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Cadick Corporation

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Engineering. . . Why?

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Author's Preface to Revisions 009a and 009b

This original version of this paper (009) was written for publication in the Winter 1992-93 edition of *NETA World*, the official publication of the InterNational Electrical Testing Association. In the ten years since that publication technology, safety requirements, and standards have all progressed. Subsequent revisions include the information found in the first version plus:

- The addition of flash-hazard studies
- New or modified regulatory information
- New or modified questions from students in training classes

I hope this revision is as useful to readers as the previous versions appears to have been.

Introduction

Over the years, in many of my electrical safety and engineering course and consultations, the relationship between safety and good engineering practice has been broached. Almost inevitably the practical and/or regulatory requirements for the performance of short circuit analysis, coordination studies, and (more recently) flash-hazard analysis are discussed. During these discussions I am reminded that many in our industry do not have a full understanding of the value and need for these critical engineering studies.

In this paper I explore the concepts which underlie short circuit analysis, coordination studies, and flash-hazard analysis including definitions, regulatory requirements, and common sense aspects for their performance. Each of the major headings which follow are questions that have been asked numerous times in many different training classes and/or client consultations. The answers that are given below each heading are summaries of the discussions that developed as a result of the questions.

What are short circuit analyses, coordination studies, and flash-hazard analyses and how are they used?

A short circuit study determines the magnitudes of the currents that would flow for faults placed at various busses throughout the power system. This information is used for several purposes including:

- Determination that interrupting ratings for fuses and circuit breakers are adequate for the available fault currents. (per Article 110-9 of the NEC)
- Setting of trip points for overcurrent and other trip devices
- Determining current cut-off points for protective device time and instantaneous characteristics
- Input data for the flash-hazard analysis

A coordination study is performed to make certain that overcurrent protective devices are selected and set to properly protect the power system. Before powerful computer platforms were available, coordination studies were performed by hand, using special graph paper and manufacturers' time-current characteristics. The modern engineer selects from a variety of commercially available software graphics programs that allow the plotting, analysis, and engineering to be performed much more efficiently. Whether performed manually or by computer the coordination study uses the information provided by the short circuit analysis. The results of the coordination study are used for the following purposes:

- Select and set overcurrent devices to insure selective tripping (per Article 240-12 of NEC).[1]
- Select and set overcurrent devices to trip as quickly as possible under various short circuit conditions
- Make certain that protective devices operate quickly enough to protect system equipment such as transformers, motors, generators, and cables (per Article 110-10 0 of NEC)..
- Provide input data for the flash-hazard analysis

Flash-hazard analysis is performed to determined the energy levels expressed in calories per square centimeter that will be present in the system during the occurrence of an electrical arc. This relatively new type of study has been introduced as a result of the number of electrical-arc injuries and the resulting research since the late 1970s. The rigorous performance of a flash-hazard analysis uses a computer program based on procedures put forward by a number of researchers and codified by the Institute of Electrical and Electronics Engineers.[2,3]

The results of a flash-hazard analysis are used for the following:

- Determine the flash-hazard boundary.[4]
- Determine the amount of energy to which a worker will be exposed in the event that an electrical arc occurs at a given location (per Article 110-16 of NEC).
- Select arc-protective clothing appropriate for personnel working on or near exposed energized conductors.[5]

Clearly, each of this studies is critical to the safe, efficient, and economical operation of a power system. For example:

- If circuit breakers or fuses are incapable of interrupting fault currents, they may explode violently, injuring personnel in the area.
- If the wrong protective device operates, a *small* outage may expand to include an entire plant.

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[1] Selective tripping means that the nearest upstream device to the short circuit is the one that trips to clear the circuit.

[2] Other approaches are allowed by NFPA 70E; however, they all require the type of information determined using the short circuit analysis and coordination study. .

[3] At this writing the IEEE standard (Std - 1584) has been approved and is available.

[4] The flash-hazard boundary is the closest approach allowed to an exposed, energized conductor without the use of special arc-resistant clothing. See the Cadick Corporation Tech Bulletin TB-001a for details.

[5] Note that arc injuries can also occur when conductors are not exposed. The arc-protective clothing should also be used anytime a worker is exposed to the possibility of an electrical arc.

- If a transformer overload relay is too slow, the transformer may be damaged by excessive temperature rise.
- An electrical worker may be severely burned or killed because he/she does not have adequate thermal protection during an electrical arc.

The only way that these and other such mishaps can be avoided is to perform the three studies discussed in this paper and use their results to properly select and set protective devices and properly select thermal protective clothing.

Are these studies required by rules or regulations?

The *National Electrical Code* (NFPA[6] 70 or NEC) and *Standard for Electrical Safety Requirements for Employee Workplaces* (NFPA 70E) are the two principle sources of regulation in the areas of electrical installation and design and safety-related work practices.[7] First, let's look at some sections of the 2002 NEC. The underlined titles are the major NEC sections.

Article 100 - Definitions

> **Interrupting Rating.** The highest current at rated voltage that a device is intended to interrupt under standard test conditions.

Article 110 - Requirements for Electrical Installations

> **110-9. Interrupting Rating** Equipment intended to break current at fault levels shall have an interrupting rating sufficient for the nominal circuit voltage and the current that is available at the line terminals of the equipment.
>
> Equipment intended to break current at other than fault levels shall have an interrupting rating at nominal circuit voltage sufficient for the current that must be interrupted.
>
> **110-10. Circuit Impedance and Other Characteristics** The overcurrent protective devices, the total impedance, the component short-circuit current ratings, and other characteristics of the circuit to be protected shall be selected and coordinated to permit the circuit-protective devices used to clear a fault without the occurrence of extensive damage to the electrical components of the circuit. This fault shall be assumed to be either between two or more of the circuit conductors, or between any circuit conductor and the grounding conductor or enclosing metal raceway.
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> **110-16. Flash Protection** Switchboards, panelboards, industrial control panels, and motor control centers that are in other than dwelling occupancies and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electrical arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing or maintenance of equipment.

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[6] NFPA is the National Fire Protection Association. The publisher of the *National Electrical Code* and *The Standard for Electrical Safety Requirements for Employee Workplaces*.

[7] Most of the Occupational Safety and Health Administration (OSHA) regulations are based on NFPA and other industry standards.

Article 240 - Overcurrent Protection

> **240-12. Electrical System Coordination** Where an orderly shutdown is required to minimize hazards(s) to personnel and equipment, a system of coordination based on the following two conditions shall be permitted:
> (1) Coordinated short-circuit protection
> (2) Overload indication based on monitoring systems of devices

NFPA 70E (2000 edition) says –

Chapter 2 General Requirements for Electrical Work Practices

> **2-1.3.3 Flash Hazard Analysis**. Flash hazard analysis shall be done before a person approaches any exposed electrical conductor or circuit part that has not been placed in an electrically safe work condition.

NFPA 70B, Electrical Equipment Maintenance, 1998 Edition also has a section which applies:

> **5-4.3** An up-to-date short circuit and coordination study is essential for safety of personnel and equipment. It is necessary to analyze the momentary and interrupting rating requirements of the protective devices. That is, will be circuit breaker or fuse safely interrupt the fault or explode in attempting to perform this function.
>
> Another phase of the study is that of developing the application of the protective device to realize minimum equipment damage and the least disturbance to the system in the invent of a fault.

Taken in their entirety, the regulations quoted here clearly require that a short circuit analysis, coordination study, and flash hazard analysis be performed.

When should these studies be performed?

Few would deny that such studies should be performed during the design of an electrical power system. But how about later, as the system ages? Several things happen to require the performance and/or re-evaluation of these studies for an existing system:

- Electric utilities continually add capacity. Your utility may have had a 200,000 kVA fault capacity when the plant was new. Now, however, the capacity may have double, tripled, or more. Such changes can cause fault duties to rise above the ratings of marginal interrupting equipment.
- Since the mid-1960s, many plants have added internal generation to their system. This generation adds to the fault capacity of the system.
- Operating procedures may have changed. A bus tie breaker that was originally operated normally-open, may now be normally-closed to carry or balance load flows. Such a change can greatly increase fault capacity by paralleling two or more sources.
- Technical standards can change. For example, since 1980 the protection requirements for liquid-filled and dry-type transformers have changed. Studies showed that many transformers were being mechanically damaged by high value through faults.[8] The protection requirements have become

[8] A *through fault* is one which occurs downstream fo the transformer and causes fault current to flow through the transformer. The transformer itself is not short circuited.

more stringent for such devices. Although the standards do not require existing systems to be changed,[9] wouldn't it make sense to at least review your system? The protection changes might be minimal.

- New installations or plant modernization may add capacity and other coordination streams to the system. For example, coordination studies require that the main breaker coordinate with at least the largest feeder device. If a larger feeder device is added later, the coordination study must be reviewed.
- Flash-hazard analysis requirements and techniques have been developed only since the mid-1990s. Most systems were built before then and probably do not have the necessary information. Note that the flash-hazard is clearly a safety-related study.

In general, the three studies should be reviewed and updated at least every five years.

Who should do my electrical studies?

These studies, like all engineering tasks, should be performed by a registered professional engineer. Many electrical testing companies and consulting engineering firms, such as my company, have the ability and experience to perform them.

A word of caution; these are specialized engineering services, and not all A&E (Architect & Engineering) firms have the experience, personnel, or software to do them.

Are there any other studies like these that should be performed?

ANSI/IEEE Standard Std-399, *Power Systems Analysis* (also called the *Brown Book*) is the standard which covers most of the engineering studies that are key to the proper design, performance, and safety of an electrical power system. The *Brown Book* is one of the volumes in the IEEE color book series and should be referenced when you are deciding what studies to perform and how to perform them.

The *Brown Book* lists eleven studies including load flow, short circuit analysis, stability, motor starting, harmonic analysis, switching transients, reliability, cable ampacity, ground mat, coordination, and DC auxiliary power system analysis. Flash-hazard analysis is relatively new and has not yet been included in the *Brown Book*. Whether any of these studies besides the three discussed in this paper are performed will be determined by the specifics of the power system and the desire of the system operators to operate it safely, efficiently, and economically.

Conclusion

This paper provides a body of information calling for the performance of these types of engineering studies. Clearly, common sense and regulatory requirements dictate that a short circuit analysis, coordination study, and flash-hazard analysis should be performed.

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[9] Article 80.9(B) of the NEC does allow the authority having jurisdiction to require changes in existing installations where an imminent danger to occupants exists.