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PERSONNEL SAFETY ON ELECTRIFIED RAILROADS

U.S. DEPARTMENT OF TRANSPORTATION
RESEARCH AND SPECIAL PROGRAMS ADMINISTRATION
Transportation Systems Center
Cambridge MA 20142

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FINAL REPORT

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16. Abstract

Potential electrical hazards to fire, police, and rescue personnel responding to emergencies on electrified railways are examined. Data on descriptions of electrical facilities, types of accidents and danger to emergency personnel, and reviews of operating procedures have been obtained during a series of visits to electrified rail and transit systems.

Programs to reduce electrical hazards to emergency personnel are proposed. These programs are evaluated by a cost-benefit comparison, and recommendations are selectively made. Joint development of emergency operating plans by rescue and railroad organizations, and installation of direct telephone lines to the power director are recommended as being most cost-effective.

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PREFACE

Hazards faced by rescue personnel were illustrated in two reports issued by the National Transportation Safety Board (NTSB). Review of these two reports indicated the need for training rescue personnel to avoid contact with overhead catenary, and a faster method to reach the Power Director.

This study was initiated at the request of the NTSB to the Federal Railroad Administration (FRA) to determine the feasibility of automatic de-energization of an electrified railroad during an accident.

Acknowledgment is due to the railroad and rescue personnel encountered during field trips to collect safety data. The constructive review of the early drafts by the Transportation Safety Institute, Illinois Central Gulf, CONRAIL, New Jersey Department of Transportation, and Southern Pennsylvania Transportation Authority has improved this document. Particular thanks are due to AMTRAK personnel for their helpful comments which have increased the value of this report.

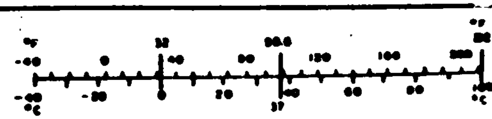
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SUMMARY

This report, prepared for the Office of Rail Safety Research, Federal Railroad Administration, presents potential electrical hazards of electrified railroads to fire, police, and other rescue personnel during an emergency. It indicates procedures for planning, organization, and equipment modification to reduce the risks from energized electrical equipment.

Visits to railroads, transit systems, fire and police departments revealed a wide variation in the training, planning, and technical skills of rescue personnel working on electrified railroad property. It seemed apparent from these interviews that fire, police, and other rescue workers responding to an emergency on an electrified railroad right of way encountered special hazards. In this report, programs are proposed to reduce these hazards, and are evaluated by a cost-benefit comparison.

The most cost-effective of the proposed programs to improve the safety of rescue personnel is the development of joint emergency rescue plans by the railroads, fire, and police organizations as well as the installation of direct telephone "hot" lines to the Power Director. Additional cost-effective programs recommended are: (a) safety training programs for police, fire, other rescue workers, and railroad employees; (b) a public education program to discourage trespassing; (c) public address systems to transmit emergency instructions at stations and in cars; and (d) load-sensing devices to circuit breakers.

The use of wayside call boxes to reach the Power Director can improve communications in an emergency; they are currently being installed on some new properties. This study shows that their high cost cannot be justified for safety of rescue personnel alone. However, the cost may be justified if they also serve for passenger evacuation during emergencies. The call boxes may significantly reduce costs and improve efficiency of both maintenance operations and revenue service.

Most of the proposed improvements in circuit breakers and fault protection are presently not cost-effective as just personnel safety measures. Therefore, it is recommended that, as this equipment is modernized and updated to handle traffic growth, the circuit-breaker trip settings be evaluated, and that improved fault sensing and fast tripping means be added to existing systems. It is also suggested that a research and development program be initiated to find alternative methods to provide these needed improvements at substantially lower costs, to make future retrofit programs more attractive.

Use of wayside trip-buttons for emergency removal of power is not recommended, since their unauthorized use can complicate normal operations, and their use by on-site rescuers can sometimes impede rescue operations by removing the power for rescue trains. It is recommended that the Power Director be the only one authorized to remove power, since he is in the best position to remove power as required.

The use of third rail covers for improved wayside safety of personnel is controversial in the transportation industry. If the space between the third rail and the rail cover above it should become clogged with debris or snow, or if a damaged rail cover reduces the running clearance for the car's current collector shoes, serious accidents can occur. Retrofitting rail covers on existing systems may not be physically possible, and the costs may be prohibitive.

The procedure of grounding a live third rail or catenary by rescue personnel to quickly remove power in an emergency is not recommended. It is a very hazardous practice and is not used in other industries. For example, public utility workers only ground a conductor <u>after</u> confirming that the high voltage has been removed. Also, it often results in a loss of power for the adjacent tracks as well, which can seriously impair the transporting of rescue and fire-fighting forces.

1. INTRODUCTION

Two accidents, reviewed by the National Transportation Safety Board (NTSB), indicate the need to develop safety measures for electrified railroads. The accidents are cited here:

> "On May 14, 1971, a male juvenile climbed on top of a draft of freight cars which had been left temporarily adjacent to the Penn Central Sixth Street Yard, Washington, D.C., and was electrocuted when he contacted the electrified catenary system. Within minutes thereafter, a police officer was seriously burned and knocked from the top of an adjacent car when he attempted to reach the stricken youth. The youth was apparently killed outright, but the police officer survived."*

> "...on August 8, 1973, an automobile carrying five teenagers was driven onto the electrified tracks of the Long Island Railroad by an unlicensed 15-year-old girl. The car's contact with the third rail caused a momentary short circuit and initiated severe electrical arcing. The car immediately began to burn at the front, and the fire spread to the rear. The two girls in the front seats escaped through the right door. The three girls in the back seat died in the fire. When the Fire Department arrived, the automobile was engulfed in flames and there was heavy electrical arcing between the car and the running rail. The firemen radioed their dispatcher, who telephoned the LIRR power director... that..power..be shut off. The Fire Department did not use their electrical tester to determine whether or not the tracks were still energized. They waited 14 minutes until receiving confirmation from the power director that the power was off. After the power was shut off, the fire was extinguished."**

The above accounts show that the police officer who climbed a frieght car to rescue the stricken youth could have avoided serious injury to himself if he had been trained to avoid any contact with

*Railroad Accident Report, Penn Central Company, Electrocution of Juvenile Trespasser on Penn Central Tracks at Washington, D.C., May 14, 1971, Report NTSB-RAR-72-3.

**Highway Accident Report, Automobile Intrusion Onto the Long Island Railroad Electrified Tracks and Fire, Garden City, New York, August 1973, Report NTSB-HAR-74-3.

the overhead catenary. In the automobile accident, the fire fighters could have begun their fire fighting and attempted rescue of the remaining automobile passengers as much as 14 minutes earlier if there had been a faster method to reach the Power Director with a request that the third rail power be tripped off. At the request of the NTSB, this study evaluated a number of alternative means of reducing hazards to those rescue personnel who respond to accidents occurring on electrified railway property.

1.1 BACKGROUND

The following rapid transit and railroad properties were visited by members of fire and police departments to collect information for this report:

- Bay Area Rapid Transit (BART)
- Boston Edison Company
- Chicago Transit Authority (CTA)
- City of Boston Fire Department
- City of Somerville (Massachusetts) Fire Department
- Consolidated Rail Corporation (Conrail)
- Illinois Central Gulf Railroad (ICG)
- Long Island Railroad (LIRR)
- Massachusetts Bay Transit Authority (MBTA)
- Metropolitan Atlanta Rapid Transit Authority (MARTA)
- National Railroad Passenger Corporation (AMTRAK)
- New Haven Railroad (NHRR)
- New York City Transit Authority (NYCTA)
- Northeast Utilities Service Company (NUSCO).

At these properties and organizations (which include the bulk of the electrified railroad and rapid-transit operators in the country), equipment and practices were observed. Personnel responsible for safety and training were interviewed. Information was also obtained on practices of the New York City fire and police departments regarding transit system emergencies.

1.2 HAZARDS OF ELECTRICAL FACILITIES

The electrical facilities that occupy the right of way of an electrified railroad and which constitute a hazard to rescue personnel include the following:

a. Third rails which are energized to 750 vdc and are located in close proximity to the grounded running rails.

b. Overhead conductors of the catenary system which are presently energized to 1500 vdc and 11,000 vac, and will be energized to 25,000 and 50,000 vac in the future.

c. Overhead railroad and electric utility transmission lines which, in some locations, are carried on extensions of the electrification towers. These lines are energized to 230,000 vac.

d. Railroad service lines on electrification and other towers for signals, shop power, station service, and other functions, energized up to 11,000 vac.

e. Substations for supply of ac and dc power to the electrification system, including transformers, bus structures, cable terminals, circuit breakers, and other equipment. The substations can be enclosed in buildings, or in the open, protected by fences.

f. Wayside passenger equipment in yards, energized to 480 v.

g. Electrical equipment on the exterior, interior and under the cars, at various voltage levels.

1.3 TYPES OF RESCUE PERSONNEL, SITES, ACCIDENTS, AND DANGERS

Rescue personnel: railroad, police, fire, and medical are exposed to electrical hazards. Accidents occurring at elevated, on-grade, and in-cut tracks, and in underground or water tunnels are of the following types:

a. Injured person lying on tracks, on or under cars, or in electrical structures

b. Non-railroad vehicle stalled or wrecked on tracks

c. Train stalled and/or on fire with passengers inside

d. Train wrecked

e. Conductors from electrification towers, or catenary down from accident or storm

f. Fire on or near railroad right of way

g. Construction equipment accidently coming in contact with energized conductors.

As a result of the types of accidents listed above, dangers to rescue personnel from the electrical equipment include the following:

a. Direct contact with energized electrical conductors or equipment

b. Indirect contact by tools, metal ladders, hose streams, and the like, with energized electrical conductors or equipment

c. Burns caused by electrical arcing from broken conductors, metal objects between third rail and running rail, and damaged electrical equipment

d. Re-energization of electrical equipment while rescue personnel are in contact with, or near, the equipment

e. Secondary contact with energized electrical conductors or equipment while rescue personnel are pulling persons or debris away from wet equipment, and other similar subtle exposures

f. Leaking current or accidental bridging to energized section

g. Inductive or capacitive coupling current when in close proximity to a de-energized line while a heavy draw of power is in progress from an adjacent line.

1.4 PRESENT PRACTICES: TWO CATEGORIES

Present practices between the railroads and rescue organizations to reduce electrical hazards fall into two categories. The first category is planning, training, and communications. Representatives of railroad and rescue organizations anticipate their operations and attempt to improve their effectiveness during rescue operation by training personnel how to react in an emergency. They may find it necessary to purchase and install test and communications equipment.

The second category is power equipment installation. The railroad installs new protective relay, control, and circuit breaker equipment to improve the fault detection and clearing capabilities of the circuit breakers, and to decrease operation time of remote breakers. The installation of other protective equipment such as insulated protection boards over third rails also falls into this category. These two categories will be treated in detail in Sections 2 and 3 of this report.

2. PLANNING, TRAINING, AND COMMUNICATIONS PRACTICES

Present practices of the railroads and rescue organizations are described here, along with suggested improvements and expected benefits.

2.1 PLANNING FOR EMERGENCIES

Employees of the property and non-employee rescue personnel must have plans that are designed to assure their personal safety and the safety of passengers during any emergency. For the safety of all concerned during an emergency situation, procedures must be established for the passengers, for railroad personnel, and for rescue personnel who may be required to provide assistance. One of the biggest improvements in safety which can be achieved will come from adequate planning before problems occur.

There must be agreements regarding the assignments of responsibilities and duties between the senior supervisor at the site representing the operating company, and the senior officers of the rescue organizations expected to assist during the emergency. For commuter and intercity railroads this may require many agreements with rescue organizations in different jurisdictions. Only the NYCTA has such an agreement, fully formalized, reduced to writing, signed by all parties, and available to any person with a valid need. Preparing these plans, and arriving at agreements between the railroad and all other parties cannot be done as part-time activity. Preparing these plans must be an assigned major responsibility of some senior personnel of the railroad. Development of an adequate plan in many cases will reveal inadequacies in the present system and will identify requirements for both equipment and training.

Examples of planning for emergencies range from the pamphlets prepared by Chicago Transit Authority (CTA) for its employees, with such titles as, <u>Emergency Alarm System for Cutting Off Traction Power in the Subways</u>; <u>State Street Subway - Emergency Exits, Ventilating Shafts, Ventilating Fans, Fire Hydrants, Emergency</u>

Alarm Boxes; When to Remove 600 Volt Power; and the 100 page document prepared by NYCTA, Interagency Standard Operating Procedure No. 1, "Response to NYCTA Engineers," July 30, 1975. The last document is a comprehensive plan for procedures to be followed under all types of emergencies requiring the assistance of the New York Police Department, Fire Department, Emergency Medical Service, or the Mayor's Emergency Control Board. Two Amtrak/Conrail documents used for safety training are, Electric Operating Instructions, Conrail/Amtrak No. CT290, and Amtrak Employee's Safety Rule Book NEC-7-C.

2.2 TRAINING OF RESCUE PERSONNEL

The employees of the railroad or transit authority are generally well trained. Their day-to-day, on-the-job safety requires the same knowledge and skills that must be used during an emergency. For this reason these employees may be better able to direct emergency activities than the non-employee emergency personnel who have entered the property. The amount and quality of the training of non-employee emergency personnel varies greatly. Certain of the properties have excellent training courses which they present on a regular basis to fire fighters, police, and medical personnel who may enter the property. One transit authority requires any person, who may have occasion to enter its property, to take a training course. On some properties, training for non-employee rescue personnel is done as an extra duty by a few property employees, frequently on their own time. In the worst situations there are no arrangements for non-employee rescue personnel to be trained by the transportation company.

Where the better courses are presented, the training usually includes periodic refresher and updating sessions. Emergency personnel are often given tours of the parts of a property where they would respond. Fire and public safety personnel, who would be the officers in charge during an emergency, frequently make annual inspections to comply with local regulations. The type of training described is just being started on some properties.

Where rescue personnel are professionals, establishing training programs is relatively simple. When the supervisors of these paid personnel recognize the need for training, the personnel are scheduled to attend the training sessions during their working hours and attendance is mandatory. Where rescue personnel are volunteers, i.e., generally in rural areas and small communities, training is voluntary. Usually the volunteer is only available for training in the evening. Each individual must therefore be convinced that he is learning enough to justify giving up his free time. Courses presented usually include the following topics:

a. Chain of command during an emergency

b. Electrically energized equipment on the right of way, and identification of various circuits and equipment

c. Opening car doors from outside and inside

d. Reaching the Power Director

e. Hazards of water near electricity

f. Third rail or catenary safety

g. Other circuits on or near the right of way

h. "Do's" and "Don'ts" of personal rescues

i. Electrical first aid

j. Identifying wayside locations

k. Locations of emergency exits

l. Evacuation of passengers

m. Ventilation facilities and control of air flow

n. Working with railroad personnel

o. Grounding techniques and their hazards to personnel

p. Tours of local facilities

q. Locations of emergency call boxes.

Test lights are provided to fire departments which may enter certain properties. Training provided to these fire fighters by one property emphasizes the circuit breakers have been known not to open, and may not be open even when so indicated on the power dispatcher's panel. When the power dispatcher informs the fire fighters "My panel shows power off," the trained fire fighters can use the test lights to verify that power is really off.

Test lights are used on one railroad where they are used to determine whether a 1500 vdc overhead catenary is energized. Rescue people are thus prohibited from attempting to ground a live catenary. This railroad has special grounding equipment to be used (after using the test light) to remove any residual voltages that may be caused by leakage on contaminated insulators.

Further examples of emergency measures are the use of "wiggies"* (to test whether or not the 600 vdc third rail is energized), and telemetered voltmeter data to enable verification by the Power Director of actual voltage on each power rail section. Wiggies are used only on third rails; they are not used to test higher voltage sources, such as an overhead catenary energized at 225 kv. Telemetered voltmeter data are displayed on some Power Directors' panels, as the condition of the voltage in each power section must be transmitted to those personnel responsible for train movement to facilitate operations.

2.3 COMMUNICATIONS FOR RESCUE

Three communications links important during rescue operations are: (1) Rescue personnel to passengers or other injured persons; (2) Rescue personnel to other rescue personnel; and (3) Rescue personnel to railroad personnel, particularly to the Power Director.

The first communications links, from rescue personnel to passengers, may be by public address systems in stations and cars. Modern rapid transit properties like BART and WMATA are extensively

*A "wiggie" is a very rugged, simple, go-no-go voltmeter.

equipped with such facilities. Major railroad stations do have public address systems, but smaller stations and older railroad cars do not.

The second communications link, from rescue personnel of the same organization to different organizations and to their dispatchers, is generally by radio. Radio equipment may be effective only for short distances in tunnels, and may not be effective to the outside.

In many locations during an emergency, facilities of the local public telephone system are used to request removal of power from the Power Director. Most of these calls are routed through a switchboard operator so that there may be long delays. In New York City, the link from the fire department to the railroad Power Director is via the fire department dispatcher and then by telephone to the Power Director. In some cities and towns, the rescue organizations do not know the procedure nor the phone numbers for contacting the Power Director. In some cases, the rescue organizations depend upon railroad personnel, who must reach the accident site to make the request for power removal.

2.4 IMPROVEMENTS IN PRESENT PRACTICES

Recommendations for improvements in planning for emergencies, training of rescue personnel, and communications are given here. It is felt that substantial improvements in safety during an emergency can result from adequate training of all personnel who would be assisting during the emergency. Each individual would have to know what he must and must not do to assure his own safety and the safety of others. This requires advance knowledge of what each organization is expected to do, how to use available equipment, and how to work effectively with all other organizations.

To accomplish this goal, training must be provided by the railroad for the employees of the local rescue organizations that may be called upon to respond to an emergency. Training courses must be prepared, instructional materials be made available, and instructors trained and made available as needed. The railroad must make this training a major responsibility of enough personnel to cover all communities along the route. (Amtrak personnel are providing some safety training of local community fire fighters and policemen along the Northeast Corridor with a voluntary, after-hours program.)

A good communications system is necessary to insure timely reporting of an accident or other emergency conditions to the proper authorities. Therefore, major improvements are required in the communications systems of some of the railroads. Better equipment and proper training are needed to insure maximum effectiveness of the present equipment with minimal impact.

While most indoor stations have public address systems, they are generally lacking at outdoor stations, where they are prone to vandalism. Consequently, in order to insure that the public can be properly instructed during an emergency situation, public address systems must be installed in all passenger stations, indoors and outdoors, and on all passenger trains.

Although Power Directors generally have direct telephone lines that bypass a manual switchboard, they are usually equipped to originate as well as receive calls, so that an incoming emergency call could be delayed by an outgoing call.

Finally, the National Fire Prevention Association (NFPA), is preparing a "Standard for Fixed-Guideway Transit Systems"; in their draft they recommended that telephones be made available along the right of way no farther than 800 feet apart, and that such phones be identified by distinctive signs and lights. The standard does not address intercity railroads. However, greater spacing would be appropriate. Battery operated emergency radios at one-mile intervals have proven successful along major highways. Similar radios along intercity railroads may be more economical than telephones. A typical radio unit is estimated to cost $2500. Measures to make these units less susceptible to vandalism would increase these costs. Further analysis of these recommendations is given in Section 4, which includes a cost-benefit analysis of their value. Development should be undertaken to provide a combination phone/alarm unit in lieu of singular phone or radio unit. Some means should be available to summon assistance if the radio/phone has been vandalized.

3. POWER EQUIPMENT INSTALLATION

The greatest hazard to rescue personnel working on the right of way of an electrified railroad is from contact with high-voltage energized equipment. The equipment can be de-energized in one of three ways: (1) The Power Director for that section of the railroad can open the circuit breakers by remote control from his location; (2) The circuit breakers can be tripped locally by railroad personnel, or by emergency buttons; or (3) The circuit breakers will trip by their own sensors when a short circuit occurs in the energized equipment. Rescue personnel must understand how the interruptions are accomplished and what hazards they are exposed to if the interruption is not accomplished, or if the circuit breakers are reclosed while they are still in proximity. Continuing train movements in the affected area of an accident will require that portions of the catenary and third rail be energized and/or de-energized while rescue efforts proceed.

3.1 ELECTRICAL SUPPLY TO WAYSIDE EQUIPMENT

Whether the system uses a third rail or a catenary, the power system is divided into sections which can be isolated from each other by circuit breakers. This makes it possible to remove power from a section of track as required for routine maintenance or for safety during an emergency. The remainder of the system can still be energized to permit normal traffic movement.

There are several methods used for connecting the power source to a section of third rail or catenary. Where the power source connects to the rail or catenary, the circuit breaker is commonly called a feeder breaker. This may be at the center of the section (center-fed) Figure 3.1 or at one or both ends of the section (end-fed) Figures 3.2 and 3.3. At locations where adjoining sections end, but where there is no power source, it is common practice to provide a circuit breaker which can connect the ends of the sections.

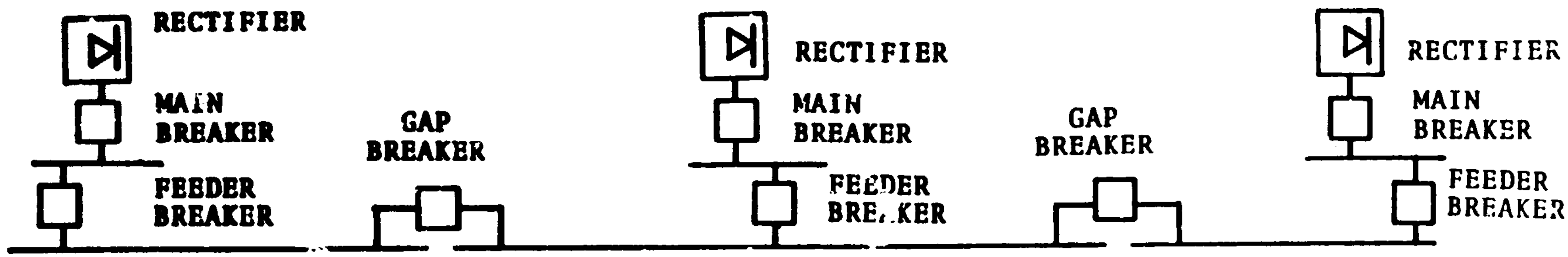

FIGURE 3-1. CENTER-FED CATENARY (OR THIRD RAIL) SECTIONS WITH GAP BREAKERS

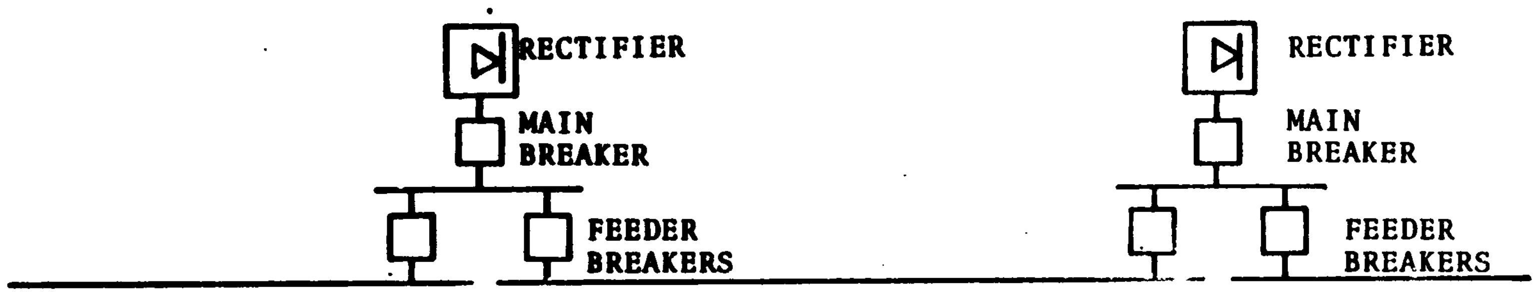

FIGURE 3-2. CATENARY (OR THIRD RAIL) SECTIONS END-FED FROM BOTH ENDS

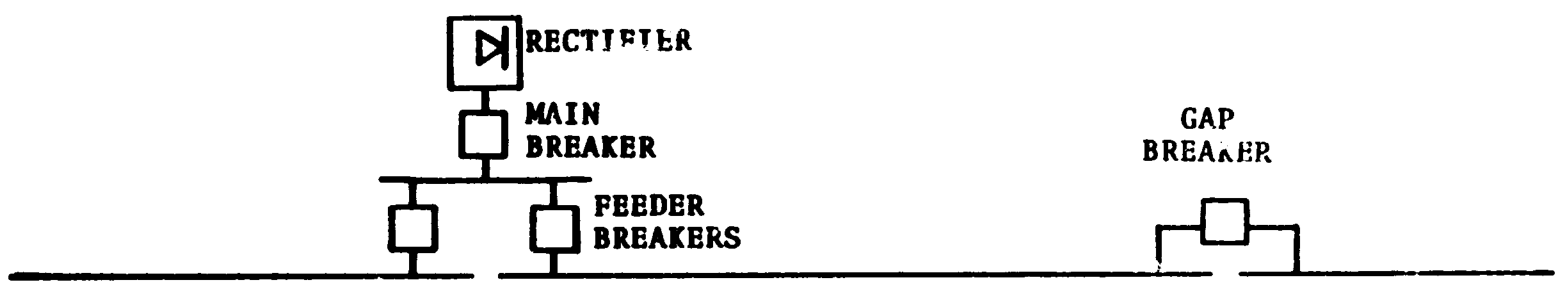

FIGURE 3-3. CATENARY (OR THIRD RAIL) SECTIONS END-FED FROM ONE END, WITH GAP BREAKERS

These are called "tie-breakers," "gap-breakers," or "equalizer-breakers." This means that each section normally has at least two circuit-breakers through which it can be energized. All circuit-breakers must be opened if the power section is to be completely de-energized.

Substantial differences exist between, as well as within, each of the electrification systems because some (e.g. MBTA) have undergone several additions or modernizations. Therefore, many types of equipment of various designs and ages are in use.

Another system, NYCTA, resulted from a merger of three properties built at different times, each of which has had additions or modernizations. Other systems, such as the former Erie-Lackawanna, now part of Conrail, were electrified as a single project. Those systems so constructed have uniformity in the equipment. The original Penn. RR and NHRR electrifications were for the same voltage and frequency, capable of handling the same locomotives and electrical multiple-units, but the details of the equipment are different. As a result, rescue personnel must understand what portions of the electric systems are dangerous to them, and what portions may be left energized to keep the railroad operating on adjacent tracks.

3.2 POWER INTERRUPTION -- MANUAL INITIATION

On every property there are standing orders for the Power Director to remove power from the third rail or catenary whenever anyone makes a request. The communications route for such requests may vary widely depending on the circumstances of the emergency. Requests from employees may come via wayside telephones, station telephones, or one of the property's radio circuits. These communications circuits frequently terminate at the train dispatchers desk, making it necessary for the train dispatcher to relay the request to the Power Director.

CTA operates a large fleet of radio-equipped buses and their operators are trained to observe at-grade and elevated rapid transit lines for trespassers, etc. All radios terminate at a bus dispatcher, who relays data to the train dispatcher, who notifies the Power Director. All dispatchers are at one location in adjoining rooms.

Most properties have established a telephone extension reserved for incoming calls at the Power Director's desk. All employees know this extension number and can use it from phones in the company exchange or from outside telephones. This reserved extension is also used for calls arriving from any outside source. All properties seek to determine who is calling, the location from which power must be removed and the reason.

The Power Director removes power as requested without attempting to validate the reason. He either operates switches at his panels which remotely operate the required circuit breakers, or he instructs personnel in the field to operate switches and circuit breakers to remove power. After removing power, the Power Director (who may be the first employee to know about an emergency) notifies appropriate personnel.

3.2.1 Emergency Power Removal Switches

One railroad and many of the rapid transit properties have emergency power removal switches, located at intervals along the right of way, to remove, but not restore, power. The location of these switches in tunnels is always identified by a distinctive light. Lights are also generally provided for switches on at-grade or elevated portions of the right of way. The type of light or color of light used is uniform throughout a property but not uniform for all properties. When anyone operates an emergency power-removal switch, the circuit breakers feeding the rail sections adjacent to the switch are automatically tripped.

On some properties separate emergency power-removal switches are available for each track in multi-track areas. These field power switches must be labelled to indicate which track is de-energized by each switch, and the Power Director's panel will also show which breakers have opened. An audible alarm is commonly provided to alert the Power Director. All of the properties which have emergency power-removal switches provide a telephone adjacent to the switch so that the person removing the power can inform the Power Director of the reason for removing power.

On some properties, emergency power-removal switches located on passenger station platforms have attracted vandals, resulting in frequent and needless removal of power. False power removal can usually be identified quickly, since no telephone call accompanies the operation of the switch. Loud, audible alarms have been added in the station area so the station agent will be immediately aware of a switch being operated. When an emergency power-removal switch has been operated, the Power Director sends a qualified employee to the location to investigate, and notifies the train dispatcher. On one property, there has been no legitimate use of emergency power-removal switches in about 15 years, but false alarms occur two to three times per week.

The use of wayside trip switches for emergency removal of power is not recommended for several reasons. False trippings by vandals can wreak havoc on operations, particularly at central locations during hours of peak activity. Also, in the event of an accident, especially in a tunnel, removal of power from the adjacent rails by persons on the scene could greatly reduce effectiveness of both rescue and fire fighting operations, since the fastest way to approach or leave the accident scene would be emergency vehicles operating on an adjacent track. It is therefore recommended that the Power Director be the only person able to remove (or restore) power during an emergency.

3.2.2 Removing Power by Short Circuiting the Power Rail or Catenary

If fault protection circuits are functioning properly, in theory power could be removed quickly by placing a short circuit between the power rail or catenary and the running rails, i.e., removing power by creating a fault. All of the Power Directors interviewed were vigorously opposed to this concept because it is very dangerous to rescue personnel. When a circuit is shorted, tremendous amounts of energy are released. Metal items such as lengths of pipe or supermarket shopping carts are often reduced to molten metal when they cause these short circuits. Flying bits of molten metal and the high energy arcs are major hazards to nearby personnel.

In one city, despite the objections of the transit authority, the fire fighters have been trained to use a length of chain to ground the power rail to the running rails after power is removed to insure that it has been removed. There have been cases where the chain has been thrown across the rails while the power was still on. In one case, the chain was almost entirely melted. In another case, the magnetic forces from the short circuit currents threw the chain away from the rails.

The obvious safety hazards to nearby rescue personnel who attempt a rapid removal of traction power by grounding or short circuiting the power rail or catenary cannot be overemphasized. Death or severe injury from flying metal, sometimes molten, can result.

Grounds on the catenary or third rail will not assure protection if a circuit breaker is prematurely closed. The source voltage will be momentarily applied when the breaker closes (see Figure 3.8). This voltage will divide across the impedance of the catenary and the impedance of the running rails. Since these impedances are generally of the same magnitude, the entire grounding device will have about half the source voltage across it until the breaker reopens. The magnitude of this voltage is high enough, and the time is long enough, for the breaker closing to be lethal.

When a catenary is used, there may be some residual voltage electromagnetically induced on the catenary wires, even though the circuit breakers feeding the catenary have been opened. Insulators which have become contaminated may provide a path for leakage current from an adjacent energized catenary (see Figure 3.4). The contamination may be from atmospheric dust, but most severe cases

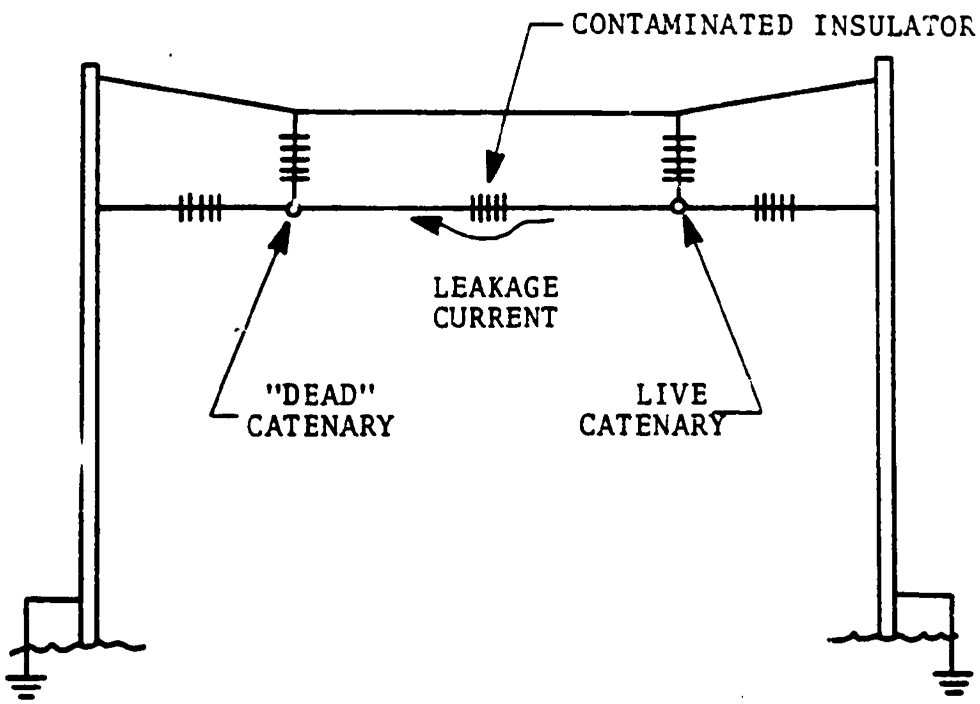

FIGURE 3-4. EFFECT OF CONTAMINATED INSULATORS ON CATENARY ELECTRIFICATIONS

occur where highway bridges over the catenary are salted for ice removal. As shown in Figure 3.5, electrified systems with third rails do not have this problem since there is no leakage path directly between the third rails of adjacent tracks.

3.3 POWER INTERRUPTION -- FAULT INITIATION

Power is interrupted in a traction system by a circuit breaker which has three characteristics: (1) the breaker must carry its normal short term overload currents without opening or damaging itself; (2) the breaker (and its relays or auxiliary devices) must sense a fault and trip when it is supposed to; (3) when it does trip, it must interrupt the fault current without damaging itself and be prepared to resume normal operation when it is reclosed. If the breaker fails to meet any one of these requirements, the consequences can be damaging to equipment and to personnel.

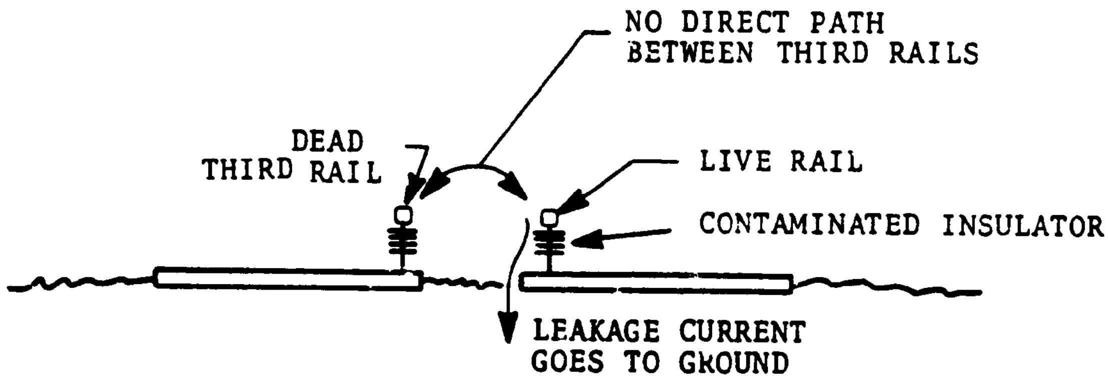

FIGURE 3-5. EFFECT OF CONTAMINATED INSULATORS ON THIRD RAIL ELECTRIFICATIONS

When a fault occurs on an ac electrification system, the highest currents will occur in the first cycle, and the fault currents will decrease slightly over the next several cycles. All of the fault protection on the railroads with ac electrification use circuit breakers with overcurrent tripping. For many years these breakers were set to trip after one-half cycle of overcurrent. With the advent of high-performance multiple-unit cars, many false trippings were experienced because the transformers on the new cars had high in-rush currents when they were energized. The circuit breakers were subsequently readjusted so that a higher value of fault overcurrent is required before the breakers will trip.

However, when a fault occurs on a dc electrification system, the current rises rapidly, but not instantaneously. At the location of the fault, arcing may occur producing much heat, possibly some molten metal, and possibly ignition of flammable material which may be present. If the fault is allowed to continue, cables will become overheated resulting in damage to the electrical insulation and possible fire. Several methods are used to detect the presence of a fault and to trip the breaker. The devices which sense the fault may be built into the circuit breaker, or may be separate. In some cases more than one method of tripping the breakers may be employed simultaneously. These methods are:

a. Instantaneous overcurrent.

A relay is used to measure the current through the circuit breaker. Whenever the current exceeds some preset value, the breaker is tripped with no intentional delay. However, there is one inherent delay since the contacts of the breaker will not move instantaneously. Typically there may be from 3 to 12 ms before the contacts part, and some additional time before the arc is long enough to break current flow. There are two problems with instantaneous-overcurrent circuit breakers:

1) The normal accelerating current from a nearby train is typically 1000 to 1500 A/car, or as much as 15000 A for the train. A fault at the far end of a long section of third rail may not produce a 15000 A fault current. When this happens there is no preset value of tripping which will provide protection and not have false tripping from nearby trains.

2) The current into a fault continues to rise until the arc voltage in the breaker equals the rectifier source voltage. For faults near the breaker, the rate of rise of current can be very high. Since the breaker may require 10 to 30 ms for this arc voltage to be produced, the current which must be interrupted may be many times the preset current which initiated the breaker operation.

b. Inverse time overcurrent.

A detector is used which will trip the circuit breaker after differing time intervals, depending on the magnitude of the current. Higher currents trip the breaker in less time. Typically this is done by use of thermal delays in the trip device. Obtaining a setting which assures protection for a distant fault of relatively low fault current without false tripping from a nearby accelerating train is very difficult. Inverse time overcurrent tripping is seldom used for feeder breakers.

c. Rate of rise of current.

A detector is used which will trip the breaker whenever the rate of rise of current exceeds some preset value. When a fault occurs, the opening of the breaker is initiated without waiting for the current to reach some preset value. This method of tripping has the limitation that the rate of rise of current as a train accelerates must be less than the rate of rise of current into a fault. For many modern propulsion systems this condition cannot be met.

d. Delayed rate of rise of current.

A detector is used which senses rate of rise of current and measures the time during which the rate of rise exists. The rate of rise in a vehicle ends abruptly when current limiting occurs. The rate of rise of a fault continues for a longer time. The combination of rate of rise and time duration is used to initiate breaker tripping. This system has the disadvantage that the deliberate time delay causes maximum current which the breaker must interrupt to be very high.

3.3.1 Fault Sensing Systems

A power section is typically fed from at least two sources simultaneously. When a fault occurs, current will flow from each source to the fault. Since the fault will generally be closer to one source, the breaker at that source will usually trip sooner. If the breakers are identical in construction and setting, and the source impedances are equal, then the breaker closest to the fault will always trip first. Secondary contacts on the breaker that is closer may be used in a circuit to trip the more remote breaker.

The technique is called transfer tripping or pilot line tripping. It is used selectively by rapid transit systems to insure that all breakers trip to clear a section in case of a fault.

Where a long power section is fed from only one source, the power section may have an intermediate gap at which a current-sensing relay is installed in the cable bridging the gap, as shown in Figure 3.6. The feeder breaker is preset to permit higher accelerating currents near the breaker, and to protect the nearer part of the power section when a fault occurs. The track relay is preset to operate with the minimum fault current which can exist in the farther part of the power section. Contacts on the track relay transfer-trip the feeder breaker if a distant fault occurs.

It was found on one railroad that none of the previously described protection methods could alone provide adequate fault protection without excessive false trippings. Newly delivered cars, which draw more current, and the reinforcement of the electrification system made it necessary to find a new fault-detection system. This system is shown in one-line diagram form in Figure 3.7. When a fault occurs, the voltage on the third rail near the fault approaches zero. Voltage sensing relays at each end and at the center of the power section are preset to operate at 350 vdc on a 740 vdc system. Contacts on the voltage sensing relays transfer-trip the feeder breakers at both ends of the power section.

If a rectifier substation must be taken off-line, a track switch is used to bridge the gap in the power section. Auxiliary contacts on the track switch interconnect the pilot wires for the two sections which are joined, forming a double length power section having six voltage sensing relays, any of which will trip the feeder breakers at the operational substations. The cars being used on the railroad have undervoltage protection which operates at about 370 vdc. If the voltage drops because of high train demand, loadshedding is used to prevent false tripping of feeder breakers. Such a system as the Voltage Sensing Pilot Wire System has been developed and installed on an operating railroad. It has about five years favorable experience. The system is now being installed on three rapid transit properties.

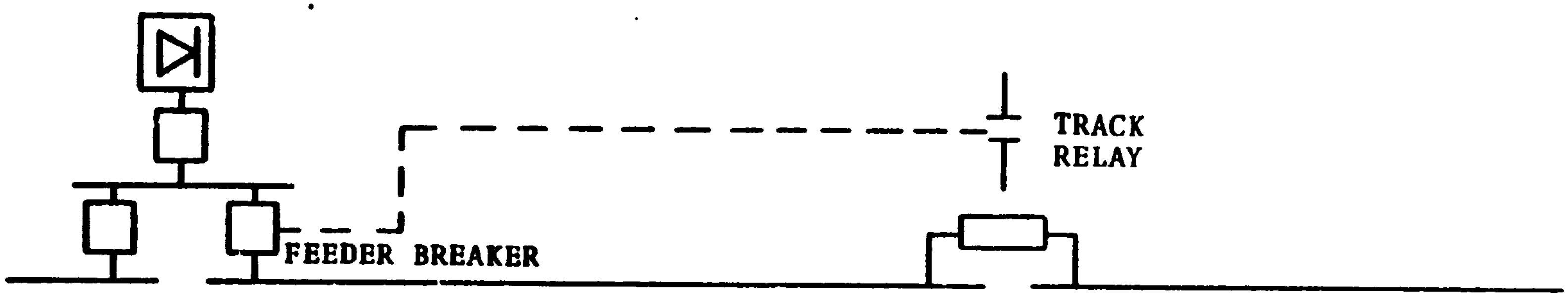

FIGURE 3-6. USE OF A TRACK RELAY IN A LONG POWER SECTION

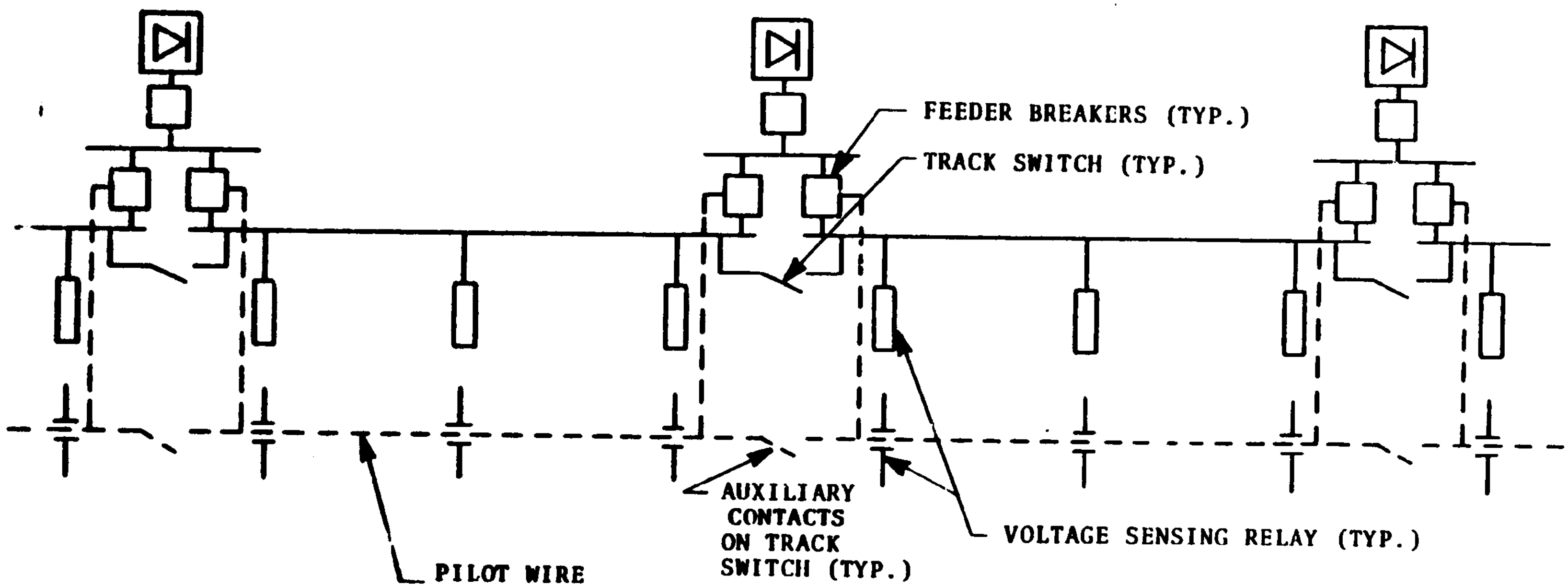

FIGURE 3-7. VOLTAGE SENSING PILOT W:RE SYSTEM

3.3.2 Clearing a Fault

Uniform methods for providing fault protection on transmission lines have been developed by the utilities in the United States. Each transmission line usually has a circuit breaker at each end. Current transformers and potential transformers are used to energize protective relays which provide automatic control of the circuit breakers. The relays are usually selected to provide inverse time overcurrent tripping sometimes supplemented by relays which monitor zero sequence currents to detect ground faults. The circuit breakers at the ends of a line are commonly interconnected such that if one trips, all trip. Since a breaker may occasionally fail to respond as intended, the breakers and relays in adjacent protective zones are adjusted to provide back-up protection by opening if the primary protection fails. The utilities do not normally provide remote control of the breakers from a power dispatchers location.

3.4 POWER RESTORATION

Power is removed from the third rail by two methods: (1) when it has been manually interrupted by the action of the Power Director for maintenance work, for an accident, or other reason; and (2) the tripping of a breaker due to a fault; in either case, power must be restored on the line by following procedures which pose no hazards to any rescue personnel on the scene.

3.4.1 Restoring Power after Removal by Manual Initiation

All of the properties have specific procedures for the Power Director to follow to get authorization to restore power. When power has been removed by use of an emergency power-removal switch, and the individual who removed power has telephoned the Director, the same individual must approve restoring power. On some systems the Power Director must also receive an approval from a supervisor who is at the site and has verified that conditions are safe. Where the person using the emergency power-removal switch is unknown, approval by a trained supervisor is required. For operation of a switch at a passenger station by a vandal, the station attendant is trained to inspect the tracks and is usually authorized to approve restoring power.

On every system, when power is removed by request of rescue personnel at the accident site, the individual making the report must approve restoring power. If several individuals have requested power removal, each of them must individually approve restoring power. There is one situation where one employee can request power removal and a different employee can authorize restoring power; on CTA, when a bus driver has requested power removal, power restoration will be authorized by the supervisor sent to the site. On all systems, power removal after a verbal request from an unknown individual requires that an on-site inspection be made by a supervisor who can then authorize restoring power.

Utilities with transmission lines above a railroad will advise the railroad Power Director where and when they plan to restore power on their own property. This notification assures the safety of any railroad personnel who may be working on the supporting structures.

3.4.2 Restoring Power after Removal by Fault Initiation

The practices followed by the Power Directors of the various railroad and transit properties are determined primarily by the capabilities built into the electrification systems. In every case, the objective is to restore power as quickly as possible after a breaker trips. Until power is restored, passengers may be stranded in cars without heating, air conditioning, or ventilation. Restoring power provides these passenger comforts, reduces the risks of panic or dangerous acts by the passengers, and minimizes the impact on train schedules.

The following reasons are the basis for the prompt reclosing of a circuit breaker after it has been tripped:

a. Some circuit breaker trips result from unknown causes (trees swaying, etc.). For example, Amtrak reports that one fourth or more of their power outages have no known cause.

b. Reclosing after equipment failure may cause the breaker to retrip, but will not greatly increase damage to the defective equipment, and the fault may burn clear.

c. High-voltage equipment on multiple-unit cars is almost entirely under the floor. That part above the floor is in locked cabinets. High-voltage equipment on locomotives is in locked cabinets. Thus restoring power will not create a hazard to passengers or train crews.

d. In stations, high-voltage equipment, except the catenary or the third rail, is located in areas not accessible to passengers.

e. Faults caused by vandals who drop shopping carts, aluminum foil, or other objects on the catenary or third rail sometimes burn clear during the initial fault. Amtrak, however, reports that shopping carts do not burn clear on the initial fault, but cause a second tripping and damage to the catenary.

f. Prompt reclosing minimizes passenger discomfort and schedule delays.

The dangers to rescue personnel from prompt reclosing are the following:

a. Rescue personnel cannot tell by visual inspection whether a catenary or third-rail is energized, or when it becomes re-energized; rescue personnel need to know the energization status of traction power because it is crucial to their safety.

b. Rescue personnel may have to act rapidly to remove persons from the tracks, cars or vehicles without waiting for the power to be removed by requests through the normal channels. If the accident caused the breakers to trip, rescue personnel would benefit by not reclosing the breakers. The time required for rescue personnel to get to the site and the impact of that time lag on traffic movement must also be considered when decisions to reclose open breakers are made. In addition, railroad operations may be impacted because other trains may cross into problem electrical circuits causing domino-type electric power outages.

The following paragraphs discuss the methods of reclosing that are used with various types of switchgear.

Manually operated circuit breakers. The oldest installations still in use have manually operated breakers, many of which are located in manned substations.

In general, the operator at the substation may have some clues to provide guidance when a breaker trips. Frequently the operator will have facilities which verify that a particular breaker has tripped, but that other breakers feeding the same section are still closed, and do not have abnormal currents. This suggests that the breaker tripped due to a momentary-high nearby load, or that some nearby fault has burned clear. In either case, it is usually safe to reclose the breaker.

When the operator finds that both breakers feeding a rail section have tripped, he may try to reclose one, to determine whether a fault still exists. If the first breaker remains closed, the other may also be reclosed. This is most apt to be done during hours when traffic is heavy. If one or two attempts to reclose the first breaker are unsuccessful, the operator will request instructions from the Power Director. There are exceptions to this practice.

NYCTA has found that experienced operators can tell whether a breaker tripped due to a light overload such as a train, or due to a heavy overload such as a fault. When there has been a heavy overload, the operator may test the feeder and rail section before attempting to reclose the breaker. In addition, NYCTA has many locations where concentric feeder cables are used. The inner conductor carries the high voltage to the third rail; the concentric outer layer of wires connects the running rails to the negative of the rectifier. Where concentric feeders are installed, NYCTA requires the operator to test the feeder and rail for faults before reclosing the breaker.

The Erie-Lackawanna does not reclose a breaker during non-rush hours without an on-site inspection. During rush hours the operator must get approval from the Power Director who will normally authorize reclosing without an on-site inspection.

Circuit breakers with automatic reclosing. On more recent installations the substation feeder breakers usually have several protective relays which will attempt to reclose the breaker in 3 to 8 seconds after the breaker has tripped. Typically these installations include some type of counter so that only two or three attempts are made if the breaker trips again. The counter resets if the breaker remains closed for some period, such as a minute or more. This automatic reclosing feature has made it possible to have unattended substations. All of the rail properties have facilities so that the opening and automatic reclosing of an unattended breaker is displayed at an attended location.

Circuit breakers with load sensing and automatic reclosing. With automatic reclosing as described above, repeated attempts to reclose a breaker into a fault have adverse effects on the breaker contacts, and may add to damages at the fault. On the newest installations, there are circuits which measure the load-circuit resistance after a breaker has tripped. If the resistance is less than some preset limit, such as 1 ohm, the automatic reclosing is disabled. The preset limit varies greatly on different properties, but none of the load-sensing circuits are sensitive enough to detect a human body in contact with the power rails and running rails. The resistance of a body is higher than any viable preset limit.

Gap breakers with voltage sensing and automatic reclosing. There are gap breaker stations equipped with automatic reclosing circuit breakers. On both sides of the gap there are voltage-sensing relays which disable the reclosing feature if either section does not have normal voltage.

Breakers on utility transmission lines. The transmission lines which presently are built over railroad rights of way operate at the lower transmission voltages; i.e., 115 or 230 kv. Circuit breakers protecting most of these lines are equipped with relaying to provide a single attempt at reclosing less than 1 second after the breaker has tripped. If the attempt is unsuccessful, the breakers lock-out. Maintenance personnel will be dispatched to inspect and repair the line. The breakers will then be reclosed manually when the Power Director authorizes it.

3.4.3 Third Rail Covers

Insulated third rail covers, placed several inches above the third rail, are used on some properties. They provide some added protection to rescue personnel against an accidental contact with the third rail. Other properties do not use these insulated third rail covers, because they can be a source of operation and maintenance problems, and sometimes are a safety hazard. Debris and foreign objects have been known to wedge between the third rail and the third rail cover, creating an obstacle to the car's contactor shoes which slide along the third rail. Ice and snow wedged into the space between the rails have often caused the contactor shoes to chatter and arc. Finally, if an object should strike the top of a third rail cover with enough force to bend it, the clearance above the third rail may be insufficient for the contactor shoe. This was a contributing factor in the BART tunnel fire in January 1979. For these reasons, it is recommended that insulated third rail covers not be used.

3.5 IMPROVEMENTS IN POWER INTERRUPTION EQUIPMENT

In concept, it would be possible to remove power from the third rail or catenary when there is no train in the section. The times of applying and removing power must be based on actual train position, not scheduled train position. This would require methods and equipment, which most railroads do not have now, so that the Power Director would know the actual position of each train and be able to apply power as needed, and to remove power after the train has passed a power section. Amtrak's proposed Traffic Control system would permit power removal since telemetered position of each train would be available.

When a circuit breaker opens or closes, even when there is no current, the mechanism is subjected to severe mechanical impacts. These impacts cause the parts of the mechanism to wear and to slip from their proper positions. When no current flows, an industrial-type circuit breaker will have a typical life of about 2500 open/close cycles. Even though circuit breakers built for RR-electrification service are capable of many more open/close cycles than corresponding industrial circuit breakers, on a busy electrified system circuit-breaker life would be measured in days instead of years.

Grounds on the catenary or third rail will not assure protection if a circuit breaker is prematurely closed. The source voltage will be momentarily applied when the breaker closes. (See Figure 3.8.) This voltage will divide across the impedance of the catenary, and the impedance of the running rails. Since these impedances are generally of the same magnitude, the entire grounding device will have about half the source voltage across it until the breaker reopens. The magnitude of this voltage is high enough, and the time is long enough, for the breaker closing to be lethal.

Circuit breakers used as main breakers, as feed breakers, or as gap breakers must have the interrupting capacity necessary to clear the most damaging fault which can occur with the highest system voltage.

Growth and improvements in system electrifications have changed the current levels which a breaker must interrupt under fault conditions. Many systems have added more feeders and substations to supply heavier trains at shorter headways. This increases the available fault current for the breaker to interrupt. In some cases existing breakers may be salvaged if the fault sensing is improved so the breaker responds more quickly when a fault exists. New studies of fault currents should be made, and breakers which are inadequate should be replaced.

Adequate Fault Sensing. As systems have grown breaker settings have frequently advanced to prevent false tripping due to heavy train loads. This can result in an unacceptable condition where

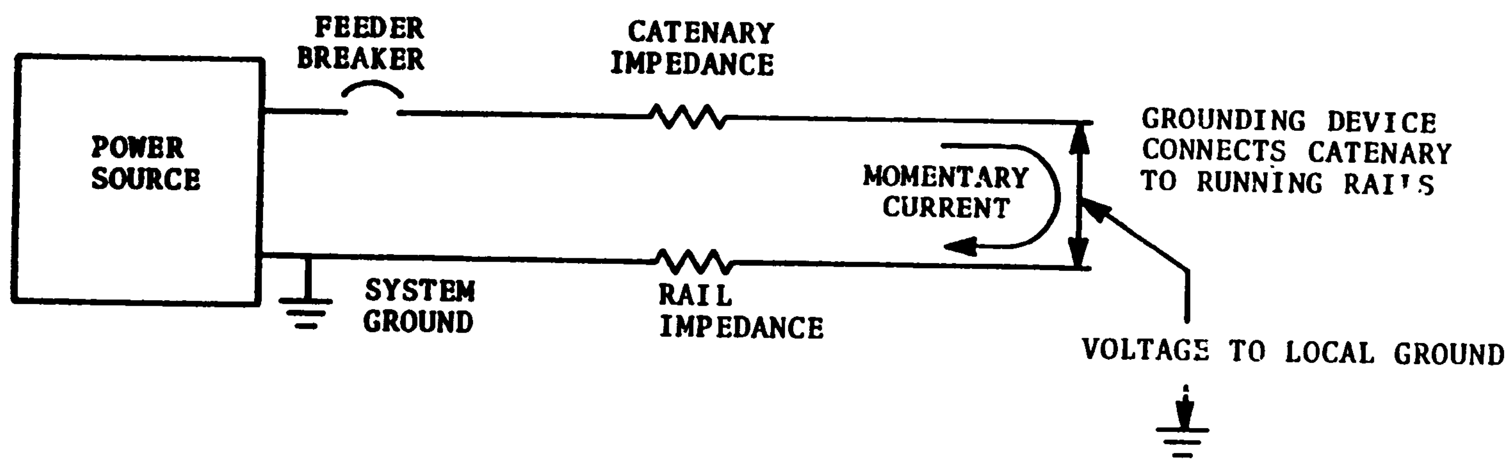

FIGURE 3-8. VOLTAGE DIVIDER WHEN A BREAKER CLOSES PREMATURELY

relay settings are not suitable to trip the breaker for all types of faults. Where the fault sensing is inadequate, but the circuit breaker is adequate, it may be possible to add equipment external to the breaker to improve the fault sensing. The voltage-sensing pilot-wire system described earlier has been found to be an excellent method of improving the fault-sensing capability of the electrification system. However, the pilot-wire system is not fail safe; it requires backup relaying.

Load Sensing. Where circuit breakers have automatic reclosing without load sensing, external protective relaying can be added to provide the load sensing. Load sensing can be used to guide operators where manual breakers are still in use.

Costs of changes will differ greatly depending on the existing installation. Typical costs for improvements to fault-sensing capabilities of circuit breakers might be as much as 8,000 to 10,000 dollars per breaker; if none of the existing equipment can be used. Where unusual problems exist, each replacement breaker will cost 25,000 to 30,000 dollars. For example, if load sensing is added when fault sensing is improved, the added costs would be negligible. To add load sensing where other changes are not needed, the cost would be 1,500 to 2,000 dollars per breaker.

4. COST-BENEFIT ANALYSIS

Cost-benefit analyses have been made on each improvement item given in Section 3 and the results are presented below. They are summarized in Table 4-1.

The existing 2400-track mile electrified railroad system shown in Table 4-1 is used as the model for the analysis. This system has a record of 20 electrical-contact accidents over a 4-year period, for an average of five accidents per year. These accidents involved employees as well as non-employees. Since the data base for rescue personnel is so small, we used the total number of electrical-contact accidents as the data base. It was assumed that improvements which reduce the overall accident number will reduce the hazards to rescue personnel in the same proportion.

To carry out the analysis, the one-time and annual costs for each improvement item were estimated and reduced to a total annual cost. A reduction of annual accidents for each improvement item was assumed, based on a minimum level of roughly two accidents per year. The "benefit" figures for Table 4-1 were developed using typical litigation figures of 1,000,000 dollars for an accident and 100,000 dollars for a death.

The cost figures have been developed for the following recommended measures: training of rescue personnel, development of emergency plans and agreements, education of the general public, improved communications to Power Directors, and protective hardware modernization and improvement. The costs developed include both the non-recurring and recurring charges. The non-recurring or capital costs are then annualized at a discount rate of 10 percent, and are also shown in Table 4-1.

4.1 COST-BENEFIT ANALYSIS OF PROPOSED IMPROVEMENTS

The model used for this analysis is the present Northeast electrified-railroad network shown in Table 4-2. There are 720 route miles and 2400 track miles for an average of 3-1/3 tracks

TABLE 4-1. ASSUMED REDUCTIONS IN ELECTRICAL CONTACT ACCIDENTS (COSTS/BENEFITS) FOR VARIOUS SAFETY PROGRAMS

Safety Program	Reduction in Number of Victims per Year: Death	Serious Injury	Cost	Benefit
A. Train Rescue Personnel	0.25	0.25	$220,000	$275,000
B. Develop Emergency Plans	0.25	0.25	35,000	275,000
C. Educate General Public	0.10	0.10	100,000	110,000
D. Improve Communications to Power Directors				
1. Wayside Call Boxes	0.17	0.17	720,000	187,000
2. P.A. Systems	0.17	0.17	153,300	187,000
3. Hot Line to Power Director	0.17	0.17	1,200	187,000
E. Improve Protective Hardware				
1. Circuit Breakers	0.17	0.17	562,500	187,000
2. Fault Sensing	0.17	0.17	983,300	187,000
3. Load Sensing	0.17	0.17	126,000	187,000

TABLE 4-2. ELECTRIFIED NETWORK FOR MODEL

Section	Passenger or Freight	Route Miles
1. Washington to New York	P/F	225
2. Philadelphia to Harrisburg, PA	P/F	95
3. Perryville, MD to Harrisburg, PA	F	150
4. Susquehanna Line (Parksburgh to Enola)	F	70
5. Trenton Branch (Trenton to Downington, PA)	F	50
6. Jamestown Branch (bypass)	F	40
7. Chestnut Hill Branch	P	7
8. South Amboys Branch	F	10
9. Media Branch	P	12
10. Manayunk Branch	P	7
11. Other Miscellaneous Branches	P/F	54
Total		720

over the entire network. There are five traction power control centers for this network. The principal one is located in Philadelphia; it can directly communicate with each of the other four centers.

Data on accidents resulting from human contact with the traction-power high-voltage catenary system have been partially assembled for a four-year period (1972-1975). There were 20 such contacts, or an average of five per year. The distribution of these human contacts between fatal and non-fatal accidents has been assumed to be:

2 fatal contacts per year

3 non-fatal contacts per year (all resulting in serious injury)

Total: 5 human contacts per year.

An average of one contact per year (a fatal one) is a railroad employee. Therefore 80 percent of these accidents involve others, such as trespassers and rescue personnel.

Costs of these accidents can be determined in large part by the typical insurance settlements obtained by the victims. Other costs incurred from delayed and disrupted train service and damaged equipment would be harder to determine, and probably would not be as significant. From experience with litigation on electrical accidents, average insurance settlements have been assumed as follows:

Average payment per death = $ 100,000
Average payment per serious injury = $1,000,000

Therefore, the costs of these accidents on a yearly basis are:

Cost of serious non-fatal accidents =
3 x $1,000,000 = $3,000,000/y

Cost of fatal accidents =
2 x $100,000 = 200,000/y

Total cost of accidents = $3,200/000/y

4.2 PROPOSED PROGRAMS TO REDUCE ACCIDENTS

In Section 2 of this report a number of possible measures are recommended to reduce the incidence of these deaths and injuries from electrical contacts. They are listed in Table 4-3 in the reverse order to that in Section 2, since they would be considered in this order for cost and effort.

4.2.1 Training of Rescue Personnel

A one-time development of educational material for safety training sessions is required. An on-going program is needed to send 2-man teams to conduct evening seminars and daytime demonstrations, complete with handouts, film, slides, models, and other teaching aids to train fire fighters, police and medical workers in communities along the right of way. Items to be covered are how to cope with special hazards of an electrified right of way, how to turn off the power, how to verify that it is turned off, etc. Estimated costs of these programs are as follows:

One-time cost of pamphlets, film, and teaching aids	= $100,000
On-going annual costs:	
4 Safety instructors (w/travel at $50,000)	= $200,000
1 Office staff (1/2 time) to set up courses	= $ 10,000
Annualization of one-time costs at 10%	= $ 10,000
Total annual cost	= $220,000

4.2.2 Emergency Plans and Agreements

Joint planning between local officials (fire and police) in communities along the right of way and railroad personnel should be carried out to formulate a chain of command and guidelines for action in case of an emergency, such as a derailment or other

TABLE 4-3. RECOMMENDED MEASURES TO REDUCE INCIDENCE OF DEATHS AND INJURIES FROM ELECTRICAL CONTACTS ON RIGHT OF WAY

Training of Rescue Personnel
Emergency Plans and Agreements
Education of General Public
Improved Communications to Power Directors
1. Provide Wayside Call Boxes
2. Provide Public Address Systems
3. Provide Direct Phone Lines to Power Directors
Protective Hardware Modernization and Improvement
1. Upgrade Breaker Capacities
2. Improve Fault Sensing (Pilot Wire)
3. Add Load Sensing to Breakers

railway accident. After agreements are reached, they should be formalized in writing and reviewed on an annual basis. The work should be done by a part-time team of a lawyer and engineer (operating or safety). Estimated cost of these programs are:

One-time cost of drafting sample plans and agreements	= $ 50,000
One-time cost of negotiating with each community	= 50,000
Total one-time cost	= $100,000
On-going annual cost of reviewing agreements	= $ 25,000/y
Annualization of one-time costs at 10 percent	= 10,000/y
Total annual cost	= $ 35,000/y

4.2.3 Education of General Public

Two major efforts are required to educate the general public in safety measures:

a. Development of a film/lecture program for presentations

b. Presentation of this material to various groups.

The development of the presentation would require professional film-making assistance to assure dramatic impact. Railroad personnel should be consulted to ensure that all pertinent safety information is properly included. Estimated costs involved are the following:

One-time cost of film, lecture aids, and handout literature	= $150,000
On-going annual costs:	
2 Safety Education lecturers (w/travel at $40,000)	= 80,000
1 office staff (quarter-time) scheduling and arranging lectures	= 5,000
Annualization of one-time costs at 10 percent	= 15,000
Total annual cost	= $100,000

4.2.4 Improved Communications to Power Directors

Three measures are considered to reduce the time lag from occurrence of an accident on the railroad right of way to the turn-off of catenary or other potentially dangerous electric circuits.

a. Provision of Wayside Call Boxes. The installation of emergency boxes (radios or telephones) at convenient intervals along the right of way can provide a direct link to the Power Director. The effectiveness and cost of the call boxes will both increase directly with the number of units installed; i.e., how closely they are spaced along the railroad. The NFPA recommendation of 800 ft. spacing (for urban transit) can serve as a reference. We will assume a unit cost of 2500 dollars for a battery-operated radio system with call boxes spaced at one-half mile intervals. The costs are given below:

One-time cost for 720 route miles (Table 4-2), with 2 stations per mile, at $2500 each	=	$3.6 M
Annual costs:		
Maintenance at 10 percent	=	$360,000/y
Annualization of one-time costs at 10 percent	=	$360,000
Total annual cost	=	$720,000

Cost of telephones, as an alternate to self-contained radio units, can also be estimated. The 10 percent/y maintenance cost is based on an assumed vandalism rate at the call boxes.

b. Provision of Public Address Systems. If an accident were to occur at or near a passenger station and/or involve a passenger train, public address (P.A.) systems at the station and on the passenger cars can be used to warn patrons and rescue personnel about the dangers of live wires and to control evacuation in an orderly manner.

Assuming 75 passenger stations (roughly one every 10 miles) and a cost of 3,500 dollars per installation at each station, the one-time cost of the passenger station units would be 262,500 dollars assuming a backup battery supply in case of a power loss.

The public address systems at the passenger stations should all be tied to a central control point so that a message broadcast from any one station can be heard on any of the stations selected by a communication director at the central station. The tie-in data links can be over telephone lines through a central switchboard. Telephone tie-in costs are estimated at 50 dollars per station, and the central switchboard would cost about 10,000 dollars.

The cost of installing public address units on passenger cars (assuming an amplifier, microphone, and speakers in each car) is assumed to be 1,000 dollars per car. Assuming a fleet of 1,000 passenger cars, of which 40 percent do not have installed public address systems, then one-time costs will be 400,000 dollars. The newer cars are assumed to be equipped with public address systems. The costs are given below:

<u>One-Time Cost</u>		
P.A. Systems at 75 stations at $3500 each	=	$262,500
Phone line tie-in for 75 stations at $50 each	=	3,750
Central switchboard for all station P.A.s	=	10,000
P.A. Systems for 400 cars at $1,000 each	=	400,000
Total one-time cost	=	$676,250
<u>Annual Costs</u>		
Maintenance at 10%	=	$ 67,625
Minimum service rate $20/mo x 75 x 12	=	18,000
Annualization of one-time costs at 10%	=	67,625
Total annual cost	=	$153,250

The 10 percent a year maintenance costs considers a fairly high rate of vandalism to those public address systems which are located at unattended stations.

c. Provisions of Direct Phone Lines to Power Directors There are five power control centers in the network, each responsible for an average of 144 route miles of eletrified roadway. If the Power Director at each control center had a "hot line" reserved for incoming emergency calls from fire, police, and medical rescue personnel, valuable time could be saved in shutting down portions of the electrified system after an accident on the railroad right-of-way. The telephone numbers could be disseminated in the training courses mentioned earlier. The cost of a special "hot line" phone should not be greater than the cost of installing any other phone, i.e., 50 dollars or less. The cost would be:

<u>One-Time Cost</u>		
Five phone lines at $50	=	$ 250
<u>Annual Costs</u>		
Minimum service rate $20/mo x 5 x 12 mi/y	=	$1200
Annualization of one-time cost at 10%	=	<u>$ 25</u>
Total annual cost	=	$1225/y

4.3 PROTECTIVE HARDWARE MODERNIZATION AND IMPROVEMENT

Three measures are considered to insure that the protective system of the electrical system operates positively to remove power following an accident involving people and equipment.

a. Upgrade of Circuit Breakers. This measure would require a review of fault currents and a survey of current breaker capacities on the entire electrical system. Circuit breakers of inadequate capacity would be replaced. It is estimated that there is one 11-kv circuit breaker for each route mile, or a total of 720 breakers considering substation breakers (420), bus tie breakers (60), and transformer breakers (240). The cost is:

One-time engineering study: 3 engineering man-years at $75,000	= $0.225M
One-time replacement of breakers: 25 percent replacement, or 180 breakers at $30,000	= $5.400M
Total one-time cost	= $5.625M
Annualized one-time cost at 10 percent	= $562,500

b. Improve Fault Sensing. This measure would require the installation of transfer tripping, voltage-sensing pilot-wire tripping, or other means to insure that catenary sections are completely cleared when a fault or accident occurs. The estimated costs are the following:

One-time engineering study: Add 1 engineering man-year to Item 1 study	= $0.075M
One-time improvement: 720 breakers at $9,000	= 6.48M
Total one-time costs	= $6.555M

Annual costs:

Maintenance at 5 percent	= $327,750/y
Annualization of one-time cost at 10 percent	= 655,500
Total annual cost	= $983,250/y

c. Add Load Sensing to Breakers. Load sensing devices would prevent the breakers from being reclosed into a fault, such as that resulting from an accident, thereby endangering rescue personnel. The cost would be absorbed in the measures to improve fault sensing. If done independently, the cost, based on an average of one breaker per route mile, would be:

One-time installation of load sensing:

720 breakers at $1,750	= $1.26M
Annualization of one-time cost at 10 percent	= $126,000/y

The estimated reduction in deaths and serious injuries per year as a result of carrying out the measures in the proposed program are also shown in Table 4-1. The dollars saved per year are based on the costs given above for both types of accidents. It has been assumed that the rate of electrical contact accidents will be reduced from its previous rate of five per year to 1.8 per year, if all of the measures are taken.

5. CONCLUSIONS AND RECOMMENDATIONS

The procedure of grounding third rails or catenaries by rescue personnel to remove power is extremely hazardous. Use of wayside trip switches for emergency removal of power will often make rescue operations more difficult and complicate normal operations. It is therefore recommended that all emergency power removals be made by the Power Director. These issues are discussed more fully in Section 3.2.

Actions and programs for improving the safety of fire, police, and medical rescue personnel during an emergency on an electrified railroad system, range from improved planning for emergencies to major rework done of the wayside electric power system. Regardless of the work done and the money expended, the electrified railroad system cannot be made 100 percent safe under all circumstances. Therefore, the cost-benefit analysis provides the best guidance of what work should be done to improve the safety for rescue operations. A list of actions is given in Sections 2 and 3 of the report.

Use of third-rail covers to protect personnel from accidental contact with live third rails is not recommended because of the additional hazards and operational problems they present, as discussed in Section 3.4.3.

On the basis of the results of the cost-benefit analysis shown in Table 4-1, the following measures on the existing electrification system have been recommended:

a. Training of rescue personnel, development of emergency plans, educating the general public, and installing "hot" lines to the Power Director, as a comprehensive program with the cities and towns along the right of way.

b. Considering the benefits of integrated station and passenger car, public-address systems for emergencies. Installation of the new equipment or upgrading old equipment if the benefits are adequate.

c. Adding load sensing to the wayside circuit breakers to prevent them from being reclosed into a fault such as that resulting from an accident. In those instances where other hardware improvements are also being carried out, the costs for this program would be greatly reduced, making it even more attractive.

In the construction of a new electrification system certain of the items shown in Table 4-1 will be incorporated as part of the initial design and cost. These items include public-address systems in cars and stations, improved communications within the railroad system, properly sized circuit breakers for the fault currents, and transfer tripping means to improve the fault-clearing capability of the wayside electric system. However, the joint planning and coordination with rescue organizations still must be developed, and communications systems established to outside fire and police departments.

Wayside data links, analyzed at stations located at one-half mile intervals along the railroad right of way, are not cost-beneficial and are not recommended for implementation as a solution to the specific safety discussions in this report.

In the areas of improved hardware, upgrading of circuit-breaker capacity in existing electrification systems should be an on-going activity for considerations other than the specific safety discussions in this report. Those considerations would include such factors as maintaining system reliability and availability. Less costly means for implementing fault sensing are necessary to achieve a favorable cost-benefit. We recommend that research and development activities be undertaken to develop and improve fault-sensing and load-sensing equipment for electrified railroad systems at lower costs than are presently available.

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