APPENDIX G.

SAFETY SUPPLEMENT

300-G.1 STATEMENT OF NEED FOR ELECTRICAL SAFETY

300-G.1.1 GENERAL. At the outset it is to be emphasized that the steel hull of a ship, which is an excellent conductor, and the probable presence of salt water and perspiration, which reduce body resistance, create conditions aboard ship which are more hazardous from the standpoint of electric shock than the conditions which are normally encountered in your homes ashore. For this reason there is a need for better and safer electrical equipment afloat, and more attention to safety precautions.

300-G.1.1.1 Electrical Safety. What is electrical safety? This may sound like a dumb question since everyone knows about the ships' electrical safety program, but not so dumb when you consider the fact that in a 24-month period (06/87 through 05/89) there were 373 cases of electrical shock and several deaths reported to the Naval Safety Center. Also, of 64 formal ships inspection reports reviewed, **only** 17 were unquestionably satisfactory. This difference indicates that the electrical safety atmosphere is severely deficient on many ships. What do these statistics mean? It could indicate that everyone from the top to the bottom in the chain of command should reevaluate their personal involvement in the electrical safety program. Most ships with a satisfactory electrical safety program have one thing in common: they communicate from top to bottom and from bottom to top on safety problems.

300-G.1.1.1.1 Many electrical safety officers have had a chance to grow into their position through many years of electrical experience, but many haven't had the opportunity to gain experience and must depend to a large degree upon the experience of others and the availability of ready sources of information.

300-G.1.1.1.2 The 115-volt circuits and equipment in your homes are usually not considered to be unduly hazardous and, in fact, are not extremely dangerous under most of the conditions existing in your homes. Certain exceptions are well recognized, notably the danger of electric shock to a person who handles electric equipment while in a bathtub. But it seems to be frequently forgotten by personnel afloat:

a. That the conditions existing on naval vessels are quite different from those that exist in your homes ashore and are far more conducive to danger from electric shock.

b. That insofar as danger from electric shock is concerned, the man afloat on a naval vessel is **living in a bathtub** practically all the time.

c. That better equipment and greater safety precautions are needed afloat than ashore to afford equivalent protection against danger from electric shock.

d. That human ingenuity has not yet been able to solve the problem of making electric equipment that will not shock its user when improperly used, and that, therefore, all who have anything to do with electric equipment must give some thought to their own safety and the safety of their shipmates.

300-G.1.2 RECENT STATISTICS OF SHOCK ACCIDENTS. Recent statistics are available to indicate the why of electrical shock accidents and the who. This indicates the reasons for why the various accidents with fatalities happened, and what type of Navy personnel were involved.

300-G.1.2.1 Shipboard Electrical Shock - Its Causes from Recent Statistics. Causes of shock accidents are all focused on human actions or failure to take specific actions. These human reasons are listed below in the order of highest cause:

a. Inattention - 46%

b. Failure to Recognize Hazard - 13%

c. Improper Maintenance - 10%

d. Inadequate Knowledge - 7%

e. Haste - 6%

f. Overconfidence - 5%

g. Equipment Design/Fault - 5%

h. Remaining - 8%

300-G.1.2.1.1 A very large number of the list can focus on the statement:

I DON'T BELIEVE

I COULD BE HURT OR KILLED.

300-G.1.2.1.2 These include Inattention, Failure to Recognize the Hazard, Haste, and Overconfidence, all adding up to 70 percent of the fatal accidents. This black on white reason for accidents is a very direct finger pointing to all levels of Navy personnel who do not believe that accidents can be lethal or will do serious harm.

300-G.1.2.2 Shock Incidents Breakdown. Accidents happen to everybody, and this is indicated by statistics which break down accidents into the grade of Navy personnel injured, and the rates of Navy personnel injured.

300-G.1.2.2.1 By Grade. Navy personnel involved in accidents related to grade of the victim involved are shown in the following list:

a. E1-3 - 21

b. E-4 - 55

c. E-5 - 44

d. E-6 - 14

e. E-7 - 7

f. OFF. - 2

7. Total 141 victims

300-G.1.2.2.1.1 It is expected that accidents are most clustered with those who are expected to be most intimately involved with electrical equipment, systems, cables, etc., i.e., the higher rated and trained seaman. The sum of accidents of the E-4, E-5, and E-6 rates is 113, or 79 percent of the total. Note that the remaining accidents are for lower rates than E-4, E-5, and E-6, and those above. This lower 21 percent are those not so well

trained, or those not intimately involved. If the highest percentage of accidents occurs for the highly trained and those closest to the events, then the reasons can be attributed to the simple occurrence of a (a) higher proximity and closeness to the lethal power, and (b) apparent lack a high respect for the lethal potential of the work.

300-G.1.2.2.2 By Rate. An analysis of lethal accidents by rate of the seaman involved indicates that anybody may be involved in a lethal accident. There are more accidents with electrically trained personnel who are closest to the equipment. Other than specifically electric and electronically trained personnel, all other rates of seaman are involved, almost equally. These statistics again point to another outstanding fact:

A LETHAL ELECTRICAL ACCIDENT

MAY HAPPEN TO ANYONE

300-G.2 BASIC CAUSES OF ELECTRIC SHOCK

300-G.2.1 CAUSES. The basic causes of electric shock are:

a. Equipment failure.

b. Human failure.

c. A combination of equipment failure and human failure.

d. A fortuitous combination of events so unlikely and so unusual that even the most prudent of men could hardly be expected to anticipate and guard against it. Accidents of this kind can happen, have happened, and will undoubtedly happen again. Fortunately, however, they are extremely rare.

300-G.2.1.1 Equipment Failure. Although equipment was necessarily involved in each of the fatal accidents, this **does not in itself mean that the accident was caused solely by equipment failure** , or would have happened if there had been no human failure. **Except for one case** , none of the fatal accidents aboard ship was caused by the sudden, unforeseen, and unpredictable failure of approved equipment that had been properly installed, tested for safety after installation, and used in accordance with applicable safety precaution. In the one case that is a possible exception, the insulation resistance of an installation was measured and found satisfactory just one day before an electric shock that killed a man working on the installation. Perhaps the insulation failure that caused the shock occurred before the man started to work on the installation, and could have been detected by another measurement of insulation resistance just before starting to work. Perhaps it did not occur until the man started to work. This case is uncertain. In all other cases, the defect in the equipment could have been found by tests before the fatal accident, or was definitely known to exist before the fatal accident because of minor shocks given by the equipment. But the tests were not made, or the warnings were disregarded, and the defect was not corrected until after the fatal accident occurred. Although there is some uncertainty with respect to the exact number of cases involved in each classification, Table 300-G-1 gives the nature of equipment defects or deficiencies and the approximate number of cases for each classification.

300-G.2.1.2 Human Failures. Human failures or **errors** which were partly or wholly responsible for the 22 shock fatalities aboard ship are listed in Table 300-G-2.

300-G.2.1.2.1 Examples of Human Error. A more detailed consideration of some of the cases will bring out more clearly the errors that led to fatal accidents.

a. In one case, a man sent to repair the control switch for No. 2 rammer motor opened the supply switch marked No. 2 rammer motor, worked on the control switch, reassembled it but left the terminals exposed, had the power turned on to test operation of the control switch, and accidentally came in contact with one of the terminals and was fatally shocked. After the accident it was found that the installation was defective in that the supply switches to No. 1 and No. 2 rammer motors were crisscrossed, No. 1 supply switch feeding No. 2 motor and vice versa. No. 1 supply switch was not opened until after the accident, so that while working on a control switch that he thought was de-energized, the man who was eventually killed was actually working on an energized circuit. His first mistake was in failing to test with a voltmeter or voltage tester to make sure that the switch he intended to work on was de-energized. This mistake, it so happened, was not fatal although it might well have been had the man working on the switch been less fortunate. But the second mistake, failure to avoid contact with a terminal that was known to be alive, was immediately fatal.

b. In another case, a man repaired a portable wire brushing machine, plugged it in to try it out, and was fatally shocked. It was found that in reassembling the tool, a wire in the terminal box had been laid so that one of the threaded cover securing bolts scraped the insulation off, permitting current to flow to the terminal box cover. The plug had been renewed with a light-duty household type plug. The grounding conductor was properly connected in the terminal box, but was not connected to ground at the plug end of the power cable. There were at least three personnel failures in this case:

Table 300-G-1 EQUIPMENT DEFECTS

Defect or Deficiency	Number of Cases
Defects in original installation	7
Defects in equipment after repair aboard ship	4

Table 300-G-2 HUMAN FAILURES OR ERRORS

Failure or Error	Number of Cases
a. Unauthorized modifications to equipment or use of unauthorized equipment	3
b. Failure to observe the necessary safety precautions when using or working on equipment that would be perfectly safe if handled properly. This includes:	
1. Failure to test equipment to make sure that it is de-energized before working on it	2
2. Failure to exercise sufficient care to avoid contact with equipment or conductors that were known to be energized.	13
3. Others	3
c. Failure to make adequate repairs on equipment that has given warning of an unsafe condition by nonfatal shock or shock prior to fatal shock.	2
d. Failure to test equipment for insulation resistance and correctness of ground connection **after making** repairs but**before trying** the equipment for operability or putting it to use.	2
Note that the total number of human failures exceeds the number of fatalities. This is because in some cases more than one error was made.	

1 Failure to use a standard Navy type plug.

2 Failure to make a ground connection.

3 Failure to test the tool for insulation resistance to ground and integrity of ground connection before plugging it in to try it out.

c. In another case involving a portable drill, a man using a drill received two nonfatal shocks before the fatal shock, one in the morning when his hands were bare, and another in the afternoon when wearing a pair of greasy gloves. After the second shock he wore a pair of clean gloves for a time, but ultimately discarded these and was working with bare hands when he picked up the drill late in the afternoon and was fatally shocked. Mistake was piled upon mistake to lead to a fatal conclusion. The first mistake was made by the person who

should have tested, but did not test, the drill for insulation resistance and soundness of ground connection before it was put into use. The second mistake was made by the user of the drill when, after receiving a nonfatal shock while working with bare hands, he failed to have the drill repaired and merely put on greasy gloves. The third mistake was made when a nonfatal shock was received while wearing greasy gloves. It was still not too late to fix the drill, but all that seems to have been done was to shift from greasy to clean gloves. And then, finally, one more mistake. The clean gloves were discarded, probably while the drill was not being used, the drill was picked up with bare hands, and a man was killed in an accident that would have been avoided had proper attention been paid to the warnings that preceded it.

d. In another case, a man was killed when he touched a portable submersible bilge pump. The pump had been repaired shortly before, tested without accident, and found to run. But no test had been made to check insulation resistance to ground and correctness of the ground connection. After the accident it was found that phase A of the power supply was connected to the ground terminal on the motor terminal block, and that the grounding conductor was connected to terminal A of the motor. The motor ran when it was tested, but it was nonetheless connected improperly and was deadly.

e. Another accident involved a portable electric grinder. The grinder was correctly connected to the grounded plug on the cord. Unfortunately, however, the user inserted the plug into the receptacle in the wrong position and made a direct metallic connection between one side of the power line and the metal case of the grinder. The plug and receptacle were of an early type (now obsolete) designed to prevent insertion of the plug into the receptacle in any but the correct position. Unfortunately, after the plugs were battered and worn and the polarity pins were broken, or bent, the plug could, by the use of sufficient force, be jammed into the receptacle in the wrong position.

f. In some of these examples, the absence of a correctly made ground connection contributed to a fatal shock. The reasons for using a grounding conductor to make a ground connection, why it is a protection against electric shock when connected correctly, and why it is dangerous when connected incorrectly are considered in some detail later in this text.

300-G.2.1.2.2 Reasons for Human Failure. It is probable that many of the human failures that are responsible for fatal electric shocks on board ships are due to a natural but extremely unfortunate tendency to carry from shore to ship the rather casual regard for the deadly potentialities of electric circuits and equipment that is acquired ashore. The 115-volt circuits and equipment in our homes are usually not considered to be unduly hazardous and, in fact, are not extremely dangerous under most of the conditions existing in our homes. Certain exceptions are well recognized: the largest is the danger of electric shock to a person who handles electric equipment while in a bathtub. Certain conditions regarding shock are forgotten by naval personnel afloat:

a. That the conditions existing on naval vessels are quite different from those that exist in our homes ashore and are far more conducive to danger from electric shock.

b. That insofar as danger from electric shock is concerned, an individual on a naval vessel is **living in a bathtub** practically all the time.

c. That better equipment and greater safety precautions are needed afloat than ashore to afford equivalent protection against danger from electric shock.

d. That human ingenuity has not yet been able to solve the problem of making electric equipment that will not shock its user when improperly used, and that, therefore, all who have anything to do with electric equipment must give some thought to their own safety and the safety of their shipmates.

300-G.3 FUNDAMENTALS OF ELECTRIC SHOCK

300-G.3.1 GENERAL. It is the purpose of the following discussion to point out certain fundamental principles relating to electric shock in order that the need for and the nature of safety precautions may be properly appreciated.

300-G.3.1.1 Shock Intensity. To begin with, current rather than voltage is the proper measurement of the amount of shock intensity. If 60-hertz alternating current is passed through a person from hand to hand or from hand to foot, the effects noted when the current is gradually increased from zero are as follows:

a. At about 1 milliampere (0.001 ampere), the shock is perceptible.

b. At about 10 milliamperes (0.010 ampere), the shock is of sufficient intensity to prevent voluntary control of the muscles and the man may be unable to let go and free himself from the electrodes through which current entered his body.

c. At about 100 milliamperes (0.100 ampere), the shock is fatal if it lasts for 1 second or more.

300-G.3.1.1.1 These figures are approximate only because individuals differ in their resistance to electric shock, but the results of a number of investigations show that the figures given above represent correctly the magnitude of 60-hertz currents that will produce the effects indicated. The same measures that are used to protect personnel from shock by 60-hertz alternating currents should also be used to protect personnel from shock by direct current. Because 60-hertz alternating current is used more extensively than direct current on U.S. naval vessels, the rest of this section will deal with 60-hertz alternating current.

300-G.3.2 BODY RESISTANCE. At the outset of any consideration of safety from electric shock, it is important to recognize that the resistance of the human body cannot be relied upon to prevent a fatal shock from 115-volt or even lower voltage circuits. To be sure, when the skin is dry, it has a high resistance where it makes contact with the electrodes through which current enters and leaves the body. The resistance may be high enough in this case to protect a person from fatal shock even if one hand touches a bare conductor on one side of a 115-volt line while the other hand (or a foot) touches a bare conductor on the other side of the line. But this is an exceptional case. On board a ship, it is far more likely that the skin will be wet with perspiration or salt water. The contact resistance falls when the skin is wet, and the body resistance, measured from electrode to electrode, is low. Tests made by the National Institute of Standards and Technology show that the resistance of the human body may be as low as 300 ohms under unfavorable conditions such as are encountered on naval vessels because of the presence of water and perspiration. If 0.1 ampere is enough to cause death, and if the body resistance can be as low as 300 ohms, it follows immediately that 115-volt circuits can supply more than enough current to be fatal. Mute witness to the correctness of this conclusion is furnished by the graves of people who have been killed by 115-volt and even lower voltage circuits. All circuits, even if of only a few volts, are potentially dangerous in that they may give rise to currents that are immediately fatal, or that keep a person from letting go and ultimately cause death if they are not rescued by their shipmates, or that cause a person to jump and perhaps fall under conditions that will cause serious injury. The resistance of the body itself cannot be relied upon to provide protection from shock.

300-G.3.3 GUARD AGAINST ELECTRIC SHOCK. The application to safety is immediate. To guard against electric shock:

a. A person should, if possible, see to it that his body never forms part of a closed circuit through which current can flow.

b. If this is not possible and it is necessary to include any part of his body in a closed circuit, he should be absolutely sure (1) that the resistance in the circuit is high, (2) that any voltage or difference of potential tending to cause current flow in the circuit is low, or still better, (3) that the resistance is high and the voltage is low. The reasons are obvious. High resistance and low voltage both mean low current. See paragraph 300-2.5 for procedures if it is necessary to work on energized equipment.

300-G.3.3.1 If a person does none of the above and allows his body to form part of a closed circuit in which there is an appreciable voltage and in which the total resistance is low, he will never have another chance. In this connection, it should always be kept in mind that a circuit may be closed by metallic conductors, nonmetallic conductors, or capacitors. A capacitor passes alternating current (and also direct current when the voltage is changing) and does not open a circuit in which it is included even though the plates of opposite polarity are separated by insulation material.

300-G.3.4 CONDITIONS FOR SHOCK. Two conditions must be satisfied for current to flow through a person, namely:

a. The person must form part of a closed circuit in which current can flow.

b. Somewhere in the closed circuit there must be an electromotive force or a difference in potential to cause current flow.

300-G.3.4.1 Touching Power at One Point, Perfectly Isolated. Follow the adventures of Seaman I. R. Drop in his dealings with electric circuits and equipment, and see when he will be in danger of being shocked. First, suppose that Seaman Drop, desiring for some reason to emulate the birds he has seen sitting on electric power transmission lines, swings by one bare hand from a bare conductor on one side of a power line as in Figure 300-G-1. Inspection of the figure shows that Seaman Drop does not form part of a closed circuit. No current can flow through his body, and he will not be shocked even if there is no insulation between his hand and the conductor it grasps. This conclusion does not necessarily hold for high voltage or high frequency circuit, but is valid for 60-hertz, or lower frequency, 115-volt or 450-volt circuits.

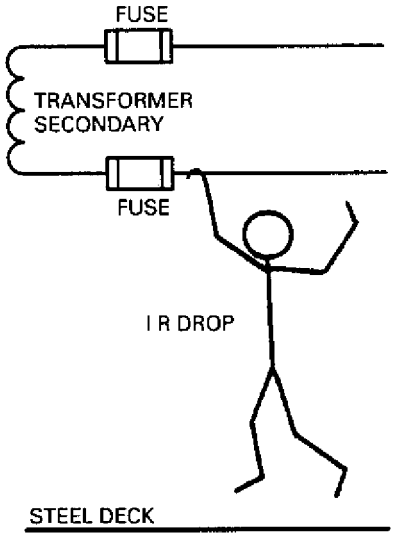

Figure 300-G-1. I. R. Drop Hanging by One Hand

300-G.3.4.2 One Hand Touching Each Power Line. Now suppose that I. R. Drop is foolish enough to reach up with his free hand, also bare, and grasp a bare conductor on the other side of the power line, Figure 300-G-2. Both conditions for current to flow through him are satisfied. He forms a part of a closed circuit through which current can flow from A to B to C to D and back to A, and the power source supplies a voltage causing current to flow. If the power line is a 115-volt or even a lower voltage circuits I. R. Drop will almost certainly be killed. He might survive if he is lucky enough to have dry hands so that they have enough resistance to prevent a fatal shock. Unless he is very lucky indeed, a stunt like this will end his adventure.

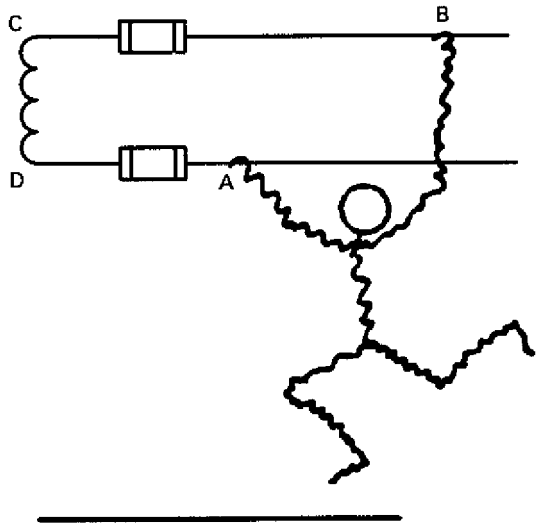

Figure 300-G-2. I. R. Drop Hanging by Two Hands

300-G.4 GROUNDED AND UNGROUNDED SYSTEMS

300-G.4.1 GENERAL. An ungrounded distribution system is one in which there is no intentional metallic or conducting connection from ground (the steel hull) to either line conductor of a two-wire distribution system (ac or dc), or between ground and any line conductor or the neutral of a three-phase ac distribution system, or between ground and either line conductor or the neutral of a three-wire dc distribution system. On United States naval vessels:

a. All ac power and lighting distribution systems, both three-phase and single-phase, are ungrounded.

b. Some polyphase, high voltage ac electric propulsion systems have a neutral which is grounded through a resistor.

c. Most three-wire dc distribution systems are ungrounded.

d. A few three-wire dc distribution systems are grounded with a grounded neutral. These last are the only examples of grounded power and lighting distribution systems in United States naval vessels.

300-G.4.2 TOUCHING THE GROUND SIDE OF A GROUNDED SYSTEM. Take a new I. R. Drop, and for the first of his adventures, suppose that he stands on a steel deck and touches a bare energized conductor of a grounded distribution system. A grounded distribution system is one which is intentionally provided with a solid metallic connection from ground (the steel hull) to one or the other of the two line conductors of a two-wire distribution system, or to one of the line conductors or the neutral of a three-wire dc distribution system, or to one of the line conductors or the neutral of a three-phase ac distribution system. In order to be specific, consider a grounded two-wire ac distribution system, Figure 300-G-3, in which one side is grounded by a metallic connection from C to D.

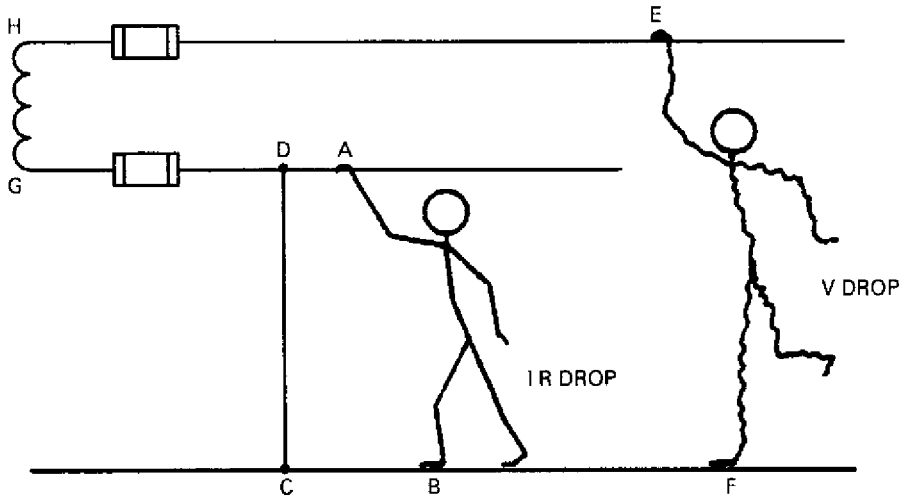

Figure 300-G-3. I. R. Drop and His Brother on Grounded System

300-G.4.2.1 Suppose that I. R. Drop touches the grounded side of the grounded distribution system. He forms part of a closed circuit which runs through his body from A to B and then through metallic conductors from B to C to D and back To A. One of the conditions for current to flow through I. R. Drop is satisfied. The other, however, is not. The closed circuit in which I. R. Drop is connected contains no appreciable voltage to drive current through this circuit. There will be a line drop between D and A if the distribution system is loaded to the right of point A, but the line drop is small and I. R. Drop is in no danger.

300-G.4.2.2 But look at his brother, Seaman V. Drop. He has touched a bare conductor on the ungrounded side of the system. There is a closed circuit through him, E F B C D G H E, and there is a large voltage in this circuit, the full voltage of the power system. In all likelihood I. R. Drop will soon be burying his brother.

300-G.4.3 PERFECT UNGROUNDED SYSTEM. Since almost all distribution systems on naval vessels are ungrounded, let us now suppose that I. R. Drop stands with his foot on the steel deck while with one one bare hand he grasps a bare conductor on one side of a perfect ungrounded distribution system, Figure 300-G-4. By a **perfect** ungrounded system we mean one in which the insulation is perfect on all the cables, switchboards, circuit breakers, receptacles, and other fitting of the distribution system. There are no capacitors in electromagnetic interference (EMI) filters connected from ground to any of the conductors in the system, and there is no way for current to flow to ground, either through conductors, insulators, capacitors, or other means, from any of the conductors in the system. For the sake of having something definite to talk about, consider the specific case of a two-wire, single-phase, ungrounded ac distribution system supplied by power from the secondary of a perfectly insulated transformer so that any grounds there may be on the primary side do not carry over the transformer to the secondary. Refer to Figure 300-G-4. Note that one of the conditions for current to flow through I. R. Drop is not satisfied, namely, he is not part of a closed circuit. His hand at A grasps a bare conductor on one side of the power line, his feet rest on the steel deck at B, but in the perfect ungrounded system we are considering, there is no way in which current can get from ground (the steel deck) back to any point C on the side of the power circuit that he is not holding in his hand. He does not form part of a closed conducting path from one side of the power circuit to the other side. The insulation on the perfect ungrounded system forms a line of defense that protects I. R. Drop from shock.

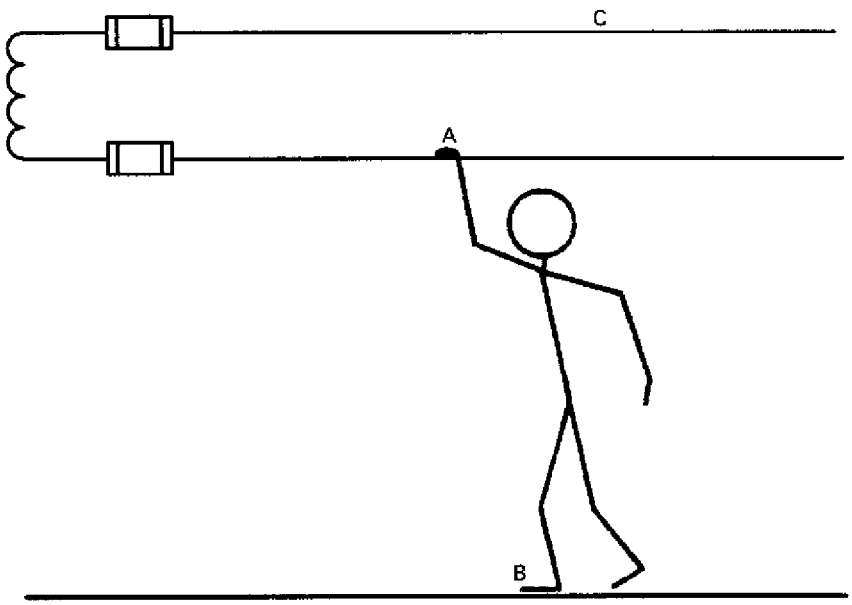

Figure 300-G-4. I. R. Drop and Perfect Ungrounded System

300-G.4.4 REAL UNGROUNDED SYSTEM. **Let it never be assumed that I. R. Drop can safely stand on a steel deck and touch a bare conductor on a real ungrounded system** . He could in the case of the perfect ungrounded system we have just considered, but in the case of a real ungrounded system, he might survive, and then again he might not. There are a number of reasons for this extremely important difference between **perfect** and **real** ungrounded systems. Only four shall be considered:

a. Possible low insulation resistance to ground.

b. Possible presence of poorly designed or improperly installed EMI filters.

c. Possible total **capacitance-to-ground** value (sum of capacitances to ground for cables, connected loads, transformers, EMI filters, and so on) that is large enough to have a low impedance for alternating current and that will, therefore, be a shock hazard.

d. The virtual impossibility of making any tests or check that will establish in advance that it is safe to touch one of the live conductors while standing on the steel deck.

300-G.4.4.1 Low Insulation Resistance. In the case of the perfect ungrounded system, it was the assumed perfect insulation between the live conductors and ground (the steel hull) that formed the line of defense that protected I. R. Drop from shock. In a real ungrounded system this line of defense is formed by real insulation instead of insulation that is assumed to be perfect. Real insulation is not perfect. It is a matter of common knowledge that grounds develop on real ungrounded systems. Except for preventive maintenance, the resistance from the live conductors to ground becomes progressively lower. Water vapor may condense in junction boxes, dirt and dust may accumulate on bare terminals in fittings and fixtures, and insulation may be abraded and broken down. The mere size of a large system is in itself a factor that makes it difficult to maintain high insulation resistance to ground. On a 115-volt system of any size, there will be numerous cables, lighting fixtures, switches, boxes, receptacles, and other fittings. Even though each individually may have a respectable insulation resistance to ground, the combined effect of all is to give a much lower resistance to ground for the entire system. Suppose that the insulation resistance sinks to 300 ohms from each side of the line to ground. This level is much lower than it ought to be, but still not as low as it may be from time to time. Current can then flow from one line conductor to ground through a resistance of 300 ohms, and back to the other line conductor through another resistance of 300 ohms. The resistance from line to line is 300 + 300 or 600 ohms and the line voltage is 115 volts. The leakage current from line to line is, by Ohm's law, about 0.2 amperes. This is too small to overload the source that supplies power to the system, or to interfere with operation of the system. But it is more than enough to kill a person. If I. R. Drop's body resistance is low, as it will be if he is wet with perspiration or salt water,

and if he stands on the deck and touches a live conductor on either side of the power line, he will probably be killed. Some of his fellow members of the Navy have been killed in just this way.

300-G.4.4.2 EMI Filters. A second reason for the difference between **perfect** ungrounded systems, in which EMI filters were assumed to be absent, and **real** ungrounded systems is the possible presence of unsafe EMI filters on **real** ungrounded systems. The Bureau of Ships is well aware of the shock hazard created by poorly designed or improperly installed EMI filters, and is working to eliminate this hazard in two different ways. One way is to eliminate electromagnetic interference at its source so that it is not necessary to use any EMI filters at all. The other way is to make sure that only well-designed and safe EMI filters are properly used in those cases where filters are still needed.

300-G.4.4.2.1 In certain types of EMI filters, capacitors are connected from both sides of the power line to ground, see Figure 300-G-5. This figure is not intended to be a circuit diagram of a filter, it is merely intended to show the capacitors connected from the line conductors to ground. Capacitors pass alternating current, and also direct current when the voltage is changing. In a well-designed filter for this application, the capacitors will have voltage ratings high enough to ensure that the insulation will not break down under any voltage to which they may be subjected. Furthermore, the capacitance of the capacitors will be small enough that the current that can pass through the capacitors will be too small to harm I. R. Drop.

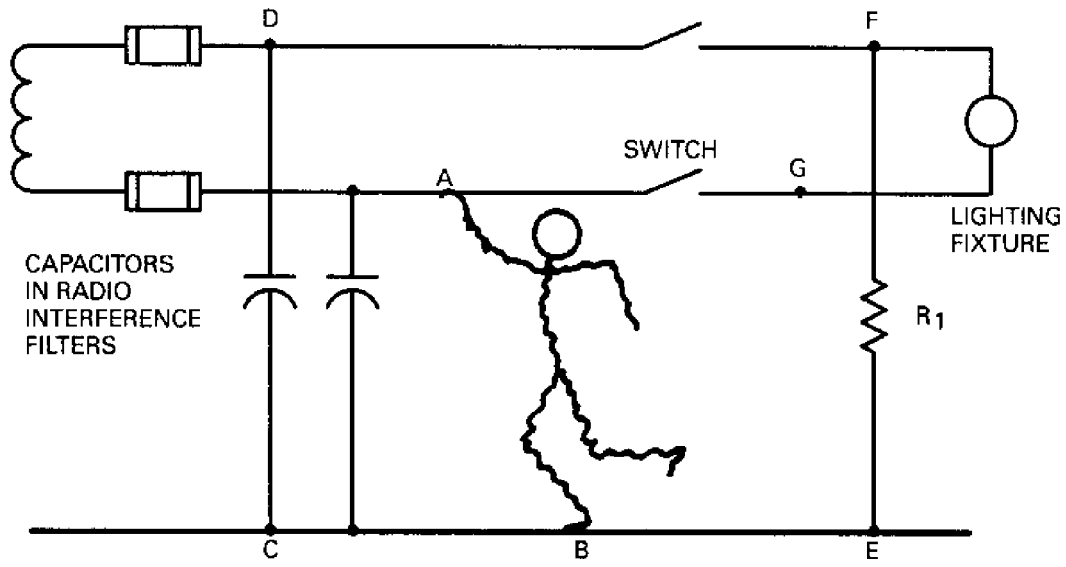

Figure 300-G-5. I. R. Drop and Radio Interference Filters

300-G.4.4.2.2 Things are different with a poorly designed or an improperly installed filter. The capacitors may have a voltage rating not much greater than the 115-volt line voltage so that they break down when a 500-volt megger is used to measure insulation resistance. Even if the insulation is perfect, the value of capacitance may be so high that enough current can flow through the capacitors to kill I. R. Drop.

300-G.4.4.2.3 Consider the case of too much capacitance in more detail. Assume that each of the two capacitors shown in Figure 300-G-5 has a capacitance of 5 microfarads. This is far too much, but no more than has been found in some filters. A capacitance of 5 microfarads has a reactance of 530 ohms at 60 hertz. Suppose that I. R. Drop's body resistance is 800 ohms. Reference to Figure 300-G-5 shows that I. R. Drop's body resistance is connected in series with the reactance of the capacitor in a circuit that goes from one side of the power line at A through B and C to the other side of the line at D. A few moments with vector diagrams and calculations will show that the impedance of the series circuit is 960 ohms and that the current through it, for 115-volts, is 0.12 amperes. This is enough to kill I. R. Drop.

300-G.4.4.2.4 Naturally this filter is not the kind that anyone wants to have on our naval vessels. It is extremely difficult, however, to make absolutely sure that there are none to be found. For this reason, it is no more than common sense to assume that filters like these may still be left, and to take adequate precautions to guard against the possibility of their presence.

300-G.4.4.3 Too Much System Capacitance. A third reason why it is dangerous to stand on a steel deck and touch a live conductor is the possibility of a large value of system capacitance to ground. In all electric power systems there is capacitance to ground from live conductors in cables and connected equipment. The value of capacitance for each foot of cable and for each individual item of equipment is small, but the values add up just as pennies add up to nickels, dimes, and dollars if there are enough of them. In a large system, there are many feet of cable and many individual items of equipment. The total capacitance to ground may be considerable, even if no EMI filters are connected to the system. A large value of capacitance to ground means low impedance for alternating current and danger for I. R. Drop. This danger exists whenever the system capacitance is large, whether the insulation is good or bad.

300-G.4.4.4 Not Knowing If a System Is Safe. Never stand on a steel deck and touch a live conductor. Suppose that I. R. Drop, for obscure and foolish reasons of his own, decides he is going to demonstrate that he can stand with bare feet in a puddle of salt water on a steel deck and touch a live conductor on a real ungrounded system, and do all this without becoming a corpse. Suppose, also, that I. R. Drop, although foolish indeed to have such an idea, is nevertheless not completely foolish and has sense enough to make some tests in advance of his stunt. He carefully de-energizes the 115-volt ac system on which he is going to defy electric shock, uses a voltmeter or voltage tester to make sure it is de-energized and, finding that it is, uses an insulation resistance measuring meter to megger the circuit. The insulation resistance is well up in the megohms.

300-G.4.4.4.1 This looks all right to I. R. Drop. He energizes the circuit and takes up his position with bare feet firmly planted in a puddle of salt water on the steel deck. Just as his finger approaches the bare conductor he is going to touch, doubt assails him. Perhaps he had better make another test. He measures the live conductor he was going to touch with a voltmeter, taking care to avoid a shock as he does this. The voltmeter reads 102 volts. I. R. Drop's knees buckle somewhat as he seats himself on his ditty box to ponder over this unforeseen development. At length it occurs to him that he has seen an EMI filter connected on the system. With pencil and paper, he makes a diagram, and sees how the capacitors in the EMI filter will pass current and give him a reading on a voltmeter connected from line to ground.

300-G.4.4.4.2 He can take care of that. He de-energizes the system again, disconnects the EMI filter, measures the insulation resistance to ground once more, and finds that it is still up in the megohms. He then energizes the system and repeats the voltmeter test from line to ground. This time there is only the tiniest movement of the voltmeter needle. This time he is ready. Somewhat gingerly he touches the bare conductor with the tip of an outstretched finger. Nothing happens. He pushers harder. Still nothing happens. He grasps the conductor firmly in his bare hand. Still nothing happens. A smile of triumph spread over his face. He knew he could do it. And then his face and body are suddenly distorted with pain as electric shock claims still another victim.

300-G.4.4.4.3 How could it happen? Very easily. Refer back to Figure 300-G-5, mentally erase the capacitors in the EMI filter which I. R. Drop disconnected, and look at the switch. This switch is but one of a multitude of switches on the system and I. R. Drop failed to notice that it was open when he made the tests prior to his death. It connects to a lighting fixture that has a low resistance ground, R_1 , from F to E. While I. R. Drop was still triumphantly grasping the bare conductor in his hand, one of his shipmates flipped the switch to have light by which to read a copy of appendix G - Electrical Safety Supplement. That was the end of I. R. Drop.

300-G.4.4.4.4 Of course it did not have to happen that way. The switch might not have been turned on, the low resistance ground might have been on the other side of the lighting fixture, from G to E instead of from F to E, or there might have been no low resistance ground at all. Any of these things would have saved I. R. Drop, and a man who had done a very foolish thing would have lived to tell the tale simply because he was not called upon to pay for his folly. Sometimes individuals don't have to pay, but sometimes they do, and sometimes the price is high.

NOTE

These are four reasons why it is dangerous to stand on a steel deck and touch a bare energized conductor even on an ungrounded system. There are still other reasons, but even one is enough.

300-G.5 PRECAUTIONS

300-G.5.1 BASIC RULES. It should be perfectly clear by now that standing on a steel deck and touching a bare conductor on either a grounded or a real ungrounded distribution system is very much like playing Russian roulette. You pull the trigger and take your chance. If you want to be safe and make sure that your career will not be terminated prematurely by a fatal electric shock, you must:

a. Make sure that you never touch a bare conductor.

b. When the nature of your work is such that it is necessary to touch a bare conductor, then you must either:
   1 De-energize the conductors on which you are going to work plus all those in the vicinity that you might accidentally touch, and tag these circuits to make sure that they will stay de-energized until you are through with your work; or
   2 If you have to work on live conductors, which sometimes happens, observe the safety precautions that are necessary to protect you from shock.

300-G.5.1.1 These seem like relatively simple things to do. Actually, there are many ways in which you can slip up. It is not possible to consider them all in detail. The best that can be done is to consider a few important points and then emphasize that in the final analysis, it is up to YOUR intelligence to save YOUR life.

300-G.5.2 TOUCHING CONDUCTORS. Avoiding contact with live conductors requires continuous caution and work habits that minimize the possibility of contact. The following are merely two of the things to keep in mind.

300-G.5.2.1 Never use portable cords and other equipment in such a way that a male plug can be energized EXCEPT when it is in a receptacle. The reason is obvious. If the plug is energized when it is not in a receptacle, there is danger of accidental contact with a live terminal. People have died because of this.

300-G.5.2.2 Remember that there are right and wrong ways to rig casualty power to a motor, for example. If you are unwise, you will start by connecting the casualty power cables to the source of power. From then on you will be working with live conductors. It's not invariably fatal, but it is sometimes, and it's very poor practice besides.

300-G.5.2.3 A right way is to start at the motor, disconnect it from its normal source of power and from all alternate sources of power, if it has any, to make sure that the motor cannot be energized by the closing of a circuit breaker not known to you, or by the restoration of power on a circuit that has had a power failure. Observe the same precautions that you would when working on live conductors. Then connect the casualty power from there toward the source of power, making all intermediate connections as you go along. You'll be working with dead conductors all the way. As the last step, make the connection to the source of power. This may have to be made on energized conductors and all necessary precautions should be observed to avoid a shock.

300-G.5.2.4 Another way would be run the cables and make all intermediate connections before those at either end. As the next to the last step, connect to the motor, and as the last step, connect to the source of power.

300-G.5.3 De-energize AND TAG CIRCUITS. When you must work on bare conductors, and there is no compelling need to keep the power on, de-energize the circuits on which you are going to work and all those in the vicinity that you might accidentally touch, and tag them so that they will not be energized before you are through. Remember that when you open a circuit breaker, you will de-energize the power circuit on the load side of the breaker, but you will NOT always de-energize associated metering and control circuits. In many cases these are connected to the live side of the circuit breaker and are not affected by opening it. People have died because of overlooking this. Play it safe. It may be necessary to pull fuses as well as open circuit breakers or switches to de-energize all the circuits around where you are going to work. All the de-energized circuit breakers, switches and fuses shall be tagged out in accordance with the Tag-Out User Manual S0400-AD-URN-010/TUM, to make sure that someone else will not inadvertently turn on the power. After you think the circuits are de-energized, make sure by testing with a voltmeter or voltage tester. In addition, it would be well to observe the same safety precautions that you would if you were working on live conductors. This practice could be the factor of safety that would save you if you missed one place through which power could be delivered to the conductors on which you are working. On a large system with numerous metering and control circuits, it is difficult to find all these places. It could be that one of the circuits you tested and found to be de-energized was that way only because a circuit breaker or switch happened to be open on a switchboard in another part of the ship. If you have failed to tag it, someone might close it and cause you to be shocked. Remember that your shipmates are not psychic and cannot be expected to know what you are doing. It's up to you to locate all danger spots and tag them, and if you are wise, you will also provide yourself with the back-up protection that comes from working on the conductors as if they were alive.

300-G.5.4 WORKING ON LIVE CONDUCTORS. Sometimes it is necessary to work on conductors when they are alive. This can be done safely if you do it right. Paragraph 300-2.5 gives safety precautions to be observed when working on live conductors. There is no intention to repeat these here, but rather to give the reasons for them. Current cannot flow through your body unless it can get in AND get out. If you work on live conductors with your bare hand, your hand is the point of entry. Remember to wear rubber gloves. Should current enter your body, your safety depends upon seeing to it that there is no point of exit. That's why you must use rubber mats or another suitable insulator to insulate yourself from ground and all metallic or conducting structures connected to ground, and from all conductors on the power line except the one on which you are working. That's why you should use only one hand for the job whenever possible; one hand for the ship, and one hand tucked away in your pocket for you. If you see to it that the current that gets into your body through your working hand cannot get out anywhere, a little consideration will show that your situation is like that of the birds sitting on a transmission line, or I. R. Drop hanging by one hand from one side of a power system. You'll be all right.

300-G.6 PORTABLE ELECTRIC TOOLS

300-G.6.1 EXAMPLES. It is high time to introduce I. R. Drop to portable electric tools and equipment, follow his adventures with them, see how he might be shocked while using them, and study what can be done to promote his safety. Portable electric tools shall be used as representative of the entire class of portable electric equipment and that the tools are used on a 115-volt, single-phase, ac distribution system. Also suppose, as before, that power is supplied by the secondary of a transformer that is perfectly insulated so that any ground on the primary side does not carry across the transformer to the secondary side. The discussion will begin with a tool that is not provided with a grounding conductor. A grounding conductor is a conductor that is entirely separate and distinct from those used to conduct power to the tool, and that is connected to the metal case of a tool at one end

and to ground at the other end. The discussion will show that insulation alone, when in good condition, will protect I. R. Drop from electric shock even when no grounding conductor is present. The discussion shall then show that:

a. A grounding conductor, when of proper size and correctly connected, will protect I. R. Drop from shock even in case of insulation failures.

b. A grounding conductor must be of low resistance and adequate current-carrying capacity to do its job.

c. A grounding conductor of high resistance or inadequate current-carrying capacity will not protect I. R. Drop from electric shock.

d. An incorrectly connected grounding conductor will not protect I. R. Drop from shock and may cause him to be fatally shocked.

e. It is, therefore, essential that grounded receptacles on the distribution system, and portable electric tools, their flexible cords, and their plugs be correctly wired. It is also essential that grounded plugs be inserted into grounded receptacles in the right position.

300-G.6.1.1 Perfect Insulation. First suppose that the insulation is perfect on the power distribution system, on the tool, and on the flexible cord; that the total system capacitance to ground is very small; and that no grounding conductor is provided. Conditions will then be as shown in Figure 300-G-6. I. R. Drop is all right in this case. There is no way for current to get from one side of the distribution system to the steel deck on which I. R. Drop stands, and also no way for current to get back to the other side of the distribution system from the metal handle of the tool that I. R. Drop holds in his hands. Hence, no current can flow from I. R. Drop's feet to his hands.

300-G.6.1.1.1 Next, look at I. R. Drop's hands. A closed circuit, which starts at I. R. Drop's right hand, goes through his right and left arms back to his left hand, and through the metal handle back to his right hand. But there is no voltage or potential difference in this circuit to cause current to flow because all parts of the metal case and handle are at the same potential. Similar considerations apply to I. R. Drop's feet. I. R. Drop is perfectly safe in this case. This condition is obviously one to strive for, no difference in potential between any points which I. R. Drop's two hands (or feet) can contact, and perfect insulation of the transformer, cables, and tool.

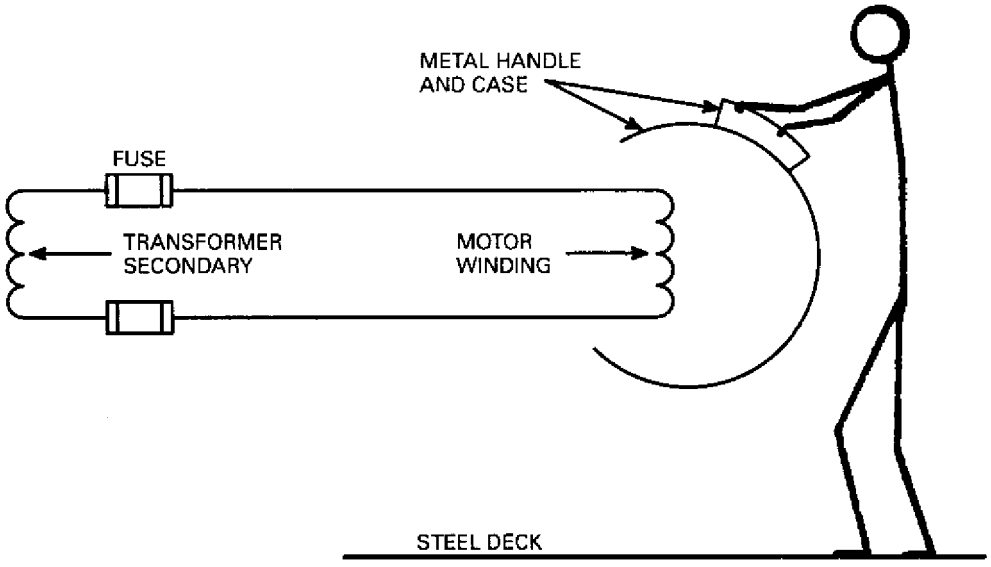

Figure 300-G-6. I. R. Drop and Perfectly Insulated Tool and Distribution System

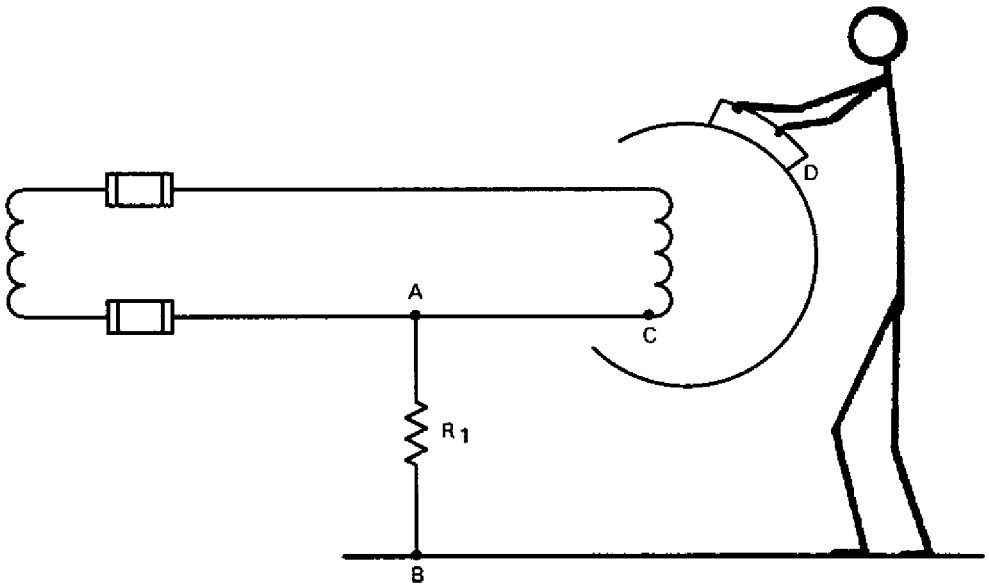

Figure 300-G-7. I. R. Drop and One Insulation Failure, on Line

300-G.6.1.2 One Insulation Failure. Perfect insulation is not possible to maintain under all conditions. It is, therefore, necessary to see what happens when the insulation falls short of perfection. In Figure 300-G-7, suppose that the insulation has failed or deteriorated with the result that there is low insulation resistance, R_1 , between points A and B instead of the extremely high resistance that we would have for perfect insulation. The low resistance, R_1 , may be the result of an insulation failure at point A alone while all the rest of the insulation remains perfect. Alternatively, it may be the result of a multitude of insulation failures spread out all along the side of the power line on which point A is located, none of the individual failures in itself giving very low insulation resistance to ground, but all combining in parallel to give a resultant resistance that is much smaller than that of any of the individual failures. In either case the result is the same, low insulation resistance to ground from one side of the power line. This is considered as one insulation failure without concern over whether the failure is at a single point or a multitude of points.

300-G.6.1.2.1 **Insulation failure** does not mean a complete breakdown of insulation to the extent that the insulation resistance drops to zero. It means a decrease from the high value of good insulation to a much lower value that can be dangerous to personnel. This lower value may be zero in the extreme case, or may be higher, a few hundred or even a thousand ohms. One insulation failure on an ungrounded system will not interfere with its operation. Neither will two failures, even if there is one on each side of the line, unless both are of very low resistance, not more than a few ohms. If the resistance to ground on one side or both sides of the line is a few hundred ohms, the system can still operate even though the insulation resistance is so low that it would be dangerous for a person to stand on the steel deck and touch a live conductor with their bare hand. This point is stressed hereto emphasize that a distribution system may be operating satisfactorily so far as power distribution is concerned but still be dangerous if one of its live conductors is touched.

300-G.6.1.2.2 Now return to Figure 300-G-7 which shows I. R. Drop using a portable tool on a system that has low insulation resistance from one side of the line to ground. Consideration of the figure shows that he will not be shocked even if R_1 is small, a few hundred ohms, or, indeed, even if it is zero. The reason is that I. R. Drop does not form part of a closed circuit. To see this, start from point A. From here there is a current path through R_1 to B, then to I. R. Drop's feet through the steel deck, and through his body, legs, and arms to the handle and the metal case of the tool. But there the path stops. There is no return to A and no current can flow through I. R. Drop this way.

300-G.6.1.2.3 Now look at the circuit that starts where I. R. Drop's right hand grasps the tool handle, runs through his arms to the left hand, and through the handle back to the right hand. This is a closed circuit, but there is no electromotive force to cause current flow since all parts of the tool handle will be at the same potential. Similar considerations apply to I. R. Drop's legs.

300-G.6.1.2.4 In Figure 300-G-8, suppose that the insulation has failed between points C and D, and that the insulation resistance between these points is R_2 . Here again there is no closed current path which includes I. R. Drop and he will not be shocked.

300-G.6.1.2.5 Note that in the case of Figure 300-G-7, the insulation on the tool saved I. R. Drop from shock; in the case of Figure 300-G-8, the insulation on the power line. A grounding conductor was not present in either case.

300-G.6.1.3 Two Insulation Failures. Now suppose, in Figure 300-G-9, that there is an insulation failure between A and B and another between C and D. This time there is a closed current path which includes I. R. Drop's body. It runs from A through R_1 to B, through the steel deck and I. R. Drop to D, through R_2 to C, and finally back to A through the cable between C and A. Furthermore, there is a difference in potential between points A and C to cause current flow in the circuit of which I. R. Drop forms a part. However, this difference in potential is merely the voltage drop in the cable between points A and C and normally will not be greater than about 5 volts.

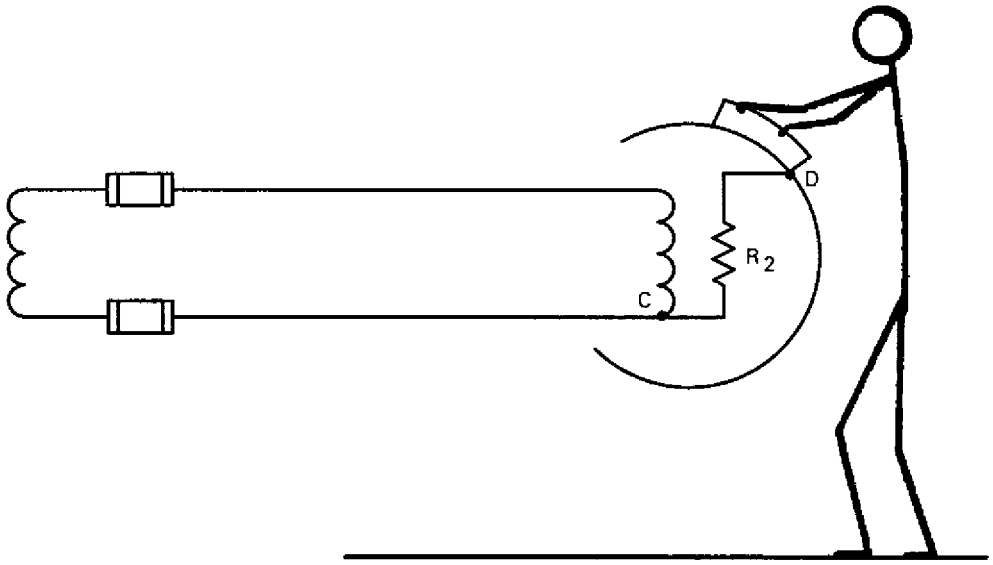

Figure 300-G-8. I. R. Drop and One Insulation Failure, on Tool

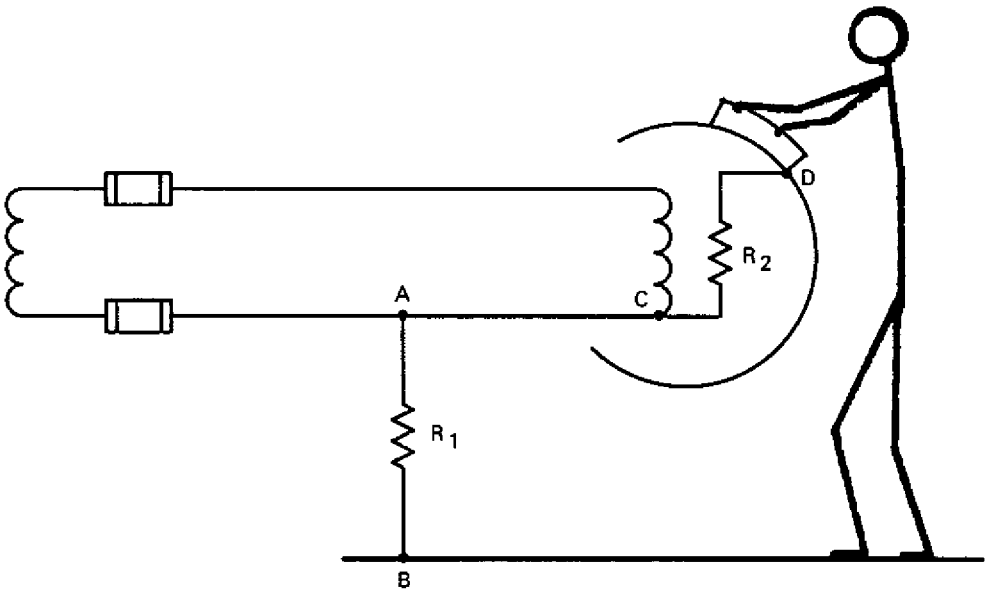

Figure 300-G-9. I. R. Drop and Two Insulation Failures, One on Line and One on Tool

300-G.6.1.3.1 Even if R_1 and R_2 are both zero and I. R. Drop's resistance is only 300 ohms, the current through his body will be only 5/300 or 0.017 amperes. This should not be fatal, but will be enough for I. R. Drop to feel, and conceivably might be enough so that he cannot let go. If this happens, he should lower the tool to the steel deck and ground it by pressing the case against the deck. He should then be able to let go.

300-G.6.1.3.2 Of course, this situation should never arise, for I. R. Drop should have grounded the tool before using it, in accordance with the instructions given later. But, if he has neglected to do so and feels a shock so severe that he cannot let go, he may still be able to lower the tool to the deck on which he is standing and ground it in this way. In any event, whether the tool has a grounding conductor or not, for the conditions illustrated in

Figure 300-G-9, I. R. Drop is not likely to receive a fatal shock, and if either of the resistances R_1 or R_2 is several thousand ohms, or if his own resistance is high, he may not receive a shock that can be perceived.

300-G.6.1.3.3 Now look at Figure 300-G-10. The only difference from Figure 300-G-9 is that a circuit between A and C, which was supposed to be closed in Figure 300-G-9, is supposed to be open in Figure 300-G-10 (broken power conductor or loose connection in the tool cord, for example). This difference is enough to be fatal to I. R. Drop. Referring to Figure 300-G-10 , it can be seen that I. R. Drop forms part of a circuit connected to two points A and C, which differ in potential by full line voltage. This situation is entirely different from that in Figure 300-G-9 where the motor consumed practically the entire voltage produced by the transformer secondary, and the potential difference between A and C was only the voltage drop in the cable and connections between points A and C. For the condition shown in Figure 300-G-10, the current through I. R. Drop will be the potential difference between A and C divided by R_1 plus R_2 plus I. R. Drop's resistance. If the total resistance is around a thousand ohms or less, as it may well be if I. R. Drop's hands and feet are wet, the current will be about 0.1 ampere for a 115-volt circuit and in all likelihood will be fatal.

300-G.6.1.3.4 For the next case to consider, see Figure 300-G-11 and suppose that there is an insulation failure between points A and B, and another between points D and E. Here again I. R. Drop is in real trouble, and this time quite regardless of whether the circuit between A and C is open or closed. His own resistance may be only a few hundred ohms, 500 ohms, for example, if he is gripping the tool in sweaty hands and standing on a wet deck, sitting on a wet deck, or bracing a sweaty back against a steel bulkhead. The potential difference between points A and E that will cause current flow through his body is 115 volts, and the current will be $115/(500 + R_1 + R_3)$ amperes. If R_1 and R_3 are only a few hundred ohms, it is almost certain that shortly thereafter a board will be convened to investigate the accidental death of I. R. Drop.

300-G.7 THINGS TO BE DONE TO PROTECT AGAINST SHOCK

300-G.7.1 GENERAL. Now, what can be done by the Navy, by I. R. Drop's shipmates, and by I. R. Drop himself to keep this from happening? First, look at the steel hull, water, and perspiration. The steel hull is bad from the standpoint of safety from electric shock because it is an excellent conductor and may form a part of a complete electric circuit which includes I. R. Drop as another part, as in Figure 300-G-10 and Figure 300-G-11. Water and perspiration are bad because they reduce the contact resistance between I. R. Drop and his surroundings.

300-G.7.1.1 Thus, the steel hull, water, and perspiration are all not friendly to safety from electric shock. Nevertheless, nothing can be done about them. Steel ships are here to stay, and it is probable that in the future water and perspiration will be associated with naval life, as in the past. They represent obstacles to safety from electric shock that cannot be removed from naval installations.

300-G.7.1.2 A further question raises: Can anything be done to protect I. R. Drop from shock despite these obstacles? Fortunately, it turns out that something can be done, and even more fortunately that enough can be done to protect I. R. Drop perfectly, PROVIDED THAT THE NECESSARY THINGS ARE DONE. They will do I. R. Drop no good if they are neglected.

300-G.7.2 TWO SAFEGUARDS TO BE SURE OF. There are basically two different things that can be done to prevent the flow of a dangerous current through I. R. Drop when he is connected in an electric circuit. One is to make sure that he is in series with a high resistance. The other is to make sure that there is only a small potential difference to cause current flow.

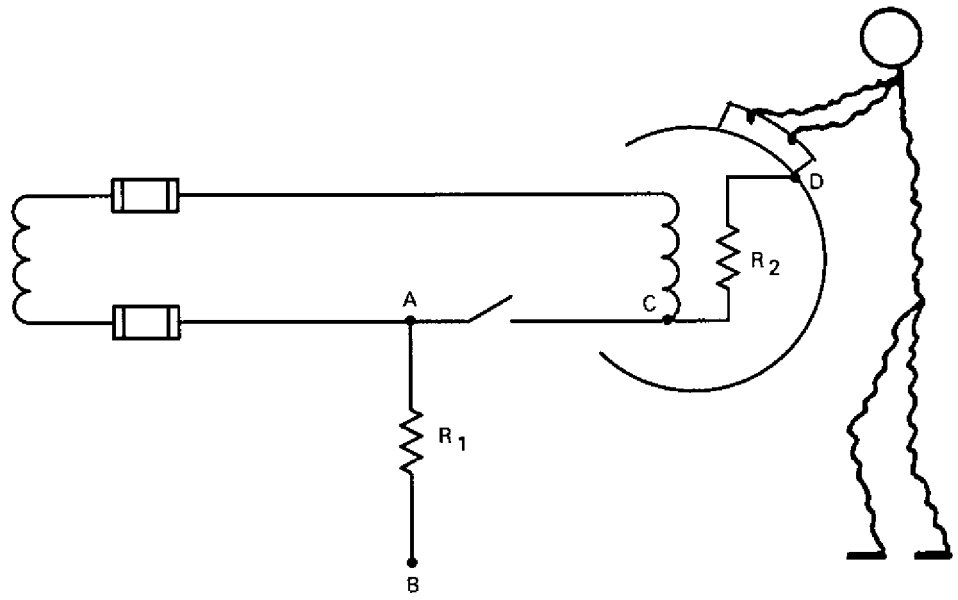

Figure 300-G-10. I. R. Drop Shocked by Broken Lead

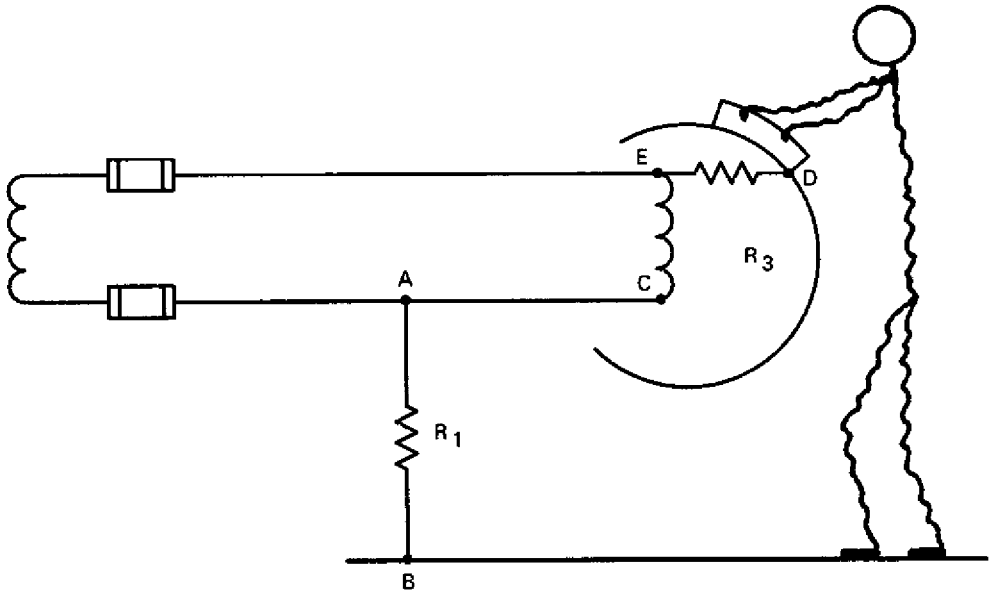

Figure 300-G-11. I. R. Drop Shocked by Two Insulation Failures

300-G.7.2.1 High Resistance. To see the effect of high resistance, refer back to Figure 300-G-11. The current through I. R. Drop is equal to the voltage between points A and E, 115 volts, say, divided by R_1 plus R_3 plus the resistance of I. R. Drop, that is:

$I = 115/(R_1 + R_3 + \text{body resistance})$.

300-G.7.2.1.1 As the National Institute of Standards and Technology tests show, and as numerous fatalities on 115-volt circuits (both afloat and ashore) conclusively prove, the body resistance may be so low that if R_1 and

R_3 are zero or small, the current through I. R. Drop will be enough to kill him. If, however, R_1 is 100,000 ohms, the current will be only 1.1 milliamperes even if R_3 and the body resistance are zero. Similarly, if R_3 is 100,000 ohms, the current will be only 1.1 milliamperes even if R_1 and the body resistance are zero. In either case, I. R. Drop will be protected from a fatal shock, and the protection will be better, the higher R_1 and R_3 are.

300-G.7.2.1.2 R_1 is the insulation resistance from ground (the metal hull of the ship) to one side of the circuit, which supplies power to the tool. All alternating-current power and lighting distribution systems on naval vessels, if constructed in accordance with the General Specifications for Machinery, are ungrounded systems. Present Navy practice is also not to ground the neutral or either leg of three-wire direct-current distribution systems, although a few installations with grounded neutral may be found in older vessels or conversions. In all cases where the system is designed to be ungrounded, R_1 , the insulation resistance to ground, should be kept as high as possible by clearing grounds from circuits and connected equipment. The high insulation resistance so obtained contributes directly to safety from shock. In the few installations with grounded neutral, R_1 will be zero and safety from shock depends upon R_3 and upon the grounding conductor, which is considered later.

300-G.7.2.1.3 R_3 is the insulation resistance from the live conductors in the electric tool to its metal case and handles. This resistance should be measured frequently. The higher the resistance is, the safer the tool will be from the standpoint of safety from shock. An insulation resistance of at least several megohms is to be expected for portable tools. The minimum permissible insulation resistance for portable electric tools and equipment that are to be used on 115-volt circuits is 1 megohm. The minimum permissible insulation resistance for portable electric tools and equipment that are to be used on higher voltage circuits is a resistance such that the line-to-line voltage divided by the insulation resistance gives a current not greater than 0.001 amperes, 1.0 milliampere. Every effort should be made to keep the insulation resistance well above the minimum values.

300-G.7.2.1.4 The maintenance of a high value of resistance for R_1 and R_3 is one measure that will protect I. R. Drop from shock. The other is to make sure that there is only a small difference of potential to cause current flow in the circuit of which I. R. Drop forms a part. A grounding conductor will do this. To see how a grounding conductor protects against shock, refer to Figure 300-G-12. Figure 300-G-12 differs from Figure 300-G-11 by the addition of a grounding conductor between points B and F. This addition makes a big difference to I. R. Drop. In Figure 300-G-11, it was shown that the potential difference causing current flow was the difference in potential between points A and E, or about 115 volts. If I. R. Drop's resistance is 500 ohms, R_1 is 200 ohms, and R_3 is zero, the current through I. R. Drop will be 115/(500 + 200) or 0.16 amperes. This is enough to kill.

300-G.7.2.1.5 Now look at Figure 300-G-12. Suppose that I. R. Drop's resistance is 500 ohms, R_1 is 200 ohms, and R_3 is zero, just as before. Nevertheless, I. R. Drop will be safe provided that the total impedance is low or zero for the metallic path which extends from G (I. R. Drop's feet) through the deck to point B; from B to F through the grounding conductor, and F to D through the metal case. Suppose first that this impedance is zero. Since there can be no difference in potential between points that are separated by zero impedance, the potential of point G will be the same as the potential of the handle of the tool (point D), there will be no potential difference between I. R. Drop's hands and feet, there will be no current through his body, and he will not be shocked. For I. R. Drop, under the conditions just considered, the difference between the presence and absence of a zero impedance grounding conductor means nothing less than the difference between life and death. That is why grounding conductors are important.

300-G.7.2.2 Impedance and Resistance. For practical purposes, the impedance of the metallic path from G through B and F to D can be considered as being very nearly equal to its resistance. It must be remembered, however, that this is permissible only when resistance and impedance are nearly equal and is not valid if someone constructs a very low resistance, but high impedance coil and uses it as the grounding conductor between points B and F of Figure 300-G-12.

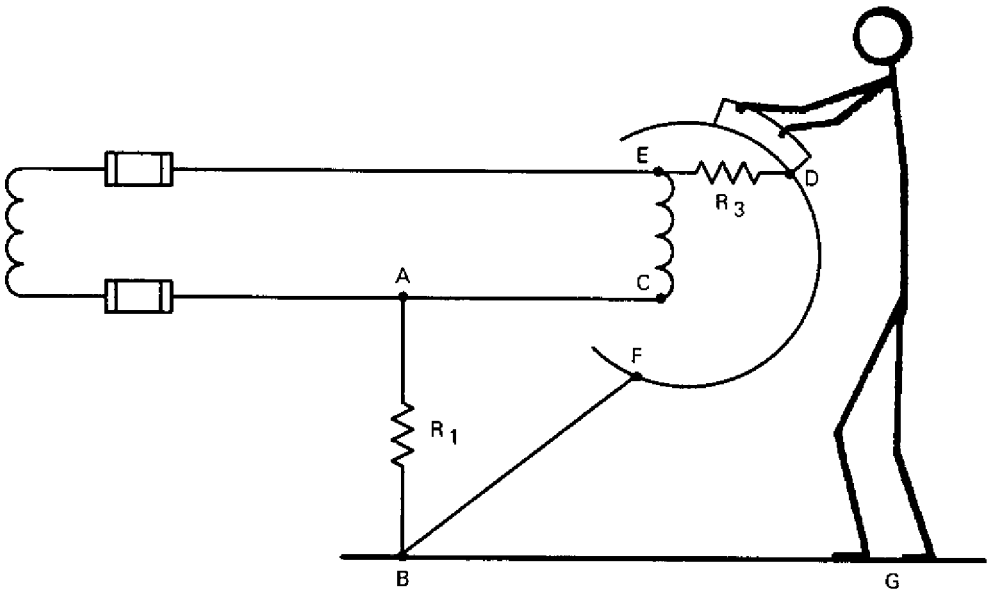

Figure 300-G-12. I. R. Drop Saved by Grounding Conductor

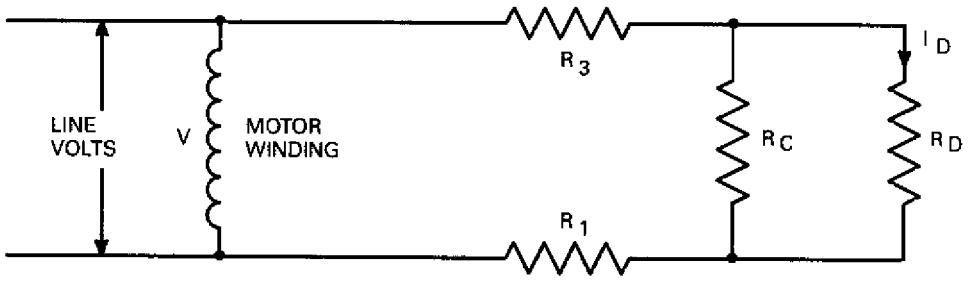

Figure 300-G-13. Simplified Diagram Corresponding to Figure 300-G-12

300-G.7.2.3 Grounding Conductor Resistance. While it is possible to install a low resistance grounding conductor, it is quite impossible to use a zero resistance grounding conductor. It is interesting to look into the effect of finite resistance to see whether a low resistance grounding conductor is really needed. To do this, let R_C denote the resistance of the grounding conductor between points B and F (see Figure 300-G-12) plus the resistance of the metal case between points F and D. Let R_D denote the resistance of I. R. Drop's body from D to G plus the resistance of the steel deck from G to B. The resistance of the metal case of the tool and the resistance of the steel deck are small; consequently, for practical purposes, R_C is the resistance of the ground connection and R_D is the resistance of I. R. Drop's body. Let R_1 and R_3 be the resistances indicated in Figure 300-G-12. The circuit diagram corresponding to Figure 300-G-12 will then be as shown in Figure 300-G-13.

300-G.7.2.3.1 From the circuit diagram of Figure 300-G-13 it is a simple matter to show that the current, ID, which passes through I. R. Drop's body is given by the following expression:

$$I_D = \frac{VR_C}{(R_1 + R_3)\,R_D + (R_1 + R_3 + R_D)\,R_C}$$

300-G.7.2.3.2 Furthermore, the potential difference across the circuit that includes I. R. Drop, namely, the potential difference between points B and D of Figure 300-G-12, will be:

$$P.D. = I_D R_D = \frac{VR_C \times R_D}{(R_1 + R_3)\,R_D + (R_1 + R_3 + R_D)\,R_C}$$

300-G.7.2.3.3 Now assume that the body resistance, R_D is 500 ohms, that R_1 and R_3 are 200 and zero ohms, respectively, and that V is 115 volts. Then compute ID and the potential difference for different values of R_C , the resistance of the grounding conductor. This gives the values in Table 300-G-3.

300-G.7.2.3.4 Inspection of this table shows a number of things. In the first place, if the resistance of the ground connection is 222 ohms or more, the current through I. R. Drop's body will be equal to 0.1 ampere or more. This is enough to be fatal. To be sure, humans vary in their susceptibility to shock, and there are doubtless some who are lucky enough or rugged enough to survive a current of 0.1 amperes. There are not many, however, who are either lucky enough or rugged enough to survive much more than 0.1 ampere, and it is impossible to be sure that someone will not be killed by even somewhat less current. It can be concluded, therefore, that under the conditions assumed for the preparation of Table 300-G-3, the shock will probably be fatal if the resistance of the grounding conductor is 200 ohms or more.

Table 300-G-3 CURRENT I_D THROUGH I.R. DROP'S BODY

R_C (ohms)	I_D (amperes)	P.D. (volts)
0.001	0.00000115	0.000575
0.01	0.0000115	0.00575
0.1	0.000115	0.0575
0.87	0.001	0.5
9.3	0.01	5
222	0.1	50
1000	0.14	70

300-G.7.2.3.5 Furthermore, the table shows that if the resistance of the grounding conductor is 9.3 ohms, the current through I. R. Drop will be 0.01 amperes. This is about the limit a person can stand and still be able to let go. Consequently, if a person is caught while working alone, he may not be able to let go and the result may be a fatality even though the current is not enough to cause immediate death.

300-G.7.2.3.6 Nor is this all. If the resistance of the ground connection is 0.87 ohms, the current through I. R. Drop's body is 0.001 amperes. On the basis of present knowledge, this is neither enough to kill nor enough to keep I. R. Drop from releasing his hold upon the tool. However, it is enough to be perceptible. Such a shock, while insufficient to do any direct damage, may nevertheless be fatal to I. R. Drop indirectly by causing him to fall from a ladder, for example.

300-G.7.2.3.7 Consequently, under the conditions assumed for this discussion, the resistance of the ground connection must be less than one ohm to protect I. R. Drop from direct injury by electric shock. Furthermore, it should be very much less than one ohm to provide an ample factor of safety to cover the following contingencies:

a. I. R. Drop may be particularly susceptible to shock and may perceive or be injured by a current smaller than would produce the same effects on other people.

b. I. R. Drop's body resistance may be less than the 500 ohms assumed for this discussion. Remember that the National Institute of Standards and Technology has measured body resistances as low as 300 ohms and that this figure does not necessarily represent an absolute minimum.

c. The insulation resistance R_1 may be lower than the 200 ohm value assumed. To be sure, R_1 and R_3 should both be of the order of hundreds of thousands of ohms, or more, except for grounded systems in which R_1 is zero. But past experience shows that insulation resistances are not always what they should be. A ground connection provides protection against shock when insulation resistances are low, but to do this, the resistance of the ground connection must be very small, the smaller the better.

300-G.7.2.3.8 The last column in Table 300-G-3 shows the potential difference across the circuit in which I. R. Drop is connected. This column shows that for a ground connection of 0.01 ohms resistance, for example, the potential difference across the circuit of which I. R. Drop forms a part is only 0.00575 volts. This is too small to be dangerous. Consequently, one way of looking at the ground connection is that it protects I. R. Drop by preventing the establishment of a large potential difference across the circuit in which I. R. Drop is connected. This means that the current will be small and that I. R. Drop will be protected from shock.

300-G.7.2.3.9 It should be clear from the preceding discussion that the resistance of the ground connection must be low, the lower the better, to afford adequate protection against electric shock. But this alone is not enough. The current-carrying capacity of the ground connection should be high, for if it is too low, I. R. Drop may still receive a fatal shock. To see how this may happen, refer back to Figure 300-G-12 and suppose that the resistance of the grounding conductor, R_C , is 0.04 ohms, that I. R. Drop's resistance, R_D , is 1000 ohms, but that the sum of R_1 and R_3 has fallen to a very low value, 5 ohms, for example. Suppose, further, that the tool is provided either with a double pole switch, which opens both sides of the power line to the left of the motor winding, or with a single pole switch, which opens the upper side of the line to the left of point E. So long as the switch is open, I. R. Drop can hold the tool without receiving an electric shock. Now suppose that he closes the switch to start the motor. The connections will then be as in Figure 300-G-12. A little calculation shows that for a line voltage of 115 volts and resistance values as assumed above, the current through I. R. Drop's body will be about 0.9 milliamperes. This is slightly below the limit of perceptibility and probably will not be perceived by I. R. Drop. So far, the ground connection is affording protection.

300-G.7.2.3.10 What happens thereafter as I. R. Drop continues to use the tool will depend upon the current-carrying capacities of the grounding conductor and the fuses protecting the line that supplies power to the tool. If $R_1 + R_3$ is equal to 5 ohms, the current through the grounding conductor will be 115/5=23 amperes. The current through the fuses will be 23 amperes plus the current taken by the motor plus the current taken by any other devices receiving power from the same circuit. Three things may happen as I. R. Drop uses the tool for an extended period of time. These possibilities are as follows:

a. The fuses may remain intact and the grounding conductor may remain intact. In this case, the current through I. R. Drop will remain at 0.9 milliamperes and he will not be fatally shocked.

b. The fuses may blow while the grounding conductor remains intact. The blowing of either fuses or of both will cut off current through I. R. Drop and protect him from shock.

c. The grounding conductor may burn out while the fuses remain intact. If this happens the conditions in the circuit immediately revert to those illustrated in Figure 300-G-11. The current through I. R. Drop will be 115/(1,000 + 5) = 0.115 amperes and is enough to be fatal. To guard against such an occurrence, the grounding conductor should have sufficient current-carrying capacity to blow the fuses on the line that supplies power for the tool. If the current-carrying capacity is insufficient to do this, the grounding conductor may fail to provide adequate protection.

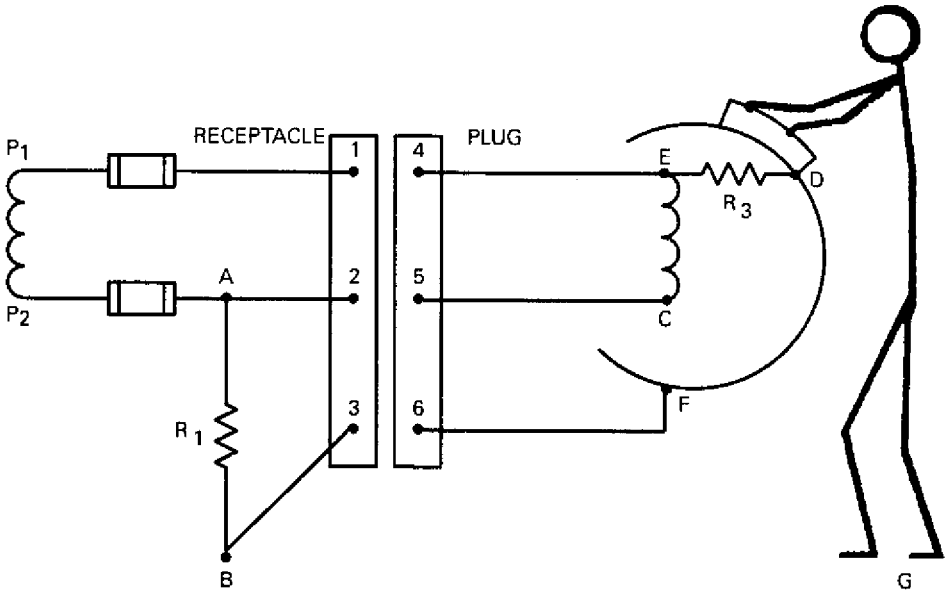

Figure 300-G-14. Schematic Diagram of Grounded Plug and Receptacle

300-G.7.2.3.11 It should be clear from the preceding discussion that when the insulation resistances R_1 and R_3 are high, they will afford adequate protection against electric shock even without a grounding conductor. When the insulation resistances are both low, the entire burden of protecting I. R. Drop from shock is thrown upon the grounding conductor, which must be of low resistance and of ample current-carrying capacity to be effective.

300-G.7.2.3.12 Since the purpose of the grounding conductor is to provide protection when insulation fails, great care should be exercised to make sure that it is of low resistance and of ample current-carrying capacity. Just any wire wrapped around a paint-covered stud or bolt is not enough.

300-G.7.2.4 Grounded Plugs and Receptacles. To facilitate connection of the grounding conductor, installation of grounded-type receptacles has been authorized for all surface ships and submarines. See paragraph 300-2.7.2.1 for grounded type receptacles.

300-G.7.2.4.1 Figure 300-G-14 is a schematic diagram of a grounded plug and receptacle for a two-wire dc or single phase ac power supply. The receptacle has contacts 1 and 2, which are connected to the source of power, and contact 3, which is connected to ground. The plug has contacts 4 and 5, which are connected to the two power conductors in the portable cord and contact 6, which is connected to the grounding conductor that runs to the metal case of the tool at F. Note that the numbers shown on the receptacle and plug contacts and the P_1 and P_2 used to identify the two sides of the power line are added to Figure 300-G-14 and subsequent figures only for convenience of reference, and do not correspond to markings on the plug and receptacle contacts and the power leads in actual installations.

300-G.7.2.4.2 The plug and receptacle are so designed that when the plug is inserted, contact is made first between contacts 3 and 6, thus connecting the grounding conductor before the power supply is connected. When the plug is withdrawn, the power supply is disconnected first, and the grounding conductor last. Thus, with the grounded lugs and receptacles, the grounding conductor is automatically connected first and disconnected last.

300-G.7.2.4.3 Refer now to Figure 300-G-14 and suppose that the plug is inserted into the receptacle making contact between 3 and 6, 2 and 5, and 1 and 4. A little consideration will show that the electrical connections are precisely as in Figure 300-G-12, and that the grounding conductor is connected correctly.

300-G.7.2.4.4 Three conditions MUST be satisfied to ensure that the grounding conductor will be connected correctly, namely:

a. The connections in the receptacle MUST be right.
b. The connections between the flexible cord and the plug at one end, and between the cord and the tool at the other end, MUST be right.
c. The plug MUST be inserted into the receptacle in the right position.

300-G.7.2.4.5 Correct connections are shown in Figure 300-G-14. The essential point about correct connections in the receptacle is that the ground contact, contact 3 in the figure, MUST be connected to ground, point B. If this is done, it is a matter of indifference whether we have:

a. P_1 to 1 and P_2 to 2; or
b. P_1 to 2 and P_2 to 1.

300-G.7.2.4.5.1 Either of these situations is correct. In an installation with numerous receptacles, it is to be expected that some of these receptacles will be connected one way and some the other way. There are four ways of making the receptacle connections incorrectly, as follows:

a. Two ways with B connected to 2, namely
   1 P_1 to 1 and P_2 to 3. to 1.
   2 P_1 to 3 and P_2
b. Two ways with B connected to 1, namely
   1 P_1 to 2 and P_2 to 3.
   2 P_1 to 3 and P_2 to 2.
c. Now assume that the portable cord is connected correctly to both the plug and the tool, that the plug is inserted into the receptacle in the right position, that the insulation on both the system and the tool is in good condition so that R_1 and R_3 can be considered infinite, and that the receptacle is connected incorrectly as shown in Figure 300-G-15. Note that I. R. Drop is connected in series with the motor winding directly across the power line. The resistance of the motor is small, and if I. R. Drop's body resistance is low, he will be shocked. It has been assumed, for the sake of simplicity, that the insulation is perfect and that R_1 and R_3 are infinite. The same unfortunate consequences for I. R. Drop will follow, however, even if R_1 and R_3 are not infinite, but are high in value, corresponding to good but not perfect insulation.
d. Assume that everything is the same in Figure 300-G-16 as in Figure 300-G-15 except that instead of being infinite or up in the megohms, R_1 is zero, R_3 is 300 ohms, and R_D , I. R. Drop's body resistance, is 500 ohms. Here it is not quite so easy to determine the current paths as in Figure 300-G-15, and it is desirable to draw a simplified diagram corresponding to Figure 300-G-16. Note that since R_1 is assumed to be zero, A and B are at the same potential and can be represented by a single point AB. This gives Figure 300-G-17 as the simplified diagram which corresponds to Figure 300-G-16 for R_1 equal to zero.
e. Reference to Figure 300-G-17 shows that between points D and AB there are two paths in parallel, a 500-ohm resistance through I. R. Drop, and a low resistance path D-F-AB through the grounding conductor. For the

sake of having a specific figure to talk about, suppose that the resistance of this path is one ohm. The combined resistance of the two paths in parallel is slightly less than one ohm, which is negligible in comparison with the 300 ohms assumed for R_3 . The current I, through R_3 will be approximately 115/300=0.38 amperes. Of this, only I/501=0.00076 amperes or 0.76 milliamperes will go through I. R. Drop if his resistance is 500 ohms and that of the path D-F-AB is one ohm. I. R. Drop will not be shocked in this case.

f. Note that in Figure 300-G-15 there is a mistake in the receptacle connections combined with perfect insulation on the system and tool. This combination would give I. R. Drop a fatal shock if his body resistance were 500 ohms. In Figure 300-G-16 there is the same mistake in receptacle connections combined with two more mistakes, R_1 equal to zero and R_3 down to 300 ohms. These mistakes add up to leave I. R. Drop unharmed. Of course this is NOT an argument for low insulation resistance. It simply goes to show that here, as in adding a column of figures, one mistake will give a wrong answer, but two or more mistakes may cancel so that the right answer is obtained. But here, also, as in adding a column of figures, the only way to be sure of getting the right answer is to have EVERYTHING RIGHT.

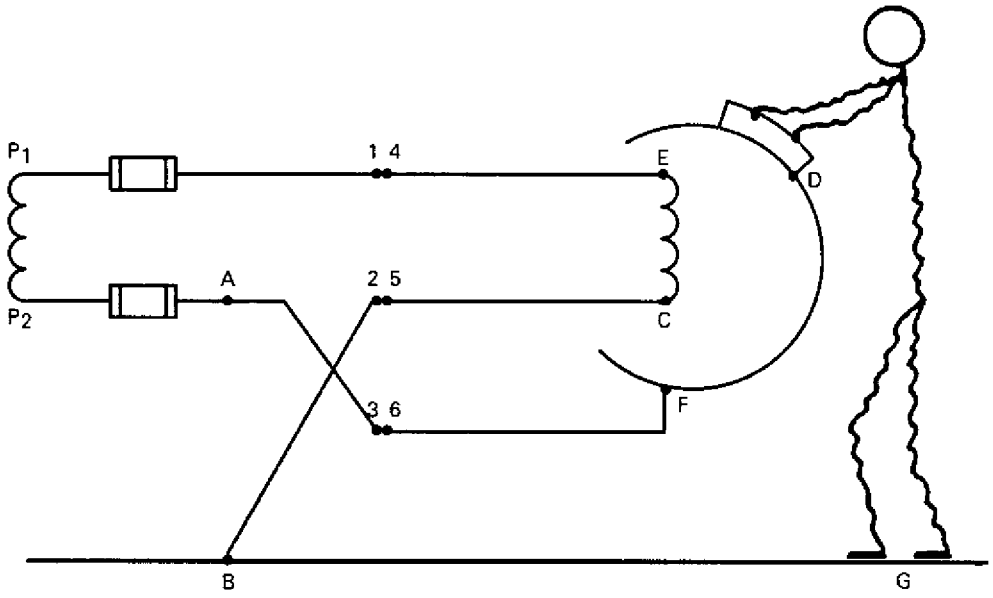

Figure 300-G-15. Wrong Connections in Receptacle, Perfect Insulation on Tool and System

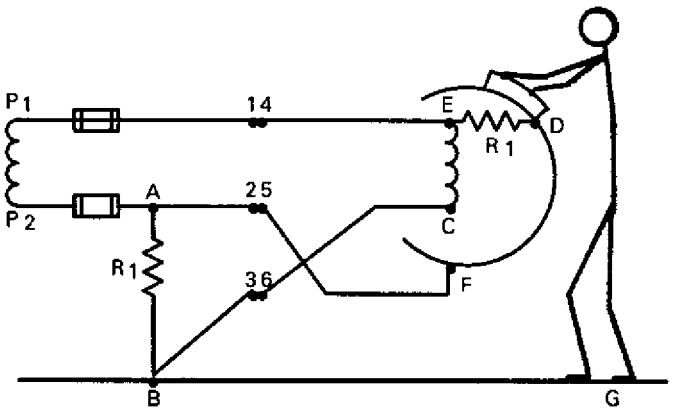

Figure 300-G-16. Wrong Connections in Receptacle, Perfect Insulation on Tool and System

300-G.7.2.4.6 The essential step is to make sure that the ground contact of the plug is connected by the grounding conductor to the metal case of the tool or equipment. An extremely hazardous condition arises if one end of the grounding conductor is connected to the metal case of the tool or equipment and the other end is attached to a plug contact which touches either of the line contacts in the receptacle. Be sure to identify the line contacts and the ground contact correctly, connect the cable to the plug making sure that there are no loose strands of copper that may accidentally connect the grounding conductor to either side of the line, and finally, test the work after the connections have been made, but before inserting the plug in the receptacle. Use a megger or insulation resistance measuring instrument to make this check. With the plug out of the receptacle and with the switch of the tool in the ON position, connect one megger lead to the exposed metal case of the motor equipment and the other megger lead to the ground terminal of the plug. Measure the insulation resistance. It should be zero. Then, with one megger lead still connected to the metal case of the equipment, shift the other megger lead to either line terminal of the plug and measure the resistance. It will be normal insulation resistance (usually well in excess of one megohm) if the ground wire is connected correctly. Repeat with one megger lead still connected to the metal case of the equipment and with the other megger lead connected to the other line terminal of the plug (or to each of the other line terminals if there are more than two). There should be normal insulation resistance in each case if the ground wire is connected correctly. See paragraph 300-2.7.5 for testing of portable equipment. This test should be repeated after a new plug is installed on the tool or equipment after any repair work is done on the equipment or plug, and after a fuse blows on a circuit on which the tool is be infused. The fault that caused the fuse to blow may also have caused the ground connection to burn out.

300-G.7.3 SENSIBLE TESTING. Suppose that I. R. Drop notices a damaged cord on a tool he wants to use, replaces the cord with a new one, connects it to the tool and plug, and then, being lazy, as most of us are inclined to be at times, concludes that a test like that described above is simply too much trouble for him to fool around with. He will do it quick and dirty. Without making any tests at all he puts the plug in a grounded receptacle in the shop and switches the motor on. The tool runs perfectly, so far as he can tell, and he has received no shock at all. He then notices that when he did all this, he was standing in water-soake d shoes in a pool of salt water on an unpainted spot on the steel deck. He realizes that this was a highly stupid thing to do but consoles himself with the thought that **a miss is as good as a mile** , and casually concludes that the tool must surely be all right since it gave him no shock under conditions like these. He hurries off to the place where he is going to use the tool, inserts the plug into a receptacle, flips the switch to **ON** , and is fatally shocked.

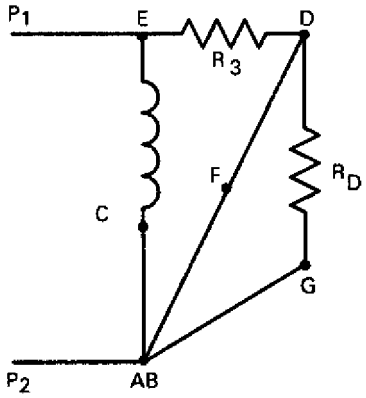

Figure 300-G-17. Simplified Diagram Corresponding to Figure 300-G-18

300-G.7.3.1 Testing. It is worthwhile to see how this could happen. First consider what could have happened when I. R. Drop tried out the tool in the shop. Assume the following:

a. That the receptacle into which he put the plug is wired correctly as shown in Figure 300-G-18.

b. That the flexible cord is connected incorrectly as shown in Figure 300-G-18.

c. That the P_2 side of the power line has a very low resistance ground from A to B which the electricians have not found and cleared, and that R_1 can, therefore, be taken equal to zero.

d. That R_3 , the insulation resistance between the live conductors and the case of the tool, is 300 ohms.

e. That R_D , I. R. Drop's body resistance, is 500 ohms.

f. That the resistances of all the cables and of all the contacts in the receptacle are so small that they can be assumed equal to zero.

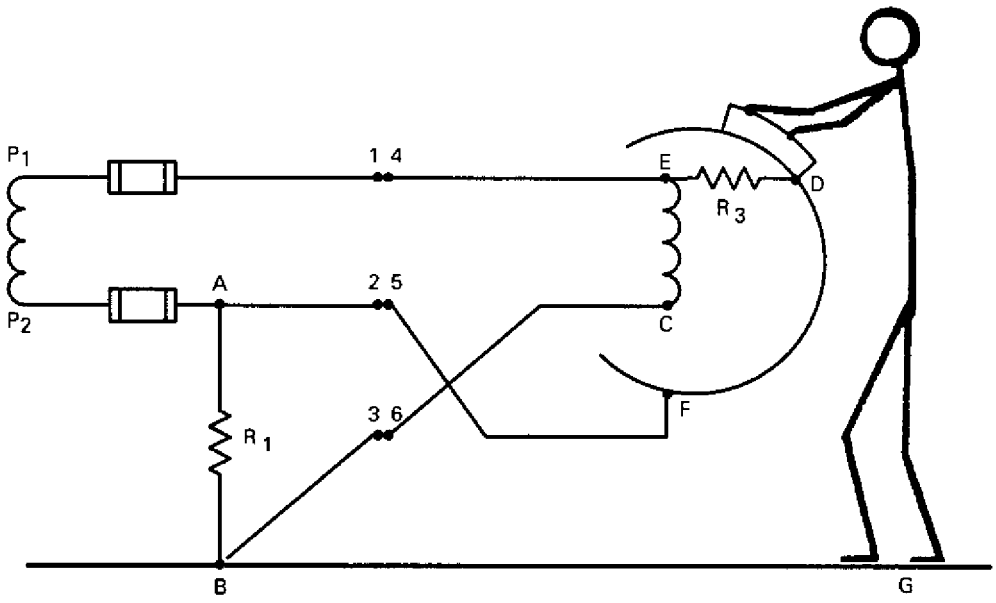

Figure 300-G-18. Conditions at Trial in Shop

300-G.7.3.1.1 A little consideration will show that when the plug is inserted into the receptacles, the connections will be as shown in Figure 300-G-17, which we considered previously. Note that the motor is connected directly across the line and will run. Note also that I. R. Drop is in parallel with the low resistance path D-F-AB which carries most of the current that goes through R_3 and leaves only a fraction of a milliampere to go through I. R. Drop, as we have seen in the previous discussion of Figure 300-G-18. In the shop test, therefore, the motor will run and I. R. Drop will not be shocked. This is why I. R. Drop erroneously concludes that everything is all right.

300-G.7.3.2 Testing Tools in Use. Now suppose that when I. R. Drop puts the tool to use, everything is just the same as when he tried it in the shop except that the receptacle is connected as shown in Figure 300-G-19 instead of as in Figure 300-G-18.

300-G.7.3.2.1 As pointed out before, the receptacle connections shown in Figure 300-G-18 and Figure 300-G-19 are both correct. Some receptacles will be connected one way, some the other. Suppose that I. R. Drop hit the kind shown in Figure 300-G-18 when he tried the tool in the shop, and that he hits the kind shown in Figure 300-G-19 when he puts the tool to use. From Figure 300-G-19 a simplified diagram is shown in Figure 300-G-20 in which R_1 is assumed to be zero. Again a single point AB instead of two points A and B is used.

300-G.7.3.2.2 Reference to Figure 300-G-20 shows that the motor will not run. But this is not the worst. I. R. Drop is connected directly across the power line. To be sure, his 500-ohm body resistance is connected in parallel with the 300-ohm resistance between D and AB. This, however, does him no good. The potential difference across him is 115 volts, his resistance is 500 ohms, and the current through him is 0.230 amperes or 230 milliamperes. This is more than enough to kill.

300-G.7.3.2.3 The moral of all this should be clear. You can NEVER assume that a portable tool is safe simply because you have tried it, found that it runs, and has not shocked you. The tool could kill you the next time you try it. If I. R. Drop had taken a few minutes after he changed the cord and had tested it in accordance with the paragraph on CORRECT CORD CONNECTIONS, he would have found:

a. That the cord connections were wrong, and

b. That the insulation resistance from the live conductors to the case of the tool was only 300 ohms.

300-G.7.3.2.3.1 He should never have used a tool with an insulation resistance so low. Even if he had been foolish enough to do this, but had changed the cord connections to make them right, the grounding conductor would have saved him. But he assumed instead that his quick and dirty trial proved that everything was all right. This killed him.

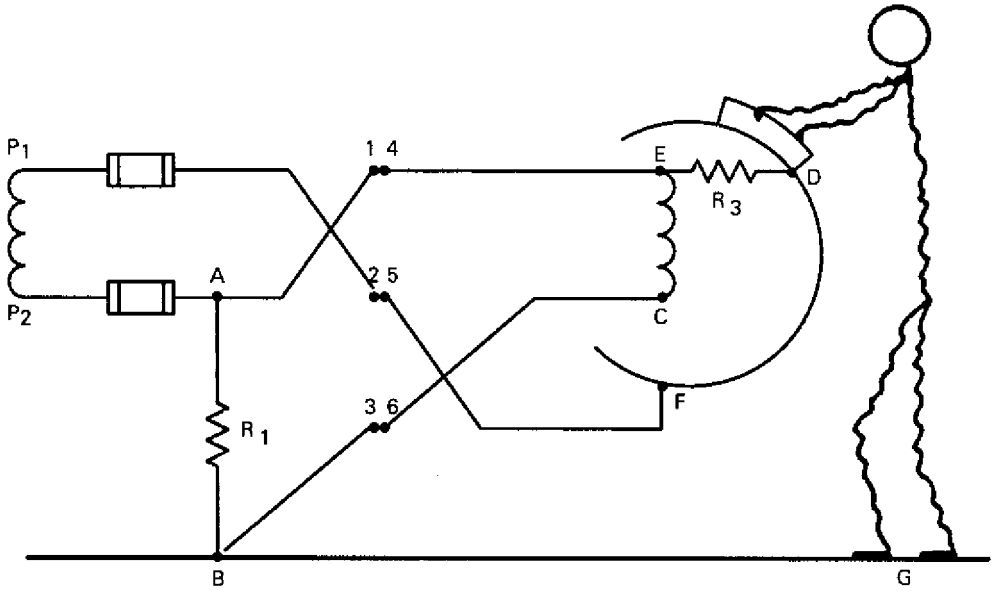

Figure 300-G-19. Conditions with Tool in Use

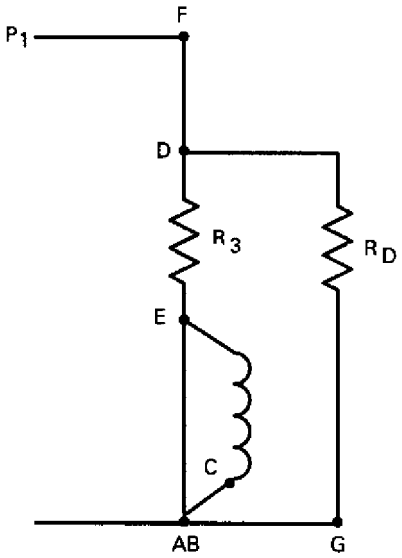

Figure 300-G-20. Simplified Diagram Corresponding to 300-G-19

300-G.7.4 TESTING PORTABLE EQUIPMENT. Portable electric tools and equipment should be tested periodically to make sure that they are maintained in good condition. For periodic testing of portable equipment, see paragraph 300-2.7.5.2.1. Two acceptable tagging methods for approved equipment can be found in paragraph 300-2.7.3.6.2.

300-G.7.4.1 Proper Plug Positions. The connections in the receptacle and to the cord must be right to protect I. R. Drop from shock. So, too, must the position of the plug be right when it is inserted into the receptacle.

300-G.7.4.1.1 Grounded plugs and receptacles are designed with the objective of making it impossible to insert the plug in any position except the right position, but to do this requires the cooperation of personnel who use the equipment. Make sure that the covers of the receptacle boxes are assembled correctly to guide the plug in the right position. Then don't force a plug into a receptacle when it does not want to go. Perhaps you can succeed, and perhaps it will kill you when you use the tool.

300-G.7.5 THREE LINES OF DEFENSE. Summarizing the results, when I. R. Drop is using a portable tool on an ungrounded system, assuming all connections are correct and that the plug is inserted in the right position, there are three lines of defense that protect I. R. Drop from shock. These are:

a. The insulation on the distribution system.

b. The insulation on the tool and cord.

c. The grounding conductor.

Each of these three lines of defense, if it holds, is enough to save I. R. Drop from a fatal shock. The following paragraphs describe them in more detail.

300-G.7.5.1 The First Line of Defense. The first line of defense is the insulation on the power distribution system. The weakness of this line is that it covers a lot of territory, is spread thin as a consequence, and can be breached in a number of ways, such as by insulation failure, by poorly designed or improperly used EMI filters, by a large value of system capacitance, by the closing of a switch to connect ground detector lamps or voltmeters if either are installed, or in other ways which may not be obvious. Furthermore, as described before, it is extremely difficult and perhaps impossible to make a test which will establish with certainty whether this line of defense is intact or not. For these reasons, the first line of defense CANNOT be depended upon to protect you from a fatal electric shock. This does not mean, however, that the first line of defense is to be despised. Every effort should be made to maintain it by keeping the insulation resistance to ground as high as possible. This line of defense has undoubtedly saved many a person's life in the past and will undoubtedly save many a person's life in the future. However, you gamble with death when you assume that this line of defense alone will save you from a fatal shock.

300-G.7.5.2 The Second Line of Defense. The second line of defense is the insulation between the live conductors and the metal case of portable electric tools and equipment. This is a concentrated line of defense. It is all in the tool and its cord and plug. It can be tested to determine whether it is sound or whether a hole has been punched in it. It should be considered the main line of defense.

300-G.7.5.3 The Third Line of Defense. The third line of defense is the grounding conductor. If the grounding conductor is of low resistance and adequate current carrying capacity, if the grounded receptacles and plugs are connected correctly, and if the plug is inserted into the receptacle in the right position, then the grounding conductor will save I. R. Drop from a fatal shock even after the other two lines of defense have failed. The third line is the last gasp line of defense. Note that when the second or main line of defense is maintained intact by keep-

ing the tool insulation resistance high, something which should always be done, the grounding conductor has nothing to do. It provides a safety factor and is something like the safety grips that keep an elevator from falling if the cables break.

300-G.8 CONCLUSION

300-G.8.1 SUMMARY. This section does no more than begin to consider all the different ways in which a person can be killed by electric shock. There are many possible combinations of events which can lead to a fatal shock. The important things to keep in mind are:

a. If you do things in the wrong way when dealing with electric circuits and equipment:
   1 Some fortuitous combination of circumstances may save you from a fatal shock; or
   2 A different combination of circumstances may kill you.

b. If you do things in the right way in dealing with electric circuits and equipment, you will be safe.

300-G.8.2 Navsea Concern. NAVSEA is vitally interested in providing the safest possible electric equipment for use by personnel on U.S. Navy ships. But neither NAVSEA nor any other organization can protect you from electric shock. NAVSEA can help you in various ways, but in the final analysis, you and your shipmates must do the job. It is a job well worth doing. It may be tiresome to study about safety, it may be unpleasant to devote the time and effort that are necessary to ensure safety, but it is far better to be safe from electric shock than to become I. R. Drop, deceased, or to have one of your shipmates become I. R. Drop, deceased.