ELECTRICITY

INTRODUCTION

Rescue Squad and Truck Company personnel respond to a wide variety of incidents, from auto accidents with wires down to entrapment in heavy industrial equipment. Many of these incidents have one thing in common; they involve or need to involve electricity. Some will involve electricity as a hazard to overcome and some will require the use of electricity to meet the operational objectives. A basic understanding of electricity is essential for safe operations.

OBJECTIVES

The student will gain a basic understanding of AC and DC electrical circuits, electrical terminology, and several types of electrical systems. The student will understand the five ways electrical safety is provided, the lock-out/tag-out process, and the priorities for electrical utility control. He/she will understand the Unit system, will calculate power requirements of electrical devices, capacities of supply cords, and determine the power available from a given generator or inverter system.

BASIC ELECTRICITY & TERMINOLOGY

Electricity is defined as a form of energy associated with the movement of electrons through a conductor. A more useful definition is a safe and convenient form of energy that is used to power tools and appliances that increase our capability to work. Outside the field of electronics (radios, thermal imagers, etc.) we use electricity in 2 basic ways. First is the magnetic field - the basis of the electric motor. Electric motors power fans, saws, drills, and hydraulic pumps. Second is the resistive circuit. Resistance creates heat as in portable heaters. Heat can create light as in floodlights. If used improperly or in the wrong environment, electricity can be very dangerous.

Alternating Current (ac): A flow of electric charge that reverses its direction periodically. The alternating current used in the USA has a frequency of 60 cycles per second (hertz).

Ampacity*:* The current, in amperes, that a conductor can carry continuously without exceeding its temperature rating.

Ampere: A unit of measure of the current or volume of electricity.

Capacitor: A device that stores an electric charge on two metal plates separated by an insulator, such as air or paper.

Circuit Breaker: A device designed to open and close a circuit manually and to open the circuit automatically on an overcurrent without damage to itself.

Conductor: A material, such as copper or aluminum, with a very low resistance to electric current.

Current: The flow of electric charge. The volume of electricity, measured in amperes

Dead: The condition of an electrical circuit or line that is de-energized, tested and has "short and grounds installed".

Direct Current (dc): a flow of electric charge in one direction, it may be steady or fluctuating but it never reverses direction.

Disconnect: (noun) a device, such as a switch, or a group of devices, used to connect or isolate portions of a circuit.

Electric Contact Injury: An injury or shock caused by contact with an energized device or line.

Fault: An inadvertent contact between an energized conductor and ground or another conductor of a different potential. A.k.a.: a short circuit.

Flash Burn: An injury caused by the heat produced from electrical arcing and molten metal.

Fuse: An overcurrent protection device that uses the melting of a metal strip to interrupt the flow of current.

Generator: A machine that converts mechanical energy into electrical energy. The mechanical energy moves conductors through a magnetic field, which induces electric currents in them.

GFCI: Ground Fault Circuit Interrupter, A safety protection device that gives protection against electric contact injury by measuring the current flow in both legs of a circuit. If the return current in the neutral is not equal to that in the supply, the current is interrupted.

Ground: (noun) A conducting connection, intentional or accidental, between an electrical circuit or equipment and earth or to some object with the same potential as the earth.

Ground: (verb) The act of connecting a conductor to ground

Grounding Conductor, Equipment: The conductor used to connect the noncurrent carrying metal parts of equipment, raceways and enclosures to ground. A safety feature of an electrical system that prevents metal parts from becoming electrically charged.

Grounding Conductor, System: See "Neutral"

Ground Fault: An unintentional short circuit between an energized conductor and ground or a conductor of ground potential.

Impedance: The apparent resistance in an ac circuit that corresponds to the true ohmic resistance in dc circuits.

Insulator: A material that does not conduct any significant amount of electric current.

Inverter: A machine or electronic circuit that converts direct current to alternating current.

Kilo: A prefix meaning 1000

Kilovolt (kV): a unit of 1000 volts.

Kilowatt (kW): a unit of 1000 watts. A 7.5 kW generator produces 7,500 watts of electricity.

NEC : National Electrical Code, NFPA 70 is an advisory code published by the National Fire Protection Association. Most localities adopt it as law.

Neutral: A grounded conductor used to return the system current to the source. The conductor, usually white in color, used in inside wiring that is grounded at the source of feed.

Open Circuit: an electrical system that is not complete and does not allow current to flow. Opening a switch stops current flow. Closing a switch will complete a circuit and allow current to flow.

Overcurrent: Any current more than the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit or ground fault.

Overload: Operation of equipment in excess of normal full load rating or of a conductor in excess of rated ampacity that would cause damage or dangerous overheating.

Phase: The relative time of change in values of current or voltage. Refers to ac conductors with a potential between them and to ground.

Short Circuit: A very low resistance connection between two conductors of different potential usually causing a large current flow.

Unit: A Fire Department term equal to 500 watts.

Volt: The electrical pressure or electromotive force (EMF) required to cause a current of one ampere to flow through a resistance of one ohm. Volts (E) equals Current (I) in amps times Resistance (R) in ohms. E=IR (Ohm's Law)

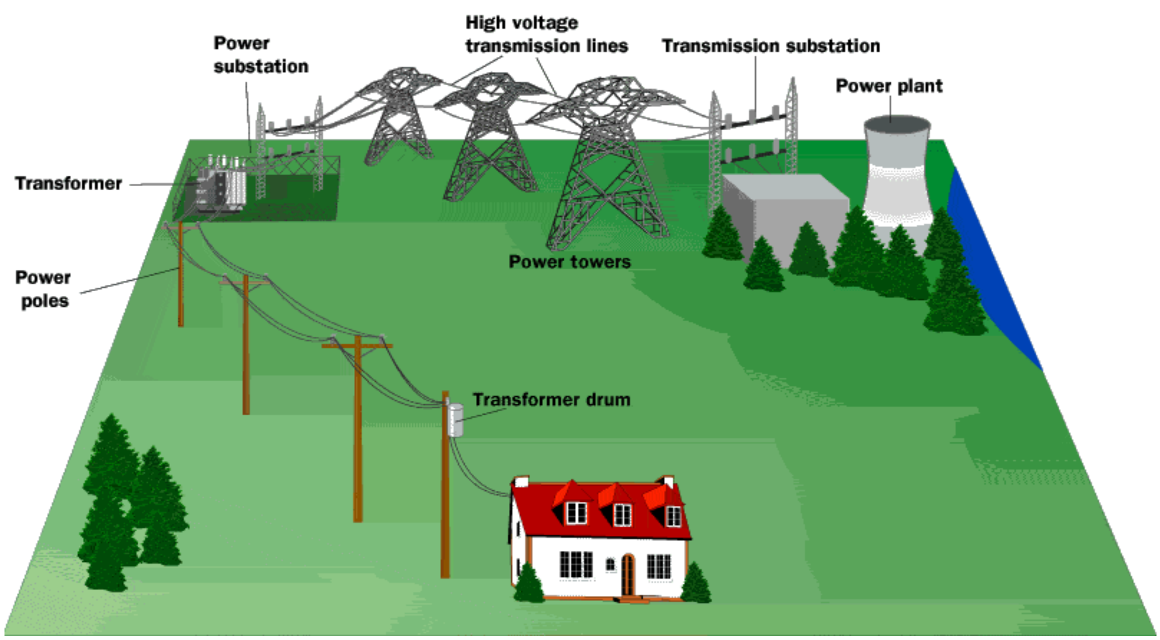
Watt: The total power developed or used. Watts(W) equals Current(I) times Voltage(E). W=IE

The table below is from NFPA 907M and compares elements of an electrical system to the basic elements of a hydraulic system. Water flowing through a hydraulic system is familiar to most personnel in the fire service. The analogy is used to make it easier to understand an electrical system. Unfortunately, there is no direct analogy between alternating current electrical systems and the hydraulic system. For the majority of applications in this text, however, it is satisfactory to visualize AC circuits as if they were the more easily understood DC circuits. The specifics of the differences between the behavior of AC versus DC circuits are beyond the scope of this manual.

Hydraulic System	*Electrical System*
Pump………………………………..	Generator
Pressure……………………………	Voltage
Pounds per square inch (psi)…….	Volts
Pressure gauge……………………	Voltmeter
Booster pump………………………	Transformer (ac only)
Water………………………………	Electrons
Flow…………………………………	Current
Gallons per minute (GPM)……….	Amperes (amps)
Flowmeter…………………………	Ammeter
Valve……………..…………………	Switch
Friction……………………………..	Resistance (ohms)
Pipe size – inside diameter………	Wire size – AWG No.

The Generic Electrical System

Electrical systems come in many different sizes. These include small portable generator systems up to large metropolitan power grids. The basic components of an ac electrical system include:



Power Source

Generators come in many sizes and can be powered in many different ways, from large hydroelectric dams to gasoline engine powered portables.

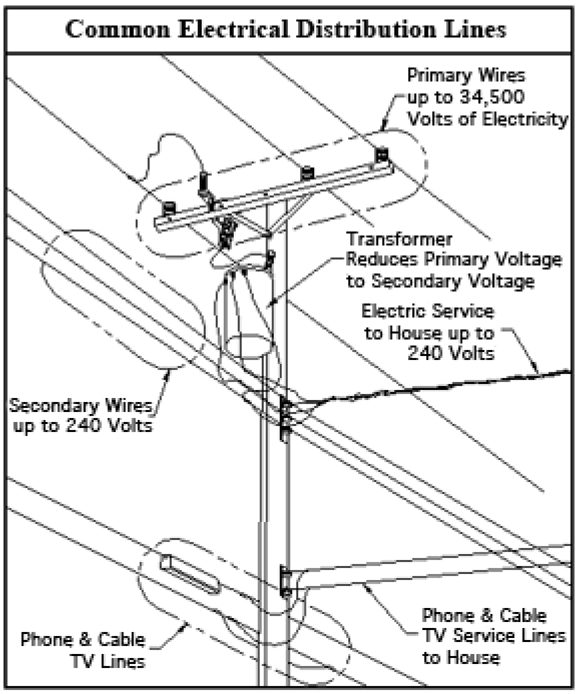
Transmission System

This moves power from the source to receiving or sub-stations. Transmission voltages may exceed 700kv. Sub-stations step down the voltage and feed the distribution system.

Distribution System

The distribution system moves power from the sub-station to the distribution transformer. This transformer lowers voltage further to a voltage usable by the consumer. This secondary voltage is usually less than 500 volts.

Power Substation



Service Entrance

The service entrance equipment delivers electricity from the supply system to the consumer's premises. It consists of the service drop (overhead wires) or service lateral (underground wires), the meter base, and the meter. This is the point where power company maintenance ends in a commercial system.

Service Equipment

Consists of a main disconnect and/or a distribution panel. Here power may be shut down to the entire building. The different styles include single box and switch, circuit breaker panels, or fuse panels. If the disconnect is part of a breaker panel there may be up to 6 main breakers which need to be turned off in order to shut down all power to a building.

Branch Circuits

Each branch circuit begins with an appropriate sized fuse or circuit breaker. All circuits may be shut off at the panel. Some types of circuits will have other means of disconnect built into them but general use lighting and outlet circuits may only be shut off at the panel. Direct wire appliances may have a remote disconnect at the appliance. Designated outlet appliance circuits may have a special style outlet, such as a clothes dryer, which allows disconnection by simply unplugging the appliance service cord.

The components listed here are common to the average residential and commercial electrical system. Systems may have some or all of these components. Larger industrial systems may include other, more complex, components.

Apparatus Based Electrical Systems

Typical Apparatus Based Electrical System

These systems follow the basic component list above. The power source may be a generator or an inverter. Generators can be powered directly by separate diesel and gasoline engines or be driven by the apparatus engine through a PTO. An inverter may be used to power smaller systems. Generally, smaller subsystems on a Rescue Squad, usually 500-1500 watts, could use an inverter. Since apparatus based systems generate electricity at a useable voltage; transmission systems, sub-stations, distribution systems and distribution transformers are not necessary.

The service entrance consists of the cable or wiring delivering power from the generator to the main disconnect or breaker panel. This portion of the system is not circuit breaker protected. The service entrance powers the breaker panel. This contains the breakers that feed the branch circuits. The branch circuits will feed direct wire appliances, fixed floodlights, hydraulic pumps, fixed cord reels, and designated use or general use outlet circuits. General use outlet circuits are usually 20 amp circuits. The L5-20 outlet and plug are the standard FD, 3 prong, twist-lock connectors.

NEMA L5-20P

It is very important that wire ampacity match breaker size.

#14 wire - 15 amps max.
#12 wire - 20 amps max.
#10 wire - 30 amps max.
#8 wire - 40 amps max.
#6 wire - 50 amps max.

Maintenance & Inspections

One of the most important duties the rescue squad driver performs is preventive maintenance. Inspecting and maintaining electrical equipment will ensure safety, reliability, & prolonged equipment life.

Generators require maintenance and periodic testing. Maintenance includes changing fluids and filters. Voltage output and proper frequency should be tested periodically. Circuit breaker panels should be checked for signs of overheating and screw connections tightened. Test GFCI breakers by connecting a voltage tester between hot & ground. This will cause a “current leak” and should trip the GFCI breaker.

If circuit breakers trip during normal usage, you should investigate to find the cause. Equipment malfunctions; short circuits in wiring and overloaded circuits are potential causes. Ensure newly installed wiring ampacity matches circuit breaker size. Outlets and cords should be checked for proper polarity and grounding.

Vehicle Electrical Systems

Knowledge of vehicle electrical systems has always been important. Today, however, it is becoming more important than ever due to new technology. Front airbags, curtain air bags and/or side-impact air bags are now in all newer vehicles. Seat belt pretensioners can be very dangerous to patients and rescuers. Electric vehicles and hybrid electric vehicles are increasing in popularity.

The 12-volt dc automobile electrical system is the most common system. It is found in most vehicles on the road. Luckily, these systems are relatively easy to deal with. However, higher voltage systems are being developed.

The average vehicle system includes several components. The battery or batteries store electricity. Multiple battery systems are common in diesel-powered vehicles. Vehicle manufacturers are becoming more creative with battery placement. They may be found under rear seats, in trunks, inside wheel wells, or out of sight under the hood.

The charging system is generally not a problem for rescuers because shutting off the engine easily disables it.

Accessories affecting rescuers include electric door locks, electric windows, electric seats, cell phones and electric fuel pumps.

Safety features concerning rescuers include driver and passenger front airbags, side impact & curtain bags, knee protection systems, foot protection systems, seat belt pretensioners, and pop-up or flip-up roll bars on convertibles. Dual charge airbags became a concern, beginning with the 2000 model year.

Disconnecting the battery or batteries can alleviate many of the hazards associated with these components. Increasingly, manufacturers are locating the batteries in less obvious locations, making your job more difficult. It is important to operate the necessary accessories, such as electric windows, door locks and seats, before shutting off the electricity. However, disconnecting the power as early as possible is very important. This will ensure shut down of the electric fuel pump and begin deactivation of the airbag system. Vehicle airbag systems contain a capacitor to activate the system should the battery become disconnected in a collision. The capacitor will store an electric charge for a given time period. This period varies by model and manufacturer but can be anywhere from several seconds to 30 minutes. The vast majority of vehicles will deactivate in 5 minutes or less. There are concerns about portable electronic devices, such as cell phones, causing back feeds and maintaining a charge on the system even after vehicle batteries are disconnected.

Electric and hybrid vehicles are becoming more popular as emission control regulations become stricter. These vehicles bring new challenges to the rescuer.

Electric vehicles are powered by a bank of batteries and may contain voltages as high as 300v. These batteries may be located under the hood, in the trunk or under the vehicle. A separate 12v-battery system operates accessories such as the radio and headlights as well as the safety systems.

Safely operating in and around these vehicles requires different methods. Never cut into battery packs or traction cables. Shut off the on-off switch, engage the drive train parking brake (use wheel chocks if necessary) and look for a switch to shut down the high voltage. Electric vehicles do not idle and may accelerate unexpectedly if not shut down properly. Beware of hazardous chemicals such as lead/acid batteries. New battery technologies include nickel metal hydride, lithium ion, and lithium polymer. Fuel cells are under development and are complicated electrochemical devices that use a fuel and an oxidant to generate electricity.

Hybrid vehicles combine two sources of energy; usually a battery powered electric motor and an internal combustion engine. These vehicles combine all of the problems of conventional vehicles with those of electric vehicles. Be aware that electric hybrid vehicles can be very quiet. When battery voltage drops, the internal combustion engine will automatically engage. This could cause sudden movement of the vehicle. Shut off the ignition switch and engage the brake system to disable the vehicle.

Honda's Hybrid Vehicle
The Insight

Electrical Safety

Electrical safety, for the most part, depends on the persons designing, testing, installing & inspecting electrical equipment. Everyone should know how to use electrical equipment safely and how to avoid potentially hazardous situations.

Electrical safety is provided in several ways. **Isolation** - High voltage wires placed high overhead. **Guarding** - TV cabinets guard against touching wires with up to 30,000 volts. **Insulation** - Ensures current is confined to its proper path but must be in good condition. Even small cracks can be a big problem. **Grounding** - All noncurrent carrying metal parts (conduits, boxes, motor frames, etc.) are connected to the ground wire. This prevents any voltage above ground on any enclosure and provides a current path to operate a fuse or circuit breaker in a live line with a fault. True grounding occurs only with an earth ground. **Shock Limitation** - GFCI or Ground Fault Circuit Interrupters instantly sense if a current of only a few milliamps leaves the normal circuit and flows to ground. It senses the shift and opens a circuit breaker. These provide a high degree of safety against shock or electrocution. Non-GFCI breakers protect the wiring and connected devices but provide poor shock protection.

All safety provisions depend on safe work practices and proper maintenance. Keep ladders and light towers away from power lines. Keep equipment enclosures intact. Insulation must be intact and in good condition. Double insulated power tools depend on intact plastic housings. Ensure proper grounding where required. 3 prong plugs need all 3 prongs! GFCI outlets must be properly installed and tested. Inadequate in-house repairs, by well meaning individuals, can be very hazardous. Short cuts and improper methods can endanger the next user.

Lock-out / Tag-out

Safe work practices require locking and tagging an open switch or disconnect whenever inadvertent re-energization could endanger personnel. Open the appropriate switches or disconnects then lock them open and tag them. Each individual working on the equipment should provide a lock at the lock-out and keep the key. This prevents anyone else from re-energizing the circuit. OSHA 29CFR 1910.147 provides requirements for the Lock-out/Tag-out process.

Generally, lock-out / tag-out is required for; confined space incidents, elevator rescues, and industrial equipment rescues.

Control of Electric Utilities

Montgomery County SOP assigns utility control to the rescue squad. This activity should be coordinated through the command post.

Controlling electric utilities is essential for safe fire or rescue scene operations. Every attempt should be made to shut off power only to the area or equipment necessary for safe operations. Shutting off power to large areas or entire buildings can cause unnecessary damage. In the commercial or industrial setting, critical systems and complex equipment can be damaged or destroyed.

Power should be shut off using the following priority. Operate remote disconnects or unplug the appliance. Turn off the branch circuit in the circuit breaker box. Operate the main disconnect for the building. This will shut off power to the entire building. **Montgomery County will no longer pull or remove surface mounted electrical meters (See MCFRS Directive 06-03).** Notify the local power company to interrupt the service. Many commercial and industrial meters are of the current transformer type and are connected in parallel. Pulling these meters does not shut off the power. Remember to install meter socket covers for safety. If it becomes necessary to shut down power at commercial or industrial buildings, rely on building engineers or power company personnel.

It is very important to note any breakers that are tripped before shutting off circuit breakers at fire related incidents. The fire investigator will need this information.

Commercial meter bank showing main disconnect, meters and individual occupancy disconnects.

General Rules for Safety

- Treat all wires as hot.
- Beware of wires in contact with metal structures such as wire fences or guard rails
- Electricity will always seek ground through the path of least resistance.
- Don't become the path of least resistance.

Power Tools, Appliances and Supply Cords

All power tools and appliances use a given amount of electricity. Total power generated or consumed is measured in watts. Motorized equipment requires a higher current to start than to run. Preplanning the power available or required is very important.

The key number system is based on Units of 500 watts (1 unit = 500 watts). A 10 kW generator creates 10,000 watts of power. This is equivalent to 20 units. A certain amount must be held as a safety factor. For generators rated at less than 1000 watts, limit use to one appliance. For 1000-5000 watt systems, reserve one unit as a safety factor. Greater than 5000 watts, reserve two units. Thus, a 10 kW generator has 18 available units.

You can determine the power requirements (wattage) of a given tool or appliance by multiplying the operating voltage by the listed amperes (V x A = W). This will give you an accurate wattage for dc appliances however it will not be exact for ac appliances. Although we generally operate with ac appliances, this method may still be used as a rule of thumb and will give a reliable number. Once the wattage is obtained, you must divide by 500 to obtain the number of Units.

Example: A tool is marked as 120 volts ac and 6.25 amps. 120v x 6.25amps ≅ 750 watts. 750 watts divided by 500 equals 1.5 units.

Power requirements of specific tools:

Flood light, 500w		1 Unit
Flood light, 1500w		3 Units
Fan, 16" 1500w start/ 500w run		3 Units/1 Unit
Fan, 24" 3000w start/1000w run		6 Units/2 Units
Salvage Vacuum \		
Submersible Pump \		
Chain Saw	> 750w	1.5 Units
Circular Saw /		
Drill /		

Acme

½ Inch Drill
Variable Speed

Double Insulated

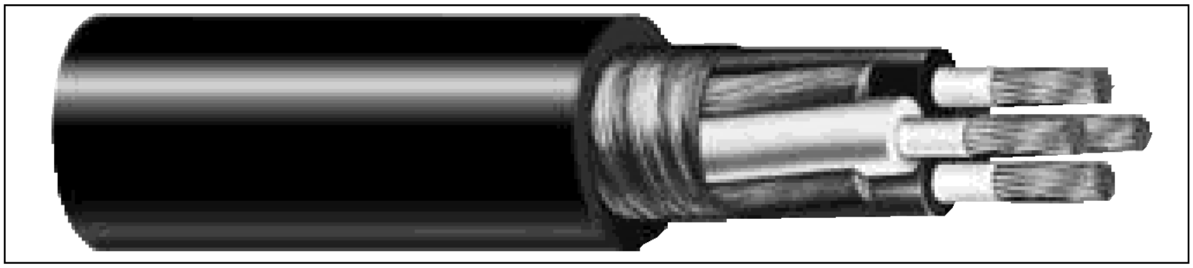
110-120 Volts 60Hz AC Only 6.25 Amps
Model 336.10280
Acme Drill Company

FOR SAFE OPERATION – SEE OWNERS MANUAL – USE ONLY IDENTICAL REPLACEMENT PARTS
Made in USA

Sample Electric Tool Label

Supply Cords

Electrical wire and supply cord conduct electrical current. Electricity must flow in a complete circuit. It starts at a source, which in most cases is the service panel box, and it must have a way to return to the source or service panel box. Different wires in a system or cord are different colors to distinguish hot, neutral and ground which are the roles the wires play in the flow of electricity. The hot or “live” wire carries 120 volts from the service panel box. It’s outer jacket or insulation is usually black or red and sometimes blue. The neutral wire or system ground conductor completes a circuit by providing a path for electricity back to the service panel box and then to ground. The neutral is always covered with white or light gray insulation and has zero voltage when not in use, although there is still current potential in the wire. The ground wire or equipment ground is normally covered with green insulation but is sometimes bare copper. It normally carries no voltage or current, but it provides a safe path to ground in case of a short circuit in an outlet, appliance or in the cable itself.



4 Conductor SOW drop cord showing the outer insulation, sheathing and filler, inner insulation and copper conductors

Drop cord can be used in many ways but there are types rated for each application. It is important to use the proper type of cord. Flexible Cord and Cable types are listed in the NEC in table 400-4. Here are a few of the more common types.

S: Heavy-duty, rubber-insulated portable cord. Stranded copper conductors with separator and individual rubber insulation. Two or more color-coded conductors, cabled with filler, wrapped with separator, and rubber jacketed overall. Rated for 600V maximum.

S O: Hard service cord, same construction as type S, except with oil-resistant outer jacket. 600 V, 60° to 90°C.

S O W: Same as SO with the added UL and CSA approval for outdoor use and water resistance.

All conductors have resistance, some more than others do. Steel conductors have more resistance than aluminum conductors, aluminum more than copper, and copper more than gold. Copper is the most cost effective and therefore the most common conductor material used. The longer the cord, the higher the resistance and, therefore, the higher the voltage drop.

Using the wire ampacities listed;
- #16 AWG wire - 13 amps max.
- #14 AWG wire - 18 amps max.
- #12 AWG wire - 25 amps max.
- #10 AWG wire - 30 amps max.
- # 8 AWG wire - 40 amps max.
- # 6 AWG wire - 55 amps max.

We now introduce voltage drop. Wire size and length must be adequate to handle the total tool load. Larger wire size = higher capacity and shorter length = higher capacity. Calculating supply cord capacities is similar to calculating appliance power requirements. Again, volts times amps will yield watts. Example: #10 wire on a 30 amp breaker at 120 volts. 120 volts x 30 amps = 3600 watts. 3600 watts ÷ 500 = 7.2 units. Keep one unit as a safety factor and you have 6.2 units available or rounded down, 6 units. We also have to consider voltage drop in longer cords operating at or near capacity, so subtract ½ unit for each 100' of cord over 200'. However, using larger cord, in this example #8 wire, will allow you to double the length of cord before voltage drop becomes a concern. Therefore, you could have a 400' cord of #8 wire operating at 30 amps and still deliver the full 6 units.

Heavy duty supply cord (#10 wire, 30 amp breaker)

50'-200'	6.0 Units
200'-300'	5.5 Units
300'-400'	5.0 Units

Medium duty supply cord (#12 wire, 20 amp breaker)

50'-200'	3.5 Units
200'-300'	3.0 Units

Light duty supply cord (#14 wire)

Up to 200'	2.5 Units

Extra light duty supply cord (#16 wire)

Up to 100'	2.0 Units

Extra light duty cords should not exceed 100'

Ideally, all drop cord for Fire/Rescue Service use should be no smaller than #12 wire. This is based on the standard 20-amp general use outlet and L5-20 plug. Light duty cord, if used, should be limited to powering one appliance.

These calculations are very conservative and have safety factors beyond requirements. They should be used in preplanning your electrical needs and will prevent on scene problems. It is a good practice to mark the capacities on junction boxes and the power requirements on electrical tools and appliances. This can eliminate faulty calculations, mistakes and overloads on the scene of an incident.

In general, remember the following. Keep all supply cords as short as possible. Limit residential and commercial house current outlets to 3 Units. Empty reels of all cord to prevent heating and additional voltage drop, especially when operating at or near cord capacity. Preplan supply cord ampacities for on scene use. Know your portable equipment Unit requirements. Know your supply cord Unit capacities. Prevent overloading.

Maintenance and Inspections

Double Insulated tools rely on outer casing for safety

Power tools and appliances need to be checked periodically for damage. Double insulated power tools depend on intact outer cases for safety and do not require 3 prong grounded plugs. Be sure these outer cases are not damaged. Some appliances will have a polarized 2-prong plug with one prong wider than the other. This ensures the proper conductor is the hot and the other is the neutral. Never alter these polarized plugs. Ensure grounding prongs are present for appliances that are not double insulated. Inspect for signs of overheating, arcing, or exposed wiring. A major source of problems is inadequate equipment repair. Refer repairs to qualified personnel and beware of poor quality repairs performed by others.

Check cords for damage. Any cracks, cuts, or exposed wiring should be repaired. Exterior insulation on cords should be oil & water-resistant. Interior conductor insulation may not be resistant, therefore it is important for the outer insulation to be intact. Ensure cords have not pulled loose from attachment plug clamps allowing tension to transmit to the terminals.