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Electrical power distribution system operating experience review for fusion applications

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Abstract

This paper describes safety research on electrical distribution systems applicable to fusion facilities. Electrical power has many uses in both magnetic and inertial fusion experiments; it is the most important support system for any fusion experiment. Electricity powers a wide variety of plant equipment, including vacuum pumps, magnets, coolant pumps, air handlers, compressors, and either plasma heating or target implosion drivers. Electricity also powers instrumentation and controls, control and data acquisition computers, accident mitigation systems and site security systems. Most facilities use electrical power to ensure adequate confinement of radioactive materials via air pressure zone control, valve isolation, and operation of cleanup systems. As a result, operating experiences of electrical switchgear, cabling, motor control centers, and electrical panels have been examined for reliability, maintenance times, accident case histories, accident initiating event frequencies, and personnel safety issues. Electrical component failure rates and repair times, and initiating event frequencies are presented in this paper.

Keywords: Failure rate data; Electrical equipment; Initiating event frequencies

1. Introduction

Many fusion experiments have experienced one or more electrical fires that resulted in unscheduled downtime for repairs, so frequencies of electrical fires are modestly high. Consequences from electrical fault events have typically been low at past fusion experiments, but as power demands increase, plant damage from failures is expected to increase. Failure rates presented here support operational safety assessment of existing fusion experiments and provide feedback to designers of near-term experiments.

The effects of an electrical fire on plant safety must be examined on a case-by-case basis. Each facility will have a unique electrical distribution system design to accommodate its needs; failure effects can be evaluated by a fault model of the distribution system. Component failure rate data given in this paper can quantify a generic electrical distribution system fault model. Initiating event (IE) data on electrical fires are also important to plant safety. These component failure rates and IE frequencies support risk assessment for magnetic and inertial fusion experiments. Operating experiences with electrical power distribution systems in

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the Department of Energy (DOE) and commercial nuclear facilities have been reviewed to understand the types of events that have, and could, occur with these systems at a fusion facility [1]. Event severity has also been studied. Electrical equipment fire events have been reviewed. Failure rates for components in electrical power systems and representative average repair times have been selected from the literature for safety or risk analyses of fusion facility power distribution systems.

2. In-plant electrical distribution system component failure rates

Table 1 presents recommended electrical system component failure rates. These data were harvested from the literature, compared, and recommended values were chosen based on similarity of data. In a few cases, geometric averaging was used. The failure modes and statistical error for these failure rates are also given in the table. The data values have mainly come from nuclear fission and other power plants; applying these data to fusion systems does not pose any significant uncertainties. Electrical power distribution systems are designed for efficiency; they are very similar for fusion experiments, power plants, and industrial plants. The data values presented in the table have been derived from operating experiences of matured components and are constant failure rate values.

The International Energy Agency agreement on Environmental, Safety and Economic Aspects of Fusion Power has a task on failure rate data collection [2]. The participants in this task agreed to compare their data to independent data sets to determine if there were any wide discrepancies in the failure rate data being used for fusion safety studies. A consensus among task participants was reached that if the data values were within a factor of 3, then the data compared well, or 'good'. Within a factor of 10, the data were 'fair', and beyond a factor of 10, the data compared poorly, or 'poor'. Such a comparison was made and is also shown in Table 1. The comparison data, in this case electrical equipment data, came from a published military failure rate data source [3]. The results in Table 1 show that a few values were good comparisons (20%), some gave fair comparison (40%), and some gave poor comparisons (40%). The high percentage of poor comparisons led to closer examination of those values. The failure rate values from military sources were 'all failure modes' values rather than failure mode-specific values, so there will be some fractional discrepancy with the values due to the way the data were calculated and presented. The poor comparisons are also probably partly due to differences in equipment. Component sizes were not always identified in the military data, so it is possible that the 'ground fixed' military components differ in size or rating from power plant units. For example, cables could be different ampacities, etc.

3. Electrical component repair times

Table 2 gives some estimates of repair times for most of the electrical components and equipment considered here. The repair time is useful for plant availability studies.

4. Electrical component initiating event frequencies

This section gives some values for electrical component failures that affect more than just the downstream components powered by the equipment. The equipment of interest for IEs are transformers, circuit breakers (CBs), cables and cable connectors, and switchgear. This section discusses these components individually below. A generic power plant fire IE frequency for all plant systems over a calendar year is an average of 3.2E−2/year [4]. This fire frequency value has been decreasing over time; nonetheless, electrical fires are a major contributor to that frequency. Table 3 gives some recommended IE frequencies for electrical equipment items.