

HF Series Generators
Advanced Service Manual (ASM)

Advanced Service Manual

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Line Powered HF Generator Theory

HF Series Generators

TABLE OF CONTENTS

Section	Page
1 PURPOSE AND DESCRIPTION	1
1.1 Generator Composition	1
1.2 Characteristics	2
1.2.1 RAD / Fluoro Parameters	2
1.2.2 HV Signal Characteristics	3
1.2.3 X-Ray Tubes	3
2 THEORY OF OPERATION	5
2.1 General	5
2.2 Generator Operation	5
3 FUNCTIONAL ANALYSIS	7
3.1 Power ON / OFF	7
3.2 Master Reset	9
3.3 24 V Delayed	9
3.4 Room and Inverter Switch-ON	10
3.5 Serial Link	11
3.6 ATP Console CPU	11
3.7 HT Controller	13
3.8 Preparation and Exposure Time Control	14
3.9 Filament Current Regulation	15
3.10 Closed Loop Operation	16
3.11 LF-RAC (Low Speed Rotor Controller)	17
3.12 LV-DRAC (High Speed Rotor Controller)	18
3.13 Inverter	23
3.14 Tube and Filament Change	24
3.15 KV Drive	25
3.16 HV Transformer	26
4 SCHEMATICS	27

SECTION 1 PURPOSE AND DESCRIPTION

1.1 GENERATOR COMPOSITION

The Generator is designed to energize X-Ray tubes for Radiography and optional Fluoroscopy usage.

The Generator contains the following parts / modules:

- High Voltage Transformer (see note below)
- IGBTs / High Voltage Inverter Module (Pulse Width Modulation)
- Low or High Speed Rotor Controller (LF-RAC or LV-DRAC)
- Front Panel Assembly. (Electronic Control)
- Back Panel Assembly.
- Power Input Module.
- Interconnection and Adaptation Panel for the different options
- PCB, ATP Console CPU
- PCB, AEC (optional)
- PCB, Fluoro CPU (optional)

Note 

The Generator may be controlled by either a Push-Button Control Console, Touch Screen Console (TPC) or external PC.

1.2 CHARACTERISTICS

1.2.1 RAD / FLUORO PARAMETERS

RANGE OF RADIOGRAPHIC PARAMETERS	
PARAMETER	RANGE
kW	From 32 kW to 80 kW. <i>(Depending on the Generator model)</i>
kV	From 40 kV to 125 kV or 150 kV in 1 kV steps. <i>(Depending on the Generator model)</i> Accuracy: $\pm (3\% + 1 \text{ kV})$
mA	From 10 mA to 800 mA through the following mA stations: 10, 12.5, 16, 20, 25, 32, 40, 50, 64, 80, 100, 125, 160, 200, 250, 320, 400, 500, 640, 800. <i>(Depending on the Generator model)</i> Accuracy: $\pm (4\% + 1 \text{ mA})$
mAs	Product of mA x Time values from 0.1 mAs to 500 mAs. <i>(640 mAs on request)</i>
Exposure Time	From 1 millisecond to 10 seconds through the following Time stations: Milliseconds: 1, 2, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 32, 40, 50, 64, 80, 100, 125, 160, 200, 250, 320, 400, 500, 640, 800. Seconds: 1, 1.25, 1.6, 2, 2.5, 3.2, 4, 5, 6.4, 8, 10. Accuracy: $\pm (2\% + 0.1 \text{ ms})$
AEC	mAs: 0.1mAs to 500 mAs Exposure Time: Nominal shortest irradiation Time = 1 ms

RANGE OF FLUOROSCOPIC PARAMETERS	
PARAMETER	RANGE
kV	From 40 kV to 120 kV or 125 kV in 1 kV steps. Accuracy: $\pm (3\% + 1 \text{ kV})$
mA	Fluoroscopic mA are set during calibration so as not exceed the maximum Entrance Skin Exposure (ESE) dose rate on the patient. Accuracy: $\pm 10\%$
Exposure Time	From 0 to 5 minutes. Accuracy: $\pm (1\% + 20 \text{ ms})$
PPS (Pulsed Fluoro)	Variable rate at: For 25 PPS: 1, 2, 3, 6, 12, 25 PPS. For 30 PPS: 1, 2, 4, 8, 15, 30 PPS. For 50 PPS: 1, 2, 3, 6, 12, 25, 50 PPS. For 60 PPS: 1, 2, 4, 8, 15, 30, 60 PPS.

Linearity	$(X1 - X2) 0.1(X1 + X2)$
Reproducibility	(Coefficient of Variation) ≤ 0.05

1.2.2 HV SIGNAL CHARACTERISTICS

- kV and mA adjustment during X-Ray emission gives excellent exposure reproducibility.
- The very low kV ripple qualifies the Generator as a constant voltage Generator (IEC Standard) throughout most of its operating range.
- HV Frequency: 25 kHz.

1.2.3 X-RAY TUBES

- The Generator can supply one X-Ray tube or an optional second X-Ray tube.
- These X-Ray tube(s) must be selected from the list given in the Generator Service Manual.
- The rotation speed can be 3300 and 10000 rpm.

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SECTION 2 THEORY OF OPERATION

2.1 GENERAL

The Generator is designed to equip a conventional radiology room.

The Generator provides the X-Ray tube(s) with:

- High voltage
- Filament heating current
- Anode motor control

The Generator ensures correct communication between the various pieces of equipment in the radiology room.

The Generator has a Control Console with an Anatomic Programming option.

2.2 GENERATOR OPERATION

See General and System Block Diagrams (illustrations 1 and 2)

The Power and Input Module supplies the X-Ray Room and Generator.

The Inverter rectifies and filters the line supply to provide the DC voltage for the IGBT Inverter and the LV-DRAC (from 300 to 750 v).

The inverter modulates at a fixed frequency of 25 kHz, producing an AC voltage which supplies the HVT.

The HVT converts this AC voltage to high voltage which is then rectified and filtered to supply the X-Ray tube(s) with high voltage (up to 150 kV).

The autotransformer T2, located on the Back Panel, produces the voltage (DC or AC) for the whole Generator (*see illustration 3*).

The Front Panel controls the Generator:

- Inverter control and regulation of the High Voltage (HT Controller)
- Filament heat current (Filament Control)
- mA regulation and control (HT Controller)
- Tube and Filament change (Interface)

The Filament Control produces the X-Ray filament heating current for the tubes (large and small Focal Spot).

The LF-RAC (low speed) or LV-DRAC (high speed) is used to start up and brake the rotating anode.

The Interface board is used to change the tube and the filament as well as to switch the Generator ON and OFF.

The Console is used to control and monitor the Generator (also via the Anatomic Programmer option). The Console also controls all the compatibilities (Buckies, Tomo, AEC, Spot Film, etc.)

SECTION 3 FUNCTIONAL ANALYSIS

3.1 POWER ON / OFF



MAKE SURE THAT THE MAIN CAPACITORS OF THE HIGH VOLTAGE INVERTER DO NOT CONTAIN ANY RESIDUAL CHARGE. WAIT UNTIL THE LIGHT EMITTING DIODES ON THE CHARGE-DISCHARGE MONITOR BOARDS ARE OFF BEFORE SERVICING THE EQUIPMENT (APPROX. 3 MINUTES AFTER THE UNIT IS TURNED OFF).



“IPM DRIVER BOARD” SHOULD BE CONNECTED BEFORE ACTIVATING MAINS. IF THE “IPM DRIVER BOARD” IS NOT CONNECTED, PERMANENT DAMAGE WILL OCCUR TO IGBTs.



THIS GENERATOR IS PERMANENTLY CONNECTED TO THE POWER LINE, AND POWERED ON UNLESS THE SAFETY SWITCH INSTALLED IN THE ROOM ELECTRICAL CABINET IS OFF. WHEN THE GENERATOR IS POWERED, THE GREEN LED LOCATED ON THE TRANSFORMER 6T2 (GENERATOR CABINET) IS ON.

INTERNAL PARTS OF THE GENERATOR (ALL FUSES, LINE CONTACTOR (6K5), INPUT TRANSFORMER (6T2), ON/OFF RELAY (3K3), LF-RAC OR LV-DRAC MODULE) ARE PERMANENTLY POWERED ALTHOUGH THE CONTROL CONSOLE IS OFF. BE SURE THAT THE SAFETY SWITCH IS OFF BEFORE HANDLING ANY INTERNAL PART OF THE EQUIPMENT.

The Generator has a permanent power supply of 11 V, to switch ON and OFF the whole room (see *Illustration 3A, 3B or 3C*).

When the "ON" push-button is pressed (on the Console), Mosfet Q1 is activated (ATP Console CPU board).

On the Interface Control board (Front Panel), K1 is energized through Q1. A normally open contact of the same relay keeps K1 self-energized.

Note 

K1 is a 6V DC-Coil

K1 energizes 3K3 (Rectifiers Panel). 3K3 is the general Switch-ON relay and supplies the power for the Front Panel (electronic control of the cabinet) and the ATP Console CPU.

The Master Reset circuit ensures a proper switching-on of the $\mu\text{P} / \mu\text{C}$ (microprocessor or microcomputer) PCB.

The system microcomputers begin by first checking the whole system. The line contactor K5 is not yet activated, so the room still does not have power.

When the "OFF" push-button is pressed (Console), Mosfet Q2 is activated (ATP Console CPU board).

On the Interface Control board (Front Panel), K1 removes the power supply thorough Q2, de-energizing the relay K1. The general Switch-ON relay (K3) is also de-energized.

3.2 MASTER RESET

This circuitry resets the microprocessors whenever the Voltage is not stable or between 4.75 and 5.25. This circuit activates during the start-up phase, blocking the system for approximately 100 milliseconds until the correct tension required for each board is constant.

There is a Master Reset circuit on each of the main boards with a microprocessor (μ Processor), such as the ATP, HTC and Control Drac PCB.

In the event of a drop in Voltage or a micro-cut in the power supply, the system will reset, activating the Master Reset.

Note 

Master Reset activated indicates that the μ Processor has stopped.

3.3 24 V DELAYED

The 24 V Delayed is a security voltage which appears after the Switching-ON transient in order to avoid a false (early) connection of the Filter Capacitors Bank (C1-C4 in the Inverter) through the Charge Contactor 6K6.

The 24 V Delayed is present in connector P5-2 when the relay K8 is energized. (see *Schematic 'Interface Control Board' in the Generator Service Manual*)

Two conditions must be met to energize the relay K8:

- Capacitor C14 has to be charged through R33 (Time Delay is equivalent to the time constant C14 and R33).
- The Line Contactor has to be already energized.

Once the relay K8 is energized, the 24 V Delayed is present and the Charge Contactor K6 is allowed to be energized in order to feed the Inverter.

3.4 ROOM AND INVERTER SWITCH-ON

After SWITCH-ON, the Console and the Cabinet check the system. If everything is functioning properly, the ATP Console CPU will be available to switch ON the room through Line Contactor K5. *Refer to illustrations 4 and 5 Charge Circuitry and Switch-On Sequence.*

If the Watchdog and system are functioning properly, the microcomputer activates Mosfet Q3. The network R12 and C52 produce a delay to avoid a false (early) connection of the Line Contactor during the Switching-ON transient.

Mosfet Q3 energizes K5. The contactor K5 supplies the whole room through fuses F14-F16.

The Bank Capacitors C1-C4 are soft charged (current limited) through LF1 (EMI filter) R1, Input Rectifier and L2.

The Capacitor Charge is checked by the Charge/Discharge Monitor PCB. The HT Controller verifies the correct values of the charge

When the voltage of the Bank Capacitors is correct, the HT Controller energizes the Charge contactor K6, short-circuiting the resistor R1 and thus allowing the current to flow directly to the Inverter.

3.5 SERIAL LINK

The Serial Link is a synchronized (fully isolated) communication between the Console and the Cabinet (*see illustration 6: Serial Link*).

The ATP Console CPU has all the intelligence of the Generator (tube protections and system operation). The Cabinet executes the orders received from the ATP Console CPU. All the calibration data is contained in U3 on the HT Controller PCB.

To transmit data from any side, there are two signals:

- Clock Signal, interrupting the microcomputer and synchronizing the data
- Data Signal, which is synchronized with the clock.

There are two LED's to check the proper communication. One of the LED's (DS1) is located in the HT Controller. The second LED is located on the ATP Console CPU (DS2).

The LED DS1 (HT Controller) illuminates when the microcomputer receives the first datum. DS1 remains illuminated until the microcomputer ends the transmission.

The LED DS2 (ATP Console CPU) illuminates when the microcomputer sends the first datum. DS2 remains lit until the microcomputer receives the last bit.

DS1 and DS2 are lit when the Serial Link is busy.

3.6 ATP CONSOLE CPU

The Block Diagram of the ATP Console CPU is represented in Illustration 7.

Microcomputer 8088 (U30) is the core.

The main program of the Generator is stored in the 4 Mb EPROM memory (U24).

The EEPROM (U18) stores (the same data in two different memory locations, for security reasons):

- The backup copy of the APR data (*see Illustration 8: APR Checking*)
- The workstation configuration.
- Number of X-Ray exposures.

The NVRAM (U23) stores:

- Data from the Microprocessor stack
- The Heat Units accumulated in the X-Ray tube and the corresponding Time and Date.
- The last Console selections (Exposure parameters, AEC and workstation), which are selected automatically when the Generator is switched-ON.
- The operating copy of the APR. All the APR changes are stored in the NVRAM and later (in the next power-ON) copied into the EEPROM (U18).

To avoid uncontrolled operation of the microcomputer, Watchdog is performed by U4.

The Keyboard is controlled by U25 and the Display is controlled by U11.

The Exposure Time Counter and General Purpose Timer is performed by U21.

The Synchro Serial Link is explained above (*see Section 3.5: Serial Link*).

U29 is the Interrupt Controller that manages all interruptions in the microcomputer, which are the following:

- (IR0) AEC Stop finishes the X-Ray Exposure through the Automatic Exposure Control (AEC).
- (IR1) Transmission Data Interrupt controls Output Serial Link of RS232.
- (IR2) Exposure Timer Control.
- (IR3) Fluoro Data Input serial link.
- (IR4) HT Controller Data Input serial link.
- (IR5) Input for External Synchro for Fluoro.
- (IR6) General and Exposure Back-up Timer.
- (IR7) UART (U16) RS232/422 serial link control.

U6 and U15 are general Input/Output ports to control the whole system.

The AEC Control is an option directly connected to the Data Bus of the microcomputer. Depending upon selected parameters (kV, density, film speed and calibration data), the microcomputer gives an analog demand which is compared with the output ramp of the Ionization Chamber in order to finish the X-Ray exposure.

3.7 HT CONTROLLER

The Block Diagram of the HT Controller PCB is represented in Illustration 10. The core (U5) is the 89C55 (with program memory included in the chip).

The calibration data is stored (the same data in two different memory locations, for security reasons) in a non volatile memory (EEPROM) U3.

EEPROM stores:

- Filament Current Numbers (T1 & T2).
- Extended Memory Location.
- Focal Spot Change (T1 & T2).
- Rotor Acceleration and Filament Hold-Over Time (T1 & T2).

ADC (U4) is used to monitor and control:

- Rotor current, to check the proper performance (acceleration, running or braking) of the low speed LF-RAC (Line Frequency Rotating Anode Controller).
- Filament current, to check the correct heating value of the filament.
- kVp, to check the correct (actual) value of the X-Ray exposure.
- mA, to check the correct (actual) value of the X-Ray exposure and also to close the mA loop to automatically correct the variations.

The Synchronous Serial Link is described above (*see section 3.5*).

The two D/A converters used are:

- U6, to produce the filament current demand. U21 converts the RMS current value to a DC value. Modulator U23 produces 6,6 kHz PWM to get a proper and stabilized Heating Filament Value.
- U17, to produce the kVp demand. Modulator U19 produces a 25 kHz PWM to control the Inverter.

The General Purpose outputs are performed with open collector drivers.

The General Purpose inputs are performed with optocouplers.

3.8 PREPARATION AND EXPOSURE TIME CONTROL

Preparation and Exposure switches enter in the ATP Console microcomputer U30, through U25 (see *illustration 11: Preparation and Exposure Time Control*).

The microcomputer U30 sends the preparation signal through U5 (if the Watchdog U4 is activated) and then from U7 to the Cabinet.

The preparation signal reaches microcomputer U5 (in the HT Controller) through the optocoupler U1.

The microcomputer U5 selects the filament and starts the rotor. After a certain programmable time, U5 sends the READY signal to the ATP Console CPU through the Serial Link.

When the microcomputer U30 receives the exposure order, the following happens simultaneously:

- U30 loads the exposure time in U21 (timer).
- U30 sends the exposure order to the ATP Console CPU through the gate U5 and enters in U7 (if Watchdog U4 is activated).

The exposure order reaches the cabinet microcomputer U5 (in the HT Controller) through optocoupler U2.

The modulator U19 sends 25 kHz to the Inverter, starting the X-Ray exposure. The cabinet microcomputer U5 can abort the radiation through the input “*kV safety*” if any problem occurs during the exposure.

Once the exposure has ended, the timer U21 interrupts the microcomputer U30 through the Interrupt Controller U29.

U30 stops the exposure through U5, U7, and U2. The modulator U19 stops the PWM to the Inverter, ending the X-Ray exposure.

3.9 FILAMENT CURRENT REGULATION

The Filament current is regulated through the HT Controller, the Filament Driver and the Interface Control as shown in the Closed Loop Block Diagram. *Refer to Illustrations 12 and 13.*

From the serial link from the ATP Console, U5 sends a binary signal FIL DEMAND to the DAC converter U6. Pulse-Width Modulator U23 controls the pulse width of the signal.

The product of U23 is FIL DR 1 and FIL DR2 which enters the Filament Driver at J1.

The Gate Drivers at the Filament Driver modify the FIL DR1 & 2 signals for the IGBTs which, in turn, amplify and distinguish the signals, filtering them through the Capacitors as FIL RTN and FIL SUP.

The resistor shown in the Filament Driver (*Illustrations 12 and 13*) reads the mA that passes through the filament and sends FIL I to U21 which converts the RMS signal to DC. The product of this conversion is FIL FEEDBACK and serves as a regulatory signal for the PW Modulator U23. This is also called the HARDWARE LOOP.

FIL RTN enters the Interface Control at J4-14 where it crosses through the Filament selection switch which is set according to the -FIL1 SLC signal (Filament Selection) from the HTC through U7.

The Filament selection switch routes FIL RTN to either the Small or Large Filament through P4-16 or P4-15, producing the signals FIL2 RTN and FIL1 RTN respectively.

These signals are received by the HV Transformer at J1-H or J1-F. FIL SUP coming from the Filament Driver supplies the Filament Transformer in the HV Transformer with current.

3.10 CLOSED LOOP OPERATION

Refer to illustration 13 for the Closed Loop Block Diagram.

The Generator has two different kind of loops, Hardware Loops and Software Loops.

The first Hardware Loop is the filament current. The microcomputer U5 sends the filament demand through U6 according to the calibrated data.

Modulator U23 generates a PWM of 6,6 kHz, keeping the filament current constant according to the demand received from U5. The converter U21 guaranties a stable RMS value in the filament (the proper heating value).

The second Hardware Loop is the kV. The microcomputer U5 sends the kV demand through U6 to modulator U19, according to the exposure data sent by the Console.

Modulator U19 generates a PWM of 25 kHz, according to the demand received from U5 and the feedback received from the HVT. The PWM is sent to the Inverter to drive the HVT.

The first Software Loop is the mA. The microcomputer U5 reads the mA through U4.

If mA Closed Loop operation is selected (HT Controller SW2-4 in OFF position), the microcomputer U5 regulates the filament demand in order to obtain the proper mA in the X-Ray tube. The mA Closed Loop operation is necessary to keep the mA value constant for long exposures due to the cooling effect of the filament when emitting electrons to the anode.

The second Software Loop is the kV. The microcomputer U5 reads the kV through U4.

3.11 LF-RAC (LOW SPEED ROTOR CONTROLLER)

The stator voltage is selectable as 330 V or 230 V (220 V) for every tube position

The shifting capacitor is selectable (15 or 30 microfarads) for every tube position.

The fan voltage is selectable (220 or 115 V) for every tube position.

K1 is a solid state relay mounted on the panel. This relay allows Acceleration Relay K1 (mounted on the board) to commute from acceleration voltage to running voltage without switching current (*see illustration 14*). At time 1, relay K1 selects acceleration voltage (230 (220) or 330 V).

At time 2 (50 ms later), solid state relay K1 is ON and current flows through the stator coils. The current transformers T1 and T2 sense the current. In RTRI, the value is 3.2 V, corresponding to the nominal acceleration current.

At time 3, solid state relay switches OFF to allow acceleration relay (K1) to commute at time 4 (50 ms later) to running voltage (60 or 90 V).

At time 5, solid state relay switches ON again. The voltage in RTRI at this time is 1.6 V, corresponding to the nominal running current.

At time 6, solid state relay switches OFF again, ending the running state.

At time 7 (50 ms later than time 6), relay K1 commutes to Braking or Accelerating voltage and K3 commutes to Braking position.

Between times 8 (50 ms later than time 7) and 9, the stator brakes with a DC voltage applied to both coils through CR6.

At time 10 (50 ms later than time 9), acceleration relay commutes again to the low voltage position, ending the sequence.

There are several LED's to show the proper relay status. These LED's are the following:

- DS1, indicating high voltage applied to the stator (Acceleration or Braking state).
- DS2, indicating that the tube two is selected.
- DS3, indicating Braking state.
- DS4, indicating that current is flowing through **BOTH** stator coils. High luminous intensity means Acceleration state. Low luminous intensity means Running state.

3.12 LV-DRAC (HIGH SPEED ROTOR CONTROLLER)

The Block Diagram of the LV-DRAC is represented in illustration 15.

The LV-DRAC is a fully solid state converter which digitally generates the voltages for both stator coils (auxiliary and principal) shifted 90°. This characteristic has two main advantages:

- The bulky shifting capacitors for high speed, low speed, auxiliary and principal coils are no longer needed; neither are the contactors to switch them.
- Any combination of stator type can be selected for each tube position.

The Generator will always attempt to make the exposure at Low Speed if it is allowed by the tube in order to save unnecessary heat and mechanical fatigue for the bearings. This means the following:

1. During Fluoro, Low Speed is always selected.
2. During Spot Film, two modes of operation can be configured:
 - a. Always at High Speed (SW3-3 ON).
 - b. High or Low Speed according to the tube characteristics, heat units and exposure selected (SW3-3 OFF)
 - c. During RAD, Low Speed is selected. Nevertheless, if the exposure is not allowed by the tube at Low Speed, then High Speed will be selected automatically.

An exposure with exactly the same parameters can be made in Low or High Speed, depending upon the actual anode temperature (heat units); this means that a series of exposures can be started at Low Speed and finished at High Speed.

The input command comes from the Generator through the optocouplers OP1 and OP2 to the microcomputer U17.

From DRAC to HTC:

- ERROR LV-DRAC is an output of the LV-DRAC used to inform the Generator on the actual status (J4-1 and J4-2).

The errors can be disconnected (SW4-7 ON) in order to let the Service Engineer to do the Troubleshooting. WARNING, when the errors are disconnected (DL1 ON), the LV-DRAC will always give the READY signal, even if the rotor is not running at the proper speed.

- READY is an output of the LV-DRAC to tell the Generator that the rotor is running at the proper speed (J4-4 and J4-7).

The output J4-5 can be used to drive an optocoupler.

Although the rotor can be accelerated to a high velocity, in a very short time the READY signal can be delayed in order to allow the Generator to heat the filament to make the proper exposure. The minimum delay time for READY can be configured (SW1-1 to SW1-3) from zero to 3 seconds.

From HTC to DRAC:

- ST (START) is an input for the LV-DRAC to start Normal Acceleration (J4-19 and J4-20).

With this input, the LV-DRAC can enter in the "SELF-RUNNING MODE" (see Service Manual) in order to avoid overheating in the stator.

- FL (FLUORO) is an input for the LV-DRAC to start the acceleration from the Fluoro workstation (J4-15 and J4-16).

The Fluoro Hold-Over Time (time that the rotor keeps running after the signal Fluoro is OFF) is programmed from zero to 120 seconds with SW2-1 to SW2-3.

- SF (SPOT FILM) is an input for the LV-DRAC to start the acceleration from the SPOT FILM workstation. (J4-13 and J4-14).

The Spot Film Hold-Over Time (time that the rotor keeps running after the signal Spot Film is OFF) is programmed from zero to 40 minutes with SW4-1 to SW4-4.

The X-Ray tube can always start at High Speed if this feature is selected with SW3-3 ON.

- HS (HIGH SPEED) is an input for the LV-DRAC to select high speed operation (J4-17 and J4-18).
- TUBE 2 is an input for the LV-DRAC to select tube 2 (J4-23 and J4-24). The X-Ray tube type is selected with SW2-4 to SW2-8.
- To select TUBE 1, the input signals Tube 2 must be OFF. The X-Ray tube type is selected with SW1-4 to SW1-8.

The microcomputer U17 makes the calculations, generates and controls the logic sequence according to the configuration made in SW1 to SW4.

The voltage magnitude of both stator coils are controlled by PWM (Pulsed Width Modulation), sent from the microcomputer U17 to the logic control U16.

The logic control U16 decodes and generates all the signals needed for the Three Phase IGBT Inverter (PTR1). The logic control also limits the Inverter current through U11 (the output of the inverter is fully short-circuitable).

The ADC (Analog to Digital Converter) informs the microcomputer on four important data:

- The DC voltage, in order to calculate the PWM and apply the proper voltage to the stator, despite any line variations (the voltage applied to the stator is kept constant with line variations from 320 to 550 VAC).
- The auxiliary wire current, to check the proper stator operation.
- The Main wire current, to check the proper stator operation.
- The common wire current (obtained with the difference between the auxiliary and principal wires), in order to check the proper 90° phase shifting.

The LV-DRAC has a very useful error detection tool with 43 different codes for troubleshooting. These errors can be disabled (SW4-7 ON) in order to perform tests.

The error code is sent to the Generator through the Synchronous Serial Link.

There are 8 LED's in the LV-DRAC:

- DL1 is illuminated when the LV-DRAC errors are disabled with the switch SW4-7 ON.
- DL2 is connected to the LV-DRAC ERROR CODE serial link. The microcomputer sends the error status to the Generator, every 1.4 seconds so DL2 flashes all the time, indicating that the serial link is operating properly.
- DL3 indicates that the Rotor is ready when is illuminated.
- DL4 indicates the selection of tube 1.
- DL5 indicates the selection of tube 2.
- DL6 indicates that the DC brake is operating.
- DL7 and DL8 indicate the presence of high voltage in the Power Inverter.

The Power Inverter output of the IGBTs, is connected to 2 transformers (Auxiliary and Main) to adapt the voltage and isolate the stator from the input line (Inverter Power Supply).



THE LV-DRAC OUTPUT VOLTAGE CAN BE AS HIGH AS 1000 VRMS. FOR SAFETY REASONS (TO AVOID ELECTRIC SHOCKS), THE STATOR CABLE MUST BE SHIELDED. BOTH ENDS OF THE SHIELD MUST BE CONNECTED TO THE GROUND TO AVOID ELECTROMAGNETIC INTERFERENCE (EMI) PROBLEMS. THE IGBT'S HEATSINK IS NOT GROUNDED, IT IS CONNECTED TO THE NEGATIVE TERMINAL OF THE INPUT RECTIFIER. TO AVOID ELECTRIC SHOCK, BE SURE THAT THE INPUT LINE IS DISCONNECTED AND THE CAPACITOR BANK IS PROPERLY DISCHARGED, BEFORE MANIPULATING ANYTHING IN THE LV-DRAC.

There are two braking modes in the LV-DRAC (see *Illustration 16*):

- **Active Brake** applies an electromagnetic field with the same magnitude, but in the opposite direction to the actual anode rotation (reverse electromagnetic field).

This brake rapidly decelerates the anode in order to pass through the resonant frequencies as quickly as possible, in order to avoid damage to the rotor bearings and glass insert.

This braking mode can be compared to the one used to decelerate an aircraft, reversing the air flow of the turbines.

- **Passive Brake** applies a constant electromagnetic field (DC current) in order to stop the rotor completely.

This braking mode can be compared to the one used to brake and completely stop the aircraft wheels.

Speed changes of the anode, controlled by the LV-DRAC, are shown in illustration 17.

- From T1 to T2, the LV-DRAC applies a 3300 rpm acceleration voltage.

From T2 onwards, the LV-DRAC applies a 3300 rpm running voltage with the READY signal activated (if the minimum delay time for READY has passed).

- The Low Speed (3300 rpm) brake can be disabled (SW3-1 ON), letting the anode coast freely.

If the LS brake is enabled (SW3-1 OFF), the LV-DRAC applies the 3300 rpm Active Brake from T3 to T4, reversing the electromagnetic field and rapidly decelerating the anode.

If the DC Brake is disabled (SW4-8 OFF), the anode coasts freely at approximately 600 rpm.

But if the DC Brake is enabled (SW4-8 ON), the LV-DRAC applies the Passive Brake (DC Brake) from T4 to T5 to completely stop the anode.

In any case, the READY signal is OFF from T3 onwards.

- From T6 to T7, the LV-DRAC applies a 10000 rpm acceleration voltage.

From T7 onwards the LV-DRAC applies a 10000 rpm running voltage with the READY signal activated (if the minimum delay time for READY has passed).

- From T8 to T9, the LV-DRAC applies a 10000 Active Brake, reversing the electromagnetic field and rapidly decelerating the anode.

If the DC Brake is disabled (SW4-8 OFF), the anode coasts freely at approximately 600 rpm.

However, if the DC Brake is enabled (SW4-8 ON), the LV-DRAC applies the Passive Brake (DC Brake) from T9 to T10 in order to completely stop the anode.

In any case, the READY signal is OFF from T8 onwards.

- From T11 to T12, the LV-DRAC applies a 10000 rpm acceleration voltage in order to go from low to high speed. The READY signal is OFF.

From T12 onwards, the LV-DRAC applies a 10000 rpm running voltage with the READY signal activated (if the minimum delay time for READY has passed).

- From T13 to T14, the LV-DRAC applies the 10000 Active Brake, reversing the electromagnetic field and rapidly decelerating the anode.

From T14 to T15, the LV-DRAC applies a 3300 rpm acceleration voltage in order to go from high to low speed.

From T15 onwards, the LV-DRAC applies a 3300 rpm running voltage.

The READY signal is ON all the time.

The switch SW4-6 is to check the actual tube selection:

- SW4-6 ON: the microcomputer U17 doesn't test the tube selection.
- SW4-6 OFF: the microcomputer U17 checks the actual tube selection.

The fan voltage is selectable (220 or 115 V) for every tube position.

3.13 INVERTER

The Inverter Block Diagram is represented in Illustration 18.

AC input line is rectified in the Input Rectifier Board. The board also contains R-C networks for the diodes. There are also capacitors connected from the line to the ground to filter the conducted high frequency (EMI) noise.

Filter Capacitors C1 to C4 are charged through inductance L2 to avoid high di/dt currents in the input lines, thus limiting the high frequency noise.



DUE TO ELECTROMAGNETIC INTERFERENCE (EMI) PROBLEMS, THE METALLIC PARTS OF THE INVERTER (CHASSIS) ARE NOT GROUNDED. INSTEAD, ALL OF THEM ARE CONNECTED TO THE NEGATIVE TERMINAL OF THE INPUT RECTIFIER. TO AVOID ELECTRIC SHOCK, BE SURE THAT THE INPUT LINE IS DISCONNECTED AND THE CAPACITOR BANK PROPERLY DISCHARGED BEFORE MANIPULATING ANYTHING IN THE INVERTER.

The two Charge/Discharge Monitor Boards have the following purposes:

- To equalize the voltage in the capacitors connected in series to avoid overvoltage in one of the branches.
- To obtain a fast discharge of the Capacitor Bank (C1 to C4) when the Generator is switched-OFF.
- To show the Service Engineer the presence of high and very dangerous voltage in the Capacitor Bank by means of LEDs.
- To inform the HT Controller of the proper charge of the Capacitor Bank.

Every IGBT module contains a half bridge inverter (one vertical). The IPM Driver converts the low voltage PWM (25 kHz signal coming from the HT Controller) to the voltage needed for the IGBT module.

Also, every IGBT module has an overcurrent and overheating detection device to protect the power stage from any damage due to an overload in the High Voltage Transformer (HVT). This protection sends the signal IGBT FAULT to the HT Controller which then displays "*Generator Overload*" on the Console.

5L1 is an air core inductance that matches the input impedance of the HVT in order to obtain the maximum power from the IGBT Inverter.

5C9 is a series capacitor to cancel the DC component in the primary side of the HVT. The capacitor avoids an HVT core saturation due to the elimination of the DC component.

The output cables of the Power Inverter are shielded (the shields are connected to the negative input terminal) to avoid noise problems. Both cables go through an isolated metallic tube, which is also connected to the negative input terminal.

3.14 TUBE AND FILAMENT CHANGE

The filament and tube change are performed in the Interface Control Board located on the Front Panel (*see illustration 19*).

The Tube 2 Change Order begins at the ATP Console CPU, passing to the HT-Controller through the Serial Link and then to the LF-RAC. Later this change command is sent to the Interface Control (P4-18), activating the relay K5.

The relay K5 sends the order to the HVT solenoid in order to change the High Voltage Switch position.

The HVT informs the ATP Console of the actual position of the High Voltage Switch. The signal “- HV INTLK” from J1-J on the HVT (for Vertical and Compact Generators) is sent to 6J3-13 at the Power Input Module of the Generator Cabinet and then to J3-13 of the ATP Control CPU to check the proper tube selection.

The filament selection begins at the HT Controller (P1-13) and goes to the Interface Control (P4-19), activating the relay K7.

C17, BR2, K11 and its associated circuitry detect the filament selection, sending it back (through P4-22) to the HT Controller (P1-8) in order to check the correct operation.

Due to the physical structure of the High Voltage Switch inside the HVT, Filament 1 has two different states, each one depending upon the tube selected:

- Filament 1 is Small Focus when Tube 1 is selected.
- Filament 1 is Large Focus when Tube 2 is selected.

L1, L2 and L3 are inductances to preheat the two filaments (only used for Rad and Fluoro Generators).

3.15 KV DRIVE

KVDR1 and KVDR2 are signals coming from the PWM U19. *See illustration 18 for more information.* U19 modifies the duty cycle of the signals according to the Voltage while keeping a constant frequency of 25 KHz.

At the IPM Driver, these signals pass through a protective isolator (opto-coupler). The IPM driver also serves as a feedback point, isolating the fault detection signals which go to the HTC in case of an IGBT malfunction. The power supply for the embedded electronic components of the IGBT boards are also found at the IPM Driver, where the 115VAC is converted to 15V.

KVDR1 and KVDR2 pass through the 2 synchronized pairs of IGBTs and are then filtered by 5L1 and 5C9 to ensure a continuity in the current and ensure a proper voltage at the primary of the HV Transformer.

3.16 HV TRANSFORMER

The main functions of the HV Transformer are shown in illustration 20.

The required maximum voltage (Instantaneous Power) enters at the Primary as P1 and P3 from the Inverter and passes to the secondary where it will be proportional to the amount of voltage at the primary. The Voltage Doublers, whose outputs are placed in series, also function as AC to DC converters. Their maximum output, proportional to the maximum input, is -75 kV and +75kV.

This output is read by 2 pairs of resistors for +kV and -kV respectively which divide the voltage by a certain ratio. This reading is then communicated to the HT Controller as +KV FEEDBACK and -KV FEEDBACK. mA is equally read by two separate pairs of resistors which are designed to compensate both high and low levels of mA.

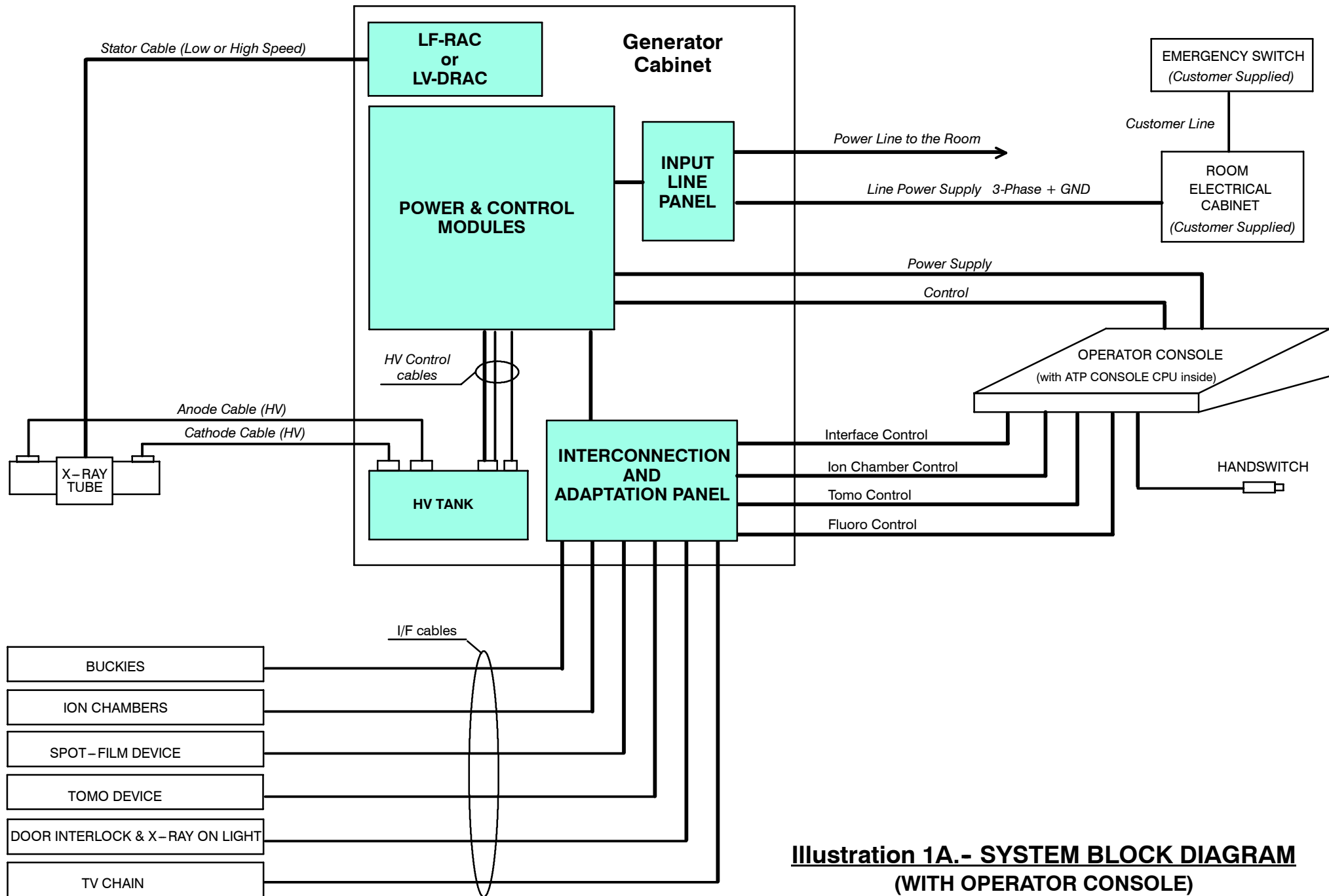
The Hi mA relay serves to close the Hi mA switches thus producing a ratio to compensate for high mA levels. This relay is controlled by the HT Controller according to the selected mA. Low mA is from 10 mA to 80. High mA is greater than or equal to 100 mA. The scale of compensation is reflected below:

Low 1 mA = 1 V (10 mA - 80 mA)

High 10 mA = 1V (greater than 100 mA)

SECTION 4 SCHEMATICS

1. System Block Diagrams
2. Generator Block Diagrams
3. Switch ON / OFF
4. Charge Circuitry
5. Switch ON Sequence
6. Serial Link
7. ATP Console CPU Block Diagram
8. APR Checking
9. Interrupt Controller
10. HT Controller Block Diagram
11. Preparation and Exposure Time Control
12. Filament Connection Block Diagram
13. Closed Loop Block Diagram
14. LF-RAC
15. LV-DRAC Block Diagram
16. LV-DRAC Brake
17. LV-DRAC Speed Control
18. Inverter Block Diagram
19. Tube Change for Generator with LF-RAC
20. HV Transformer



**Illustration 1A.- SYSTEM BLOCK DIAGRAM
(WITH OPERATOR CONSOLE)**

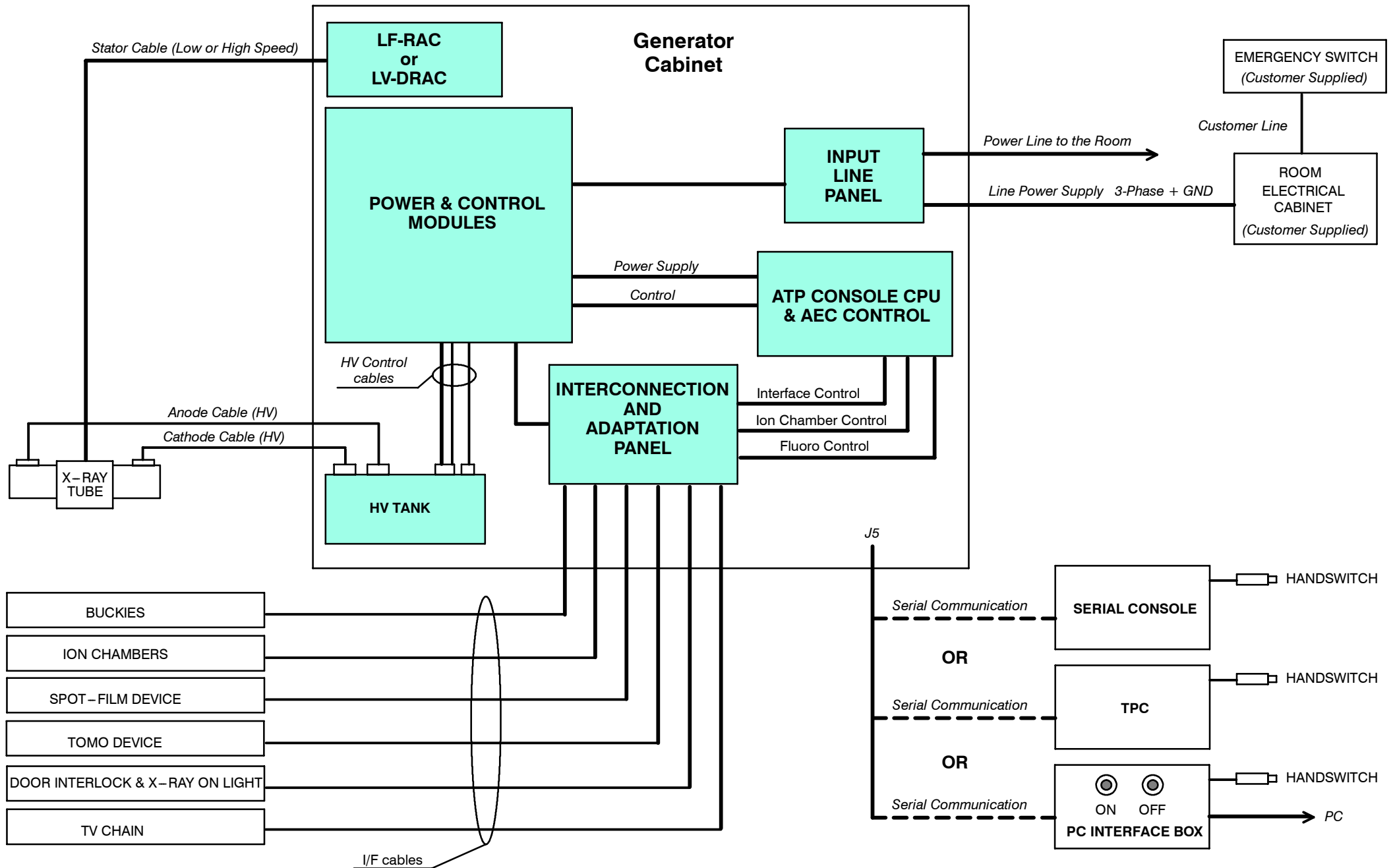


Illustration 1B.- SYSTEM BLOCK DIAGRAM (WITH SERIAL COMMUNICATION)

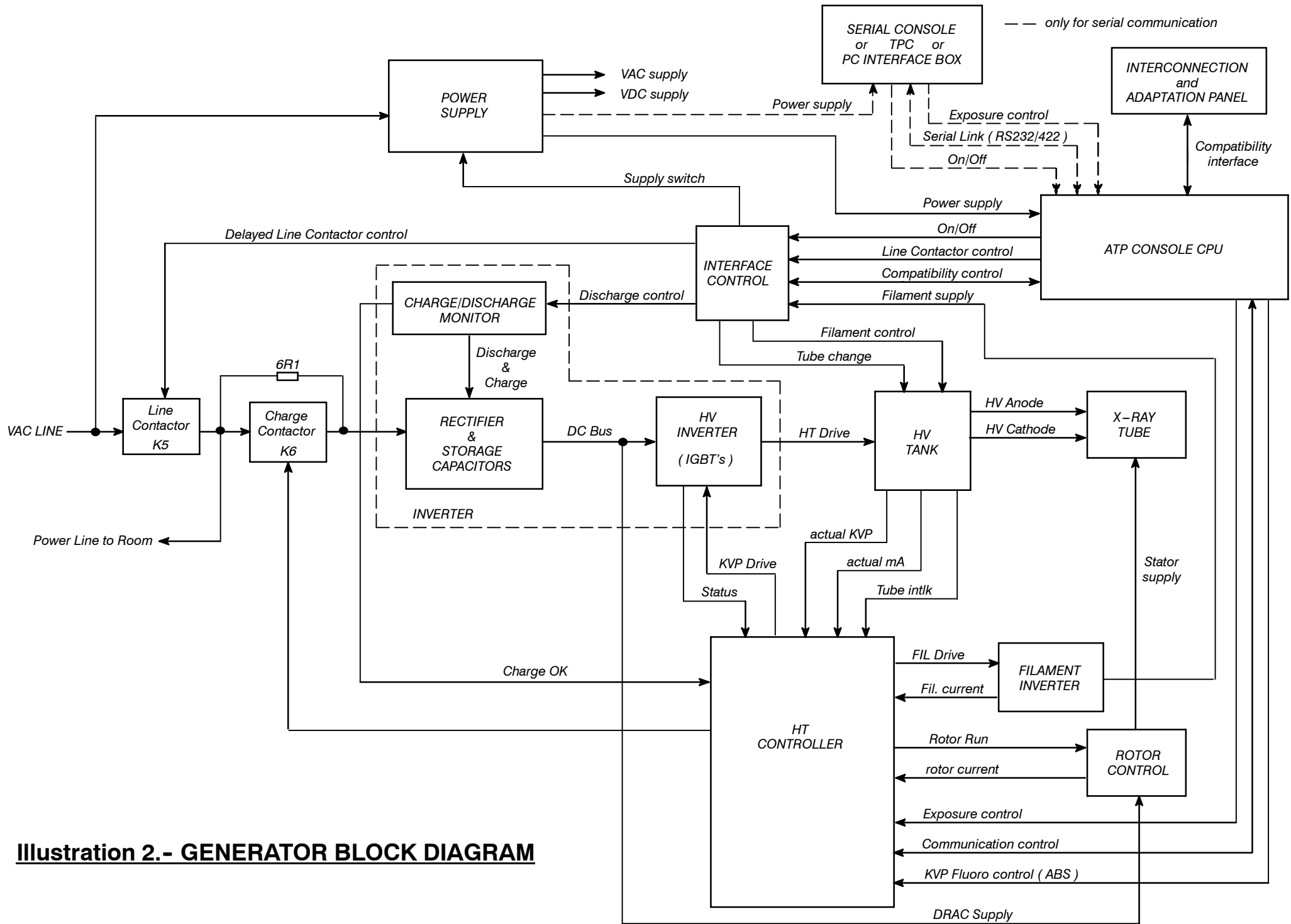


Illustration 2.- GENERATOR BLOCK DIAGRAM

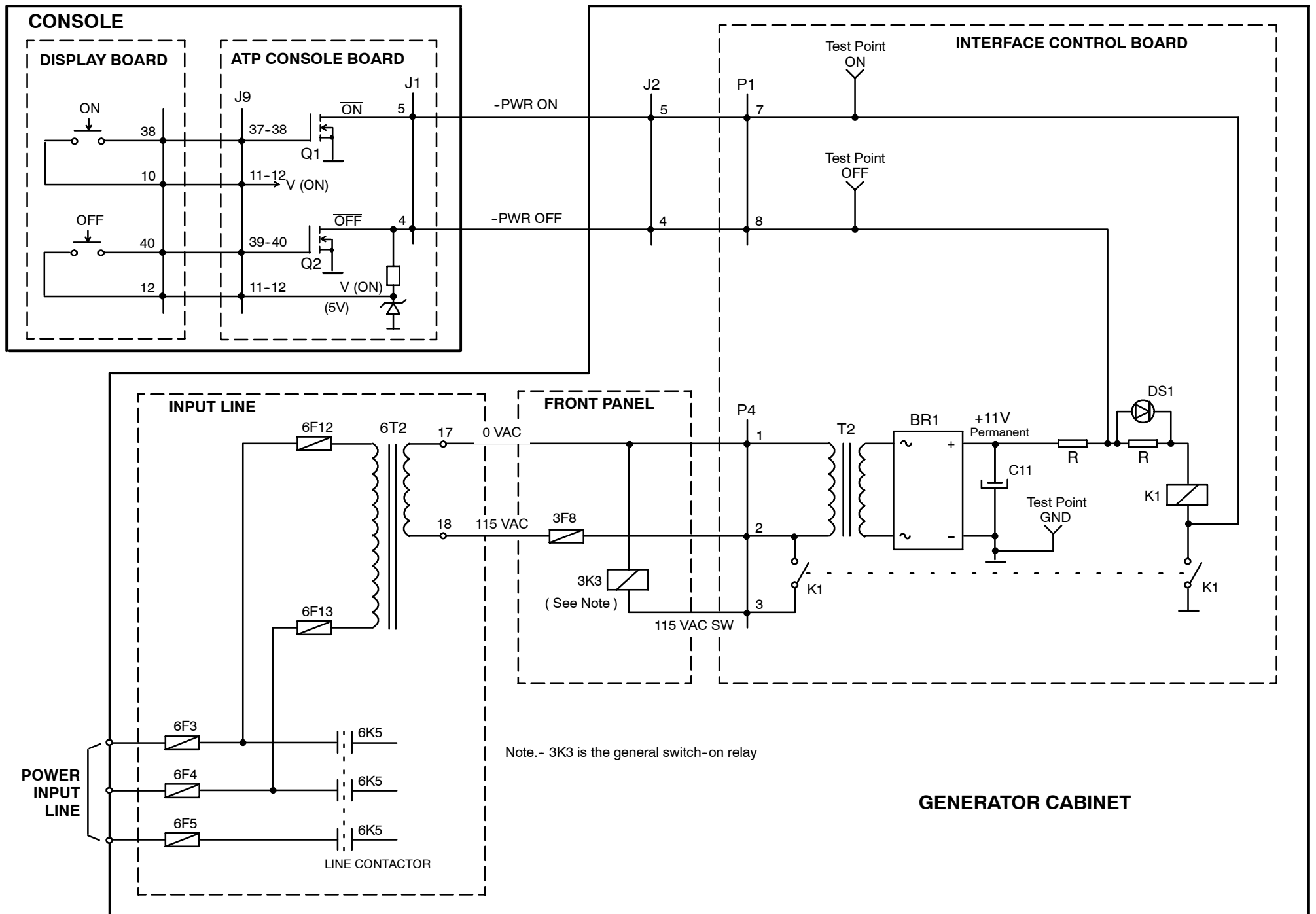


Illustration 3A.- SWITCH ON-OFF (WITH NON-SERIAL CONSOLE)

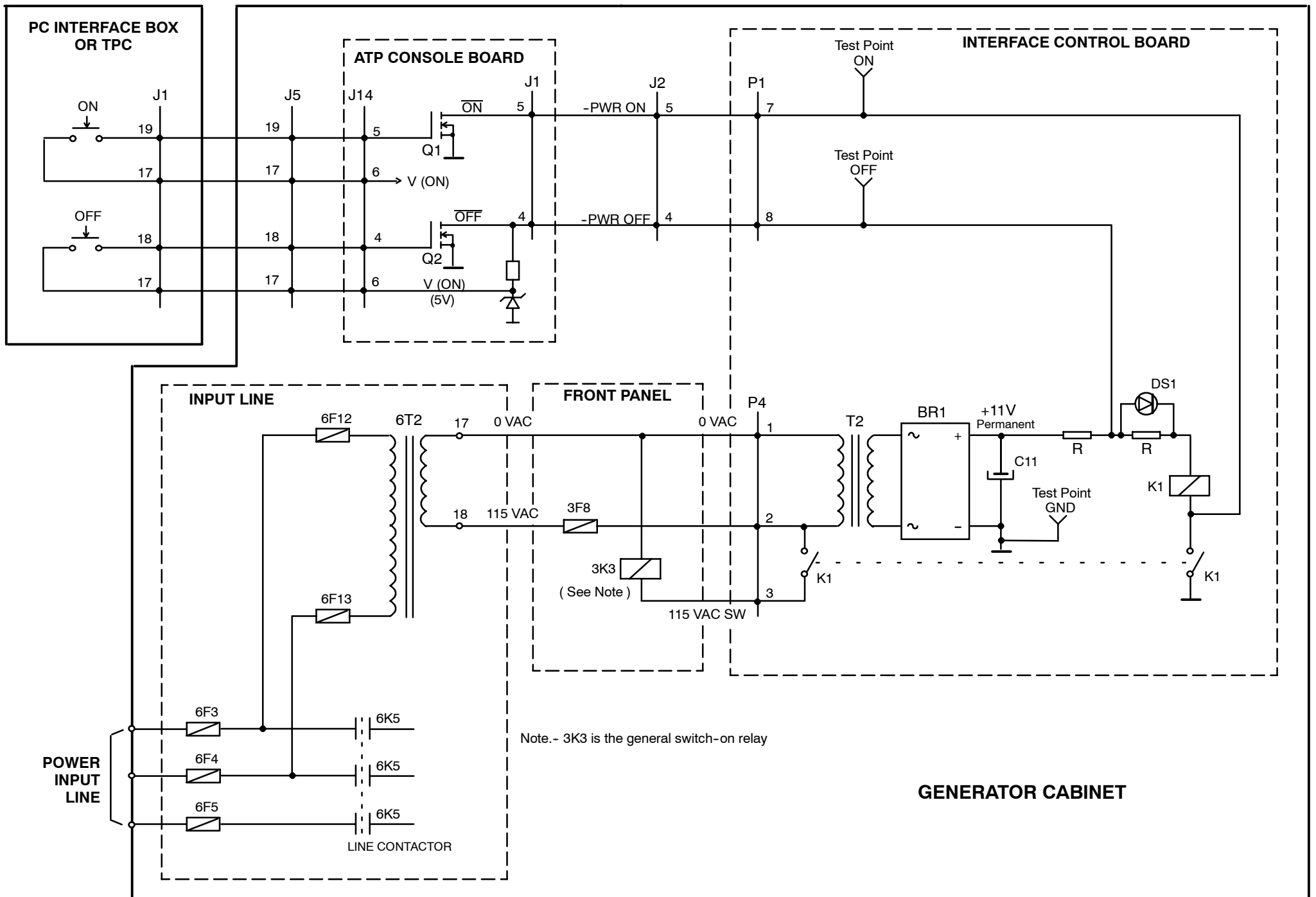


Illustration 3B.- SWITCH ON-OFF (WITH PC INTERFACE BOX / TPC)

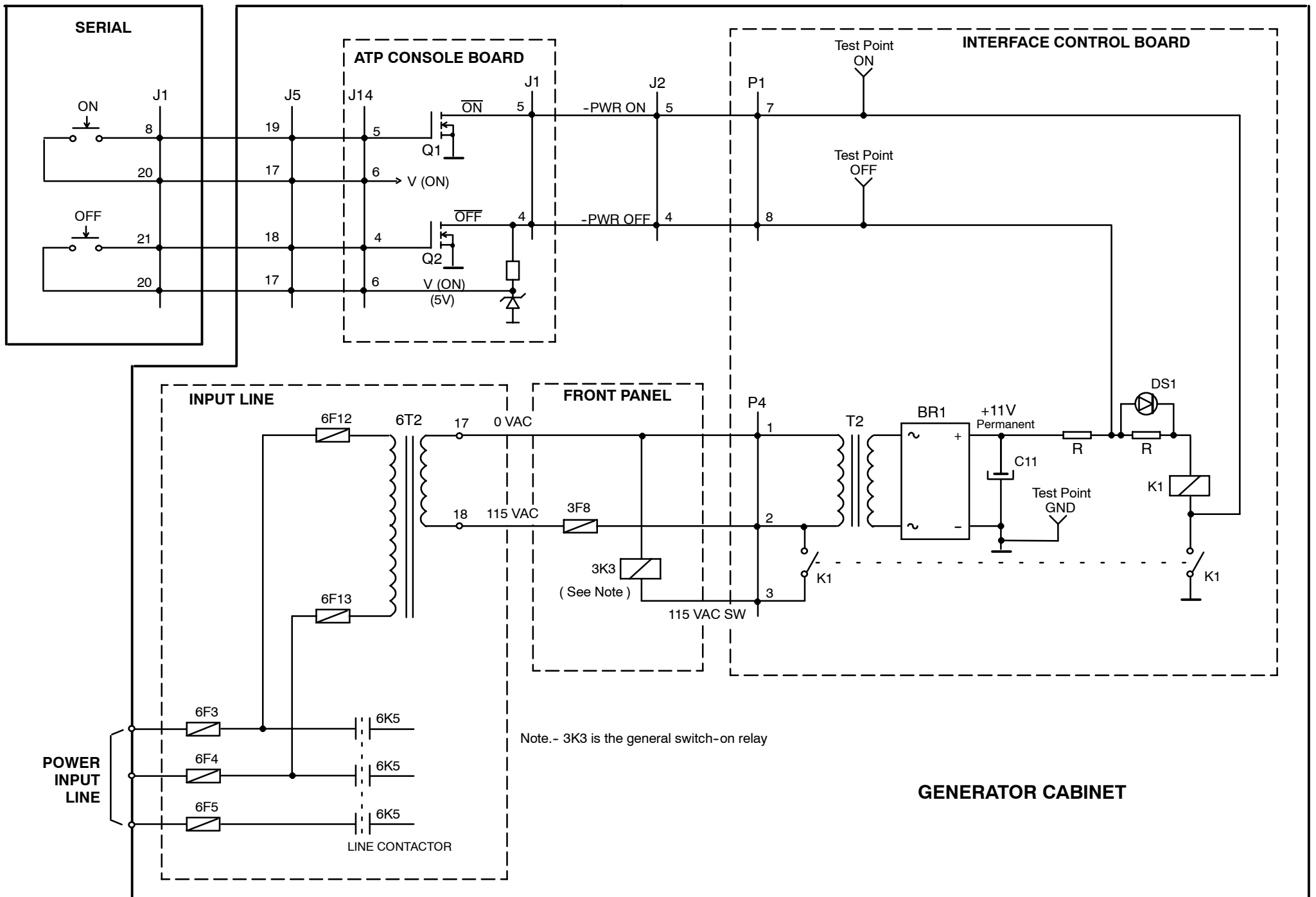


Illustration 3C.- SWITCH ON-OFF (WITH SERIAL CONSOLE)

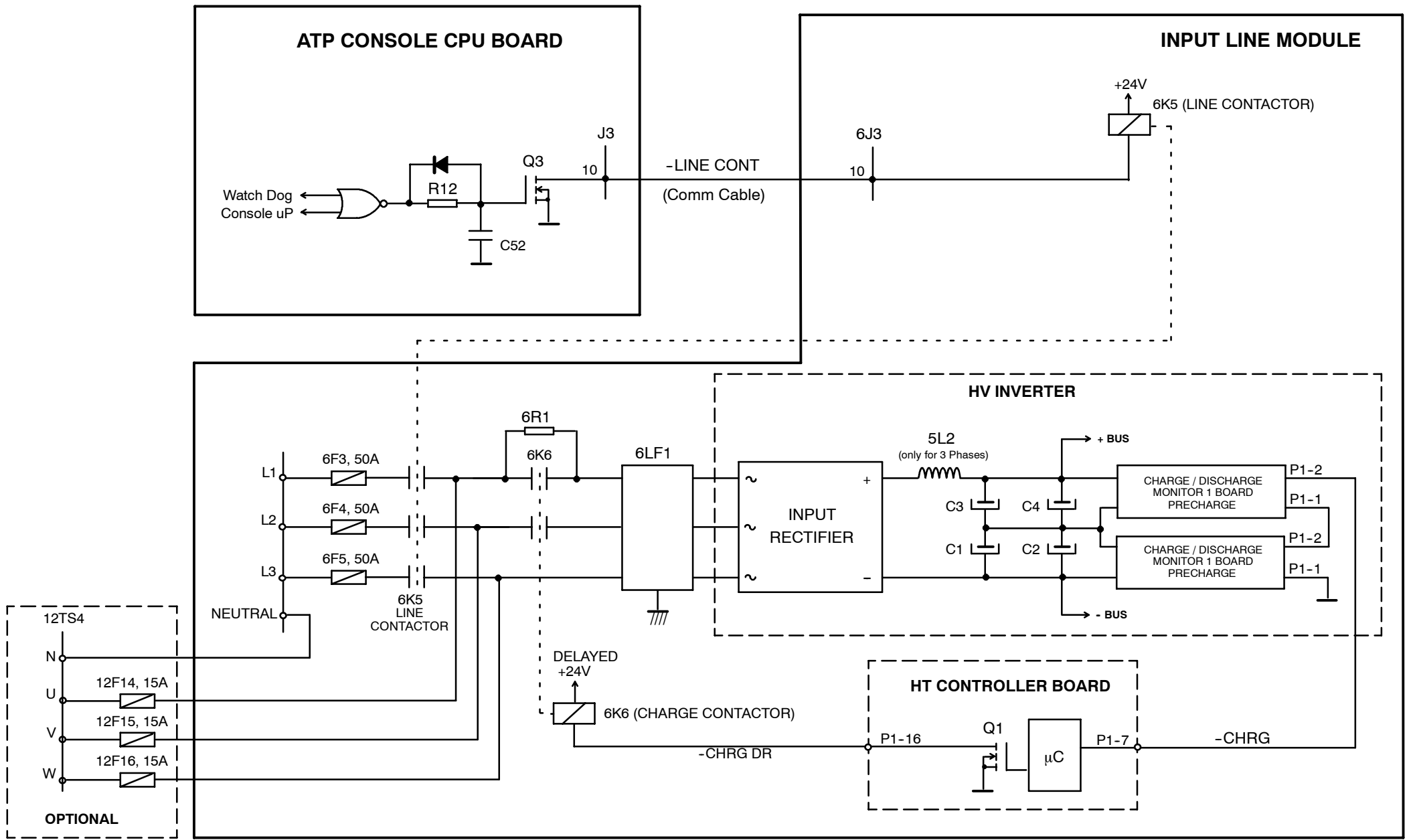


Illustration 4.- CHARGE CIRCUITRY

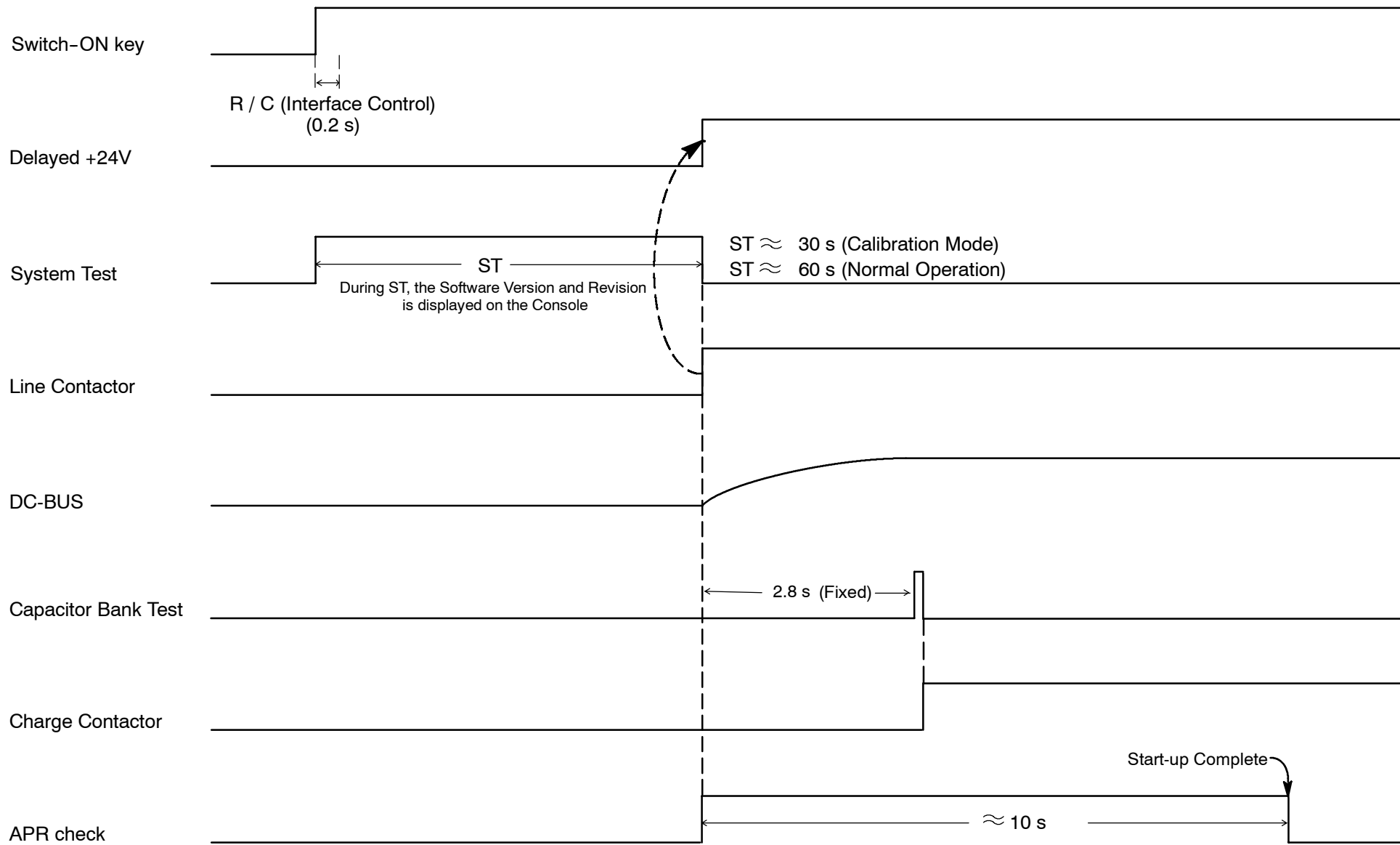


Illustration 5.- SWITCH-ON SEQUENCE

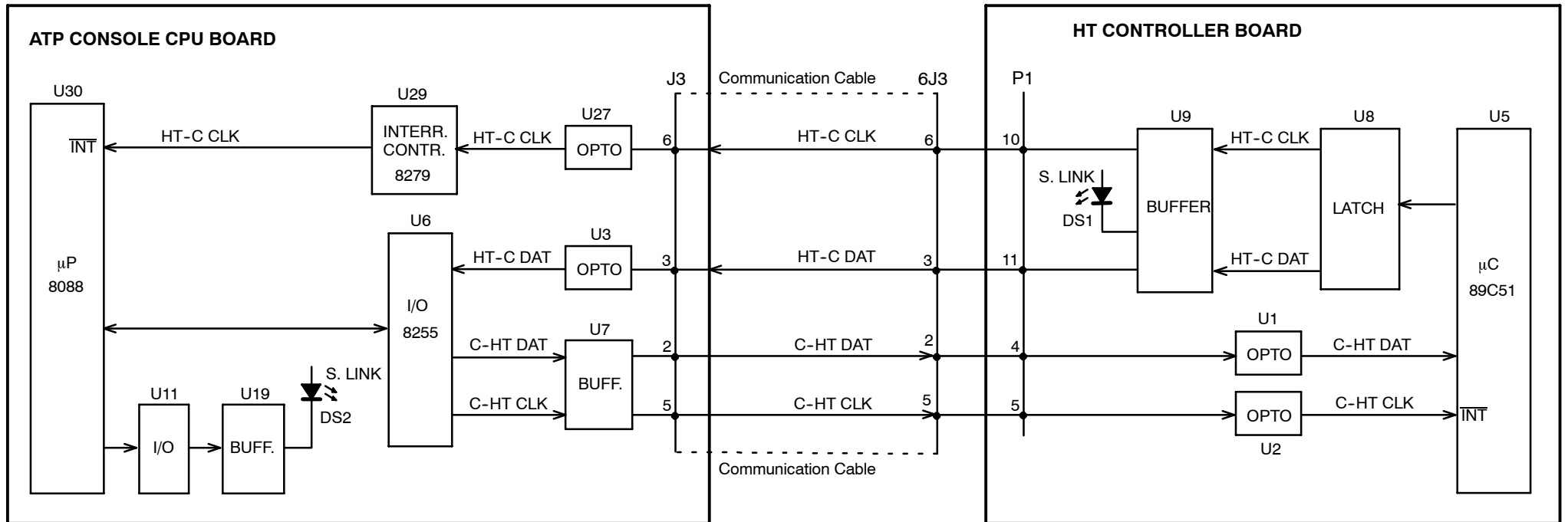


Illustration 6.- SERIAL LINK

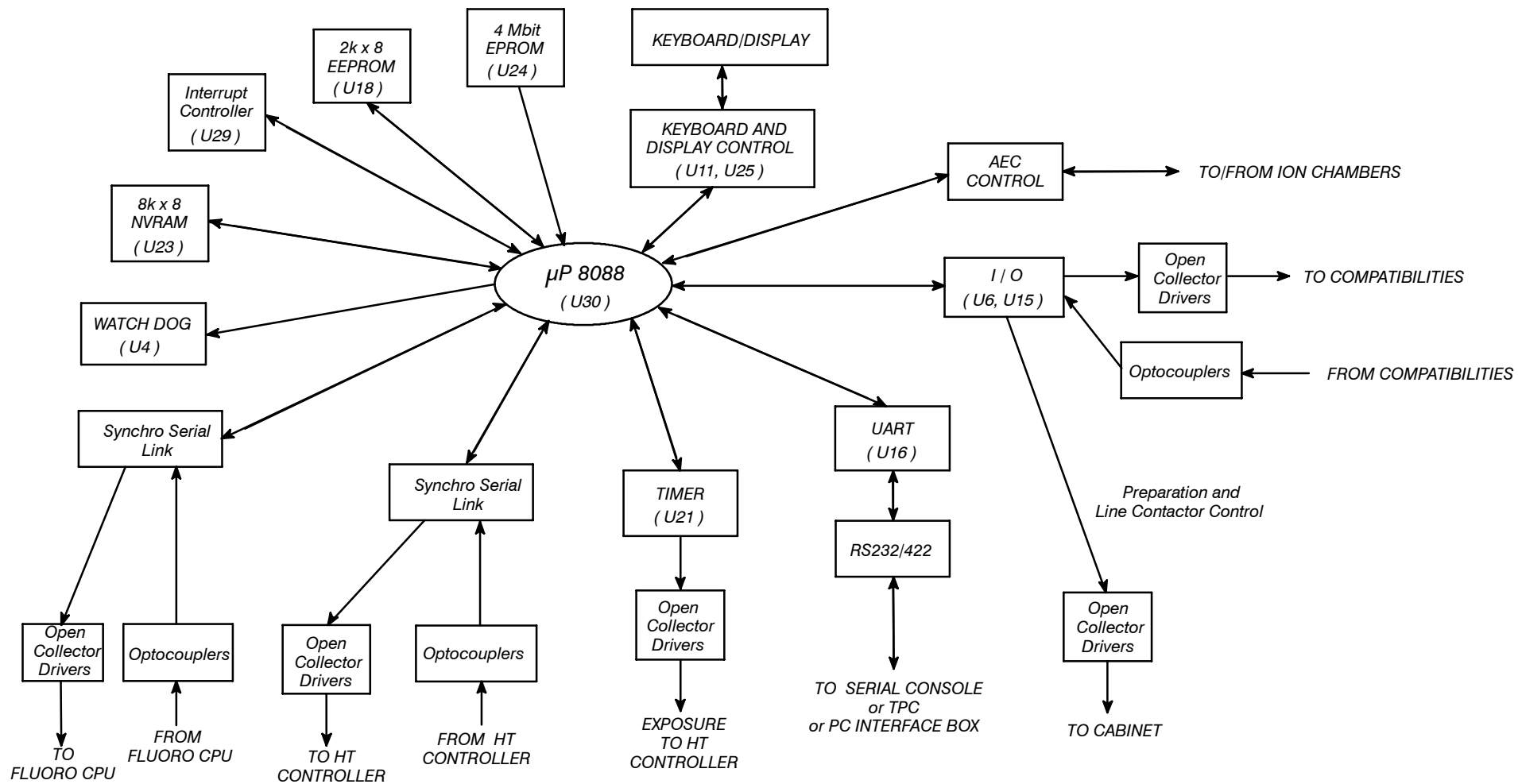


Illustration 7.- ATP CONSOLE CPU BLOCK DIAGRAM

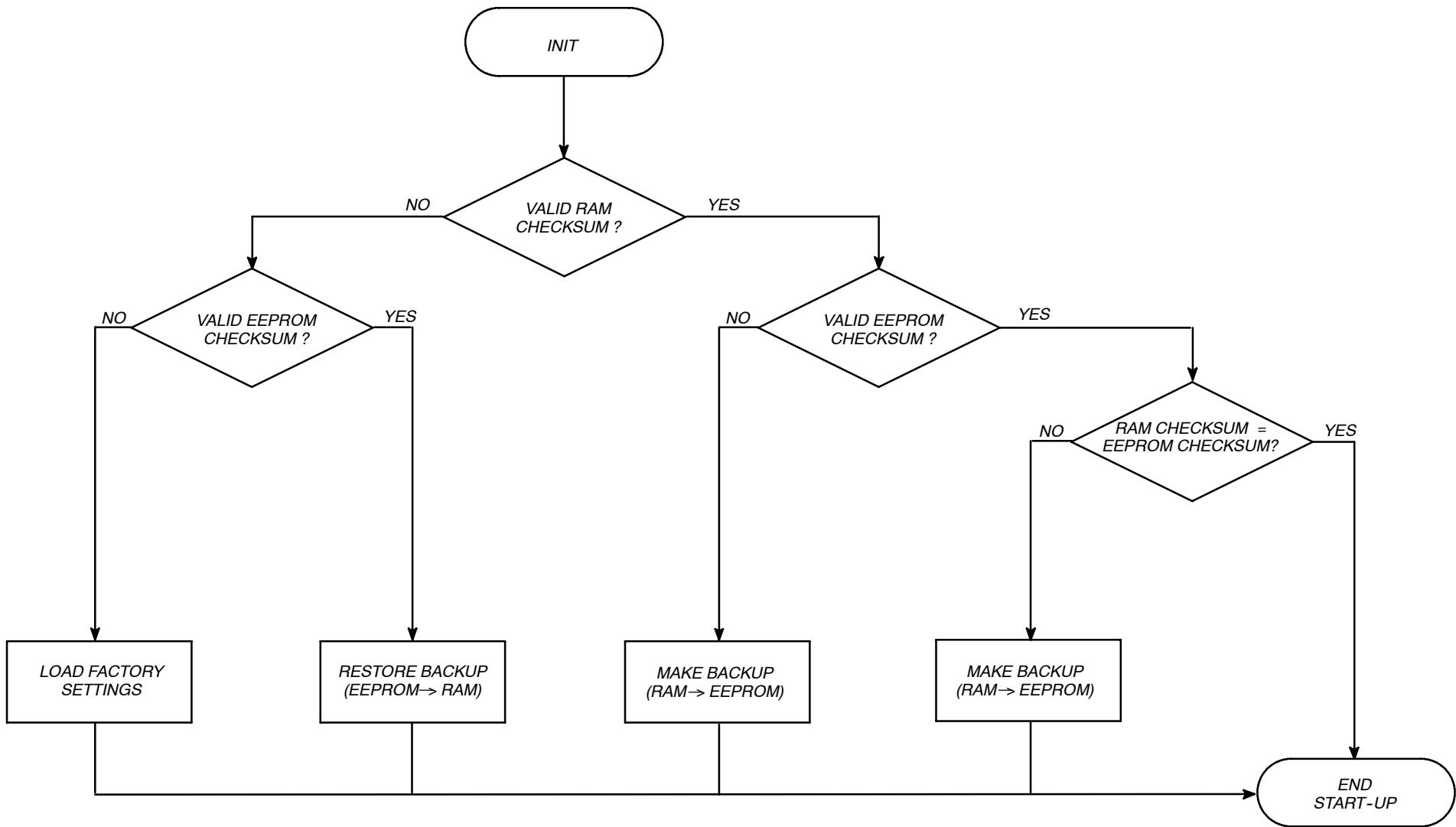


Illustration 8.- APR CHECKING

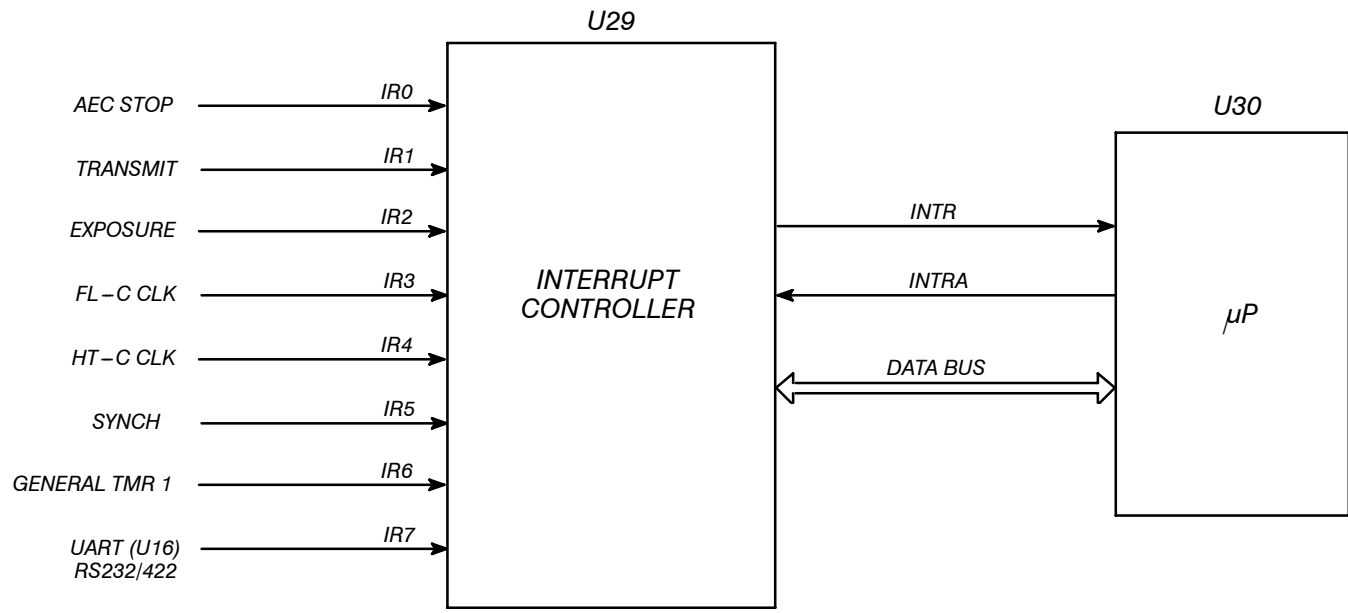


Illustration 9.- INTERRUPT CONTROLLER

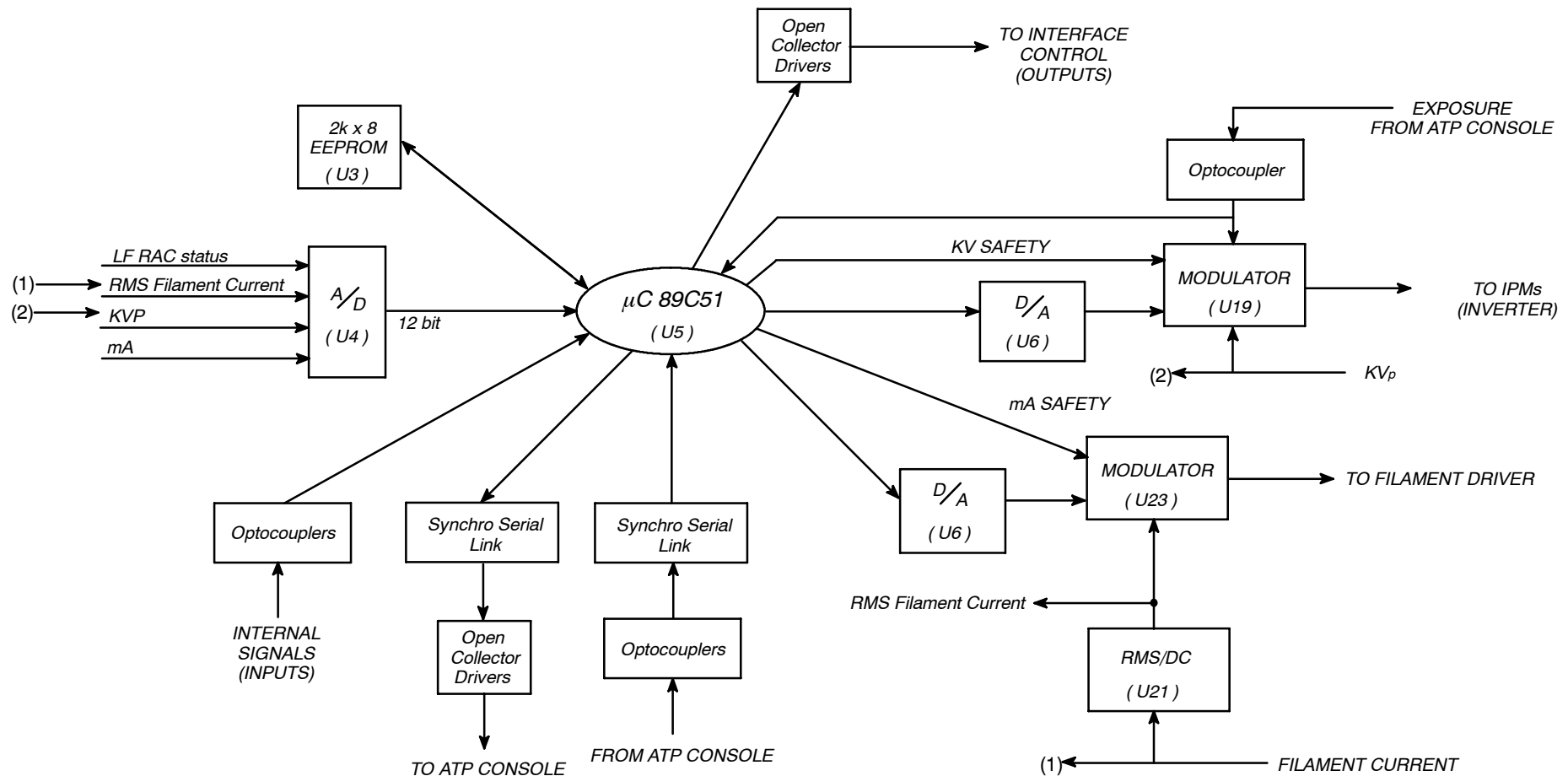


Illustration 10.- HT CONTROLLER BLOCK DIAGRAM

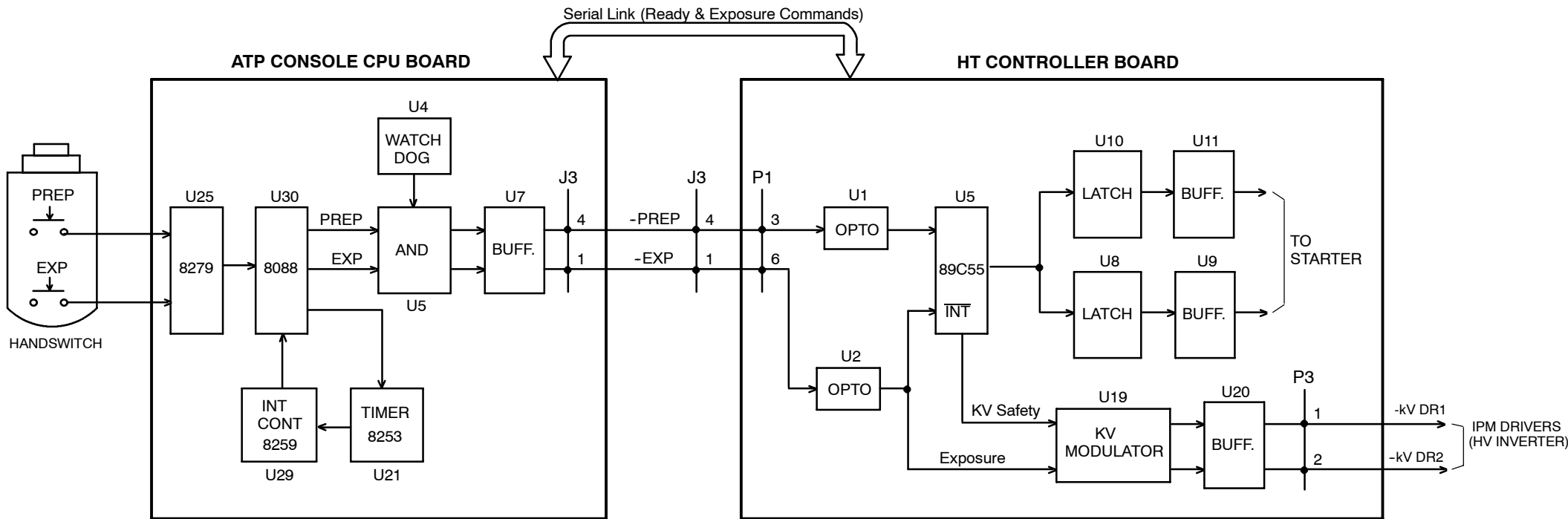
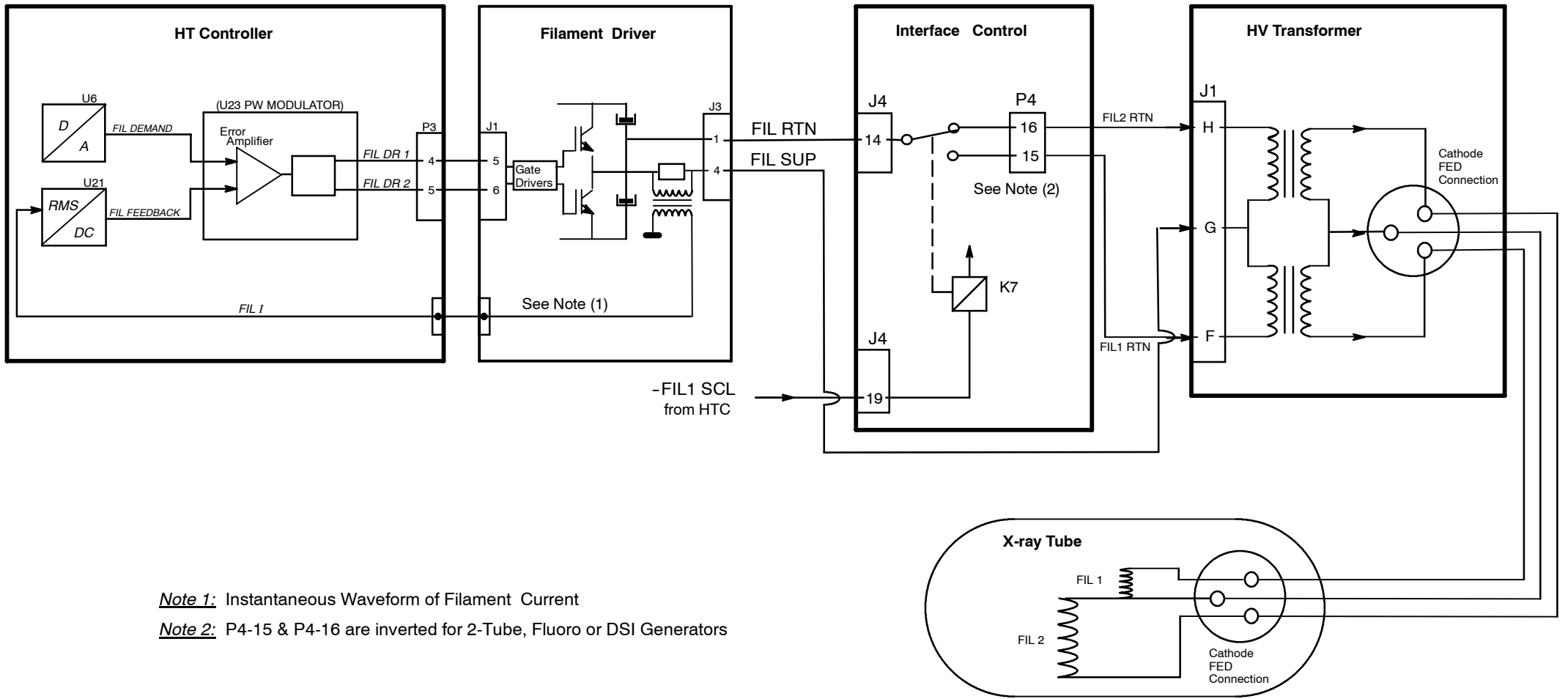


Illustration 11.- PREPARATION AND EXPOSURE TIME CONTROL



Note 1: Instantaneous Waveform of Filament Current

Note 2: P4-15 & P4-16 are inverted for 2-Tube, Fluoro or DSI Generators

Illustration 12.- FILAMENT CONNECTION BLOCK DIAGRAM

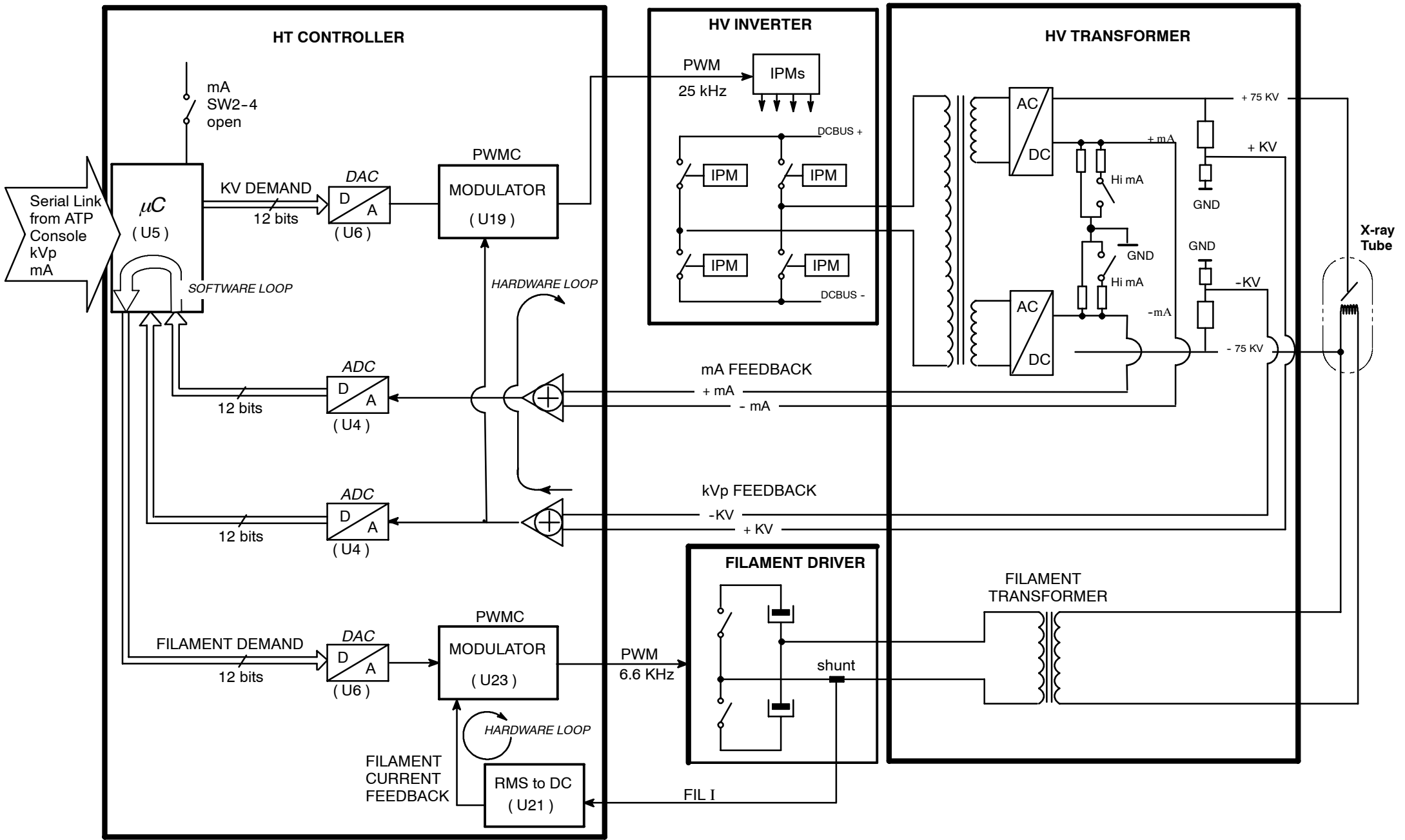


Illustration 13.- CLOSED LOOP BLOCK DIAGRAM

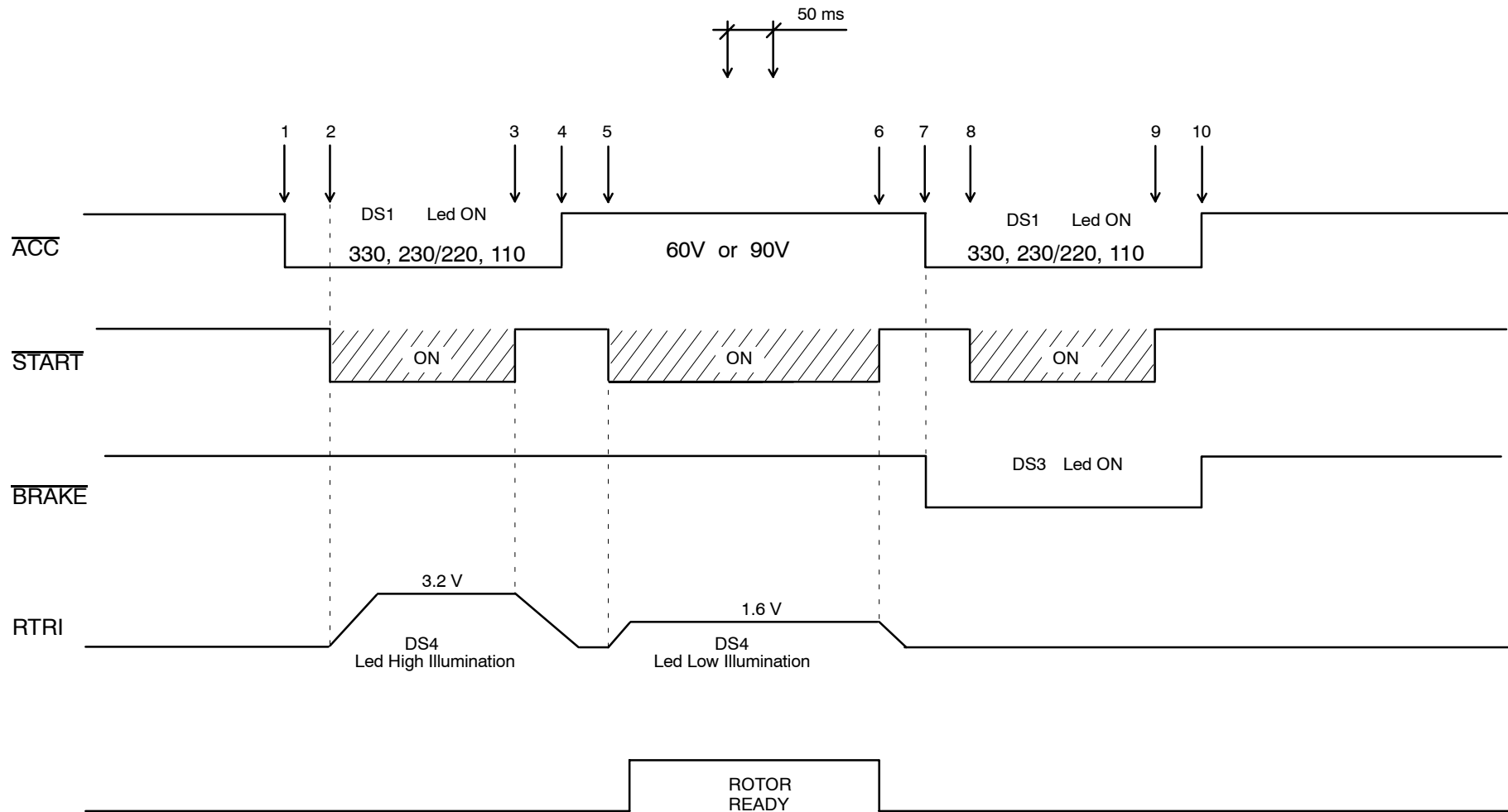


Illustration 14.- LF-RAC

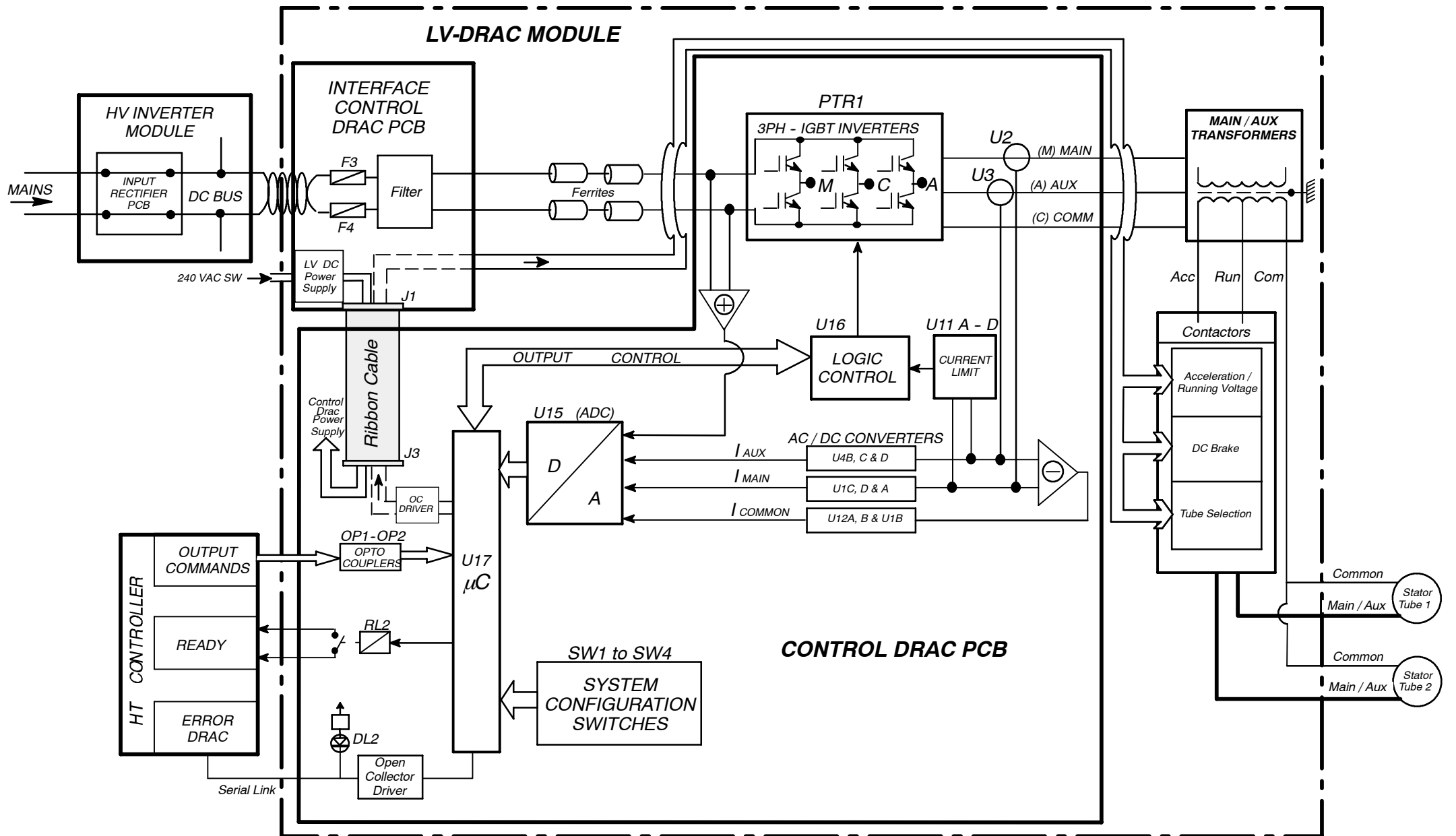
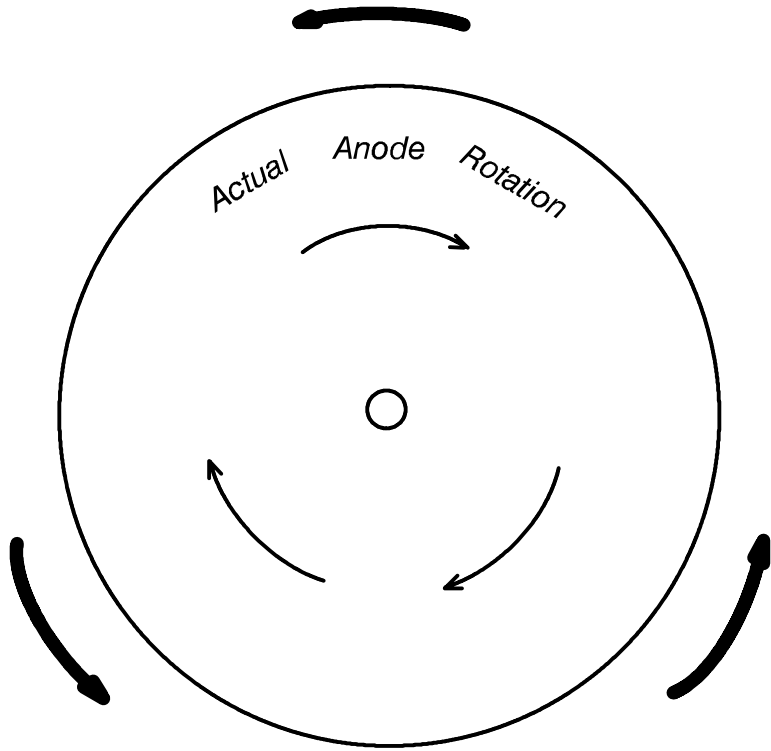
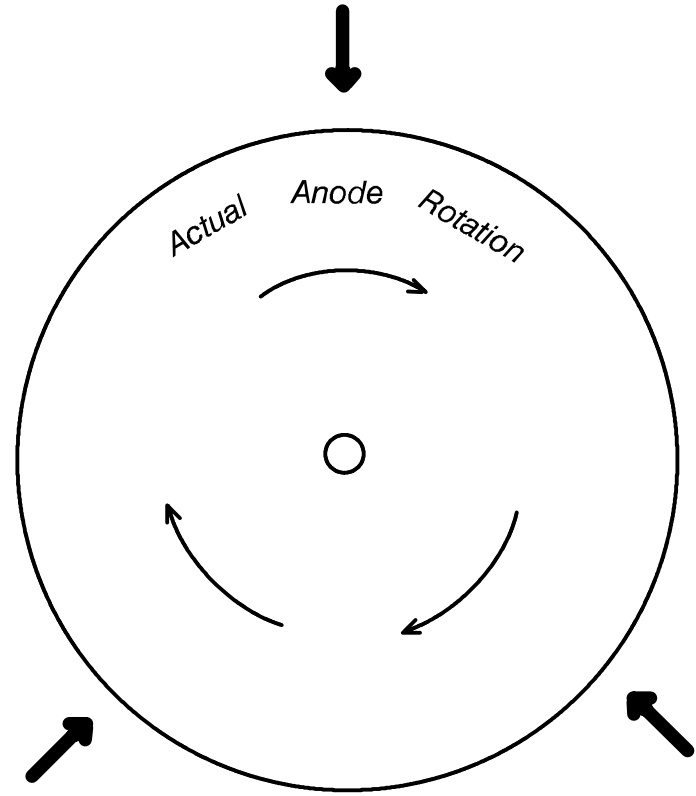


Illustration 15.- LV-DRAC Module Block Diagram



Active Brake

(Reverse Electromagnetic Field)



Passive Brake

(DC Brake)

Illustration 16.- LV-DRAC BRAKE

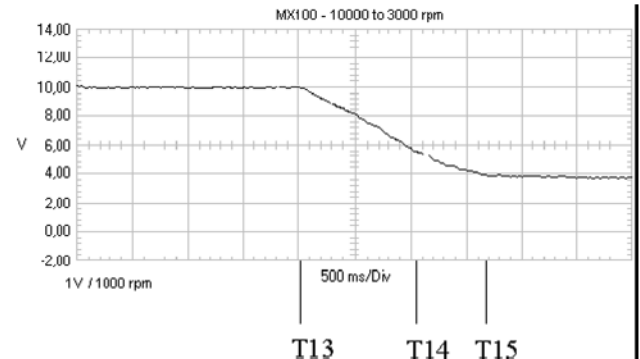
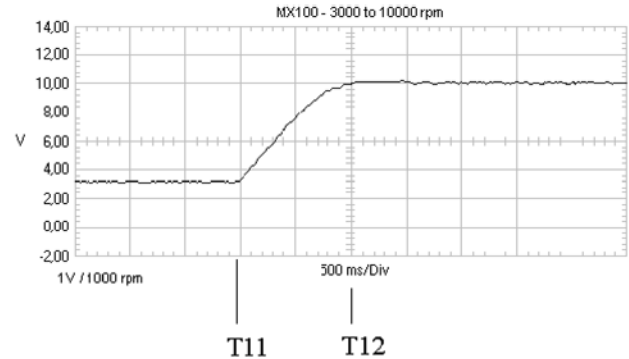
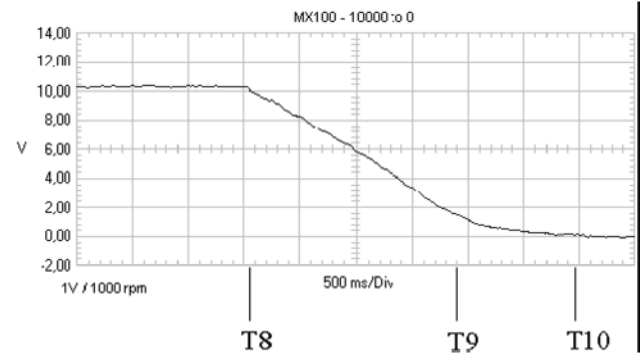
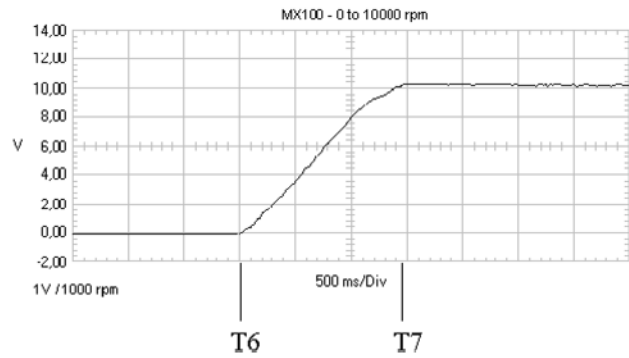
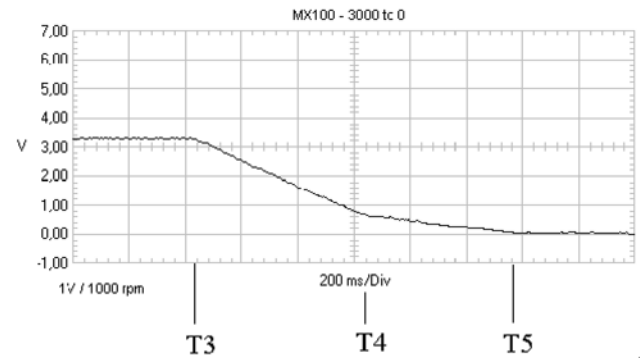
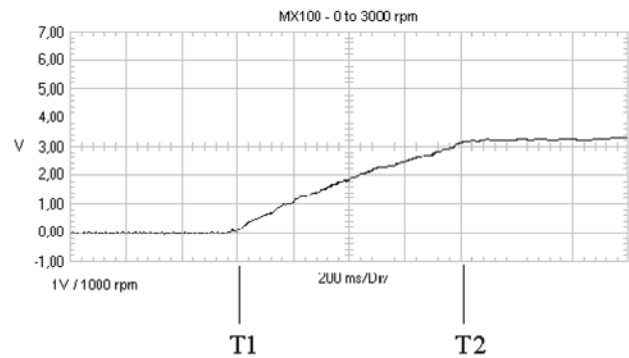


Illustration 17.- LV-DRAC SPEED CONTROL

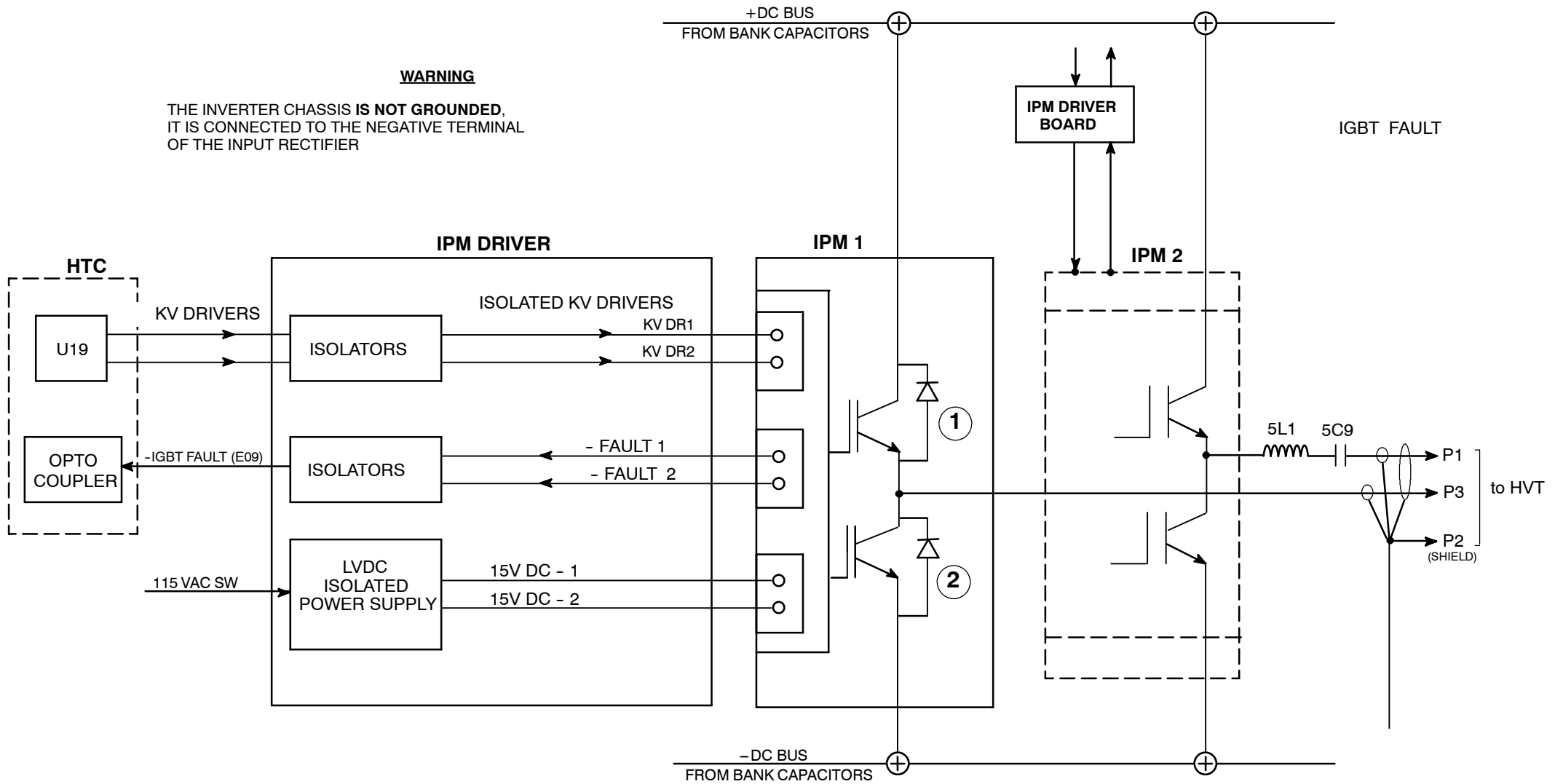
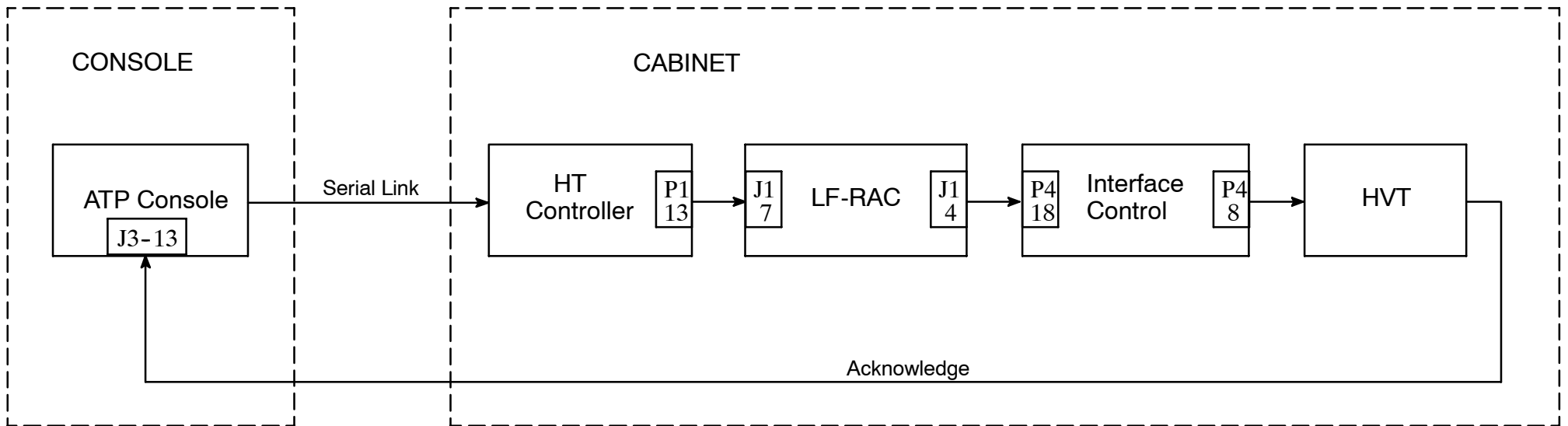


Illustration 18.- INVERTER BLOCK DIAGRAM



Note: For Vertical Generators

Illustration 19.- TUBE CHANGE FOR GENERATOR WITH LF-RAC

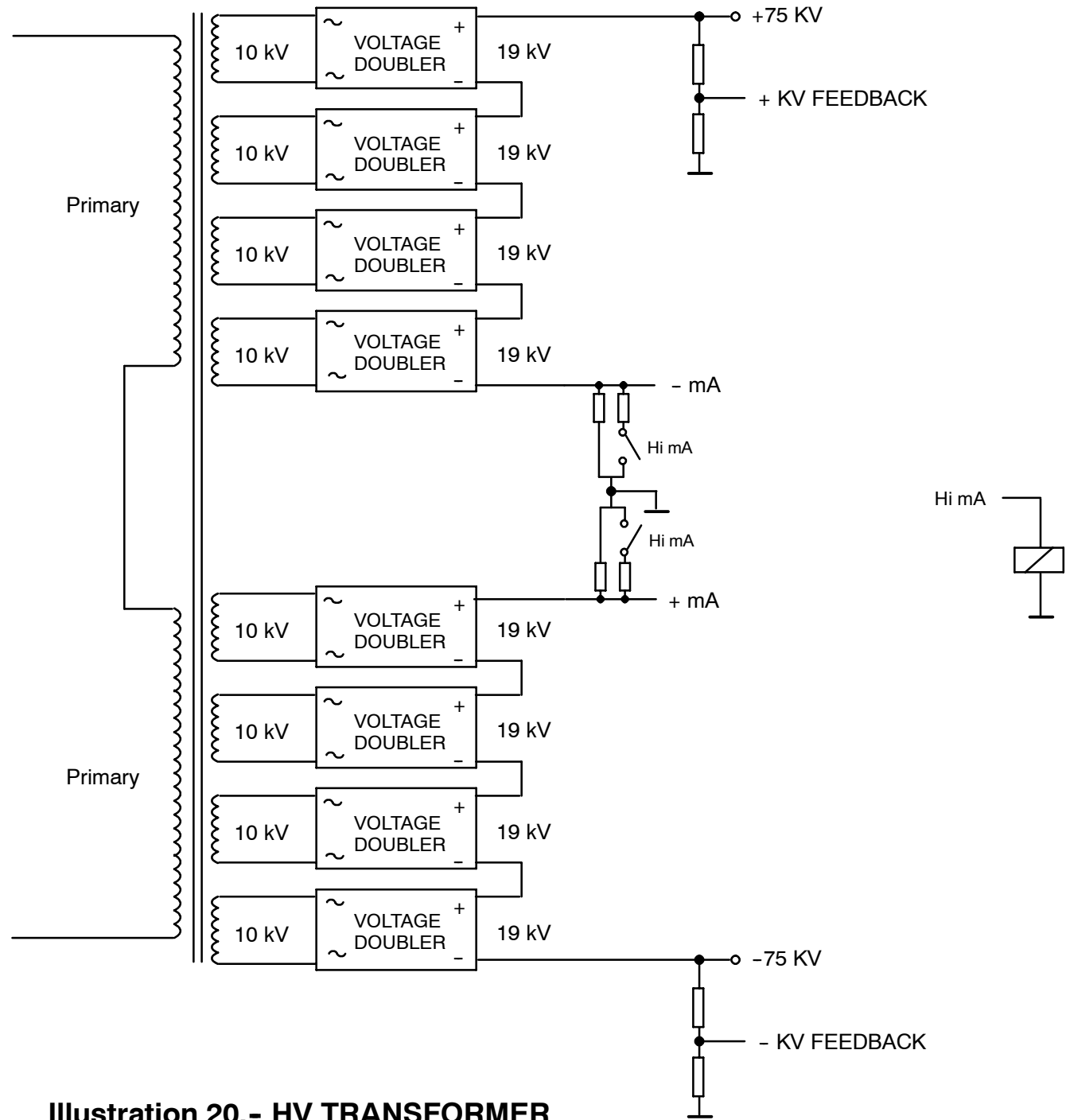


Illustration 20.- HV TRANSFORMER