



APOLLO TRAINING

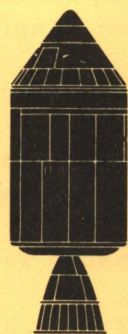
APOLLO OPERATIONS HANDBOOK-
CSM BLOCK II, PRELIMINARY

SUBSECTION 2.6
ELECTRICAL POWER SYSTEM

28 SEPTEMBER 1967

FOR TRAINING PURPOSES ONLY





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ELECTRICAL POWER SYSTEM

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SYSTEMS DATA

SECTION 2

SUBSECTION 2.6

ELECTRICAL POWER SYSTEM

2.6.1 INTRODUCTION.

The electrical power subsystem (EPS) consists of the equipment and reactants required to supply the electrical energy sources, power generation and controls, power conversion and conditioning, and power distribution to the electrical buses (figure 2.6-1). Electrical power distribution and conditioning equipment beyond the buses is not considered a part of this subsystem. Power is supplied to fulfill all command and service module (CSM) requirements, as well as to the lunar module (LM) for operation of heater circuits after transposition and docking.

The EPS can be functionally divided into four major categories:

- Energy storage: Cryogenics storage, entry and postlanding batteries, pyrotechnic batteries.
- Power generation: Fuel cell power plants.
- Power conversion: Solid state inverters, battery charger.
- Power distribution: D-C and a-c power buses, d-c and a-c sensing circuits, controls and displays.

In general, the system operates in three modes: peak, average, and minimum mission loads. Peak loads occur during performance of major delta V maneuvers, including boost. These are of relatively short duration with d-c power being supplied by three fuel cell power plants supplemented by two of three entry batteries. A-C power is supplied by two of three inverters.

The second mode is that part of the mission when power demands vary about the average. During these periods d-c power is supplied by three fuel cell power plants and a-c power by one or two inverters.

During drifting flight, minimum power is required. During these periods d-c power can be supplied by two fuel cell power plants with one on open circuit and a-c power by one or two inverters.

2.6.2 FUNCTIONAL DESCRIPTION.

2.6.2.1 Energy Storage.

The primary source of energy is provided by the cryogenic gas storage system that provides fuel (H₂) and oxidizer (O₂) to the power

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generating system. Two hydrogen and two oxygen tanks, with the associated controls and plumbing, are located in the service module. Storage of reactants is accomplished under controlled cryogenic temperatures and pressures; automatic and manual pressure control is provided. Automatic heating of the reactants for repressurization is dependent on energy demand by the power generating and/or environmental control subsystems. Manual control can be used when required.

A secondary source of energy storage is provided by five silver oxide-zinc batteries located in the CM. Three rechargeable entry and postlanding batteries supply sequencer logic power at all times, supplemental d-c power for peak loads, all operating power required for entry and postlanding, and can be connected to power either or both pyro circuits. Two pyro batteries provide energy for activation of pyro devices throughout all phases of a mission.

2.6.2.2 Power Generation.

Three Bacon-type fuel cell power plants, generating power through electrochemical reaction of H_2 and O_2 , supply primary d-c power to spacecraft systems until CSM separation. Each power plant is capable of normally supplying up to 1420 watts at 27 to 31 volts to the power distribution system. During normal operation all three power plants generate power, but two are adequate to complete the mission. Should two of the three malfunction, one power plant, with non-essential loads removed, will insure successful mission termination.

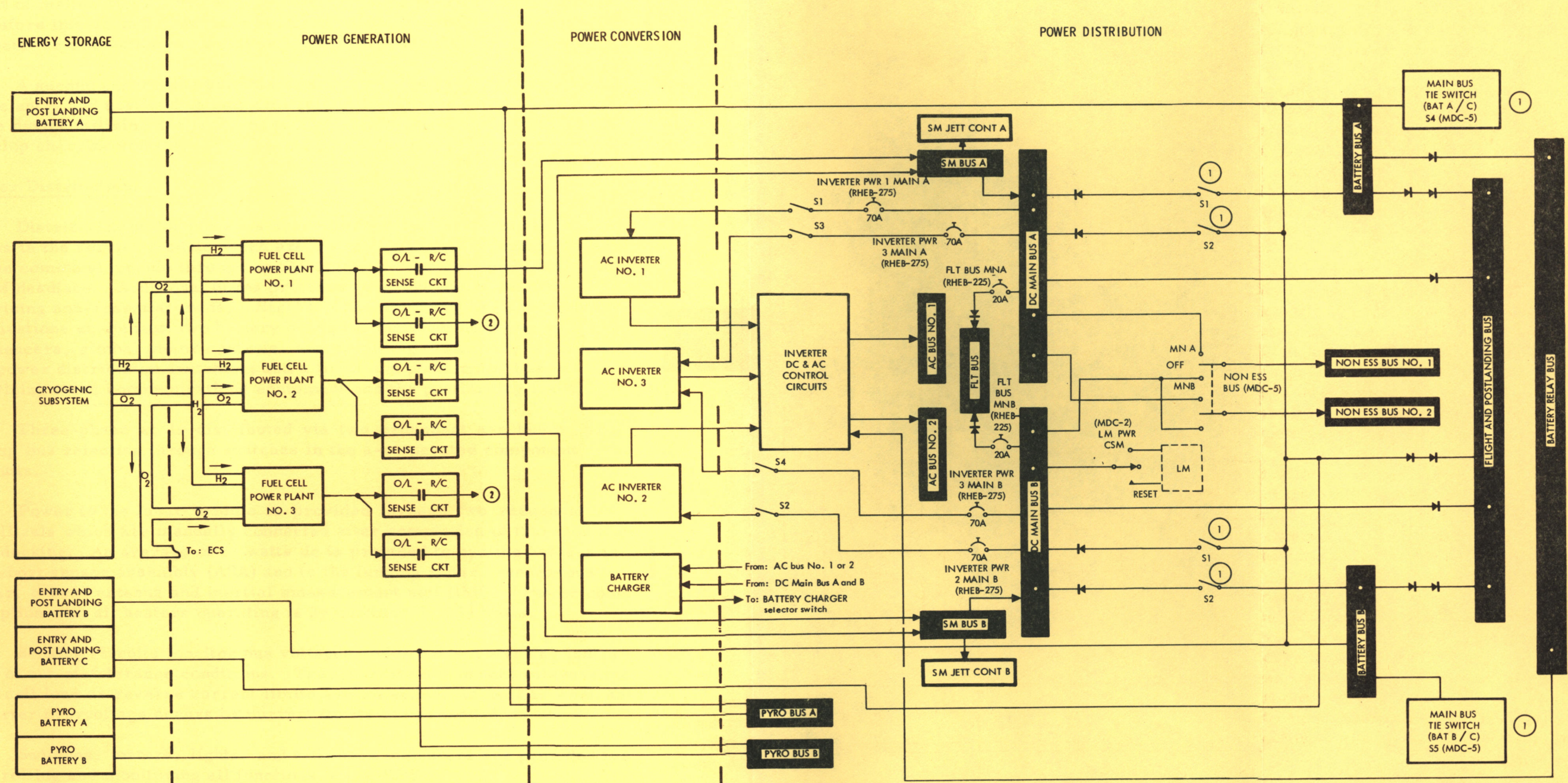
Normal fuel cell connection to the distribution system is: Fuel cell 1 to main d-c bus A; fuel cell 2 to main d-c bus A and B; and fuel cell 3 to main d-c bus B. Manual switch control is provided for power plant connection to the distribution system, and manual and/or automatic control for power plant isolation in case of a malfunction.

During the CSM separation maneuver the power plants supply power through the SM buses to two SM jettison control sequencers. The sequencers sustain SM RCS retrofire during CSM separation and fires the SM positive roll RCS engines two seconds after separation. Roll engine firing is terminated 5.5 seconds after separation. The power plants and SM buses are isolated from the umbilical through an SM deadface. The sequencers are connected to the SM buses when the CM/SM SEP switch (MDC-9) is activated; separation occurs 100 milliseconds after switch activation.

2.6.2.3 Power Conversion.

Primary d-c power is converted into ac by solid state static inverters that provide 115/200-volt 400-cps 3-phase a-c power up to 1250 volt-amperes each. A-C power is connected by motor switch controls to two a-c buses for distribution to the a-c loads. One inverter has the capacity to supply all spacecraft primary a-c power. One inverter

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- NOTES:
- Motor switches S1 and S2 close when main bus tie switches S4 and S5 are set to Bat A/C and Bat B/C.
 - FC1 can be connected to SM bus B & FC3 to SM bus A.
 - DC bus control circuit breakers are illustrated in battery charger and CM DC bus control circuits schematic.

Figure 2.6-1. Electrical Power Subsystem Block Diagram

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can power both buses while the two remaining inverters act as redundant sources. During delta V maneuvers, each bus is powered by a separate inverter. Provisions are made for bus and/or inverter isolation in the event of malfunctions. Inverter outputs cannot be phase synchronized, therefore interlocked motorized switching circuits are incorporated to prevent the connection of two inverters to the same bus.

A second conversion unit, the battery charger, assures keeping the three entry and postlanding batteries in a fully charged state. It is a solid state device utilizing d-c from the fuel cells and ac from the inverter to develop charging voltage.

2.6.2.4 Power Distribution.

Distribution of d-c power is accomplished via two redundant d-c buses in the service module which are connected to two redundant buses in the command module through an SM deadface, the CSM umbilical, and a CM deadface. Additional buses provided are: two d-c buses for servicing non-essential loads; a flight bus for servicing inflight telecommunications equipment; two battery buses for distributing power to sequencers, gimbal motor controls, and servicing the battery relay bus for power distribution switching; and a flight and postlanding bus for servicing some communications equipment and the postlanding loads.

Three-phase ac is distributed via two redundant a-c buses, providing bus selection through switches in the a-c operated component circuits.

Power to the lunar module is provided through two redundant umbilicals which are manually connected after completion of transposition and docking. An average of 81 watts dc is provided to cycling heaters in the abort sensor assembly (ASA) and to the landing radar, rendezvous radar, S-band antenna and inertial measurement unit (IMU). Power consumption with all heaters operating is approximately 209 watts.

Sensing circuits monitor bus voltages and provide a warning indication of out-of-tolerance conditions. They activate disconnect relays when fuel cell load or reverse current limits are exceeded, as well as when an inverter overvoltage occurs or current limits are exceeded.

Switches, meters, lights, and talk-back indicators are provided for controlling and monitoring all functions of the EPS.

2.6.3 MAJOR COMPONENT/SUBSYSTEM DESCRIPTION.

The subsequent paragraphs describe the cryogenic storage subsystem, and each of the various EPS components.

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2.6.3.1 Cryogenic Storage.

The cryogenic storage subsystem (figure 2.6-2) supplies hydrogen to the EPS, and oxygen to the EPS, ECS, and for initial LM pressurization. The two tanks in the hydrogen and oxygen systems are of sufficient size to provide a safe return from the furthest point of the mission on the fluid remaining in any one tank. The physical data of the cryogenic storage subsystem are as follows:

Weight of Usable Cryogenics (lb/tank)		Design Storage Pressure (psia)	Minimum Allowable Operating Pressure (psia)	Approximate Flow Rate at Min dq/dm (+145°F environment) (lb/hr-2 tanks)	Approximate Quantities at Minimum Heater & Fan Cycling (per tank) (min dq/dm)
O ₂	320 (min)	900±35	150	1.71	40 to 25%
H ₂	28 (min)	245 (+15, -20)	100	0.140	50 to 28%

Initial pressurization from fill to operating pressures is accomplished by GSE. After attaining operating pressures, the cryogenic fluids are in a single-phase condition, therefore completely homogeneous. This avoids sloshing which could cause sudden pressure fluctuations, possible damage to internal components, and prevents positive mass quantity gauging. The single-phase expulsion process continues at nearly constant pressure and increasing temperature above the 2-phase region.

Two parallel d-c heaters in each tank supply the heat necessary to maintain design pressures. Two parallel 3-phase a-c circulating fans circulate the fluid over heating elements to maintain a uniform density and decrease the probability of stratification. A typical heater and fan installation is shown in figure 2.6-3. Relief valves provide overpressure relief, check valves provide tank isolation, and individual fuel cell shutoff valves provide isolation of malfunctioning power plants. Filters extract particles from the flowing fluid to protect the ECS and EPS components. The pressure transducers and temperature probes indicate the thermodynamic state of the fluid. A capacitive quantity probe indicates quantity of fluid remaining in the tanks.

Repressurization of the systems can be automatically or manually controlled by switch selection. The automatic mode is designed to give a single-phase reactant flow into the fuel cell and ECS feed lines at design pressures. The heaters and fans are automatically controlled through a pressure switch-motor switch arrangement. As pressure in the tanks decreases, the pressure switch in each tank closes to energize the motor switch, closing contacts in the heater and fan circuits. Both tanks have to decrease in pressure before heater and fan circuits are energized. When either tank reaches the upper operating pressure limit, that respective

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OXYGEN STORAGE SYSTEM

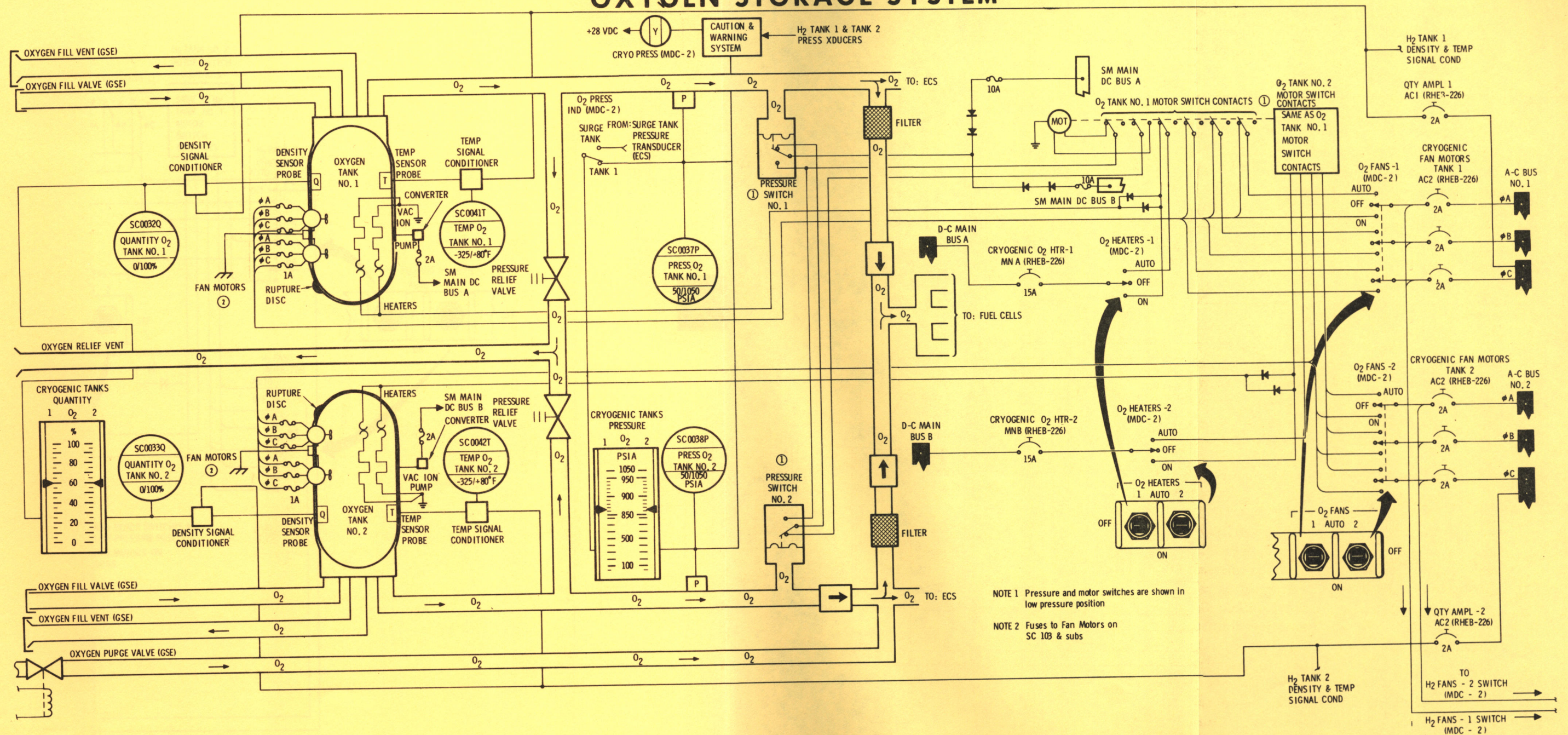
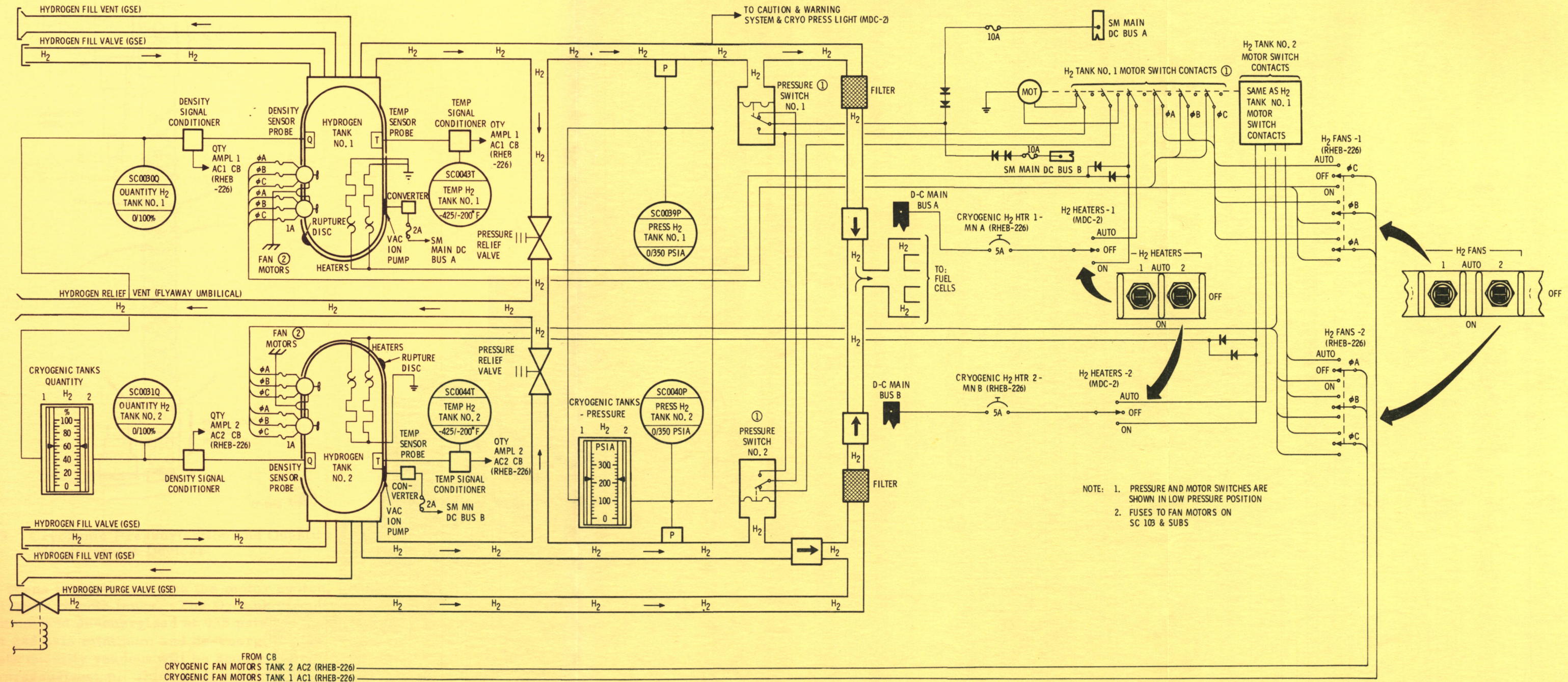


Figure 2.6-2. Cryogenic Storage Subsystem (Sheet 1 of 2)

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HYDROGEN STORAGE SYSTEM



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Figure 2.6-2. Cryogenic Storage Subsystem (Sheet 2 of 2)

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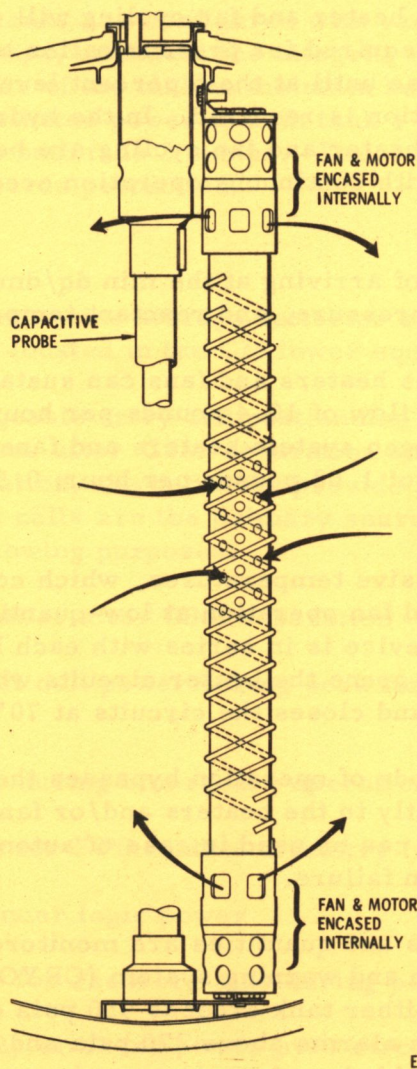


Figure 2.6-3. Cryogenic Pressurization and Quantity Measurement Devices

pressure switch opens to again energize the motor switch, thus opening the heater and fan circuits to both tanks. The O₂ tank circuits are energized at 865 psia minimum and de-energized at 935 psia maximum. The H₂ circuits energize at 225 psia minimum and de-energize at 260 psia maximum. The most accurate quantity readout will be acquired immediately after completion of repressurization. During all other periods partial stratification will degrade quantity readout accuracy.

When the systems reach the point where heater and fan cycling is at a minimum (due to a reduced heat requirement), the heat leak of the tank is sufficient to maintain design pressures provided flow is within the min dq/dm values shown in the preceding tabulation. This realm of operation is referred to as the min dq/dm region. The minimum heat requirement region for oxygen starts at approximately 40 percent quantity in the tanks and terminates at approximately 25 percent quantity. Between these tank

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quantities, minimum heater and fan cycling will occur under normal usage. The amount of heat required for pressurization at quantities below 25 percent starts to increase until at the 5 percent level practically continuous heater and fan operation is required. In the hydrogen system, the quantity levels for minimum heater and fan cycling are between approximately 50 and 28 percent, with continuous operation occurring at approximately 1 percent.

The time rate of arriving at the min dq/dm point is dependent upon load demands, tank pressure, and reactant temperature.

The O₂ systems heaters and fans can sustain design pressures for 30 minutes at a total flow of 10.4 pounds per hour; 5.2 pounds per hour per tank. The hydrogen system heaters and fans can sustain design pressures at a total flow of 1.02 pounds per hour; 0.51 pound per hour per tank.

To avoid excessive temperatures, which could be realized during continuous heater and fan operation at low-quantity levels, a thermal sensitive interlock device is in series with each heater element. The device automatically opens the heater circuits when internal tank temperatures reach 90°F, and closes the circuits at 70°F.

The manual mode of operation bypasses the pressure switches, and supplies power directly to the heaters and/or fans through the individual control switches. It can be used in case of automatic control failure, heater failure, or fan failure.

Tank pressures and quantities are monitored on meters located on MDC-2. The caution and warning system (CRYO PRESS) will alarm when oxygen pressure in either tank exceeds 950 psia or falls below 800 psia. The hydrogen system alarms above 270 psia and below 220 psia. Since a common lamp is provided, reference must be made to the individual pressure and quantity meters (MDC-2) to determine the malfunctioning tank. Tank pressures, quantities, and reactant temperatures of each tank are telemetered to MSFN.

Oxygen relief valves vent at a pressure between 983 and 1005 psig and reseal at 965 psig minimum. Hydrogen relief valves vent at a pressure between 273 and 285 psig, and reseal at 268 psig minimum. Relief valve opening should be prevented if possible to minimize the probability of improper reseating resulting in the eventual depletion of one tank.

Overpressurization may be prevented in two ways. The first being to disable the heater and fan circuits when tank quantities reach approximately 55 percent, allowing pressure in the system tanks to decrease. This provides a wider range for eventual pressure increase during min dq/dm operation. This method retains the maximum amount of fluid for spacecraft use. The second method of preventing overpressurization is to perform an unscheduled fuel cell purge to deplete tank pressures prior to reaching relief valve opening pressures.

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The reactant tanks are configured with vac-ion pumps. The pumps, functioning as ion traps, maintain the integrity of the vacuum between the inner and outer shells of the tank to maintain heat leak at the design level. SM main bus A distributes power to both tank 1 pumps and SM main bus B distributes power to both tank 2 pumps. Fuses are provided in each circuit for power source protection.

2.6.3.2 Batteries.

Five silver oxide-zinc storage batteries are incorporated in the EPS. These batteries are located in the CM lower equipment bay.

Three rechargeable entry and postlanding batteries (A, B, and C) power the CM systems after CSM separation and during postlanding. Prior to CSM separation, the batteries provide a secondary source of power while the fuel cells are the primary source. The entry batteries are used for the following purposes:

- Provide CM power after CSM separation
- Supplement fuel cell power during peak load periods (Delta V maneuvers)
- Provide power during emergency operations (failure of two fuel cells)
- Provide power for EPS control circuitry (relays, indicators, etc.)
- Provide sequencer logic power
- Provide power for recovery aids during postlanding
- Batteries A, B, or C can power pyro circuits by selection.

Each entry and postlanding battery is mounted in a vented plastic case and consists of 20 silver oxide-zinc cells connected in series. The cells are individually encased in plastic containers which contain relief valves that open at 40 ± 10 psig, venting during an overpressure into the battery case. Each battery case is vented overboard through a manifold, the normally open BATTERY VENT valve (RHEB-252), and the ECS urine/water dump line. The vent line prevents battery-generated gas from entering the CM crew compartment.

The BATTERY VENT valve is placed in the CLOSE position in the event of a battery-case fracture. A closed valve and battery out-gassing could cause a pressure buildup in the battery case and manifold. The battery manifold pressure is monitored on the SYSTEMS TEST meter (LEB-101). When the manifold pressure approaches CM pressure the vent valve is opened to vent the case and prevent out-gassing into the cabin. Battery manifold pressure can be used as an indication of urine/waste water dump line plugging.

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Each battery is rated at 40-ampere hours (AH) minimum and will deliver this at a current output of 35 amps for 15 minutes and a subsequent output of 2 amps, or at a current output of 25 amps for 30 minutes and a subsequent output of 2 amps for the remainder of the rating.

At Apollo mission loads each battery is capable of providing 50 AH and will provide this amount after each complete recharge cycle.

Open circuit voltage is 37.2 volts. Since sustained battery loads are extremely light (2 to 3 watts), open circuit voltage will be indicated on the spacecraft voltmeter, except when the main bus tie switches have been activated to tie the battery outputs to the main d-c buses. Normally only batteries A and B will be connected to the main d-c buses. Battery C is isolated during prelaunch by opening the MAIN A-BAT C and MAIN B-BAT C circuit breakers (RHEB-275). Battery C will therefore provide a backup main d-c bus power in case of failure of battery A or B. The two battery configurations provide more efficient use of the fuel cell power during peak power loads and decreases overall battery recharge time. The MAIN A- and MAIN B-BAT C circuit breakers are closed prior to CSM separation. Battery C, through circuit breakers BAT C to BAT BUS A and BAT C to BAT BUS B (RHEB 250) provides backup power to the respective battery bus in the event of failure of entry battery A or B. These circuit breakers are normally open until a failure of battery A or B occurs.

The circuit, through these breakers, allows simultaneous charging of the entry and postlanding batteries. By closing the BAT C to BAT BUS A circuit breaker, batteries A and C can be recharged simultaneously. The same principle applies to the battery B circuit. By closing the BAT C to BAT BUS A and B circuit breakers, all three batteries can be recharged simultaneously. Presently, use of the simultaneous recharge capability is subject to test verification.

The two pyrotechnic batteries supply power to initiate ordnance devices in the SC. The pyrotechnic batteries are isolated from the rest of the EPS to prevent the high-power surges in the pyrotechnic system from affecting the EPS, and to ensure source power when required. These batteries shall not be recharged in flight. Entry and postlanding battery A, B, or C can be used as a redundant source of power for initiating pyro circuits in the respective A or B pyro system, if either pyro battery fails. This can be performed by proper manipulation of the circuit breakers on RHEB 250. Caution must be exercised to isolate the failed battery prior to connecting the replacement battery.

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Performance characteristics of each SC battery are as follows:

Battery	Rated Capacity per Battery	Open Circuit Voltage (max.)	Nominal Voltage	Minimum Voltage	Ambient Battery Temperature
Entry and Postlanding, A, B, and C (3)	40 amp-hrs (25 ampere rate)	37.8 vdc max. (37.2 vdc in flight)	29 vdc (35 amps load)	27 vdc (35 amps load)	50° to 110°F
Pyro A and B (2)	0.75 amp-hrs (75 amps for 36 seconds)	37.8 vdc max. (37.2 vdc in flight)	23 vdc (75 amps load)	20 vdc (75 amps load) (32 vdc open circuit)	60° to 110°F

NOTE Pyro battery load voltage is not measurable in the SC due to the extremely short time they power pyro loads.

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2.6.3.3 Fuel Cell Power Plants.

Each of the three Bacon-type fuel cell power plants is individually coupled to a heat rejection (radiator) system, the hydrogen and oxygen cryogenic storage systems, a water storage system, and a power distribution system. A typical power plant schematic is shown in figure 2.6-4.

The power plants generate d-c power on demand through an exothermic chemical reaction. The by-product water is fed to a potable water storage tank in the CM where it is used for astronaut consumption and for cooling purposes in the ECS. The amount of water produced is equivalent to the power produced (figure 2.6-5).

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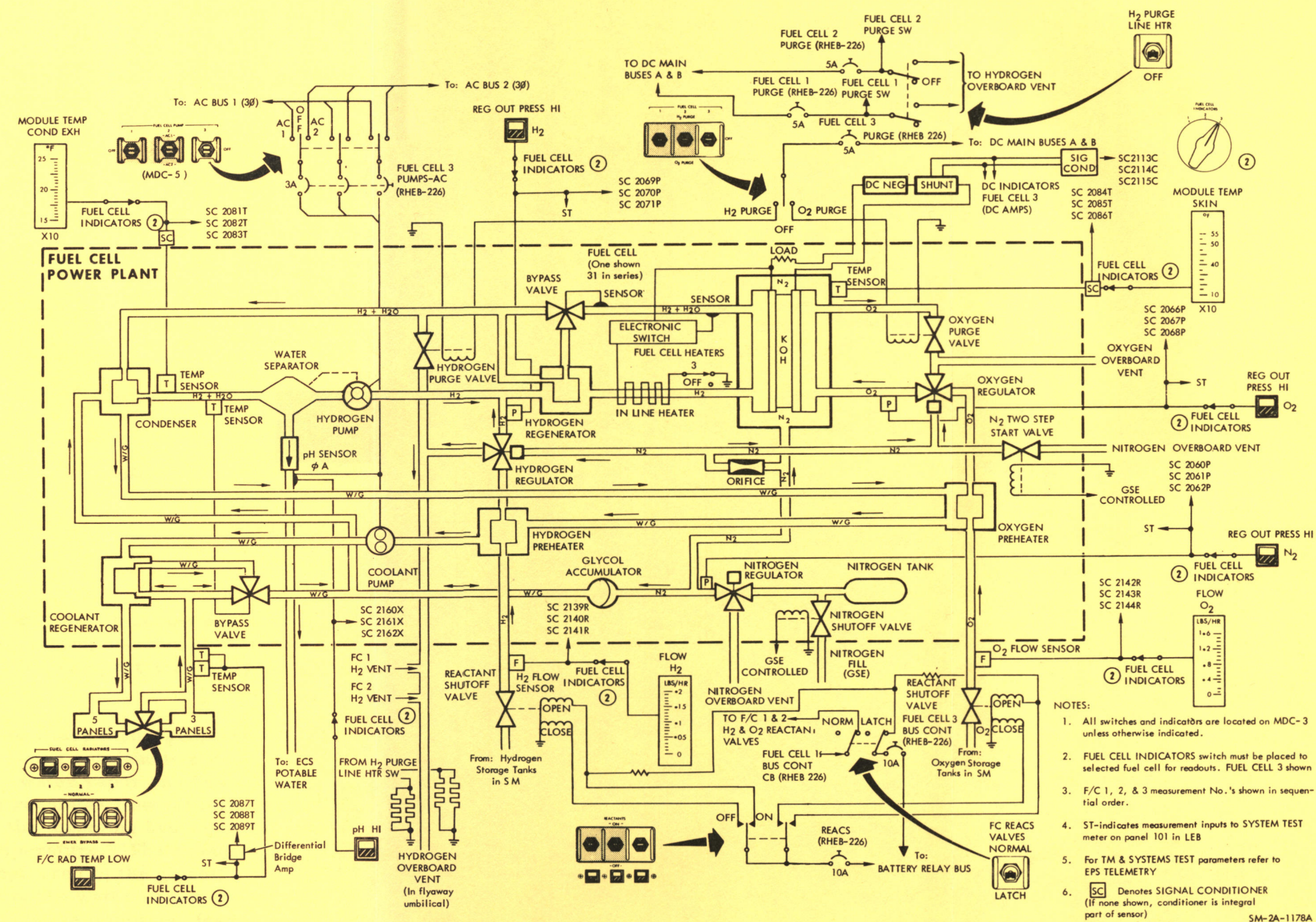
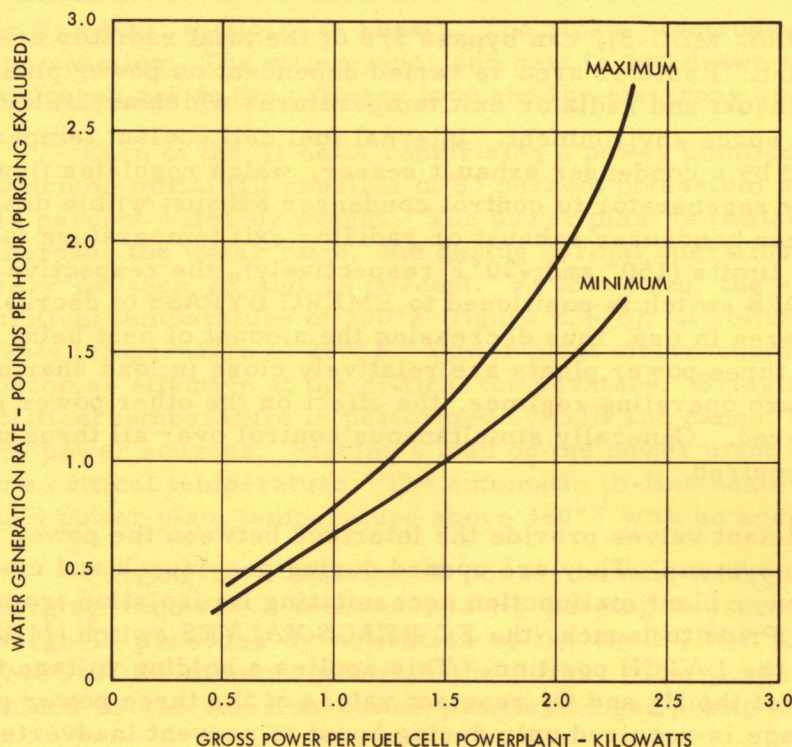


Figure 2.6-4. Fuel Cell Schematic

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Figure 2.6-5. Water Production vs Power Output

2.6.3.3.1 Component Description.

Each power plant consists of 31 single cells connected in series and enclosed in a metal pressure jacket. The water separation, reactant control, and heat transfer components are mounted in a compact accessory section attached directly above the pressure jacket.

Power plant temperature is controlled by the primary (hydrogen) and secondary (glycol) loops. The hydrogen pump, providing continuous circulation of hydrogen in the primary loop, withdraws water vapor and heat from the stack of cells. The primary bypass valve regulates flow through the hydrogen regenerator to impart exhaust heat to the incoming hydrogen gas. Flow is regulated in accordance with skin temperature. The exhaust gas flows to the condenser where waste heat is transferred to the glycol; the resultant temperature decrease liquifying some of the water vapor. The motor-driven centrifugal water separator extracts the liquid and feeds it to the potable water tank in the CM. The cool gas is then pumped back to the fuel cell through the primary regenerator by a motor-driven vane pump, which also compensates for pressure losses due to water extraction and cooling. Waste heat, transferred to the glycol in the condenser, is transported to the radiators located on the fairing between the CM and SM, where it is radiated into space. Individual controls (FUEL CELL

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RADIATORS, MDC-3), can bypass 3/8 of the total radiator area for each power plant. Radiator area is varied dependent on power plant condenser exhaust and radiator exit temperatures which are relevant to loads and space environment. Internal fuel cell coolant temperature is controlled by a condenser exhaust sensor, which regulates flow through a secondary regenerator to control condenser exhaust within desired limits. When either condenser exhaust or radiator exit temperature falls below tolerance limits (150° and -30°F respectively), the respective FUEL CELL RADIATORS switch is positioned to EMERG BYPASS to decrease the radiator area in use, thus decreasing the amount of heat being radiated. Since the three power plants are relatively close in load sharing and temperature operating regimes, the effect on the other power plants must be monitored. Generally simultaneous control over all three power plants will be required.

Reactant valves provide the interface between the power plants and cryogenic system. They are opened during pre-launch and closed only after a power plant malfunction necessitating its isolation from the d-c system. Prior to launch, the FC REACS VALVES switch (MDC-3) is placed to the LATCH position. This applies a holding voltage to the open solenoids of the H₂ and O₂ reactant valves of the three power plants. This voltage is required only during boost to prevent inadvertent closure due to the effects of high vibration. The reactant valves cannot be closed by use of the REACTANTS switches (MDC-3) with the holding voltage applied. The FC REACS VALVES switch is positioned to NORMAL after earth orbit insertion. Following this, the three FC REACS circuit breakers (RHEB-226) are opened to prevent valve closure through inadvertent REACTANTS switch activation.

N₂ gas is individually stored in each power plant at 1500 psia and regulated to a pressure of 53±3 psia. Output of the regulator pressurizes the electrolyte in each cell, the coolant loop through an accumulator, and is coupled to the O₂ and H₂ regulators as a reference pressure.

Cryogenic oxygen, supplied to the power plants at 900±35 psia, absorbs heat in the lines, absorbs additional heat in the preheater, and reaches the oxygen regulator in a gaseous form at temperatures above 100°F. The differential regulator reduces oxygen pressure to 9.5 psia above the N₂ reference, thus supplying it to the fuel cell stack at 62.5±2 psia. Within the porous oxygen electrodes, the O₂ reacts with the H₂O in the electrolyte and the electrons provided by the external circuit to produce hydroxyl ions ($O_2 + 2H_2O + 4e = 4OH^-$).

Cryogenic hydrogen, supplied to the power plants at 245 (+15, -20) psia, is heated in the same manner as the oxygen. The differential hydrogen regulator reduces the pressure to 8.5 psia above the reference N₂, thus supplying it in a gaseous form to the fuel cells at 61.5±2 psia. The hydrogen reacts in the porous hydrogen electrodes with the hydroxyl ions in the electrolyte to produce electrons, water vapor, and heat

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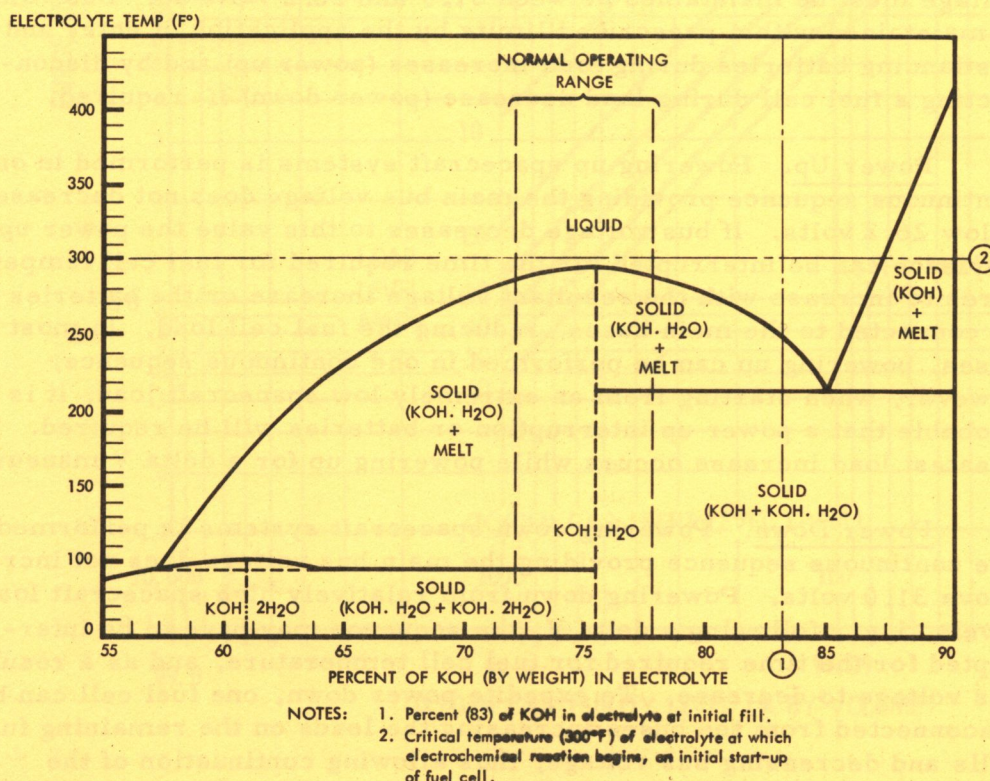
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($2\text{H}_2 + 4\text{OH}^- = 4\text{H}_2\text{O} + 4\text{e} + \text{heat}$). The nickel electrodes act as a catalyst in the reaction. The water vapor and heat is withdrawn by the circulation of hydrogen gas in the primary loop and the electrons are supplied to the load.

Each of the 31 cells comprising a power plant contains electrolyte which on initial fill consists of 83 percent potassium hydroxide (KOH) and 17 percent water by weight. The power plant is initially conditioned to increase the water ratio, and during normal operation, water content will vary between 23 and 28 percent. At this ratio, the electrolyte has a critical temperature of 300°F (figure 2.6-6). It solidifies at an approximate temperature of 220°F. Power plant electrochemical reaction becomes effective at the critical temperature. Bringing power plants to critical temperature is performed by GSE and cannot be performed from SC power sources. Placing a load on the power plant will maintain it above the critical temperature. The automatic in-line heater circuit will maintain power plant temperature above 360°F with no additional loads applied.

Purging is a function of power demand and gas purity. O_2 purging requires 2 minutes and H_2 purging 80 seconds. A hydrogen purge is preceded by activation of the H_2 PURGE LINE HTR switch (MDC-3) 30 minutes prior to the purge. The purge cycle is determined by the mission power profile and gas purity as sampled after

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Figure 2.6-6. KOH H₂O Phase Diagram

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spacecraft tank fill. Figures 2.6-7 and 2.6-8 can be used to calculate the purge cycles, dependent on gas purity and load. A degradation purge can be performed if power plant current output decreases approximately 3 to 5 amps during sustained operation. The O₂ purge has more effect during this type of purge, although it would be followed by an H₂ purge if recovery to normal was not realized after performing an O₂ purge. If the pH talk back indicator (MDC-3) is activated, a hydrogen purge will not be performed on the fuel cell with the high pH. This prevents the possibility of clogging the hydrogen vent line.

2.6.3.3.2 Fuel Cell Loading.

The application and removal of fuel cell loads causes the terminal voltage to decrease and increase, respectively. A decrease in terminal voltage, resulting from an increased load, is followed by a gradual increase in fuel cell skin temperature which causes an increase in terminal voltage. Conversely, an increase in terminal voltage, resulting from a decreased load, is followed by a gradual decrease in fuel cell skin temperature which causes a decrease in terminal voltage.

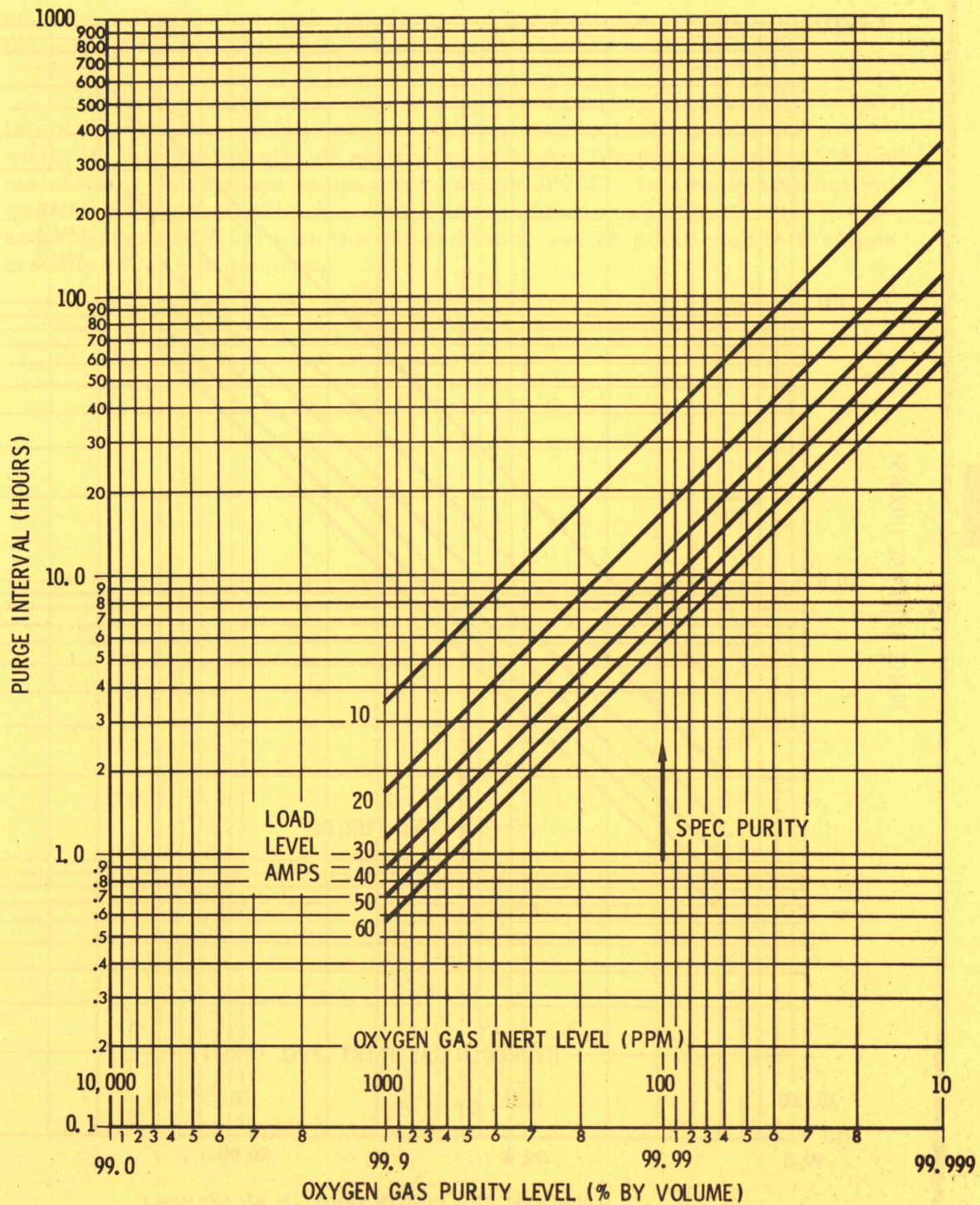
The range in which the terminal voltage is permitted to vary is determined by the high and low voltage input design limits of the components being powered. For most components the limits are 30 volts dc and 25 volts dc. To remain within these design limits, the d-c bus voltage must be maintained between 31.0 and 26.2 volts dc. Bus voltage is maintained within prescribed limits by the application of entry and postlanding batteries during load increases (power up) and by disconnecting a fuel cell during load decrease (power down) if required.

Power Up. Powering up spacecraft systems is performed in one continuous sequence providing the main bus voltage does not decrease below 26.2 volts. If bus voltage decreases to this value the power up sequence can be interrupted for the time required for fuel cell temperatures to increase with the resultant voltage increase or the batteries can be connected to the main buses, reducing the fuel cell load. In most cases, powering up can be performed in one continuous sequence; however, when starting from an extremely low spacecraft load, it is probable that a power up interruption or batteries will be required. The greatest load increase occurs while powering up for a delta V maneuver.

Power Down. Powering down spacecraft systems is performed in one continuous sequence providing the main bus voltage does not increase above 31.0 volts. Powering down from relatively high spacecraft load levels, i. e., following a delta V, the sequence may have to be interrupted for the time required for fuel cell temperature, and as a result, bus voltage to decrease. To expedite power down, one fuel cell can be disconnected from the buses increasing the loads on the remaining fuel cells and decreasing bus voltage, thus allowing continuation of the power down sequence.

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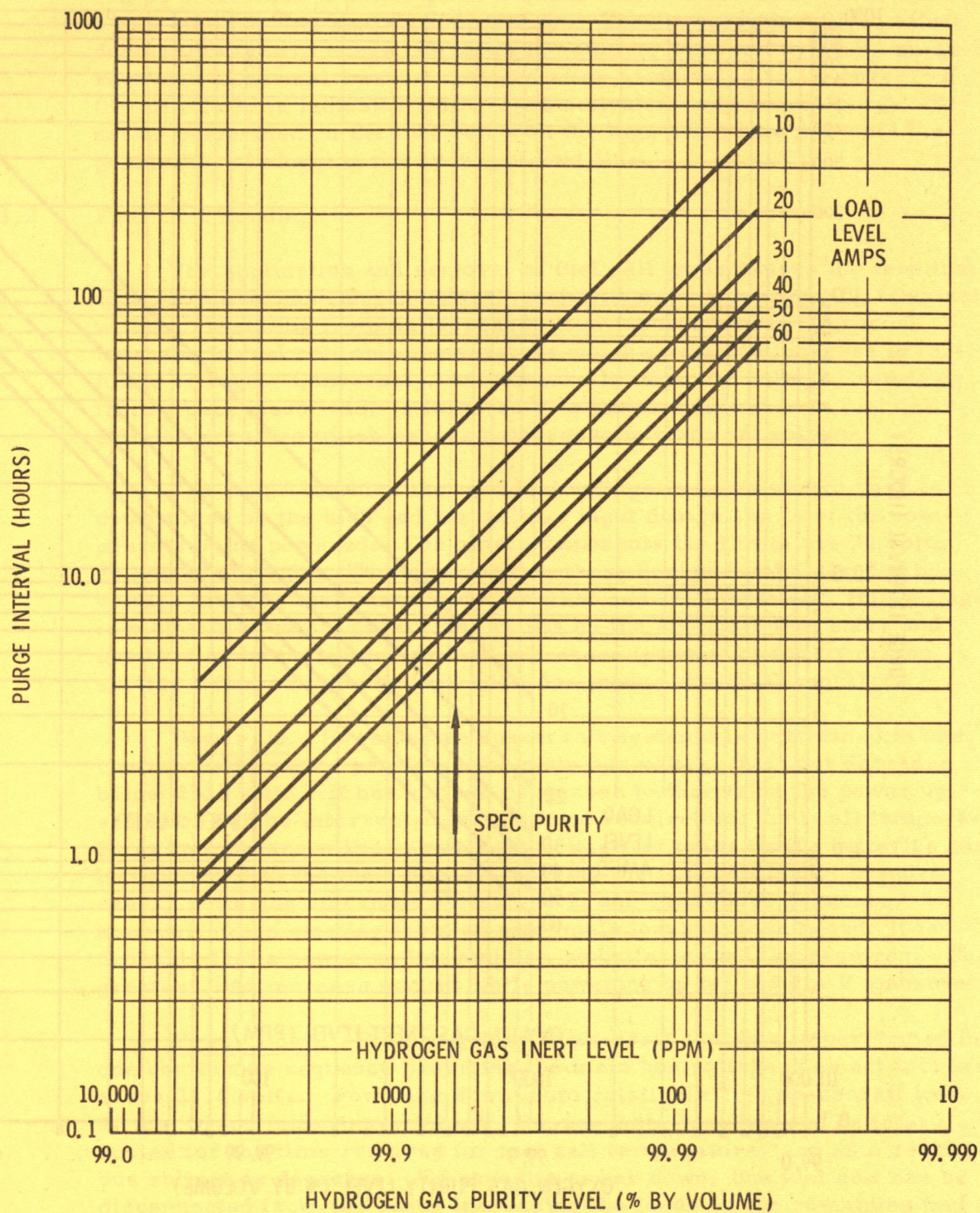


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Figure 2.6-7. O₂ Gas Purity Effect on Purge Interval

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Figure 2.6-8. H₂ Gas Purity Effect on Purge Interval

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Fuel Cell Disconnect. A fuel cell can be disconnected from the main d-c buses to expedite power down if bus voltage limits (31 vdc) are attained. Power down can be completed, and after a cool-down period of the open circuited fuel cell, it can be reconnected to the system.

If the requirement arises to maintain a powerplant on open circuit, temperature decay would occur at approximately $6^{\circ}/\text{hr.}$, with the automatic in-line heater circuit activating at a skin temperature of 385°F and maintaining powerplant temperature above 360°F . In-line heater activation can be confirmed by a 4.5 to 6 amp indication as observed on the d-c amps meter (MDC-3) with the d-c indicator switch positioned to the open circuited fuel cell position.

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Figure 2.6-9. Deleted

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Prior to disconnecting a fuel cell, if a single inverter is being used, the two remaining powerplants are connected to each main d-c bus to enhance load sharing since bus loads are unbalanced. If two inverters are being used, each of the remaining powerplants is connected to a separate main d-c bus for bus isolation, since bus loads are relatively equal. When powering up to configurations requiring three fuel cells, reconnection is accomplished prior to the time heavy load demands are made to permit proper conditioning of the disconnected fuel cell. The time required for proper fuel cell conditioning is a function of skin temperature and load demands.

2.6.3.3.3 through 2.6.3.3.5 (Deleted.)

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All data deleted from page 2.6-25.

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2.6.3.4 Inverters.

Each inverter (figure 2.6-10) is composed of an oscillator, an eight-stage digital countdown section, a d-c line filter, two silicon-controlled rectifiers, a magnetic amplifier, a buck-boost amplifier, a demodulator, two d-c filters, an eight-stage power inversion section, a harmonic neutralization transformer, an a-c output filter, current sensing transformers, a Zener diode reference bridge, a low-voltage control, and an overcurrent trip circuit. The inverter normally uses a 6.4-kc square wave synchronizing signal from the central timing equipment (CTE) which maintains inverter output at 400 cps. If this external signal is completely lost, the free running oscillator within the inverter will provide pulses that will maintain inverter output within ± 7 cps. The internal oscillator is normally synchronized by the external pulse. The subsequent paragraphs describe the function of the various stages of the inverter.

The 6.4-kc square wave provided by the CTE is applied through the internal oscillator to the eight-stage digital countdown section. The oscillator has two divider circuits which provide a 1600-pps signal to the magnetic amplifier.

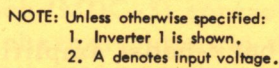
The eight-stage digital countdown section, triggered by the 6.4-kc signal, produces eight 400-cycle square waves, each mutually displaced one pulse-time from the preceding and following wave. One pulse-time is 156 microseconds and represents 22.5 electrical degrees. The eight square waves are applied to the eight-stage power inversion section.

The eight-stage power inversion section, fed a controlled voltage from the buck-boost amplifier, amplifies the eight 400-cycle square waves produced by the eight-stage digital countdown section. The amplified square waves, still mutually displaced 22.5 electrical degrees, are next applied to the harmonic neutralization transformer.

The harmonic neutralization section consists of 31 transformer windings on one core. This section accepts the 400-cycle square-wave output of the eight-stage power inversion section and transforms it into a 3-phase 400-cycle 115-volt signal. The manner in which these transformers are wound on a single core produces flux cancellation which eliminates all harmonics up to and including the fifteenth of the fundamental frequency. The 22.5-degree displacement of the square waves provides a means of electrically rotating the square wave excited primary windings around the 3-phase, wye-connected secondary windings, thus producing the 3-phase 400-cycle sine wave output. This 115-volt signal is then applied to the a-c output filter.

The a-c output filter eliminates the remaining higher harmonics. Since the lower harmonics were eliminated by the harmonic neutral transformer, the size and weight of this output filter was reduced. Circuitry in this filter also produces a rectified signal which is applied to the Zener

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Figure 2.6-10. Inverter Block Diagram

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diode reference bridge for voltage regulation. The amplitude of this signal is a function of the amplitude of a-c output voltage. After filtering, the 3-phase 115-volt a-c 400-cycle sine wave is applied to the a-c buses through individual phase current-sensing transformers.

The current-sensing transformers produce a rectified signal; the amplitude of which is a direct function of inverter output current magnitude. This d-c signal is applied to the Zener diode reference bridge to regulate inverter current output; it is also paralleled to an overcurrent trip circuit.

The Zener diode reference bridge receives a rectified d-c signal, representing voltage output, from the circuitry in the a-c output filter. A variance in voltage output unbalances the bridge, providing an error signal of proper polarity and magnitude to the buck-boost amplifier via the magnetic amplifier. The buck-boost amplifier, through its bias voltage output, compensates for voltage variations. When inverter current output reaches 200 to 250 percent of rated current, the rectified signal applied to the bridge from the current sensing transformers is of sufficient magnitude to provide an error signal causing the buck-boost amplifier to operate in the same manner as during an overvoltage condition. The bias output of the buck-boost amplifier, controlled by the error signal, will be varied to correct for any variation in inverter voltage or a beyond tolerance increase current output. When inverter current output reaches 250 percent of rated current, the overcurrent trip circuit is activated.

The overcurrent trip circuit monitors a rectified d-c signal representing current output. When total inverter current output exceeds 250 percent of rated current, this circuit will effect an inverter disconnect in 15 ± 5 seconds. If current output of any single phase exceeds 300 percent of rated current, this circuit will effect an inverter disconnect in 5 ± 1 seconds. The disconnect is provided through relays located in the motor switch circuits that connect the inverters to the a-c buses.

D-C power to the inverter is supplied from the main d-c buses through the d-c line filter. The filter reduces the high frequency ripple in the input, and the 25 to 30 volts dc is applied to the silicon-controlled rectifiers.

The silicon-controlled rectifiers are alternately set by the 1600-pps signal from the magnetic amplifier to produce a d-c square wave with an on-time of greater than 90 degrees from each rectifier. This is filtered and supplied to the buck-boost amplifier where it is transformer-coupled with the amplified 1600-pps output, of the magnetic amplifier, to develop a filtered 35 volts dc which is used for amplification in the power inversion stages.

The buck-boost amplifier also provides a variable bias voltage to the eight-stage power inversion section. The amplitude of this bias voltage is controlled by the amplitude and polarity of the feedback signal from the

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Zener diode reference bridge which is referenced to output voltage and current. This bias signal is varied by the error signal to regulate inverter voltage and maintain current output within tolerance.

The demodulator circuit compensates for any low-frequency ripple (10 to 1000 cps) in the d-c input to the inverter. The high-frequency ripple is attenuated by the input filters. The demodulator senses the 35-volt d-c output of the buck-boost amplifier and the current input to the buck-boost amplifier. An input d-c voltage drop or increase will be reflected in a drop or increase in the 35-volt d-c output of the buck-boost amplifier, as well as a drop or increase in current input to the buck-boost amplifier. A sensed decrease in the buck-boost amplifier voltage output is compensated for by a demodulator output, coupled through the magnetic amplifier to the silicon-controlled rectifiers. The demodulator output causes the SCRs to conduct for a longer time, thus increasing their filtered d-c output. A sensed increase in buck-boost amplifier voltage output, caused by an increase in d-c input to the inverter, is compensated for by a demodulator output coupled through the magnetic amplifier to the silicon-controlled rectifiers causing them to conduct for shorter periods; thus producing a lower filtered d-c output to the buck-boost amplifier. In this manner, the 35-volt d-c input to the power inversion section is maintained at a relatively constant level irrespective of the fluctuations in d-c input voltage to the inverter.

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The low-voltage control circuit samples the input voltage to the inverter and can terminate inverter operation. Since the buck-boost amplifier provides a boost action during a decrease in input voltage to the inverter, in an attempt to maintain a constant 35 volts dc to the power inversion section and a regulated 115-volt inverter output, the high boost required during a low-voltage input would tend to overheat the solid state buck-boost amplifier. As a precautionary measure, the low-voltage control will terminate inverter operation by disconnecting operating voltage to the magnetic amplifier and the first power inversion stage when input voltage decreases to between 16 and 19 volts dc.

A temperature sensor with a range of +32° to +248°F is installed in each inverter and provides an input to the C&WS which will illuminate a light at an inverter overtemperature of 190°F. Inverter temperature is telemetered to the MSFN on SC 103 and subsequent.

2.6.3.5

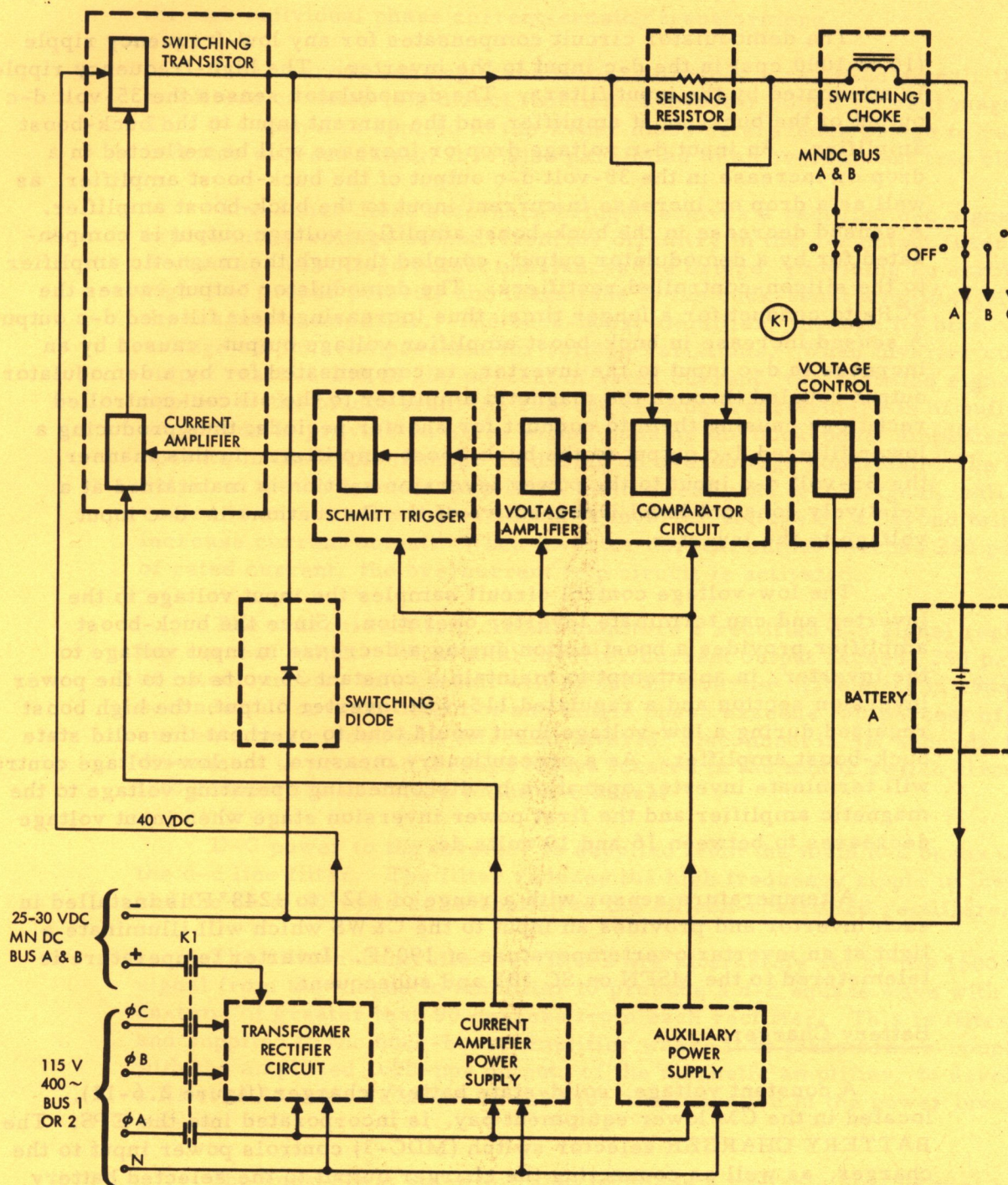
Battery Charger.

A constant voltage, solid-state battery charger (figure 2.6-11), located in the CM lower equipment bay, is incorporated into the EPS. The BATTERY CHARGER selector switch (MDC-3) controls power input to the charger, as well as connecting the charger output to the selected battery (figure 2.6-15). When the BATTERY CHARGER selector switch is positioned to entry battery A, B, or C, a relay (K1) is activated completing

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Figure 2.6-11. Battery Charger Block Diagram

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circuits from a-c and d-c power sources to the battery charger. Battery charger output is also connected to the selected battery to be charged through contacts of the MAIN BUS TIE motor switch. Positioning the MAIN BUS TIE switch (A and C or B and C) to OFF for battery A or B, and both switches to OFF for battery C will disconnect main bus loads from the respective batteries and also complete the circuit from the charger to the battery.

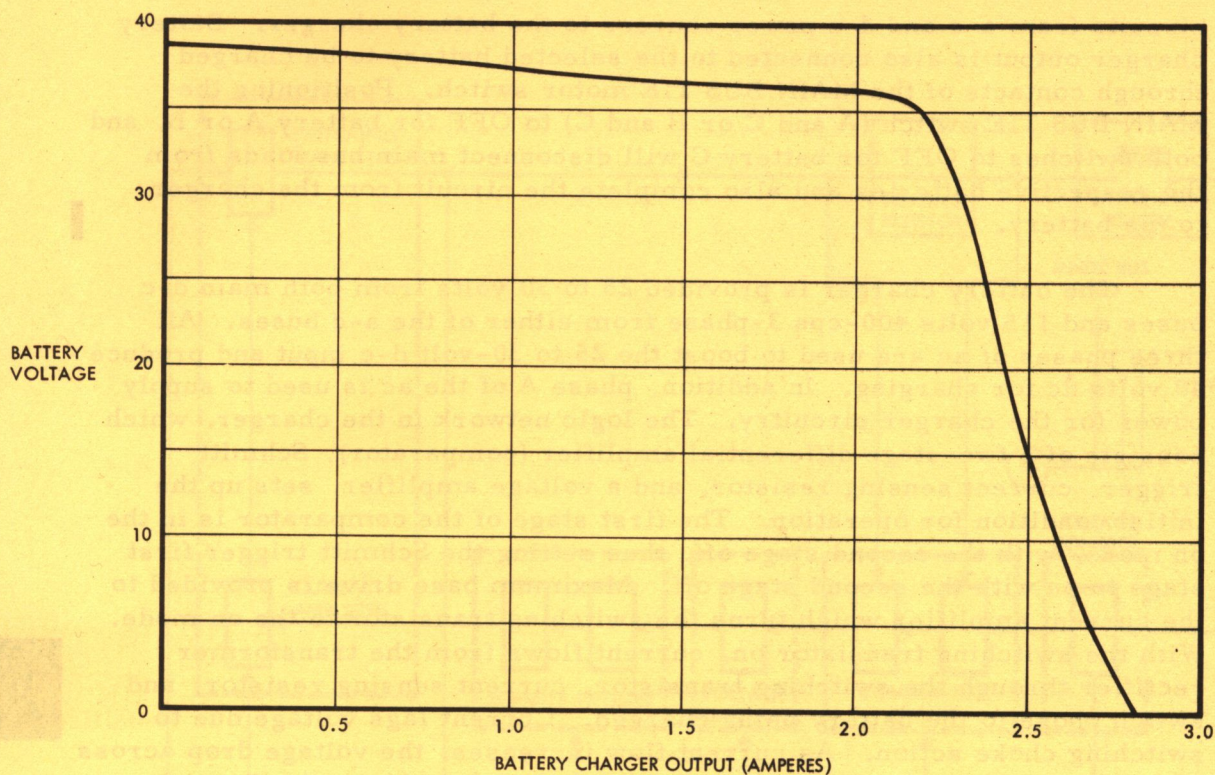
The battery charger is provided 25 to 30 volts from both main d-c buses and 115 volts 400-cps 3-phase from either of the a-c buses. All three phases of ac are used to boost the 25 to 30-volt d-c input and produce 40 volts dc for charging. In addition, phase A of the ac is used to supply power for the charger circuitry. The logic network in the charger, which consists of a two-stage differential amplifier (comparator), Schmitt trigger, current sensing resistor, and a voltage amplifier, sets up the initial condition for operation. The first stage of the comparator is in the on mode, with the second stage off, thus setting the Schmitt trigger first stage to on with the second stage off. Maximum base drive is provided to the current amplifier which turns the switching transistor to the on mode. With the switching transistor on, current flows from the transformer rectifier through the switching transistor, current sensing resistor, and switch choke to the battery being charged. Current lags voltage due to switching choke action. As current flow increases, the voltage drop across the sensing resistor increases, and at a specific level sets the first stage of the comparator to off and the second stage to on. The voltage amplifier is set off to reverse the Schmitt trigger to first stage off and second stage on. This sets the current amplifier off, which in turn sets the switching transistor off. The switching transistor in the off mode terminates power from the source, causing the field in the choke to continue collapsing, discharging into the battery, then through the switching diode and the current sensing resistor to the opposite side of the choke. As the EMF in the choke decreases, current through the sensing resistor decreases, reducing the voltage drop across the resistor. At some point, the decrease in voltage drop across the sensing resistor reverses the comparator circuit, setting up the initial condition and completing one cycle of operation. The output load current, due to the choke action, remains relatively constant except for the small variation through the sensing resistor. This variation is required to set and reset the switching transistor and Schmitt trigger through the action of the comparator.

Battery charger output is regulated by the sensing resistor until battery voltage reaches approximately 36 volts. At this point, the biased voltage control network is unbiased, and in conjunction with the sensing resistor provides a signal for cycling the battery charger. As battery voltage increases, the internal impedance of the battery increases, decreasing current flow from the charger. At 39 volts, the battery is fully charged and current flow becomes negligible. (See figure 2.6-12.) Recharging the batteries until battery charger output indicates 0.4 amp,

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Figure 2.6-12. Battery Charging Rate Chart

assures they are charged to maximum capacity for flight. Prior to deorbit, the charger can be operated until a 0.25-amp output is indicated to assure that the batteries are at peak capacity for entry and postlanding.

Charger voltage is monitored on the DC VOLTS METER (MDC-3). Current output is monitored on the inner scale of the DC AMPS meter (MDC-3) by placing the DC INDICATORS switch (MDC-3) to the BAT CHARGER position. Battery charger current output is telemetered to the MSFN.

Simultaneous battery charging can be performed by proper manipulation of the BAT C to BAT BUS A & B circuit breakers on panel 250 (RHEB), as previously stated (subject to test verification).

2.6.3.6 Power Distribution.

D-C and a-c power distribution to components of the EPS is provided by two redundant buses in each system. A single-point ground on the spacecraft structure is used to eliminate ground loop effects. Sensing and control circuits are provided for monitoring and protection of each system.

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Distribution of d-c power (figure 2.6-13) is accomplished with a two-wire system and a series of interconnected buses, switches, circuit breakers, and isolation diodes. The d-c negative buses are connected to the single-point ground. The buses consist of the following:

- Two main d-c buses (A and B), powered by the three fuel cells and/or entry and postlanding batteries A, B, and C.
- Two battery buses (A and B), each powered by its respective entry and postlanding battery A and B. Battery C can power either or both buses if the batteries A and/or B fail.
- Flight and postlanding bus, powered through both main d-c buses or directly by the three entry and postlanding batteries, A, B, and C.
- Flight bus, powered through both main d-c buses and isolation diodes.
- Nonessential bus, powered through either d-c main bus A or B.
- Battery relay bus, powered by entry and postlanding batteries through the individual battery buses and isolation diodes.
- Pyro buses, isolated from the main electrical power system when powered by the pyro batteries. A capability is provided to connect either entry battery to the A or B pyro system in case of loss of a pyro battery.
- SM jettison controllers, powered by the fuel cell power plants and completely isolated from the main electrical power system until activated during CSM separation.

Power from the fuel cell power plants can be connected to the main d-c buses through six motor switches (part of overload/reverse current circuits in the SM) which are controlled by switches in the CM located on MDC-3. Fuel cell power can be selected to either or both of the main d-c buses. Six talk back indicators show gray when fuel cell output is connected and striped when disconnected. When an overload condition occurs, the overload-reverse current circuits in the SM automatically disconnect the fuel cell power plants from the overloaded bus and provide visual displays (talk-back indicator and caution and warning lamp illumination) (FC BUS DISCONNECT) for isolation of the trouble. A reverse current condition will disconnect the malfunctioning power plant

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from the d-c system. D-C undervoltage sensing circuits (figure 2.6-14) are provided to indicate bus low-voltage conditions. If voltage drops below 26.25 volts dc, the applicable d-c undervoltage light on the caution and warning panel (MDC-2) will illuminate. Since each bus is capable of handling all EPS loads, an undervoltage condition should not occur except in an isolated instance; if too many electrical units are placed on the bus simultaneously or if a malfunction exists in the EPS. A voltmeter (MDC-3) is provided to monitor voltage of each main d-c bus, the battery charger, and each of the five batteries. An ammeter is provided (MDC-3) to monitor current output of fuel cells 1, 2, 3, batteries A, B, C, and the battery charger.

During high power demand or emergencies, supplemental power to the main d-c buses can be supplied from batteries A and B via the battery buses and directly from battery C (figure 2.6-15). During entry, spacecraft power is provided by the three entry and postlanding batteries which are connected to the main d-c buses prior to CSM separation; placing the MAIN BUS TIE switches (MDC-5) to BAT A&C and BAT B&C provides this function after closing the MAIN A-BAT C and MAIN B-BAT C circuit breakers (RHEB 275). The switches are manually placed to OFF after completion of RCS purge and closing the FLIGHT AND POST LDG-BAT BUS A, BAT BUS B, and BAT C circuit breakers (RHEB-275) during main chute descent. The AUTO position provides an automatic connection of the entry batteries to the main d-c buses at CSM separation. This function is used only on the launch pad after the spacecraft is configured for a LES pad abort.

A nonessential bus, as shown on figure 2.6-13, permits isolating nonessential equipment during a shortage of power (two fuel cell power plants out). The flight bus distributes power to in-flight telecommunications equipment. The flight and postlanding bus distributes power to some of the in-flight telecommunications equipment, float bag No. 3 controls, the ECS postlanding vent and blower control, and postlanding communications equipment. In flight and up to CSM separation, the postlanding bus receives power from the fuel cell and/or entry and postlanding batteries through the main d-c buses. After CSM separation and completion of RCS purge, the entry batteries supply power to the postlanding bus through the main d-c buses or directly through individual circuit breakers. These circuit breakers (FLIGHT & POST LANDING-BAT BUS A, BAT BUS B, and BAT C—RHEB-275) are normally open in flight and closed during main chute descent just prior to positioning the MAIN BUS TIE switches to OFF.

Motor switch contacts which close when the MAIN BUS TIE switches are placed to ON, complete the circuit between the entry and postlanding batteries and the main d-c buses, and open the connection from the battery charger to the batteries. The battery relay bus provides d-c power to

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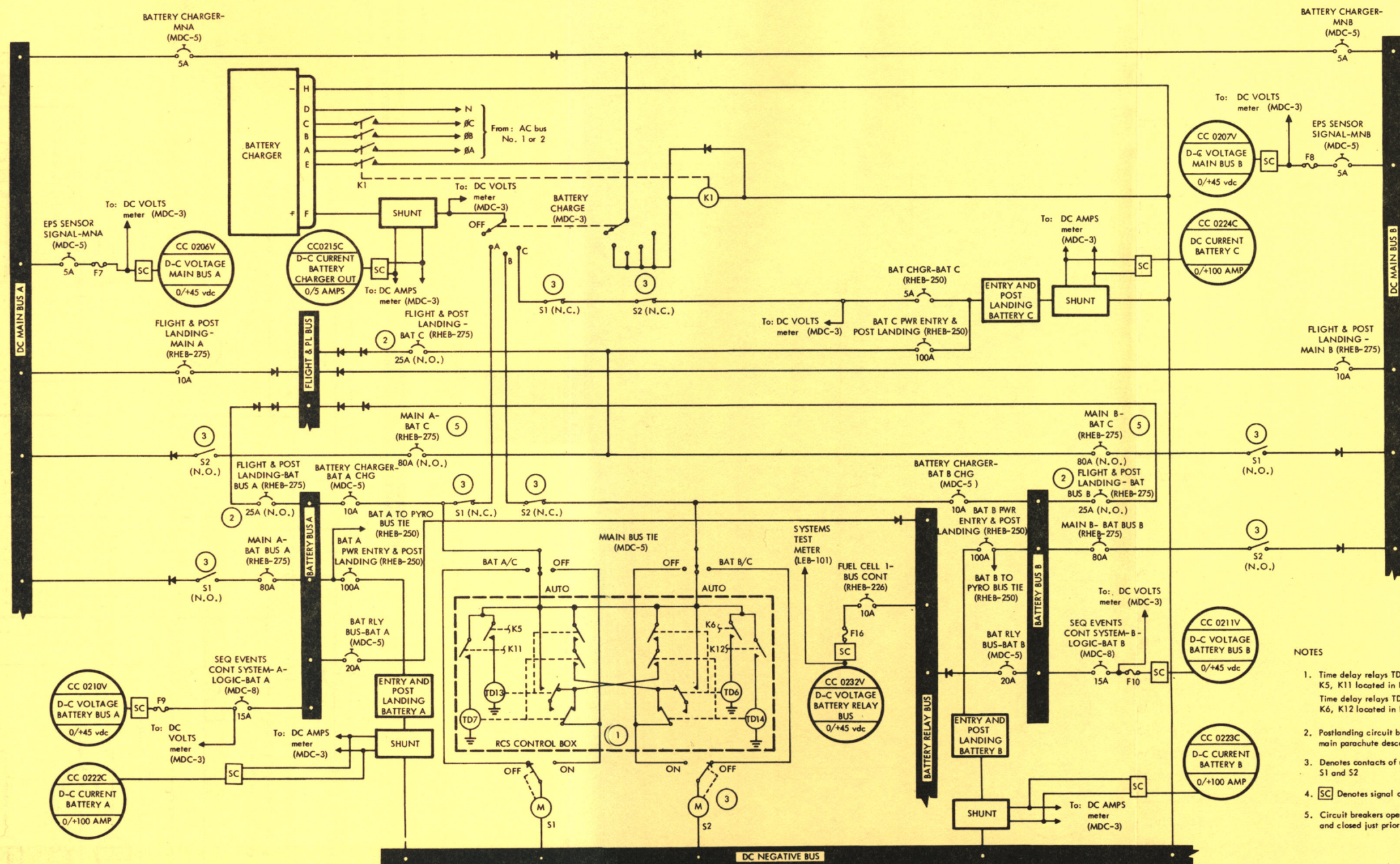
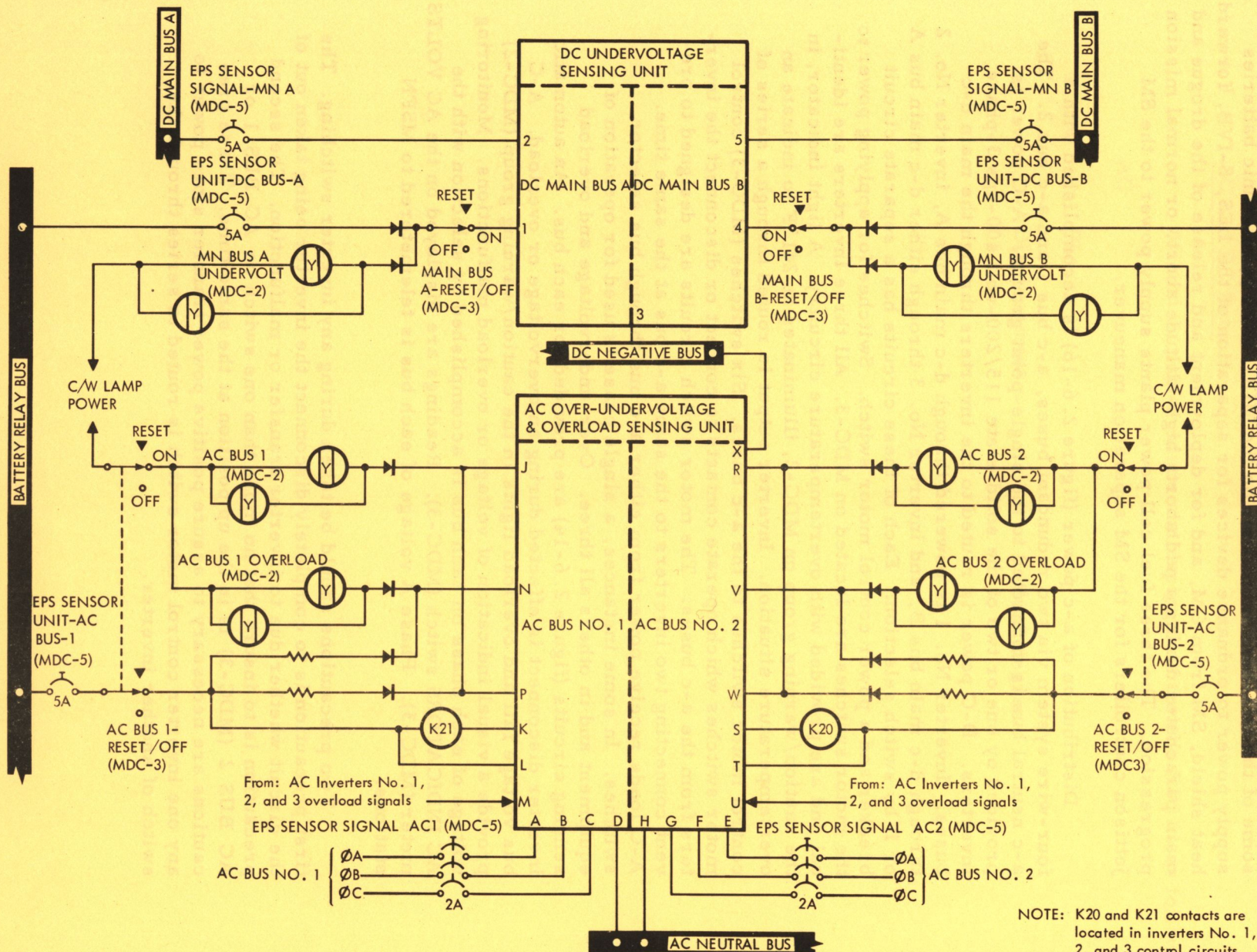


Figure 2.6-13. D-C Power Distribution

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Figure 2.6-14. DC and AC Sensing

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the d-c and a-c sensing unit, the fuel cell, inverter control circuits, and some of the talk-back indicators on the MDC. The pyrotechnic batteries supply power to ordnance devices for separation of the LES, S-IVB, forward heat shield, SM from CM, and for deployment and release of the drogue and main parachutes during a pad abort, high-altitude abort, or normal mission progression. The three fuel cell power plants supply power to the SM jettison controllers for the SM separation maneuver.

Distribution of a-c power (figure 2.6-16) is accomplished with a four-wire system via two redundant buses, a-c bus 1 and a-c bus 2. The a-c neutral bus is connected to the single-point ground. A-C power is provided by one or two of the solid-state 115/200-volt 400-cps 3-phase inverters. D-C power is routed to the inverters through the main d-c buses. Inverter No. 1 is powered through d-c main bus A, inverter No. 2 through d-c main bus B, and inverter No. 3 through either d-c main bus A or B by switch selection. Each of these circuits has a separate circuit breaker and a power control motor switch. Switches for applying power to the motor switches are located on MDC-3. All three inverters are identical and are provided with overtemperature circuitry. A light indicator, in the caution/warning group on MDC-2, illuminates at 241°F to indicate an overtemperature situation. Inverter output is routed through a series of control motor switches to the a-c buses. Six switches (MDC-3) control motor switches which operate contacts to connect or disconnect the inverters from the a-c buses. The motor switch circuits are designed to prevent connecting two inverters to the same a-c bus at the same time. A-C loads receive power from either a-c bus through bus selector switches. In some instances, a single phase is used for operation of equipment and in others all three. Over-undervoltage and overload sensing circuits (figure 2.6-14) are provided for each bus. An automatic inverter disconnect is effected during an overvoltage or overload. A-C bus voltage fail and overload lights in the caution/warning group (MDC-2) provide a visual indication of voltage or overload malfunctions. Monitoring voltage of each phase on each bus is accomplished by selection with the AC INDICATORS switch (MDC-3). Readings are displayed on the AC VOLTS meter (MDC-3). Phase A voltage of each bus is telemetered to MSFN stations.

Two precautions should be taken during any inverter switching. The first precaution is to completely disconnect the inverter being taken out of the circuit whether due to inverter transfer or malfunction. The second precaution is to insure that no more than one switch on AC BUS 1 or AC BUS 2 (MDC-3) is in the up position at the same time. These precautions are necessary to assure positive power transfer since power to any one inverter control motor switch is routed in series through the switch of another inverter.

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2.6.4 PERFORMANCE AND DESIGN DATA.

2.6.4.1 AC and DC Data.

AC and dc performance and design data for the EPS is as follows:

AC

Phases	3
Displacement	120±2 degrees

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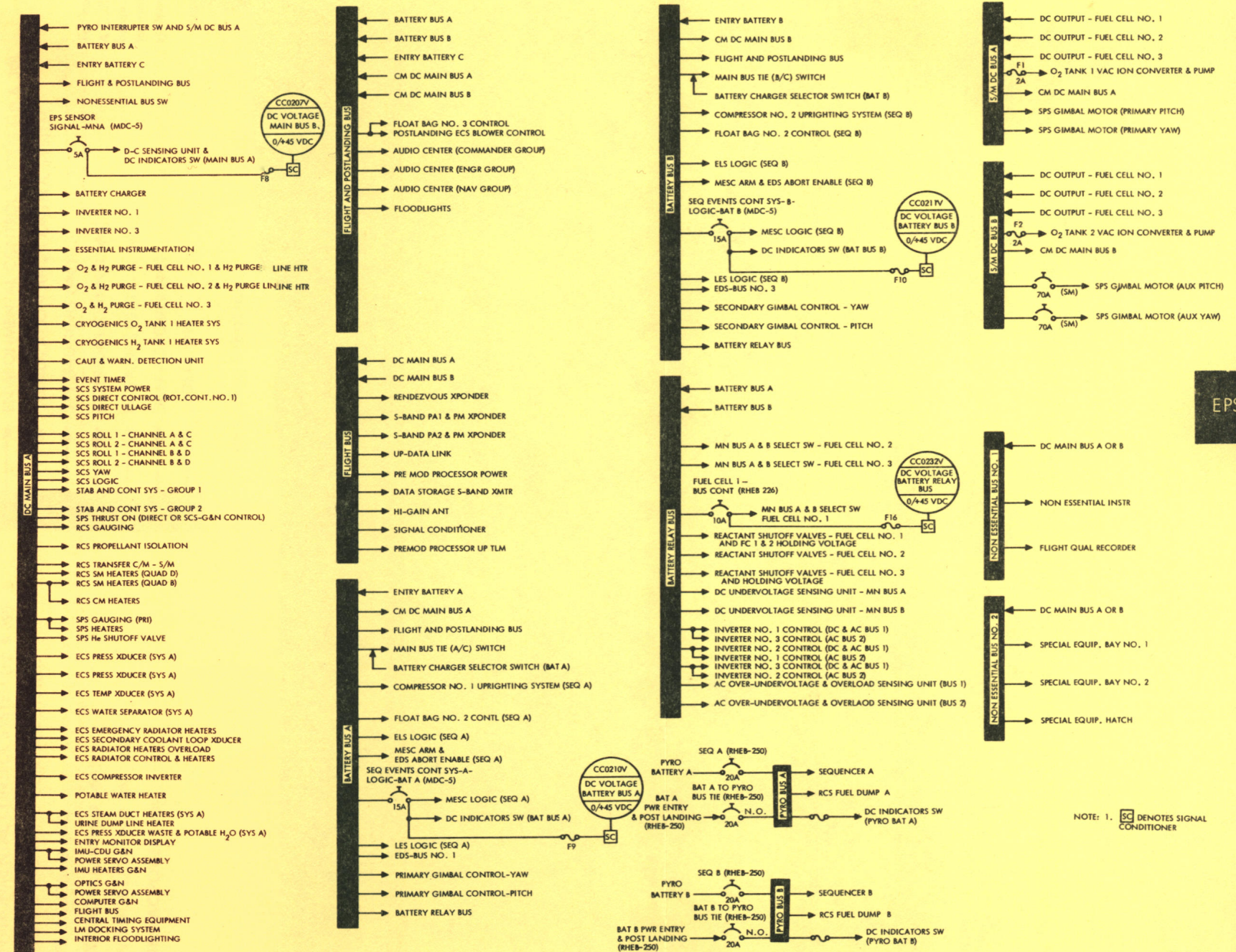
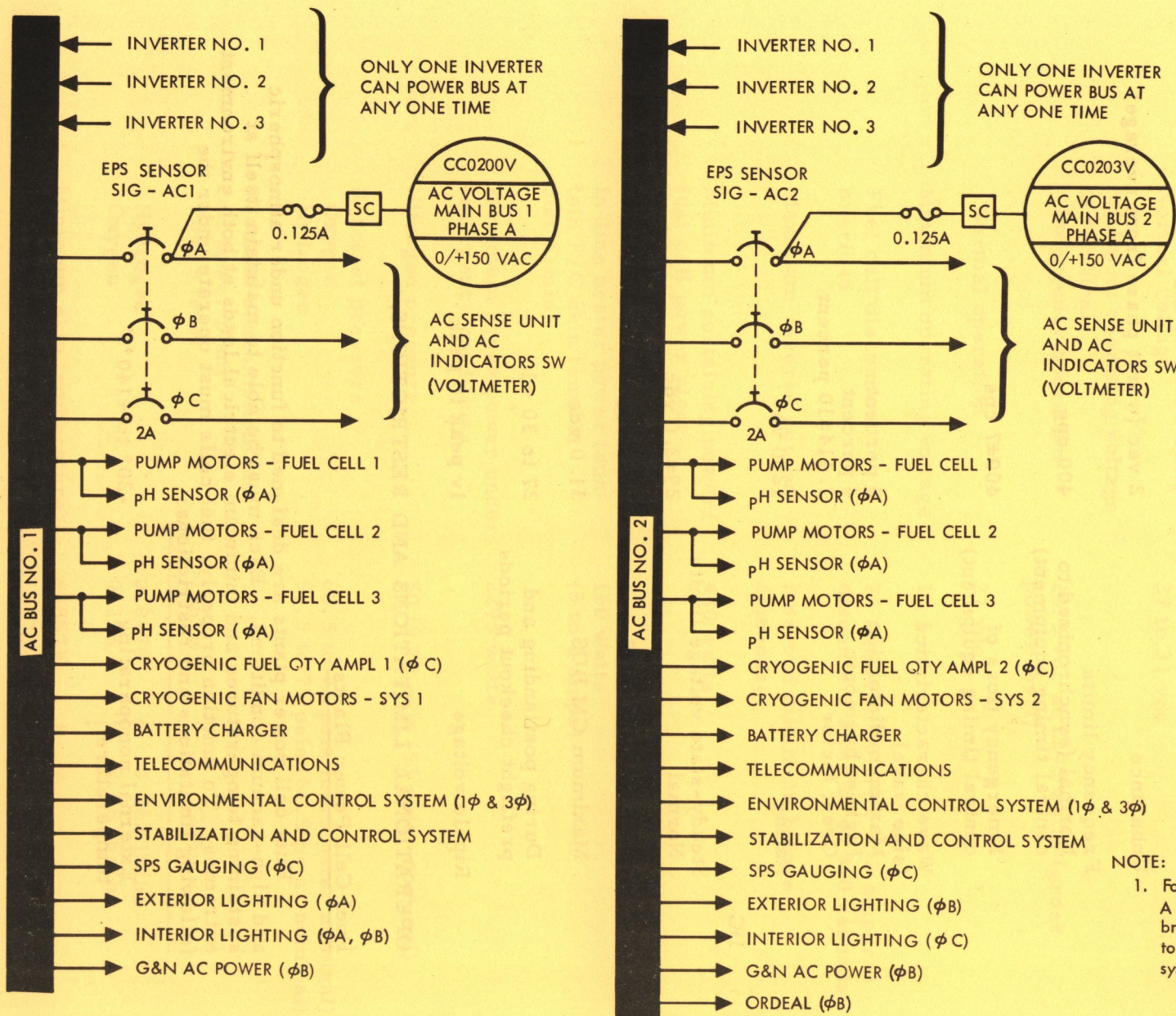


Figure 2.6-15. Battery Charger and CM D-C Bus Control Circuits

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NOTE:
1. For complete A C distribution breakout refer to individual system section

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Figure 2.6-16. A-C Power Distribution

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Steady-state voltage	115.5 (+1, -1.5) vac (average 3 phases)
Transient voltage	115 (+35, -65) vac
Recovery	To 115±10v within 15 ms, steady state within 50 ms
Unbalance	2 vac (worst phase from average)
Frequency limits	
Normal (synchronized to central timing equipment)	400 cps
Emergency (loss of central timing equipment)	400±7 cps
Wave characteristics (sine wave)	
Maximum distortion	5 percent
Highest harmonic	4 percent
Crest factor	1.414±10 percent
Rating	1250 va

DC

Steady-state voltage limits	
Normal	29±2.0 vdc
Minimum CM BUS	26.2 vdc
Maximum CM BUS	31.0 vdc
During postlanding and preflight checkout periods	27 to 30 vdc
Ripple voltage	1v peak to peak

2.6.5 OPERATIONAL LIMITATIONS AND RESTRICTIONS.

2.6.5.1 Fuel Cell Power Plants.

Fuel cell power plants are designed to function under atmospheric and high-vacuum conditions. Each must be able to maintain itself at sustaining temperatures and minimum electrical loads at both environment extremes. To function properly, fuel cells must operate under the following limitations and restrictions:

External nonoperating temperature	-20° to +140°F
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Operating temperature inside SM	+30° to 145°F	
External nonoperating pressure	Atmospheric	
Normal voltage	27 to 31 vdc	
Minimum operating voltage at terminals		
Emergency operation	20.5 vdc at 2295 watts (gross power level)	
Normal operation	27 vdc	
Maximum operating voltage	31.5 vdc	
Fuel cell disconnect overload	75 amperes no trip, 112 amperes disconnect after 25 to 300 seconds	
Maximum reverse current	1 second minimum before disconnect	
Minimum sustaining power/fuel cell power plant (with in-line heater OFF)	420 watts	
In-line heater power (sustain F/C skin temp at 360°F min)	160 watts (5 to 6 amps)	
Maximum gross power under emergency conditions	2295 watts	
Nitrogen pressure	50 to 70 psia (53 psia, nominal)	
Reactant pressure		
Oxygen	60.5 to 75 psia (62.5 psia, nominal)	
Hydrogen	59.5 to 75 psia (61.5 psia, nominal)	
Reactant consumption/fuel cell power plant		
Power level	563w	2295w
Hydrogen	0.0476	0.262 lb/hr
Oxygen	0.378	2.08 lbs/hr
Minimum skin temperature for self-sustaining operation	+385°F	

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Minimum skin temperature for recovery in flight	+360°F
Maximum skin temperature	+500°F
Approximate external environ- ment temperature range outside SC (for radiation)	-260° to +400°F
Fuel cell power plant normal operating temperature range	+385° to +475°F
Condenser exhaust normal operating temperature	+150° to +175°F
Purging nominal frequency	Nominally every 24 hours (dependent on reactant purity after tank fill).
O ₂ purge duration	2 minutes
H ₂ purge duration	80 seconds
Additional flow rate while purging	
O ₂	Up to 0.6 lb/hr
H ₂	Up to 0.75 lb/hr (approx 0.67 H ₂ and 0.08 H ₂ O)

2.6.5.2 Cryogenic Storage Subsystem.

The cryogenic storage subsystem must be able to meet the follow-
ing requirements for proper operation of the fuel cell power plants and
the ECS:

Minimum usable quantity	
Oxygen	320 lbs each tank (min)
Hydrogen	28 lbs each tank (min)
Temperature at time of fill	
Oxygen	-297°F (approx.)
Hydrogen	-423°F (approx.)
Operating pressure range	
Oxygen	
Normal	865 to 935 psia
Minimum	150 psia
Hydrogen	
Normal	225 to 260 psia
Minimum	100 psia

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Temperature probe range	
Oxygen	-325° to +80°F
Hydrogen	-425° to -200°F
Maximum allowable difference in quantity balance between tanks	
Oxygen tanks No. 1 and 2	15 lbs
Hydrogen tanks No. 1 and 2	1 lb
Pressure relief valve operation	
Crack pressure	
Oxygen	983 psig min.
Hydrogen	273 psig min.
Reseat pressure	
Oxygen	965 psig min.
Hydrogen	268 psig min.
Full flow, maximum relief	
Oxygen	1010 psig max.
Hydrogen	285 psig max.

2.6.6 SYSTEMS TEST METER.

The SYSTEMS TEST meter and the alphabetical and numerical switches, located on panel 101 in the CM LEB, provide a means of monitoring various measurements within the SC, and verifying certain parameters displayed only by event indicators. The following can be measured using the SYSTEMS TEST meter, the respective switch positions, and the range of each sensor. Normal operating parameters of measurable items are covered in the telemetry listing.

Systems Test Indication (Telemetry Identity and Code No.)	Switch Positions		Sensor Range
	Numerical Select	Alphabetical Select	
N ₂ pressure, psia			0 to 75 psia
F/C 1 SC 2060P	1	A	
F/C 2 SC 2061P	1	B	
F/C 3 SC 2062P	1	C	0 to 75 psia
O ₂ pressure, psia			
F/C 1 SC 2066P	1	D	
F/C 2 SC 2067P	2	A	
F/C 3 SC 2068P	2	B	

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Systems Test Indication (Telemetry Identity and Code No.)	Switch Positions		Sensor Range
	Numerical Select	Alphabetical Select	
H ₂ pressure, psia			0 to 75 psia
F/C 1 SC 2069P	2	C	
F/C 2 SC 2070P	2	D	
F/C 3 SC 2071P	3	A	
EPS radiator outlet temperature			-50° to +300°F
F/C 1 SC 2087T	3	B	
F/C 2 SC 2088T	3	C	
F/C 3 SC 2089T	3	D	
Battery manifold pressure, psia	4	A	0 to 18 psia
Batt relay bus CC 0232V	4	B	0 to +45 vdc
LM power	4	D	0 to +10 ma
SPS oxidizer line temperature SP 0049T	5	A	0 to +200°F
CM-RCS oxidizer valve temperature			-50° to +50°F
-P engine, sys A CR 2100T	6	B	
+Y engine, sys B CR 2116T	5	D	
-P engine, sys B CR 2110T	5	C	
CW engine, sys B CR 2119T	6	D	
CCW engine, sys A CR 2114T	6	A	
-Y engine, sys A CR 2103T	6	C	
Power monitor	XPNDR	A	2.5 to 5 vdc
AGC (self-test)	XPNDR	B	2.5 to 5 vdc
Frequency lockup	XPNDR	C	4.5±0.5 vdc
AGC (normal)	XPNDR	D	0.0±0.1 vdc

Conversion of the previously listed measurements to the SYSTEMS
TEST meter indications are listed in the following chart. The XPNDR
measurements are direct readouts and do not require conversion.

ELECTRICAL POWER SYSTEM

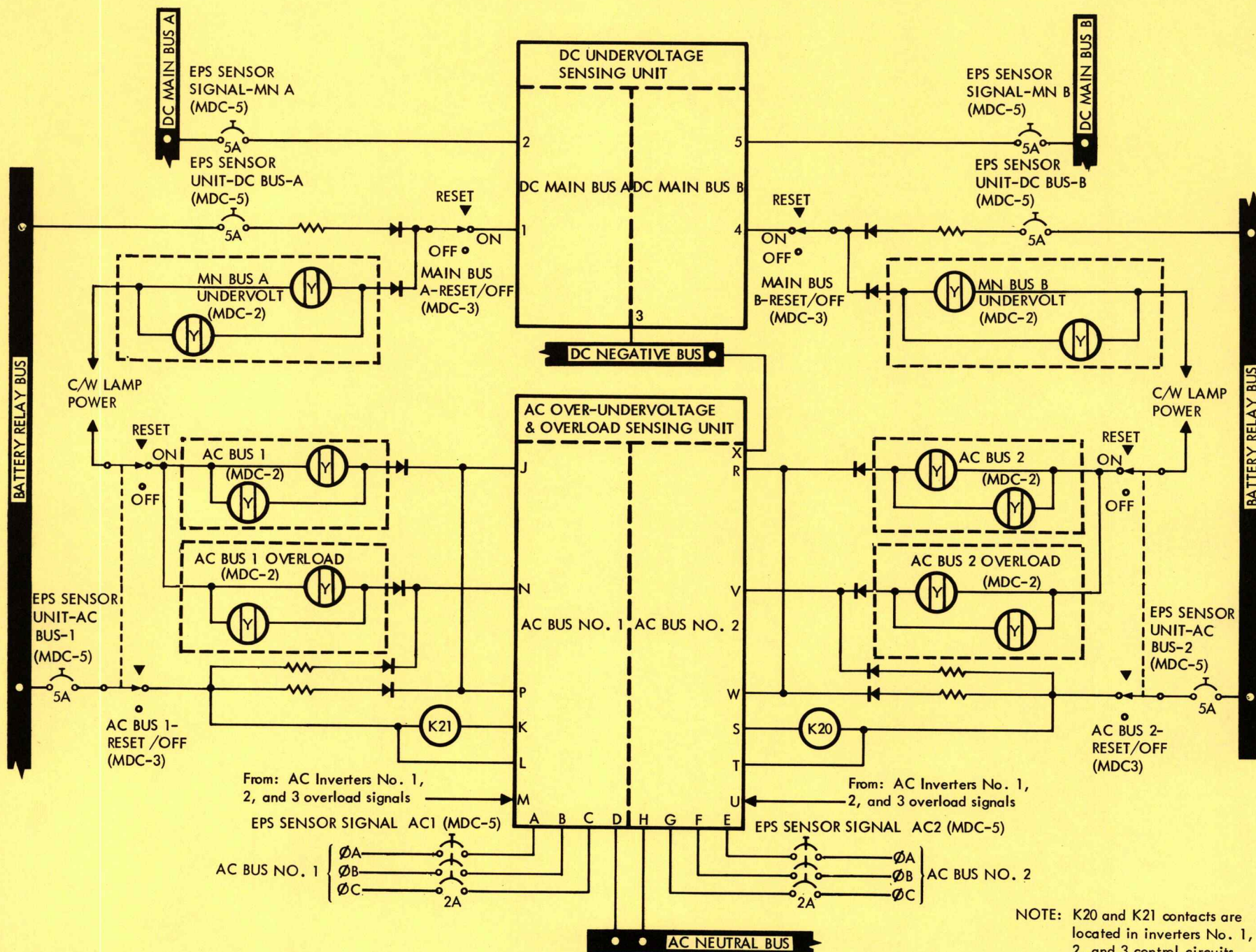
SM2A-03-BLOCK II
APOLLO OPERATIONS HANDBOOK

SYSTEMS DATA

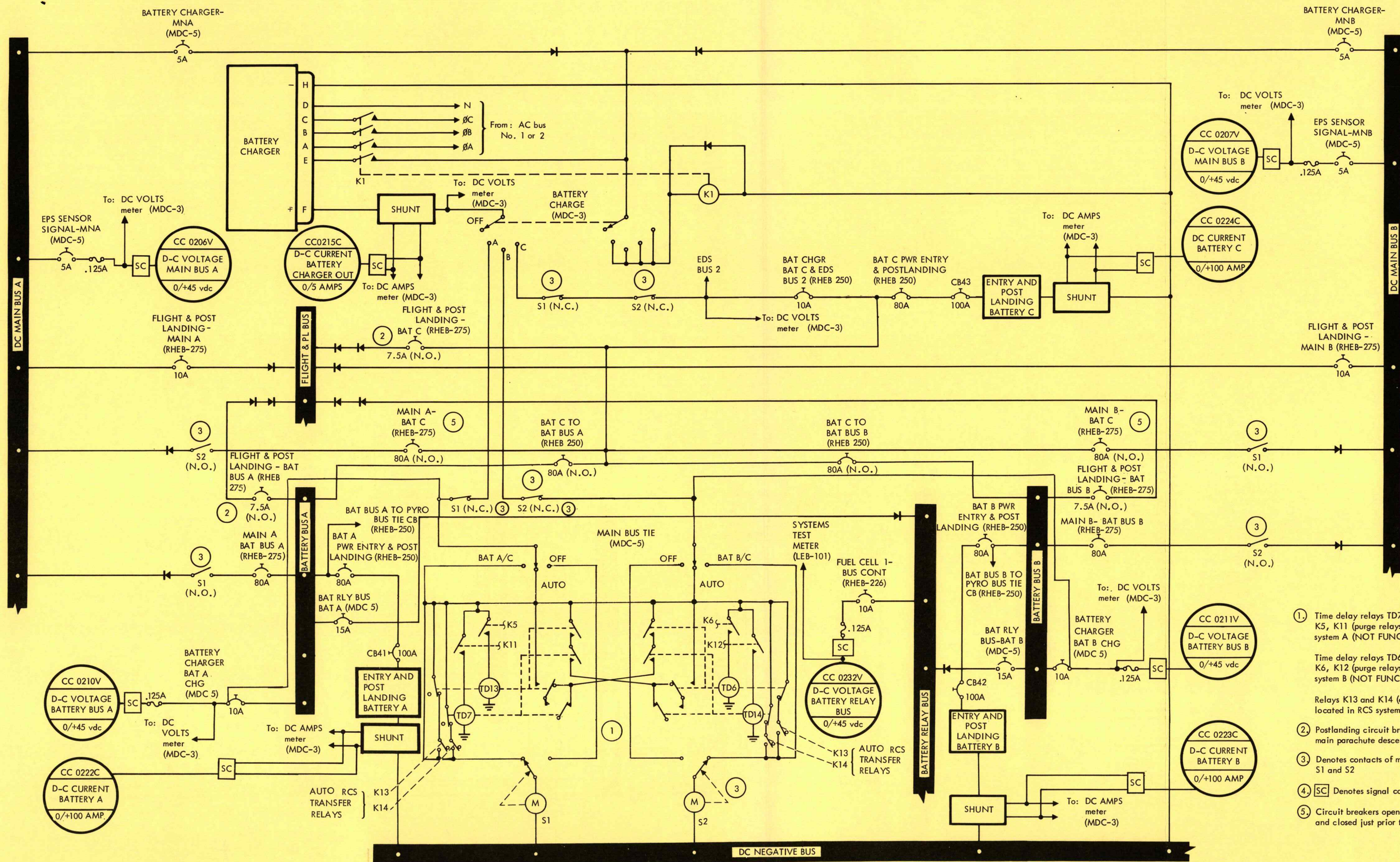
Systems Test Meter Display	N ₂ , O ₂ , H ₂ Pressure (PSIA)	EPS Radiator Outlet Temperature (°F)	CM-RCS Oxidizer Valve Temperature (°F)	LM Power (Amps)	SPS Temperature (°F)	Battery Manifold Pressure (PSIA)	Battery Relay Bus (VDC)
0.0	0	-50	-50	0	0	0.00	0
0.2	3	-36	-46	0.4	8	0.72	1.8
0.4	6	-22	-42	0.8	16	1.44	3.6
0.6	9	-8	-38	1.2	24	2.16	5.4
0.8	12	+6	-34	1.6	32	2.88	7.2
1.0	15	+20	-30	2.0	40	3.60	9.0
1.2	18	+34	-26	2.4	48	4.32	10.8
1.4	21	+48	-22	2.8	56	5.04	12.6
1.6	24	+62	-18	3.2	64	5.76	14.4
1.8	27	+76	-14	3.6	72	6.48	16.2
2.0	30	+90	-10	4.0	80	7.20	18.0
2.2	33	+104	-6	4.4	88	7.92	19.8
2.4	36	+118	-4	4.8	96	8.64	21.6
2.6	39	+132	0	5.2	104	9.36	23.4
2.8	42	+146	+4	5.6	112	10.08	25.2
3.0	45	+160	+10	6.0	120	10.80	27.0
3.2	48	+174	+14	6.4	128	11.52	28.8
3.4	51	+188	+18	6.8	136	12.24	30.6
3.6	54	+202	+22	7.2	144	12.96	32.4
3.8	57	+216	+26	7.6	152	13.68	34.2
4.0	60	+230	+30	8.0	160	14.40	36.0
4.2	63	+244	+34	8.4	168	15.12	37.8
4.4	66	+258	+38	8.8	176	15.84	39.6
4.6	69	+272	+42	9.2	184	16.56	41.4
4.8	72	+286	+46	9.6	192	17.28	43.2
5.0	75	+300	+50	10.0	200	18.00	45.0

EPS

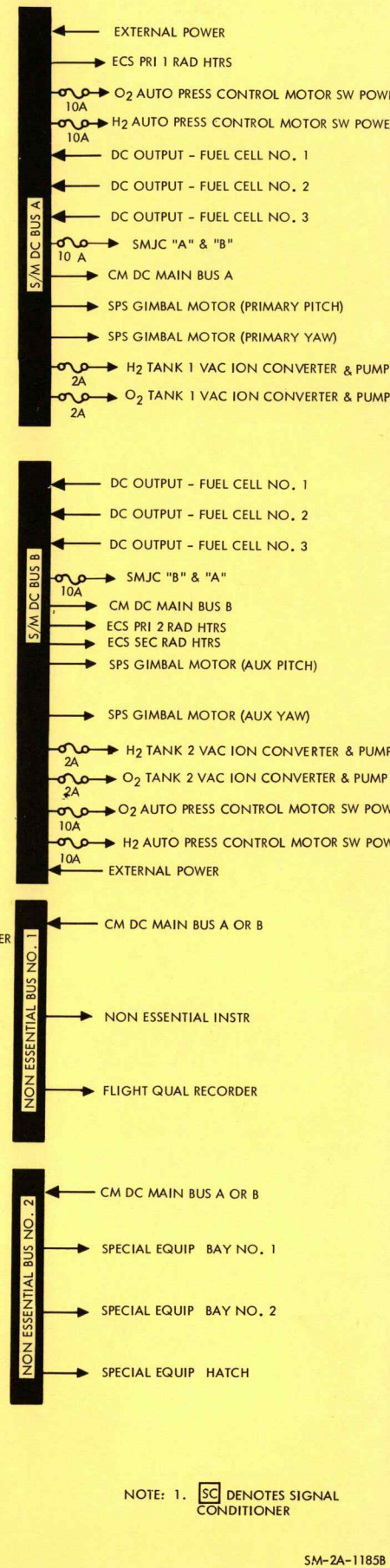
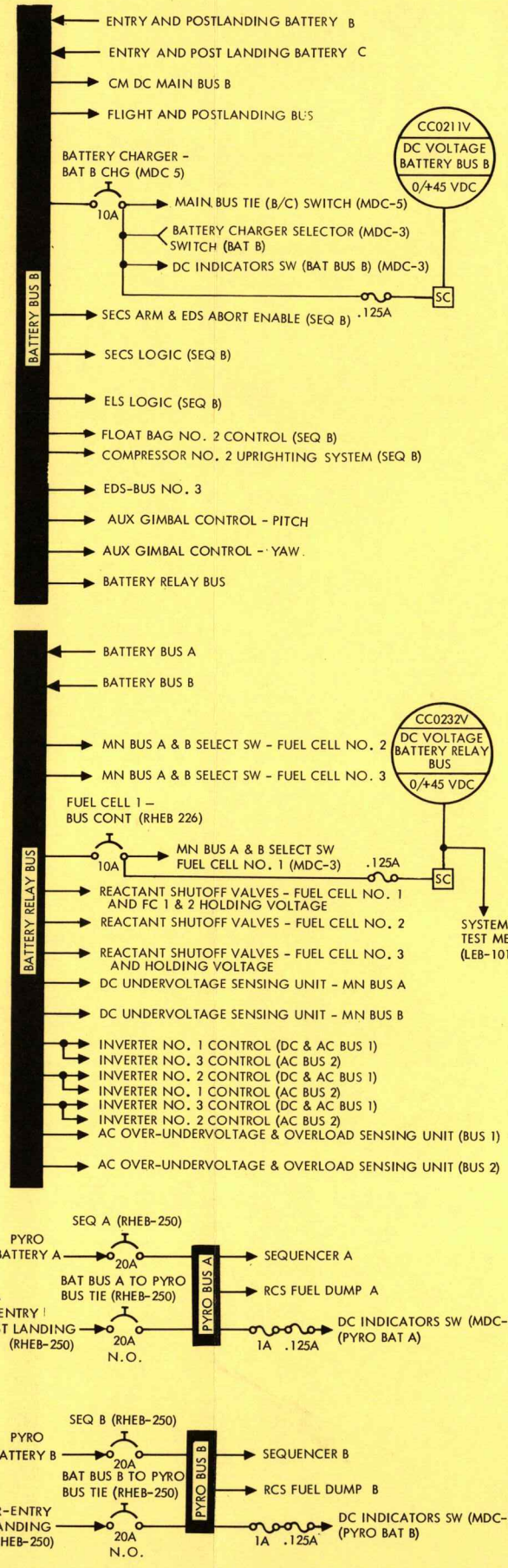
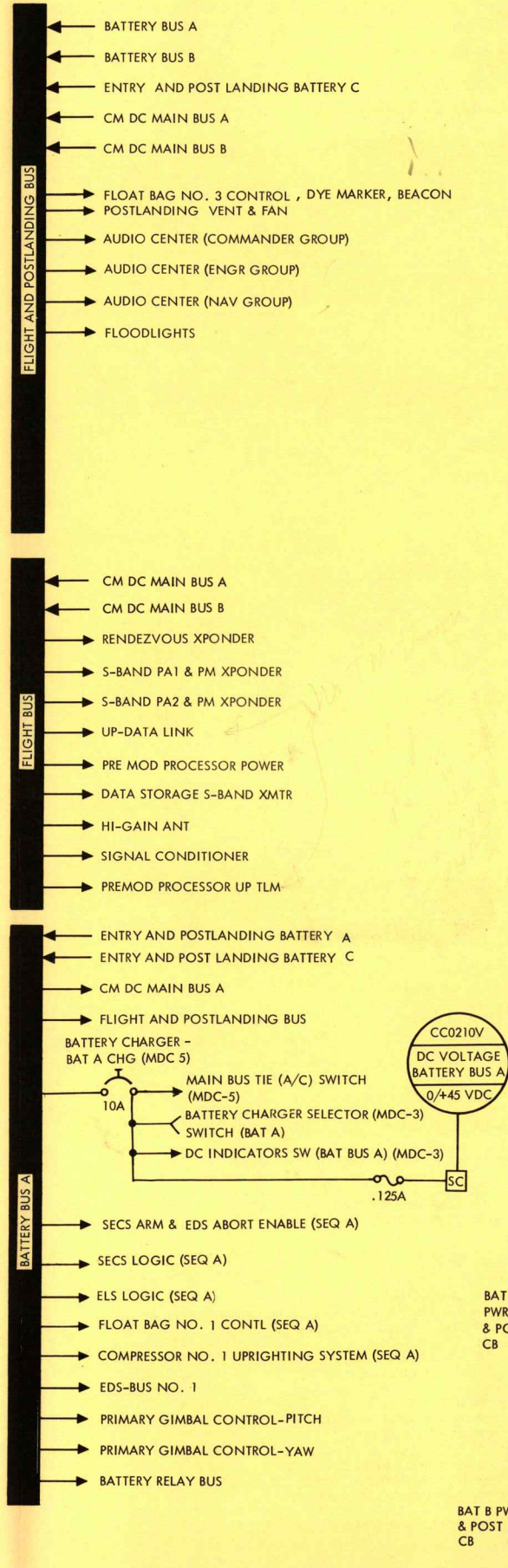
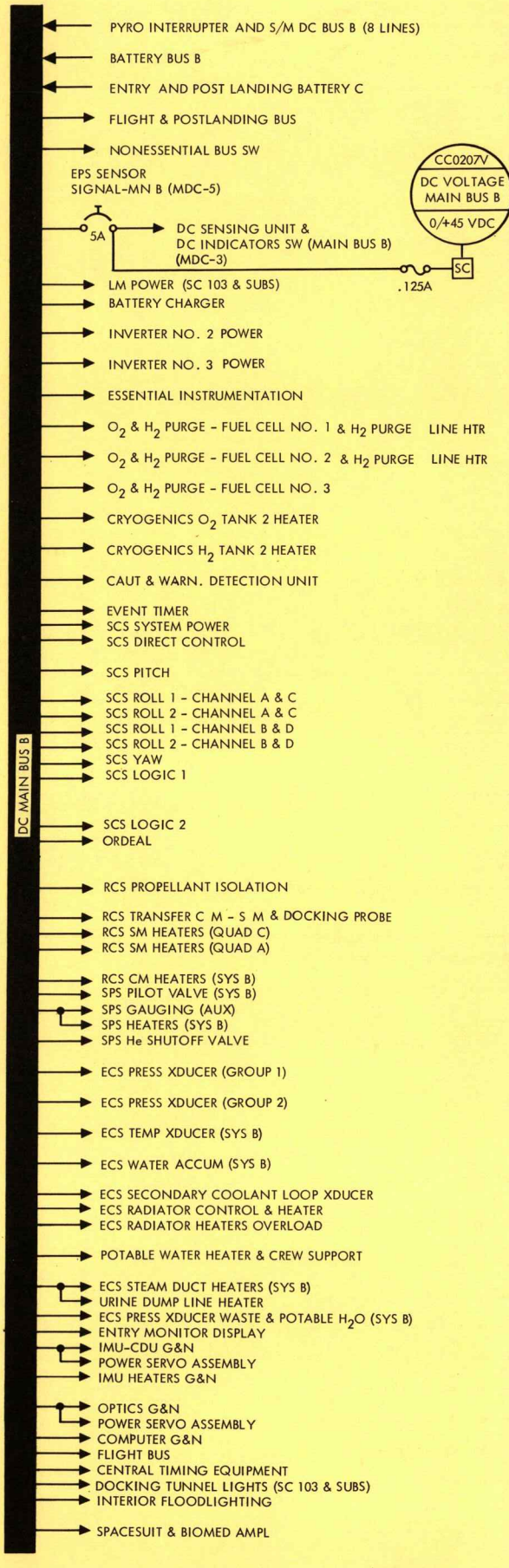
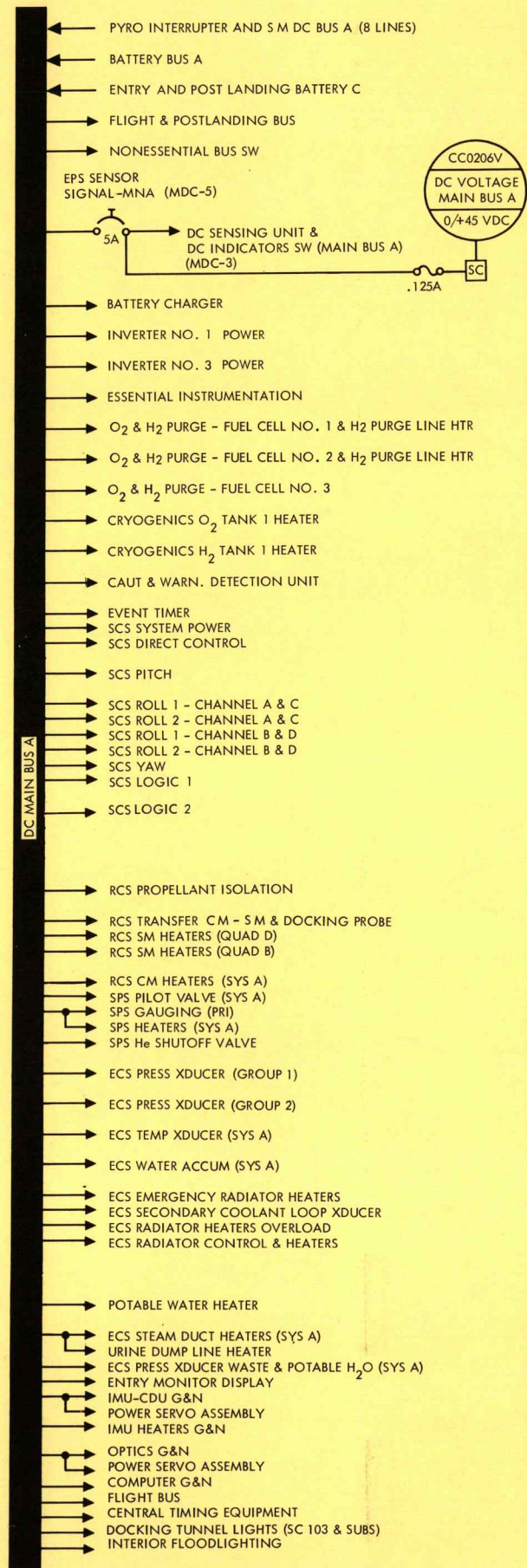
ELECTRICAL POWER SYSTEM



NOTE: K20 and K21 contacts are located in inverters No. 1, 2, and 3 control circuits.



- ① Time delay relays TD7, TD13, and relays K5, K11 (purge relays) located in RCS system A (NOT FUNCTIONAL IN EPS)
Time delay relays TD6, TD14, and relays K6, K12 (purge relays) located in RCS system B (NOT FUNCTIONAL IN EPS)
Relays K13 and K14 (auto RCS transfer) located in RCS system A & B respectively
- ② Postlanding circuit breakers (3) open until main parachute descent
- ③ Denotes contacts of motor switches S1 and S2
- ④ SC Denotes signal conditioner
- ⑤ Circuit breakers opened on prelaunch and closed just prior to CSM separation



NOTE: 1. SC DENOTES SIGNAL CONDITIONER