint NRC-RES/EPRI testing and circuit analysis efforts for DC circuits, expert panels were formed to evaluate the phenomena that influence the spurious operation duration and to develop conditional spurious operation duration estimates as inputs to fire probabilistic risk assessments (Fire PRAs). The results of these efforts are documented in NUREG/CR-7150, Volumes 1 and 2 (EPRI 1026424 and EPRI 3002001989), "Joint Assessment of Cable Damage and Quantification of Effects from Fire (JACQUE-FIRE)." In Volume 2, an approach for quantifying the conditional spurious operation duration likelihood was developed for AC and DC circuits for incorporation into Fire PRAs. In this approach, a floor estimate was added to the conditional spurious operation duration likelihood curve to represent the probability of a fire-induced spurious operation never clearing. The floor point estimates are 0.0071 for AC circuits and 0.022 for DC circuits. Although this approach is technically adequate when used in a risk-informed / performance-based fire protection program, the simplified assumptions and dataset rejection techniques do not support direct development of a spurious operation duration limit for use in deterministic analysis.

Additionally, the duration likelihood estimates contained in Volume 2 of NUREG/CR-7150 can be applied to several spurious operations within a scenario, provided a joint probability limit is not exceeded. While this is an acceptable approach in Fire PRA, for deterministic analysis, placing a limit on the duration of a spurious operation is only applicable for a single component or signal. The test data and duration likelihood estimates are used elsewhere to inform a limit on the number of spurious operations to consider.

Analysis:

To support development of a fire-induced spurious operation duration limit for a single hot short-induced spurious operation, the test data documented in NUREG/CR-2128 was used as a starting point. Two bins were developed. An AC duration data bin included all hot short-induced spurious operation duration data from the NEI/EPRI, NRC-CAROLFIRE, and NRC-DESIREE-Fire (AC portion) data. A DC duration data bin included all hot short-induced spurious operation duration data from the NRC-DESIREE-

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Fire (dc portion) tests, with the exception that the medium voltage switchgear control circuits were not included. The switchgear data was not used because by design, only a momentary spurious operation is needed to cause the device to change state (i.e., momentary energization of either the close or trip coil). The histograms with best fit distributions for the empirical data are presented in Figure 1. Figure 1a and 1b present the distributional fit (shown as probability density functions) and data histograms for the AC and DC data bins, respectively. Figure 1c and 1d provides illustrations for the empirical data set and distributional fit, including a 95^{th} percentile confidence interval, for AC and DC bins, respectively. Figure 1e presents the AC and DC empirical data on the same plot. Figure 1c-e are shown as survivor functions, which is the same as the complementary cumulative distribution function, and used to visualize the likelihood of a hot short-induced spurious operation exceeding a certain time.

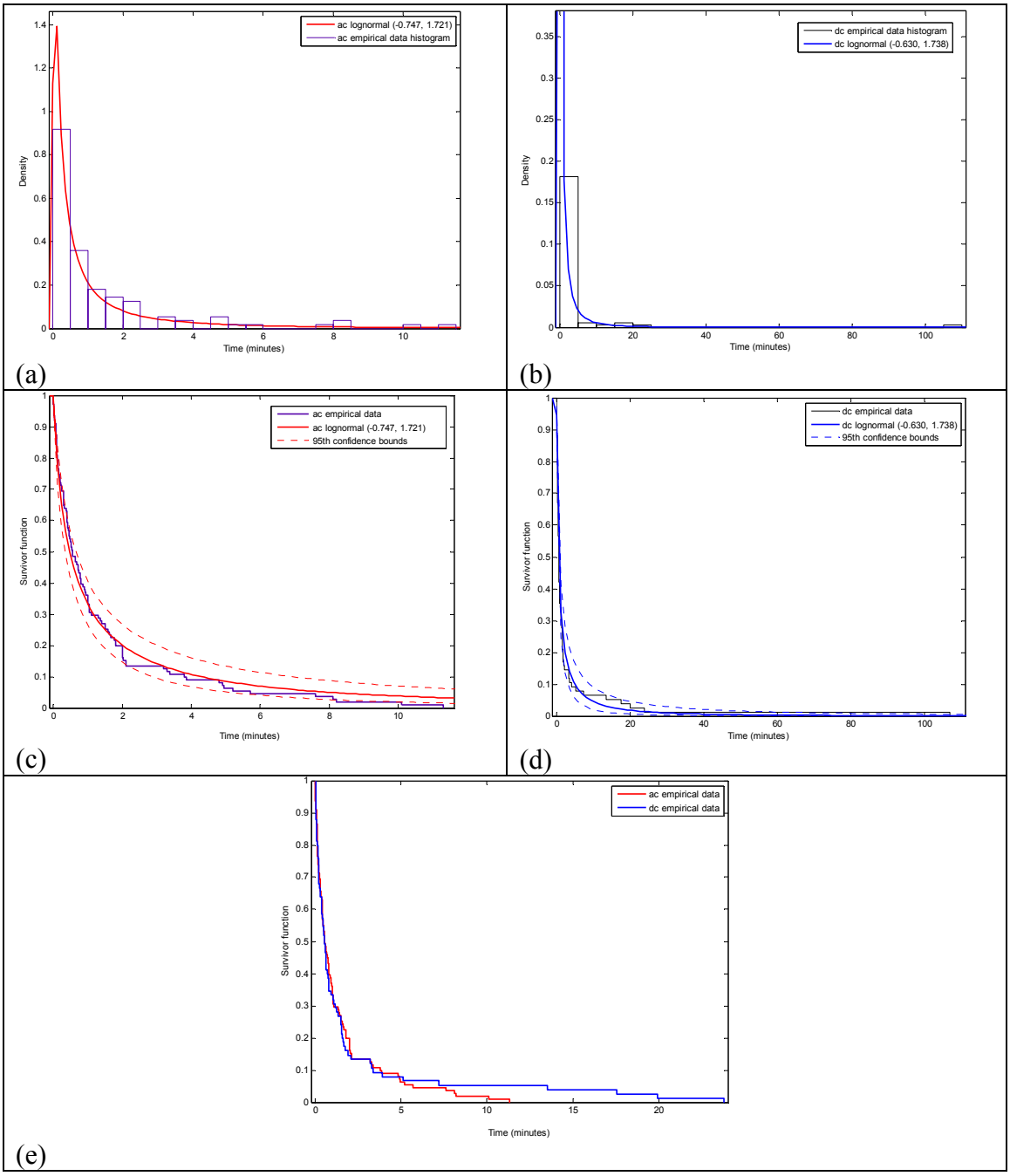

Figure 1. **Empirical data and parametric distributions for AC and DC spurious operation duration. Histogram and probability density function (a, b), empirical and distribution survivor function (c,d), empirical data survivor function (e).**

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Resolution:

Based on the knowledge and review of the test data, along with discussions held during the meetings, the working group reached a consensus recommendation, as stated below.

Recommendation: The duration of a single hot short-induced spurious operation may be limited to 20 minutes for AC circuits, and 40 minutes for DC circuits. This limitation is not applicable to spurious operations of circuits involving a "sealing in" or "latching" mechanism.

Basis: The tests performed on AC circuits resulted in 111 fire-induced spurious operations, the longest being 11.3 minutes which was observed in the NEI testing. The DC circuit testing resulted in approximately 76 fire-induced spurious operations (excluding switchgear) with five (5) of the 76 lasting longer than the longest AC spurious operation duration (i.e., 13.5, 17.5, 19.9, 23.8, and 107 minutes). Based on an understanding of the test data, and consensus amongst working group members, a limit of 20-minutes for AC circuits and 40-minutes for DC circuits appears reasonable. The working group chose to maintain the existing 20-minute limit for AC circuits based on the margin between this limit and the longest observed AC circuit spurious operation duration. Maintaining the existing duration of 20-minutes for AC circuits also has a minor benefit in that consistency of regulatory guidance is maintained. The 20-minute limit equates to less than a 1 percent chance of experiencing a fire-induced spurious operation lasting greater than 20 minutes for AC circuits, based on currently available test data and corresponding distribution fit presented in Figure 1c. Using this same criterion of less than 1 percent for DC circuits, along with the comparison of the relative difference between the DC and AC data, the corresponding limit for DC circuits is 40-minutes.

The recommendation of the working group on this topic is technical in nature. The working group sees no technical basis for applying this information differently to components classified as either required for hot shutdown, important to safe shutdown or high impact. Therefore, the working group does not provide regulatory recommendations on use of the technical information. As such, any application of this information to circuits for components classified as either "required for hot shutdown," "important to safe shutdown," or "high impact", based on these regulatory classifications is outside of the scope of this recommendation.