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METROLINER AUXILIARY POWER ELECTRICAL SYSTEM RELIABILITY STUDY

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16. Abstract

The reliability of the electrical system of any vehicle is greatly affected by the way the system is configured. The propulsion and braking systems of a train must be unaffected by failures occurring in the nonessential power areas. With these criteria in mind the so-called "Auxiliary Power System" of the Metroliner car was analyzed. This auxiliary power system was found to be deficient in achieving these ends. Recommendations suggest methods of satisfying these criteria by segregating the essential from the nonessential elements, thereby enhancing the overall availability of the Metroliner car.

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INTRODUCTION

The purpose of this study is to provide technical inputs to the Office of High Speed Ground Transportation (OHSGT) in its efforts to improve the operational reliability of the Metroliner cars. In addition the study will provide guidelines for the design of electrical and electronic systems of future high speed transit cars. The study is restricted primarily to the "auxiliary power system", which has been one of the primary areas of failure to date.

SUMMARY OF CONCLUSIONS

The reliability of the electrical system of these or any other cars is greatly affected by the way the system is configured. The Metroliner's electrical system apparently was not configured with overall system reliability in mind. Although extensive changes in the total system of the existing cars is likely to be impractical, the recommendations made below would reduce the present vulnerability of the propulsion and braking systems to failure of the motor-alternator set, thus leading to potentially higher system reliability.

The recommendations are in two parts: those on which decisions can be made at once, leading to specific action, including hardware procurement for the cars; and those that would be desirable but which would require extensive development of hardware. In addition, some specific improvements are identified that would be useful on new systems but which would be too extensive or too expensive for these cars.

1. Short term actions:

   a. The propulsion and braking systems must be unaffected by failures occurring in the nonessential power areas. To approach this condition two things can be done in the near future (six months).

      (1) The battery should be fed by a separate battery charger designed to protect the battery from both overcharging and undercharging. A specific piece of off-the-shelf hardware does not exist, but a specification for one is

being developed. An outline for this specification is included in Appendix E and a procurement of a prototype could be done rapidly.

(2) All essentical dc loads should be removed from dependence on the motor-alternator set, and should be fed from their own 25 Hz to dc converter. A specification for this component is being developed. A preliminary outline is included in Appendix E, and this unit could be developed in a reasonable amount of time.

b. Procedures at the terminals should be modified to insure that the batteries are not used for utility power and lights when the trains are in the stations. This is an operational procedure that could be implemented by Penn Central at any time.

c. A much more effective record keeping system for part and equipment failures must be instituted so that the real causes of failure can be pinpointed and corrected with a minimum loss of time. This could only be done by the railraod. TSC could help them set up such a system, monitor its operation, and perform failure analysis of a limited sort to more fully categorize the kinds of failure prevalent.

2. Long term actions:

a. Since the motor-alternator set has caused numerous failures, replacement of the rotating machinery with static inverters is very tempting. No firm recommendation to do this can be made at this time, because off the shelf inverters of adequate size are not available, and there is no assurance that newly developed inverters would be even as reliable as the present motor-alternator set. This idea must therefore be one for future consideration, and should certainly be thoroughly evaluated in any new high speed train design.

b. Essential blower motors now fed from the motor-alternator set should either be put on 25 Hz or dc. Firm recommendations on how to do this cannot be made at this time, due to inability to locate adequate 25 Hz or dc motors; further investigation must be made before a change can confidently be recommended

DEFINITIONS

The "primary power system" is defined as the system composed of the propulsion motors and their respective propulsion and braking controls. The "secondary power system" is defined as the system composed of all the electric and electronic equipment not included in the primary power system. The secondary power system is further divided into essential and nonessential elements. "Essential elements" are those elements whose failure would impair the normal operation of the propulsion, braking, and control systems of the train. Failure of a "nonessential element" such as air conditioning, food service, etc., may impair passenger comfort but would not prevent a car from pulling its own weight to complete a normal run. The Metroliner's "auxiliary power system" is in fact the secondary power system, containing both essential and nonessential elements. It will henceforth be referred to as such.

APPROACH

To gain a thorough understanding of the design rationale of the secondary power system, an in-depth review was made of the original car specifications (see Appendix C) and the manufacturers' drawings. The various related support groups, The Budd Company, Penn Central, The General Electric Company, and The Westinghouse Electric Corporation, etc., were also contacted for consultation. See Appendix D for a full list of all companies and people contacted. The boundaries of the secondary power system were then defined and the corresponding block diagrams were generated (see Section 2). A survey of failure data was then made to pinpoint specific equipment failures and problem areas (see Appendix A). A number of alternative systems were then derived (see diagrams of the six alternatives shown in Section 4). The following sections provide technical descriptions of these systems along with general recommendations and conclusions.

DESIGN RATIONALE

DESIGN SPECIFICATIONS

The design specifications for the Metroliner were written by Louis T. Klauder Associates of Philadelphia, Pennsylvania, under contract to the Penn Central Company. These specifications were then levied on the two manufacturers, General Electric, and Westinghouse. As far as the secondary power system is concerned these specifications are fairly specific and as a result both manufacturers' systems are similar. Appendix C includes those sections of the Metroliner design specification that directly apply to the secondary power system. Section S9 Auxiliary Power System and Apparatus of the Metroliner specification, which specifies the secondary power system, outlines the basic design philosophy. It calls for all apparatus to be designed for operation at 11,000 V, 25 Hz, with a future possibility of operation at 25,000/11,000 V, 60 Hz. It specifies that to facilitate this conversion the secondary load shall be supplied, to the greatest extent possible, from the alternator of a motor-alternator set. It also specifies that motor-blower sets be provided on each car as required to provide equipment ventilation. The motors required shall be 220 V, 3 phase, 60 Hz induction motors, hence they shall be powered by the output of the motor-alternator set. The specification also stipulates the particular battery to be used for emergency conditions, and describes the method by which it shall be charged and regulated.

> "The battery shall be charged through a 3 phase transformer and silicon rectifier taking power from the motor-alternator set."

> "Voltage Regulation - Battery Output, an inline completely static voltage regulator shall be supplied to control the voltage supplied to the cab signals,..... It shall maintain 64 volts ± 3%."

SYSTEM BLOCK DIAGRAMS

By studying the General Electric and Westinghouse maintenance manuals and the Budd Company engineering drawings, it was possible to develop block diagrams for the secondary power systems of each manufacturer. Simplified block diagrams showing the basic areas within the secondary power system are shown in Figures 1 and 2. These figures provide insight into how the basic secondary power system works, but for a more detailed description of what comprises the different elements see Figures 3 and 4.

Because of Klauder's specifications, both block diagrams are very similar. The basic differences between the two systems, as exemplified in the block diagrams, are as follows:

1. The General Electric system converts 448 V, 25 Hz, single phase power from the secondary tap of the main transformer through a rectifier to 400 Vdc to supply power to the motor of the motor-alternator set. Westinghouse, however, takes 600 V, 25 Hz, single phase power from the secondary winding of their main transformer, and rectifies it to 600 Vdc to power the motor of their motor alternator set. Both General Electric and Westinghouse, however, supply 448 V, 25 Hz, single phase power to the heaters, and 200 V, 25 Hz, single phase power to the water heater. The method used by both manufacturers to produce these different voltages is illustrated in Figure 5.

2. General Electric provides cooling to the main transformer by means of a pyranol pump system which operates on 448 V, 25 Hz, single phase power, while Westinghouse cools its main transformer with a "transformer pump motor", and a "transformer fan motor" both of which operate on 220 V, 60 Hz, 3 phase power.

3. Only the General Electric equipped cars provide food service (galleys).

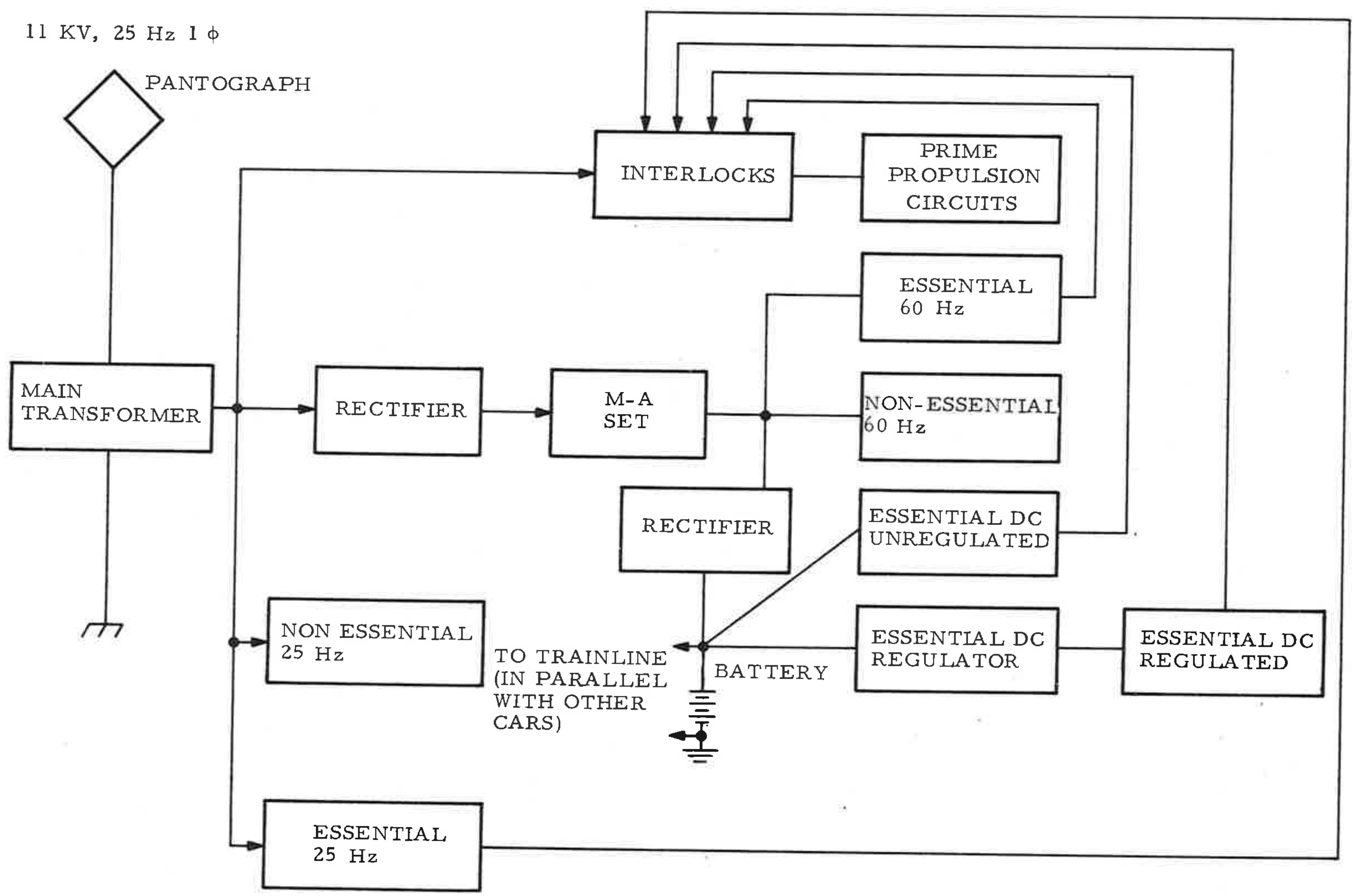


Figure 1. Simplified Block Diagram - Secondary Power System General Electric Design

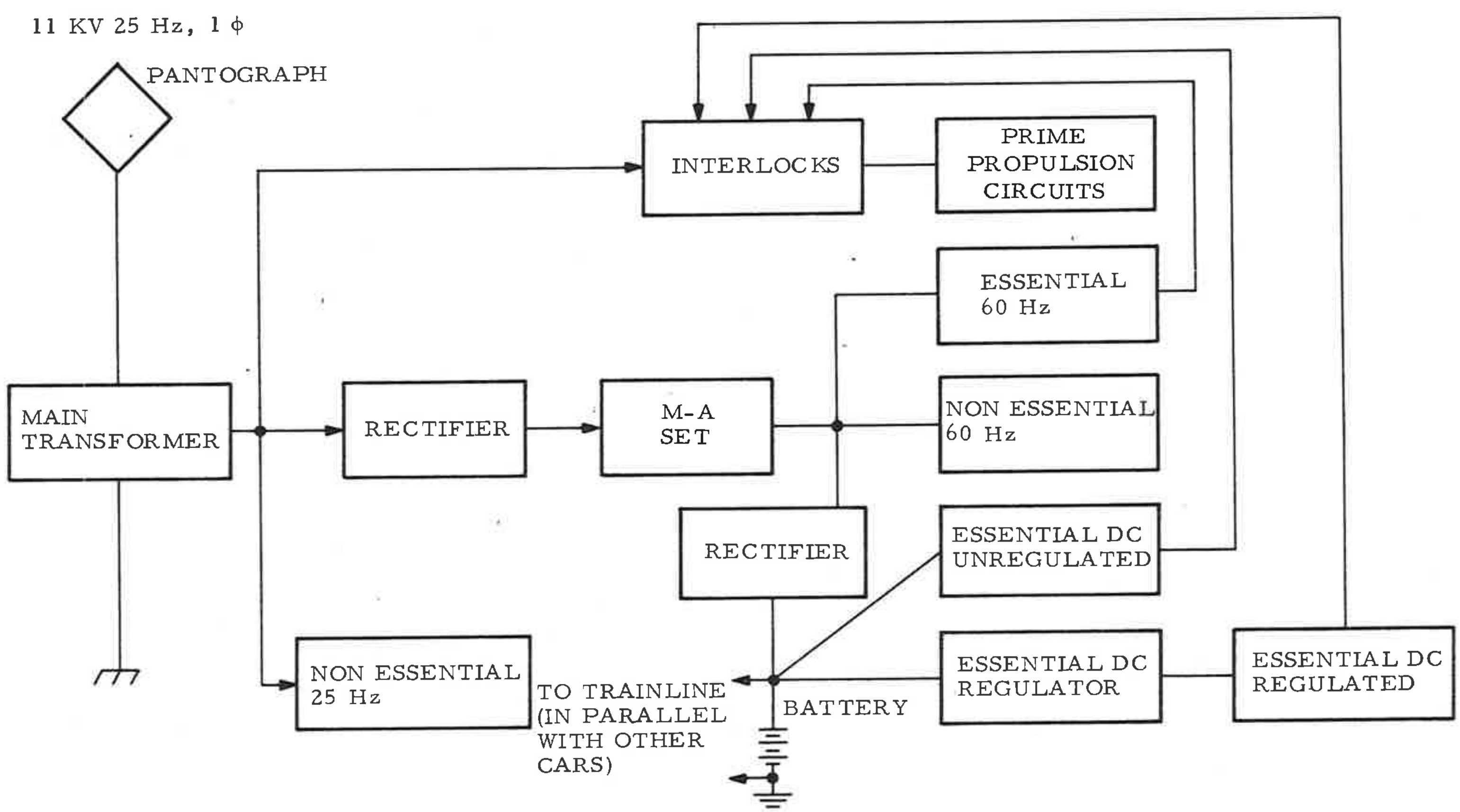
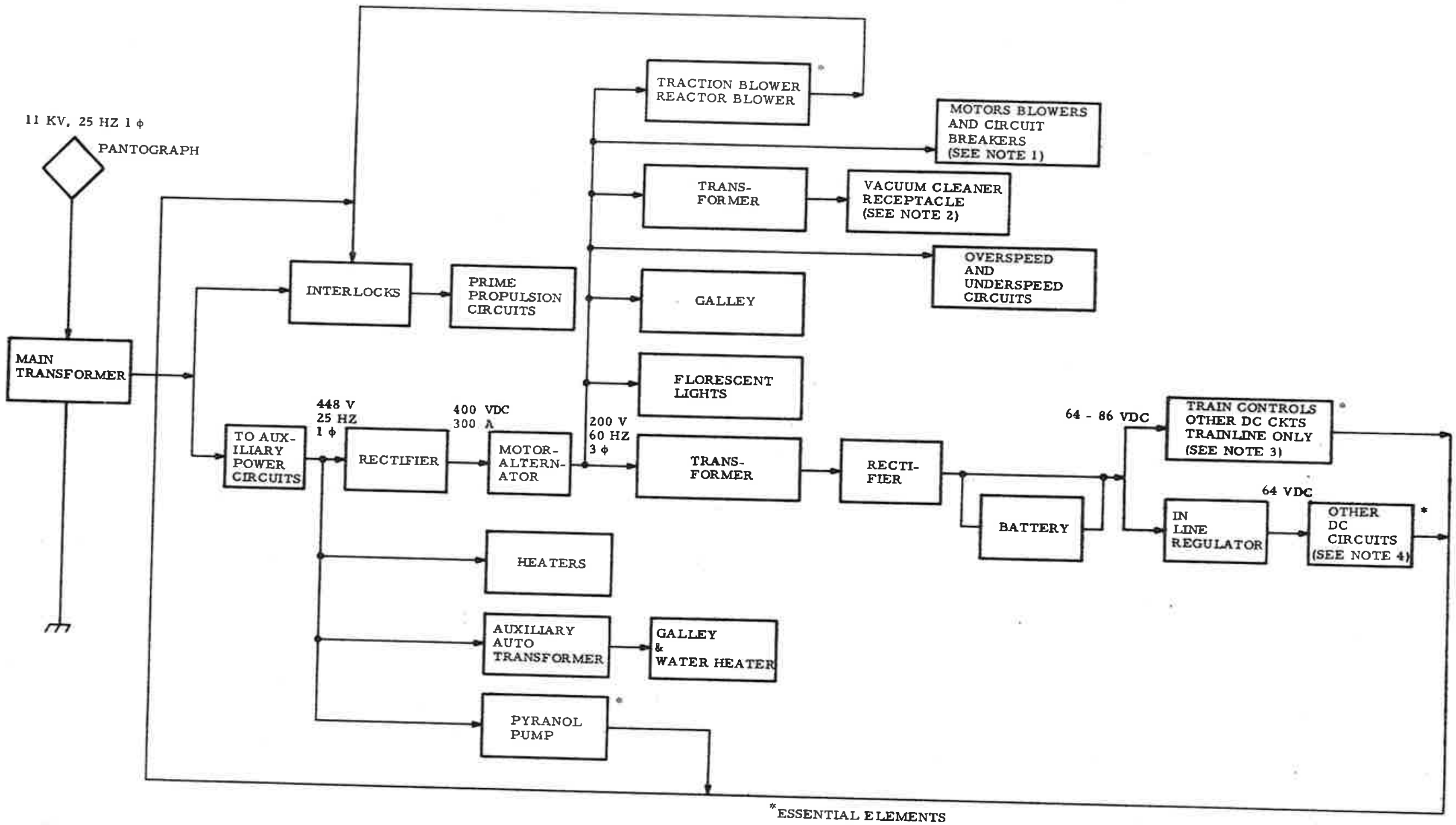


Figure 2. Simplified Block Diagram - Secondary Power System Westinghouse Design



NOTE 1

RESISTOR BLOWER
#1 TRANSFORMER BLOWER
#2 TRANSFORMER BLOWER
#1 BLOWER FAN MOTOR
#2 BLOWER FAN MOTOR
#1 CONDENSER FAN MOTOR
#2 CONDENSER FAN MOTOR
#1 FREON COMPRESSOR MOTOR
#2 FREON COMPRESSOR MOTOR
AIR COMPRESSOR MOTOR

NOTE 2

VACUUM CLEANER RECEPTICLES
CAB HEATER BLOWER
READING LIGHTS
DEFROSTER
LOW CEILING LIGHTS
EXHAUST FANS
ENTRANCE-EXIT LIGHTS
THRESHOLD HEATERS
TOILET LIGHTS
ILLUMINATED SIGNS

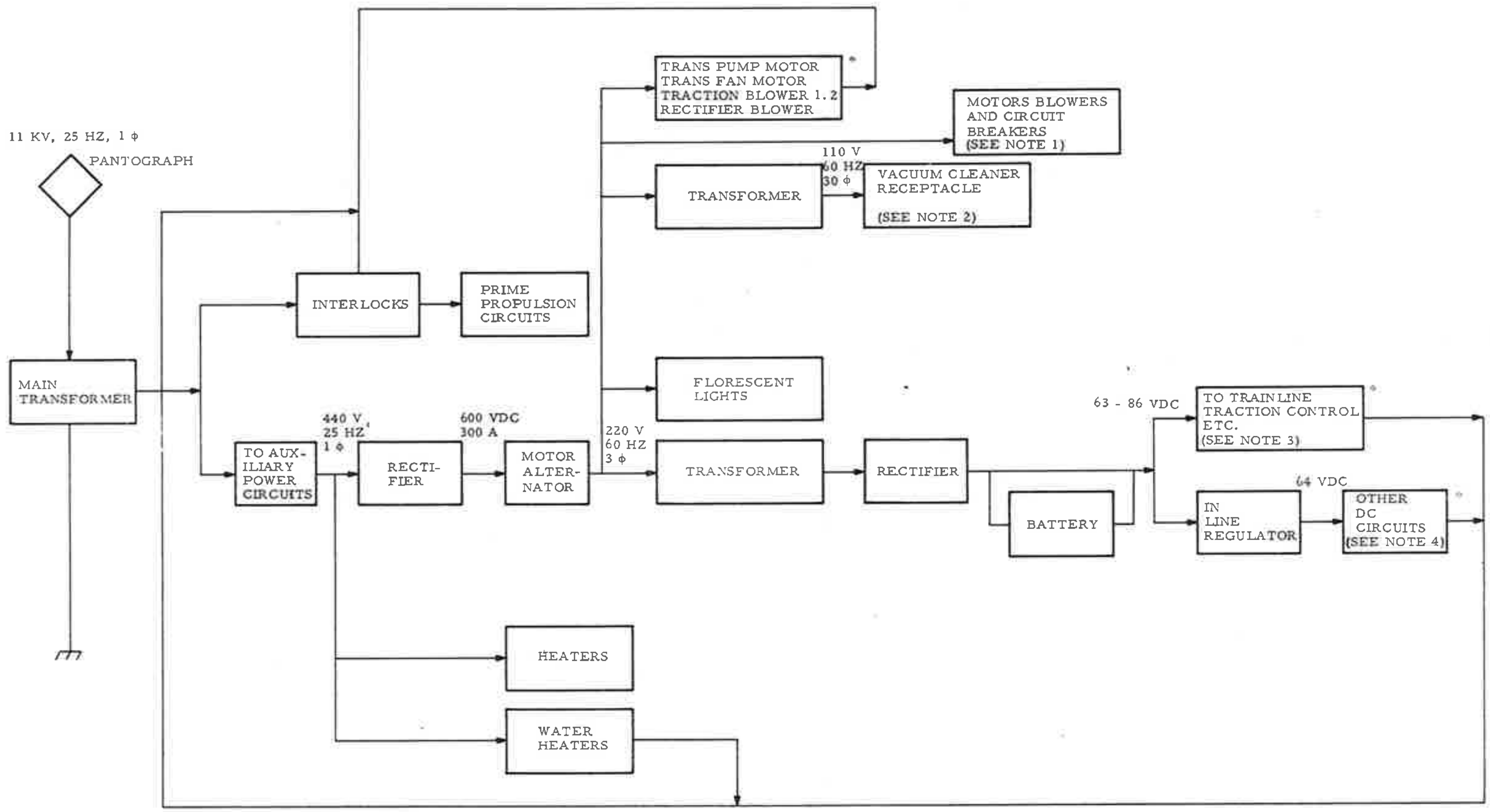
NOTE 3

DRAIN ANTIFREEZE
TELEPHONE
AIRCONDITIONING CONTROL
HEAT CONTROL
DOOR CONTROL
SIGNAL DOOR OPERATION
COUPLER CONTROL
TRACTION CONTROL

NOTE 4

HEADLIGHTS
OSCILLATING HEADLIGHTS
BACK UP AND MARKER LIGHTS
CAR AND SIGN, GAGE LIGHTS
WINDSHIELD WIPERS
VESTIBULE, CAB CEILING,
ELECTRICAL LOCKER LIGHTS
EMERGENCY LIGHTS

Figure 3. Block Diagram - Secondary Power System General Electric Design



NOTE 1

#1 BLOWER FAN MOTOR
#2 BLOWER FAN MOTOR
FREON COMPRESSOR MOTOR
#1 CONDENSER FAN MOTOR
#2 CONDENSER FAN MOTOR
AIR COMPRESSOR
DIAPHRAM MOTOR

NOTE 2

VACUUM CLEANER RECEPTACLES
CAB HEATER BLOWER
READING LIGHTS
DEFROSTER
LOW CEILING LIGHTS
EXHAUST FANS
ENTRANCE-EXIT LIGHTS
THRESHOLD HEATERS
TOILET LIGHTS
ILLUMINATED SIGNS

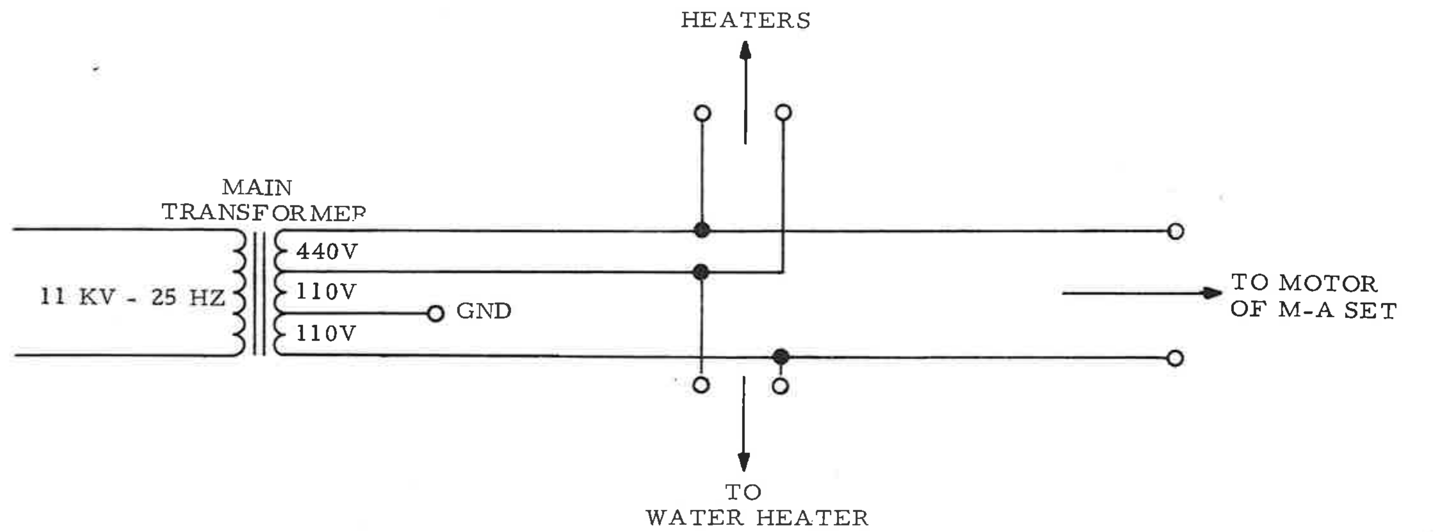
NOTE 3

DRAIN ANTIFREEZE
TELEPHONE
AIRCONDITIONING CONTROL
HEAT CONTROL
DOOR CONTROL
SIGNAL DOOR OPERATION
COUPLER CONTROL
TRACTION CONTROL

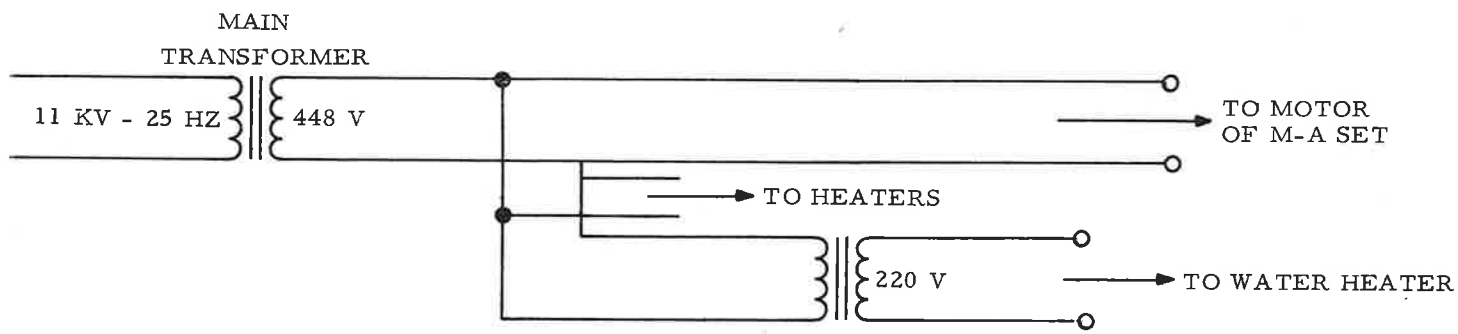
NOTE 4

CAB LIGHTS
EMERGENCY LIGHTS
VESTIBULE LIGHTS
CAB SIGNALS
COMMUNICATIONS
HEADLIGHTS
MARKER LIGHTS

Figure 4. Block Diagram - Secondary Power System - Westinghouse Design



WESTINGHOUSE SYSTEM DESIGN



GENERAL ELECTRIC SYSTEM DESIGN

NOTE: NO ATTEMPT IS MADE TO MAKE THESE DRAWINGS COMPLETE; THEIR SOLE PURPOSE IS TO SHOW THE DIFFERENT METHODS EACH MANUFACTURER USED TO SUPPLY POWER TO THE M-A SET, HEATERS, AND WATER HEATER. ALL OTHER CONNECTIONS ARE PURPOSELY OMITTED.

Figure 5. One of the Differences Between the Two Systems

ESSENTIAL ELEMENTS

There are essential elements that are critical to the operation of the train, they are:

1. The various dc circuits which provide propulsion control,

2. The traction motor-blower set and the reactor motor-blower set,

3. The main transformer cooling device.

General Electric uses a pyranol pump (25 Hz), and Westinghouse uses a pump motor (60 Hz) and a fan motor (60 Hz). These are noted in the block diagrams by an asterisk(*).

These essential elements are connected by interlocks to the prime propulsion circuits. The different blowers are interlocked by means of a probe that is located within the air ducts. If no air is flowing, no power can be supplied to move the vehicle. The other interlocks are implemented similarly, that is by energizing relays. These interlocks are necessary because without them it would be possible to operate the prime movers (traction motors) without cooling or speed control. Operation of the vehicle without these functions could cause equipment failure or risk of injury to the passengers of the vehicle.

LOAD REQUIREMENTS

One item that could not be completely obtained from the available documentation, but is required if any meaningful discussion of possible solutions to the problems that exist is to take place, is a technical description of the individual elements of the secondary power system, both essential and non-essential. It would be impossible for example to propose replacing a certain motor without knowing precisely the ratings (horsepower, rpm, etc.) of this machine. Some of this information was available in the two manufacturers' maintenance manuals, a little more was obtained from the Budd Company's assembly drawings, but the bulk of this information was obtained during a visit to Penn Central's Metroliner repair shops in Wilmington, Delaware. At the Wilmington shops, the data was obtained by actually crawling under the cars with a flashlight and steel wool, and then scraping clean the nameplates on the different motors. This data was then verified by correlating it with some of the preliminary design specifications that were available at the Wilmington shops. As a result of work, it was possible to define the load characteristics of the different elements of the secondary power system.

These load requirements and equipment characteristics as they presently exist in the Metroliner are shown in Figure 6 for the General Electric system, and in Figure 7 for the Westinghouse system. A clear understanding of the relationship of the different loads to the whole secondary power system can be obtained by examining Figures 8 and 9. These figures, one for the General Electric system and the other for the Westinghouse system, show the combined loads for all the individual equipment that comprises each block within the block diagram.

Due to the somewhat stringent specifications that were imposed on the two manufacturers, their secondary power systems are functionally very much the same. As a result of the load definition exercise, this similarity is shown even further, and the problems that have been experienced haven't been exclusive to one manufacturer, but have plagued both. For simplicity in the discussion concerning the various problems and their possible solutions, only one system is used as a demonstration tool. The General Electric secondary power system is chosen for discussion. This choice is made primarily because the General Electric system has everything that the Westinghouse system has, plus the food service requirement. It should be understood, however, that the description of the problems and their possible solutions described for the General Electric secondary power system apply equally as well for the Westinghouse secondary power system.

Load	kw's	
230 Vac, 60 Hz, 3Ø		
ESSENTIAL ELEMENTS		
Traction Blower	13.2	
Reaction Blower	4.7	
Transformer Blowers	0.7	
	18.6	
NONESSENTIAL ELEMENTS		
Air Conditioning Unit		
Blower Fan Motor #1&#2	2.5	
Condenser Fan Motor #1&#2	3.2	
Freon Compressor Motor	22.5	
Air Compressor Motor	7.5	
Galley	5.0	
Fluorescent Lights	5.6	
Vacuum Cleaner Receptacle Block	4.7	Total
Cab Heater Blower	0.09	
Reading Lights	1.1	
Defroster, Threshold Heater	1.4	
Toilet, Low Ceiling Lights	0.5	
Exhaust Fans	1.4	
Illuminated Signs	0.2	
Resistor Blower	1.5	
Water Cooler	0.3	
Total	52.1	
TOTAL 230 Vac LOAD	70.7	
448 Vac, 25 Hz, 1Ø		
ESSENTIAL ELEMENTS		
Pyranol Pump	2.24	
NONESSENTIAL ELEMENTS		
Heaters	62.2	
Galley	20.0	
Total	82.2	
TOTAL 448 Vac LOAD	84.4	
64 Vdc, UNREGULATED		
ESSENTIAL ELEMENTS		
Drain Antifreeze	0.54	
NONESSENTIAL ELEMENTS		
Telephone	0.64	
TOTAL UNREGULATED LOAD	1.18	

Figure 6. General Electric Load Definition.

64 Vdc, REGULATED	kw's
ESSENTIAL ELEMENTS	
Headlights	0.5
Oscillating Headlights	0.9
Backup and Marker Lights	0.3
Car # Sign, Gage Lights, WW	0.5
Vestibule, Cab Ceiling, Elec. Lock.	0.3
Emergency Lights	0.3
TOTAL REGULATED LOAD	2.8

Figure 6. General Electric Load Definition (Continued).

	kw's	
230 Vac, 60 Hz, 3Ø		
ESSENTIAL ELEMENTS		
#1 Blower Motor (Rectifier)	11.2	
#2 Blower Motor (Traction)	7.5	
#3 Blower Motor (Traction)	7.5	
Transformer Fan Motor	1.1	
Transformer Pump Motor	3.0	
TOTAL	30.3	
NONESSENTIAL ELEMENTS		
Air Conditioning Unit		
Blower Fan Motor #1&#2	2.5	
Condenser Fan Motor #1&#2	3.2	
Freon Compressor Motor	22.5	
Air Compressor Motor	7.5	
Florescent Lights	5.6	
Vacuum Cleaner Receptacle	4.9	Total
Cab Heater Blower	0.1	
Reading Lights	1.3	
Defroster, Threshold Heater	1.4	
Toilet, Low Ceiling Lights	0.5	
Exhause Fans	1.4	
Illuminated Signs	0.2	
Resistor Blower	1.5	
Water Cooler	0.3	
TOTAL	52.9	
TOTAL 230 Vac LOAD	82.2	
448 Vac, 25 Hz, 1Ø		
NONESSENTIAL ELEMENTS		
Heaters	62.2	
64 Vdc, UNREGULATED		
ESSENTIAL ELEMENTS		
Drain Antifreeze	0.4	
64 Vdc, REGULATED		
ESSENTIAL ELEMENTS		
Headlights	0.5	
Oscillating Headlights	0.9	
Backup and Marker Lights	0.5	
Car # Sign, Gage Lights, WW	0.5	
Vestibule, Cab Ceiling, Elec., Lock.	0.3	
Emergency Lights	0.3	
TOTAL	3.0	

Figure 7. Westinghouse Load Definition.

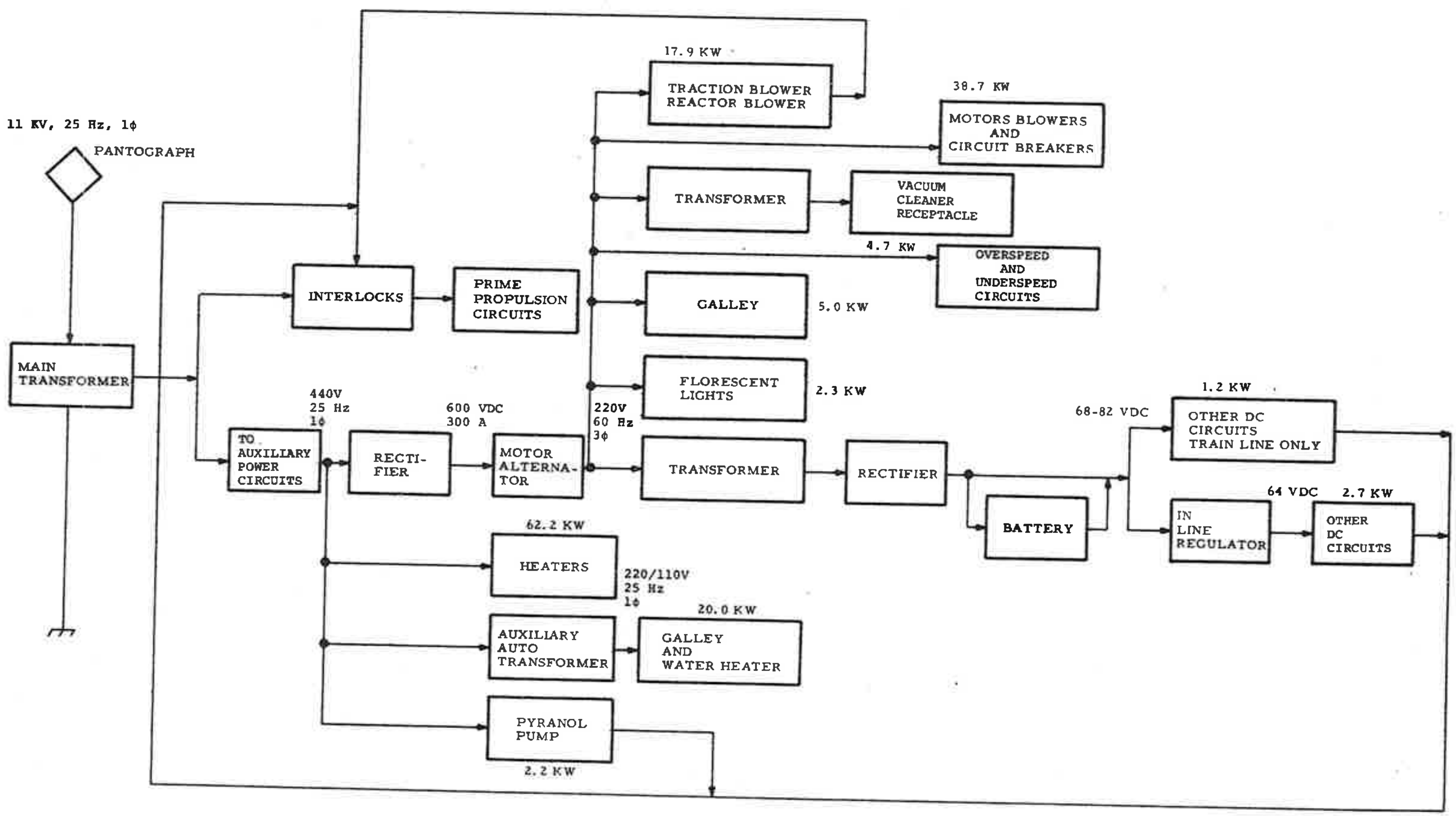


Figure 8. Block Diagram - Secondary Power System Load Factors General Electric Design

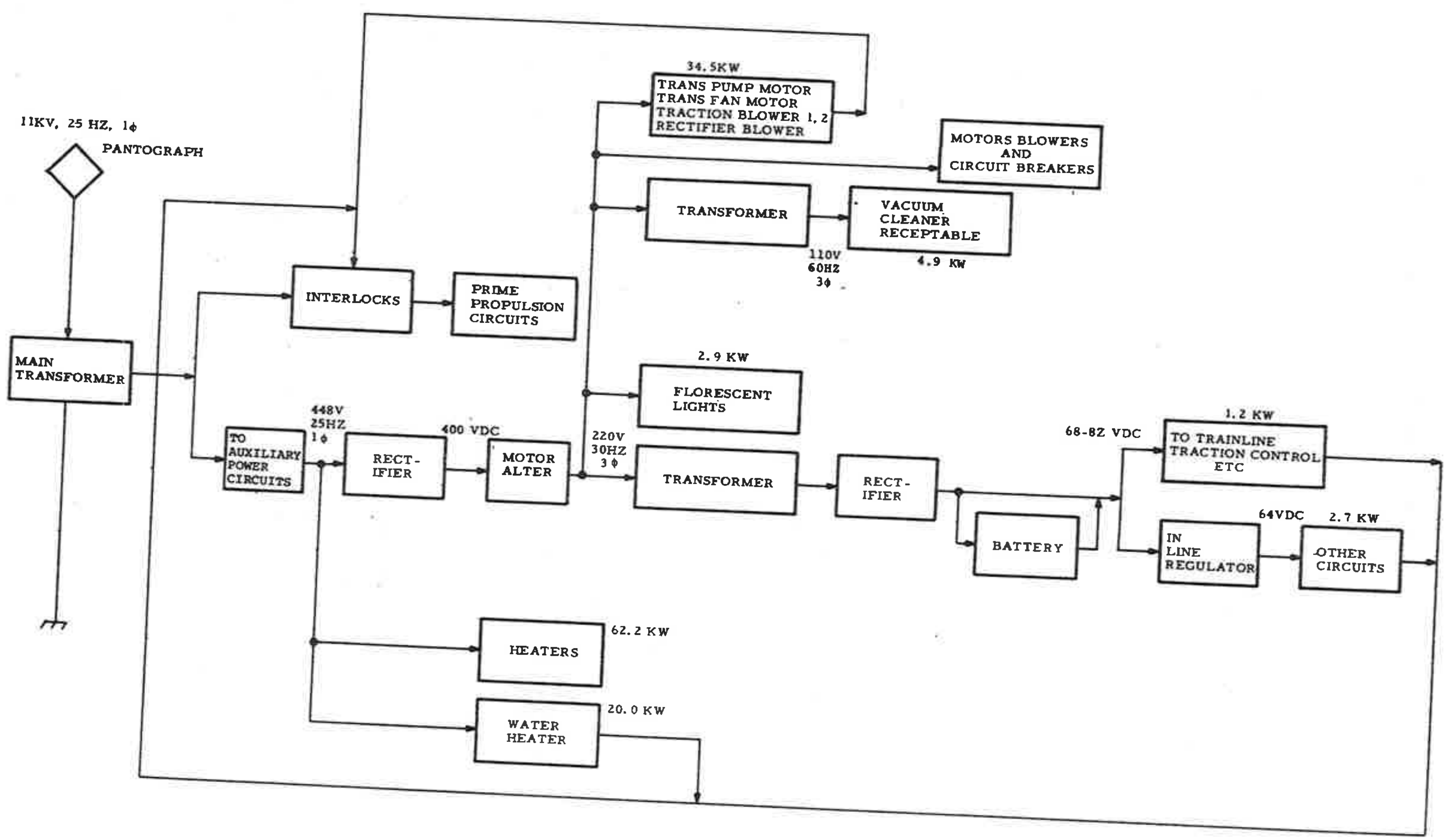


Figure 9. Block Diagram - Secondary Power System Load Factors Westinghouse Design

PROBLEM AREAS

FAILURE DATA

Analysis of the available failure data (Appendix A) has shown that there are two major areas of concern in the secondary power system; the motor-alternator set and the emergency power system (the batteries).

THE MOTOR-ALTERNATOR SET

If it is assumed that a critical train failure means failure of the propulsion system, one basic criterion should be that no failure of nonessential elements of the system should impair the propulsion, braking, or control systems of the train. A car should be able to suffer complete failure of the motor-alternator system and still be able to pull its weight to complete a scheduled run, even if without normal lights, heat, air conditioning, food service or any other of the amenities of the Metroliner service. This would at least insure preservation of the propulsion motors, associated equipment, and the safety if not the comfort of the passengers.

Using this one criterion as a guide, the present secondary power system is not adequate. Because of the many interlocks, a complete or even partial failure of the motor-alternator set simply turns off the propulsion power to the car, taking it out of service in a moving train, and therefore raising the possibility of overloading the propulsion systems of the other cars in the train. In addition, individual failures, if any, in any of the essential elements that interlock with the prime propulsion circuits would also turn off the prime power. This type of failure is indistinguishable from a motor-alternator failure. Thus, a straightforward and simple diagnosis of the problem is difficult if not impossible, and leads to much additional time in fault diagnosis and repair.

At the Wilmington, Delaware shops, the Penn Central repair facility for the Metroliner, there are no attempts made to determine why an individual component failed or what part of a component failed, it is just replaced with a new one and the damaged unit is sent to some other area of the repair shops to be fixed. It is repaired and added to the stockpile of equipment, ready to be used again. The problem is that this repair cycle is an open loop; no record of why the component failed is kept. Therefore, the actual cause of failure of a component, such as the motor-alternator, is unknown. All that is known is that the motor-alternator sets have been failing and the failures result in train inoperability.

THE EMERGENCY POWER SYSTEM

The purpose of the battery in the system is to provide emergency power to specific loads in the event of power loss or equipment failure. The batteries for each car are all connected in parallel through the trainline. That is, the unregulated 64 Vdc nominal bus for each car is interconnected through a 0.1 ohm current limiting resistor to all the other cars in the train. A rough schematic showing this configuration is presented in Figure 10. With this arrangement all the batteries are connected in parallel, there is no isolation between the cars. Therefore if power is lost to one of the cars, power for the emergency loads will not only be drawn from its own battery but also from the unregulated supply of all the other five cars in the train. This would then extend the period over which the batteries would be effective.

Exide, Power Systems (the battery supplier), quotes this configuration as resulting in a 36 hour charge rate. On alternate nights the trains are cleaned and checked. When this is done, the pantograph is lowered and as a result, power for these functions is drawn from the battery. More often than not the lights remain on throughout the night, and continually drain the battery. Also since the pantograph is lowered during the night, the battery can only be charged during the daytime when the train is in operation. This duration is only about twelve hours, resulting in only partially charging the battery. As a result of this schedule and the 36 hour charge rate, the batteries are never completely charged. Hence, their ability to perform their prescribed function when an emergency arises can often be marginal.

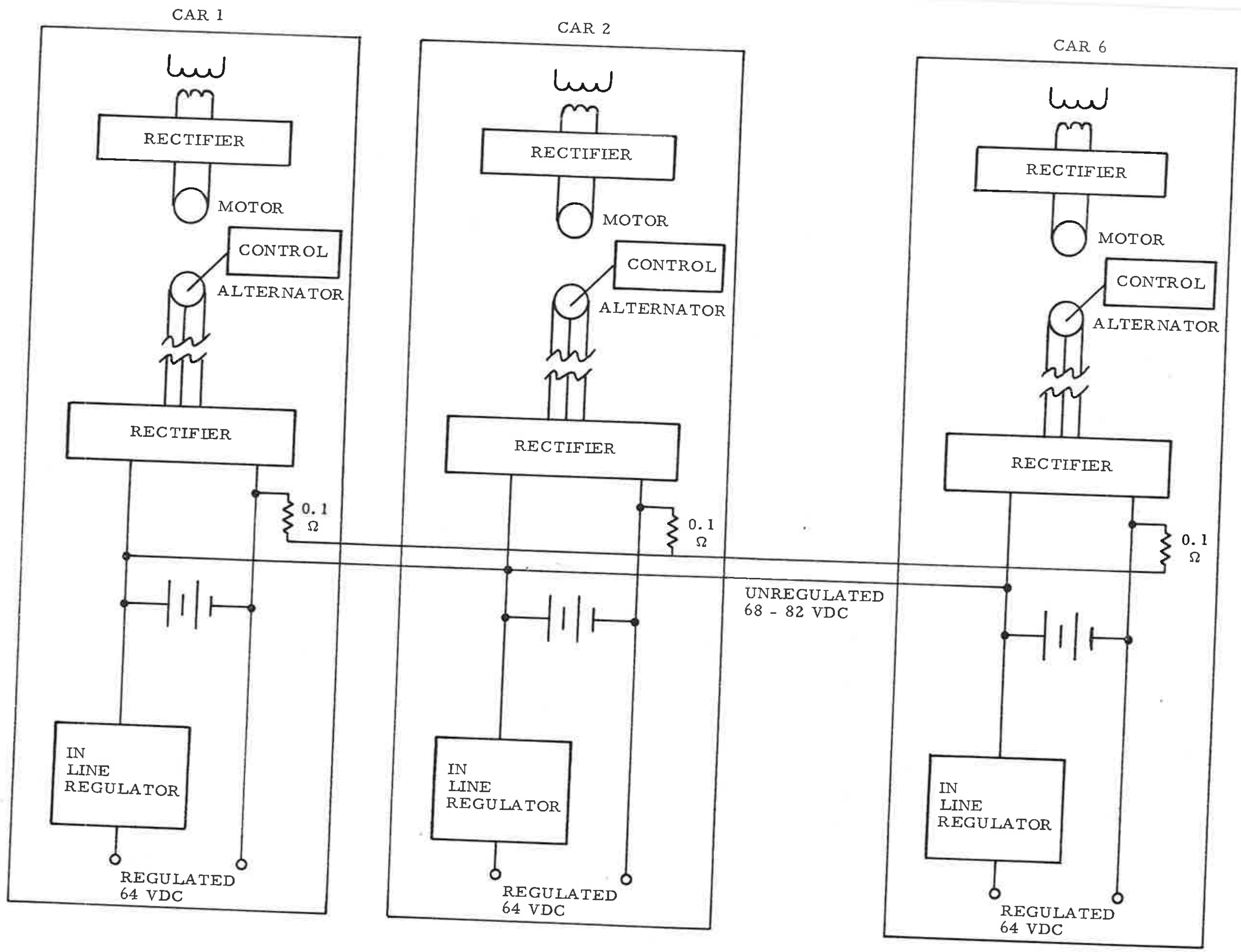


Figure 10. Present System - Unregulated dc Voltage Trainlined

Another cause of battery problems is improper watering. The normal battery watering schedule does not consider these nightly raids on the battery power. Therefore, even assuming that the batteries are watered as prescribed, they aren't watered enough. This improper watering has resulted in some battery failures.

There has also been a series of battery fires. One cause of these fires has been attributed to the poor watering. When a battery isn't watered, it will generate heat and could eventually ignite. Another possible cause of battery fires is overcharging. This too can generate internal heat and ultimately cause ignition.

Because the battery is never completely charged, it cannot supply the required emergency power when the need for it arises. The question now is: if the battery were completely charged, would it then be capable of performing its prescribed emergency function? According to Exide, the battery supplier, the Metroliner uses 50 B6H battery cells. These cells when completely charged are each capable of providing 1.4 volts. With 50 cells this amounts to 70 volts.

If a worst case condition is assumed, when the lead car experiences a failure, the following loads are the bare minimum that must be maintained by the battery:

emergency lights

oscillating headlights

headlights

traction control

communications

drain antifreeze

These minimum emergency loads would constitute an approximate 50 ampere drain on the battery.

Exide performed a series of tests to determine just how well the battery could perform its function. In one case during the month of May, the battery was charged to capacity at the

Exide facility in Valley Forge, Pennsylvania, and then put on the train. Power was disconnected and the emergency loads were turned on. With a completely charged battery, the starting voltage was 1.18 volts per cell; in less than one hour the battery voltage had dropped to 1 volt per cell. In another test in the Exide laboratory, a battery was completely charged and a load equivalent to the Metroliner's emergency load was connected to the battery terminals. In 70 minutes the battery voltage had dropped to 1 volt per cell. No ambient temperatures were given for either of these tests.

The curve in Figure 11 shows the general characteristics for a nickel-iron battery. According to Exide, this relationship varies only slightly for different types of cells. It was impossible to get data that was any more specific than this. The curve is for a battery with a 100 amp-hour capacity at an 8-hour discharge rate. The batteries that the Metroliner uses are rated at 127 amp-hours at an 8-hour discharge rate, a little higher capacity. According to the curve, the battery is capable of providing 50 amps for one hour. Extrapolating a little higher for the Metroliner's batteries, they should be able to supply 50 amps for a little longer than one hour. This extremely rough interpolation seems to fall in line with the testing that Exide did with a battery in their laboratory. It lasted 70 minutes with a 50 amp load.

The 1 volt per cell (50 cells therefore 50 volts) is important because the traction control, which is a function of the lead car will be lost when the dc potential drops below 50 volts. With traction control lost the car automatically goes into emergency stop condition. Failures of this type have indeed occurred on the lead cars, with this predicted result. The problems discussed leave a question to be resolved. If the nickel-iron battery were completely charged, would it be sufficient or should another type of battery be used? This question is discussed in the next section which considers alternative solutions to the problems.

The previous discussion and data was for an ambient temperature of 77°F. What happens when the temperature drops? While this question seems to be academic because the ambient temperature within the battery box, although not heated, remains

EXTRACTED FROM: "THE NICKEL-IRON INDUSTRIAL STORAGE BATTERY - ITS FUNDAMENTAL PRINCIPLES, OPERATION AND CARE"
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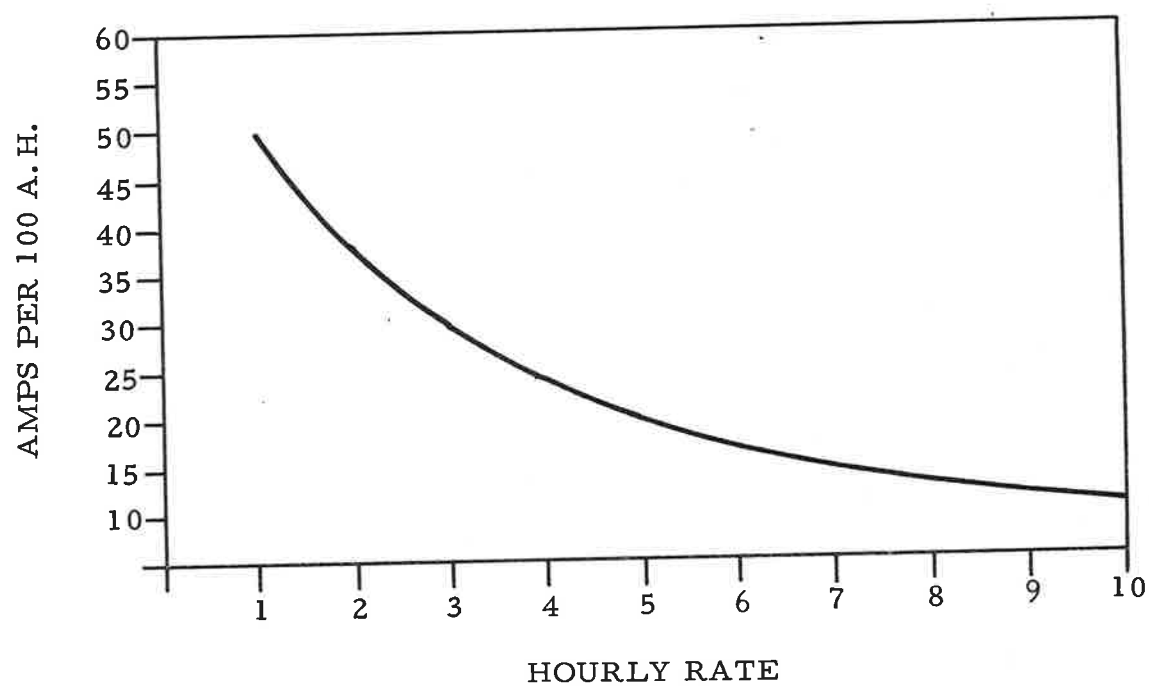


Figure 11. Capacity-Rate Curves to a Final Voltage of 1.0 Volt Per Cell at $77^{\circ}F$

relatively high, it is of interest to review the low temperature characteristics of the battery. A test was made during the wintertime when the outside temperature was below freezing (approximately 25°F) and the temperature within the battery compartment was well over 70°F (approximately 75°F). Figure 12 shows the effect of temperature on the output capacity of a nickel-iron battery. The curves are for a one-hour rate of discharge and a three-hour rate of discharge to coincide with the one-hour travelling time between two stops and the three-hour travelling time to the end of a complete run. The present battery is capable of providing the required 50-amps for one hour at room temperature, but as the temperature drops, its capacity to provide any power at all drops significantly. According to Figure 12, the battery will essentially be dead at any of the low temperatures that would be experienced during the wintertime. Therefore, although a completely charged battery is capable of supplying the required emergency power at 77° ambient, it is completely ineffective at lower temperatures.

The specific battery that is in use was not chosen by either General Electric or Westinghouse but was specified for use by Penn Central. It is probably for this reason that neither company has emphasized the possibility of an improper choice of battery as a problem. However, Penn Central is acutely aware of this and is presently looking into the possibilities of changing the battery.

EXTRACTED FROM: THE NICHEL-IRON INDUSTRIAL STORAGE BATTERY - ITS FUNDAMENTAL PRINCIPLES, OPERATION AND CARE, EXIDE INDUSTRIAL MARKETING DIVISION P. 11

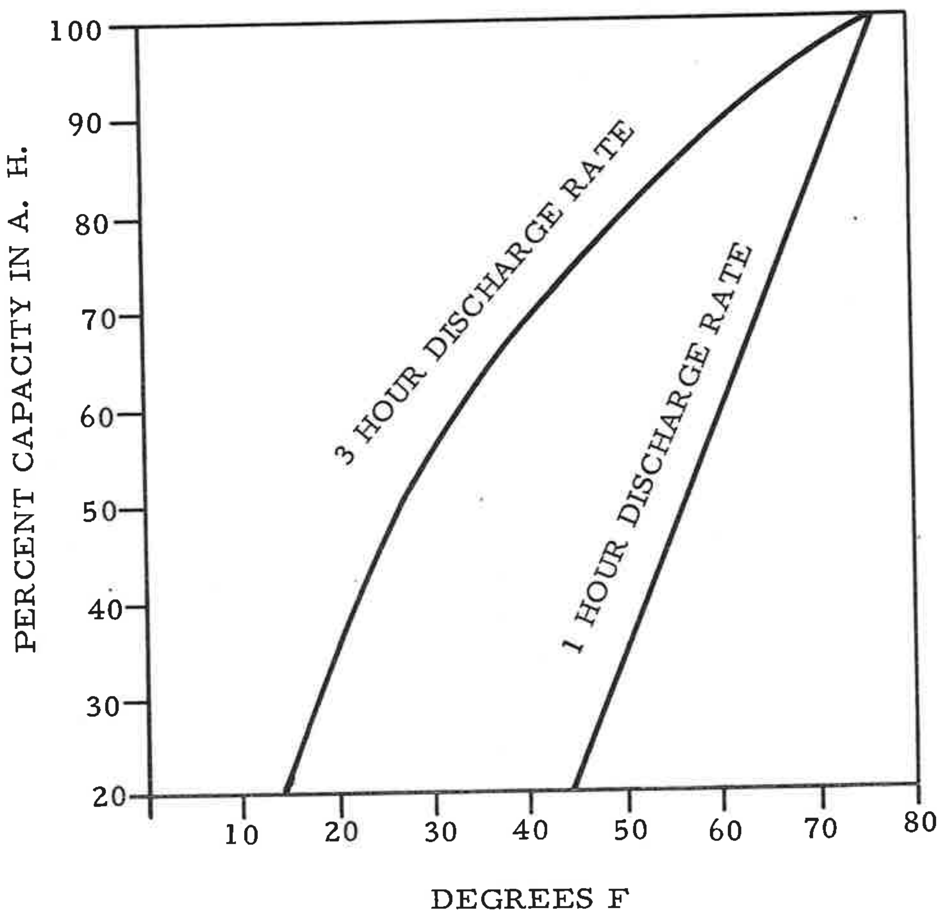


Figure 12. Effect of Temperature on Capacity at Various Rates of Discharge

POSSIBLE SOLUTIONS

As a result of classifying the loads which comprise the secondary power system as essential and nonessential, it seems logical that the secondary power system be segmented into two distinct areas, namely the essential and the nonessential areas. Because of the interlocking system of the essential elements it is desirable that these two areas of the secondary power system be electrically independent to the greatest extent possible. This idea is shown pictorially in the simplified block diagram of Figure 13.

There are a number of possible solutions to the problems that are outlined in the previous section. These possible solutions are discussed below. Briefly they are:

1. Install a battery charger.

2. Supply power to the essential dc circuits with a dc to dc converter.

3. Supply power to the essential dc circuits with an ac to dc converter.

INSTALL A BATTERY CHARGER

Since one of the problems with the emergency power system is insufficient charging of the batteries, one obvious solution is to provide some way to insure that the batteries will be completely charged. This could be accomplished by inserting a battery charging circuit in line before the battery, as exemplified in Figure 14.

An exhaustive search was made in an attempt to find a battery charger, presently available, that would do the job; it was futile. Apparently there is nothing presently available that can be applied to this application. However, Exide, Engineered Magnetics, and General Electric are investigating different types of battery charging techniques for this particular application. A preliminary rough sketch of the Engineered Magnetics version of this battery charger is shown in Figure 15. This diagram shows how it would be tied into the to be proposed ac-dc converter. Although this is the preferred approach, it could

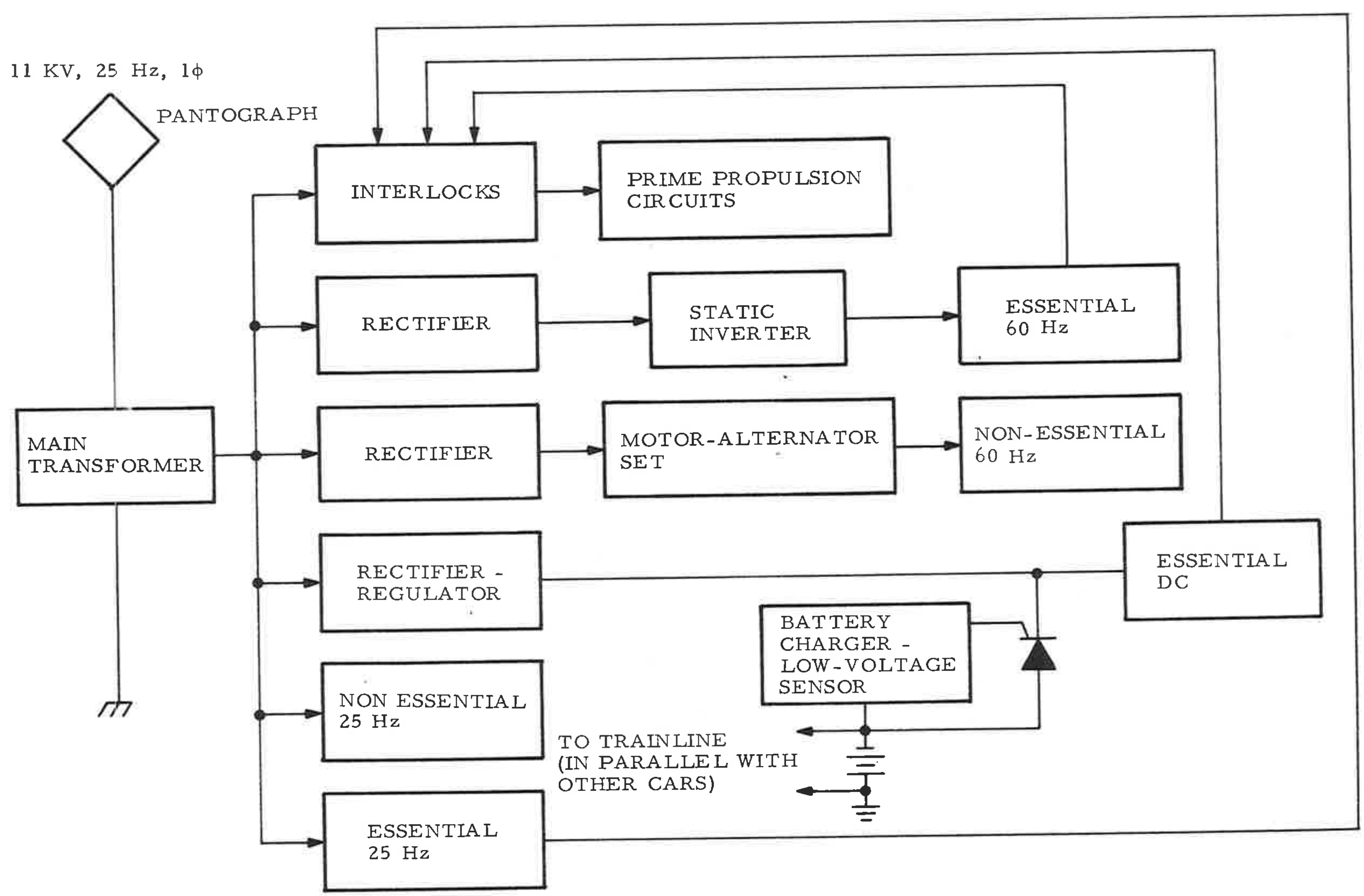


Figure 13. Simplified Block Diagram - Showing Segmented Secondary Power System

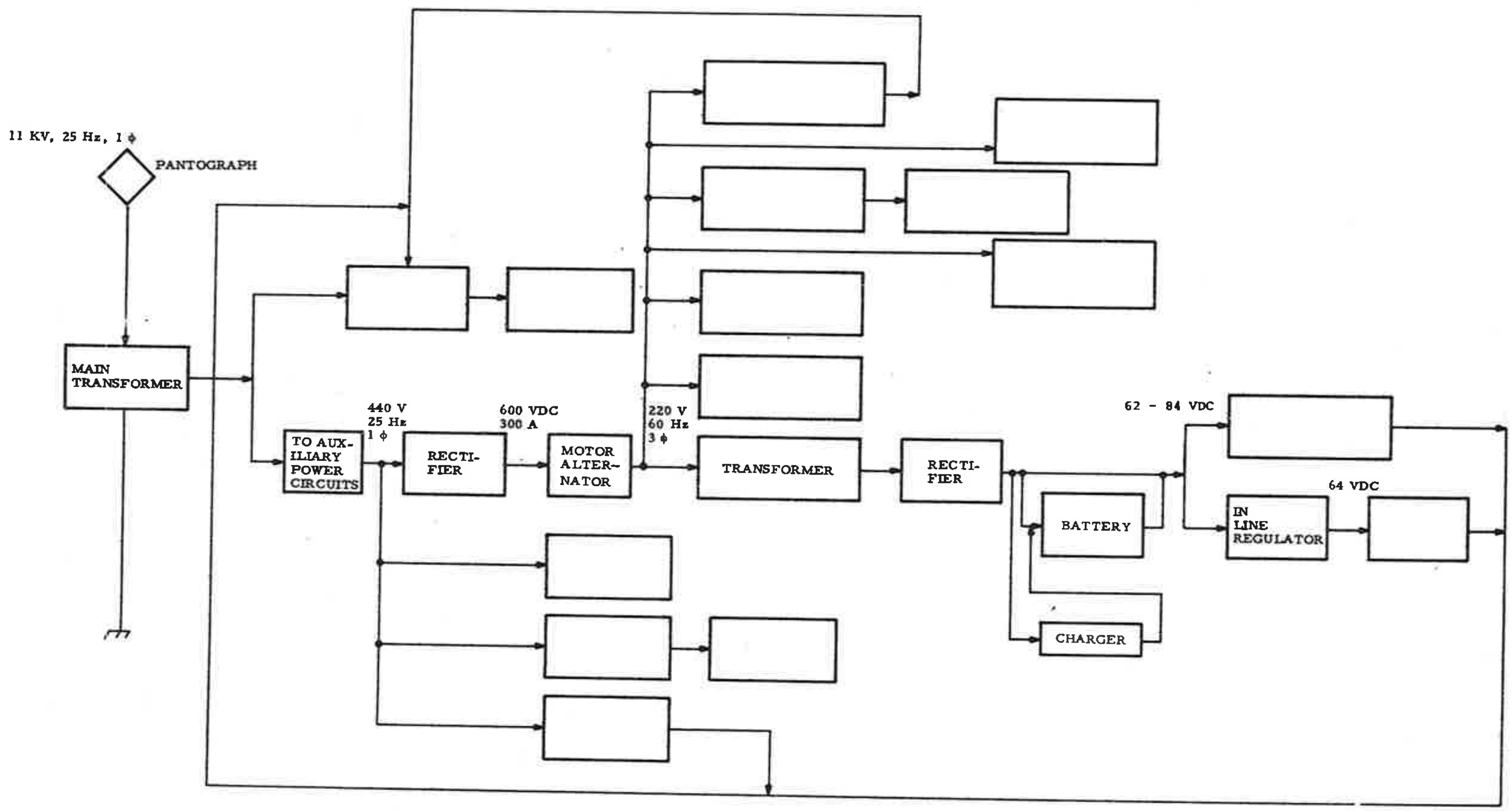
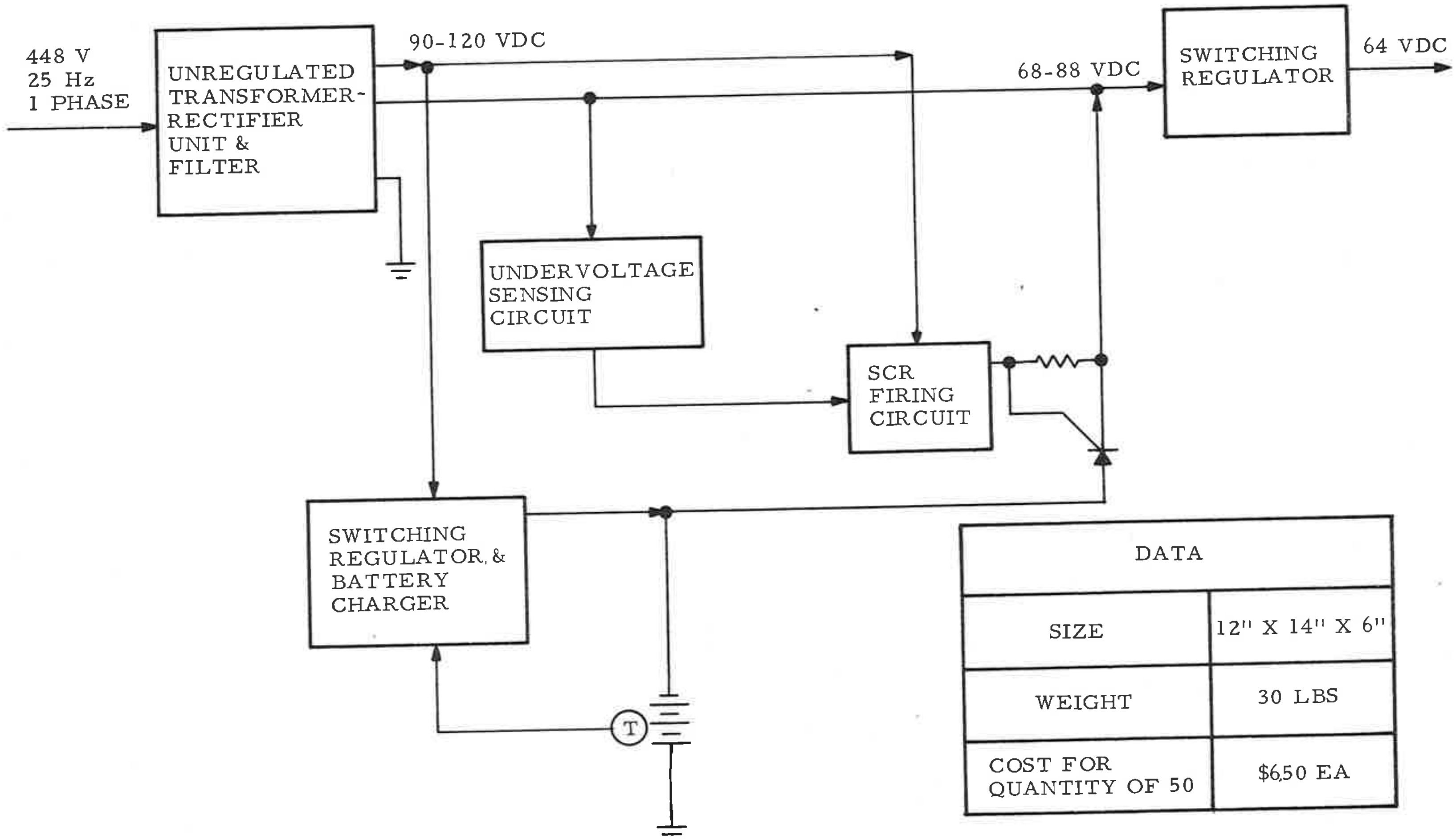


Figure 14. Battery Charger to the Battery



DATA	
SIZE	12" X 14" X 6"
WEIGHT	30 LBS
COST FOR QUANTITY OF 50	$650 EA

Figure 15. An Example of a Battery Charger

also be tied into the present system, in front of the battery with no difficulty. This technique uses a 20 ampere constant current level to charge the battery. A voltage monitor will be an integral part of the charger to insure that the battery is not overcharged. The SCR and its associated firing circuit, and undervoltage sensing circuit will insure that the battery will be in-line only during emergency conditions, thereby insuring proper charging. There would be absolutely no problem physically implementing and installing this unit. It would only require about 1/2 square foot of surface area under the car, and it would only weigh about 30 pounds.

This is indeed an attractive solution to the battery charging problem. When the final results of these previously mentioned investigations into battery charges are made available, they should be seriously considered for implementation into the Metroliners' secondary power system. Appendix E is a compilation of the battery charger data that has been compiled during this study.

INSTALL A DC TO DC CONVERTER

One method of eliminating the dependency of the dc circuits on the motor-alternator set is to convert the 300 volt dc output of the main rectifier group to 64 volts dc. A block diagram showing how this would be implemented is outlined in Figure 16. Although this method is a conceivable solution to the problem, the dc to dc conversion requires somewhat complex, involved electronics circuitry; a much simpler conversion is to convert ac to dc.

INSTALL AN AC TO DC CONVERTER

Figure 17 describes a third, more preferred, method of providing 64 volts dc to the essential control circuit, by circumventing the motor-alternator set. This scheme, an ac to dc converter, would convert the 448 V, 25 Hz, single phase output of the main transformer to the required 64 volts dc. One method of providing this conversion is outlined in Figure 18. It would consist of basically two units: a transformer-rectifier unit to convert the 448 V, 25 Hz input to a dc level, and a switching regulator to provide the required 64 Vdc ± 1 V.

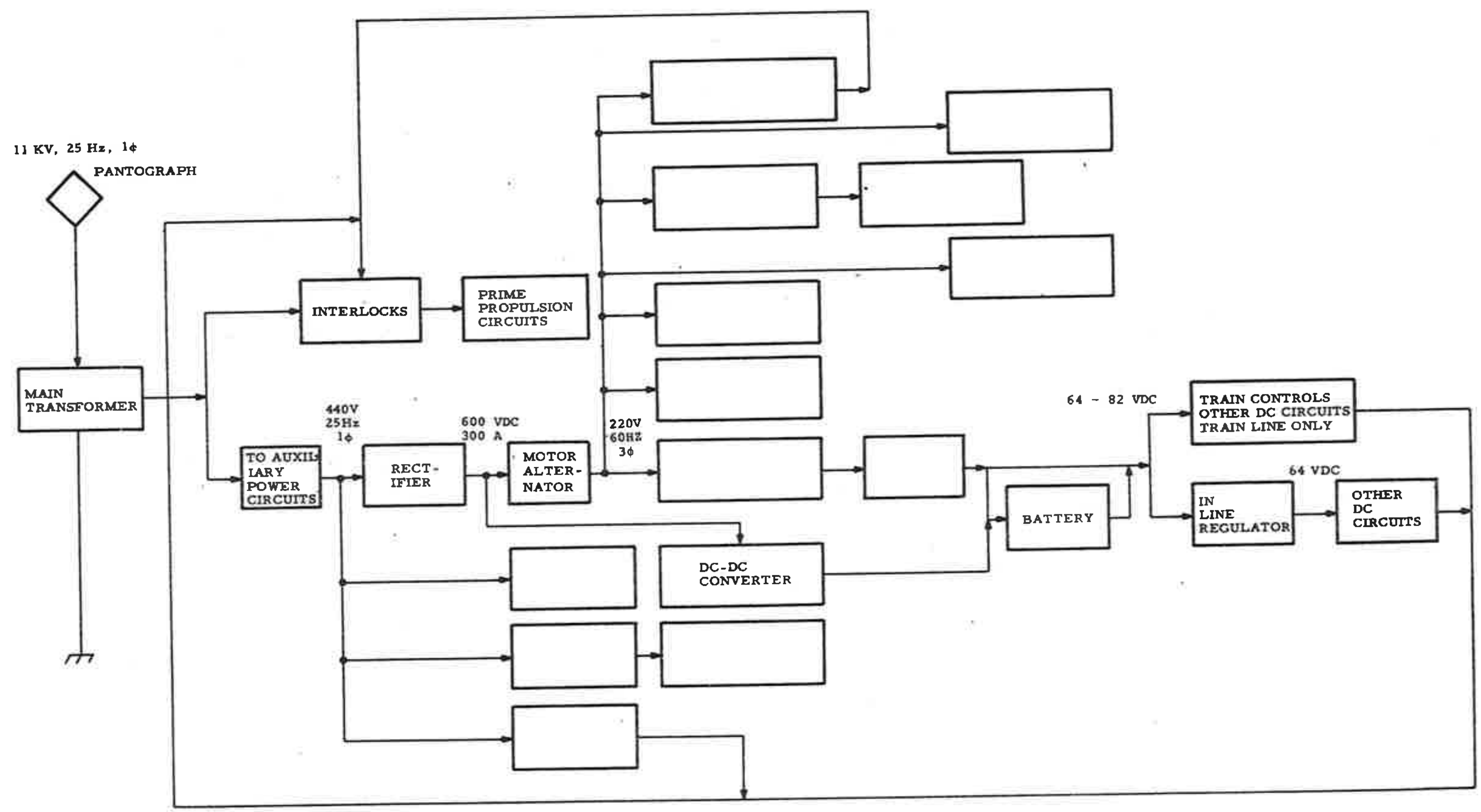


Figure 16. dc to dc Converter to Provide 64 Vdc to Essential Controls

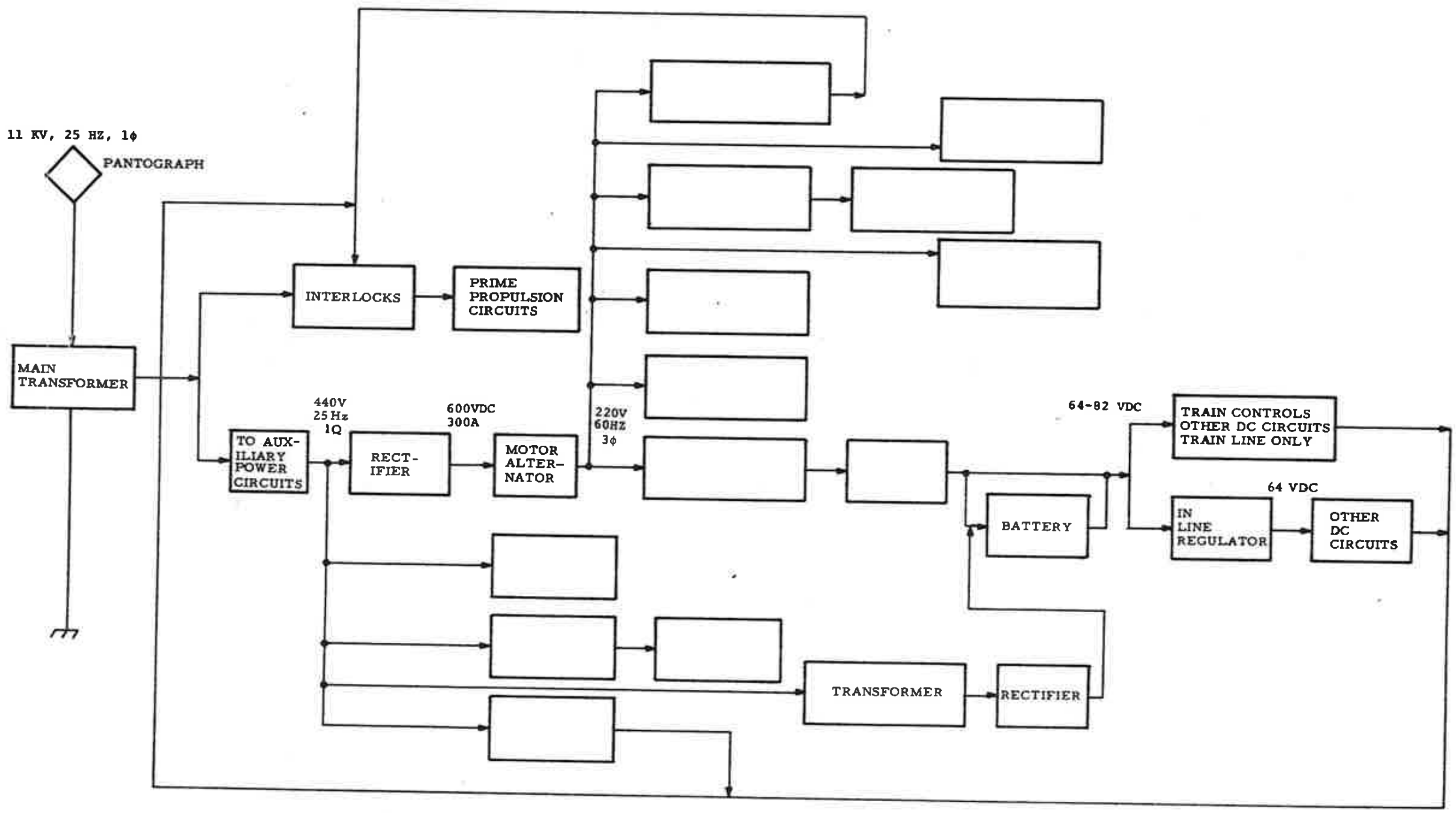


Figure 17. ac to dc Converter to Provide 64 Vdc to Essential Controls

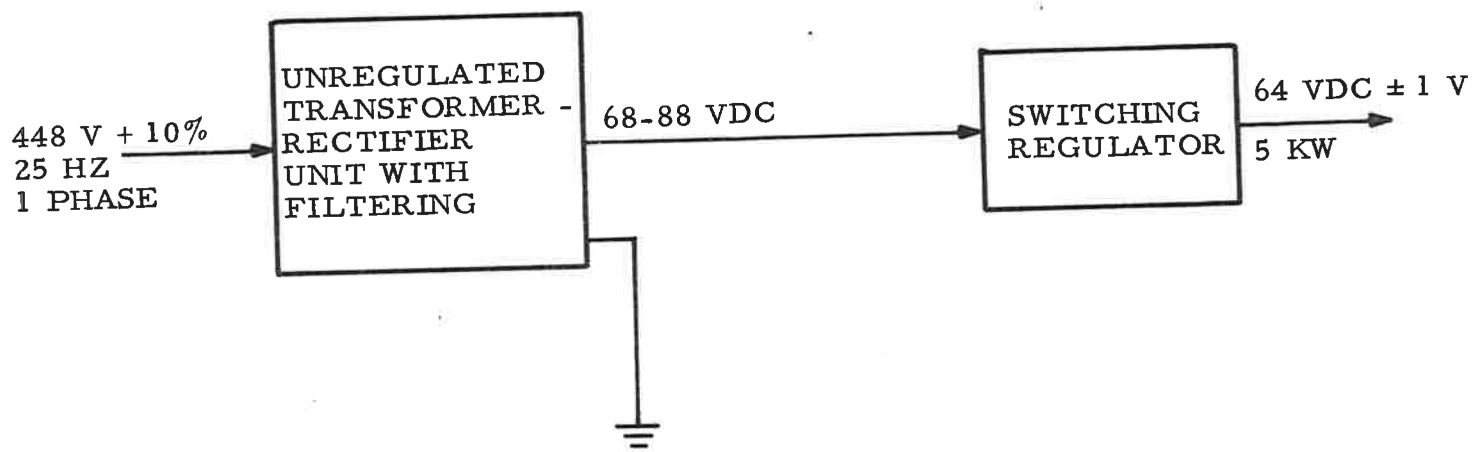


Figure 18. A Possible Approach to ac-dc Conversion

This unit could now provide power to all of the dc circuits. This converter would be capable of providing steady state and dynamic voltage regulation for fluctuations in the 448 Vac input, and step changes in the output loading. With the switching regulator in place there would no longer be any need for the inline regulator.

The Engineered Magnetic Division of Gulton Industries has been able to derive some rough estimates for these two units. This data is shown in Figure 19. From these estimates it appears that there would be no problem of physically implementing this scheme. The total surface area, under the car, that would be required by both units would be less than 4 1/2 square feet, and their combined weight would only be approximately 450 pounds. With these initial rough estimates it seems that this alternative would be a very worthwhile improvement to the secondary power system of the Metroliner.

	Transformer-Rectifier Unit	Switching Regulator
Output power	7.5 kW	5 kW
Size	20"x20"x24"	10"x10"x10"
Weight	350 lbs.	100 lbs.
Cost for Quantities of 50	$2,500	$1,000

Figure 19. Rough Estimates for ac-dc Converter

OTHER AUXILIARY SYSTEM STUDIES

Along with the possible solutions of the previous section, a number of other alternatives to the problems of the Metroliner car have been investigated. Although these other areas that were investigated do not constitute firm recommended changes to the present Metroliner system, they must however be considered for any new systems, and therefore must be mentioned here. Briefly they are:

1. Replace the 60 Hz motors with dc motors.
2. Replace the 60 Hz motors with 25 Hz motors.
3. Replace the motor-alternator set with a static inverter.
4. Proper battery selection.

Due to the problems that have been experienced with the motor-alternator set, one possible solution is to eliminate the dependency of the essential elements on the motor-alternator set. No element of the cars electrical system powered by the present motor-alternator set should in any way be interlocked with propulsion, braking or control. This means that every essential element must be powered directly from the main power source in the car, the main transformer, but by bypassing the motor-alternator set. This would mean a considerable shifting around of the accessory, cooling, emergency, and control circuits.

The motor-alternator set would remain to supply power to the nonessential elements, but essential elements would be replaced by either dc machines or 25 Hz machines. The 64 Vdc required for the controls could be supplied by either an ac to dc converter or a dc to dc converter, as already proposed in the previous section.

REPLACE MOTORS WITH DC MOTORS

One method of eliminating the dependency of the essential motors on the sporadic performance of the motor-alternator set is to replace them with equivalent dc machines. Figure 20 outlines the change in the block diagram that would result from this substitution. All the motors, both essential and nonessential, rotate at approximately 1800 rpm. Figure 21 is a listing

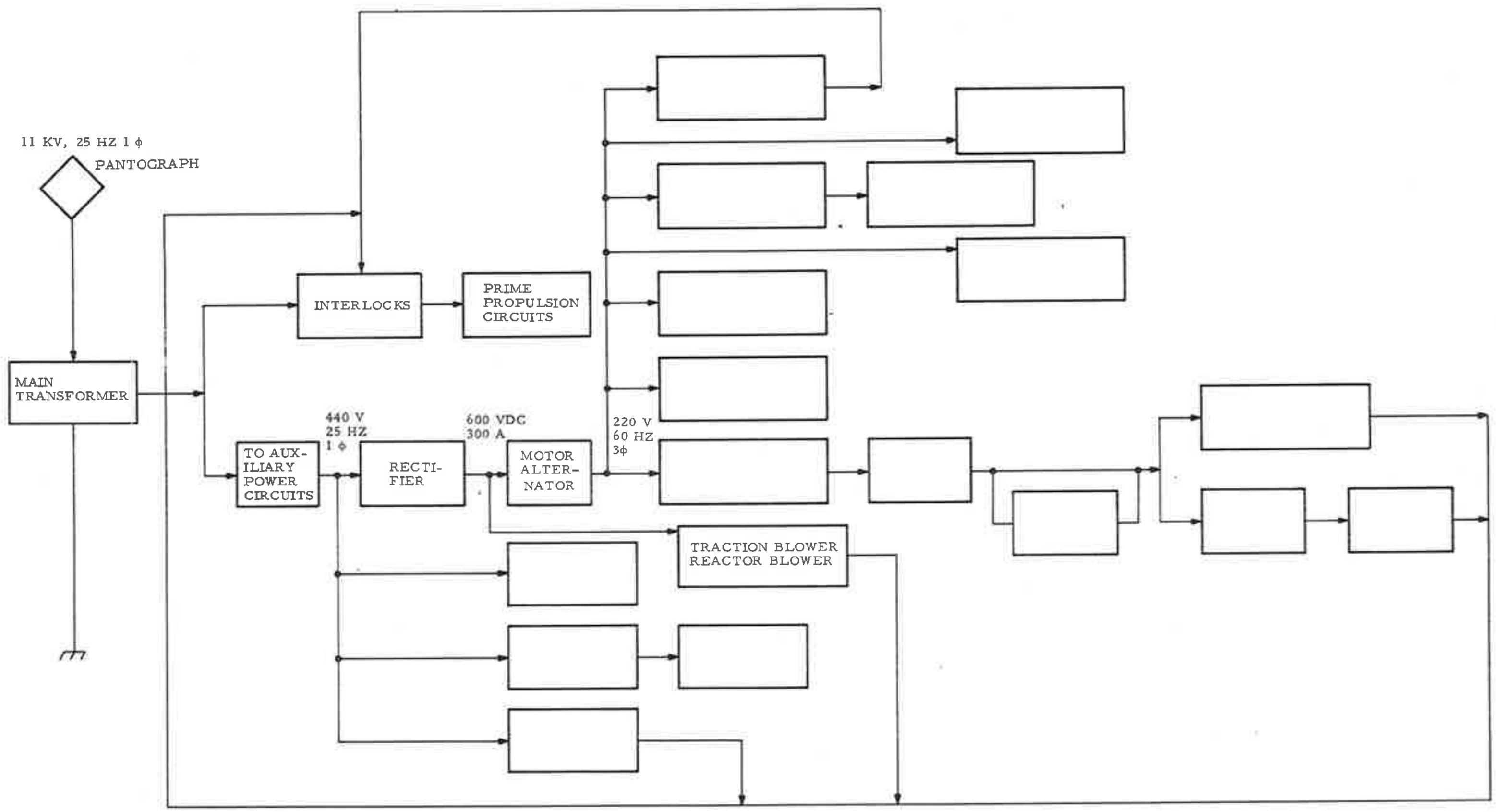


Figure 20. dc Machine Equivalent for Essential Motors

of all these motors and their respective ratings. From this listing the only nonstandard motors are the two essential motors: the reactor blower motor and the traction blower motor. To evaluate the feasibility of implementing this proposed change a size and weight comparison was done. The comparison is between typical 220 V, 60 Hz, 3 phase machines (size and weight data was not available for all the motors in question) and typical dc machines of equivalent horsepower and rpm ratings. Figure 22 outlines the result of this comparison. These figures have been derived from NEMA standards and various motor manufacturers specification sheets.

If the essential motors are to be replaced by dc machines, 2 traction blower motors would be required. This is because the present system uses the motor-alternator shaft to drive #2 traction blower. With this addition of an extra 20 horsepower dc motor, the size/weight comparison for replacing only the essential motors comes out to be: 445 square inches of required surface area and 268 pounds for the present system as opposed to 1187 square inches of required surface area and 788 pounds for the dc motor equivalent. This is the dc machines would require more than 2-1/4 times the surface area and almost three times the weight as the present system.

Motors	Vac/Hz/Phase	RPM	HP
Reaction Blower Motor	220/60/3	1760	6.3
#1 Traction Blower Motor	220/60/3	1750	17.5
#1 Transformer Blower Motor	220/60/3	1735	0.5
#2 Transformer Blower Motor	220/60/3	1735	0.5
Air Compressor Motor	220/60/2	1800	10
Freon Compressor Motor	220/60/3	1800	30
Condensor Fan Motor #1	220/60/3	1710	2
Condensor Fan Motor #2	220/60/6	1710	2
Blower Fan Motor #1	220/60/3	1710	1.5
Blower Fan Motor #2	220/60/3	1710	1.5

Figure 21. Ratings of Present Motors

MOTOR SIZE HP	60 Hz SIZE A B	60 Hz WEIGHT	DC (1750 RPM) (240 VDC) SIZE A B	DC WEIGHT	DIFFERENCE SIZE A B	DIFFERENCE WEIGHT
1/2	7.0 10.7	33				
1 1/2	7.0 11.7	44	8.5 19.25	149	1.5 7.55	105
2	7.0 11.7	44	8.5 19.25	149	1.5 7.55	105
5	9.0 13.7	82	10.0 22.75	248	1.0 9.05	166
7 1/2	10.6 15.75	124	10.0 24.75	290	- 9.0	166
10	10.6 17.25	144	11.75 26.62	373	1.1 9.37	229
15	12.5 20.5	185	13.5 29.5	475	1.0 9.0	290
20	12.5 22.25	214	13.5 31.0	525	1.0 8.75	311
30	14 24.8	310	17.25 31.75	915	3.25 6.95	605

Figure 22. Comparison 60 Hz vs. dc Machines

There should be no problem with the Metroliner handling the extra 500 pounds; this only amounts to about three passengers. However, accommodating the extra 742 square inches of surface area under the car could present some difficulties, because the area under the car is pretty compact already.

REPLACE MOTORS WITH 25 Hz MOTORS

Investigation into the possibility of replacing the essential motors with 25 Hz machines has not been as fruitful. There are still a limited number of 25 Hz, 3 phase motors being manufactured for special application in the steel industry, but there are not 25 Hz, 1 phase machines presently being manufactured. However, it would be possible to have these motors designed and built specifically for this application. If such motors were available, their weight and size would undoubtedly be prohibitive. For the sake of completeness, the variation to the block diagram, (should this alternative be implemented) is shown in Figure 23.

REPLACE THE MOTOR-ALTERNATOR SET WITH A STATIC INVERTER

Another solution to the motor-alternator dilemma is to eliminate the motor-alternator itself. It could be replaced by one or more static inverters. This is to convert the 400 Vdc to 220 V, 60 Hz, 3 phase with electronics instead of the present method of using rotating machines. The primary advantage of using two static inverters would be for the sake of redundancy and to isolate the essential elements from the nonessential elements. One static inverter would be used to power the essential loads and the other to power the nonessential loads. This method is pictorially described in the block diagram of Figure 24.

The redundancy would be implemented by a switchover capability. If the inverter powering the essential loads were to fail, the inverter powering the nonessential loads could be switched over to supply power to the essential loads thereby preventing train immobility.

By implementing this alternative, the control circuits, about 5 kW load, could be powered either by the essential inverter or an ac to dc converter, or a dc to dc converter. These two converters would be the same as those outlined previously.

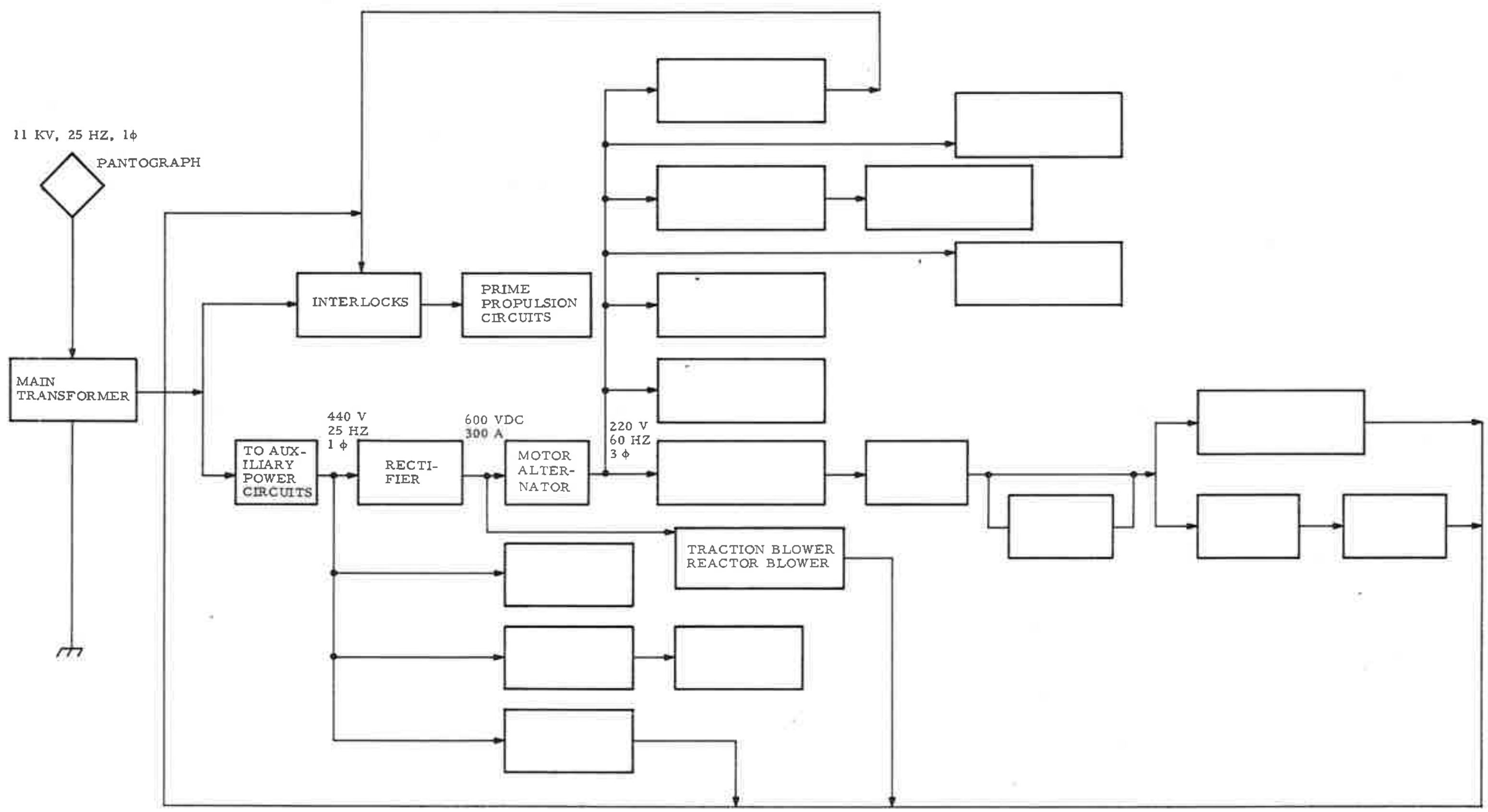


Figure 23. 25 Hz Machine Equivalent for Essential Motors

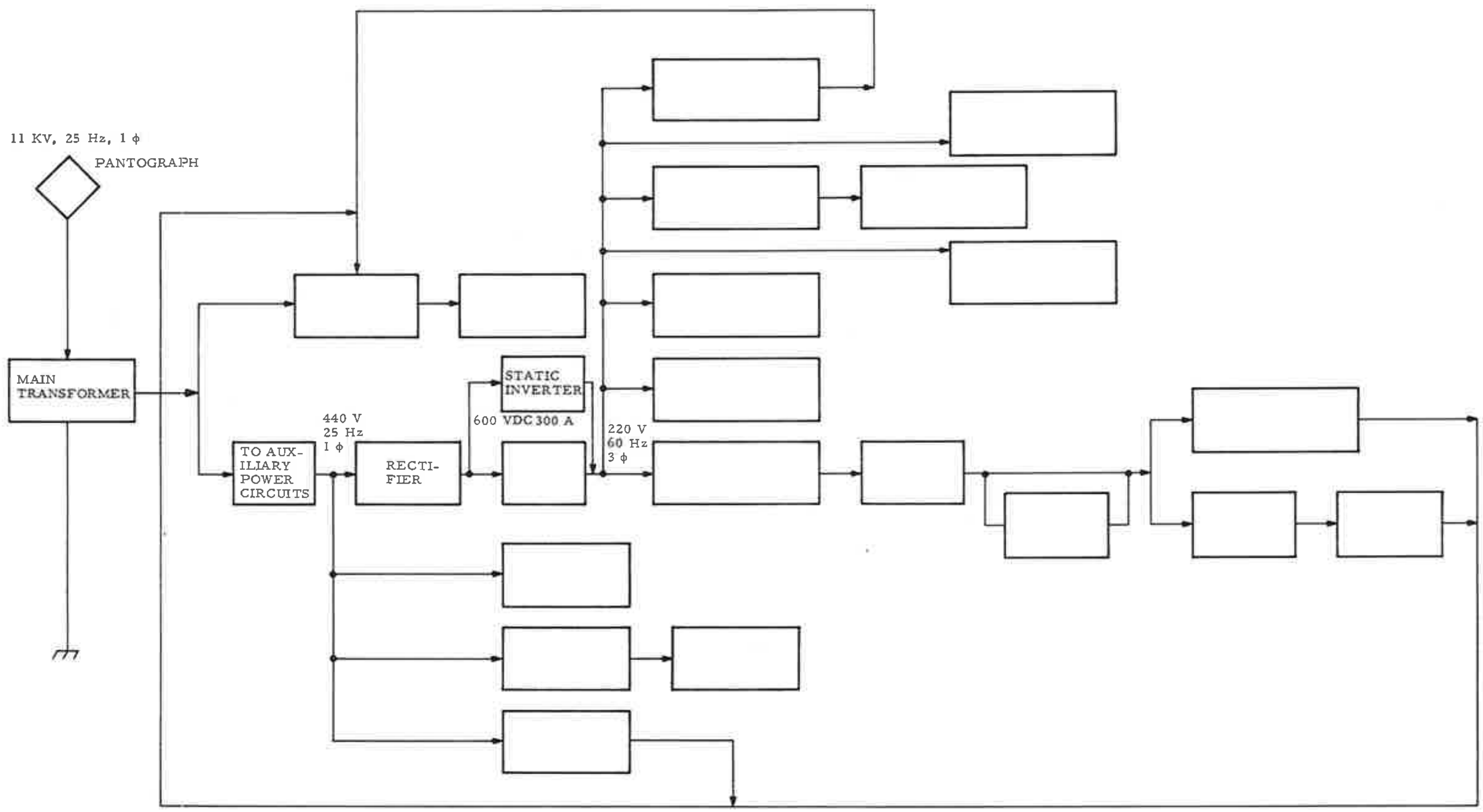


Figure 24. Static Inverter to Replacement Set

The power requirement for the essential loads is approximately 26 kW, and the nonessential load requirement is approximately 52 kW, twice the essential load requirement. It would be conceivable therefore, to introduce triple redundancy, by powering the nonessential loads if necessary. Implementing this alternative, two static inverters to supply power to the nonessential loads, would be dependent on the size, weight, and cost differences between the two different size inverters.

Although there are a variety of approaches that can be used to provide the required inversion, only one approach, a basic one, will be discussed here. This exemplary static inverter is shown in block diagram form in Figure 25. This approach incorporates two power sections; a master 3 Ø SCR bridge static inverter, and a slave 3Ø SCR bridge static inverter. The phase shift method is used for voltage control. By this approach, voltage control is accomplished by delaying the phase of the slave inverter such that the outputs of the master inverter and the slave inverter do not directly add. For example: no delay results in maximum output voltage, and 180 degree phase delay results in zero voltage output. Logic would be incorporated into the driver circuits to minimize any output harmonic distortion without filtering.

It has been possible to obtain some rough estimates, (size, weight, and cost) of an inverter such as the one described above. These preliminary rough estimates are outlined in Figure 26. The 100 kVA unit could be a direct replacement for the present motor-alternator set. Its total dimensions (ac-dc power supply and SCR static inverter) are approximately 3' x 4' x 5' with a weight of 1600 pounds. The dimensions for the motor-alternator set are approximately 2' x 2-3/4' x 5-1/2' with a weight of 3000 pounds. Although the SCR inverter would be a larger unit, it would require less surface area under the already crowded Metroliner car (13 square feet versus 14 square feet), and the difference in weight, 1400 pounds, could not help but be beneficial to the overall performance of the car. However, this approach is the least desirable of the two. The most favorable method of implementing static inverters is to use two of them, one for the essential loads, and another for the nonessential loads.

Using the available data from Figure 26, the 25 kVA static inverter would supply power to the essential loads and the 50 kVA static inverter would supply power to the nonessential loads.

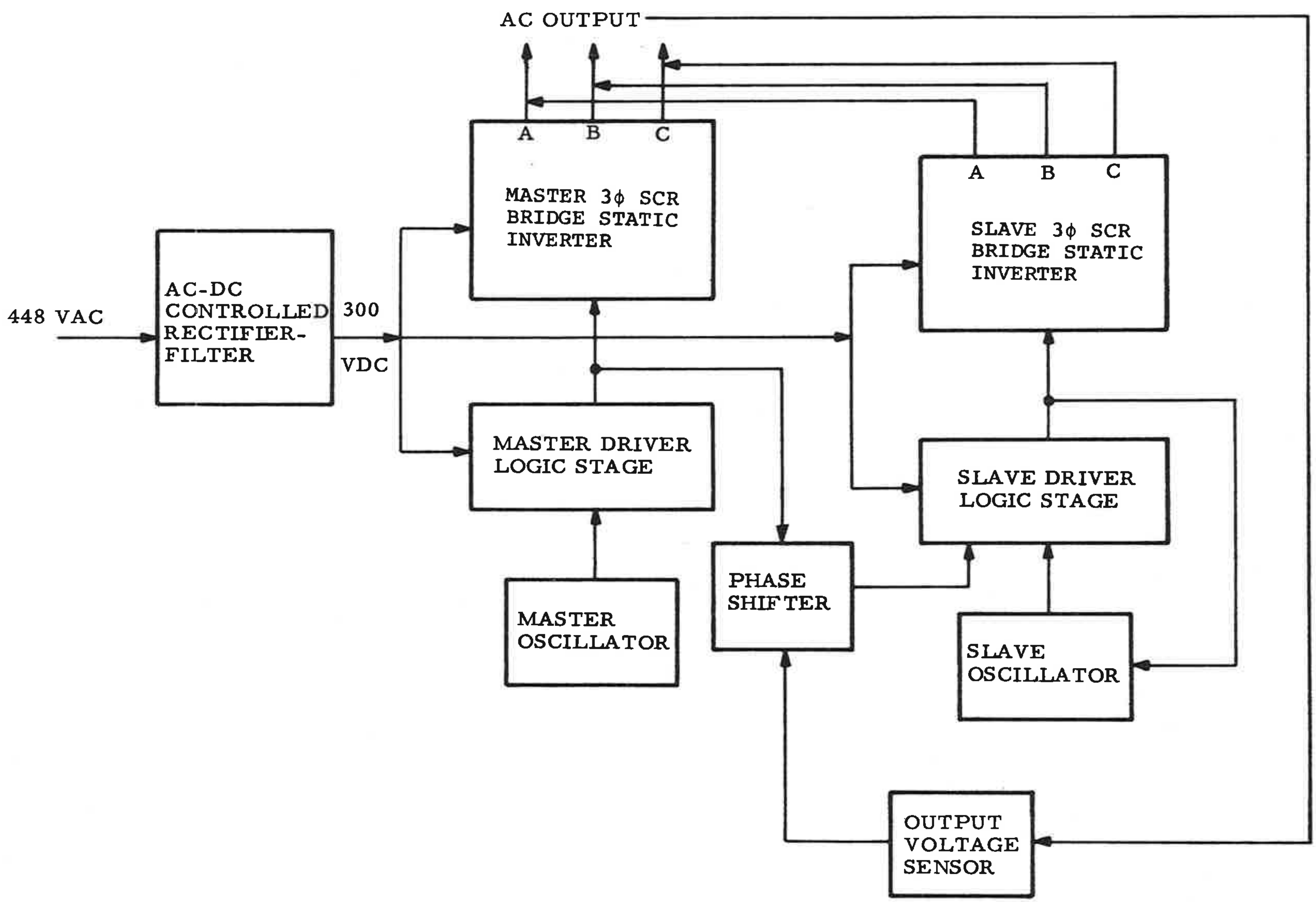
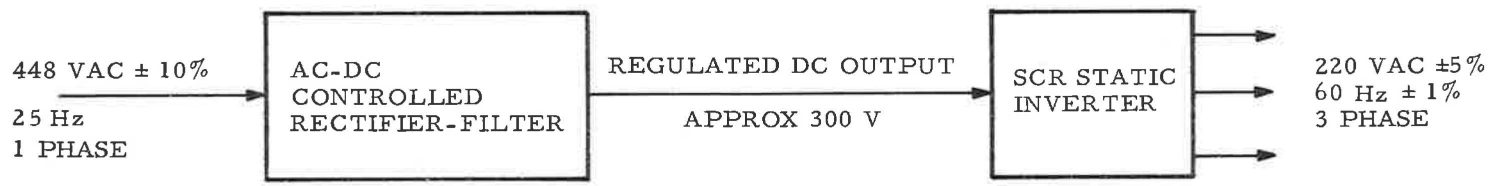


Figure 25. One Example of a Static Inverter



INVERTER POWER OUTPUT (KVA)	AC-DC POWER SUPPLY		SCR STATIC INVERTER		APPROXIMATE SYSTEM COST	
	SIZE (IN)	WEIGHT (LBS)	SIZE (IN)	WEIGHT (LBS)	DEVELOPMENT	PER UNIT
100 KVA	36 X 36 X 48	1200	24 X 24 X 48	400	$250K	$75K
50 KVA	30 X 30 X 36	900	24 X 24 X 36	300	$200K	$50K
25 KVA	24 X 24 X 30	750	20 X 20 X 36	200	$150K	$35K

ESTIMATED DEVELOPMENT TIME INCLUDING A PROTOTYPE - 1 YEAR

Figure 26. Rough Estimates for Metroliner Static Inverter

This would result in a size and weight comparison between the proposed two static inverters and the present motor-alternator set of: 3' x 4' x 4-1/2' and 2150 pounds for the two static inverters as opposed to 2' x 2-3/4' x 5-1/5' and 3000 pounds for the motor-alternator set. In this case, the static inverter would require more surface area under the car than the present motor-alternator set (18 square feet versus 14 square feet).

There is, however, one area in the present motor-alternator set that has been indeterminant. We have been unable to obtain any figures for the size and weight of the controls that are actually as much a part of the motor-alternator set as the motor and the alternator themselves. These controls, although they are located in the electronics control boxes with all the other controls for the train, are actually part of the motor-alternator set, and as such would be eliminated if the motor-alternator set were to be replaced. These controls would add size and weight to the figures already used for the present motor-alternator set, but just how much is unknown at this time.

By taking advantage of the inherent reliability of the electronics elements and the redundancy of using two static inverters, the overall reliability of the Metroliner car stands to benefit substantially. But there still remains one possible problem area: transient changes in the input voltage. The present motor-alternator set has certain advantages that may more than offset the possible increased reliability, realizable through the use of a static inverter. The motor-alternator has a tremendously large inertia which would effectively serve the purpose of isolating the alternator output from large transient changes in the input. There are apparently large transients superimposed on the 448 volt input line during normal train operation. At the present time it appears that it is impractical to build sufficient energy storage capacity into the static inverter to completely isolate these voltage fluctuations. This is an area that should be given much more attention before any firm recommendations can be made for a static inverter.

PROPER BATTERY SELECTION

The question has arisen: Is the nickel-iron battery the best suited choice for the Metroliners application? A comparison was made between the nickel-iron battery and the nickel-cadmium battery to determine which has more desirable qualitites. The results of this comparison are discussed below.

Temperature Characteristics. Nickel-cadmium batteries have much better low temperature characteristics. This difference is outlined graphically in Figure 27 for a one hour discharge rate and in Figure 28 for a three-hour discharge rate. These curves clearly point out a definite advantage of nickel-cadmium batteries. However, as explained in previous section, temperature is not a critical criterion because the ambient temperature within the battery box remains fairly warm during the wintertime.

Discharge Characteristics. Also nickel-cadmium batteries have much better discharge characteristics, as shown in Figure 29. This shows that where the nickel-iron battery would be able to deliver 50 amperes for one hour, an equivalent nickel-cadmium battery would be able to deliver the 50 amperes for one and a half hours. This would definitely be an advantage. Primarily because it would be able to supply power to the emergency circuits for a longer time, and also because when the emergency condition ceased, (either the next stop was reached or help arrived) the nickel-cadmium battery would not be as run down as the nickel-iron battery would be, and therefore would be easier to recharge.

Cycling Capabilities. The cycling capabilities of both nickel-iron batteries and nickel-cadmium batteries must also be analyzed. During discharge of the nickel-cadmium battery the negative plate is oxidized. This oxidation can build up over repeated cycles and eventually may result in shorting the positive and negative plates. However no such oxidation takes place during either charge or discharge of the nickel-iron cell. Actually the nickel-iron battery is said to "thrive" on repeated cycling. In the case of the Metroliner where repeated cycling of the battery is the rule rather than the exception, the nickel-iron battery has a definite advantage over the nickel-cadmium battery.

Recharge Characteristics. Another major plus in favor of the nickel-iron battery as opposed to the nickel-cadmium cell is its ability to accept a charge. Figure 30 compares the time that each cell requires to reach 100% of its capacity with a charge rate of C/5 (20% of the maximum current capacity). The C/5 rate is the optimum recommended charge rate of both cells. As can be seen from these curves a completely dead nickel-iron battery will reach 100% of its

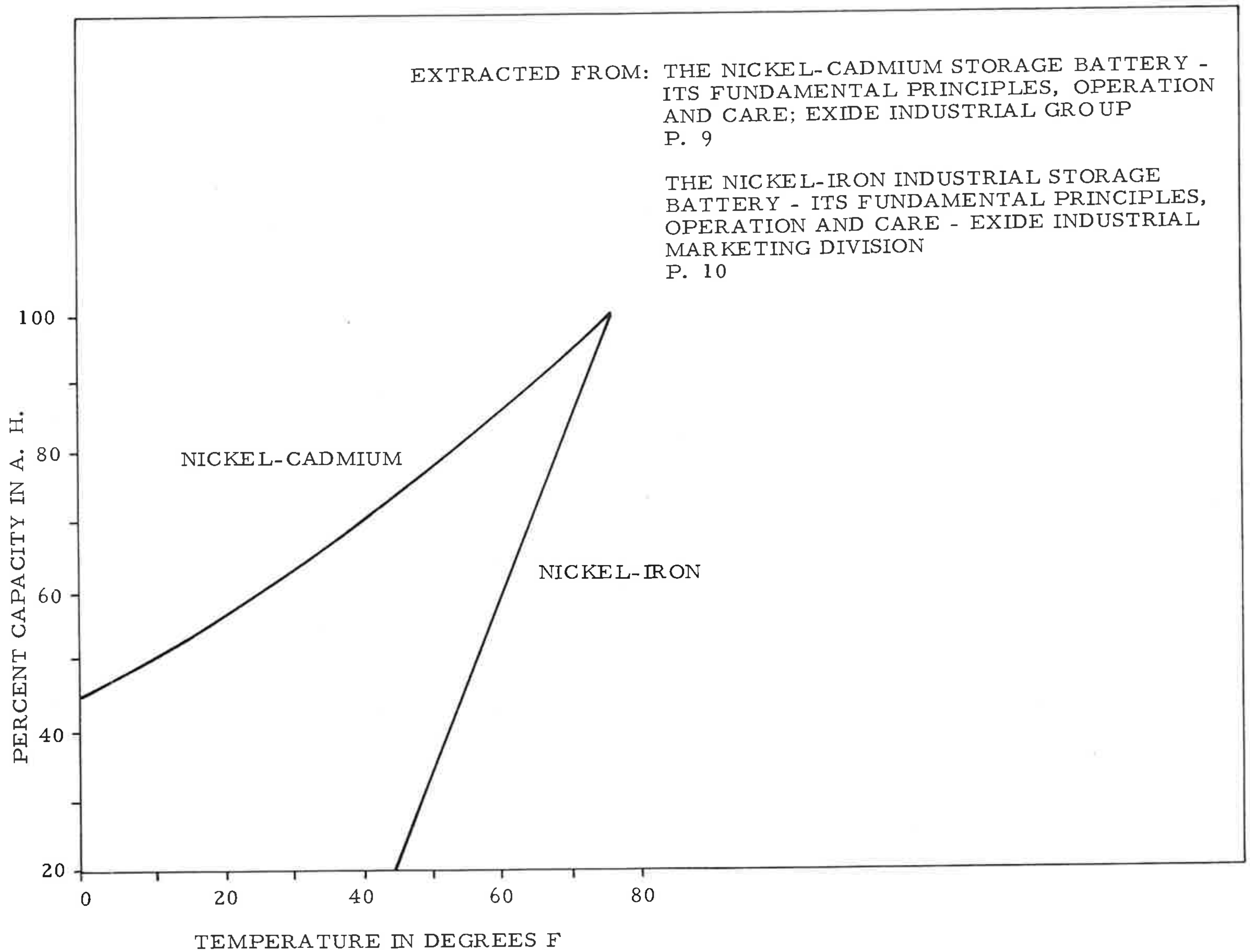


Figure 27. Effect of Temperature on Capacity at 1 Hour Discharge Rate

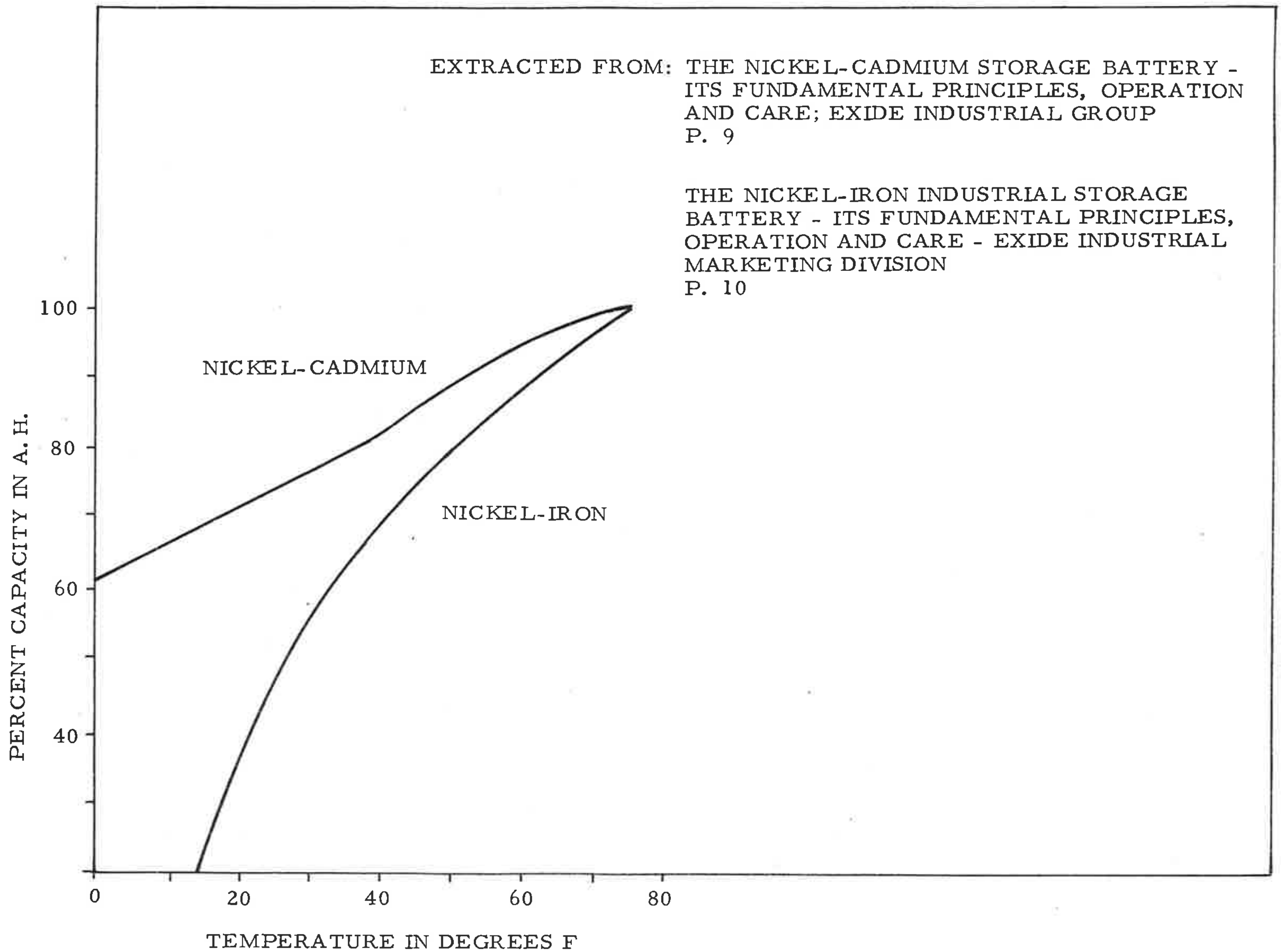


Figure 28. Effect of Temperature on Capacity at 3 Hour Discharge Rate

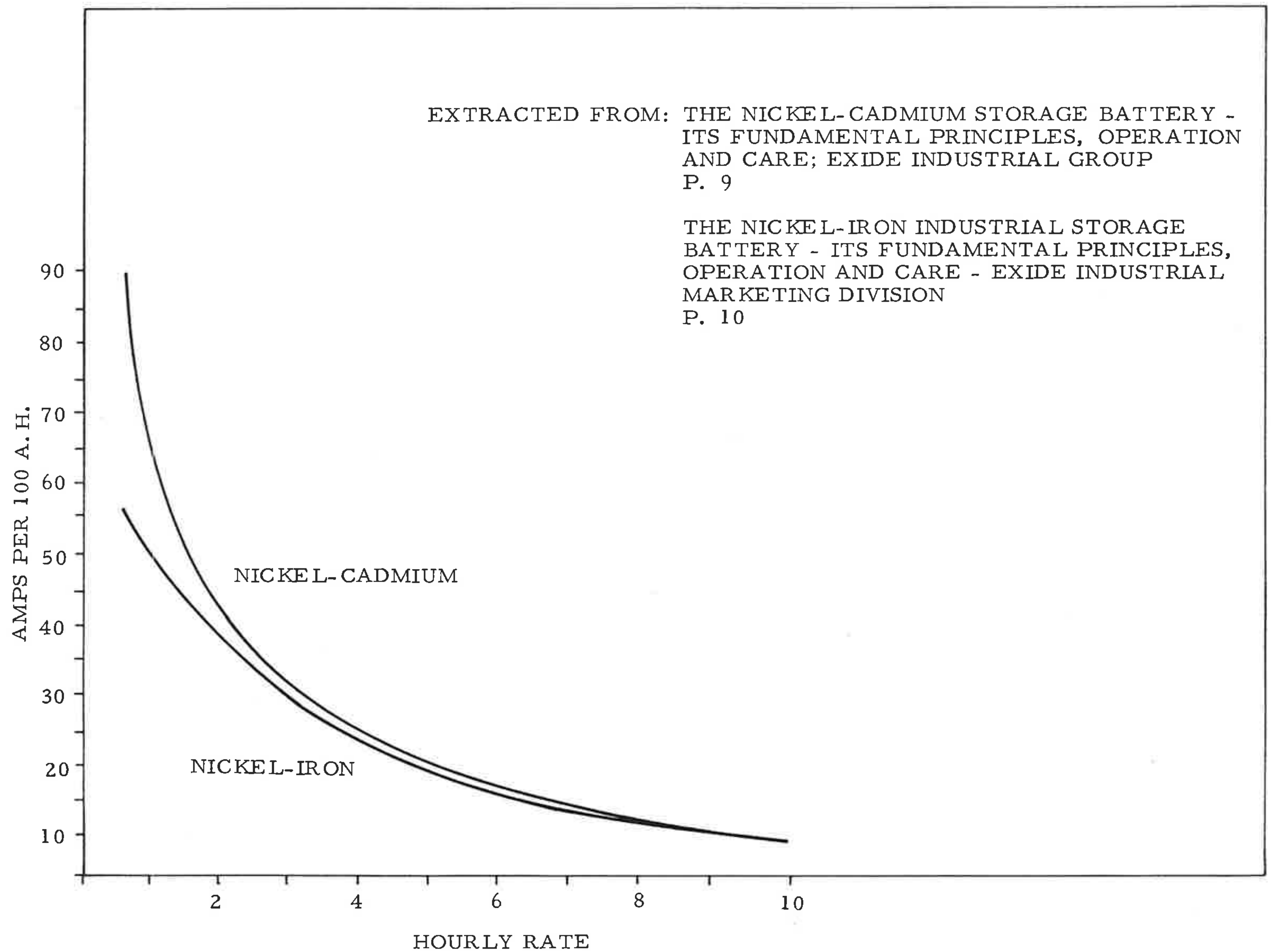


Figure 29. Capacity vs. Time Curve to 1.14 Final Voltage Per Cell at 77°F

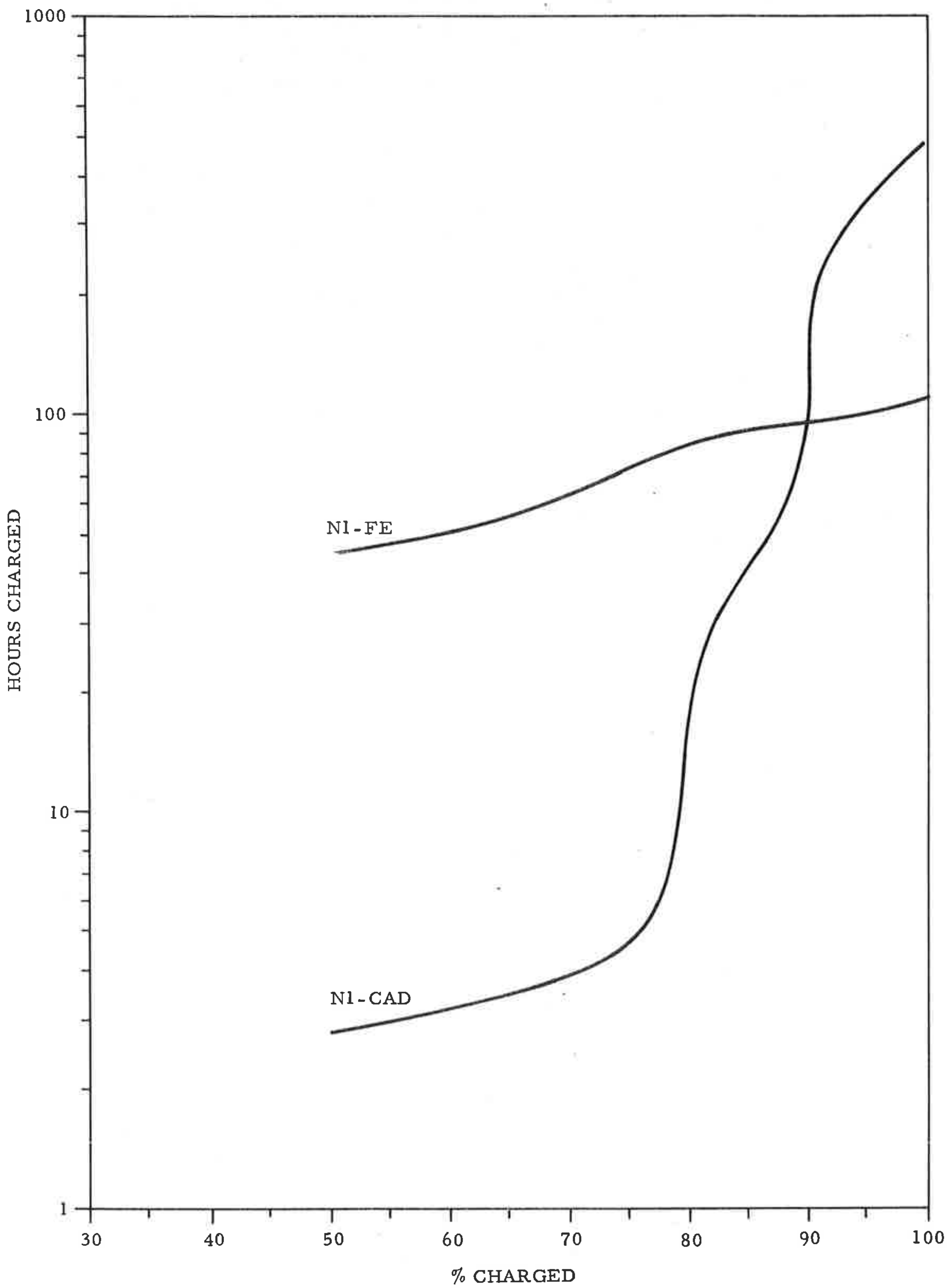


Figure 30. Charge Rates

capacity in 110 hours, when it would take a nickel-cadmium battery 500 hours to reach full capacity. This is an admirable feature of the nickel-iron cell, however, even more important is the batteries' ability to recharge when it is not completely dead but only partially discharged. Let us assume that the battery is discharged to 50% of its capacity. The curves in Figure 30 show that the nickel-cadmium cell will take 497.2 hours to return to full capacity, while the nickel-iron battery will return to 100% capacity in only 65 hours. For another example, if the battery is drained to 80% of its capacity, the nickel-cadmium battery will be fully recharged in 484 hours, while the nickel-iron battery will take only 25 hours to reach 100% capacity. From this point of view the nickel-iron cell is a much more desirable battery for the Metroliner's application.

A summary of this discussion is outlined in Figure 31. It is apparent that the nickel-iron battery is better suited to the environment of the Metroliner than the nickel-cadmium battery.

	Temperature	Discharge	Cycling	Recharging
Nickel-Iron	Completely In-effective at Low Temperatures	50 Amps for 1 Hour	"Thrives" on Cycling	Recharges from 50% in 65 Hours 80% in 25 Hours
Nickel-Cadmium	Good at Low Temperatures	50 Amps for 1-1/2 Hours	Oxidation May Result in Shorting	Recharges from 50% in 497 Hours 80% in 484 Hours
Remarks	Not Very Im-portant - Battery Box Remains Warm	NI-CAD is Better	NI-FE is Better	NI-FE is Better Also Negates Discharge Ad-vantage of NI-CAD

Figure 31. Comparison: Nickel-Iron vs Nickel-Cadmium

RECOMMENDATIONS AND CONCLUSIONS

The following are recommended changes to the Metroliner's secondary power system:

1. Install a battery charger in the emergency power system. The implementation of a battery charger, to insure that the battery is capable of supplying power when an emergency condition exists, is highly recommended. This condition has apparently been recognized as a problem by all concerned, and incorporation of a battery charger should receive general approval.

2. Reconfigure the 60 Hz power system so that the essential loads are powered directly from the main power source. There are two phases to this reconfiguration; although each can be implemented independently, maximum increased reliability will be attained if both are implemented.

    a. First, install an ac to dc converter. The implementation of the ac to dc converter to supply power to the essential 64 Vdc loads is highly recommended. As outlined in the previous section, this desirable alternative could be implemented with a minimum amount of difficulty and the increased availability resulting from eliminating the dc circuits' dependancy on the motor-alternator set would more than offset the cost of the converter.

    b. Second replace the essential 60 Hz motors with either dc or 25 Hz motors. The primary potential drawback is whether there is sufficient room under the car; this should be investigated further.

3. Upgrade the failure reporting method. As was previously stated, the failure method presently used by Penn Central for the Metroliner system is appropriate for their immediate purposes. It enables them to predict what type of failures to expect and how frequently to

expect them. However, for the purpose of upgrading the design of this vehicle, or for assistance in the design of future vehicles, the present failure reporting system is sadly lacking.

If there are to be future Metroliner cars manufactured; obviously a record of the failures encountered would be of great assistance in upgrading the design of the cars. But even if this is not the case, if there is no Metroliner production in the future, information concerning the causes of equipment and component failures would be of assistance in the design of any type of similar vehicle.

The experiences and information gained by any type of experiment, if they are to be useful to anybody in the future, must be documented, and documented to the extent that complete understanding of the situation can be obtained. The same applies here. If this demonstration project is to be beneficial in the design of future high speed systems, and we feel that it should, the problems and failures that occur should be recorded. What component actually failed; what caused it to fail; under what conditions did it fail (speed of train, environmental conditions etc.); what are some possible recommendations to insure that this failure doesn't occur again; these are some of the areas that should be addressed in a complete failure recording scheme.

4. Change the terminal lighting procedures. To eliminate the nightly raids on the battery power when the cars are cleaned and checked, some form of external power should be supplied. One method is simply to run extension cables from the stations to provide some lighting for these functions.

   Under the present scheme of operation when the trains are put into service the secondary power system, specifically the battery is already in a state of deterioration, because of battery usage at the terminals.

The following constitute areas that require further investigation before any firm recommendations can be made:

1. Remove the motor-alternator set from the system. This can be accomplished by implementing the following.

   a. Replace all the 60 Hz motors with either dc or 25 Hz motors. The feasibility of replacing the 60 Hz motors with equivalent dc or 25 Hz machines isn't that straightforward. The biggest question here is: Is there enough room under the car to accommodate them? We cannot determine this from the information that was made available to us, but if there is sufficient surface area under the car, it definitely is a worthwhile improvement to make.

   b. Install a small static inverter to supply power to the convenience outlets.

   c. Install an Inverter Fluorescent Lamp Ballast to supply power to the fluorescent lights. The New Haven Railroad's new commuter cars will have this type of arrangement. Luminator, a division of Gulton Industries, is supplying these units for the New Haven.

2. Replace the motor-alternator set with a static inverter. With the static inverter approach implemented, the dc machine alternative to increasing reliability wouldn't be required. However, there still remains one big question with this approach: Can a filtering network be built that can handle the transients that this inverter will be subjected to? Admittedly this is a big question, but we feel that the advantages to be gained by replacing the motor-alternator set with a static inverter more than warrant further investigation into this possibility. Therefore, for the potential advantages in reliability and availability, further investigation into this static inverter approach is recommended.

3. Reassess the battery application. Nickel-cadmium batteries are being considered as a replacement for the nickel-iron batteries presently in use, however it appears from the data that has been compiled that the nickel-iron battery is better suited to the present cyclic environment of the Metroliner car. The justification of this environment is in doubt and should be investigated further.

The following tables outline the various recommendations and briefly compare the present and proposed systems.

	Weight	Size (W x L x H) (in.)	Rating	Cost	Remarks
Present	--	---	Floating Charge	--	Battery is practically never charged.
Proposed	30	12 x 14 x 6	20 Amp Constant Current Charge	$650 Each for Quantities of 50	Will insure battery is completely charged and provide voltage regulation.

Figure 32. Recommendation: Install Battery Charger

	Power Source	Weight	Size (W x L x H) (in.)	Cost	Remarks
Present	Output of M-A Set	?	?	--	Subject to erratic performance of M-A Set.
Proposed	Secondary of Main Transformer	450 Pounds	20 x 30 x 24	$3500 Each for Quantities of 50	Eliminates dependancy of dc loads on M-A Set.

Figure 33. Recommendation: Install ac-dc Converter

APPENDIX

A. Failure Data

B. Sample Reporting Scheme

C. Specification for Secondary Power System

D. References

E. Battery & Battery Charger Information

F. Sample Specifications

APPENDIX A. FAILURE DATA

The failure reporting practices of the Penn Central company at the Wilmington repair shops leave much to be desired. When a train comes in for repair, there apparently is no attempt made to determine the cause of a particular element failure. Whatever it was that failed is simply replaced or repaired. Penn Central does however keep records. Their New England Corridor Office keeps four types of records.

1. a daily "worksheet" showing current operating status (time, train #, car #, failure mode, correction made, and time if and when made) kept up to the minute via excellent communications system with equipment personnel, each train, station, and on-site maintenance personnel,

2. a book record, kept chronologically, summarizing the sequence of failures experienced by date,

3. a book record by car number and date, indicating correction made and when,

4. a monthly summary of failure modes (control ground failures, erratic power, gear unit, all unit features, brake failures, etc.) and the contribution of each to car-day down time, subtotals and grand totals for the month. These are further reduced by responsibility: car (Budd/Penn Central) and propulsion (General Electric or Westinghouse) equipment.

These failure mode reports show effects not causes. The average down-time per car is 40% and almost all of this is due to General Electric or Westinghouse equipment (39% and 41%, respectively). This is a painful car utilization record. Each Metroliner train has six cars and each car is capable of operating independently. Therefore, the cars that are operating can help any disbaled car along so the train utilization record can in fact be improved.

For their own purposes Penn Central's failure reporting system is sufficient. They know what kind of failures to expect, and the frequency and severity of these failures. They have people to correct the failures and get the equipment back in service in, for most cases, a reasonable time. This approach keeps the cars running in a somewhat predictable manner, but it is in no way beneficial to upgrading the system. This would require the reporting of the causes of failures and reporting down to the individual component.

Louis T. Klauder and Associates have been another source of failure data. They have been involved with the Metroliner since its inception. They prepared the original specifications for the train, supervised the acceptance testing for the cars, and are now keeping current records of the availability of the system, and the subsystems of it, using the operational data collected by the Penn Central Company. As part of this latter involvement, Klauder and Associates provides weekly failure reports to the Office of High Speed Ground Transportation.

The Metroliner car is divided into approximately 56 different categories. These weekly failure reports list the total number of occurrences of failures experienced for the week according to these different categories. These categories are listed in Figure A-1. We have been able to obtain copies of these weekly reports for the ten week period for the week ending November 17, 1970 to the week ending January 19, 1971. A summary of the failure data over this ten week period for the ten categories of most concern to us is shown in Figure A-2.

The Office of High Speed Ground Transportation has combined 29 of these weekly reports, for the week ending June 6, 1970 to the week ending December 29, 1970, and has developed a set of curves for various prominent categories. Figures A-3, A-4, A-5, and A-6 show the curves for the areas of most concern here. A curve for general information showing the daily average of cars out of service is shown in Figure A-3. The overall average is about 17 cars. Figure A-4 shows the total number of failure occurrences per week, approximate average 60 failures. Getting down to specifics, Figure A-5 is for the weekly occurrences of motor-alternator failures. Although the curve shows a decreasing trend in this type of failure, it cannot be disregarded as a critical area because of its importance to train operation, as explained in the body of this report. The opposite has been the case, that is a rising trend, of occurences of failure within the control wiring, as is seen from Figure A-6. The bulk of these failures are due to the "shorts" between the dc lines and the conduit that have been plaguing the Metroliner cars.

From Figure A-2 we can see a fine example of how much of a problem the motor-alternator failures have been. Over the ten week period in question, the motor-alternator set has experienced 81 (48 + 33) failures. However the essential elements have experienced only 26 (9 + 3 + 7 + 7) failures over the same ten week period. Since the motor-alternator set supplies power to these essential elements, the resultant loss of essential elements has been more than 4 times what it normally would have been.

The batteries are obviously also a major problem as evidenced in Figure A-2 (78 failures in ten weeks). Since the batteries are the sole source of emergency power, they are of necessity critical, and an average of 8 failures per week is far from tolerable.

It is for these reasons that Mr. K. B. Ullman of the Office of High Speed Ground Transportation has suggested that this study be focused around the motor-alternator set, and the emergency power system, with attention placed on improving the chances that the essential elements will always have the power they require, and the battery will be capable of supplying its full potential when an emergency arises.

Monthly Inspection

Air Compressor, Mechanical (Including Governor)
Air Compressor, Electrical (Including Governor)

Batteries
Battery Charging

Blowers, Mechanical
Blowers, Electrical
Blowers, Control and Power Supply

Control Wiring: Grounds and Opens
Other Low Voltage Wiring: (Signals, Communications)

Couplers, Mechanical
Couplers, Electrical

Doors

Dynamic Brake, Control
Dynamic Brake, Power Elements

Brake, Electro-pneumatic

Gear Units and Flexible Couplings

Damage, Accidental or Malicious, Body and Enclosures

Motor-alternator
Motor-alternator Power Supply and Control

Overspeed System

Overload System

Pantographs, Failed
Pantographs, Accidentally or Maliciously Damaged
Pantographs, Control Including PL Relay

Figure A-1. Metroliner Master Defect List (Third Revision)

Automatic Train Operation System

Power Handling Switches, Rectifiers, Relays, etc., not
Otherwise Identified
Low Power
Erratic Power
Dead (Cause Not Identified)
Defective Control Cards
Contactors Flashed
Firing Panel Defects Not Otherwise Identified
Ground Relay Unless Identified As Due to Power Circuit Ground
High Motor Current
Rectifier Defects
Sequence Error
Console and Immediately Related Power Control Elements

Miscellaneous Power Circuit Elements; e.g., Surge Resistors
Power Circuit Grounds (Between Main Components)
Smoothing Reactors
Slip-slide System
Speedometers and Axle Alternators

Traction Motors, Mechanical
Traction Motors, Electrical

Trucks, Unidentified
Trucks, Wheels
Trucks, Bearings
Trucks, Springs and Dampers
Trucks, Leveling Control

Automatic Train Control and Cab Signals

Alertor
Heating and Air Conditioning Apparatus
Train Radio and Intercom
Other

Figure A-1. Metroliner Master Defect List (Third Revision) (Continued)

MANUFACTURER	W/GE	W/GE	W/GE	W/GE	W/GE	W/GE	W/GE	W/GE	W/GE	W/GE	TOTAL	COMBINED TOTAL
WEEK ENDING	11/17	11/24	12/1	12/8	12/15	12/22	12/29	1/5	1/12	1/19		
BATTERIES	11/7	5/7	0/7	0/6	0/3	0/8	0/7	0/7	0/7	0/7	12/66	78
CONTROL WIRING GROUNDS & OPENS	8/19	3/18	10/9	15/10	5/0	9/4	24/4	10/0	3/10	2/7	89/81	170
M-A	0/4	0/0	0/0	0/2	2/2	1/2	0/0	0/4	0/14	5/12	8/40	48
M-A POWER SUPPLY & CONTROL	0/0	0/0	0/4	1/3	0/2	0/0	0/10	0/6	0/3	2/2	3/30	33
AUTOMATIC TRAIN CONTROL	0/0	0/1	0/0	4/0	0/1	0/0	0/1	0/0	0/2	0/0	4/5	9
AIR COMPRESSOR MECHANICAL	0/0	0/0	0/0	0/0	4/4	0/0	0/7	0/0	0/0	0/0	4/11	15
AIR COMPRESSOR ELECTRICAL	0/0	2/0	0/0	0/2	0/0	3/1	0/1	2/0	2/0	6/5	15/9	24
BLOWERS MECHANICAL	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	3/0	0/0	3/0	3
BLOWERS ELECTRICAL	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	7/0	7/0	7
TRAIN RADIOS & INTERCOM	0/0	0/0	0/0	0/0	0/0	0/0	0/1	0/0	0/5	0/1	0/7	7

Figure A-2. Weekly Compilation of Metroliner Out of Service Report Defects

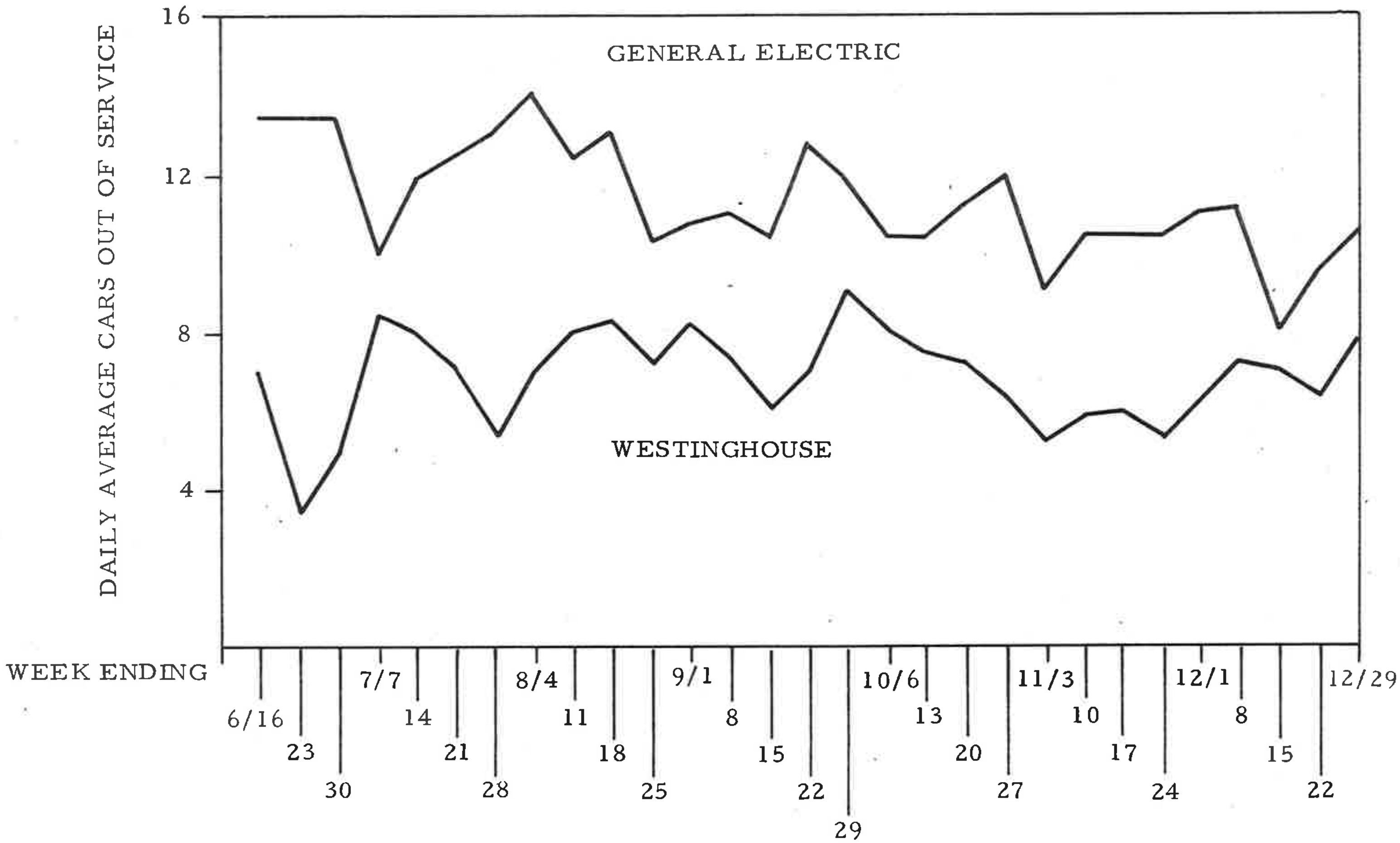


Figure A-3. Daily Average of Cars Out Of Service

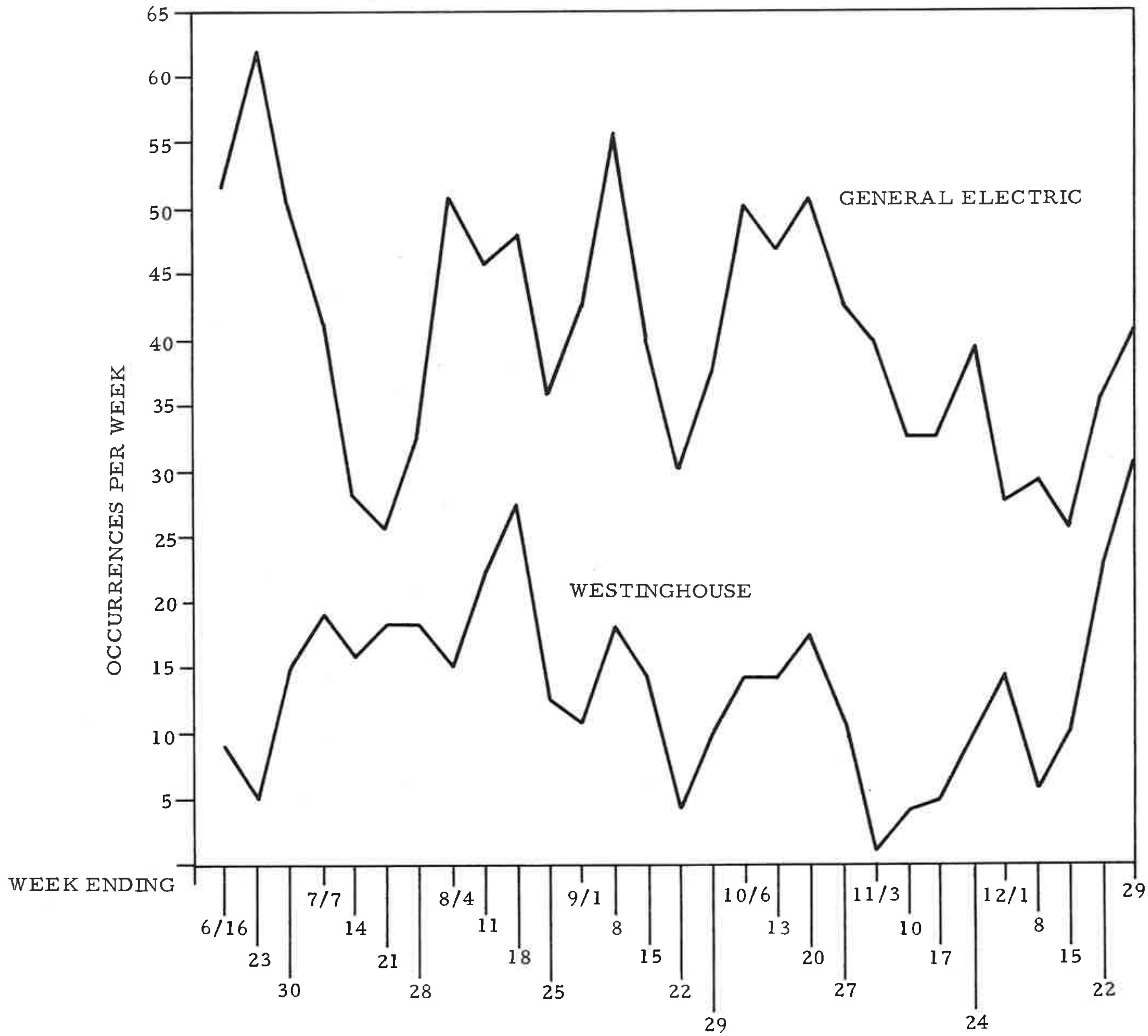


Figure A-4. Failure Occurrences Per Week

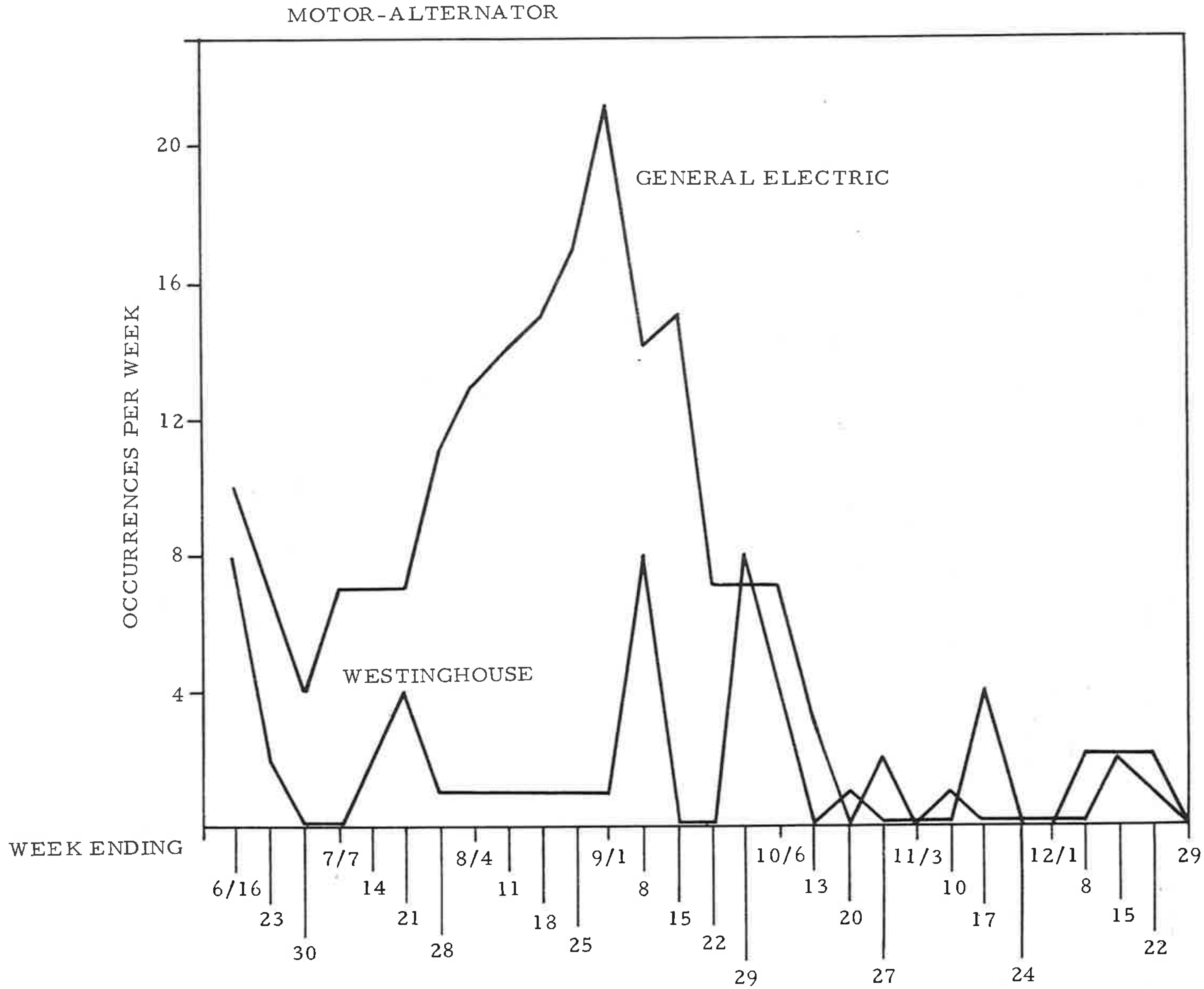


Figure A-5. Weekly Occurrences of Motor Alternator Failures

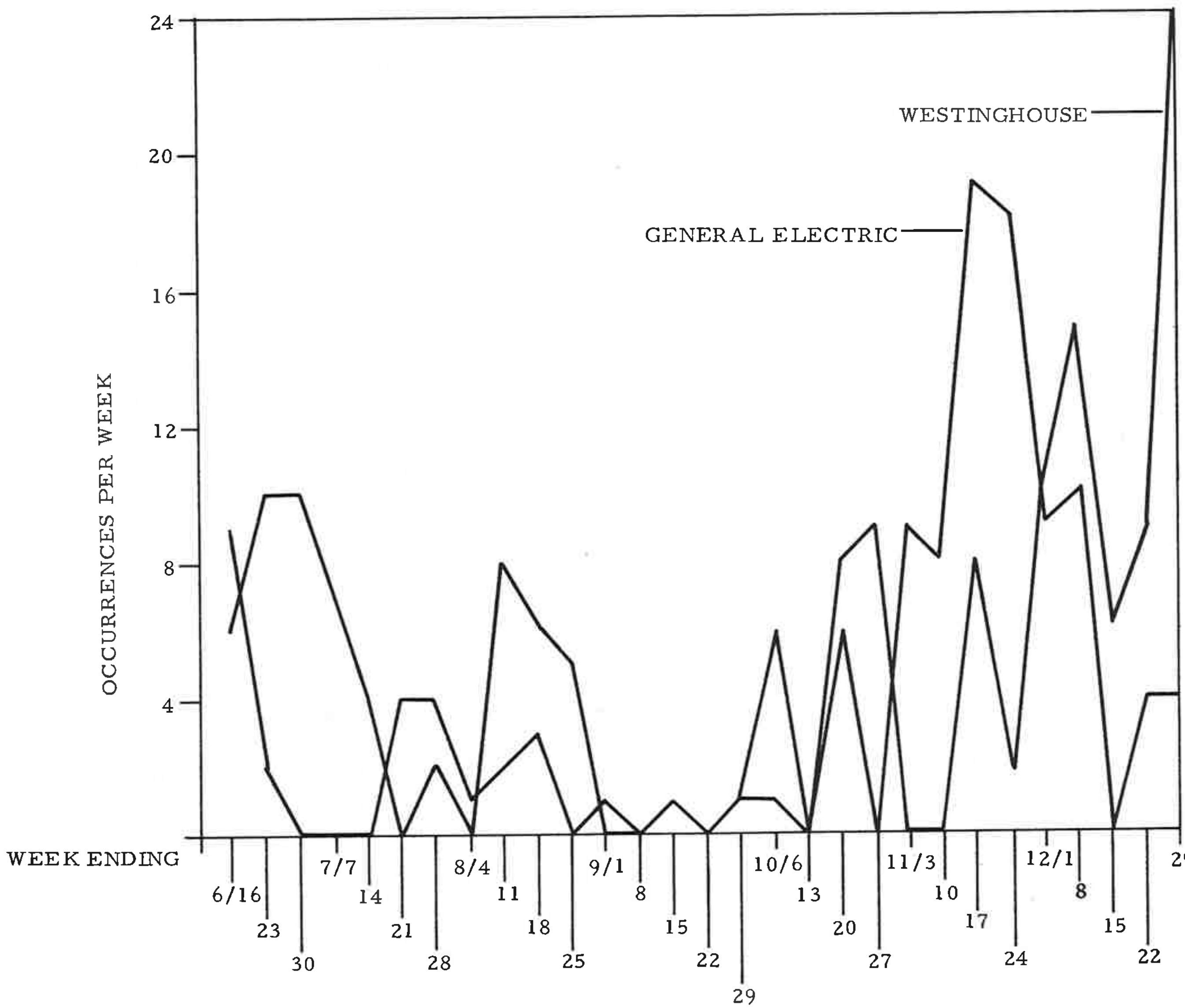


Figure A-6. Weekly Occurrences of Control Wiring Failures

APPENDIX B. SAMPLE REPORTING SCHEME

Date________
Time of Failure
Train #
Car #
Speed at Time of Failure
Environment
Sympton
Failed Component
Cause of Component Failure
Correction Made
Time Correction Made
Recommendations

Figure B-1. Sample Reporting Scheme

APPENDIX C. SPECIFICATION FOR SECONDARY POWER SYSTEM

Included in this Appendix are those sections of the Metroliner design specification, written by Louis T. Klauder and Associates, that apply to this particular study. These sections are:

Section S6: Door Control and Communication Systems

Section S7: Heating, Ventilating, and Air Conditioning

Section S8: Lighting

Section S9: Auxiliary Power System and Apparatus

SECTION S6 – DOOR CONTROL AND COMMUNICATION SYSTEMS

DOOR CONTROL

The side entrance doors shall be arranged for remote control electrical operation. The control shall be trainlined so that all the doors on either side of the train may be operated from any vestibule.

The traction controls shall be interlocked with the door controls so that the doors cannot be opened until the train has stopped and the train cannot be started until the doors are closed. The amount of resistance required to resist the closing force of the door shall be subject to purchaser's approval.

A master door control switch panel, controlling the doors on that side of the train only, shall be provided on each side of each vestibule.

A bypass switch shall be provided at each side door operator so that in the event of door operator failure on a car in service the operator may be bypassed and made inoperative. The switch shall bypass the door circuit so that the engineman's cab signal light shall function in the normal manner.

A door interlock bypass switch shall be provided in the engineman's control console to permit moving the train in the event of side door interlock circuit failure. Switch shall be arranged to be sealed in the open position requiring that the seal be broken to use it.

A pair of cut-out switches shall be provided, in the electric locker, which will permit breaking the door control trainline at any point in the train, so that cars can be deadheaded in a train and their doors kept closed at station stops.

Door control shall operate on 64 volts dc.

DOOR CONTROL SWITCHES

a. Conductor's Door Control Switch Panel

A key-energized master door control switch panel shall be provided on each side of each vestibule. It shall be located so that the conductor can operate the switches to close the doors while standing in the doorway. The panel shall be activated by the P.R.R. standard coach key.

The door control shall be arranged so that the doors on a train side shall be controllable only from door control panels on that side of train. At each door control position, provision shall be made for independent control of doors forward and rearward of that position, and of the door at that position.

The panel shall be fitted with six shrouded push buttons, arranged in three vertical rows of two push buttons each. One pair of push buttons shall open and close the side entrance doors in the section of the train forward of the active control position; one pair of push buttons shall open and close the side entrance doors in the section of the train rearward of the active control position; and the third (center) pair of push buttons shall open and close the door at that position. The section of the train which each pair of push buttons controls shall be suggested by the locations of the push buttons, and the directions shall also be indicated by arrows and the words "THIS DOOR ONLY," or similar approved wording. In each pair of push buttons, the bottom button shall close and the top button shall open the doors.

Control panel shall be inoperative when not energized with the key.

Door control panels shall have an unpainted bright metal finish.

Door control switches shall be of the momentary contact type and circuitry shall be arranged so that once the button is pressed the operation cycle shall be completed even if button is immediately released.

b. Crew Switches

Key switch stations for crew use shall be provided on the outside of each car adjacent to each side entrance door. The switch shall operate the adjacent door. Operation of the switch station shall be from outside the car and it shall be possible to remove the key with the door in either the open or closed position. Key-holes on the outside of the car shall be covered with stainless steel snap covers to insure weathertightness.

The crew switches shall be activated by the P.R.R. standard coach key, and the outside switch shall be located so that it can be operated while standing on the loop step, as well as on a high station platform.

c. Emergency Door Operation

All electrically operated side doors shall be so arranged so that they may be manually opened for emergency exit.

This may be achieved by manual release of the linkage. The release lever or handle shall be located high enough so that it will not interfere with normal egress of passengers or the operation of the door. A sign "For Emergency Use Only" shall be applied near the release handle.

DOOR SIGNALS

a. Outside Door Signal Lights

A small red indicating light in an unpainted bright metal housing shall be provided above one side entrance door on each side of the car. Light shall be visible from either end of the train. The circuiting shall be arranged so that the lights shall be on when any door in the car is open.

Lights shall operate on 64 volts dc.

b. Engineman's Door Signal Lights

An engineman's signal light shall be provided in all cars. Circuiting shall be arranged so that in the leading car only, the light shall be on when all side entrance doors are closed. One signal light shall be provided for each side of the train.

Lights shall operate on 64 volts dc.

BUZZER AND BELL SIGNAL SYSTEM

a. Bell Signal - Door Closing Warning

A door-closing warning bell shall be provided at each side door. This bell shall sound for 2 to 2 1/2 seconds just before the doors begin to close. The warning bell shall be connected, with a timing relay or similar device, to the door closing control switch.

The cycle should be arranged as follows:

After pressing door close button: (momentary contact)
Bell shall ring for 2 to 2 1/2 seconds
Waiting period of 1 to 1 1/2 seconds
Door closing cycle, nominally 4 seconds

The circuitry shall be so arranged that the "Door Opening Switch" will stop the operation any time and restore the cycle to its starting point.

The entire cycle of warning bell and door closing shall not exceed 7 to 8 seconds. The timing devices shall be adjustable. (See S3.11 (a) for Side Door Operating Mechanism.)

b. Buzzer Signal

A signal buzzer shall be provided in each operating compartment arranged for 64 volts dc operation. The buzzer shall be operated by the push button located in each vestibule. (See S5.05 (c).

COMMUNICATION SYSTEMS

a. General

Communication equipment shall be provided on the cars to provide the following services:

1. One-way communication from the train crew or engineman to the passengers. (Public Address System)

2. Two-way communication between wayside stations and the engineman or train crew. (Train Radio System)

3. Two-way communication between the engineman and the train crew. (Intercommunication system)

4. Public telephone for passengers' use.

b. Public Address and Intercommunication System

1. General

The public address and intercommunication system shall permit the train crew to make announcements to the passengers by use of the speakers in the passenger areas of the cars and shall permit the engineman to page the train crew or to make announcements by use of the same speakers. It shall also permit private two-way intercommunication between any two communication control panels; for example, between train crew and engineman. All Public Address and Intercommunication equipment, including Tape Recorders, Speakers, racks, receptacles, antenna and amplifiers, will be leased by the Railroad and furnished to the Car Builder. The Car Builder shall furnish all conduit, wiring, supports and enclosures, and shall make the installation, which shall have the approval of the Railroad.

2. Tape Recorder

A tape recorder shall be installed in an approved location in the snack bar area in each of the snack bar coaches. The tape recorder shall be connected to the public address system train line and shall be so arranged that voice announcements shall override the music when such announcements are made.

The tape recorder shall be transistorized and of rugged construction and shall be arranged for continuous playing. The tape recorder shall be AMPEX 602-02 full track type or approved equal.

3. Communication and Public Address Equipment

The following equipment shall be located in the operating compartment or as close to it as possible (but not underfloor):

Public address and intercommunication amplifier unit

Train radio unit

Convenient access to this equipment for repairs and adjustments shall be provided.

4. Communications Control Panel

The communications control panel, located as described in S3.02, shall be provided in operating compartment. It shall contain:

Handset with push-to-talk button

Speaker

Selector switch with the following positions:

Off
Public Address
Intercommunication
Train Radio

Cartridge-type tape deck with reversing heads, fast forward and reverse control, signal shut-off capability, tape position indicator, and 30-minute two-track sealed cartridge for pre-recorded announcements and information.

5. Speakers

Ten speakers shall be installed in the passenger area of each car in the ceiling, evenly spaced longitudinally, and alternately mounted on opposite sides of the air duct. The distance between the end of the passenger area and the first speaker shall be one-half the longitudinal spacing between two adjacent speakers. An additional speaker shall be mounted in the ceiling of each toilet room and in each vestibule.

The speakers shall be connected in parallel with uniform polarity, to a pair of wires running the length of the car and terminating in the electrical portion of the automatic coupler. This pair of wires shall also connect to the output of the public address amplifier unit.

Such speaker shall mount behind a baffle which shall be flush mounted in the car ceiling by means of screws and hinge fittings or screws only. The baffle shall be of bright metal, or integrally colored plastic, to suit the decorative treatment of the car.

The wire used, and wiring for the speaker system, shall conform with requirements of S12.08 and S12.09. Since no significant amount of current is carried, fusing of the speaker distribution system is not required.

The speaker shall be a direct radiating, permanent magnet field type capable of handling up to 10 watts of audio power. The frequency response shall be plus or minus 5 dB from 80 to 8,000 cycles per second. The nominal axial sensitivity shall be at least 92 dB at 4 feet with 1 watt input. The speaker shall have a wide dispersion characteristic.

The speaker shall include a multi-tapped line matching transformer securely mounted on the speaker frame by the Manufacturer. The matching transformer shall have taps of 4,000, 8,000 and 16,000 ohms on the primary. The secondary of the transformer shall properly match the voice coil of the speaker. The primary of the matching transformer shall be connected to the speaker distribution wires by means of a two conductor lead which shall be provided at one end with a connector which shall plug into a matching connector in the speaker distribution circuit mounted in the car ceiling. The transformer end of the lead shall be arranged to permit connection or reconnection of the conductors to any two of the taps.

The speakers shall be phased so that when the primary is connected to the distribution line according to the labeling, all speaker cones will move in the same direction at the same time.

The speaker shall have a one piece stamped steel frame with an outside diameter of approximately 8-1/4" and shall mount to a flat baffle with four equally spaced slots or holes on a bolt circle of approximately 7-5/8" diameter. The overall depth shall not exceed 4". The cone, voice coil assembly and suspension shall be moisture resistant. All ferrous metal parts shall be made rust resistant by plating.

The speaker shall be protected by a metal or plastic enclosure. The enclosure shall adequately protect the speaker from the effects of dust, moisture, magnetic materials such as steel filings, etc. The protective enclosure shall be rustproof. It shall mount on the speaker baffle completely enclosing the speaker from the rear. The enclosure shall include knockouts and gaskets for the dust-tight entrance of the speaker connection leads. The enclosure shall be so constructed that no mechanical resonances or vibrations occur.

An example of acceptable items is as follows:

Protective enclosure	- RCA Model MI-14869
Baffle	- RCA Model MI-14874
Speaker	- RCA Model MI-12478 with addition of required connector features

Speaker, baffle and enclosure shall be supplied by the same Manufacturer. They shall be as manufactured by Electro-Voice, Inc., Jenson Manufacturing Company, LTV University, or Radio Corporation of America.

6. Amplifier

The amplifier shall consist of a completely transistorized unit, housed in an aluminum box. The amplifier shall be mounted in such a way that it may be removed from the front without removing the rear of the enclosure. All electrical connections shall be made through a fixed plug in the amplifier and a self-aligning receptacle in the back of the enclosure. The amplifier shall be secured in the enclosure by captive, tamper-proof screws of the correct size.

Design, materials and workmanship shall be of the best quality and suitable for the intended use.

The amplifier shall be capable of driving the speakers in a train of up to 20 cars.

A system transmitting a pre-amplified microphone or other input signal over train lines to the audio amplifier on each car may be used if the performance of the system is equal to that obtained by transmitting a fully amplified signal.

The gain controls shall be adjustable from the front of the amplifier with the cover in place, but shall be accessible only to authorized personnel.

All terminals and wires shall be properly identified.

With speech input, the amplifier shall operate continuously with full output, at rated input voltage, without damage to transistors or other components.

The amplifier shall be capable of operating without injury in any temperatures to which the interior of the car may be subjected with heat and air conditioning inoperative.

Handset: Handset shall be of the best quality, of a type suited for the service.

8. Switches

All switches shall be of approved design, rugged constructed, providing ample wiping contact be positive in action

9. Experience

Manufacturers of this equipment shall have proven experience in the successful design and manufacture of equipment of this type.

c. Train Radio

Provision shall be made in the communication and public address locker of each car for the installation by others, after the delivery of the cars, of two-way radio equipment.

Radio will be Wabco 2R, Motorola Motrac, or equivalent two-way railroad radio, as furnished by Radiation Service Company, Philadelphia, Pennsylvania.

All car body conduit and wiring (ending in receptacles) racks, supports, tapping, etc. shall be furnished and installed by Car Builder. "Sinclair" Model 221A type antenna shall also be installed by Car Builder, but will be furnished by Radiation Service Company.

Installation provisions shall conform to the recommendations of Radiation Service Company and the radio manufacturer.

d. Public Telephone

Provisions shall be made in each parlor car and each snack bar coach for the installation of a public telephone pay station at location as shown on the floor plan. Auxiliary equipment shall be located adjacent to the public telephone, if space permits, or in the electric locker.

Telephone equipment will be furnished after delivery of the cars.

All car body conduit and wiring (ending in receptacles), racks, supports, tapping, enclosures, etc. shall be furnished and installed by the Car Builder. Antenna shall also be installed by Car Builder, but will be furnished by others.

Installation provisions shall conform to the recommendations of the telephone manufacturer.

Each parlor car shall be equipped with an annunciator system actuated by a push button in the side wall of the car beside each seat. The annunciator shall have its indicating panel mounted vertically in the "A" end bulkhead beside the body end door opening and by the food service facility. Audible signal shall be provided by two chimes, one chime shall be located in the car by the indicating unit, and the other shall be located in the "A" vestibule.

SECTION S7 — HEATING, VENTILATING AND AIR CONDITIONING

HEATING SYSTEM

a. General

The cars shall be electrically heated by a thermostatically controlled system using a combination of overhead and floor heat. Electric heaters shall operate on alternating current direct from the main transformer, not exceeding 600 volts, and controls shall operate on 64 volt dc.

The system shall be designed to be capable of providing an inside temperature of 75^{O}F with an ambient temperature of -10^{O}F giving full consideration to heat losses to be expected at maximum operating speed.

Control of heating and air conditioning shall be fully automatic when energized by means of the heating and air conditioning control breaker located in the electric locker and the control plug in the operating compartment of any one car in a train.

b. Overhead Heat

Overhead heat shall be provided in the passenger area, toilets, vestibules and the operating compartment by electric heaters supplied as a part of the overhead air conditioning evaporator. One heater shall be provided with each evaporator unit. The heaters shall be arranged to operate in two stages. Heater staging shall be proportioned to provide the best possible operation during the reheat cycle and the regular heating cycle.

The heater coils shall be located downstream from the cooling coils, and shall have high limit thermostats to cut off power in case air circulation is stopped. The overhead heat coils shall have sufficient capacity to heat the total input of fresh air but in no case shall capacity be less than 15 kW per car end and this capacity shall be available when catenary potential is 9900 volts ac or higher.

Circuitry shall be arranged so that evaporator blowers will operate whenever power is being supplied to overhead heat coil.

c. Floor Heat

Panel type floor heating shall be provided in the passenger area and conventional type floor heating in the toilets using electric strip heaters mounted behind stainless steel heater guards along the side walls at the floor.

Strip heaters shall have voltage rating 10% above their operating voltage when catenary potential is 11,000 volts ac. Strip heaters shall have a wattage density of approximately 3 watts per square inch or less.

Air shall enter the heater guard through slots in the bottom and pass over the strip heaters. In the panel type floor heaters, it shall rise by convection through a vertical duct behind the side lining under the passenger windows and discharge through a slot in the plastic window unit just below the window. These slots shall be protected against entry of foreign material by means of stainless steel screening or grilles.

Holes shall be provided in the front of the heater guard at the top so that some air shall circulate through the heater guard without passing up behind the side lining. Heater guards shall be designed to facilitate the convection of hot air and to prevent the surfaces which may come in contact with the passengers from exceeding 140°F. Top of heater guard shall be sloped to prevent collection of dirt.

Strip heaters shall be arranged to provide two stages of floor heat. Floor heater staging shall be proportioned to provide the best possible operation during the reheat cycle and the regular heating cycle. Floor heat system shall have sufficient capacity to maintain required interior car body temperatures with the overhead heating and ventilation system shut down. In no case shall the capacity be less than 20 kW. Required capacity should be available when catenary potential is 9900 volts ac or higher.

No floor heat shall be provided in the vestibules.

See S7.01 (e) for operating compartment floor heat.

d. Layover Heat

The cars shall be equipped with layover heating system operating the first stage of floor heat only. A 45^{o} thermostat located on a seat pedestal near the middle of the car shall control this heat.

When the heating and cooling control breaker is in the "ON" position and the control plug has been removed layover heat shall be provided at the dictates of the layover heat thermostat.

e. Operating Compartment Floor Heat

The operating compartment shall be provided with a convection type floor heater having a minimum capacity of 1 kW and so designed as to maintain a temperature not less than 60^{o} in the compartment, giving full consideration to heat losses to be expected at maximum operating speed.

The unit shall be constructed of heat resistant material and contain a "Calrod" type of heater element.

Engineman shall be provided with a three-position switch for control of the operating compartment floor heater. It shall provide Off, Half Heat and Full Heat positions.

A pilot relay controlled over the control plug shall be used to control the cab heater contactor, so that heat will be available only in the operating cab in use, and to prevent the heater being inadvertently left on when the operating compartment is not in use.

Defrosting of Engineman's end window shall be by means of heated glass. See S3.09 (f).

VENTILATION

a. General

Ventilation of the car shall normally be accomplished by the blower fans supplied as a part of the overhead evaporator units. Fresh air shall enter through screened openings in the roof on each side at both ends, pass through stainless steel ducts, sloped to drain outside of the car, and filter into a plenum chamber at both ends of the car.

Recirculated air shall pass through a ceiling grille and filter into the plenum chambers at both ends of the car where it shall mix with the fresh air.

An Aireactor of Pennsylvania, or equal, air purifier shall be provided in the main air duct at both ends of the car.

The air conditioning blower fans shall force the mixed air into both ends of the main air duct from which it will be discharged into the passenger section. See S7.02. (f) for description of duct.

Fixed baffle plates shall be used to adjust the volumes of fresh and recirculated air. Baffle plates shall be located downstream of the filters. (Baffle plate shall be attached to grille with safety chain.)

A total of 900 cfm (225 cfm each fan) of air shall be exhausted from the car by four fans located above the ceiling, two at each end of the car, and by the fans built into the incinerating hoppers and rubbish incinerators. Air shall be drawn through exhaust ducts in the luggage racks into the exhaust fan enclosures from which it will be discharged through cross ducts sloped to drain, and exhausted through screened openings in the roof on both sides.

Ventilation system shall be balanced so as to provide a pressurization of the car body (body end doors closed) of 0.25 inches of water.

b. Air Diffuser

Air shall be discharged in the normal ceiling area through two rows of continuous, flush slot type air diffusers. The diffusers shall extend longitudinally on both sides of the main air duct bottom panels.

Air shall be discharged into the toilets, vestibules and operating compartment through Anemostats, or similar approved diffusers.

All exposed surfaces of the diffusers shall be of unpainted, satin finish, anodized aluminum.

The diffusers shall be designed so that the air flow may be adjusted using a screw driver on the exposed surface without dropping the panels.

c. Air Grilles

A recirculated air grille shall be provided in the vestibules, in the low ceiling at the "B" end, and in the end wall or the low ceiling at the "A" end, connecting with the air conditioning evaporator units. A recirculated air grille shall also be provided in the partition between the operating compartment and vestibule.

The grilles shall be sight-tight, have unpainted bright metal frames and be hinged to provide access to the evaporator unit controls. Grilles shall be provided with safety catch and limit chain. Grilles shall be designed to pass the required quantity of air without producing objectionable noise. The Car Builder may submit alternative recirculated air grille locations for Purchaser's consideration.

An exhaust air grille shall be located over the snack bar and parlor car food service area, connecting with the exhaust duct. The grille shall have an unpainted bright metal frame and be hinged as required to provide access to the exhaust fan. Grilles must be provided with safety catch and limit chain. A small exhaust air grille, which is described in S3.07 (j), shall be mounted in the bottom of the luggage rack exhaust air duct over each seat to exhaust cigarette smoke at its source. No exhaust or recirculated air grille shall be provided in the toilet rooms. All toilet room air shall be exhausted by the fans that are built into the incinerating hoppers.

d. Air Filters

Fresh and recirculated air shall be filtered by disposable type filters furnished in P.R.R. standard sizes. Filters shall be 2" in thickness.

e. Exhaust Fans

Air shall be exhausted from the passenger area of the car by four centrifugal type fans arranged for operation on 110 volts ac. The fans shall be mounted in a stainless steel enclosure above the ceiling at each end of the car. The fans shall be designed to provide quiet operation. Convenient access to the fans shall be provided.

f. Air Ducts

Fresh air intake and exhaust cross ducts shall be constructed of stainless steel and shall be sloped to drain outside of the car. The top and sides of the main air distribution duct shall be constructed of stainless steel. The duct shall be constructed with a diagonal splitter of stainless steel running the entire length so that a separate duct is provided for each blower. The bottom shall be formed by the integrally colored melamine-faced plymetal ceiling panels.

Flexible transition ducts of Neoprene coated fiberglass fabric shall connect the overhead air conditioning units to the main air distribution duct. Transition ducts shall be fire resistant and shall be able to withstand, without damage, the maximum temperature developed by the overhead heat unit before over-temperature cut-off in the event of blower failure.

g. Roof Ventilators

Air intake and exhaust openings in the roof shall be round in shape covered with stainless steel expanded metal screening, and set in stainless steel rectangular frames.

AIR CONDITIONING SYSTEM

a. General

Car Builder shall submit Drawings and Specifications of thermostatically controlled air conditioning system, capable of handling 3600 cfm of air at full speed. Ducts shall be capable of handling 4000 cfm of air at a maximum velocity of 1200 ft/min. without objectionable noise. Air distributor design shall be approved by Purchaser.

The cars shall be air conditioned using electro-mechanical equipment having sufficient capacity to cool the cars under the following temperature conditions (but in no case shall the capacity be less than 12 tons):

Ambient Temperature	-	95^{o} F Dry Bulb (105^{o}F Dry Bulb air into condenser)
	-	78^{o} F Wet Bulb
Inside Temperature	-	75^{o} F Dry Bulb
(Passenger Area)	-	55% relative humidity
Passenger Load	-	80

Relative humidity in car must not exceed 60 percent under any condition. The system shall use refrigerant 12.

b. Cooling, Heating and Blower Units

The cars shall be equipped with two overhead cooling units each enclosed in the plenum changer located above the low ceiling at the ends of the cars. Each unit shall consist of an evaporator, a centrifugal blower fan and an electric heater.

The evaporator coil shall be constructed with copper tubes and aluminum fins and shall be split for modulated cooling. Minimum fin thickness shall be 0.008".

The blower fans shall be arranged for 220 volt, 3 phase to cycle ac operation and each shall handle the following volumes of air:

Fresh Air	-	600 cfm
Recirculated Air	-	1200 cfm
Total Circulated Air	-	1800 cmf

c. Compressor - Condenser Unit

Each car shall be equipped with a hermetically sealed compressor and compressor motor, liquid receiver, air-cooled condenser, condenser fan and motor, high and low pressure cutouts, safety switch, suction and discharge gauges, motor starters, contactors, etc., all combined in a single unit.

The condenser coil shall be constructed of copper fins. Minimum fin thickness 0.008". The compressor shall be the unloading type for modulated cooling.

The compressor-condenser unit shall be resiliently mounted under the floor of the car and arranged for 220 volt, 3 phase, 60 cycle ac operation. The unit shall operate satisfactorily with any catenary potential between 9900 and 12,100 volts ac.

d. Insulation

The sides of the main air distribution duct shall be insulated with 1" thick unfaced fiberglass cemented to the duct with waterproof adhesive and retained with fireproofed muslin.

Refrigerant suction lines above the floor shall be wrapped with asbestos covered hair felt insulation. Drain lines above the floor shall be insulated with asbestos tubing.

e. Manufacture

Air conditioning compressor-condenser unit, and evaporator unit shall be as manufactured by Safety Electric Equipment Corporation, Trane Company or approved equal.

HEATING AND AIR CONDITIONING CONTROLS

a. General

The heating and air conditioning control system shall be energized by means of the heating and air conditioning control breaker (normally left closed) in the electric locker and the insertion of the control plug in its receptacle in the operating compartment. The heating and air conditioning control breaker shall in the "OFF" position completely shut off air conditioning and heating. In the "ON" position it shall set up lay-over heat (for control by layover thermostat) and set up normal heating and cooling so that it may be energized by the insertion of the control plug in any operating compartment in the train.

The control system shall permit pre-cooling of cars by insertion of a special plug in any control plug receptacle in the train. The plug shall energize the cooling and heating controls in all cars without energizing any of the other control circuits.

The heating and air conditioning system shall be controlled by preset liquid filled bellows thermostats or mercury tube thermostats and transistorized or pilot relays.

Humidity control shall be provided through a re-heat cycle using the overhead cooling and heating coils.

Care shall be taken in mounting thermostats to insure that they are not unduly influenced by local sources of heat, such as motors or resistors; also, that they are not exposed to sun load or outside air and are reasonably tamperproof.

All heating and air conditioning apparatus and controls shall meet the requirements of A.A.R. Electric Section - Recommended Specifications for Air Conditioning, unless otherwise approved by the Purchaser. Exception: The requirement of $1/4^{\circ}$ accuracy of the thermostats. Thermostat accuracy shall be that required to comply with the requirements of S7.04 (b) 1. The electric heating controls and/or apparatus shall be approved by the Purchaser.

b. Required Interior Car Temperatures

The following temperatures shall be maintained within the car (including toilet rooms) when the associated ambient temperatures are present:

Ambient	Interior Car Temperature
$0^{o}F$ to $55^{o}F$	$72^{o}F$
$55^{o}F$ to $95^{o}F$ (Interior temperature requiring reheat)	$71^{o}F$ to $73^{o}F$ depending on functioning of reheat cycle.
$55^{o}F$ to $95^{o}F$ (Interior temperature not requiring reheat)	$74^{o}F$ to $75^{o}F$
Above $95^{o}F$	$20^{o}F$ below ambient (this is an air conditioning apparatus limitation, not a control function).

Under no condition shall the relative humidity exceed 60%.

The temperature in the vestibule, with side doors closed, shall be no more than $10^{o}F$ higher than the interior car temperature when air conditioning is in use; and shall be no more than 20^{o} lower than the interior car temperature when heating is in use.

The temperature in the operating compartment, with side window closed and operating compartment heater turned off, shall conform to the requirements for interior car temperature when air conditioning is in use; and shall be no more than 10^{o} lower than the interior car temperature when heating is in use.

The following variations in interior car temperatures are the maximum that shall be allowed:

1. At any given point in the car, between the low ceiling sections and at least 12" from the ceiling and 6" from the floor and walls, throughout the cycling of the heating and cooling apparatus (except low temperature modulated cooling cut-off in reheat): 2°F.

2. At any given time, except during pull-down and warm-up, among 11 points in the same horizontal plane from one end of the car to the other (except under low ceiling sections where 3° variation is acceptable): 2°F.

3. At any given time, except during pull-down and warm-up, between any point approximately 48" above the floor and the corresponding point 6" above the floor in a vertical plane: 2°F.

c. Suggested Control Arrangement

The following is a suggested arrangement of thermostats to obtain the control desired. Car Builder may submit, for approval, alternate arrangements to obtain the same results. Use of this suggested control arrangement shall in no respect relieve the Car Builder of responsibility for the satisfactory functioning of the system.

Location	Function
1. In fresh air duct, (at "A" end of car)	Reheat set-up, closed above 55°F ± 3°. Set up modulated cooling through a 71°F control thermostat. Set up first stage of overhead heat through 73°F control thermostat.
	Set up floor heat, second stage below 45°F ± 3°.
	Set up overhead heat second stage - below 20°F ± 3°.

Location	Function
2. Behind recirculated air grille and upstream of filters ("A" end of car) mercury tube thermostats or liquid filled bellows thermostats.	Control full cooling to maintain car temperature of 75^{o}.
	Control modulated cooling to maintain car temperature of 74^{o}F (active only when the fresh air reheat thermostat is open).
	Control first stage overhead heat for reheat cycle to maintain car temperature of 73^{o}F.
	Control floor and overhead heat to maintain car temperature of 72^{o}F.
	Control modulated cooling for reheat cycle to remove cooling at a car temperature of 71^{o}F and restore it at a temperature of 73^{o}F.
3. On wall side of seat pedestal in center of car	Control layover heat - floor heat only - to maintain car temperature of $45^{o}F \pm 5^{o}$.
4. At each overhead heating unit	High limit cutout.

APPROVALS

The entire heating, ventilating and air conditioning system, including apparatus and controls shall be submitted to the Purchaser for approval before any manufacturing is commenced.

4.1 Contamination consisting of hydrocarbons, ozone, water, salt spray, and complete encrustment by ice or snow.

4.2 Vibration and shock - (3 Axis): Continuous from 20 to 100 Hz at 6.0 G's (10 milliseconds).

5.0 PROTECTION

5.1 Input transients, Paragraph 3.1.1, low voltage, or reversed polarity to the battery will not damage the circuit.

5.2 Output current is limited, Paragraph 3.1.2, and circuit damage will not occur if the unit is to operate continuously into a short circuit at 120°F.

5.3 External equipment protection is provided in the event of a charger failure by limiting maximum fault current to 75 amperes for five (5) seconds maximum.

5.4 All protection shall be automatic.

6.0 RELIABILITY

6.1 Calculated meantime between failures: 10,000 hours.

6.2 Service life is 15 years operation with minimum maintenance.

SECTION S8 — LIGHTING

LIGHTING – PASSENGER AREA

a. General

Passenger area lighting shall be by means of an approved arrangement of background cove lighting, aisle lights located under every other seat, and individual reading lights. Background lighting shall employ hot cathode fluorescent lamps operating on 220 volt (nominal), 60 cycle, ac with the actual voltage requirements being coordinated between the lighting manufacturer and the motor-alternator set manufacturer. Reading lights and aisle lights shall operate on 60 cycle, ac.

The lighting system shall not produce objectionable glare, shall not deteriorate rapidly in effectiveness through the collection of dirt, shall permit easy cleaning and easy renewal of lamps, and shall be free of rattles.

b. Intensity

The intensity of illumination at an elevation of 33" above the floor and on the upper surface of a transverse 45^{o} plane at passenger seats, with reading lights only, shall be 20 to 25 foot-candles at rated voltage when the equipment is new.

The lighting intensity in the aisle shall be 15 foot-candles on a horizontal plane 33" above the floor.

c. Arrangement

Background lighting shall be arranged so as to provide general indirect illumination of the passenger area, and shall also illuminate the top surface of luggage rack.

Reading light fixtures shall be located in the bottom of the luggage rack. Each passenger shall have an individual reading light, controlled by an easily accessible switch. Fixtures shall be of an approved type and design.

d. Construction

Fluorescent fixtures shall be designed to accommodate 48" T-12 lamps, except as approved by Purchaser. Fluorescent fixture sockets shall be an approved spring type and designed to provide support to the edge of the lamp in addition to that obtained from the terminal pins by means of fiber locking devices or similar arrangement. The ballasts and resistors shall be integral parts of the fixtures and shall be conveniently located on the fixture. Necessary ballasts and resistors shall be provided to assure proper operation of the lamps.

Reading light fixtures may be individual for each passenger, or the two lights for a two-passenger seat may be combined in a single fixture. Lenses shall focus the light in the best pattern for each passenger's reading, regardless of direction seats are facing.

All fixtures shall have lenses of tempered glass and shall be arranged for re-lamping from the front. Fixtures shall be dust and moisture proof. Cove lights shall have lenses top and bottom, in order to illuminate both ceiling and side wall. Lamps shall be of an approved type and color.

e. Control

Passenger area lighting control shall be trainlined. A control switch shall be provided in each Communications Control Panel which shall permit the train crew to illuminate one row of fluorescent tubes in the cove fixtures. The aisle lights, the other row of fluorescent tubes in the cove fixtures, and the reading lights shall not be trainlined.

LIGHTING – OTHER AREAS

a. Intensity

Lighting intensity in vestibules and passageways shall equal or exceed A.A.R. requirements.

b. Vestibule Lighting

An approved incandescent light fixture with lens, operating on 60 Vdc shall be located in the ceiling over the steps at the "B" end of the car and in corresponding locations at the "A" end. Light fixtures shall be located so as to illuminate the steps.

c. Low Ceiling Area Lighting

Low ceiling areas shall be illuminated by approved incandescent fixtures operating on 110 V, 60 cycle, ac, or fluorescent fixtures operating on 220 V, 60 cycle, ac.

d. Toilet Room Lighting

An approved cove type fluorescent fixture with an emergency lamp shall be mounted between the two stainless steel pilasters above the urinal and hopper.

e. Snack Bar Lighting

Lighting arrangement in the snack bar area shall be submitted by the Car Builder as part of the overall lighting arrangement. In general, it shall consist of fluorescent indirect lighting substantially similar to the passenger area fluorescent indirect lighting; additional fluorescent or incandescent fixtures shall be used for adequate local illumination of counters, attendants' working area, etc. Snack bar lighting shall be controlled by switches in the snack bar area.

HEADLIGHTS AND MARKER LIGHTS

a. Position

Dual headlights and a Translite Inc., "Gyralite", or similar approved oscillating white light shall be provided at the "A" end of each car. Headlights and oscillating lights shall be enclosed by a watertight glass shroud.

Two red marker lights shall be furnished on each end of each car. Headlight and oscillating light locations shall be subject to Purchaser's approval. Marker lights shall be located above the end window at the "A" end of the car, and at a similar height at the "B" end. A single "back-up" light shall be provided at the "B" end. Oscillating light shall not be required to exhibit a red light.

b. Headlights and Back-up Lights

Headlights shall consist of two sealed beam lamps each 200 W, nominal 30 V, mounted in a Translite, Inc. or approved equal fixture, and shall be adjustable with headlight locking device to permit proper horizontal and vertical alignment and shall comply with I.C.C. Rule 91-425. Back-up light shall consist of a single sealed beam lamp, 200 W, nominal 30 V, mounted in a Translite, Inc. or approved equal adjustable fixture.

c. Source

Headlights, oscillating light, back-up light and marker lights shall be arranged to operate on the battery circuit. Lights shall not be wired in series.

d. Servicing

Headlights and marker lights shall be designed for relamping and for aiming from the interior of the car.

e. Control

The headlights, marker lights and number sign lights shall be controlled in each cab by an approved arrangement of switches.

EMERGENCY LIGHTS

a. Location

Each coach shall be provided with eighteen emergency lights of suitable design, eight recessed within the indirect fluorescent lighting fixtures, eight incorporated in the aisle fixtures, and one in the ceiling fixtures in the low ceiling area at each body end door. An additional emergency light shall be provided in each toilet room, if toilet room lights are operated on ac.

b. Control

Emergency lights shall be controlled by relays so designed that when any of the car body lighting switches is closed, and the source of the car body lighting circuits is interrupted, the emergency lights shall be energized from the battery circuit.

ILLUMINATED CAR NUMBER SIGNS

a. Location

Each car shall be provided with two illuminated car number signs, located as described in S5.03 (b).

b. Source

Illuminated car number signs shall operate on the battery circuit.

c. Control

Car number signs shall be displayed whenever the headlight is illuminated, whether bright or dim.

ILLUMINATED ENTRANCE AND EXIT SIGNS

a. Location

The car shall be provided with illuminated entrance and exit signs at each end of the passenger area, in the low ceiling header, and adjacent to each side entrance door on the outside of the car.

b. Wording

Interior sign at "A" end of car shall read "EXIT". Interior sign at "B" end of car shall read "ENTRANCE ONLY - EXIT OTHER END." Exterior signs by "A" end side doors shall read "EXIT ONLY - ENTER OTHER END."

Exterior signs at "B" end side doors shall read "ENTRANCE."

Wording shall be approved by Purchaser.

Illumination of signs shall be controlled by a trainline. A control switch shall be provided in each communications control panel for use by the train crew. The interior signs shall appear blank when not illuminated.

ILLUMINATED "NO SMOKING" SIGNS

Signs which display the words "No Smoking" when illuminated shall be provided at both end of the Coaches, adjacent to the Entrance and Exit Signs. Switch (not trainlined) shall be located in each Car Lighting switch panel. When not illuminated, the signs shall appear blank.

SECTION S9 — AUXILIARY POWER SYSTEM AND APPARATUS

GENERAL

This section describes the various pieces of apparatus, switches, panels, etc. to be supplied to perform the required auxiliary functions required on the car.

All apparatus supplied shall be designed for immediate operation at 11,000 volts, 25 cycle, but shall have the capability of conversion to 25,000/11,000 volt, 60 cycle operation at some future date. To facilitate this conversion the affected auxiliary load shall be supplied from the alternator of the motor alternator set to the greatest extent possible. Furthermore, the arrangement and design of the apparatus shall, with the future addition of the required devices and accessories, allow the car to operate on a mixed frequency system changing over from one frequency or voltage system to the other enroute, by the movement of a control switch by the engineman or receipt of an appropriate signal from the wayside. The possible range of power system voltage and frequency are: 11,000 volts, 25 cycles; 11,000 volts, 60 cycles; 25,000 volts, 60 cycles.

The entire auxiliary power system except for the battery and air compressor, and not necessarily including auxiliary device protection breakers, shall be the responsibility of the supplier of the propulsion and control system apparatus specified in S10. All apparatus to be supplied shall be manufactured by this supplier or under his control. The following apparatus shall not required replacement when conversion to 60 cycle or mixed frequency operation is made: Transformer, Auxiliary Power Supply, Reactors, Traction Motors and Rectifiers. Circuitry shall be capable of being readily revised for 60 cycle or mixed frequency operation. Space provisions shall be made for the required devices and accessories for mixed frequency changeover.

MOTOR ALTERNATOR

a. Location

A motor alternator set shall be provided on each car. The set shall be dynamically balanced, supported on suitable vibration isolated mountings, and equipped with a ground connection. The set, when operating under full load, shall conform to the manufacturer's rating, and shall be capable of quiet, safe and ample performance with 11,000 volts ±10 percent on the overhead wire. The set shall be arranged for ready removal and replacement, ordinary inspection, servicing and adjustment. Safety straps shall be provided.

b. Lubrication

The motor alternator set shall be equipped with "sealed relubricable" anti-friction type bearings of approved type with fittings for supplemental lubrication.

c. Motor

The motor of the set shall be a shunt wound dc motor and shall have sufficient capacity to drive the alternator while it is delivering all power required for air conditioning, air compressor, apparatus ventilating blowers, fans, other auxiliary equipment, car lighting, controls, and battery charging. Motor shall have its field excited by the same voltage that is applied to its armature, and its speed regulation shall be sufficiently low that the alternator output will be maintained at 55 to 65 cycles. Power supply to motor shall be from main transformer and rectified by silicon diodes. If required to maintain this frequency, speed control, preferable using only static devices may be provided.

d. Alternator

The alternator of the motor alternator set shall deliver nominal 220 volt, 3 phase, 60 cycle power and shall have sufficient capacity to start individually the various compressors and to supply simultaneously the air conditioning apparatus, air compressor, apparatus ventilating blowers, fans, car lighting, controls, and battery charging. The alternator shall be of the brushless type.

e. Regulation

The motor alternator set shall be equipped with a voltage regulator. This regulator shall be capable of maintaining the output voltage constant within plus or minus five percent over the range from no load to 125 percent load.

f. Starting Preference

Control shall be provided to insure that compressors will not start simultaneously. This control shall be the responsibility of the motor alternator set manufacturer.

g. Noise

The noise level of the motor alternator shall not exceed a maximum of 85 decibels as recorded on the flat response scale of a standard sound level survey meter located 20 feet from the centerline of the track, in line with and on the same side as the motor alternator.

MOTOR BLOWER UNITS

a. Location

A motor blower set or sets shall be provided on each car as required to provide equipment ventilation. Each set shall be dynamically balanced, supported on vibration-isolation mountings and equipped with a ground connection. The noise level of each unit shall be no more than 85 decibels under the same conditions established in S9.02 (g). Each set, when operating under load, shall conform to the manufacturer's rating and shall be capable of quiet, safe and ample performance at rated supply voltage plus or minus 5 percent. The set or sets shall be arranged for ready removal and replacement, ordinary inspection, adjustment and servicing. Safety straps shall be provided. Air intakes to the blowers shall be shielded and shall be located to reduce the possibility of their clogging with debris.

b. Lubrication

The motor blower set or sets shall be equipped with "sealed relubricable" anti-friction bearings of approved type with provisions for supplementary lubrication.

c. Motor

The motor for each of these sets shall be a 220 volt 3 phase 60 cycle induction motor and shall have sufficient capacity to drive the cooling blower to which it is attached while delivering the required volume of air at the proper static pressure.

STORAGE BATTERY

a. Battery

Each car shall be provided with a 64 volt nickle iron alkaline battery of approved type, arranged in four 13-cell trays. The rated capacity shall be not less than 112 ampere hours with a five hour discharge rate.

b. Connection

The batteries of all cars in a train shall be connected in parallel through the B-minus trainline. A B-minus trainline shall run throughout and shall not be grounded on the car body.

c. Breaker

A 100 amp battery circuit breaker of approved design shall be mounted in the lighting and control breaker panel, but shall have no automatic tripping device. Breaker shall be as specified in S9.05 (a) 3.

d. Box

The battery shall be housed in an approved rattle-proof plastic or stainless steel battery box located under the car floor in an approved convenient location. Ventilation shall be provided through holes in the box.

The batteries shall be mounted lengthwise and accessible for servicing. Cover shall be hinged at the top and shall be reasonably watertight. See S3.03 (p) for further description of underfloor boxes.

SWITCH AND BREAKER PANELS

a. General Arrangement

1. <u>Panel Arrangement</u>: Switch and breaker panels shall be built into the electric locker to house the electrical apparatus as described below. The panels shall be of laminated phenolic of approved quality suitable for switchboards. Each panel shall carry the necessary apparatus, so arranged as to be easily accessible to connections and designed to prevent an operator from coming in contact with live parts when operating switches or replacing fuses. Each switch and breaker shall be provided with a nameplate clearly identifying the circuit which it controls. The backs of all panels shall be accessible.

2. <u>600 Volt Switches and Breakers</u>: 600 volt switches shall be of the toggle action, indicating type, or approved equivalent. The 600 volt breakers shall be of approved manufacture and mounted under the car. Breaker shall be an approved type of high shock resistant design suitable for railway service.

3. <u>64 Volt Breakers</u>: All 64 volt dc battery circuits requiring overload protection shall be provided with circuit breaker type switches with magnetic and thermal type trip as manufactured by the General Electric Company or Westinghouse Electric Corporation, or approved equal, and shall clearly show "ON" and "OFF". Breaker shall be of an approved type of high shock resistant design suitable for railway service.

4. <u>220 Volt Switches and Breakers</u>: 220 volt switches shall be of the toggle action, indicating type, or approved equivalent. The 220 volt breakers shall

be of approved manufacture. Breaker shall be of an approved type of high shock resistant design suitable for railway service.

b. Engineman's Control Console

An engineman's control console shall be located in each operating compartment, as specified in S3.02 3., and shall consist of the following switches and apparatus:

Headlight, gauge and speedometer light and number sign light, double pole, double throw switch with center "off" arranged for "dim" and "bright" headlight operation (gauge and number sign lights to be illuminated when headlight is either dim or bright).

Oscillating headlight switch.

Buzzer cut-out switch.

Operating compartment heater.

Defroster control (heated glass).

Pantograph raise button.

Pantograph lower switch.

Trainlined dynamic brake cut-out switch with red indicator light.

Three duplex air guages - See S10.12 (o).

Master controller - electrical control with reverser and deadman control. Handle shall rotate in longitudinal vertical plane.

Brake valve

Control plug receptacle

Speedometer with electric recorder

Cab signal

Windshield wiper control

Horn valve

Door indicator lights

Coupler control

Order and timetable light and switch

Console illumination switch with rheostat to provide variable intensity.

Hook for pocket watch

Brake test lights

Train speed control cutout switch

Control reset button

Propulsion system protective device indicating light (overload, ground relay and hot transformer)

Console shall be arranged in a neat and orderly fashion with all lights, switches, controls located in a manner that shall not cause confusion to the engineman. Console shall be back-lighted using translucent plastic identification signs which shall not produce glare or shall be "black lighted" using an ultraviolet light source and luminescent identifications. Other means of producing effective, glare-free illumination may be submitted for consideration. Console illumination shall be submitted to the Purchaser for approval.

c. Lighting and Control Breaker Panel

A lighting and control breaker panel shall be located in the electric locker. This panel shall consist of the following breakers and switches:

1 - Marker light and backup breaker - 2 pole.

1 - Headlight breaker - 2 pole.

1 - Gauge light and number sign light breaker - 2 pole.

1 - Oscillating headlight breaker - 2 pole.

1 - Emergency light breaker - 2 pole.

1 - Control cutout breaker - 1 pole.

1 - Battery breaker - 2 pole.

1 - Heating and air conditioning control breaker - 2 pole.

1 - Cab signal power breaker - 2 pole.

1 - Interior and exterior entrance-exit sign and No Smoking sign light breaker - 2 pole.

3 - Fluorescent car body lighting breakers - 2 pole.

2 - Reading light and Aisle light breakers - 2 pole.

1 - Toilet room light breaker.

1 - Vestibule light breaker - 2 pole.

1 - Pantograph control switch with switch positions DOWN and TRAINLINE.

1 - Communication system power breaker.

1 - Dynamic braking cutout switch.

1 - Door control power breaker - 2 pole.

1 - Door operator power breaker - 2 pole.

1 - 110 volt supply breaker - 2 pole.

2 - Motor cutout switches - 2 pole.

1 - Compressor governor cutout breaker.

1 - Test jack for portable ammeter.

1 - Dynamic brake test receptacle.

d. Car Lighting Switch Panel

A car lighting switch panel will be located in the door of or adjacent to the electric locker with switches operable from the aisle. This panel shall consist of single throw switches to control the following circuits independently: Cove Lights No. 1; Cove Light No. 2; Aisle Lights; Reading Lights; Low Ceiling Lights; No Smoking Signs. Each Cove light and Aisle light switch shall be so arranged that any one switch or combination will energize the emergency light circuit as far as the emergency relay.

e. Vestibule and Market Light Switch Panel

A vestibule and marker light switch panel shall be located in the ceiling of each vestibule. Each panel shall contain two single pole single throw switches. One switch shall control the vestibule lights in that vestibule. The other switch shall control the marker lights at that end of the car. At the "B" end, the panel shall also include a switch for the back-up light.

f. Auxiliary Power Breaker Panel

An auxiliary power breaker panel shall be located in a box under the car, accessible from the side of the car. This panel shall contain the following breakers:

2 - Floor heat breakers.

2 - Evaporator heater breakers (one for each evaporator heater).

2 - Snack bar breakers (one 60 cycle and one 25 cycle), snack bar coaches only.

2 - Food service facility breakers (one 60 cycle and one 25 cycle). Parlor cars only.

2 - Water heater breakers. (One on parlor car.)

1 - Incinerator breakers (all coaches).

1 - Breaker for each toilet and urinal on car.

1 - Main lighting breaker - 3 pole.

1 - Transformer coolant pump breaker.

1 - Receptacle transformer primary breaker.

1 - Battery charging transformer primary breaker.

1 - Motor alternator set motor breaker.

1 - Motor alternator set alternator breaker - 3 pole.

1 - Blower motor breaker - 3 pole (one breaker for each blower motor).

1 - Air compressor motor breaker - 3 pole.

1 - Operating compartment heater breaker - 2 pole.

See S3.03 (p) for description of underfloor boxes.

An air conditioning breaker panel shall be located in a box under the car near the air conditioning condensing unit. This panel shall be accessible from the side of the car and shall contain:

1 - Compressor motor and condenser motor breaker - 3 pole.

2 - Evaporator motor breaker - 3 pole.

See S3.03 (p) for description of underfloor boxes.

g. Snack Bar Breaker Panel

The breaker panel for all snack bar power shall be located in the snack bar area. This includes both the 60 cycle and 25 cycle power. A suitable and readily accessible main junction box shall be installed in the compartment. This panel is to contain all necessary terminal boards, circuit breakers and other items needed to enable distribution and protection of wiring and equipment for the snack bar including:

Hot plates
Meat warmer
Warming cabinet
Water heater
Refrigeration equipment
Coffeemakers
Soup containers
Local lighting
Auxiliary outlets

The snack bar manufacturer shall be responsible for fully coordinating with the car builder and the engineer to assure that the design and installation of the electrical power system is acceptable.

AUXILIARY ELECTRICAL SYSTEM – ARRANGEMENT

a. Trolley Power

Trolley voltage, after being transformed and converted, shall be used for car propulsion, heating, snack bar, food service facilities, car body lighting (except emergency lamps), other auxiliaries, and air conditioning apparatus.

b. Battery

Headlights, marker lights, cab signals, number signs, instrument lights, door controls, door operators, communication systems, emergency lights, and heating, air conditioning and traction controls shall receive their power from the battery.

c. Battery Charging

The battery shall be charged through a three phase transformer and silicon rectifier taking power from the motor alternator set.

d. Voltage Regulator - Battery Output

An inline completely static voltage regulator shall be supplied to control the voltage supplied to the cab signals, communication systems, headlights, marker lights, vestibule lights and emergency lights. It shall maintain 64 volts plus or minus three percent.

e. Circuit Layout

Car builder shall submit proposed circuit layouts for approval by purchaser.

f. Receptacles - 110 Volt

Six receptacles supplying 110 volt 60 cycle power from the motor alternator set through a small single phase (or three phase, if required) transformer shall be provided in each car. One shall be located in each side wall below the seats at the diagonally opposite quarter points; one on the car body side of "A" end bulkhead below seat level; one in the aisleway partition at the "B" end of the car; and one in each toilet room. Receptacles shall be rated at 15 amps 110 volts and will be used to operate vacuum cleaners as used by car cleaners, electric shavers, etc. Two additional such receptacles shall be provided in each snack bar area and one each in the Parlor Car Food and Beverage Galleys.

g. Snack Bar Power

Snack bars in those coaches so equipped shall be supplied with 220/110 volt power directly from the main transformer. An auxiliary transformer may be used if required to provide proper voltage.

20 kW of 25 cycle power shall be made available to the snack bar. Snack bars shall also be supplied with 5 kW of 60 cycle power for refrigerators and freezers.

h. Food Service Facility Power

The food service facility in the parlor cars shall be supplied with 220/110 volt power directly from the main transformer. An auxiliary transformer may be used if required.

20 kW of 25 cycle power shall be made available to the food service facility. Food service facilities shall also be supplied with 5 kW of 60 cycle power for refrigerators and freezers.

APPENDIX D. REFERENCES

1. High Speed Multiple Unit Electric Car Equipment
   Pennsylvania Railroad Northeast Corridor
   Demonstration Project
   Maintenance Manual
   Transportation Systems Division
   General Electric Company
   Erie, Pennsylvania

2. Inspection and Maintenance of Propulsion and Auxiliary
   System Control and Rotating Apparatus for the Penn
   Central Company Metroliner Multiple Unit Cars
   Maintenance Book
   Westinghouse Electric Corporation
   Transportation Division
   East Pittsburgh, Pennsylvania

3. Draft Report of Government-Industry Task Force
   on the Washington-New York High Speed Rail
   Service Demonstration Project
   May 20, 1968

4. Metroliner Design Specification
   Louis T. Klauder and Associates
   Philadelphia, Pennsylvania

5. The Nickel-Iron Industrial Storage Battery -
   Its Fundamental Principles, Operation and Care
   Exide Industrial Marketing Division
   The Electric Storage Battery Co.

6. Installation, Maintenance and Operating
   Instructions - Exide Nickel-Iron Batteries
   Exide Industrial Marketing Division
   The Electric Storage Battery Co.

7. The Nickel-Cadmium Storage Battery - Its
   Fundamental Principles, Operation and Care
   Industrial Group
   The Electric Storage Battery Co.

8. NEMA Standards Publication: Motors and Generators
Pub No. MG 1-1967
National Electrical Manufacturers Association

The following people have been contacted and have provided valuable information to this report:

LOUIS T. KLAUDER & ASSOCIATES
- Donald Adams
- Al Ferrari
- Thomas Lynch
- Karl Mallory, Jr.
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GENERAL ELECTRIC CO.
- John Bell
- Robert Brey
- John Cunningham
- Carl Lewis

GULTON INDUSTRIES, INC.
- Mitchell Bernard
- Burton McComb
- James Snodgrass

EXIDE POWER SYSTEMS
- James Byrne
- Joseph Blankely

J. W. MARCHETTI, INC.
- John Marchetti
- Roy Pennini

APPENDIX E. BATTERY CHARGER INFORMATION

This Appendix includes information which pertains to battery chargers which was compiled during the course of the Metroliner Reliability Study. It is included here for reference. The information compiled includes:

1. Specification for Battery Charter DMBC164
   Engineered Magnetics Division
   Gulton Industries, Inc.

2. Specification: Battery Charger EMBC171
   Engineered Magnetics Division
   Gulton Industries, Inc.

SPECIFICATION FOR BATTERY CHARGER EMBC164

1.0 SCOPE

This specification describes the electrical and mechanical characteristics of a battery charger to be used with a pocket plate nickel cadmium storage battery rated at 120 ampere hours at an eight-hour discharge rate, ED 120 or equivalent. The battery consists of 25 cells.

2.0 GENERAL DESCRIPTION

2.1 ELECTRICAL

Supply voltage will be 34 Vac - 3Ø provided by appropriate taps on the control/lighting transformer. A fully discharged battery is charged to rated capacity in six hours.

An SCR rated at 75 amperes puts the battery on the train line if a drop of 10 percent occurs in the input voltage.

2.2 MECHANICAL

The enclosure is a Hoffman A-16 H 12 ALP (6 x 12 x 16 inches) or equivalent Nema type 4. Mounting consists of flanges drilled to accept (4) 5/16 inch bolts.

3.0 DETAILED REQUIREMENTS

3.1 ELECTRICAL

3.1.1 Input voltage is 34 Vrms - 3Ø - 3 wire - 48 to 60 Hz, with transients of 3,000 volts for 5 microseconds.

3.1.2 Output is a maximum of not less than 20 amperes at a voltage sufficient to fully charge the battery discharged condition to 100 percent of rated capacity in six hours.

3.1.3 Automatic operation results in the charger going into the charging mode when the battery is at less than rated capacity. When the battery reaches approximately 85 percent of full charge, the charger goes into a controlled voltage pulse charge mode until the battery reaches full capacity. At that time the charger will not provide charging current or voltage until the charge on the battery falls below its raged capacity due to leakage, load, or self discharge.

3.1.4 Temperature control is provided by an external sensor mounted in the battery box and connected to the charger by a two-conductor shielded cable. Charging does not occur when battery temperature is outside the limits of $0^{\circ}F$ to $120^{\circ}F$.

3.1.5 Undervoltage will shut the charger off when the input is insufficient for normal operation.

3.1.6 Load connection is by means of an input level detector switching the battery on line when the input drops 10 percent below normal. When input voltage is correct, the battery is off line and connected to the charger. The switch is an ACR with a rating of 75 amperes continuous.

3.1.7 Duty cycle capability continuous at rated level.

3.1.8 Connections for input and outputs are 5/16 studs and have a weather-proof cover attached to the case permanently to prevent its loss.

3.1.9 Insulation between case and input or output terminals to withstand 3000 Vrms - 60 Hz for 1 minute without damage.

3.1.10 Radio interference shall be limited to a maximum intensity of 1.5 microvolts/meter at 10 feet in any direction from the enclosure (450 kHz to 250 MHz).

3.1.11 A timer with a six-hour period shall be started when the charger starts charging the battery. Each time the charger is shut off by the operation of its voltage detection circuitry, the timer will be reset to zero. Time-out of the timer shall shut the charger off. With the charger locked off by the timer, the charging operation shall be restored by interrupting the ac input for approximately three minutes. Charger lockout by the timer shall be indicated by a lamp located on the case.

3.2 MECHANICAL

3.2.1 Enclosure meets NEMA-4 standards, is approximately 6 x 12 x 16 inches with provisions for four 5/16 inch mounting bolts. It is sealed against water, snow, ice and such other contaminants as exist in railroad operation. Electrical connections are watertight.

3.2.2 Finish is gray hammertone enamel inside and out over phosphatized surfaces.

4.0 ENVIRONMENT

The charger operates under the following external environmental conditions.

4.1 TEMPERATURE

Temperature range: $-40^{\circ}F$ to $+140^{\circ}F$.

SPECIFICATION FOR BATTERY CHARGER EMBC171

1.0 SCOPE

This specification describes the electrical and mechnical characteristics of a battery charger to be used with a pocket plate nickel cadmium storage battery rated at 240 ampere hours at an eight hour discharge rate, ED240 or equivalent. The battery consists of 26 cells.

2.0 GENERAL DESCRIPTION

2.1 ELECTRICAL

The charger shall operate from a nominal input voltage of 45 Vac, 3Ø, 60 Hz and will draw 50 amperes maximum to charge a fully discharged battery to rated capacity in 10 hours. There are no special requirements relating to ripple or impedance on the supply voltage.

The battery will be isolated from the load by a switching device during charging and connected to the car loads, defined as 315 amperes for 75 seconds and 230 amperes continuously, when the car load voltage supply drops to 35.5 ±0.5 Vdc.

2.2 MECHANICAL

Maximum dimensions of the charger will be 13 inches x 7 inches x 16 inches. Mounting dimensions are 10 inches x 14-3/4 inches on centers. (4 - 5/16 inch diameter holes.)

3.0 DETAILED REQUIREMENTS

3.1 ELECTRICAL

3.1.1 Input Voltage. The input voltage will be 45 Vac ±5 percent, 3Ø, 60 Hz ±5 percent.

3.1.2 Output. The output current will be regulated to 41 ±1 amperes.

3.1.3 Automatic Operation. Automatic operation results in the charger going into the charging mode when the battery is at less than rated capacity. When the battery reaches approximately 85 percent of full charge the charger goes into a controlled voltage pulse charge mode until the battery reaches full capacity. At that time the charger will not provide charging current or voltage until the charge on the battery falls below its rated capacity due to leakage, load, or self discharge.

3.1.4 Temperature Compensation. External temperature sensors will be mounted in the battery box. These sensors control voltage characteristics, and shut the charger off when the battery temperature reaches 120°F. Connection from the charger to sensors is provided by a 4 conductor shielded cable 5 feet long.

3.1.5 Load Connection. During charging the battery shall be disconnected from the car loads by a switching device. When the car loads' normally available voltage supply drops to 35.5 ±0.5 Vdc the switch will connect the battery to the car load. The switch rating is 315 amperes for 75 seconds and 230 amperes continuously.

3.1.6 Duty Cycle. The unit shall be capable of continuous duty.

3.1.7 Connections. Connections for the charger will be 5/16 inch studs for both input and output. Terminals shall have a weather proof cover attached to the case permanently to prevent its loss.

3.1.8 Insulation. Insulation between case and input or output terminals will withstand 3000 Vdc for 1 minute without damage.

3.1.9 Radio Interference. Radio interference shall be limited to a maximum intensity of 1.5 microvolts/meter at 10 feet in any direction from the enclosure (450 kHz to 250 MHz).

3.2 PROTECTIVE DEVICES

3.2.1 Constant Current Timer. The charger shall incorporate a 10 ±1 hour timer. Timing starts when input voltage is supplied to the charger, if, after 10 hours, nominally, the charger has not gone into the pulse mode the unit is shut down. An external reset is supplied to reactivate the charger.

3.2.2 Pulse Mode Timer. The charger shall incorporate a pulse mode timer. Timing is initiated as each pulse occurs and if the pulse is abnormally wide, the charge is shut down. An external reset is supplied to reactivate the charger.

3.2.3 Circuit Breakers. Circuit breakers will be supplied on the input and on the output.

3.2.4 Input Protection. Input transients, reverse polarity, or undervoltage will not damage the charger.

3.2.5 Output Protection. Output current is limited and damage will not occur if the charger is operated into a short circuit at 120^{o}F.

3.3 OPERATION MODE INDICATION

External signal lamps will be supplied to indicate: charging mode; pulse mode; fault condition.

3.4 TEST POINTS

Test points will be provided to facilitate troubleshooting.

4.0 ENVIRONMENT

The charger will operate under the following external environmental conditions.

4.1 TEMPERATURE

-40^{o}F to 120^{o}F.

4.2 MOISTURE AND CONTAMINATION

Contamination consisting of hydrocarbons, ozone, water, salt spray, and complete encrustment by ice or snow.

APPENDIX F. SAMPLE SPECIFICATIONS

SPECIFICATION FOR A SWITCHING REGULATOR

1.0 SCOPE

This specification describes the electrical and mechanical characteristics of a switching regulator to be used in conjunction with a transformer-rectifier unit to provide 64 Vdc ± 1 Vdc.

2.0 GENERAL DESCRIPTION

2.1 ELECTRICAL

Input voltage to the unit shall be 78 Vdc ± 10 Vdc and the output shall be 64 Vdc ± 1 Vdc. Power handling capability shall be 5 kW.

2.2 MECHANICAL

The size of the regulator shall be a maximum of 1 cubic feet and it shall weigh less than 100 pounds.

3.0 DETAILED REQUIREMENTS

SPECIFICATION FOR A BATTERY CHARGER

1.0 SCOPE

This specification describes the electrical and mechanical characteristics of a battery charger to be used with a nickel-iron alkaline storage battery rated at 127 ampere hours at an eight hour discharge rate. The battery consists of 50 Exide B6H cells.

2.0 GENERAL DESCRIPTION

2.1 ELECTRICAL

Supply voltage will be 105 Vdc ± 15 Vdc provided by an unregulated transformer-rectifier unit. A fully discharged battery is charged to rated capacity in 6 hours. An SCR with associated firing circuitry and undervoltage sensing circuit will put the battery on trainline if the voltage drops below 68 Vdc.

2.2 MECHANICAL

The size of the enclosure should be no more than 1 cubic feet, and the total unit should weigh no more than 50 pounds.

3.0 DETAILED REQUIREMENTS

SPECIFICATION FOR A TRANSFORMER-RECTIFIER UNIT

1.0 SCOPE

This specification describes the electrical and mechanical characteristics of a transformer-rectifier unit to be used to convert 448V ± 10%, 25 Hz, 1 phase power to two different dc voltage levels. This unit shall be used in conjunction with a battery charger and a switching regulator.

2.0 GENERAL DESCRIPTION

2.1 ELECTRICAL

Input voltage to the unit shall be 448V ± 10%, 25 Hz, 1 phase. The output shall have two taps: one at 105 Vdc ± 15 Vdc and another at 78 Vdc ± 10 Vdc. Power handling capability shall be 7.5 kW.

2.2 MECHANICAL

The overall size of the unit shall be no more than 6 cubic feet and the total weight should be no more than 400 pounds.

3.0 DETAILED REQUIREMENTS