

## OPERATING LIGHTING UNITS ON COAL MINE DC POWER SYSTEMS

by

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ABSTRACT

Fluorescent, mercury-arc, and sodium-vapor lamps for coal mine face illumination, when powered from dc lines, usually utilize solid-state power supplies. The 300-vdc or 600-vdc electric power from the lines varies widely in level and often contains high-voltage transients that can cause temporary blackouts or permanent damage to the lighting systems. These problems must be guarded against by power-supply design. In this paper, power-supply designs utilized in various present lighting applications are discussed, and the available transient-protection techniques are described.

## INTRODUCTION

The ordinary mine machine headlamp is an incandescent light, which tolerates rather large changes in voltage level without either damage or full blackout. However, the inefficiency of these lights has precluded using them for the extensive illumination task required in the proposed regulations. The other systems that have been used--sodium-vapor, mercury-arc, and fluorescent lamps--are usually dependent upon a power supply of some sort for proper operation on dc. The fluorescent lamp itself also tolerates a wide voltage range, but its power supply may not. The supplies are usually solid state. Sodium-vapor and mercury-arc lamps, also usually supplied through solid-state circuits, tolerate increased voltage and will operate with diminished brilliance when a steady low-level voltage is applied; however, they cannot maintain the arc when voltage suddenly drops to a low level. Furthermore, when they do go out, they require a relatively long period--several minutes in the case of the mercury-arc lamp--to restrike and return to full brilliance.

Where solid-state components are used in inverters, ballasts, or other power supplies, failures due to overcurrents and those due to transient voltages are serious sources of failure and must be provided for in the design. The problems, then, for the power-supply designer are those of maintaining adequate voltage to a rather high wattage load and of preventing malfunction or damage due to high-voltage transients. Sometimes compounding these problems is the necessity of achieving a very rugged but very small package to mount on a mining machine.

## POWER SYSTEM CONSTRAINTS

Direct-current line voltages may be nominally in the regions 250 to 300 or 500 to 600 vdc. Long-term variations of the current level may be

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expected to be as low as 180 vdc for the lower nominal values and as high as 750 vdc for the higher. Peak voltage due to ac ripple may be well over 400 volts for a 300-volt line or over 750 volts for a 600-volt line. Line transients are often two to three times the nominal voltage and may sometimes go considerably higher; therefore, the power-supply circuits must be protected against these values as will be discussed later. The basic circuit must be designed to withstand the continuous power presented by the long-term variations and the ac ripple that is on the line. Good design calls for the rating of components such as the pass transistor in a switching-regulator type of power to have much higher voltage and current ratings than indicated by the required output values.

Line transients are often due to switching of large transformers and motors somewhere on the ac distribution line feeding the dc rectifier station. Prediction or even measurement of these transients is a very uncertain matter. Vacuum switches get the credit for some of the worst transients. Some of the in-mine measurements taken under our contract with the Pennsylvania State University show peaks such as 32 kv on a 7.2-kv line. They contain high frequencies, so that an important portion of their energy can be transferred through transformer interwinding capacitance to the dc line. Calculations indicate a 9,000-volt peak can occur on the secondary, with durations in the neighborhood of 0.5 to 5 Msec. They have been observed to occur in bursts, with total calculated energy on the secondary side of about 5 to 50 joules.

Switching and arcing of the dc line itself also causes transients, which are usually not extremely high in voltage but which sometimes have long duration. Shown in figure 1 is a transient reaching about 2.5 times the dc line voltage in amplitude, with a duration of about 500 msec. It contains significant energy at frequencies up to about 120 kHz. As shown in figure 2, which is also a dc switching transient, both polarities of voltage can be present; this must be considered with regard to protecting solid-state power-supply circuits.

Transients coming in from the line may be somewhat diminished by cable inductance and capacitance. However, transients generated on the machines may be otherwise affected by the line inductance, as well as by any local solenoids. Ringing can occur. The voltage peaks may be regeneratively amplified and even on a quiet line, transients of several thousand volts may still be seen by the power supply. Therefore, transient protection and voltage-regulating ability must be part of or closely associated with the power-supply circuit, not something at the load center or at the input to the machine.

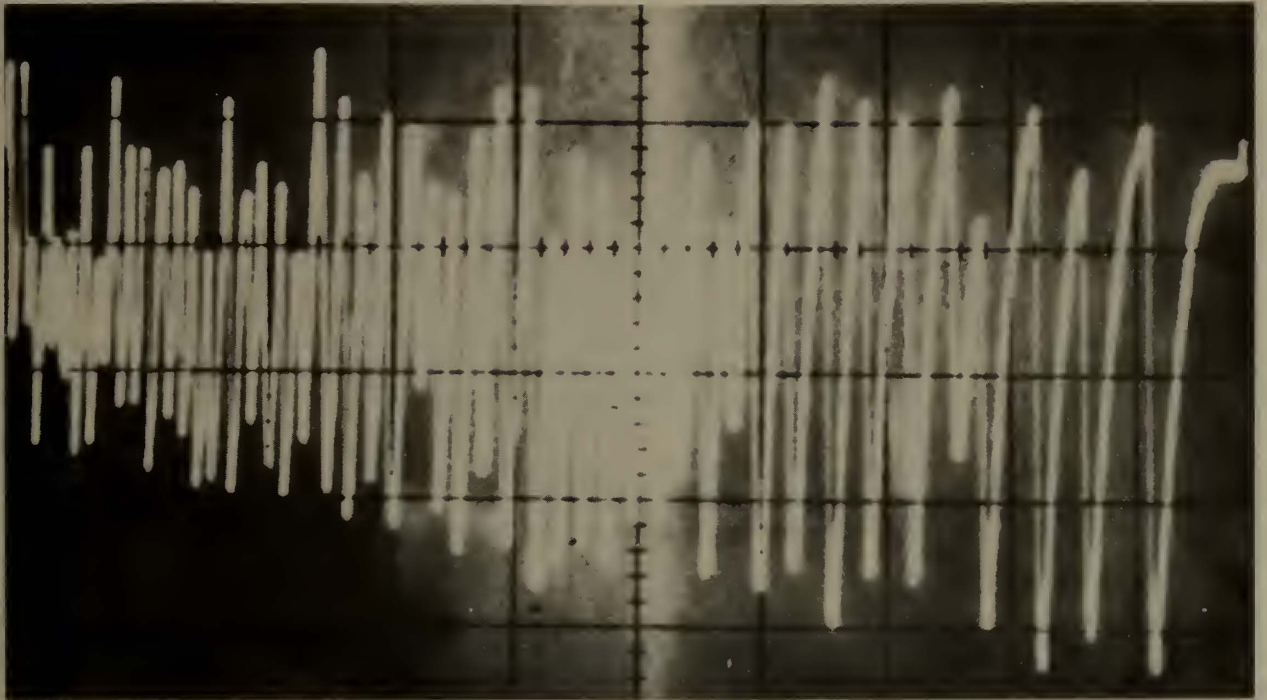


FIGURE 1. - Direct-current switching transient with multiple restrikes.

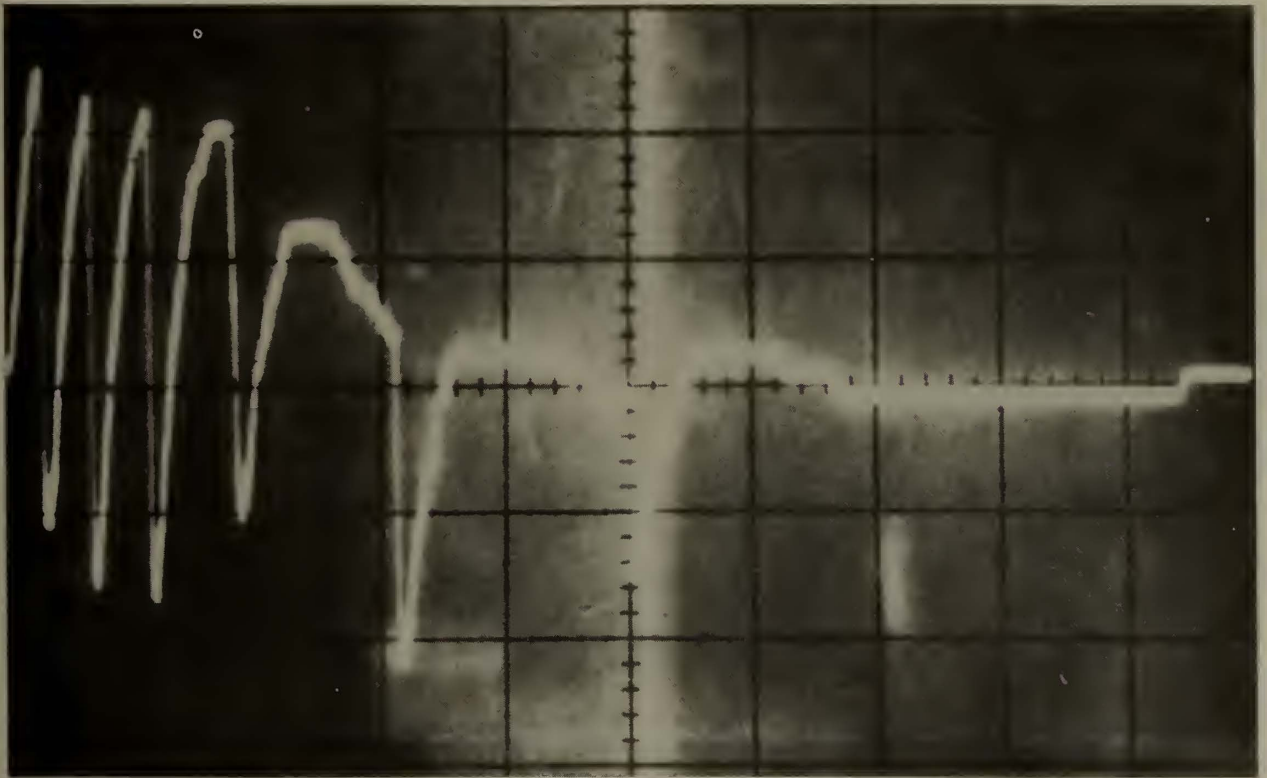


FIGURE 2. - Direct-current switching transient with polarity revised.

## LIGHTING UNIT REQUIREMENTS

Fluorescent lights used at present on mining machines range from 8 to 30 watts per lamp. The voltage at the lamp depends on the type of lighting system, but it is at least 100 volts steady state, with a starting pulse of about 200 volts. The frequency may be 600 Hz or much higher. Lamp efficiency is higher at high frequency, and the inverter-ballast inductive components are smaller and lighter. Because the inverter is enclosed in the luminaire with the lamp, so that connecting leads are short, losses due to line impedance at high frequency are not a problem; the frequency supplied by Ocean Energy Co.'s<sup>2</sup> inverter-ballast can be from 18,000 to 100,000 Hz. Voltage regulation is obtained in this system by varying the frequency so that the voltage drop through a series element changes.

The input to the preceding inverter is nominal 12 vdc. Therefore, operation from a 300-volt line requires a dc-to-dc converter to supply up to about 3-1/2 amp at 12 volts. The system employs one converter for each luminaire.

Mercury-vapor lamps presently used are either 100 watts or 175 watts. These are the same units found in many industrial applications, where they are usually operated from ac lines at about 125 to 135 volts. The lamps may

be operated on dc with a slightly decreased brilliance and total life. A pulse of about 200 volts or higher is also used to start these lamps. The lamp is constructed as illustrated in figure 3, which shows a third electrode providing a shortened starting gap to permit breakdown to the gap at reasonably low value of voltage. Figure 4 shows the voltage and current that must be supplied by the power supply-ballast while the lamp is building up to its full brilliance.

The curves apply to a 100-watt mercury-vapor headlight. As seen, voltage across the lamp is initially about 30 volts and gradually increases to a steady value of about 130 volts in about 4 min. The current through the lamp starts at about 1.3 amp and descends to 0.8 amp. An interesting thing about the arc is that it will

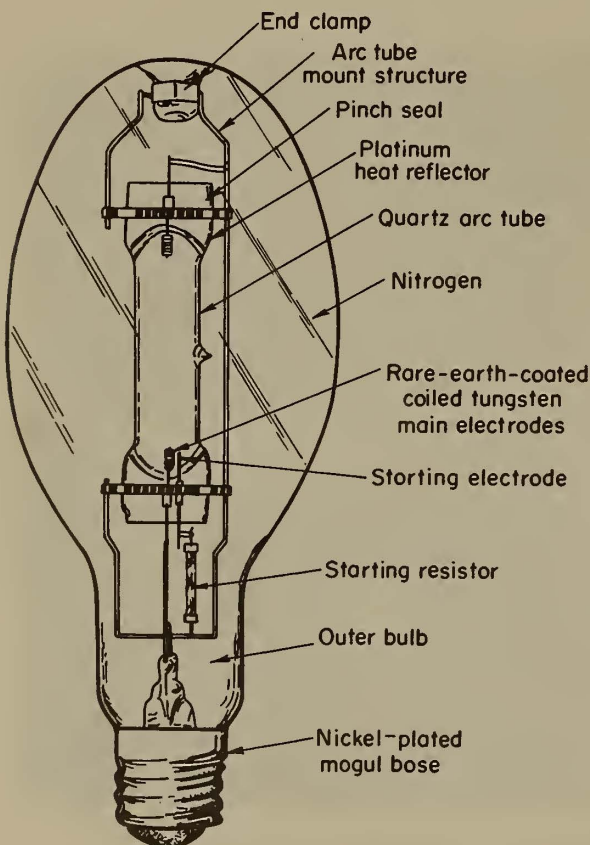


FIGURE 3. - General Electric mercury lamp.

<sup>2</sup>Reference to specific companies is made for information only and does not imply endorsement by the Bureau of Mines.

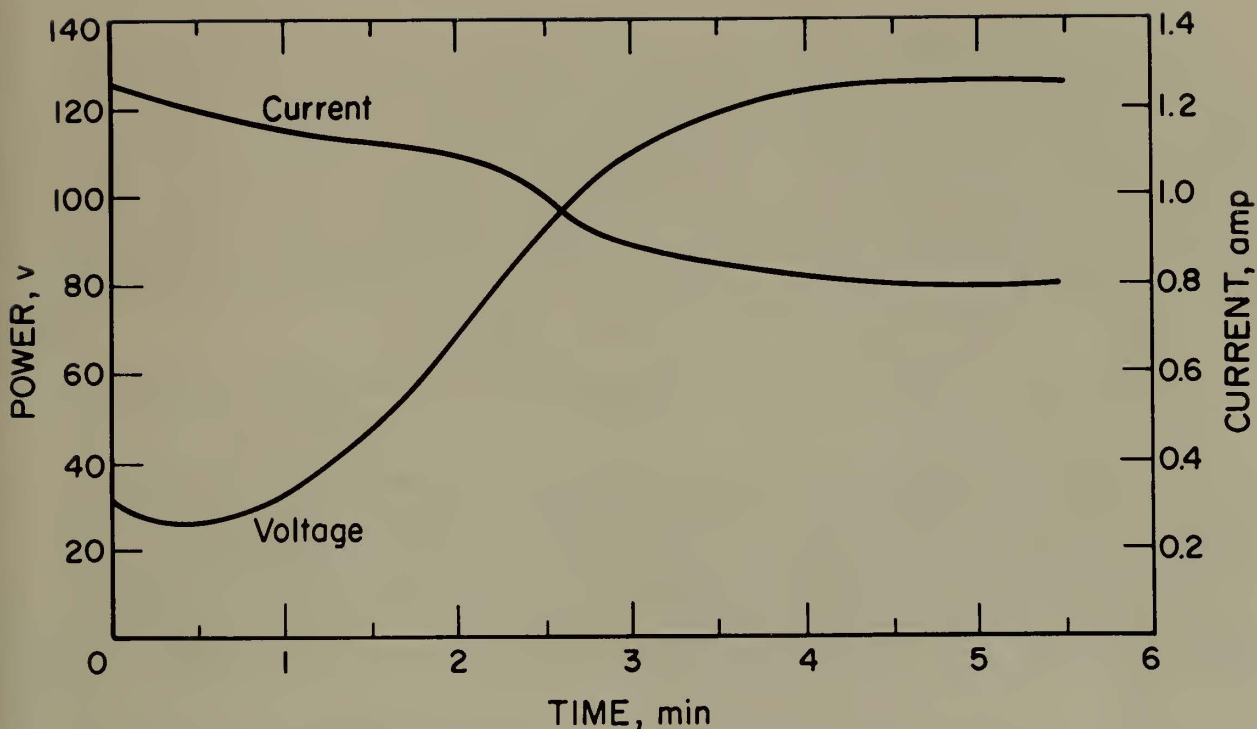


FIGURE 4. - Mercury lamp starting curves.

maintain about the same voltage behavior and final value even if the series ballast impedance is much smaller in value or line voltage is higher. The current will simply go up to the point where ballast-voltage drop results in about 130 volts across the lamp. In this case, the lamp would dissipate more energy than that for which it is designed, with consequently higher brilliance and shorter life. With an excessive value of series impedance, the lamp will provide light at a diminished level as long as the arc voltage can reach about 45 volts or higher. This does not mean that the lamp will remain lit if operating voltage suddenly drops from normal to that value. What can happen when a heavy motor starting current flows in a trailing cable is that voltage at the lamp drops suddenly to, say, 90 volts and, instantly, the lamp goes out. Then it takes several minutes to fire and finally regain full brilliance.

Mercury-arc lamp behavior with frequency is not covered in literature or, so far, in Bureau testing. Some special equipment would be necessary to supply the necessary power and ballast action at a variable frequency. This may be an interesting area to investigate.

One other novel lamp has been tried: The high-pressure, sodium-vapor lamp. This is an arc lamp utilizing mercury plus some sodium. Owing to its two-electrode construction, an impulse of about 1,500 volts is required to start the arc. The power supply is a specialized inverter circuit providing the necessary high-voltage kick periodically while the lamp is not lit. Because of the high voltage, restriking time may be only about 30 sec for these lamps. So far, a commercial dc supply is not available to us.

## POWER SUPPLIES UTILIZED

The basic circuits used for powering the types of lamp considered have been either switching regulators or inverters, except for a series-resistor configuration. A series-resistor application consists of two 240-volt, 500-watt strip heaters placed in series with a 100-watt mercury headlamp across the 300-vdc line. The package is shown in figure 5. Total resistance in series with the lamp is about 220 ohms under operating conditions, resulting in a drop of about 175 volts when the lamp is at steady state. Consol has successfully utilized this, and U.S. Steel and others are now installing them. Control Products sells them at around \$100.

Although this system is simple and rugged, it has a couple of disadvantages. There is some heating, and there is no voltage regulation.

The basic circuit of a switching regulator used as a lighting power supply is shown in figure 6. A 300- to 115-vdc built by FMC is shown in figure 7. Several of these units operated from April 2 to October 10 in Jenny mine. They were tried in a Consol mine that has hard-working dc track haulage, where they were damaged by transients and thus were unsuccessful. Since then, they have been redesigned and are in the mine for further trials.

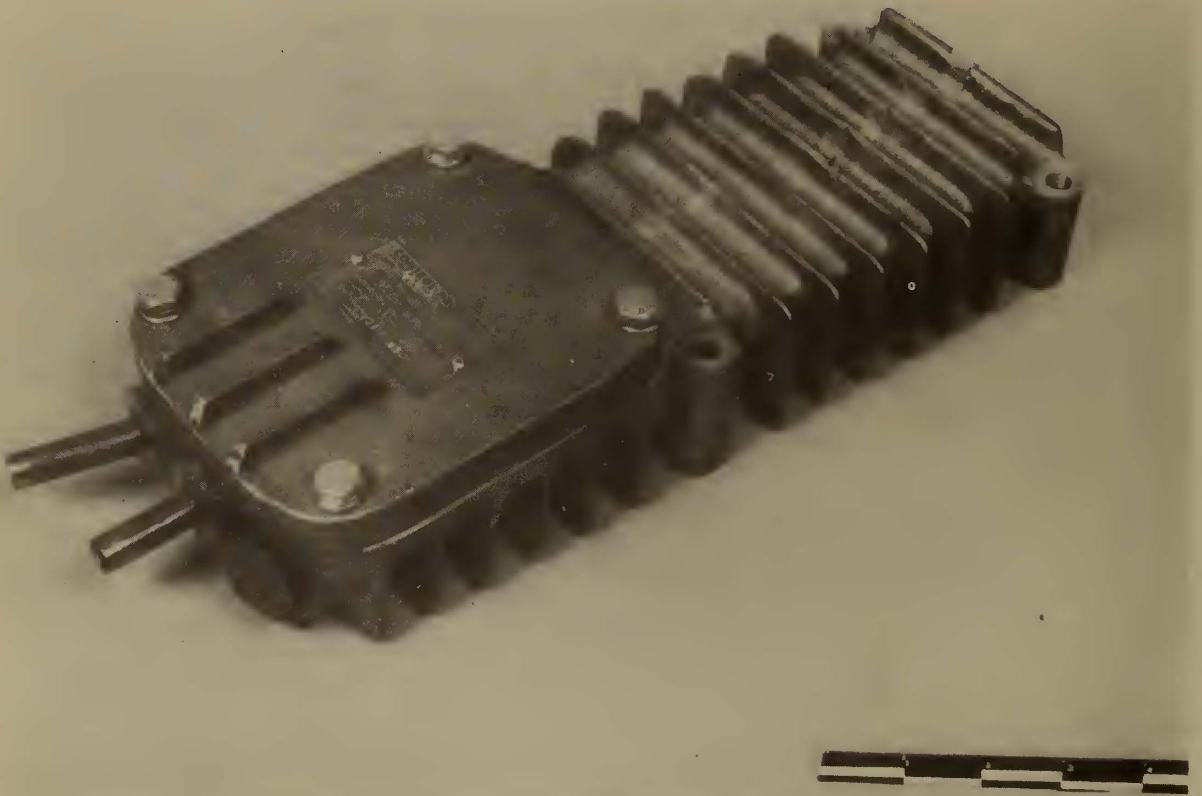


FIGURE 5. - Mercury lamp resistance ballast.

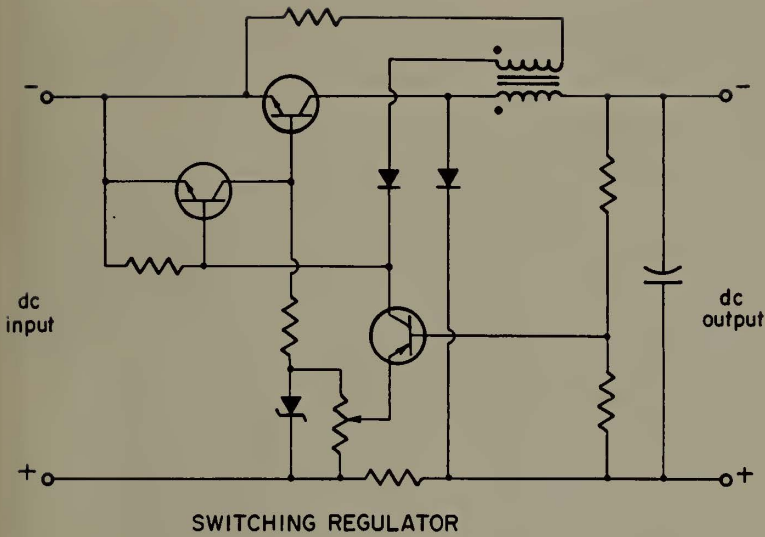


FIGURE 6. - Switching regulator basic circuit.

180 vdc, on a nominal 300-volt line. They can be obtained from FMC for about \$250.

The output voltage is a pulsating wave whose exact shape depends on the value of the input voltage as it varies around nominal value. Figure 8 shows instantaneous output when the input is at, below, and above nominal value. The average voltage is the same for each case.

The switching regulators installed in mines up to the present time can provide usable output for 175-watt mercury-vapor lights with input varying from 390 to

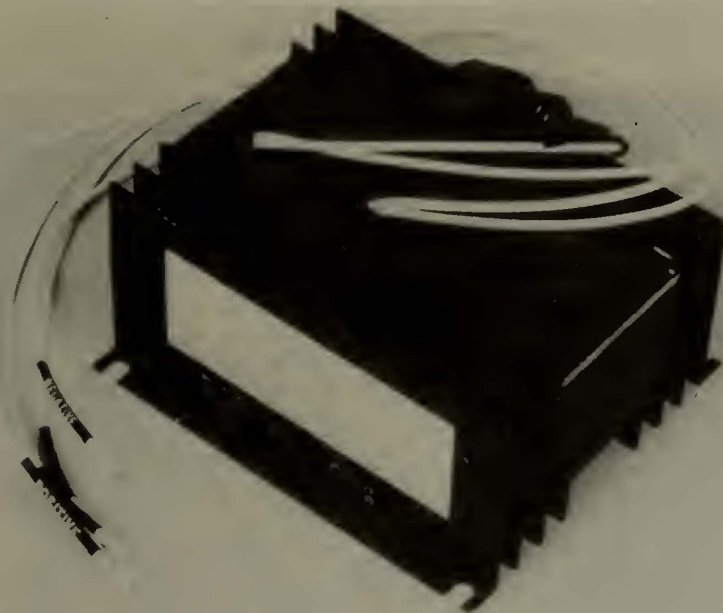


FIGURE 7. - FMC switching regulator.

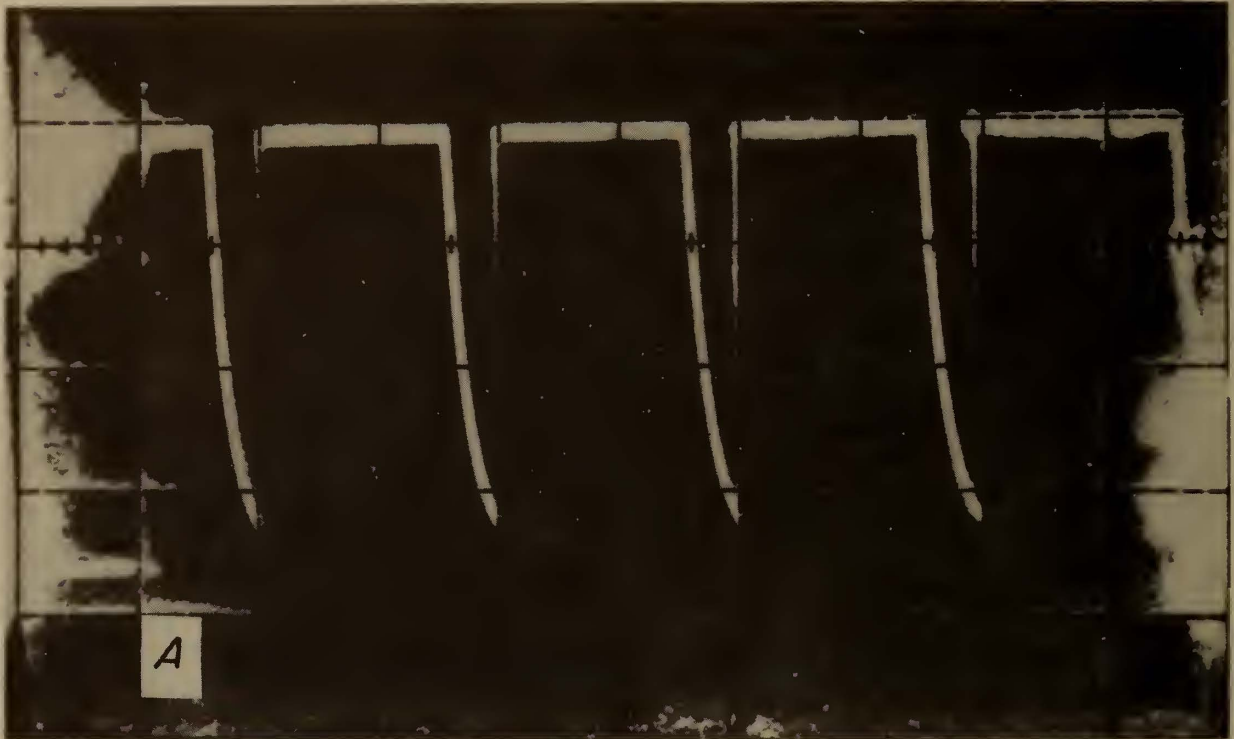


FIGURE 8A. - Switching regulator output waveform. Input voltage at nominal value.



FIGURE 8B. - Switching regulator output waveform. Input voltage below nominal value.

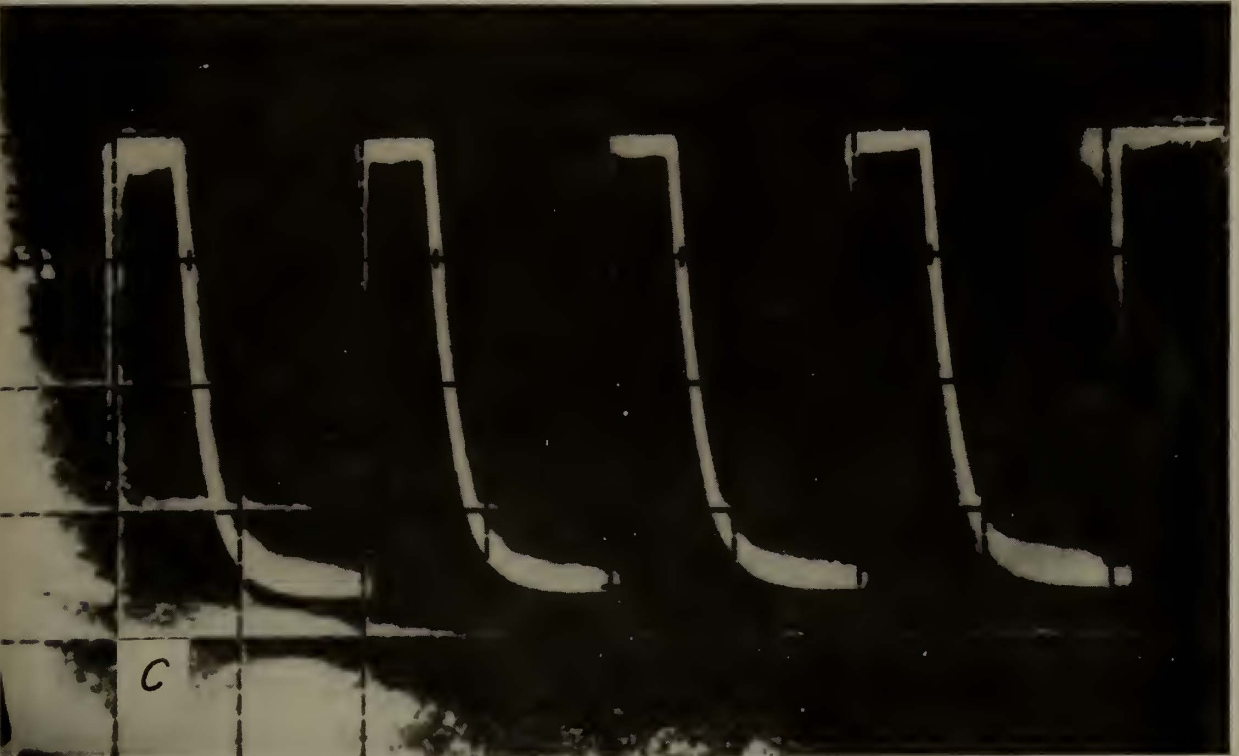


FIGURE 8C. - Switching regulator output waveform. Input voltage above nominal value.

The basic circuit of an inverter is shown in figure 9. The output may be transformed and rectified to any desired voltage. Figure 10 shows a 300-vdc Ocean Energy converter that supplies 20 amp at 12 vdc. Figure 11 shows a complete system, with the line converter sending dc to the inverter contained in the luminaire, which then supplies ac to the fluorescent lamp. These are installed in Consol's Williams mine and others. The power supply, which is part of a system of 8 to 16 lamps, costs about \$1,200.

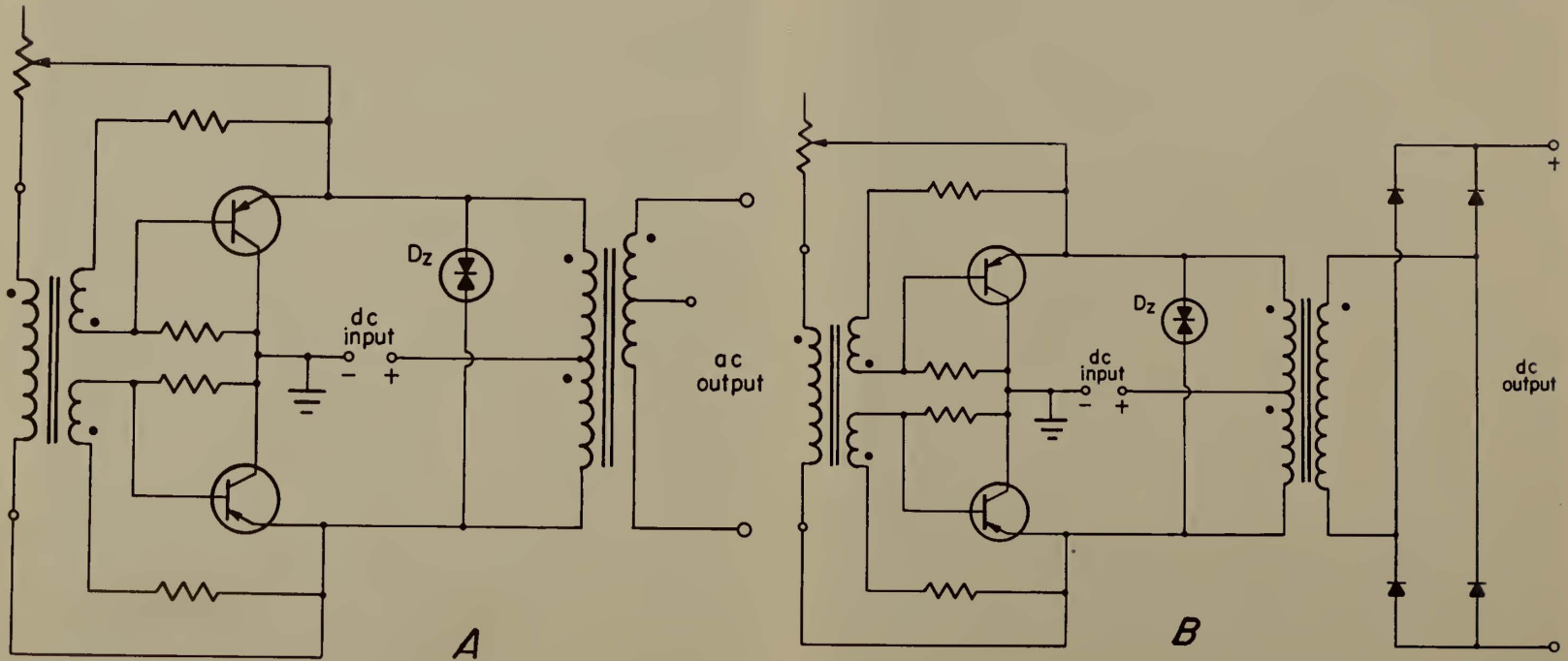


FIGURE 9. - Inverter basic circuit. *A*, Alternating-current output (inverter); and *B*, rectified dc output (converter).

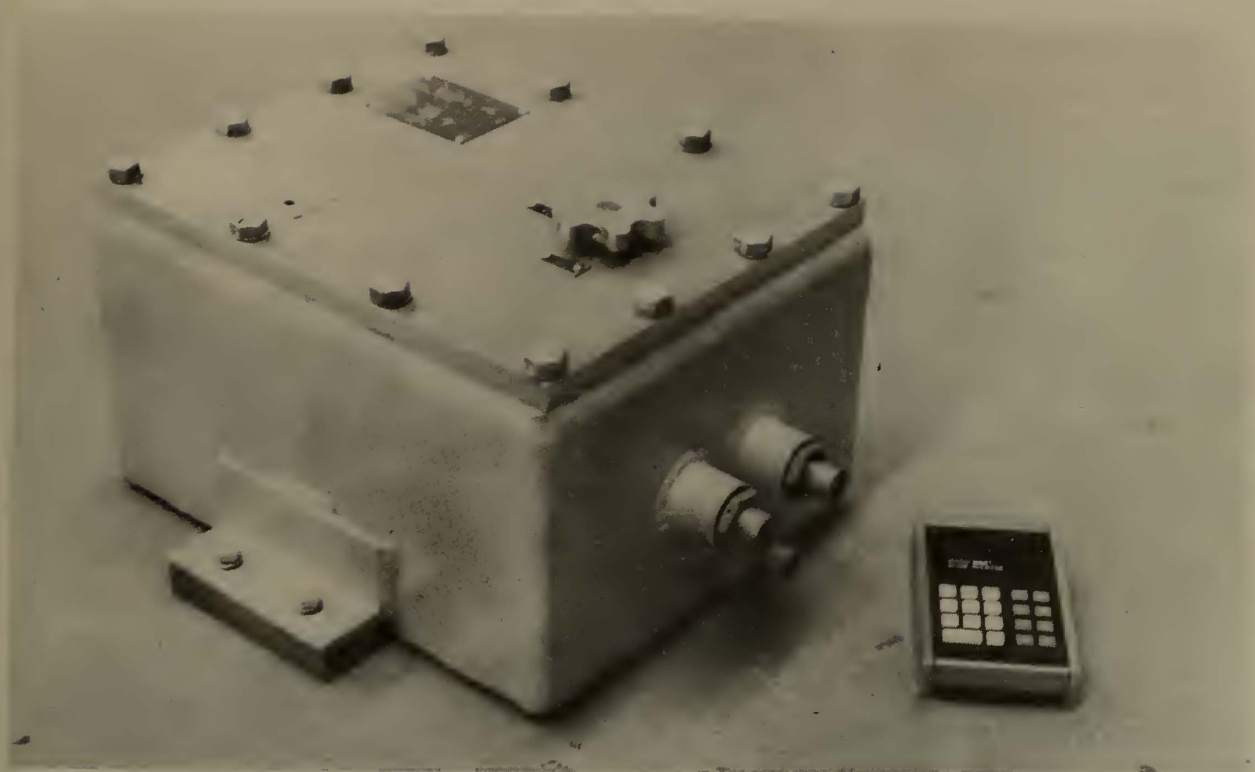


FIGURE 10. - Ocean Energy converter.

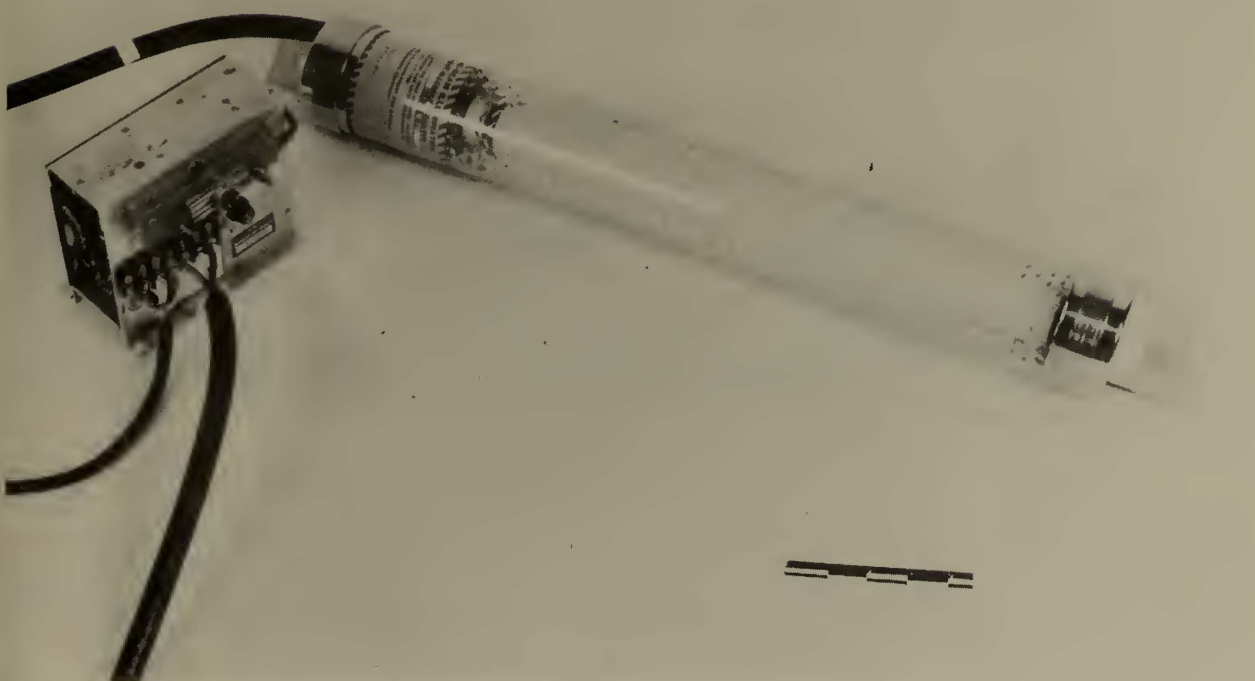


FIGURE 11. - Ocean Energy luminaire system.

## TRANSIENT PROTECTION

Whether the solid-state power supply utilized is basically a switching regulator or an inverter, it is in danger of malfunction or destruction when the line is subject to voltage transients. The use of transient-protection devices is practically mandatory.

The types of device utilized to protect solid-state circuits against transients are as follows:

1. Fuses and circuit breakers operating on overcurrent. Delays are from several milliseconds to fractions of a second.
2. Suppressors--Capacitors, metal oxide or selenium varistors, and zener diodes. Response time is in nanoseconds.
3. Crowbars--Spark gaps and semiconductor devices. They operate within a few microseconds after being triggered.

An adequately designed circuit for a 300-vdc mine-lighting power supply might include pass transistors that are not overstressed at about 600 volts at the highest possible current for the design, taking into account all portions of the characteristic curve of the transistor. This can mean a 900-volt or higher nominal rating. Internal snubbers or zener diodes are necessary to suppress the switching transients of the circuit itself. Externally, a zener diode or varistor would be used to rapidly clamp the voltage when short transient peaks are encountered; a semiconductor crowbar in combination with an overcurrent device would be used to protect against long-duration transients that have energies beyond the capabilities of the suppressor.

## SUMMARY

There have been severe problems with all of the solid-state power supplies tried, but the recent results have been encouraging. Availability can be summarized as follows: (1) for fluorescent lights, Ocean Energy supplies a solid-state converter; (2) for mercury-arc lamps, there is a resistor ballast from Control Products and a solid-state ballast from FMC; and (3) for sodium-vapor lamps, there is no supply presently available. The Bureau has at least four projects underway to improve our standing with respect to dc power supplies.

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