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POWER AND LOAD PRIORITY CONTROL CONCEPT FOR A BRAYTON CYCLE POWER SYSTEM

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16. Abstract

A load-oriented control system is conceived and applied to a Brayton cycle turboalternator. The concept provides speed control and field current control for the alternator and a load simulation which includes energy storage. A laboratory model was constructed and tested with the Brayton Cycle Demonstrator at the Manned Spacecraft Center, Houston, Texas.

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SUMMARY

The control systems that have evolved with Brayton cycle power systems have been directed at power-source control. The purpose of this study is to develop a concept which will maintain this control while providing usable power for spacecraft loads. Studies of such end-use loads have been made, and some information concerning the type and number of loads using conditioned power has been obtained. The effort described herein entails a control system that was oriented to the needs of the power user while maintaining a tight control of power source parameters.

The power conditioning and control concept is presented in general form as would be applied to any spacecraft power source and then tailored specifically to the isotope Brayton turboalternator. Simulation of a load profile was provided in a laboratory model of the power conditioning equipment that was tested with the Brayton Cycle Demonstrator operating at the Manned Spacecraft Center, Houston, Texas.

INTRODUCTION

A number of studies over the last decade, such as Manned Orbiting Research Laboratory (MORL), Skylab, and Space Station/Space Base, have shown the basic NASA interest in long-term earth-orbital manned missions. Power requirements for such missions range from 10 to 100 kW of electrical power and numerous power sources have been evaluated for their ability to support these long-term missions. The Brayton power system, coupled with a nuclear reactor or isotope heat source, is one candidate for such missions; and considerable effort has been expended in the study, design, evaluation, and optimization of components and subsystems. The control systems which have evolved, however, have been oriented toward control of the power source (refs. 1 to 3). Consideration of the users of the electrical power has been secondary on the basis that such design will be mission peculiar.

The detailed technical decisions concerning the characteristics of user electrical power to be distributed have not been made. This has further contributed to neglect of the development of load-oriented control. It was the intent of the effort described herein to devise a method of control oriented toward user demands and to demonstrate the feasibility of the concept by building and testing a laboratory model. The concept, design, and testing are reported with recommendations toward future efforts.

CONCEPT REQUIREMENTS

The power control system is the link between power source and load. Available electrical energy from any source is seldom in the desired form with respect to voltage, current, frequency, or degree of regulation. In order to obtain the desired characteristics, suitable conversion devices are required. Also any given power source has critical parameters that require external control under the application of a load profile. Finally, loading priorities must be considered as to their individual influence on the overall mission power profile and on any emergency operation.

All power sources proposed to date have one or two critical parameters that must be controlled. A suitable sensing device is required to recognize direction and magnitude of deviations of these critical parameters. The parametric sensor, which is a part of the adaptive load control system shown in figure 1, represents such a sensing device and may take the form of a voltage, current, frequency, or speed sensor to match the requirements of the power source to the requirements of the end load.

The power and load controller block shown in figure 1 provides the adaptive control logic to program power to the connected loads, to select conditioning equipment appropriate to system status, and, in conjunction with the parametric sensor, to provide for closed-loop operation of the system. Loop closure may be obtained either directly or indirectly, depending on system design. Examples of direct-loop closure would be alternator-field-current control, isotope-heater heat-dump control, and nuclear-reactor

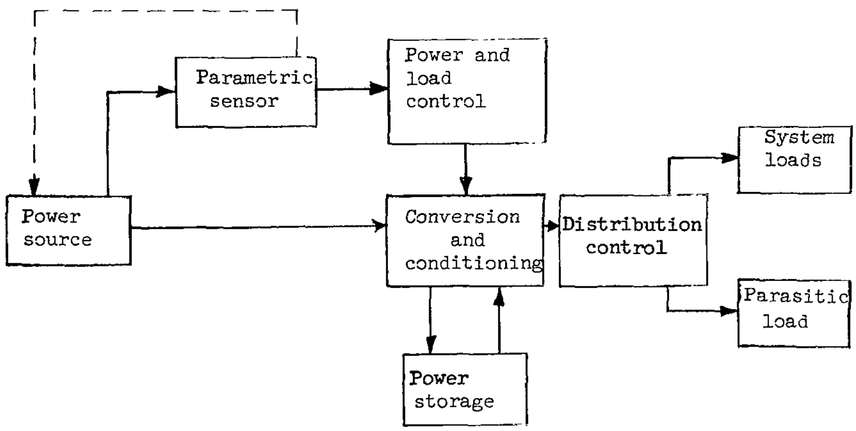

Figure 1.- Block diagram of adaptive load control system.

control-drum control. A more probable method of normal operation would use the indirect loop closure afforded by adjusting load to match average generated power.

Load adjustment in such a system is provided by controlling connected parasitic load, real load, and real load operated parasitically.

Manned missions, in general, will require an emergency power source to provide power for critical loads and to permit a planned abort in the event of loss of the overall power system. Such an emergency system can be used for power storage and, consequently, for load leveling. Design of most power systems is enhanced by designing the power source to provide for average load conditions. Peak-power requirements and absorption of surplus power are managed by a secondary system such as a battery or rechargeable fuel cell. Such a device is shown on the block diagram of figure 1 as power storage.

Load priority cannot be presented by a system block. It must be determined by the particular mission and be programed into the power and load controller.

Generally, this system concept is applicable to a variety of sources and mission requirements. In order to demonstrate the application process, a Brayton cycle power source was selected – more specifically the Brayton Cycle Demonstrator constructed by AiResearch Manufacturing Co. of Arizona and on loan to Manned Spacecraft Center. It is a reasonable choice as the Brayton engine is an attractive candidate for the missions under consideration and has undergone considerable development by the Lewis Research Center.

BRAYTON-CYCLE-SYSTEM CHARACTERISTICS

The Brayton cycle power system is a closed-loop, inert-gas cycle power generation system. A schematic representation is shown in figure 2. The combined rotating

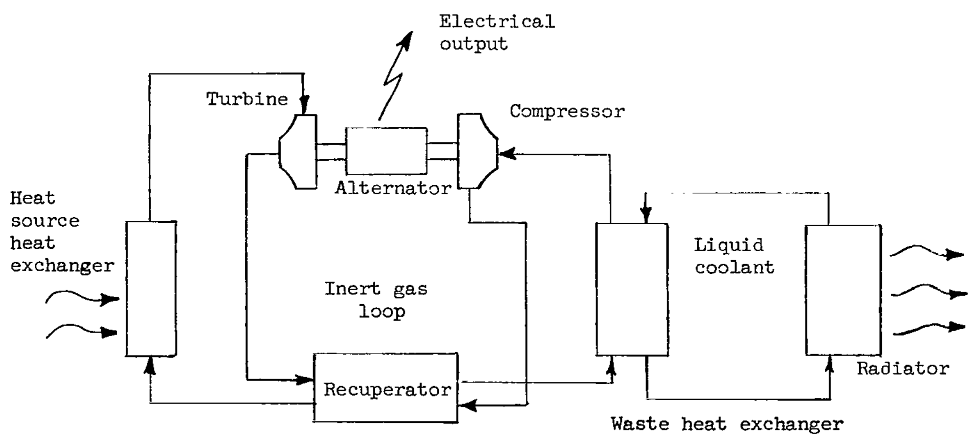

Figure 2.- Brayton cycle power system.

unit consists of a turbine, alternator, and compressor mounted on a single shaft. Three separate heat exchangers are contained within the gas loop. Heat from an external source such as an isotope or a reactor is transferred to the working gas through the heat-source heat exchanger and waste heat is rejected to a liquid-coolant loop through the waste-heat exchanger.

The high conversion efficiency of the Brayton conversion system (25 to 30 percent) is obtained by use of the recuperator which reclaims a large portion of the waste-heat energy within the gas loop. Although the Brayton power system under development by Lewis Research Center is capable of 15 kW output, the Brayton Cycle Demonstrator has a maximum output of 3.0 kW. The Brayton Cycle Demonstrator was assembled by AiResearch Manufacturing Co. from off-the-shelf components and provides a conversion efficiency of approximately 18 percent. Automatic controls are provided for working gas pressure and various critical temperatures. Rotational speed of the alternator constitutes the control parameter.

The design speed must be held constant in order to achieve design efficiency. If the load were to be held at a constant value, speed could be maintained by variations in field current. For test purposes this is adequate, but for a real system a constant real load is highly improbable.

Rotating speeds above or below the design value reduce the efficiency of the heat-power-conversion process. Variations of approximately ±5 percent from design speed will result in a corresponding 1 percent decrease in available output power. Thus, the speed control must provide a capability for operation within a ±5-percent speed variation under even the most stringent transient load conditions.

APPLICATION CONSIDERATIONS

In a flight system it is paramount that maximum utilization be made of available electrical energy. Hence, the parasitic control must maximize energy-storage capability and determine both underload and overload priorities. Only when excess power cannot be used at all, should it be dumped.

Speed Control

Due to the small range of allowable speed error, a concept based on the relatively slow control of heat input from a reactor or isotope would, by itself, be inadequate. This does not rule out heat control entirely to cope with emergencies or long-term variables. Electrical parasitic loading, however, can be designed for rapid response times and will present the constant load that the alternator demands.

Should the alternator be loaded too heavily, its speed-torque (speed-power) curve dictates that it will slow down, and, conversely, for underload conditions the alternator will speed up. Thus, a speed sensing device will yield information about the loading conditions imposed on the alternator. The parametric sensor of figure 1 should, therefore, have signal input proportional to frequency or rotational speed and an output proportional to power change. Since linear speed control allows operation off the design speed, it was decided that for this study another, more accurate, method would be investigated.

The speed-error-integration technique is an adaption of the speed-error-feedback method. (See fig. 3.) In this type sensor, normal-speed-error information is summed with the time integration of error and the resulting signal is used for speed control. With proper application of this method, all the normal characteristics of the speed-error technique are retained, but a relatively slow signal is added to eventually bring the system to zero speed error.

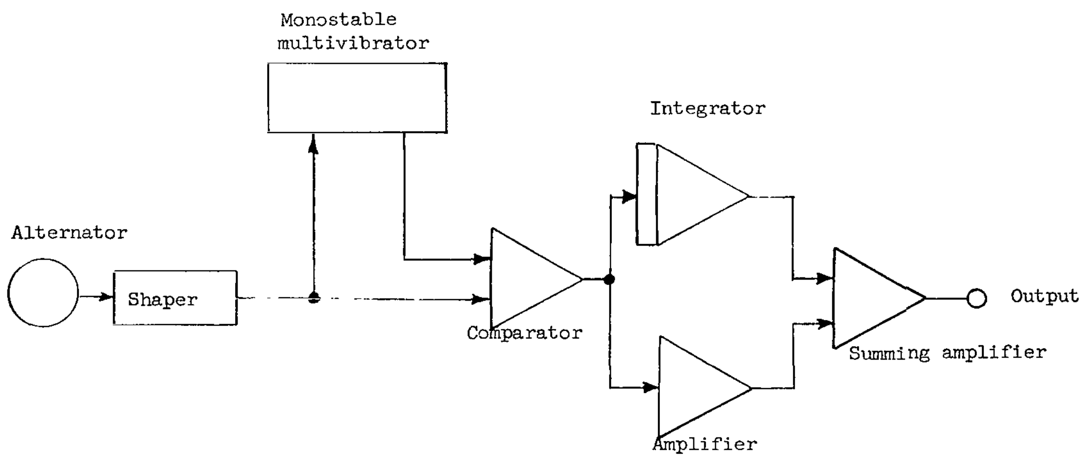

Figure 3.- Block diagram of integral speed sensor.

Computer Power

On board a manned spacecraft there are certain logic functions that must be carried out even if there is a mission power-system failure. Such logic functions require power even if the prime power source has failed. To this end it was decided that the power for these functions would be taken directly from the spacecraft main batteries with no intermediate step. Such a method should minimize the chance that system perturbations or actual power failures would endanger the input power to critical functions.

Loads

The loading of a power source by a system as complex as a space station must, by necessity, result in a rather complex load-time relationship. Until specific needs are determined, only estimates can be made as to the general shape of the load profile. Certainly the average demand cannot exceed the output of the source; and, if power output is to be maintained, provision must be made for energy storage or dissipation during times of underload and for additional power during overload. These functions are accomplished by the battery charge and parasitic load in the first case and by the battery discharge to the load in the second case.

A typical profile as indicated by the MORL studies (ref. 4) is shown in figure 4. The peak demand is 50 percent above the average and the minimum demand is 50 percent below the average. To implement this profile, ac and dc load divisions were determined. Each division was then apportioned into essential, nonessential, experimental, and emergency subdivisions. Provision was also made for critical situations under which the priority of loads will limit power usage in emergencies or critical power-drain periods.

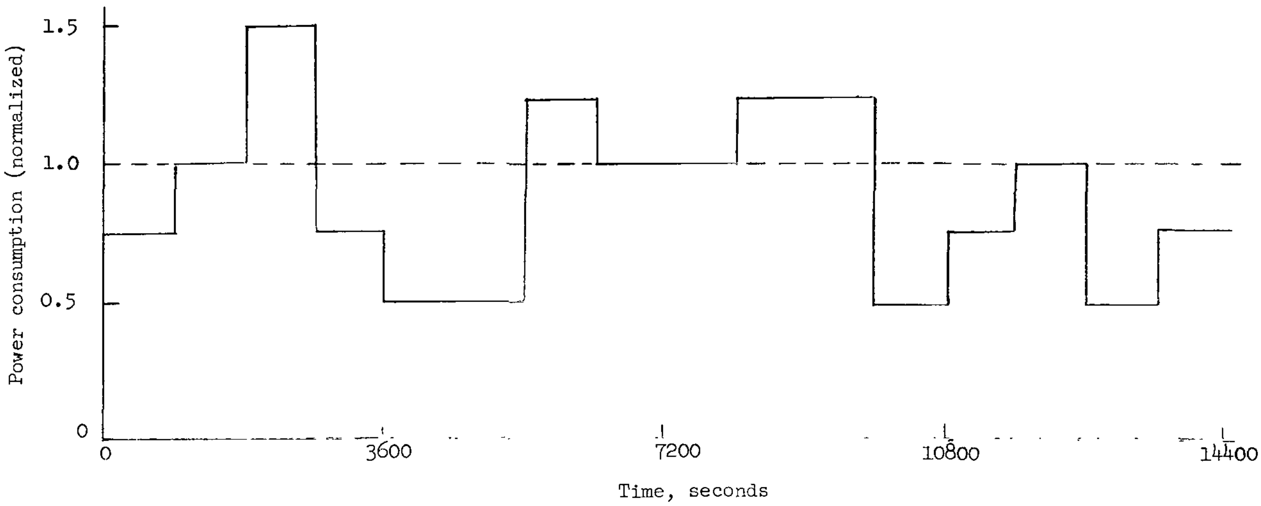

Figure 4.- Typical power profile for extended missions.

Power Conditioning

The electrical power from existing Brayton system alternators is delivered at a frequency from 0.9 to 1.2 kHz, three phase. The output voltage can be 115 volts rms, or less. Both of these values are subject to design specifications. For a given machine, the optimum frequency is fixed, but the output voltage could be provided at nearly any desired level. The selection of conditioning circuitry is somewhat dependent upon the desired bus levels, quality and quantity. It has been assumed that both an ac bus and a dc bus will be provided.

In any large space-station configuration, distribution of power over considerable distances dictates the use of high voltage to minimize line losses. For this reason, the alternator output will be assumed to be at least 115 volts. There is the possibility of using the alternator power directly, but two basic problems exist at this time. The first is the lack of end-use devices, particularly motors, that are designed for 1000 to 1200 hertz. The second involves the synchronization of two or more alternators. Since these problems have not been resolved to date, frequency changers must be included.

Frequency changers can be narrowed to two classes, the cycloconverter and the dc-link inverter. The cycloconverter principle would present a poor power factor to the alternator and result in an increase in design weight. The device is a step-down frequency changer with a minimum reduction ratio of 2.5 or 3.0 to 1.0. Its use would make multiple alternator synchronization necessary. The use of a dc-link inverter arrangement would allow multiple alternator outputs to be joined at the dc linkage. This dc linkage would be the directly rectified alternator output and would be a high voltage (±130 to ±140 volts) suitable for distribution.

At this point it is sufficient to state that ac power can be provided at some frequency at or above 400 hertz, but actual conversion was not provided for the demonstrator system. The end system will most likely provide ac from a dc-link inverter arrangement. This arrangement offers additional buffering to the alternator and works directly from the high-voltage dc bus.

The low-voltage dc bus will provide power to all electronic circuits, computer equipment, and some lighting. A positive and negative bus separation allows operation from one or both buses yielding two operating voltages. Existing devices and equipment lead to 28 volts as a logical choice. This value is applicable to wide selection of transistors, relays, and lamps.

Two choices exist concerning the source of the low-voltage dc. Since a high-voltage dc bus has been established, dc-to-dc conversion is a reasonable method that offers high efficiency and excellent regulation. The other, simpler method, would be to transform the alternator output to a lower voltage before rectification. The decision for the dc-to-dc direct conversion was based primarily on the use of the high-voltage dc bus and the desirability of regulated low-voltage dc.

Voltage control was accomplished by sensing the high-voltage dc bus, which is directly proportional to alternator voltage, and regulating it by means of the alternator field. This method of regulation also provides a regulated source for both the inverter-supplied ac bus and the converter-supplied low-voltage dc bus.

Energy Storage

Nickel-cadmium batteries offer advantages for an experimental system due to their availability and long cycle life. A flight system would no doubt be influenced by the higher energy density of the silver-cadmium cell. The principle of power storage and bus support can be demonstrated sufficiently with a less efficient, longer lived cell.

During conditions of underload, the battery becomes part of the parasitic load, accepting power in order to maintain constant alternator speed. When the load demands are in excess of alternator output, the battery must be called upon to support the dc bus. This dual operation requires both charge and discharge regulators programed by the speed sensing device. Since the battery should not be overcharged or overdischarged, some means must be provided to determine the condition of the battery. In order to demonstrate the ability of the batteries to support the entire electrical system by supporting only the low-voltage dc bus, it was necessary to build the low-voltage dc-to-dc converter. This battery support of the whole system is indirect by reflecting reduced load demand by the low-voltage converter.

Experimental Hardware

The system diagram can now be completed as shown in figure 5. It is essentially a more detailed diagram of the general concept shown in figure 1. It contains the parametric sensing, power control, conditioning, energy storage, and real and parasitic loads. In order to demonstrate adequately the principles of this concept, all principal blocks

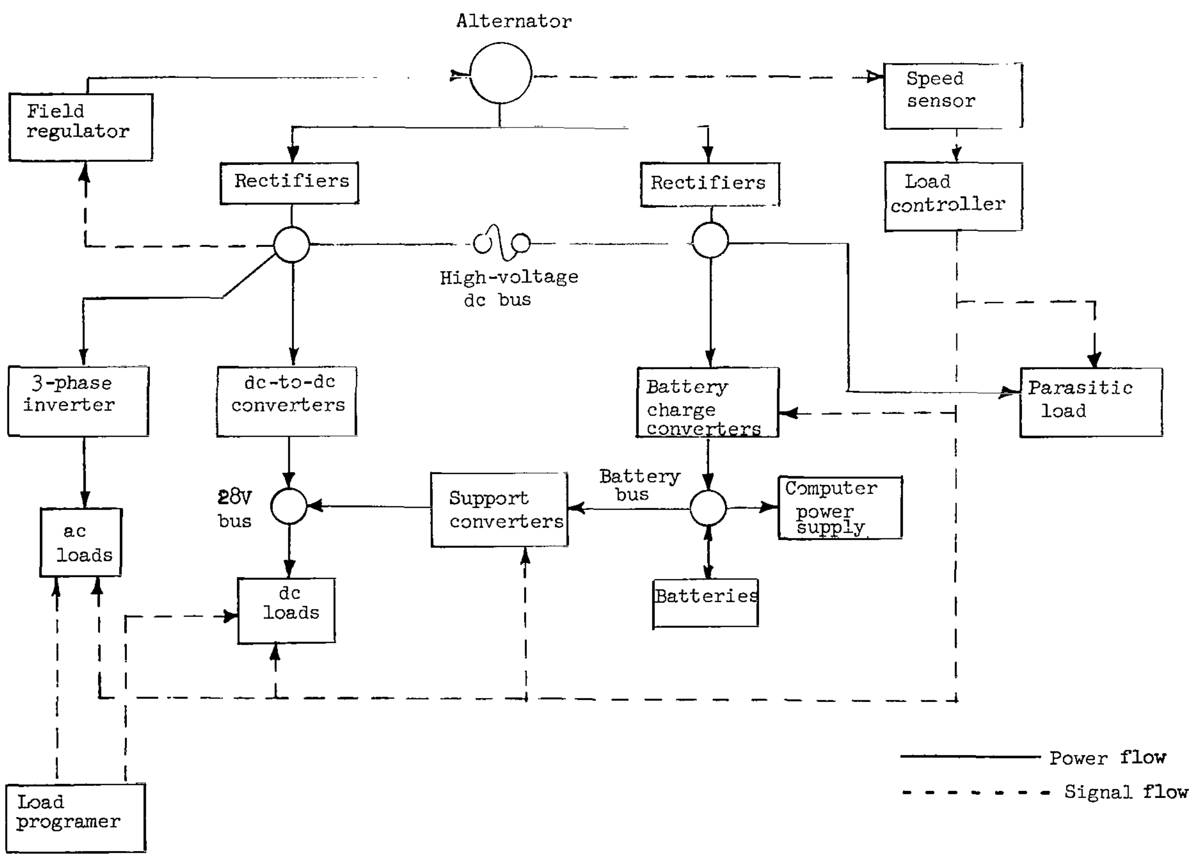

Figure 5.- Block diagram of load control system.

except the inverter were designed and breadboarded. Detailed description of circuitry (experimental hardware design) is presented in the appendix. The breadboard was housed in three consoles and tested with the Brayton Cycle Demonstrator at the Manned Spacecraft Center.

TEST RESULTS

The testing was aimed at evaluation of the feasibility of the concept rather than the gathering of numbers. It was realized that there were many areas that would require improvement and that gain factors and time constants would differ in larger or more complex systems. Improvements in converters and inverters brought about by special-case design procedures would greatly affect the reaction time and consequent effectiveness of this type of control system. However, if this breadboard model could perform within its constraints, a feasible concept would be validated and problem areas could be identified.

Two separate test periods were completed. The first, in conjunction with the Brayton Cycle Demonstrator, was at the Manned Spacecraft Center; the second, a dynamic simulator consisting of a three-phase alternator powered by a dc motor, was at the Langley Research Center.

Testing at the Manned Spacecraft Center demonstrated the concept to be a valid one. Several profile cycles were completed. The weak points proved to be the time constants of the various converters and the relative gains of the parallel channels in the frequency sensor. Each test run was followed by changes to various control circuits. Under an extreme overload application (50 percent) the maximum deviation in alternator speed was recorded as 0.5 percent of nominal. This is well within the design goal. One particular run, shown in figure 6, was of interest. During an accelerated profile run, a faulty pressure sensor caused a gradual bleeding of the Brayton gas loop pressure. The result was a steady decrease in the alternator power output from 1.5 kW to zero. The control system was noticed to drop out all parasitic and battery charge functions and initiate load drops. Only after all primary and secondary loads had been disconnected and only the essential loads remained did the speed of the alternator decrease. The battery supported these essential loads, and emergency shutdown procedures were initiated for the Brayton machinery. Included on the curve of alternator speed is the effect of a 300-watt (20-percent) load drop.

Another set of test runs was made at the Langley Research Center using the simulator described previously. The reactions of the control system to loading transients were nearly identical.

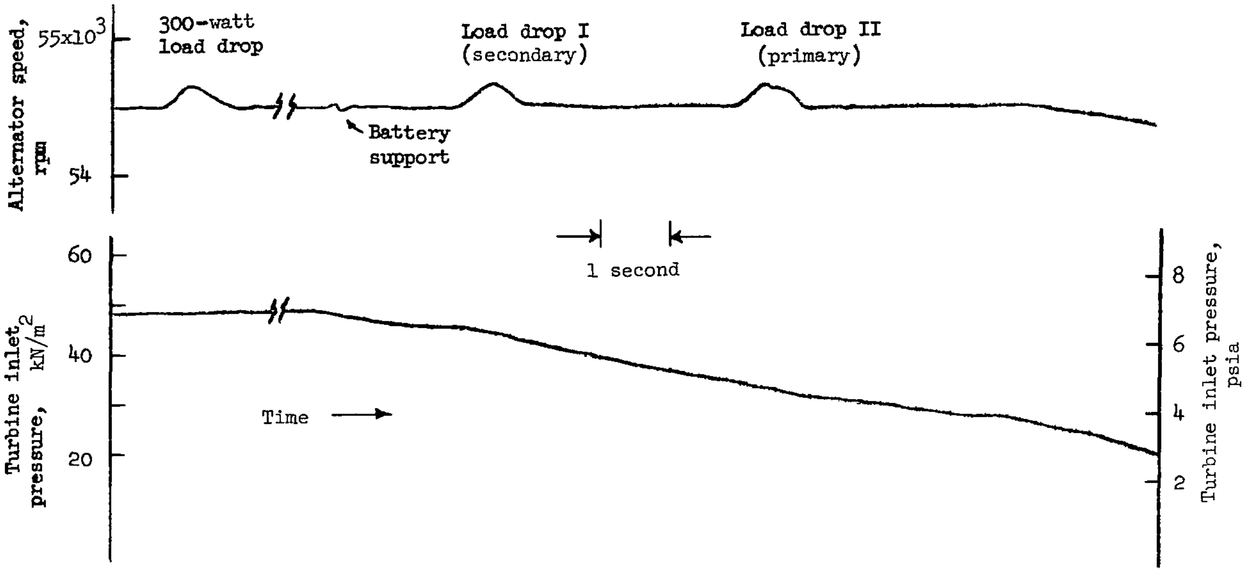

Figure 6.- System control during loss of alternator power output.

CONCLUDING REMARKS

A power and load priority control concept for a Brayton cycle power system was conceived and tested. The concept was proven to be an acceptable one, and performance was well within the constraints of the Brayton machinery and reasonable loading requirements. The system provides:

(1) A load priority control scheme which can be altered to meet the requirements of any spacecraft

(2) A tight control of alternator speed under all reasonable transient conditions

(3) A means to provide energy when load demands are in excess of source capability

(4) A means to store electrical energy during low consumption periods

(5) A transport voltage level (high-voltage dc) suitable for power transfer over long distances with minimum loss and weight

(6) A point (high-voltage dc) to which parallel alternators or other sources can be easily integrated

(7) A regulated bus (high-voltage dc) from which all power at various frequencies and voltages can be converted

The shortcomings which may not be acceptable to future systems are few but real. Any system time delays prove to be detrimental. One source of delay is inherent. A change in loading cannot initiate control until the speed sensor output changes. This, of course, cannot occur until the alternator changes speed. Hence, the alternator torque-speed curve is not only in the control loop, but is the principal factor. All system perturbations are controlled through the alternator. This is not a desirable feature. A control loop that did not rely on speed change as the control factor would be inherently more stable and introduce far less transients. Other concepts need to be tested and evaluated before a considered recommendation can be made for reliable, efficient load-oriented control.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., September 13, 1971.

APPENDIX

EXPERIMENTAL HARDWARE DESIGN

Speed Control

The block diagram of the frequency sensor used is shown in figure 3. This circuit receives its signals directly from the alternator.

One of the phases is fed into a waveform shaper, which is a zero-crossing detector. The output is fed into a one-shot (monostable) multivibrator. The set time (or unstable time) is adjustable and is set to about 500 μF. The output of this circuit is a perfect square wave when the set time exactly equals the reset time. This occurs only when the shaped frequency sample is exactly on the frequency set point of the multivibrator. Both the frequency sample and the multivibrator outputs are fed to a comparator. For zero frequency error, the signals cancel and the output is zero. If the sample frequency is high, the output is a train of positive going pulses, the width of which is proportional to power change about the original set point.

Load Controller

The task of the load controller is to connect or disconnect loads as required to maintain alternator speed and minimum battery charge. Since this test system was relatively simple in terms of number and priority of loads, an analog logic system was used as the fastest and most direct approach to maintaining essential loads and proper alternator speed. Four main levels of control were designed into the circuit:

(1) Parasitic load

(2) Battery charge

(3) Battery support

(4) Load drop

The first three levels of control are continuously variable, whereas the fourth is a bulk switching. A graph of the functions to be performed is shown in figure 7. As the speed sensor indicates a positive voltage (overspeed), battery charge current is programed until equilibrium is reached. Full battery charging rate occurs at a speed-sensor voltage of +2.5 volts. This value represents approximately 10 amperes into two batteries operating at approximately 40 volts each, or 800 watts. If the batteries are fully charged, this function is bypassed and a trickle charge of about 2 amperes is maintained.

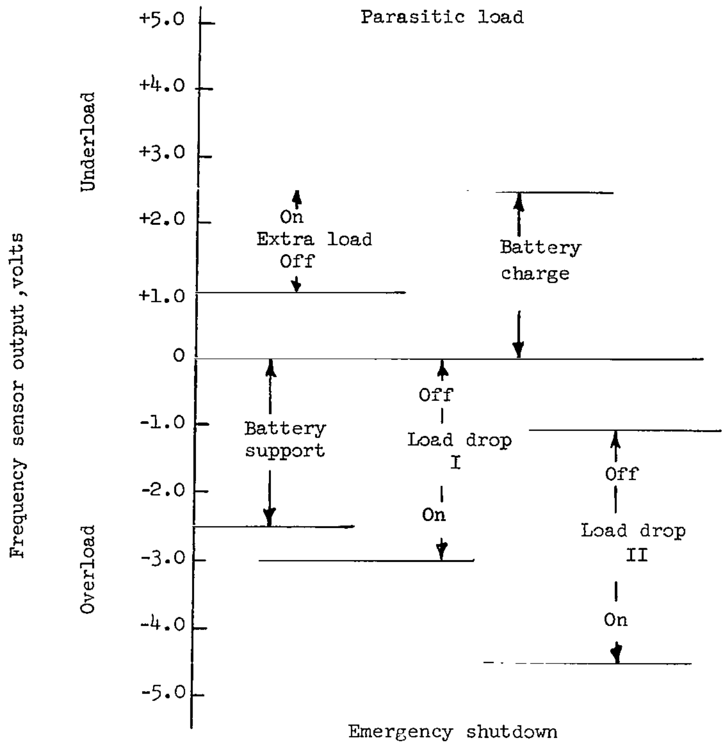

Figure 7.- Logic control.

As the speed-sensor voltage increases to +2.5 volts, a low priority or optional load is switched in. The load may take the form of a noncritical experiment load or may take advantage of real load operated parasitically. An example of the latter would be use of the life support and environmental control system as an energy storage system. Use of dead-band control of oxygen partial pressure constitutes one such method. If oxygen partial pressure is below maximum and excess power is available, electrolysis cells could be programed to consume the available power in preference to dumping parasitically. If inadequate power is available and oxygen partial pressure is above minimum, the electrolysis cells could be programed to reduce power in preference to obtaining support from the battery bus or dropping other loads. The power level selected for this load was 100 watts. For further increases in speed-sensor voltages, the parasitic load is switched in, and 100 percent of alternator load is applied at about +7.5 volts. As the speed sensor retraces this path, the parasitic load is linearly decreased to zero at +2.5 volts, the low priority load is switched out at +1.5 volts, and the battery charge is decreased to zero at 0 volts. For an underspeed condition, the output voltage from the speed sensor goes negative, causing the batteries to support the 28-volt buses. At a speed-sensor output of -2.5 volts, full support is applied, about 10 amperes on each bus or 560 watts. For more negative sensor output voltages, bulk-load drops occur, load drop I at -3.0 volts of about

400 watts and load drop II at -4.5 volts of about 600 watts. Incorporated in these load drops are dead bands, such that the voltage can become less negative without the loads being reenergized. Load drop II releases at -1.0 volts and load drop I releases at 0 volts; this operation prevents the system from going through severe load-drop cycling during a heavy overload.

Another portion of the load controller is the battery condition monitor. The purpose of this circuit is to sense the state of the charge of the battery and apply this signal to the load priority controller. When the battery is fully charged, this circuit defeats the charge signal and limits it to a maximum of 2 amperes as a trickle charge. Should the battery drop to 75 percent of capacity, this circuit removes the battery from the support converter and simultaneously drops loads to compensate. The battery will not be brought back "on the line" and loads reenergized until the battery-charge condition is brought back to 85 percent of capacity. This circuit prevents the battery from dropping below 75 percent capacity under normal use; however, under an emergency condition – that is, loss of alternator power – the battery will be allowed to discharge with no limit. It should be realized that these capacity levels were selected as nominal for test purposes only.

Since the load controller is so involved, a separate circuit was used to perform each of the logic functions required. Figure 8 is the schematic diagram of the battery-charge gate circuit. Since the battery-charger circuit is insensitive to negative voltages, such signals were permitted to go through the device. Amplifier A2 is connected so that input signals from the speed sensor greater than the set point (+2.5 volts) would make the amplifier output go negative, causing the diode to conduct. This action has the effect of clamping the maximum positive voltage into amplifier A1 to +2.5 volts. For speed sensor inputs of less than +2.5 volts, the output of amplifier A2 is positive, which reverse biases the diode and removes the clamp from amplifier A1. Thus, the circuit has a transfer function as shown in the graph of figure 8.

The battery support logic is very similar to the charge logic except that the output cannot go positive and must clamp at -2.5 volts. Amplifier A2 of figure 9 performs the negative clamping function and the diode in the output of amplifier A2 limits the output signals from going positive. Connecting the diodes within the amplifier loop as has been done here reduces the error that the diodes would normally introduce into the logic functions by the amount of the loop gain – in the case of these amplifiers, about 90 dB.

The parasitic load gate is shown in figure 10. This is a differential input amplifier which amplifies only the difference between its two inputs. The output from the speed sensor feeds into the noninverting input, and the output from the battery charge logic feeds the inverting input. Since for sensor voltages below +2.5 volts both voltages are the same, the amplifier output is zero; above +2.5 volts the output rises linearly. The gain is so set that when the speed-sensor input is +10 volts and the battery charge input

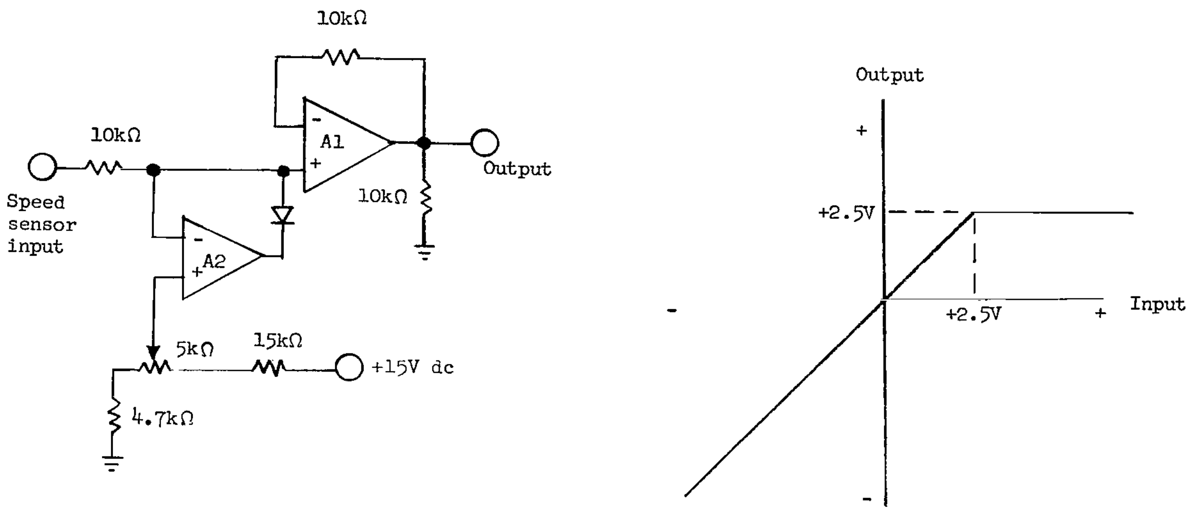

Figure 8.- Battery charge gate and transfer function.

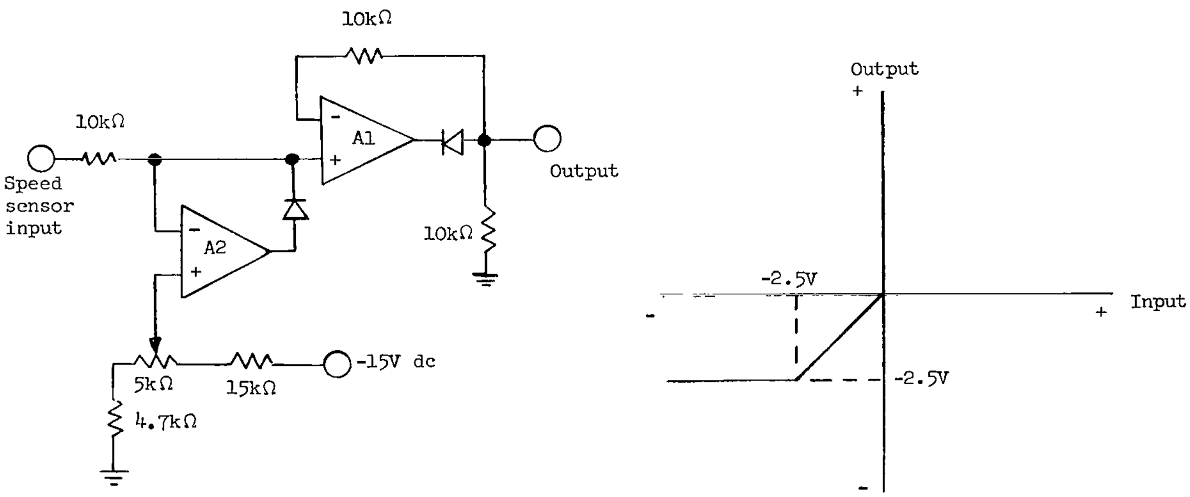

Figure 9.- Battery support gate and transfer function.

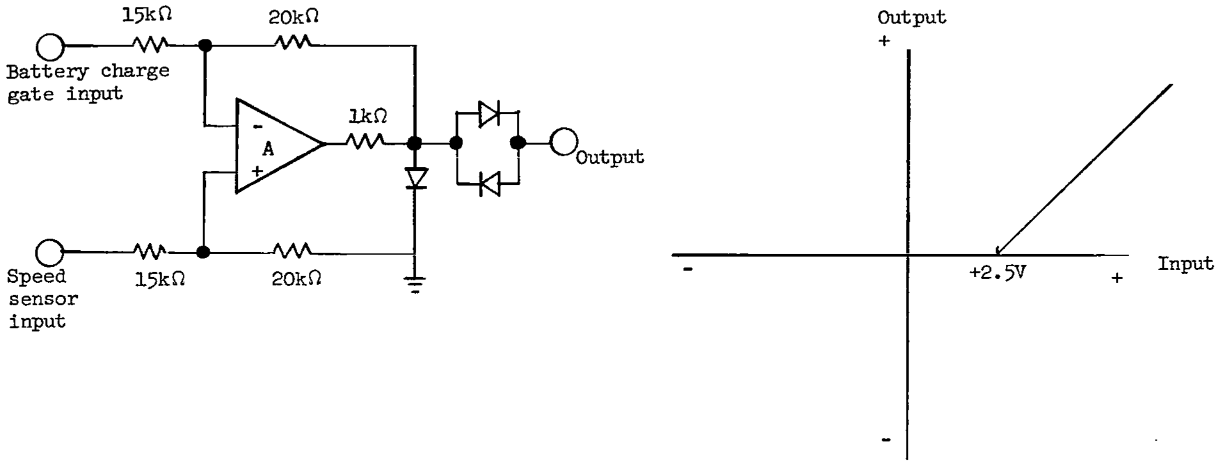

Figure 10.- Parasitic load gate and transfer function.

is limited to +2.5 volts, the output is +10 volts. This voltage is sufficient to turn the parasitic load full-on with a dissipation capacity of 150 percent of the alternator output.

The rest of the load controller switches loads in or out, depending on the output from the speed sensor. But, it is through the linear control of power provided by these circuits that the actual alternator speed is maintained. The switched load levels are provided simply to insure that under all operating conditions the output from the speed sensor returns to one of the three analog voltage ranges mentioned previously. A schematic diagram of each of the two load-drop circuits is shown in figures 11 and 12. They are Schmidt trigger-type circuits which use operational amplifiers and externally adjustable set points. Figure 13 is a schematic diagram of the add load circuit. It, too, is an adjustable Schmidt trigger-type circuit.

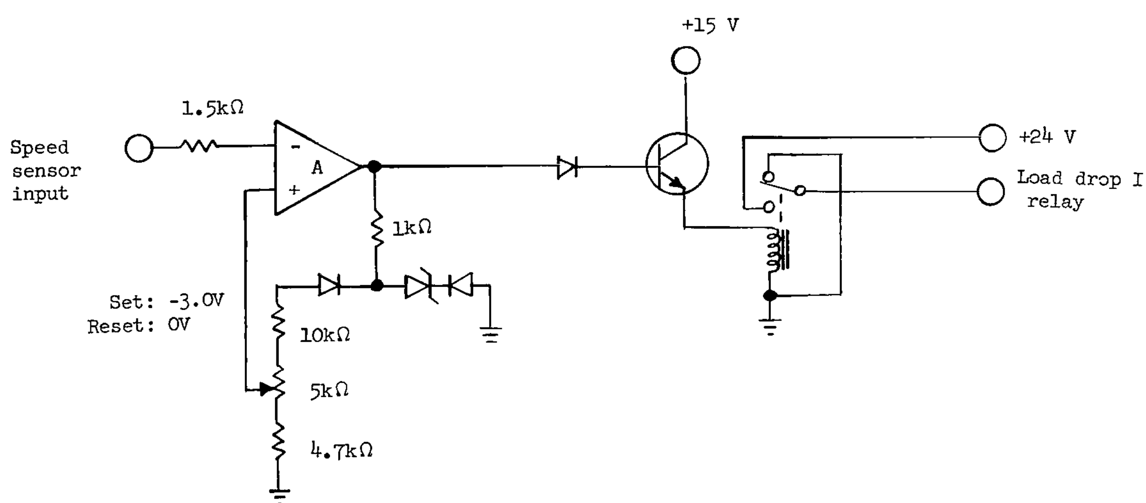

Figure 11.- Load drop I controller.

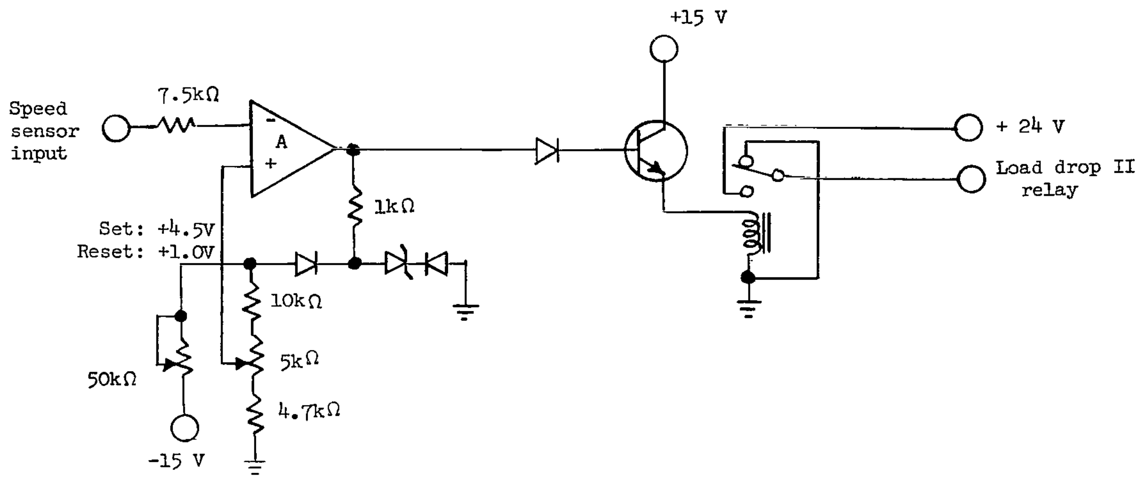

Figure 12.- Load drop II controller.

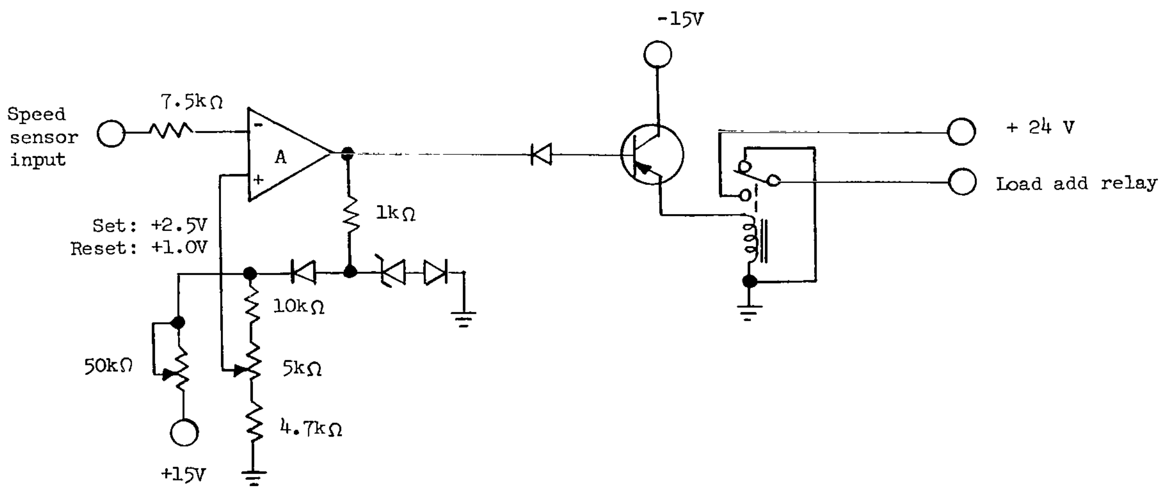

Figure 13.- Add load controller.

An integral portion of the load control circuit is the battery condition monitor. In this system, nickel-cadmium batteries were used because of their availability; but, since a method for accurately determining their state of charge was not available, a charge integrator was used to monitor the net charge and discharge currents. These circuits are shown in figure 14. They consist of a shunt in series with each battery, a differential

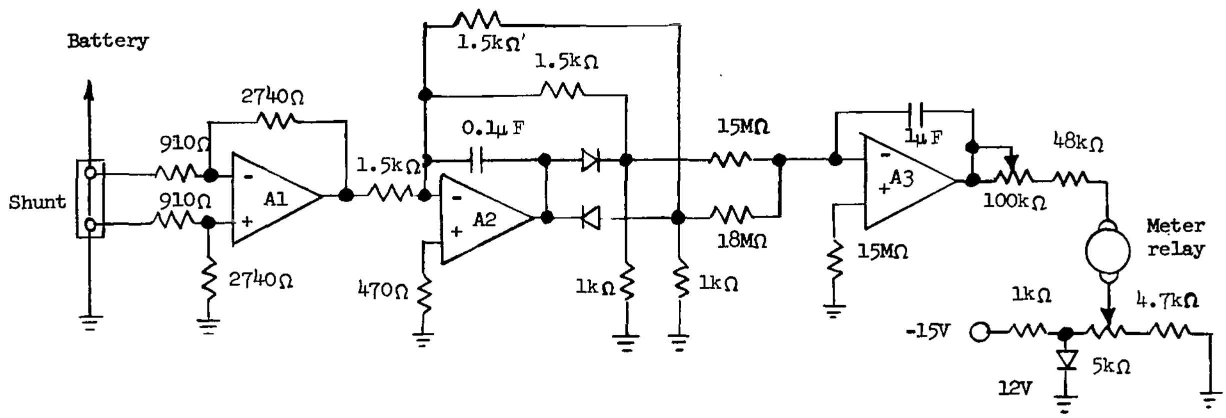

Figure 14.- Battery condition monitor.

amplifier to raise the voltage of the shunt reading and reference it to the logic ground, a nonlinear amplifier to correct for battery charge-discharge inefficiencies, and a high-quality integrator. The integrator is connected to drive a contactless meter relay with variable set points. In this manner the meter relays could be connected to perform the desired function and the set points adjusted to set the maximum depth of discharge and reset points. In this case the maximum normal depth of discharge is to 75 percent; when the battery has been recharged to 85 percent, the circuit is reset. It was assumed that both batteries would track fairly well so that it was necessary to monitor only one battery to perform this function. There is, however, an identical monitor circuit on the other battery, the purpose of which is to establish the 100-percent charge condition and readjust the battery charge to a trickle level only.

Load Profile

The total real load profile of figure 15 was divided into ac and dc divisions. The divisions were approximately 40 to 60 percent, respectively. The load profile average was 1340 watts, whereas the alternator output was maintained at 1500 watts. Maximum loads were 750 watts ac and 1550 watts dc which represented a 50-percent overload. Figures 16 and 17 present the breakdown of the ac and dc loads into essential, nonessential, and one or more cyclic loads. A motor-driven timer was incorporated to provide automatic switching of cyclic loads to establish the total load-time profile. Each load was simulated by a resistor that could be actuated either automatically with the timer

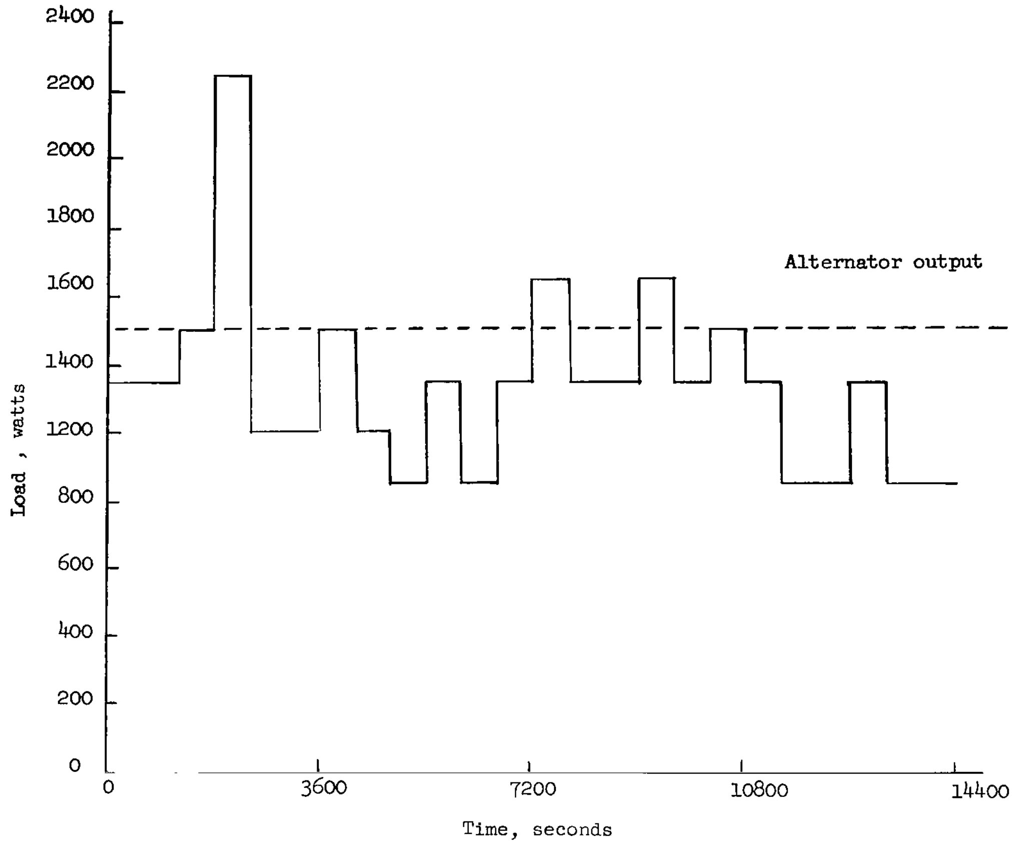

Figure 15.- Total real load profile.

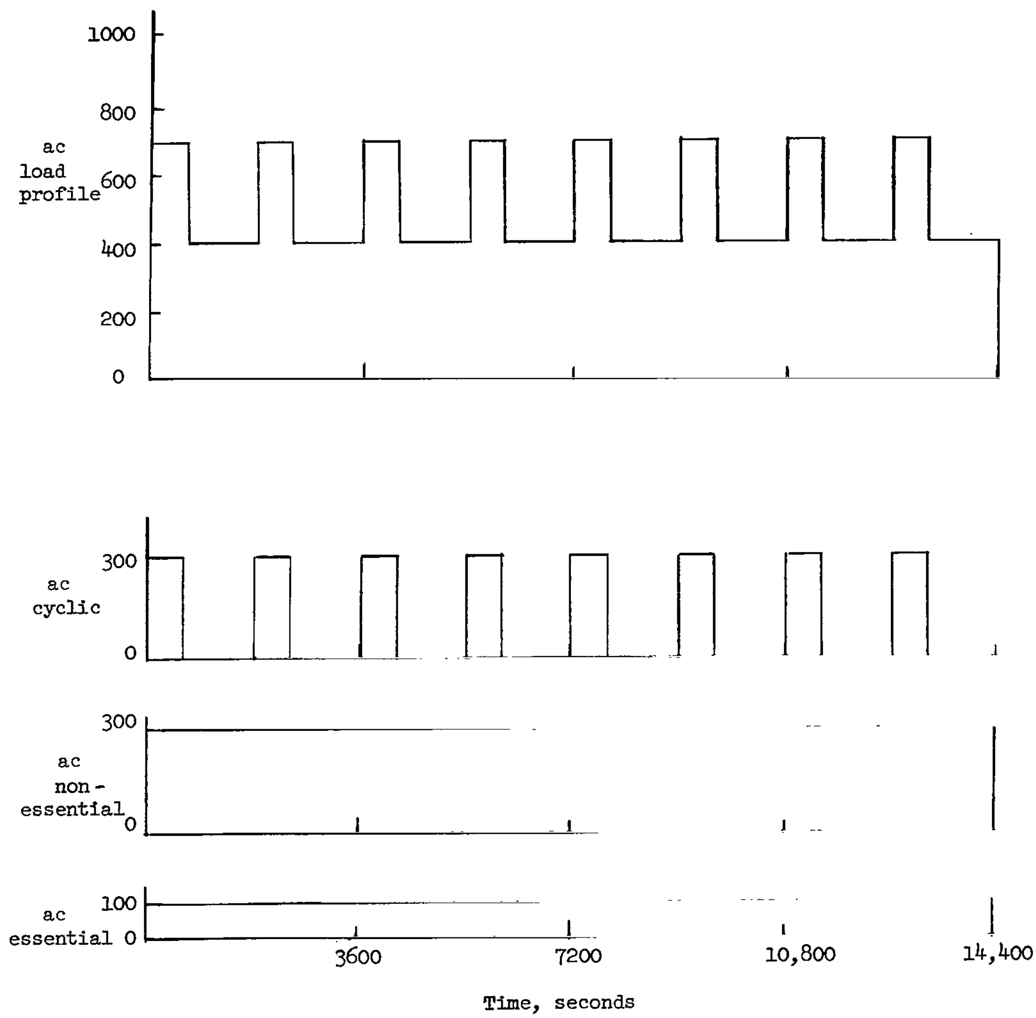

Figure 16.- Total ac load profile.

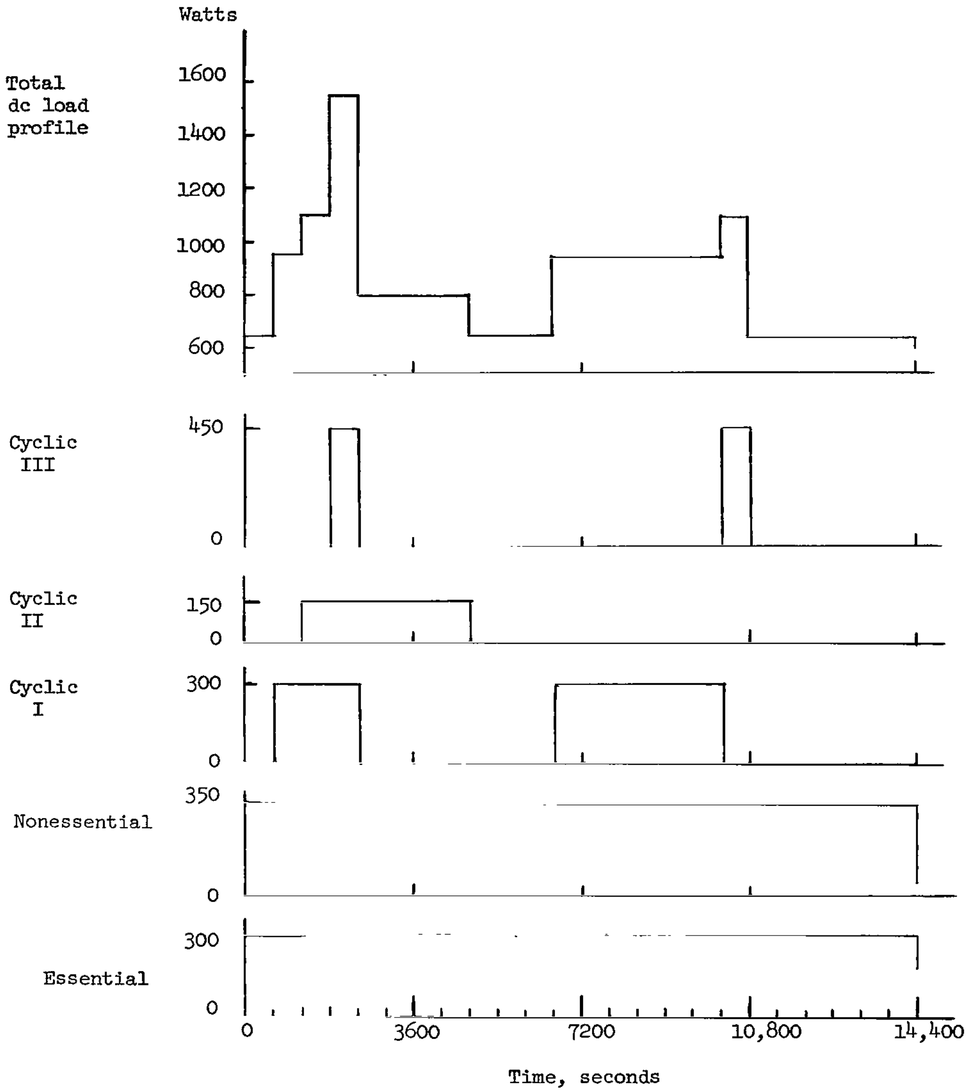

Figure 17.- Total dc load profile.

or manually through override switches. The monitoring of individual loads was provided by lights across each resistor assembly. Equal loading was maintained on the positive and negative buses. One unbalance load was provided by manual means only. All manual switches and lights were placed on a central monitor panel with metering of all critical functions.

Power Conditioning Circuitry

The field regulator was designed to sense the +130-volt bus and maintain this voltage through a pulse control method. (See fig. 18.) This circuit maintains a constant pulse frequency and simply varies the duty cycle. The circuit operation is very similar to that of the dc-to-dc converter, which will be discussed subsequently.

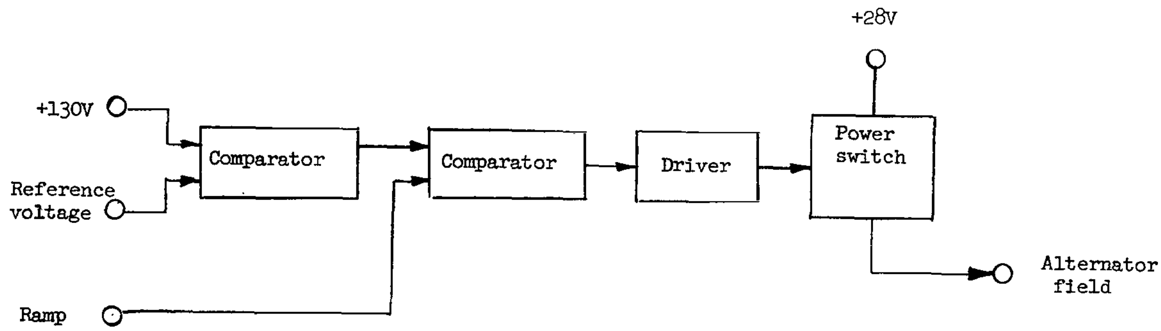

Figure 18.- Pulse modulated field regulator.

The alternator output was fed into a half-wave rectifier bridge to develop ±130 volts dc. The rectifier outputs were fed into a capacitor input filter with no additional filtering. This established the ±130-volt dc buses from which all other power is derived.

It was decided that ±28-volt buses would be provided with regulation to ±1 percent so that other subsystems would not be subjected to wide voltage variations. It was felt that this philosophy would result in an overall increase in efficiency since the subsystems using this power would not all have to provide their own regulators. Thus, a series-pass, pulse-width-modulated converter was designed. The schematic diagram of this circuit is in figure 19. On the left is a voltage reference source. This voltage is fed to a high-grain amplifier and compared with the ±28-volt buses through a voltage divider. The amplified output is compared with an input ramp function generated by a master generator operating at about 1 kHz. As the 28-volt output increases, the output pulse width from the comparator decreases and conversely increases for an under-voltage condition. The varying pulse width modulates the current through a series choke and results in increasing or decreasing the voltage as required to maintain 28 volts. This type circuit is the basic type used for all the power converters in this system. The battery charge converter, figure 20, and the battery support converter, figure 21, are nearly identical

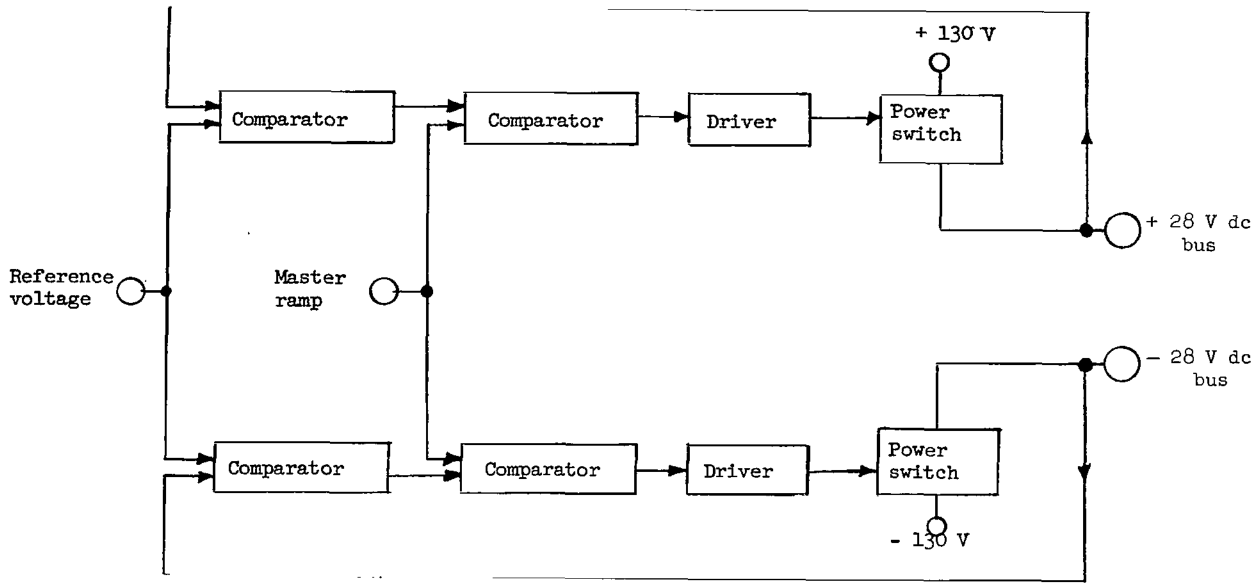

Figure 19.- Pulse-width-modulated dc-to-dc converter.

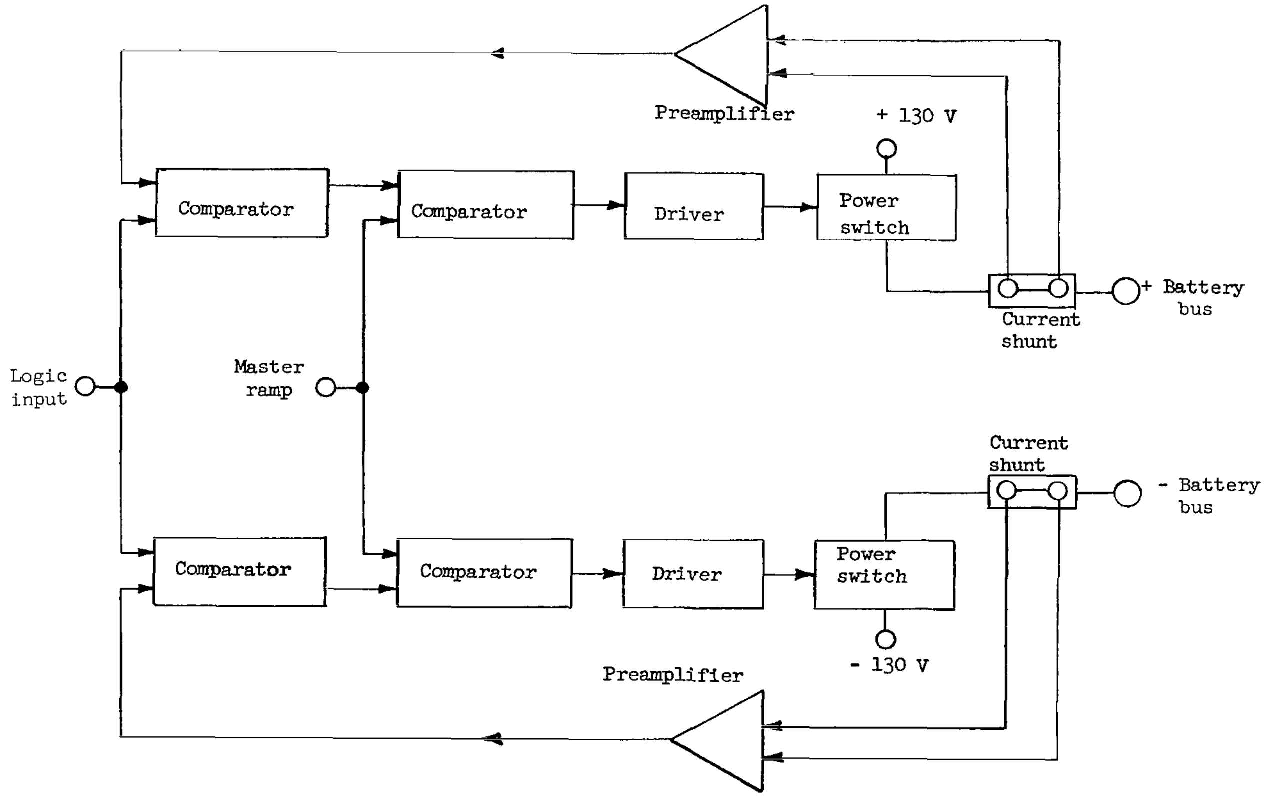

Figure 20.- Battery charge converter.

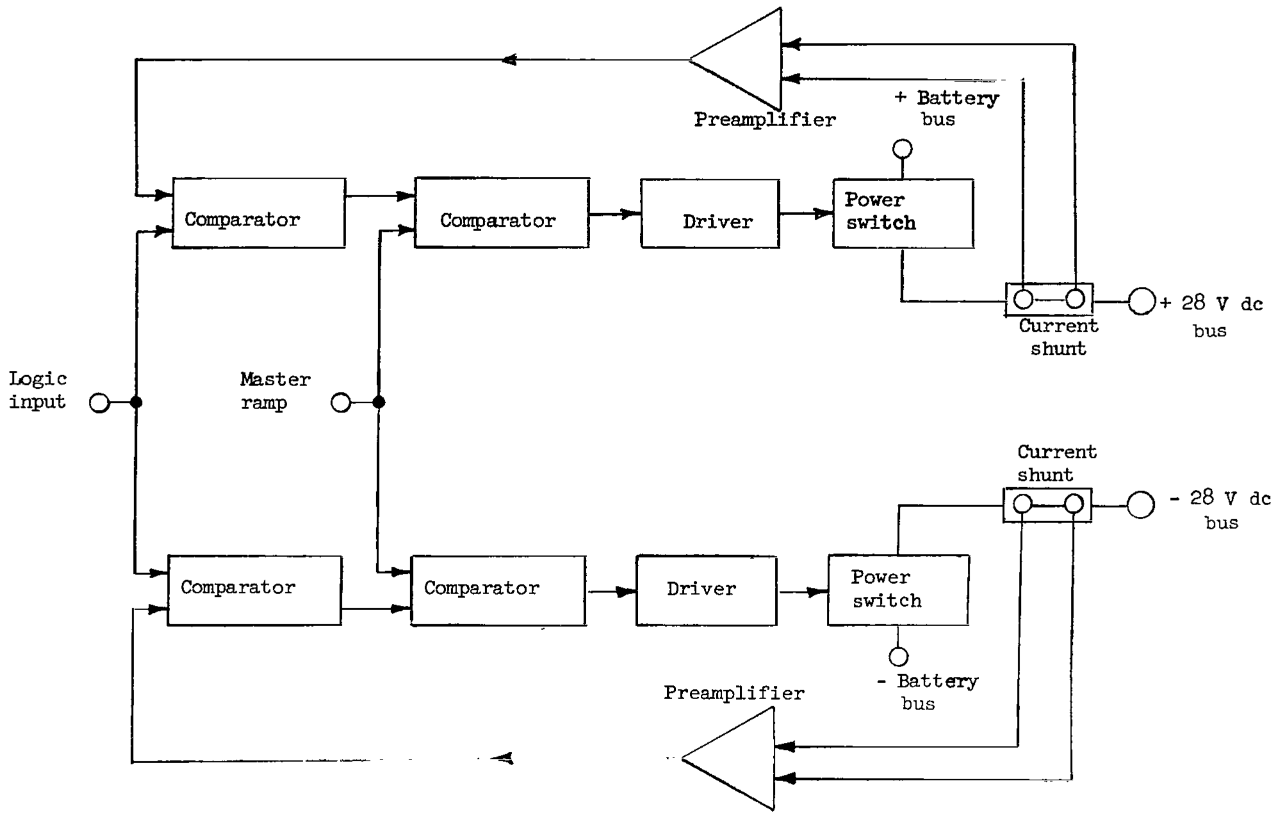

Figure 21.- Battery support converter.

in operation to the dc-to-dc converter. They differ in that they are current programed rather than voltage programed.

The parasitic load circuit, shown in figure 22, consists of pulse-modulated resistive loading on the ±130-volt-dc buses. This method of parasitic loading was used instead of the frequently used phase control for the following reasons: (1) It has better power-factor characteristics, (2) it does not distort the output voltage waveform from the alternator, (3) it does not require accurate control of the relative phases of the various loads, (4) it does not have severe effects on the alternator neutral currents, and (5) it provides equal loading if parallel alternators are necessary.

The program input is from the load controller in the form of an analog signal. The parasitic load circuit converts the analog signal to a 1-kHz pulse, the duty cycle of which is directly proportional to input voltage, that is, zero duty cycle at 0 volts and 100-percent duty cycle at +10 volts. The load resistors were sized to allow a 50-percent overload capacity on the alternator so that the parasitic load could absorb approximately 2.8 kW. With all other systems off, the parasitic load could hold the alternator speed to the desired level. Under startup conditions, the parasitic load will be the only operational load.

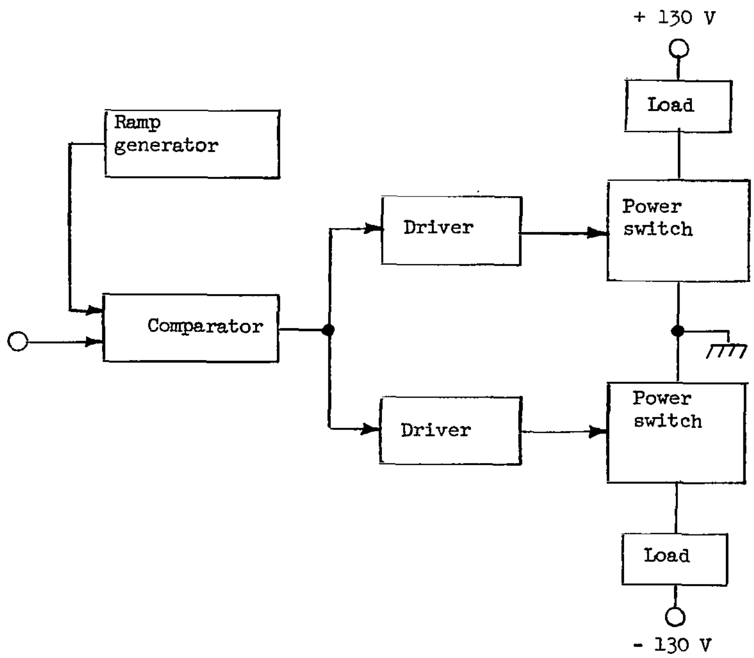

Figure 22.- Parasitic load circuit.

Operation and Monitoring

Voltage and current monitoring of all buses and converter outputs were provided on a central control panel by selector switching and digital readout. Constant monitoring of key parameters was provided by an additional array of panel meters.

Control power for relays and switching was provided by means of an external 28-volt dc supply. Activation of the battery switch applies power to all logic and the parasitic load control circuits. After the rotating equipment (Brayton) has been stabilized, the converters are activated serially.

REFERENCES

1. Word, John L.; Fischer, Raymond L. E.; and Ingle, Bill D.: Static Parasitic Speed Controller for Brayton Cycle Turboalternator. NASA TN D-4176, 1967.
2. Fisher, Raymond L. E.; and Droba, Darryl J.: Dynamic Characteristics of Parasitic-Loading Speed Controller for 10-Kilowatt Brayton Cycle Turboalternator. NASA TM X-1456, 1968.
3. Engineering Staff: Test Report – AiResearch Brayton Cycle Demonstrator Test Program. APS-5270-R (Contract NAS 9-6116), AiResearch Manufacturing Co. of Arizona, Garrett Corp., Nov. 15, 1967. (Available as NASA CR-65924.)
4. Anon.: Report on the Design Requirements for Reactor Power Systems for Manned Earth Orbital Applications. DAC-57950 (Contract NAS 1-5547), Missile & Space Systems Div., Douglas Aircraft Co., Inc., Jan. 1967. (Available as NASA CR-66254.)

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