Chapter 13

ELECTRICAL SAFETY IN THE THEATRE

Electrical current is dangerous. Every year people are killed or seriously injured by electrical accidents. There are two kinds of danger: that from electrical shock and that caused indirectly by electrical fires. The danger of electrocution is often ignored because of our familiarity with electrical equipment. Even in our homes, there is enough electrical energy at any socket or outlet to kill several people at once. In the theatre, although the voltage is the same as that at home, the amount of current can be many times that available in a home outlet. This increases both the danger from shock and the danger of electrical fire.

Even home current is dangerous.

How Much Current Is Fatal?

Electrical shock kills by overwhelming the body's own electrical system—minute electrical impulses which convey many of the signals that pass constantly through our nervous system. Heat can also play a part. The amount of damage done when current flows through the body depends on the part of the body involved and the amperage that flows. Voltage, per se, is relatively harmless without appreciable current. Therefore the body can withstand, with only minor annoyance, the effect of several thousand volts of static electricity passing through it as the result of scuffing across a dry carpet. On the other hand, a fraction of an ampere at "only" 120 volts passing through vital parts of the body can be fatal. Worse, under certain conditions a much smaller amount of electrical energy can kill. Fortunately it is not likely to happen on stage or at home, but even a few thousandths of an ampere at as low as 40 volts can kill if this current passes through the most vital parts, while say, on an operating table. Thus electrical danger varies with the part of the body included in the circuit—not a matter to be studied by trial and error!

Very small amounts of current can be deadly.

Legal Aspects

The basic hazards in the use of electrical current are based in the laws of physics, how electrical current flows, its affect on the human body and on the equipment that uses it. Since human beings do not always act in a way that conforms with the laws of physics, man-made laws are devised to control their folly. These can be state, county or city ordinances or codes that the theatrical technician must be aware of and obey if he or she is to work safely and avoid legal difficulties. Many of these laws have their origin in the *National Electrical Code* (NEC), a model safety code produced by the National Fire Protection Association, a nongovernmental body supported by the fire insurance companies. This document, generally known as "the Code," is revised every three years. Revisions have the benefit of input from theatre specialists by way of representatives to the Code revision body from the United States Institute for Theatre Technology (USITT) and from Entertainment Services and Technology Association (ESTA). Additionally, as revisions are being worked out, input is solicited from a wide variety of sources, including theatre technicians in addition to those who sit on the committee. The final version is then published and is widely available including copies in public libraries and on sale at many bookstores. It may also be purchased directly from the National Fire Protection Association, 60 Batterymarch Street, Boston, Massachusetts 02110. Every theatre technician should have a current copy in his or her library.

National Electrical Code (NEC)

Who has input into the code?

It is important to know that "The Code" has no legal status of its own; it is merely a set of recommendations. However, it is almost universally written into local law either by being accepted wholesale or as a backup to local law. This practice gives the code the power of law. Generally in large municipalities such as New York City or Los Angeles, an extensive locally-written code is enforced which is more stringent than the National Code. In such places, there is nearly always a "cover-all" stipulation that says that any areas not specifically covered by local ordinance must conform with the NEC.

The Code is the basis for most local laws.

Clearly every lighting technician must be very sure that he or she understands the safety laws. This includes not only a familiarity with the NEC, but specific understanding of local ordinances. This is important for everyday lighting activities but comes to the forefront when the lighting technician is making recommendations for renovation or construction of theatre lighting systems. Often this knowledge will work to the advantage of the technician. Local ordinances that cover general construction often impose wiring practices that are not only inappropriate to the theatre, but are excessively costly. With the exception of very large cities, few local laws involve themselves with the specifics of the theatre. Referring to the NEC will provide the technician with details specifically related to the theatre and moreover, these regulations will be better suited to the needs of the theatre.

Local codes are often inappropriate to the theatre.

The UL Label

The National Fire Protection Association also supports another safety-related activity, the Underwriters' Laboratories, Incorporated. This is an equipment-testing group which, for a fee, tests electrical equipment for safety and grants the use of the "UL label" to equipment that meets its standards. It is very important to note that the UL label relates only to the safety of the equipment, not to its durability or effectiveness. Testing is voluntary, although having a UL label can be a great advantage, particularly when local laws require UL-approved equipment and/or specifications for new facilities insist on it.

UL label

The cost of testing, which may be considerable, is borne by the manufacturer who submits the equipment to the laboratory for testing. Each model change requires a new test at additional cost. Therefore lighting equipment manufacturers tend to limit testing to those items in their inventory that are planned to be in their catalogues for long periods of time. Thus the absence of the label, particularly from rare or newly released equipment, should not be interpreted to mean that the equipment is unsafe. It will be up to the theatre technician to study the equipment and make a judgment as to its safety as well as its efficiency and durability. If a large purchase is being considered, it may be worthwhile to have a testing laboratory examine the equipment. Additionally, some municipalities require testing of equipment being purchased, sometimes even in addition to the UL test, if this has been done. This can add a great deal to the cost of the equipment.

Special Legal Obligations of the Lighting Artist or Technician

The lighting specialist's first obligation is to the audience. They are his or her guests and there is a legal obligation to protect them from injury. The second obligation is to protect the life and limb of the theatre personnel and, finally, to protect the theatre, its equipment, and the production onstage from damage.

Since the audience is the first priority, the theatre worker will find that there are usually extra-stringent laws concerning their surroundings, particularly what hangs over their heads. For example, a falling color frame is a menace anywhere, but laws usually require that frames be prevented from falling on the audience by special mesh barriers at the openings of any lighting positions over the house. Backstage however, luminaires with color frames may hang in the open on battens although many localities require that they be restrained by safety lines.

Overhead safety

In addition to the moral obligation that each member of the theatre troupe has toward the audience, there is the very real risk of personal liability suits if someone is killed or injured. When an accident happens and a suit is filed, the usual procedure is to sue everyone who might conceivably share the blame. This can include anyone working on or in the production. If the suit is successful, the damages may be apportioned among all of those sued. A judgement can cloud one's financial future for years making credit difficult to get and taking away earnings. Obviously, the best defense against this threat is to abide by safety laws in every detail and make every effort to care for the audience and one's fellow workers.

Personal liability

Lighting Equipment for Safety: Exit Lights

Backup power for exit lights

Special signs reading "EXIT" are illuminated so that they can be seen even if all other lighting is off. This means that they must operate on special electrical circuits that are guaranteed to remain on during a power outage. The extent of this guarantee depends on local law—there are even instances where the local code requires that the exit lights be baked up by gaslights on the theory that these will continue to operate for a useful period of time on the gas in the lines when all else fails. A more reasonable approach is to provide each exit sign with two lamps, one operated on its own special supply taken off at the service entrance and the other supplied by the emergency lighting batteries or an emergency generator circuited to come on if the first goes out.

Exit lights must remain on with the brightness established when they were installed. No orders from a director should be allowed to cause them to be turned off or obstructed in the theatrical interest of a complete blackout or because they distract from a dark scene. If the lighting technician cannot enforce this rule himself or herself and the remainder of the theatrical hierarchy cannot or will not enforce this rule, the fire marshal should be notified and asked to inspect the premises and explain the rule on the operation of exit lights. A reminder of the risks of personal liability suits may also help.

It is illegal to tamper with the exit lights.

Maintenance of exit lights will not ordinarily fall to the theatre technician but that person should be supplied with a stock of the proper lamps for replacing those which go out when the regular staff is not available and there is to be an audience in the theatre. It is both illegal and dangerous to go through a performance with a non-operating exit light.

Panic Lighting

Any space occupied by an audience should be equipped with special lighting to enable the audience to leave safely in case of an emergency which causes the regular lighting to fail. Even if the space is so small that the law does not require such equipment, prudence dictates that it should be present.

Panic lights operate when other power is off

Panic lighting is normally off. A special transfer switch turns it on automatically when the regular power fails. The supply is either a special bank of batteries or a special generator equipped to start up when the panic system calls for energy. The evidence of the panic system will often be the presence of a mysterious second lamp in each house lighting fixture and exit light case. It is reassuring to observe these lamps come on when there is a power outage and remain on until the power is restored even when no audience is present.

Although maintenance and testing of this system is not a normal task for the theatre electrician, that person should be familiar with the panic system and know how to operate it in an emergency. This system is subject to inspection by the fire marshal without notice. It is also required to be inspected at regular intervals by designated member of the building staff. A prudent theatre technician will accompany some of these inspections to be assured that the inspections are being properly done and that the equipment is in good working order. For example, it is not enough for a staff "inspector" to open the door to the battery room, determine that the batteries are still there close the door and move on. The batteries should be checked for proper charge and for any signs of impending trouble such as sludge in the bottoms of the containers or low electrolyte.

Inspecting the panic system

"Package" Panic Lighting

Small theatres and other locations where panic lighting is required because the laws have changed since the facility was built or where such lighting is a good idea although not legally required, can often make use of package units that can be installed with a minimum of wiring. These units contain a battery, a trickle charger to keep the battery at full charge, one or two low voltage lamps similar to automobile spotlight lamps, and a system to turn on the battery operated lamps if the AC power fails. AC is supplied for the battery charger and the sensor by a regular AC cord plugged into a convenience outlet or the unit may be hard wired to a normally-on AC line.

Clearly, these units do not provide the reliability provided by a complete panic lighting system; for example, they respond to failures in the circuit feeding them even if the remainder of the building is still powered. They too, should be checked regularly for proper operation and to determine the state of the battery. If the battery is allowed to deteriorate, the unit may come on in a crisis and almost immediately dim out—a very dangerous event.

Package units must also be inspected.

Preventing Electrical Shock

Most electrical shocks are technically grounds. That is, they are caused by the victim making a connection between a live part and something electrically connected with the earth. Of course, it is equally or even more deadly to become part of a connection between two live wires on differing phases, but this is less likely. Since the earth is a part of almost every electrical distribution system in use, one must remember that being connected to the earth is the equivalent of holding one of the wires from the generator. Only one more connection is needed. The best policy is to assume that you are grounded unless you are certain that you are not. Structural steel, stage pipe battens, concrete floors, plumbing, electrical conduit and enclosures are all grounded as are external metal parts of luminaires, microphones, sound equipment, stage floor pockets and almost any other conducting material that encloses electrical apparatus. This grounding is required by law so that, if a fault occurs and the part becomes live, this will immediately constitute a short circuit which will open the fuse or circuit breaker eliminating the danger and signaling that there is trouble.

Assume you are grounded.

Equipment is grounded for safety.

Electricians who must work with live equipment take precautions to avoid being grounded and try to work with only one hand, keeping the other in a pocket. It should rarely be necessary for stage technicians to work "hot." However, as discussed below, there may be situations where the technician finds that he or she has inadvertently encountered a live piece of equipment.

Common Backstage Hazards

Perhaps the most common hazard occurs when a luminaire goes dead and a crew member is sent to find out why and, if possible, get it back in service. The failure could be simply a burned out lamp, it could be caused by the leads burning off at the socket, or a number of other faults in the wiring. If the luminaire is properly wired with an equipment ground (below) and the burned-off lead touches its frame there should be a short circuit which trips the breaker or burns out the fuse. However equipment is not always properly wired and burned off wires do not automatically contact the frame. If an unsuspecting crew member handles the equipment without disconnecting it and the supply remains on, as it often does if another luminaire still in use is also on the same circuit, that crew member is in danger of shock if he or she contacts anything grounded. The proper practice is to unplug the equipment at the connection nearest to the luminaire before handling it. This is the reason that luminaires are equipped with short leads; there is always a connection within easy reach. Note that it is not safe to merely shut off the circuit at the console before working on it. Someone may accidentally turn it on. Even if the equipment only requires relamping, technicians should remember that many types of lamps have current-carrying parts that extend some distance from the base of the lamp and thus can be contacted as the lamp is being inserted. *Always disconnect the equipment before working on it.*

Another hazard, frayed leads where they enter the equipment, has been somewhat diminished by the use of modern materials. Until recently all luminaires were wired with asbestos-insulated leads because these could withstand the high heat inside. Asbestos, while resistant to heat, was subject to abrasion and often wore through at the point where the wires entered the housing. However asbestos is now outlawed and all lighting equipment should have heat-resistant leads of fiberglass or high-temperature plastic. Both resist abrasion better than asbestos did but both will eventually fail. The solution is proper maintenance of equipment and the use of a proper equipment ground. Note that if an old theatre still has asbestos leads in service, these should immediately be replaced observing the proper procedures for handling the asbestos.

Asbestos insulated leads are outlawed.

An equipment ground is a separate conductive path from the frame or enclosure of any piece of electrical equipment to the earth. Although this path may be connected to the grounded neutral at one point, usually at the service entrance, it must be continuous without depending on the grounded neutral. In permanently installed gear, the equipment ground is usually the metal framework of the equipment itself which is firmly connected to the earth. Where a wire is used to maintain the continuity of the equipment ground, it may be either bare copper or insulated with *green* insulation. (Note that the grounded neutral is required to be *white*.)

The equipment ground should be either bare copper or have green insulation.

Portable equipment presents a special problem. It cannot be permanently wired to the earth. Therefore it must be so wired that it becomes grounded before it is connected to any electrical supply. A third conductor, colored green, is carried along in all supply cables and connected by means of special prongs on the connectors that are longer than the current-carrying connections so they will make contact first. Inside the equipment itself the green wire is firmly attached to the conductive frame or enclosure. This makes certain that the outer parts of equipment remain at ground potential and that any contact between a live wire and the frame or enclosure will cause a fuse to blow or a breaker to open. *It is legally required that all portable equipment in new or largely renovated theatres have an equipment ground.* All old installations should be converted to the equipment ground system as soon as possible.

Modern wiring codes require that the grounded neutral contain no interruptions that might break its continuity. This is why it bypasses any fuses or breakers in the service panel. However a problem may arise in temporary installations where the power wiring is reconnected at each location. Proper procedure requires that the equipment ground be the first connection made, the neutral second, and then the live conductors. If this procedure is not followed and two or more phases are hooked up first and accidentally turned on, more than 120 volts may be applied to the equipment, including dimmers and lamps. Older dimmers may burn out (modern ones are usually capable of protecting themselves). Lamps will burn out rapidly creating a costly lamp replacement bill and the equipment will display higher and more deadly voltages where these should not be. *Always connect the equipment ground and the neutral before connecting any live conductors.*

Connect the equipment ground first and disconnect it last.

Avoiding the Dangers of Electrically Generated Heat

Electrical current is not only dangerous because shock can maim or kill, heat from an uncontrolled electrical flow can cause fire or explosion destroying equipment and buildings and very possibly taking lives. Therefore special equipment is used to be very certain that a flow of current is either under control or is cut off almost instantly.

Electrically caused heat can cause fire or explosion.

We have already examined the way electrical current almost inevitably generates heat and the way that the heat generated increases geometrically with the current (the heat formula). Except for the phenomenon of superconductivity, which is not found on stage, every flow of current involves the production of heat. The greater the amperage and/or the resistance, the greater the heat. Fuses and circuit breakers are designed to protect against unwanted increases in amperage. However they cannot protect against unwanted increases in resistance. Although heat only increases linearly with resistance, it can have an insidious effect. If, for example, a loose connection develops in a stage connector while it is in use thereby increasing its resistance, more than normal heat will develop at the connection. This heat will cause oxidation of the brass or copper parts of the connector and wire. Oxides of these metals have greater resistance than the pure metals, increasing the resistance at the loose connection still more. The greater heat hastens more oxidation and the vicious circle spins to a fiery conclusion: Parts of

Fuses or breakers will not protect against the effects of loose connections until they short out.

the connector break down and a short circuit or fire may result. Ironically, all of this can happen without any increase in the amperage (until a short occurs) and thus will not be controlled by the fuse or circuit breaker.

This sneaky heating of loose connections is often the cause of "mysterious" nighttime residential fires. A loose connection smouldering away in the attic is not a pleasant thing to contemplate. Fortunately for the theatre, this nighttime hazard seldom happens there. Theatre equipment is routinely shut down after the show and no current is available at any loose connections until the equipment is turned back on in the morning. However, when the current is on, the failure and destruction of equipment from loose connections remains a hazard. It can interrupt a production or even set the theatre on fire.

Careful maintenance and vigilance are the best protection against loose connections. Every technician should develop the habit of occasionally feeling any connectors within reach to see if they are warm or worse, hot. If any are found, they should be repaired or replaced as soon as possible.

Overloads and Short Circuits

Overload

An *overload* is defined as any flow of current greater than the equipment, or the weakest part of an array of equipment is designed to handle. This can be as little as a fraction of an ampere or it can be so massive that it has the same effect as a short circuit.

Short circuit

A *short circuit* is an essentially uncontrolled flow of current. Resistance has dropped to near zero and all of the current available will attempt to flow through the short circuit. The only limiting factor is the amount of current available in the system and the resistance of the lines leading to the short circuit. The effect of a short circuit can be fire and violent explosion if not immediately controlled by an overcurrent device. Long runs of wire can be turned into red hot copper, their insulation set afire or even vaporized almost instantly. Fire, often extended over the entire run of wiring leading to the short, is almost immediate. Even if the short circuit clears itself in moments by burning off the conductors, it can leave a fire smoldering and dangerous.

Short circuits are dangerous.

Note that there is little difference in the effect of a massive overload and a short circuit. Both impose a huge increase in current on the equipment and can have the same effect. It is academic to note that the massive overload is "controlled" by whatever low resistance exists in the circuit as compared to the totally uncontrolled flow in a short circuit.

There are two ways a short circuit can happen:

Phase-to-phase short circuit

- Two current carrying conductors fed from different phases come into direct contact with each other with no current-limiting device such as a lamp or motor between them. For example, two wires fed from different phases bared because their insulation has worn off touch and create a short circuit.

Live-to-ground short circuit

- A live conductor leading to a load comes into contact with a conductor electrically attached to the earth. Since the earth is part of the electrical system, a very low resistance circuit is completed back to the generator and all of the current available in the live conductor flows through the contact point. Again, the result is sparks, fire and explosion.

The conditions for a short or ground may occur while the current is off and the actual damage appear when the current is turned on.

If the return conductor (the grounded common neutral) from a load contacts a grounded part, a *ground fault* will occur instead of a short. Current will continue to flow normally through the load but will return through the regular return path *and through the ground*, in proportion to the resistance of each path. Although such a ground will not usually cause immediate trouble, it should be found (see ground fault circuit interrupter below) and corrected to avoid trouble with sound or other equipment that depends on a "clean" ground connection (one through which no current is flowing). Also, heat may be released at the point of contact with the ground causing a fire.

Ground fault

Control of Short Circuits and Grounds

Obviously the first defenses against shorts and grounds are the use of good quality equipment and the practice of preventative maintenance. Portable equipment, particularly cables should be checked frequently, connectors replaced when they show signs of wear and the entire cable inspected for evidence of crushing or tears. Any cable which runs hot while in use should be checked for overload and the load reduced or the cable replaced with one of higher current carrying capacity.

Good maintenance is vital.

Given good equipment and maintenance, the backup protection lies in overcurrent protection devices—in a theatre this means fuses or circuit breakers. Overcurrent devices are designed to cut off the current if trouble develops. While this will avoid a disastrous electrical fire or explosion, it will also interrupt all or part of the lighting for a show, a situation that must be avoided if at all possible.

Fuses and circuit breakers

Fuses

These are the earliest and simplest of overcurrent devices. The working part of a fuse is a piece of soft alloy (somewhat like solder) usually in the form of a ribbon sized to heat up, melt and break the circuit at the current rating of the fuse. This piece of metal, known as the *fuse link*, is located in the circuit so that all current that passes through the circuit must pass through the fuse, i.e., it is in series with the load. If too much flows, the link melts (or explodes in the case of a heavy short), breaking the circuit. Fuses up to about 60 amperes are throwaway devices. Once they have blown, they are discarded. Larger sizes are often made with replaceable links as described below.

The fuse link

Fuses are sized when the electrical installation is made following the stipulations of the NEC and/or local ordinances. Sizing is either based on the size of the wire that leads away from the fuse toward the load or on the rated amperage of the equipment to be protected by the fuse, whichever is smaller. Once established by a qualified electrician, the size should not be altered except by another qualified person who is following the latest code information.

Sizing fuses

Although there is a huge variety of fuses, only a few are normally found in theatrical lighting situations. The two most common are cartridge fuses and plug fuses (Figure 13.1). Although the working part of both is much the same, their appearance is quite different. Cartridge fuses are usually used for heavy current situations such as mains or sub-mains. Their sturdy outer enclosure can withstand the considerable explosive effect of a blowout under a massive short circuit. The larger amperage types have blade connections to handle the large amount of current they must carry. These fuses are often made so that they can be disassembled and a new fuse link installed. This allows for capacity changes within limits determined by the size of the housing and also for replacement in case of burnout. Small cartridge fuses are usually not made to be disassembled. Although small cartridge fuses rated at 30 amperes or less were common in early stage lighting installations, they are rare now. They were replaced first by plug fuses and more recently by circuit breakers.

Cartridge fuses

Plug fuses are still quite common; they are still in use in old household power boxes and in some old theatres. They come in a variety of amperages, from 5 to 30 amps, all the same size and shape. Any of these amperages will fit into the standard fuse socket designed for plug fuses. This interchangeability is their weakness. It makes it far too easy for an unknowing or careless person to increase the amperage limitation on a circuit by simply replacing a low-amperage fuse with one of greater am-

Plug fuses

Illegally up-rating fuses

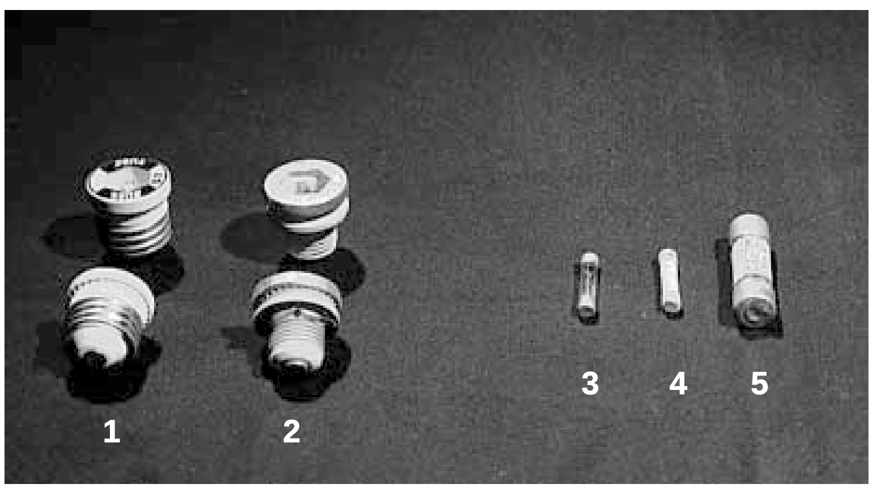

Figure 13.1. Fuses. This picture shows some of the types of fuses still found in older theatres, and in many older homes. (1) the "standard" plug fuse. This is still common in many old installations. The same mechanical size comes in amperages from 5 to 30 making up-rating very easy. (2) shows a set of Fusestats. A different thread size for each amperage makes them non-interchangeable. A special insert (not shown) must be installed in the fuse holder to accept the Fusestat.

(3), (4) and (5) show some of the many types and sizes of cartridge fuses available. The smaller ones, (3) and (4), are commonly found in low current devices such as consoles, moving light power supplies and may also be used to protect some small wattage dimmers. The larger ones such as (5) may still be found as master and submaster fuses for very outdated switchboards. Cartridge fuses come in sizes running into the hundreds on amperes. Photo by Herbst.

perage. Indeed, this practice is so common that traveling theatre technicians almost automatically expect it in old installations. Nevertheless, it is dangerous and illegal. A little reflection on the heat formula will reveal that increasing the amperage from 15 to 30 amps (the most common substitution) will result in making it possible for the system wiring to become four times as hot before a fuse blows. Fortunately most old wiring was conservatively rated when installed and will survive this treatment for a long time although not without heat damage to insulation.

Plug fuses do offer one advantage over other types. When one opens, observation will often indicate whether it opened because of a slight overload or as the result of a short circuit or very heavy overload. The top of a plug fuse contains a window through which the fuse wire itself can be seen. If the window of the blown fuse is covered with blackened or spattered metal, the fuse opened from a short circuit or a very heavy overload. If the window is still transparent and the melted-off ends of the fuse wire can be observed, the fuse opened because of a slight overload.

Overload and short blowouts

Fuse response time (lag)

Fuses can be designed to respond almost instantly to an overload or to delay cutting off the current for a predetermined amount of time. Fuses designed for use with incandescent lamp loads must be built with a sufficient delay to allow their normal inrush current to pass without opening the fuse. Therefore the fuses normally found in theatrical installations will respond relatively slowly to very slight overloads but their response time will decrease rapidly as the size of an overload increases. They will respond to a short or heavy overload almost instantly.

Lag varies inversely with the size of the overload.

This delayed response to minor overloads when combined with circuits controlled by dimmers can lead to an insidious situation: A slightly overloaded circuit may continue to operate for most of a production during which the load is dimmed, only to open at the worst possible moment—the climax. The fuse has been heating for the entire time at near-capacity and reaches overload when the cue at the climax calls for bringing the dimmer to full. Therefore:

Delayed opening on dimmed circuits

1) carefully check loads when installing equipment and avoid even the slightest overload.
2) After the luminaires are all installed and circuited, allow them a "burn-in" period of an hour or so *with all dimmers at full up*. This will not only catch any slight overloads, but may also catch any newly installed lamps about to fail because they are faulty.

Burn-in is good practice.

Fusestats

The Fusestat was developed to defeat the efforts of those who would up-rate plug fuses. It is really a system, consisting of special socket inserts, one for each fuse size from 5 to 30 amps, and appropriate fuses that fit only into the proper insert. Once an insert has been placed in a fuse socket, it cannot be removed without destroying it—an arrangement intended to permanently prevent substitution of the wrong size fuse. Unfortunately this system is rather easily defeated because the inserts are not very difficult to remove, after which a standard plug fuse can be again inserted in the socket and the amperage increased.

Both regular plug fuses and Fusestats are susceptible to heating if they become loose in their sockets. This can occur from the inevitable 120 Hz vibration induced by the AC current passing through them. Therefore it is good practice to tighten fuses on a regular schedule. This will also give the technician a chance to check the temperature of each working fuse. If the fuse is tight in its socket but running very warm, it is loaded to near capacity and may open if the voltage increases slightly causing more current to flow. Such loads should be reduced.

Changing fuses

A blown fuse is a sign of trouble.

Tracing down the cause of a blown fuse

With the exception of plug fuses that may blow because they become loose in their sockets and overheat and fuses improperly operated in an overheated enclosure, all blown fuses are a sign of trouble. Either an overload or a short circuit caused the fuse to blow. There is no such thing as fuses "wearing out." There is nothing in them that can wear out, only the inert piece of fuse wire. Therefore the first action after a fuse blows should be to discover the cause and remedy it. In the theatre this is often known from the very moment the fuse blew—someone inadvertently plugged an extra load into an already loaded circuit, or a short occurred in a connector as it was being plugged in. However, there will be times when the technician will have to hunt down the cause by tracing the path of the current from the fuse to the load looking for evidence of trouble along the way. Often it will be necessary to disconnect everything from the load circuit served by the fuse, replace the fuse and reconnect things one by one until the fuse blows again indicating that the last item connected, perhaps a luminaire with bad wiring, was the cause of the trouble. If an overload is the problem, individual luminaires should be checked for correct wattage and the entire load recalculated. Occasionally overloads can be spotted by the use of a clamp-on ammeter and a special adapter that makes it possible to clamp the ammeter around only one conductor at a time. However this will not catch very small overloads that may take hours to heat up a fuse to the point of failure.

Changing fuses

The physical act of changing the fuse is relatively simple for plug fuses; the only caution is to handle only the insulated parts of the fuse and to tighten it securely into its socket. Cartridge fuses are somewhat more risky. If possible, turn off the feed to the fuse holder before removing the blown fuse and inserting the new one. If this is not possible, disconnect or turn off the load. A fuse puller is the safest way to remove or insert cartridge fuses. This is an insulated pliers-like tool that can grasp the fuse so it can be pulled out. If a fuse puller is not available and it is necessary to pry the fuse out of its clips with a dry piece of wood or other insulating material, pry the live end out first so that the fuse will move away from the live parts as it comes loose. The new fuse can be placed in the clips and shoved firmly into place. Insulating gloves are recommended.

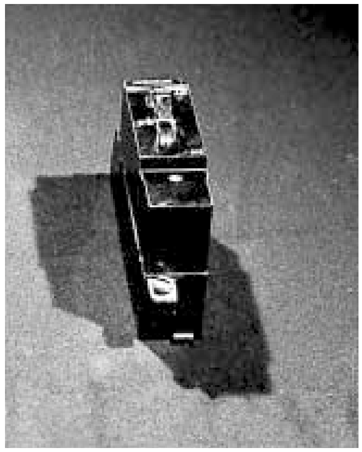

Figure 13.2. Circuit Breaker. This breaker is typical of many installed in lighting circuitry. It is a combination heat and magnetic sensing breaker. When installed, only the top, which resembles an ordinary electrical switch, is visible. When it opens, the switch handle moves to a center position between "on" and "off." To restore power, turn to "off" then to "on." *Breakers should not be used for day-to-day control of loads.* Photo by Herbst.

Circuit Breakers

These are devices that serve the same purpose as fuses while avoiding many of their problems. Breakers may work on several principles, including heat-sensitive elements which trip a switch-like spring-loaded pair of contacts, magnetic coils which also trip the switch arrangement and electronic circuitry which can cut off the current in case of overload or short circuit. Some combine the heat sensitive mechanism with the magnetic coil. Since circuit breakers are sized when installed and need no replacement when they open, there is much less chance that they will be uprated.

Circuit breakers come in an almost infinite variety of amperage ratings ranging from tiny breakers used to protect sensitive electronic gear to monstrous units that can protect an entire power plant by cutting off megawatts of power almost instantly. Those most often found in the theatre and in home service panels resemble switches. (Figure 13.2). Despite this appearance, they should not be used as a substitute for switches; their contacts are not made to handle repeated on-off action under load and they may fail. Unlike fuses, breakers which are used to control more than one live line at a time are usually mechanically linked so that the entire set of lines will be cut off if any one is overloaded or shorted. Main breakers are normally this type.

Circuit breakers are made so that it is impossible to hold the mechanism in an "on" position when a short or overload is present. The handle becomes detached from the inner parts of the breaker and will not move the contacts back into their "on" position. This same action also causes the handle to move to a middle position between "off" and "on" when the breaker trips. After the short or overload is cleared, the breaker must be switched all the way to "off" and then to "on" to restore power.

Move to "off" then to "on" to restore power.

Circuit breakers have two ratings: 1) the amperage at which they will trip, opening the circuit, and 2) the interrupting capacity, a large number indicating how large a short circuit they will handle. Breakers for ordinary service are rated at 10,000 amperes interrupting capacity. This apparently huge number may not be enough for some theatrical applications where the system is supplied by its own transformer, the wiring is conservatively rated, and there are short wiring runs between the transformer and the lighting equipment. Those designing theatrical control equipment must

Current rating

Interrupting capacity

use caution in specifying breakers because a short circuit that fails to be interrupted by the breaker(s) can quickly become a major catastrophe. Breakers installed must be capable of interrupting the largest current the system can supply plus an adequate safety margin. Obviously, if the theatre technician is faced with the task of replacing breakers in a system, he or she must make sure that the new breakers have the same as or greater interrupting capacity than the old ones.

Breakers are preferred.

For theatrical purposes, breakers are much more desirable than fuses. Not only do they avoid the problem of wrong-size replacement, they also make it easy to restore a circuit the moment the fault is eliminated, a great advantage when the fault happens during a production or rehearsal.

Breaker response time

Breaker lag time

Circuit breakers, to an even greater degree than fuses, can be made to respond to an overload almost instantly or to delay breaking the circuit (lag) by whatever period of time the engineer considers appropriate. Whatever the response time, it is designed to decrease rapidly as the overload increases and to be nearly instantaneous when a short circuit occurs. This can create the same insidious delay of cutoff mentioned above in connection with fuses. The solution is also the same: careful control of loading and a “burn-in” time to catch any errors.

Choice of breakers for theatrical use

Heat sensitive breakers may open falsely.

Heat responsive breakers are the cheapest to manufacture and are often quite satisfactory for locations where the ambient heat will always be low. However theatrical breakers are often installed in dimmer racks or in “magazines,” cabinets enclosing many breakers fed from the same source. Such locations tend to trap the natural heat caused by the flow of current. This can cause heat-sensitive breakers to trip even when the load is less than their rating. Magnetically operated breakers are a better choice. If there is a problem with harmonics created by the chopping action of the dimmers on the 60 Hz current, electronic breakers are recommended, particularly on mains.

Ground fault circuit interrupters (GFCI)

As noted above, a ground fault is a situation where some or all of the current in the return line from a load becomes detoured through the earth because the return line has made contact with a conductor that is attached electrically to the earth. This causes an imbalance between the current flowing into a load and that returning via the grounded neutral. That portion of the current straying from the normal path to the connection with the earth may cause noise in sound systems or even sparking at joints in conduit.

Much more serious, it is possible that a person can become the ground fault by making a connection between a live source and the earth. Such a connection can be deadly. Therefore ground fault interrupters are required by modern codes to be installed where there is a danger that people will be well grounded and that they will be handling equipment fed by live lines, for example, operating an electric drill in a shop with a concrete floor.

There are three principal types of GFCIs commonly available: The first combines the function of a GFCI with that of a circuit breaker and is installed in breaker panels and other permanent locations. These GFCIs normally have a small colored test button that enables the technician to test the unit for proper operation. Such GFCIs are the most sensitive of all which can cause nuisance outages if the wiring in the system is old and leaks small, harmless amounts of current. Such nuisance outages also rule against the installation of such GFCIs in theatre lighting systems. Nuisance outages cannot be tolerated during a show.

Outlet box GFCIs

Another kind of GFCI is made to be installed in place of a standard household outlet or convenience receptacle. It has no circuit breaker function but does have a test button. It includes the normal two receptacles of a standard household outlet, both of which are protected as are any circuits wired "downstream" of the GFCI. Note that outlets between the GFCI and its supply are not protected.

A third type of GFCI is often installed at the plug-end of cords attached to portable appliances, such as hair dryers, which are often used in wet, grounded locations. It protects only the appliance to which it is attached. These GFCIs are normally equipped with a test button to assure the user the device is working properly. When this test button is pressed, the appliance won't work until the button is restored to its operating mode.

Although local codes may vary, most require that GFCIs be installed wherever there is a likelihood that personnel will be grounded, say, working on a concrete floor, and will be handling electrical apparatus. In some cases this installation will be required only at new construction or at major renovations. In other localities, retrofitting may be required immediately.

GFCIs may be too sensitive for theatrical circuits.

Regular commercial GFCIs are considered too apt to react to minor, harmless ground faults and shut down vital circuits to be installed in theatre lighting systems. However, there are now highly reliable GFCIs built into special dimmers that are sensitive enough to protect swimmers in underwater acts. The shops are another matter, particularly the scene and paint shops where workers are often handling power tools while standing on a frequently damp concrete floor. Not only law, but prudence should require that GFCIs be installed on all circuits.

They should be installed in all shops.

Sizing Overcurrent Devices

In an ordinary lighting circuit in a home or building, the wire is the part that must be protected against overloads and shorts. Incandescent lamps, by their nature as resistance devices, are self protecting as long as the voltage does not rise above that for which the lamp was built. Because the wire has little resistance (the less the better), it will strive to carry whatever current is allowed to pass through it heating up rapidly according to the power formula. Thus it must be protected. However many circuits, including those containing theatrical dimmers, contain equipment that may need protection from smaller currents than the rating of the wire. In these cases, the size of the overcurrent device is determined by the "weakest link" in the circuit, i.e., that part with the lowest load capacity. In most theatrical lighting circuits, this is the dimmer. If modern dimmers are in use, this problem is automatically solved as far as the dimmer is concerned because electronic overcurrent protection is built into the dimmer. Its electronics will automatically turn it off if it is overloaded or subjected to the wrong voltage. In addition, a circuit breaker may be included in the dimmer to protect wiring. In modern systems that use modular dimmer racks, non-dim circuits are controlled by devices similar to dimmers that simply turn on and off. These too contain built in overcurrent protection. In older lighting installations there will be a bank of fuses or breakers, one for each dimmer, sized to protect it. Non-dim circuits will be sized to protect the wiring or to meet code requirements.

Electrical code regulations are stringent on the matter of wire size and current limitations. For instance, the NEC defines a standard branch circuit, such as the run from a dimmer to a luminaire as a 20 ampere circuit. This would, according to allowed wire sizes in the code, require No. 12 wire. Even if the dimmer in the branch circuit is rated at 1000 watts and is protected by a 10 ampere fuse, the wiring must be at least No 12. Moreover, if the wire run is long, say to a position in the ceiling of the house, good wiring practice will require that the wire size be No. 10 to reduce line drop from the resistance of the wire. Thus the circuit will consist of No. 10 wire, rated at 30 amperes, carrying less than 10 amperes from the 1000-watt dimmer. This also meets the requirement that the branch circuit be rated at no more than 20 amperes.

Avoiding line drop