Electrical Equipment Failures
Cause & Liability

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About the Author

Robert (Bob) Abend gained his initial career experience in the semiconductor component industry where he frequently conducted microcircuit test and failure analysis in order to improve reliability. He performed as Director of Engineering at the Air Force Space and Missile Systems Center overseeing rocket (launch vehicle) and satellite development and production. Costly launch vehicle and satellite failures are, of course, unacceptable and reliability is key. He also holds four electronics related US Patents, and is a State Registered Professional Electrical Engineer. Bob has been practicing as an expert since 1991 and recently became President of Robert Abend, PE LLC offering engineering consulting services.

Executive Summary

Many insurance claims and lawsuits are the result of electrical system failures. The basis for such actions is frequently personal injury and/or property damage that can be caused by fire or other degradation of related systems, vehicles or structures. It will be shown that electrical systems can have high inherent reliability to minimize end-product field service costs, safety hazards and, of course, liability. Failures of electrical systems are most frequently due to external factors such as poor design, improper use, faulty manufacturing, substandard service, mishandling and other causes. System malfunctions are rarely caused by random component failures and a properly executed failure analysis will almost always identify an entity liable for resultant damages. Reliability is a fairly complex topic with many different methods and definitions. This paper provides a simplified top-level view of the subject with a focus on causation, which can be the external factors referenced above. Much of the ensuing discussion also applies to mechanical equipment and readers do not need to fully comprehend included mathematical content to understand this paper.

Definitions

Component: For the purposes of this paper, a component is the lowest level system element, such as a transistor, microcircuit, capacitor, resistor, switch, connector . . . . . . Most types of components are available at various reliability levels to meet the needs of a given system application.

Subassembly: An assemblage of components performing a sub-function within a system.

Electrical System: The top-level assembly of subassemblies and components yielding a working electrical end-product such as a home appliance. Such systems also frequently incorporate mechanical and electromechanical components.

Reliability: The probability that a component, subassembly, or system will operate according to specifications for a given period of time “t”. Reliability is represented as R(t); a function of time.

Probability: A value between 0 and 1. A reliability of 0 would signify no chance of survival with 1 indicating a 100% chance of proper operation for the specified time period.

Failure Rate: The number of failures likely to occur in a specified period of time. Failures per million hours (FPMH) is a frequent metric. The symbol for failure rate is usually λ (Lambda).

Euler’s Number: 2.71828 represented as “e”, or more accurately: $e = \lim_{x \to \infty} \left(1 + \frac{1}{x}\right)^x = 2.718281828459...$

Redundancy: Replication of critical components and/or subassemblies in a system as a failsafe backup measure to improve reliability.

Burn-In: Operation of a system, subsystem or component for a specified period time to cause and correct initial Infant Mortality failures.

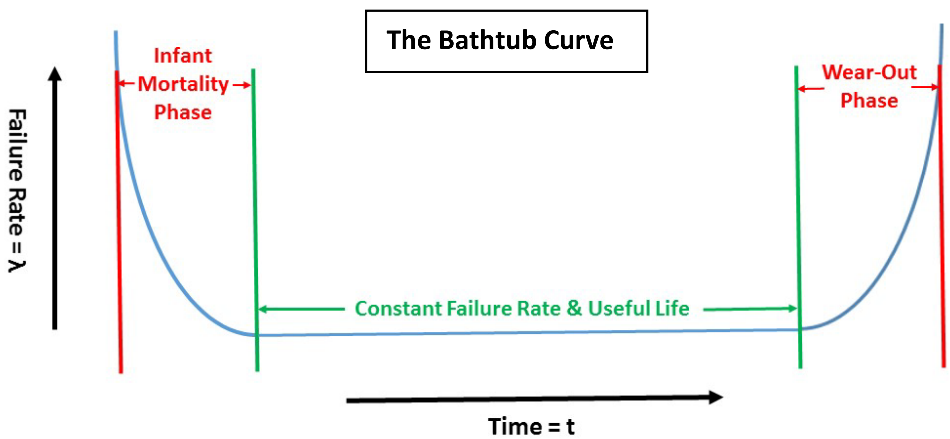
Failure Analysis: The discipline used to determine the root cause of a component or system failure. This process is frequently employed by technical litigation support experts to identify entities liable for a system failure.

The Bathtub Curve

Systems, in general, go through three phases of reliability:

1. Infant Mortality - Initial defects cause a high but decreasing failure rate
2. Useful Life - The system experiences a low and constant failure rate
3. Wear-Out - The system approaches end-of-life with an increasing failure rate

The three phases are shown in conceptual graphic form below:



It is generally accepted throughout industry that the system manufacturer is responsible for ensuring products are not released for end use until they exit the Infant Mortality Phase. Burn-in is one method that can be used to reach the Useful Life Phase before final delivery of the product. Burn-in time can be reduced by stressing a system with high temperatures and other parameters that may be beyond the normal operating environment. Careful selection of stress factors, their duration, and values is mandatory to avoid inadvertent degradation of system reliability and/or excessive consumption of Useful Life.

Component Reliability Exemplar

A hypothetical system has 100 electrical components, each with 1 failure per million hours (FPMH) of operation during the Useful Life Phase.

a. There are approximately 8766 hours per year
b. 1,000,000 hrs ÷ 8766 hrs/yr = 114 years; so each component can be expected to fail once every 114 years

c. Because there are a total of 100 electrical components, there would be 100 total FPMH for the system
d. That equates to 1 failure every 1.14 years assuming failures are evenly distributed over the 114 year period
e. Based solely on electronic component reliability, the system would have a yearly failure

In reality, there are usually additional mechanical apparatus, electrical connections, and other components that can fail in the system. Therefore, 1 FPMH for each electrical component could be considered inadequate reliability from a practical warranty cost perspective and possible safety concerns.

Component Reliability Calculation

Using the 1 FPMH assumption for each component during the Useful Life Phase, the reliability or probability a single component will operate within specifications for one year is as follows:

R(t) = Reliability

λ = Failure rate = 1 FPMH = 0.000001 FPH (Failures Per Hour)

t = Time period of operation = 1 year = 8766 hrs

e = Euler's Number = 2.71828

$R(t) = e^{-\lambda t} = 2.71828^{-(0.000001 \times 8766)} = 0.991272$

There is then a **99.1272%** chance of proper operation for 1 year.

If single component reliability = 0.991272 (R_c) and there are 100 components (n), then 1 year system level reliability would be = $(R_c)^n = (0.991272)^{100} = 0.416182585 \approx 42\%$. A 42% chance of proper operation for 1 year would be unacceptable for many if not most system applications. Fortunately, components with far greater reliability are readily available.

Redundancy

Components and subsystems can be replicated to significantly improve reliability for, as an example, a critical safety application. With double redundancy, a critical component is duplicated with the same component type so the system will continue operating within specifications if only 1 of the 2 redundant components is performing properly. The system then becomes single fault tolerant for those 2 components.

Using the 1 FPMH reliability calculation example above, the probability that both redundant components will fail in a 1 year period

$= (1- R_c)^2 = (1 – 0.991272)^2 = 0.0000762$

The probability that at least 1 of 2 components will remain operational for 1 year

= (1 – 0.0000762) = 0.99992 = **99.992%**

The above result for redundancy shows a significant improvement in reliability. Triple redundancy employing 3 components could further improve reliability and other more complex forms of redundancy can be used. Just to exemplify, if all 100 components had a 1 year reliability of 0.99992, the chance of proper system operation for that period would be = 99.2%.

Mean Time Between Failures (MTBF)

MTBF is a frequently used and often misunderstood metric, and can be calculated as $1/\lambda$. If λ is 0.000001 FPH, MTBF (m) is 1,000,000 hours. It then follows that $R(t) = e^{-\lambda t} = e^{-t/m}$. If t = m, $R(t) = e^{-1} = 1/2.71828 \approx 0.37$. There is then only a 37% chance of reaching the specified 1,000,000 hour MTBF without a failure. On that basis, R(t) may be a more indicative reliability measure.

Conclusions

In reality, many electrical components can have reliabilities that are more than an order of magnitude better than 1 FPMH, and not all component failures result in system failures. There are also other methods of improving system reliability such as predictive measurements. Product designers have numerous tools available to minimize failure rates at the system level and once a product design is complete, manufacturers can determine if required reliability levels have been reached. On that basis, electrical system failures, particularly in critical safety areas, are almost never caused by random component failures during their Useful Life Phase. If external factors to the electrical system such as design, manufacturing, testing, quality surveillance, service, installation, repair, *et al* are conducted properly, internally generated system failures resulting in fires or other critical safety issues would be virtually nonexistent. **The bottom line is that a solid failure analysis process, conducted by an expert, for an electrical system failure resulting in a personal injury and/or damage claim will very likely identify a liable entity.**