Safer Electrical Systems in Tall (or Large) Buildings

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ABSTRACT

In tall (or large) buildings, additional time and distance are involved for egress of occupants and ingress of emergency personnel to the farthest locations inside the building in an emergency, compared to smaller buildings. For this reason, tall building designs should include the maximum electrical safety systems possible, and such systems should operate at a reasonable cost.

Electrical fire safety generally focuses on using the correct components and installing them in methods conforming to building codes. However, this approach currently leaves many risks of fire and several significant electrical overheating modes without protection. These risks may be deemed acceptable in smaller buildings; however, in a tall building, a fire which may be easily escapable in a smaller building may become more serious or fatal. To improve electrical fire safety in tall (or large) buildings, an overall systematic approach is needed. It must utilize the best components in a coordinated method to achieve significant protection over heretofore unprotected electrical overheating modes.

Two such overheating modes are poor connections and insulation breakdown due to moisture exposure. Standard circuit breakers do not protect against these overheating modes, especially in their initial stages.

Suggestions for better protection against these risks include the following:

- Utilization of GFCI, AFCI, or RCD leakage protection devices on all or most electrical outlets and permanently connected appliances. The AFCI also senses other problems, however, the focus of this paper will be on the leakage protection aspect
- Usage of cord-connected appliances that have a grounding system, i.e. a grounded cord and an internal grounding network that is ideally located between the energized conductor(s) and the neutral, in all locations. This would involve development, testing, and dissemination of improved electrical products which have a more complete internal grounding system, such that leakage current would be sensed at an earlier time, de-energizing the electrical appliance. This process would most likely involve an ongoing, long term process, and multi-agency/organization/company effort; however, I believe the rewards are great and relatively economical
- Usage of smoke detectors that deenergize certain circuits inside the building
- Training and inspection to make sure less safe (i.e. dangerous and/or ungrounded) appliances do not get used in the building
- Maintenance and/or building personnel who would be available to educate the building occupants about the protocol for usage of electrical appliances and what to do if a problem arises; inspect all electrical appliances and decide what can be used and what cannot be used in the building; be trained to troubleshoot problems due to tripping of the circuit breakers, GFCI's, and AFCI's; and document problems with the electrical systems and what was done to remedy the problems
- Document problems found on a database so this information is easily accessible by maintenance personnel of the same and other tall buildings.

1 INTRODUCTION

When you are on one of the upper floors of a high-rise building, wouldn’t you feel safer if you knew that there were safety systems in place to stop electrical overheating of an appliance or building wiring that had significantly degraded before a fire started? Efforts toward better extinguishment, warnings, personnel egress, and minimizing flame spread after a fire is in the free-burning state are worthwhile and save lives; however, it would be even better if the fire did not start at all.

I am writing this paper because there is a tremendous potential for stopping unwanted electrical overheating before fires start. I have devoted much of my career to improving electrical safety in the product design and forensic engineering disciplines. At this point in time, we have an opportunity to move the safety of electrical systems ahead significantly.

If you are an architect or building designer, you may have much more control than you know in making these improvements. The challenge is to sustain an accelerated evolutionary process of engineering safer electrical systems which take advantage of the knowledge and tools that are available today and in the future. Using codes and standards to mandate minimum safety levels is a good baseline, but I believe that significant strides can be made to improve electrical safety by actively looking for creative solutions to exceed the minimum code requirements. As an added benefit many of my recommendations also include significant shock safety improvements.

Often, the building electrical codes do not require additional safety features in tall buildings, even though the risks of those on higher floors is greater than those for occupants of smaller buildings [1]. I am proposing an actively-managed systematic approach, as opposed to the typical electrical systems used at this time. These new systems include improvements in building circuit protection devices, better grounding of cords and appliances, and appropriate maintenance. The goal would be to sense problems at an early stage and to de-energize the circuit prior to a fire. Even though these ideas have an obvious application to tall buildings, they ultimately could be used in any structure.

2 ELECTRICAL FIRE BASICS [2]

Fundamentally, electrical fires start via one of three initial electrical overheating modes:

1. poor connections
2. excessive current
3. insulation breakdown

One of the most efficient fire-causing modes is the poor connection, as the heat flux is typically high and the duration of heating is often long. In contrast, the least common of these modes is excessive current, since circuit breakers and fuses usually provide adequate protection. Insulation breakdown is another significant fire-causing mode. It encompasses many types of failures such as short circuits and insulation degradation due to heat, moisture, and other contaminants which can result in the ignition of the nearby combustibles or the insulation itself. This paper will focus on examples of poor connections and insulation breakdown.

Typically, during the early stages of the overheating process, the insulation degrades and current leaks through or across the surface of the degraded insulating material from a high-voltage conductor to a conductor at zero voltage. This leakage current is often involved with the initial ignition of combustibles and can be detected by sensitive electronic circuits and used to de-energize the circuit. Smoke generation is also common during the initial stages of electrical overheating and the use of smoke alarms tied to a relay can be used to de-energize overheating circuits.

3 TYPICAL FIRE-PRONE APPLIANCES

As forensic engineers, we see fires occur fairly frequently with appliances which use a moderate to high current level, are used continuously, and are exposed to moisture. Two appliances frequently involved in fires are battery chargers and salt water aquariums. Some unique characteristics of these appliances and their failure modes are shown below. Battery chargers are prone to poor connections as the connections are often exposed to dirt and contamination, the current levels are relatively high, they run continuously, and the contact pressure can be variable.

Fig. 1. Typical battery charger for cordless power tools.

Salt water aquarium lights, heaters, power strips, cords, and pumps are prone to overheat as conductive salt water can bridge over electrical insulation and cause degradation, breakdown, and corrosion of contacts causing poor connections. These appliances also run continuously and have relatively high current levels.

Fig. 2, salt water aquarium.

4 TYPICAL ELECTRICAL PROTECTION SYSTEMS AND LIMITATIONS

The most common protection device for buildings is the circuit breaker that protects the building wiring and some components of the appliances plugged into outlets against overheating due to excessive current levels.

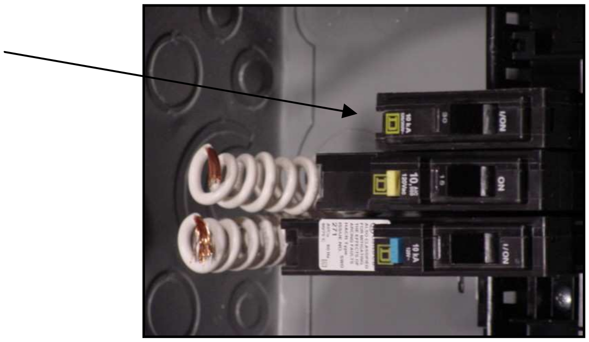

Fig. 3, Circuit breaker shown by arrow, Square D Corporation QQ, model.

However, protection systems for poor connections and insulation breakdown are generally poor or non-existent. Of the two, there are no effective building-wide protection systems for the initial effects of poor connections yet developed (like circuit breakers that protect against excessive current). The best we can do today is to look for secondary effects such as leakage current and smoke after the insulation begins to degrade, so the circuit can be deenergized soon after overheating due to a poor connection occurs.

Shown below is a typical poor connection where a solid wire makes light contact with a binding screw while conducting a high current. Note the glowing of the wire at the point that the wire touches the screw and the degradation of the wiring insulation locally at the screw.

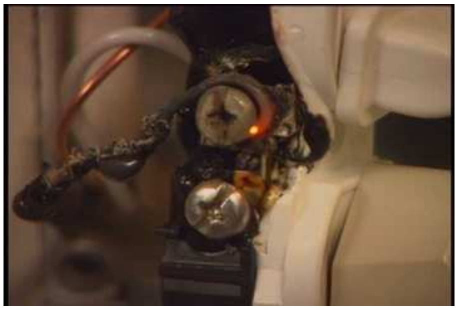

Fig. 4, Demonstration of glowing wire at a poor / loose binding screw connection, 14Amps, 14 AWG solid wire.

Shown below is a demonstration where a conductive liquid (bleach in this case) conducts or leaks current across the surface of plastic of a switch that is in the “off” position. The plastic, when dry, insulates between the hot and neutral conductors. However, when the conductive liquid is present, the current leaks across the surface of the plastic allowing the light bulb to light up. This current heats the plastic, forms carbon that glows (called arc tracking), generates smoke, and drives off flammable gases which ignite due to the arc tracking.

Fig. 5, Example of ignition of gasses from switch plastic by arc tracking across the charred plastic surface of the switch due to the presence of conductive liquid on the switch.

5 LEAKAGE CURRENT SENSING SYSTEMS

5.1 AVAILABLE TODAY - GFCI, AFCI, RCD

Ground (and Arc) Fault Circuit Interrupters (GFCI and AFCI) and Residual Current Devices (RCD) are leakage protection devices that are designed to protect against electrical shock and electrical overheating. These leakage protection devices (available as outlets, appliance plugs, and in combination with circuit breakers) continually monitor an electrical circuit for leakage current which, as we discussed before, is typically present in the early stages of electrical overheating. These leakage protection devices trip to deenergize the electrical circuit after they sense between 0.005 to 0.030 Amps (5 to 30mA) of leakage current.

Fig. 6 and 7, GFCI (yellow arrow), AFCI (blue arrow), and RCD (red arrow), Schneider Electric SA.

GFCIs are generally used for shock protection in bathrooms, kitchens, outdoor circuits, and on cords for appliances such as hair dryers that can be accidentally dropped in water [3].

They typically have a button for testing the leakage protection device which simulates leakage current to make sure the leakage protection device is working correctly. Actually, with an effective ground, the GFCI also affords a high level of fire protection. AFCIs and RCDs are used for fire protection. In the US, the current National Electric Code (NEC) requires the used of AFCIs in bedroom circuits. France already utilizes the RCD extensively and the NEC is considering adopting proposals to expand the application of AFCIs to the entire electrical system in 2008 [4,5]. The effectiveness of the fire protection of these leakage protection devices is limited to a high degree by the grounding system present, as the grounding path allows leakage current to occur so it can be sensed by the leakage protection device. The term ground is equivalent to earthing circuits.

5.2 NUISCANCE TRIPPING OF LEAKAGE PROTECTION DEVICES

To be sure, there is a concern about whether tripping of these leakage protection devices would be a nuisance [6]. More troubleshooting is necessary when these leakage protection devices are present. However, for a leakage protection device to trip, the insulation typically has degraded by a factor of more than one thousand times. Assume there is one 120V appliance plugged into a building outlet protected by an AFCI insulation value which starts at 10Meg ohm, or 10 million ohms, which is a conservative (fairly low) value. Many products have insulation resistances starting at hundreds of Meg ohms. This value is the insulation resistance of the building wiring and the appliance(s) in parallel. However, as shown in the graph below, an AFCI does not trip (at its trip level of 0.030 Amps (30mA) until the insulation value falls below approximately 4000 ohms. For this to occur, the insulation must be degraded by a factor of 2500 times.

$R_{trip} = V/I = 120V / .030A = 4000$ *ohms*
where R_{trip} = *Nominal resistance when AFCI trips,* V = *Voltage in Volts,* I = *Current in Amps*

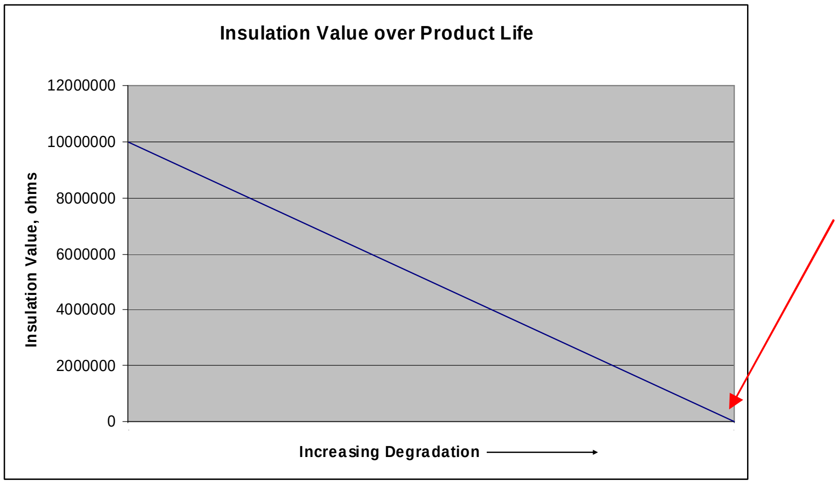

Fig. 8 is a graph that shows the insulation decrease with degradation. The red arrow points approx. to the (highly degraded) insulation level of 4000 ohms where a 120V AFCI would trip.

In regard to nuisance tripping, a tester should be used that checks both the trip characteristics of the leakage protection device at the normal trip level (AFCI should trip at approx. 31mA) and the non-trip level (leakage protection device should not trip at or under 28mA). This would show if the AFCI is tripping at too low a leakage current level and will be prone to nuisance tripping.

The standard method for troubleshooting leakage current devices is to use the process of elimination. Troubleshooting a trip that occurs consistently is fairly straight forward, but intermittent problem may be more difficult. In general, you need to do the following:

- Disconnect the electrical appliances one at a time to see if one appliance is causing the trip. If the faulty appliance is found, it can be tested on another circuit protected with the same leakage protection device (and one more or less sensitive to get more information on degradation level). Then the appliance should be discarded and replaced. If all appliances check out OK with the tripping circuit and a test circuit, the building wiring should be tested without the appliances plugged in. These appliances can then be documented and studied as to their early failure modes. This is often not available after an electrical fire.
- (If the trip still occurs), test the leakage protection device. If it does not check out (trip and non-trip level), the leakage protection device should be replaced. These failed leakage protection devices can then be documented and studied as to their failure modes.
- (If the trip still occurs), test the building circuit. These results can be confirmed with a Megger which measures the insulation resistance at a voltage such as 500V DC. When using a Megger, make sure all electronics are not present, as they can be damaged by the Megger. If the building wiring does not pass these tests, it should be replaced. Use of conduit makes this much easier. Any relays involved with de-energizing these circuits would also need to be evaluated as to their role in the building wiring functioning. These building circuits can then be documented and studied as to their failure modes.

5.3 FUTURE DEVELOPMENTS

5.3.1 BETTER GROUNDED APPLIANCES

Of course, the GFCI, AFCI, and RCD work best if there is a ground path for the leakage current. Many appliances have a grounding conductor in their cord, especially if there is accessible grounded metal in the construction of the appliance. The function of the grounds that are currently present are generally for shock protection. However, many appliances do not have a grounding conductor in their cord or body (often called double-insulated) appliances).

Wafer and I are proposing that these grounding systems be expanded, even for appliances without accessible grounded metal [7]. The expanded grounding system would, ideally, be present in the power cord and continue up throughout the entire appliance and be present between the hot and neutral conductors so it would form the path for current leakage to occur to ground so the GFCI, AFCI, or RCD could trip before ignition occurs. Thus, when used with a GFCI, AFCI, or RCD, the ground also affords us an early-warning system against electrical overheating along with shock protection. Interestingly, during the testing done for my video “Understanding Electricity and Electrical Fires,” I tried but was unable to ignite fires when the circuit was protected by a GFCI and grounding system. One currently available GFCI protected cord with a grounded mesh around the energized conductor can be seen on the website http://www.fireshield.com/FSCutaway.htm.

The most open-ended aspect of these protection systems is to work with various entities to make appliances available with improved grounding; these are generally currently not available. Some of these entities would most likely include the appliance manufacturers and various agencies such as Underwriters Labs (UL), the Consumer Protection and Safety Commission (CPSC), The National Fire Protection Association (NFPA), the International Electro Technical Commission, (IEC), and the Association for Electrical, Electronic & Information Technologies (VDE). The goal would be to set voluntary and potentially mandatory standards for leakage current and grounding for special and general-purpose appliances. The discussions, planning, testing, and regulation of these systems require a significant effort, but I believe they lead to a worthwhile goal: improving the safety of electrical systems.

5.3.2 SMOKE DETECTION SYSTEMS

For electrical loads that either are inherently dangerous or cannot be effectively protected by GFCIs, AFCIs, or RCD’s for whatever reason (such as the lack of availability of a grounded appliance) another option is available. Smoke alarms that de-energize circuits could be utilized. Smoke alarms currently are used to control fans and other electrical devices in tall buildings. This level of protection could also work with the sprinkler systems to make the building safer.

A ceiling headspace area directly above building areas (where inherently dangerous electrical appliances are located) can also be used to effectively trap smoke and hot gasses so they can be quickly sensed by a smoke detector. This ceiling headspace would be ideally a ceiling area that is above the normal ceiling level with a full-circumference rim to trap smoke. Areas such as kitchens (for cooking appliances), laundry rooms (for dryers), and work rooms (for battery chargers) would be excellent candidates for systems where a smoke detector could de-energize the electrical circuits that feed these devices. Critical electrical life systems such as lighting would need to remain functional so they would not be interrupted if smoke was sensed.

5.4 BENEFITS OF NEW PROTECTION SYSTEMS

The result of an actively managed system approach would be that the overheating electrical circuit would be de-energized prior to significant overheating or ignition, potentially saving lives and reducing property damage.

5.5 COSTS OF NEW PROTECTION SYSTEMS

The added costs of an actively managed system would consist of:

- The differential costs of GFCI, AFCI, or RCD circuit breakers over standard circuit breakers
- Planning a small-scale test in a building with the system details chosen
- Planning a large-scale test, after small-scale performance is acceptable
- The costs to fully document the electrical system (mark all circuit breakers with the loads fed, mark all outlets as to the circuit breakers feeding the outlet, and document the routing of all circuits within a building) for quick reference when problems occur. Keeping this documentation current throughout the life of the building.
- Upgrading or designing ceiling headspace and smoke detector systems that de-energize circuits, along with relays to de-energize circuits based on a smoke alarm actuation.
- Developing training and maintenance procedures to address problems such as tripping of leakage protection devices in a timely and cost-effective manner. Using the process of elimination: is it the appliance, building wiring, or GFCI causing the trip? Often, a great deal of time is spent tracing circuits; to have this documentation already done would allow the problem to be identified and rectified in a timely fashion.
- Continually review performance and make improvements.

6 RECOMMENDED ACTIONS

6.1 STUDIES ON BUILDING-WIDE AFCI/GFCI USAGE:

Prior to implementation of any large-scale building-wide electrical system changes, there is a need to set goals, plan and design the system, and to perform small-scale field tests to gather performance and cost data. Among the factors that would need to be considered are the following :

- Identification of the specific circuits to be protected (such as whether lighting circuits would be exempt from protection so that they would stay on in the case of a fire vs. whether they would be de-energized if they overheated)
- How far upstream the protection should be placed (single-phase vs. three-phase)
- Testing the dynamics of multiple leakage protection devices such as if a GFCI hair dryer is plugged into a GFCI outlet fed by an AFCI circuit breaker

6.2 MAINTENANCE

It would be beneficial to:

- Develop a long-term training program for the persons who will maintain the building.
- Monitor and catalog the electrical equipment going into the building. This needs be done diplomatically, as the needs of the occupants must be balanced with the potential risks.
- Make the expertise available to effectively and efficiently troubleshoot problems such as tripping so downtime and frustration are minimized.
- Use test power supplies to determine if the trip is due to the appliance or the circuit and the leakage protection device feeding the appliance.

7 CLOSING

If these efforts are successful, the results may not be highly visible as there sometimes may not be anything dramatic to witness when the failure is detected and stopped in its early stages. Hopefully, circuits that have started to fail can be identified and removed and the results used to show the benefits of the system. The challenge is to design the systems of hardware and maintenance such that the nuisance tripping and inconvenience is minimized. If we can show a continual decrease in electrical fires due to our efforts, our goal to improve the protection of those who occupy tall buildings will have been accomplished. It is hoped that many of the efforts made in making tall buildings safer would also translate into systems and products that will make buildings of all sizes safer.

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