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STANDBY POWER FOR RAILROAD-HIGHWAY GRADE CROSSING WARNING SYSTEMS

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16. Abstract

The requirements for standby power at railroad-highway grade crossings, as established by the states, the Association of American Railroads, and the individual railroads, are described. Standard means of satisfying these requirements, using 115 vac primary power and storage batteries for standby, are compared with a number of new techniques, now passing from experimental to operational use, that incorporate solar cells or thermoelectric generators. In addition, other even more innovative techniques are examined. The conclusion of this survey is that for most railroad grade crossing applications, the existing standard techniques (reliance on ac primary power and standby storage batteries) will continue to be the preferred choice. In a number of circumstances in which the provision of ac primary power is very expensive, the combination of solar cells or thermoelectric generators as the primary source, with storage batteries as standby, will be optimal.

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PREFACE

The work described in this report was performed by the University of Lowell Research Foundation under Contract No. DOT-TSC-589 as part of an overall program at the Transportation Systems Center to provide a technical basis for the improvement of railroad-highway grade crossing safety. The program is sponsored by the Federal Railroad Administration, Office of Research and Development.

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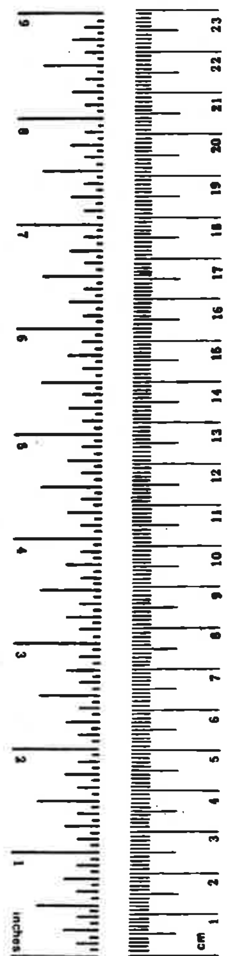
METRIC CONVERSION FACTORS

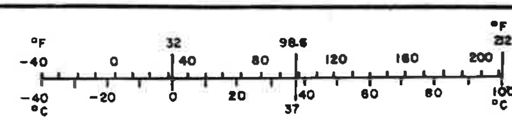
Approximate Conversions to Metric Measures

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



Approximate Conversions from Metric Measures

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



CONTENTS

ILLUSTRATIONS

1. INTRODUCTION

It has long been a requirement that automatic railroad-highway grade crossing warning systems provide safety for the motorist even when primary source of electrical power for these systems fails. This requirement is stated in the laws and regulations of a number of states, and in the recommendations of the AAR. The standard practice, though by no means the only practice for meeting this requirement, is to provide normal operating power at 115 vac from the local commercial source, and to rely on storage batteries as an alternative source available when the commercial power is interrupted.

The purpose of this report is to address the question of whether this procedure is the most economical way of guaranteeing uninterrupted protection or whether existing technology might now offer a more cost-effective means of meeting operational safety requirements. This report outlines the established requirements for grade crossing system power, the standard techniques currently employed for meeting these requirements, new techniques that are currently in the field-testing stage, and other potential techniques that are technologically possible, and an investigation of cost and reliability of the various alternatives.

The conclusion that has been reached in the course of this investigation is that in the long run, modern storage batteries are the most economical source of required levels of standby power. Although initial cost is relatively high, according to the judgments of some people, the factors of reliability, lifetime, and maintenance requirements are all favorable in comparison with other potential sources of standby power. On the other hand, as some railroads are discovering, there do appear to be alternative sources of primary power, such as solar cells and thermoelectric generators, whose characteristics offer cost advantages over commercial line power in certain installations.

2. REQUIREMENTS FOR STANDBY POWER

2.1 SELF-IMPOSED REQUIREMENTS OF THE RAILROADS

It should be noted at the outset that whatever the requirements for standby power are as set by state governments or even by the AAR, the railroads in fact set more stringent requirements upon themselves. In the back of the mind of every signal engineer that was contacted in the course of this investigation, lurked the danger of primary power to a grade crossing failing, the batteries running down to vagaries of the maintenance schedule, and an accident resulting at a then unprotected crossing. Such fears are fueled by the fact that isolated situations like this have occurred. Therefore, very conservative design criteria are used in determining required storage battery capacity for providing standby power at a given crossing.

The standard technique for calculating required battery capacity is to multiply the average amperage by the maximum maintenance interval. Average amperage is based on track circuit requirements, if any, fraction of total time on the average that flashing lights are on, number of times on the average that gates are raised and lowered, power requirements for high-current equipment such as Grade Crossing Predictors, and current requirements for line relays and other components used in the signalling system at the crossing. Then, storage batteries of the next larger standard size are specified. However, if the next larger standard size is only slightly larger than the calculated figure, the practive typically followed is to go one size larger to allow a greater margin for the unexpected. Signal engineers worry about pathological cases such as a derailment or dead train causing flashing lights to operate continuously for a period much in excess of normally expected duration.

One railroad operating in the western United States is taking a further precauting at some locations in automatic block signal territory. A sensing circuit is used to measure battery condition and this circuit is interlocked via relays with the wayside signals so that trains are not allowed to run through grade crossings with dead batteries.

2.2 AAR RECOMMENDATIONS

The fundamental AAR recommendation for standby power at grade crossings is stated in the AAR Signal Manual, Part 149, "Automatic Highway Grade Crossing Signals and Devices," paragraph 25, "Power":

> (a) Two sources of power shall be provided for the operation of each crossing signal. Where commercial power is not available this provision may be accomplished by the use of the two batteries with multiple connections between the two batteries.

In addition, American Railway Signalling Principles and Practices, Chapter XXIII, "Railroad-Highway Grade Crossing Protection" states in the section on standby power:

> Unlike ordinary street intersection traffic lights, which are operated solely by commercial power, railroad-highway grade crossing signals are inherently required to have two sources of power in the event of failure of the commercial source. This requirement means that additional apparatus is needed to provide an alternate source of power whenever the commercial power fails.

The requirement for standby power is a means for using redundancy to guarantee system safety in a situation in which the fail-safe principle alone will not suffice. Wayside signals that are used for train control and safety are presumed to be indicating the most restrictive aspect when they are unlit, and therefore failure of power in the signalling system does not result in unsafe operation. However, since grade crossing signals are normally unlit, they must obviously be lit to indicate a hazard to the motorist, even during primary power failures.

It should be noted that AAR Bulletin 7, which is the latest AAR bulletin pertaining to the installation of grade crossing warning systems, does not mention power requirements, specifically. However, Bulletin 7 does state that these systems must be safe regardless of the failure of any part, thus implying that standby power is required, should the part that fails be part of the primary power system. In addition, Bulletin 7 mandates adherence to Signal Manual Part 149.

2.3 REQUIREMENTS IMPOSED BY STATES

States vary in the manner in which they deal with the issue of standby power for grade crossings. On the one hand, some states have absolutely no requirements of their own, whatsoever. Other states implicitly impose as state law the recommendations of the AAR Signal Manual by saying in general that grade crossings shall be installed in accordance with AAR specifications. A number of states, notably New York, are quite specific in their standby power requirements. The state of New York used to have what was referred to as the "Seventy-two Hour Rule," which has now been modified to the "Forty-eight Hour Rule." This rule states that grade crossings must have standby batteries capable of providing for normal operation of the grade crossing warning system equipment installed for a period of 48 hours, based on normal traffic patterns and normal operational cycles at the crossing.

In some states, every grade crossing warning system installed must pass the scrutiny of a state safety engineer who essentially imposes a formlly unwritten requirement for some period of normal operation. The 72-hour rule originally adopted by New York is one such popular rule, in spite of the fact that New York has shortened the requirement.

Once again, it should be noted that railroads themselves always exceed, and sometimes greatly exceed, these requirements.

3. STANDARD STANDBY POWER TECHNIQUES FOR GRADE CROSSINGS

3.1 STANDARD ELECTRICAL CIRCUITRY

The standard circuit layout recommended by the AAR for grade crossing systems is shown in Figure 1. The principal components of the system are provision for 115 vac primary power, rectifier and battery charging circuitry, storage battery, and power transfer relay (power-off relay). The flashing lights require 10 volts nominally at the filaments--easily provided by provision of 12 volts rms ac or dc at the power system location, allowing for line drop. Gate arm motors require 12 volts dc for short arms, or higher voltages up to 16 volts dc for the longest used standard wooden gate arms. One advantage of using the newer lightweight gate arms is that lower battery voltages and therefore fewer cells are necessary.

Since gate arm motors represent high-current intermittent loads, and since they require dc power because of starting torque requirements, the gate arm motors are battery-operated even under normal circumstances. This saves using a rectifier circuit capable of handling the peak motor current. Since the flashing lights may be operated either on ac power or dc power, they are normally operated on 12 vac, provided by a step-down transformer. When primary power fails, they are operated from the batteries. This arrangement minimizes the charge-discharge cycling of the batteries, thus prolonging their life.

At a standard grade crossing employing dc track circuits, the track voltages are supplied by separate batteries that in the past usually have been primary batteries. These batteries provide low-voltage, low-current operation continuously for a period of from 6 months to a year, after which they are replaced. If the battery fails, track voltage fails, actuating the grade crossing protection in a fail-safe manner; thus, redundancy of track batteries is not required.

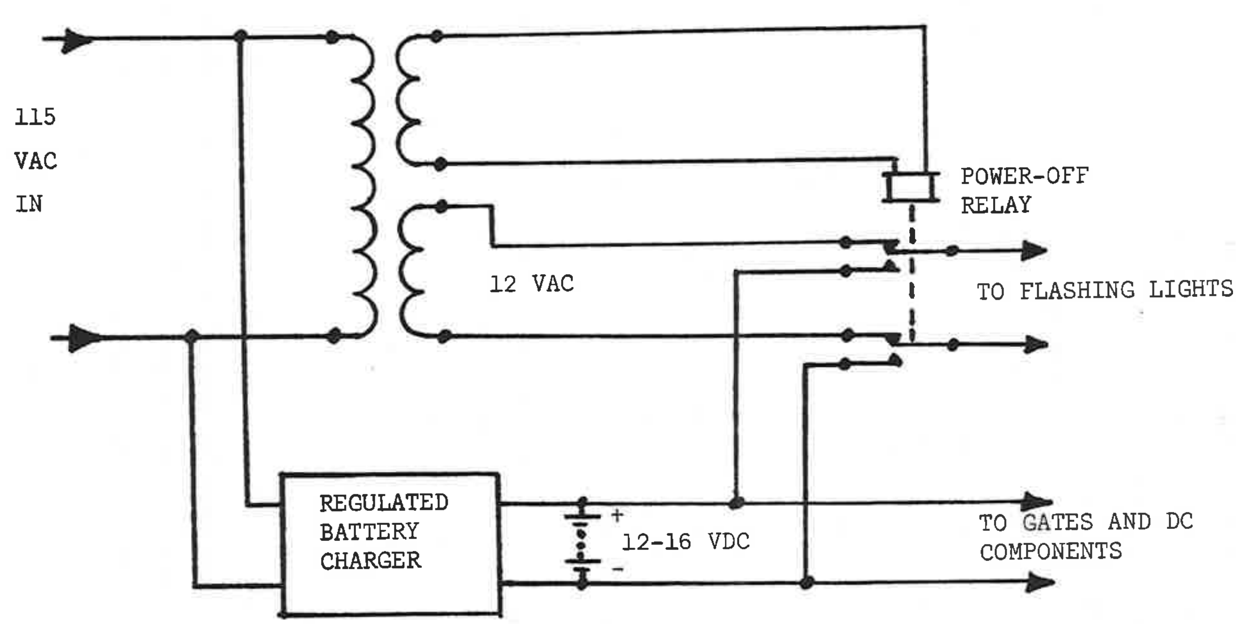


FIGURE 1. ELECTRICAL POWER SYSTEM FOR GRADE CROSSING WITH GATES AND FLASHING LIGHTS, USING 115-VAC PRIMARY POWER AND STORAGE BATTERIES FOR STANDBY

On the other hand, ac coded track circuits or audio frequency overlay (AFO) track circuits are powered by the standby battery when ac power fails. In the past, some equipment designs were quite complicated mechanically, such as one system in which a 60 Hz ac motor, a 12 vdc motor, and a 100 Hz code signal generator were mounted on a common shaft. Normally, the 100 Hz track signal was provided by the 60 Hz generator driving the motor. When primary power failed, the generator was driven by the 12 vdc motor. In modern AFO systems, dc power is always used in the signal generators and receivers, which are solid-state electronic circuits.

Grade Crossing Predictors (GCP's) ® that are used to sense train speed and calculate lead time for lowering gates to achieve constant motorist warning time, have relatively severe power requirements. A GCP for a single track circuit draws approximately 5 amperes dc continuously at 12 volts. Since GCP's are generally employed in pairs, one for each approach direction, a single-track application will require provision for an additional 10 amperes dc current continuously, or an additional 1700 ampere-hours of battery capacity if the requirement for standby power operation is for 7 days. This magnitude of battery capacity or multiples of it for multiple-track installations is felt by some railroads to be so severe that standard track circuits are used to sense distant approach of trains, and the GCP's are only turned on when a train is approaching. It should be noted that the 1700 ampere-hours required above is approximately 7 times a typical 240 a-h requirement of a crossing with gates.

The standard dc line relays used to perform the logical control operations at a crossing typically draw a small amount of continuous current, compared with the average requirements of a crossing with gates and many flashing lights.

3.2 STANDARD BATTERIES

Although lead-acid batteries and nickel-iron batteries have been used in the past and many are still in service, the standard storage battery for new or upgraded grade crossing installations is the nickel-cadmium wet cell. Nickel-cadmium cells are available from a number of manufacturers in standard capacities of 80, 120, 160, 240, 340 and 400 ampere-hours. The most popular size appears to be 240 a-h, at a price of approximately $85 per cell. Since ten cells are required to form a battery with nominal voltage of 12 volts, the price per 240 a-h battery is approximately $850.

At crossings without gates, one railroad reported that whereas 80 a-h batteries used to be standard, they were being upgraded to 160 a-h. At crossings with gates, 240 a-h batteries were standard. If a crossing has 4 gates, this railroad employs two 240 a-h batteries, each provided with its own charger. The standard procedure appears to be to install additional battery capacity in increments of 240 a-h when more is required for any reason.

Chargers used in new grade crossing applications are of the regulated low-impedance type that provides reduced charging current when the battery is fully charged, thus prolonging battery life. Chargers for grade crossing applications vary in capacity from 2 amperes to 6 amperes, typically, with the price of a 2-ampere charger being approximately $125 and that of a 6-ampere charger approximately $250.

The price of $850 for a 240 a-h 12-volt battery might appear outlandish to someone who observes that the same capacity could be purchased for $100 or less in the form of standard automotive lead-acid batteries. However, the nickel-cadmium battery, carefully constructed to AAR standards, has an expected service lifetime of approximately 20 years, compared to 3 years for the automotive battery. Thus, it will require far less maintenance and will yield far more reliable operation, resulting in a much lower annual cost for operation in the system.

It appears that in spite of future introduction of alternative sources of primary power for grade crossing warning systems, the storage battery will continue to be the standard standby power source. In comparison with solar cells or thermoelectric generators to be discussed in the next section, it offers the greatest immunity from environmental effects and the best reliability in terms of being able to provide power on a moment's notice under any circumstances, and therefore the best overall system reliability.

4. NEW TECHNIQUES

4.1 SOLAR CELLS

As their price relative to prices for other power sources diminishes, silicon solar cells are becoming increasingly attractive sources of primary power for railroad signalling applications, including grade crossing protective systems. An array of solar cells, or a solar array, is pictured in Figure 2. Each individual cell is actually a p-n junction silicon diode whose area spans the circular extent of the individual cell, as visible in the photograph. Photons of sunlight with individual energies greater than the band gap energy of silicon produce hole-electron pairs when they are absorbed in the silicon. When absorption takes place in the junction region--slightly beneath the surface of the silicon wafer--the hole and the electron produced are caused to drift in opposite directions by the "built-in" junction electric field, giving rise to a current in the external circuit. This "photocurrent" as measured in amperes has a value directly proportional to the intensity of normally incident sunlight. It flows in a direction opporite to the normal "forward" current that is conducted by a p-n junction diode. Since the forward current is given by the relation,

$$I_{fwd} = I_o(e^{V/V_t} - 1),$$

in which I_o is a constant term depending on diode construction, V_t is approximately 0.025 volts, and V in this case is the load voltage, the overall relation for load current vs. load voltage is

$$I_L = I_{ph} - I_o(e^{V/V_t} - 1).$$

A typical current-voltage characteristic is shown in Figure 3. Figure 4 shows a circuit diagram for a dc power system incorporating a solar array.

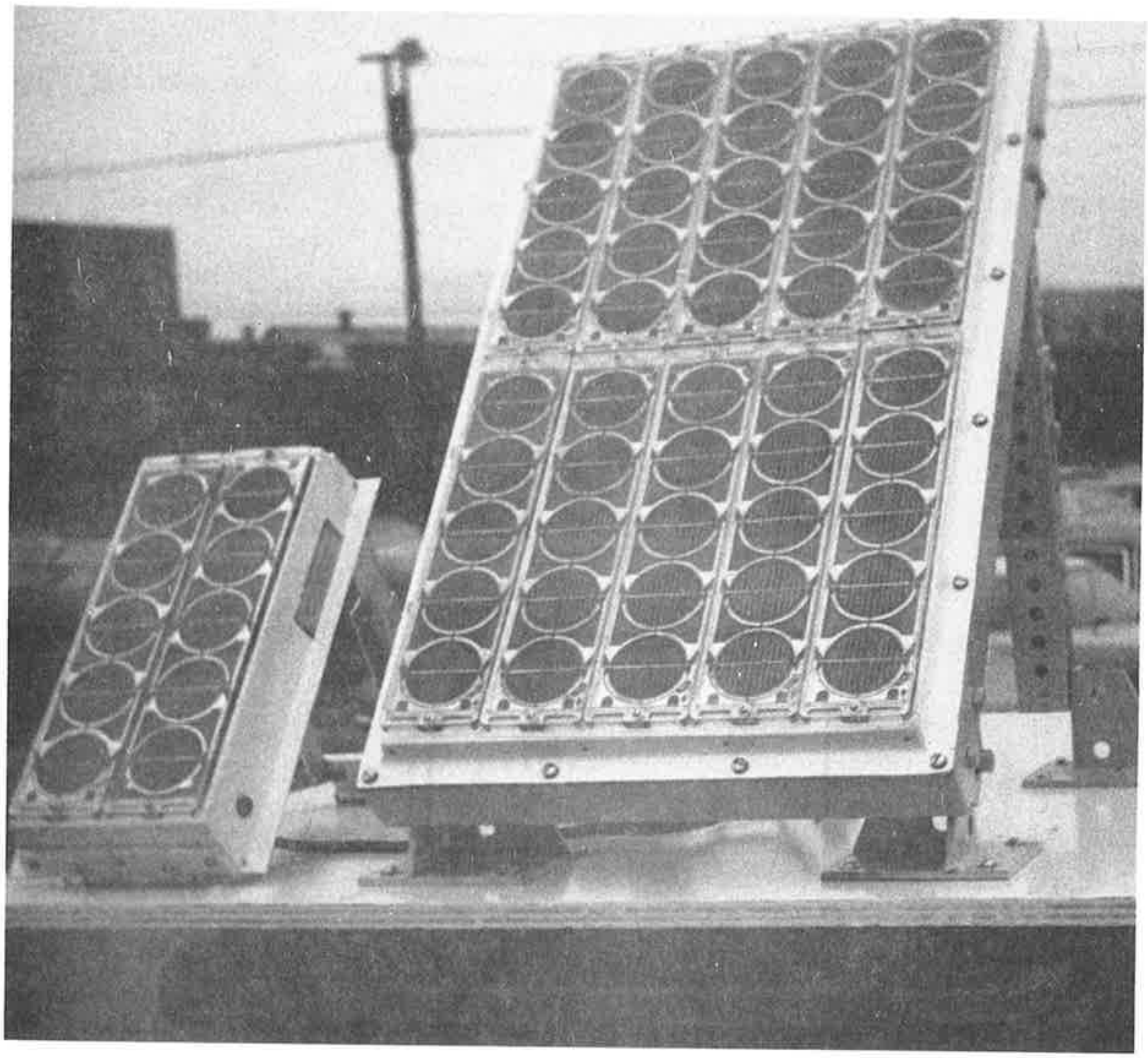


FIGURE 2. SOLAR ARRAYS DESIGNED FOR RAILROAD-SIGNALLING APPLICATION [PHOTOGRAPH FURNISHED THROUGH THE COURTESY OF SOLAR POWER CORPORATION, WAKEFIELD MA.]

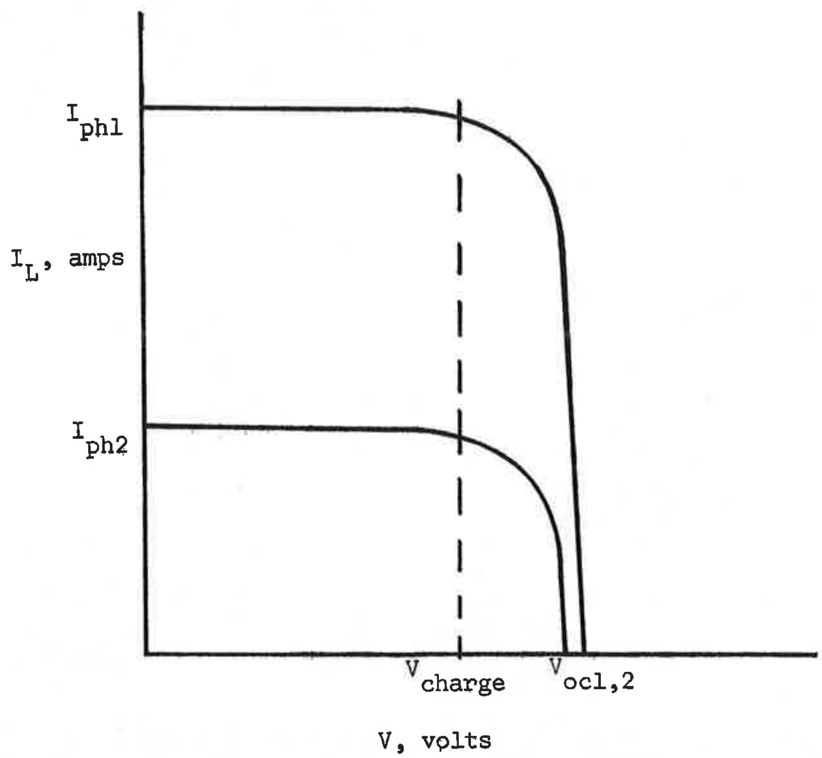


FIGURE 3. CURRENT-VOLTAGE CHARACTERISTICS OF TYPICAL SOLAR ARRAY

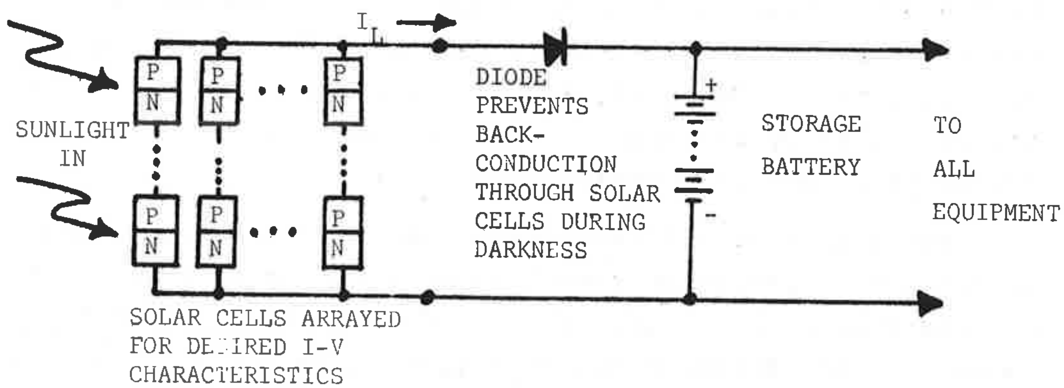


FIGURE 4. A DC-POWER SYSTEM USING SUNLIGHT AS PRIMARY POWER SOURCE, WITH STORAGE BATTERY FOR STANDBY

Since solar cells only furnish power during daylight and since the power produced is in direct proportion to the intensity of sunlight, solar cells must always be used in conjunction with storage batteries. The storage batteries must have sufficient capacity to carry the system through periods of continuous overcast, whatever the maximum duration might be at a given location. The role of solar cells appears to be to replace the 115 vac primary power source, in situations where provision of line power is costly.

Consider the situation in which a grade crossing using 15 watts of power on the average is located one mile from the nearest commercial power. It would cost $5,000 to $10,000 at current prices to run the power lines the additional mile to the crossing. On the other hand, solar cells capable of producing 125 peak watts during bright sunlight at an installed cost of approximately $24 per watt, or $3,000 total, would be sufficient to satisfy the primary power requirements of the crossing, with a saving of $2.000 to $7,000 in overall system cost.

The figure of 125 watts peak power during bright sunlight allows for an immediate reduction by a factor of 9/24 to account for the proportion of daylight to darkness during December and January in the northern United States, a factor of 0.64 to account for the average aspect of solar array to sun through the day, and a factor of 0.5 to account for average ratios of sunlight to clouds. The same 240 ampere-hour battery required at the grade crossing to provide a week's power at 15 watts average would still be required to see the system through a continuous week of dark overcast, when the maximum sunlight would be ten percent of that of a cloudless day.

The required battery capacity perhaps could be reduced by increasing solar array size but this would not be economical. Probably twice the solar array size would be needed to reduce the battery size by half, allowing average power requirements to be met at lower values of peak sun intensity, and it would cost $3,000 for the solar cells to allow a savings of $400 in batteries.

A number of railroads are presently installing solar arrays on a test basis in the field to examine their potential for eliminating requirements for bringing line power to signalling locations where power is required. To date, operation of the solar arrays has been found to be satisfactory. The decision whether or not to use solar arrays appears to be a purely economic one, depending on the distance that power lines must be run. If this distance is greater than a half mile to a mile depending on the location, solar arrays appear to be the best choice.

The decision of the one major manufacturer of copper oxide primary cells to discontinue production of these cells has spurred interest in solar arrays. These primary cells were used widely in the past to provide the only source of power for dc track circuits in automatic block signalling systems and in grade crossing protective systems. The railroads are now contemplating switching either to storage batteries charged by ac line power or to solar arrays for this application. Given the isolated locations of many track batteries, solar arrays appear to be the best choice in many instances. Future evolutionary advances in solar cell technology, including introduction of new semiconductor materials with cost and performance better than silicon, should enhance the usefulness of solar arrays.

4.2 THERMOELECTRIC GENERATORS

Thermoelectric generators of modern design appear to have some potential for use in grade crossing protective systems and in other railroad signalling applications. The advantage of the thermoelectric generator over the solar array is that it provides uninterrupted power during periods of prolonged lack of sunlight, thus potentially offering the advantage of less required standby battery capacity. This advantage is probably offset, however, by the necessity for the battery because of reliability considerations.

Modern thermoelectric generators for remote power applications are fueled by propane, butane, or natural gas. Combustion is catalytically assisted and takes place at the surface of the thermoelectric element, thus increasing overall thermal efficiency. Fuel requirements for propane or butane are approximately 1.1 pounds of fuel per week per watt of continuously generated power. Intermittent operation can be provided either via pilot light or electric igniter. The price quoted by one manufacturer was in the range of approximately $700 for the first 10 watts of capacity, plus $300 for each additional 10-watt increment. Thus, a grade crossing warning system requiring 15 watts could have primary power provided by a system costing $1,000. The fact that this price is one-third that of the solar array required for the same application must be weighed against the certainty that replenishing fuel means added maintenance. There are other maintenance requirements as well, such as reported by one railroad using a number of thermoelectric generators on an experimental basis that complained of having to clean bugs out of the intake air filters for eight months of the year.

Given the unique capabilities and limitations of thermoelectric generators and their cost and maintenance requirements, there are probably specific signalling applications in which they are the ideal choice.

5. OTHER POSSIBLE POWER SOURCES

Besides wet-cell batteries, solar arrays, and thermoelectric generators, there exist other sources of electrical power which conceivably could be considered for use in railroad signal or grade crossing applications. A number of such sources are discussed below, with indications of why they are not viable in comparison with the three already mentioned.

Storage batteries using a gel-type electrolyte do offer the advantage of never requiring adding water to the electrolyte solution. However, these batteries are notoriously unreliable compared to high-quality wet-cell storage batteries. One important attribute of gel-type electrolyte batteries--that of freedom from electrolyte spillage--is simply not important in a fixed application such as railroad signalling. When charged from a properly adjusted bleeder-type battery charger, the wet-cell storage battery probably needs less periodic attention than the gel battery in a railroad signalling application.

Fuel cells have been used in applications in which it was important to keep overall system weight as low as possible. Fuel cells work in the principle of electrolysis in reverse, consuming fuel and oxidant and producing electricity. However, even for experimental automotive applications, the inherent reliability problems associated with fuel cells appear to make wet-cell batteries a better choice, even in an application in which weight <u>is</u> important.

Nuclear-powered thermoelectric generators have been successfully used in very remote locations such as the polar regions, or in deep space beyond the orbit of Mars where sunlight is weak. In these devices, thermal energy is provided by the natural radioactive decay of radioactive isotopes. The price of such a system alone, not to mention the price of environmental safeguards, rules out such systems for most ground-based applications.