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10.1 REACTOR PROTECTION SYSTEM

Learning Objectives:

1. State the purpose of the reactor protection system (RPS).
2. Define the term anticipated operational occurrence (AOO).
3. Explain how the following design features are incorporated into the RPS:
   a. Single Failure Criterion
   b. Testability
   c. Redundancy
4. Explain the purpose of each reactor trip.
5. Explain how the two-out-of-four RPS trip logic is derived.
6. Explain the reactor trip circuit breaker (RTB) trip logic.
7. Explain the effect of placing a RPS trip in trip inhibit.
8. List the trips that are automatically bypassed.
9. List the trips that are bypassed by the zero power mode bypass.
10. State the devices that are actuated by the diverse scram system (DSS).

10.1.1 Introduction

The purpose of the RPS is to insure that plant safety limits are not violated during AOOs. The plant safety limits are departure from nucleate boiling (DNB), peak linear heat rate (LHR), and reactor coolant system (RCS) pressure. The first two limits protect the cladding boundary and the last limit protects the RCS boundary. AOOs are defined as those conditions which are expected to occur one or more times during the life of the nuclear power unit. Examples of AOOs are turbine trips, loss of condenser vacuum, and a complete loss of offsite power.

The RPS consists of four separate channels with each of the channels receiving independent safety related input parameters. If any two of the four channels sense that a parameter is at set point, a reactor trip will result.

The two-out-of-four reactor trip logic combined with the four separate inputs provide RPS redundancy and reliability. If only one transmitter input system were used and the transmitter failed in a non-conservative direction, then the RPS would not trip the reactor.

The use of a two-out-of-four system using four separate input channels as opposed to using two separate input channels and a one-out-of-two trip logic improves the ability of the RPS to generate a reactor trip signal. In a one-out-of-two system, however, if an input signal fails in the conservative direction an unnecessary reactor trip will result. Also, during testing of a one-out-of-two system, the RPS is reduced to a one sensor system. The next logical step would be the addition of a third channel and a third sensor. If a two-out-of-three logic is used in this system, a signal failure in either the conservative or non-conservative direction will neither generate an unnecessary reactor trip nor prevent a needed trip.

As stated above, a two-out-of-three system will satisfy the requirement of safety function operability even in the event of a single failure. However, a two-out-of-three system loses some of its desirable characteristics during testing. To test a two-out-of-three system, the channel to be tested is placed in a tripped condition. Tripping a channel reduces the RPS to a one-out-of-two logic.

An additional channel and a two-out-of-four trip logic will have all the desirable features of a three channel system. One channel may be bypassed (instead of tripped) for testing or maintenance. In this condition, the RPS functions as a two-out-of-three system.

To insure safety limit protection, the RPS must fail to a safe condition upon a loss of power. To meet this requirement, the RPS is designed as a de-energize to actuate system. If RPS power is lost, a reactor trip will result. The RPS is powered from four separate 120 Vac inverter supplied buses.

10.1.2 Purposes of Reactor Trips

10.1.2.1 Variable Overpower Trip (VOPT)

The VOPT provides core protection against positive reactivity excursions that are too rapid for high pressurizer pressure or the thermal margin low pressure (TMLP) trip to protect against. The following events require variable overpower protection:

1. Uncontrolled CEA withdrawal event,
2. Excess load (excess heat removal by the secondary),
3. Excess feedwater heat removal event,
4. CEA ejection event and
5. Main steam line break outside of containment.

The first three events are AOOs, and fuel integrity is maintained. The fourth and fifth are accidents and limited fuel damage may occur.

The VOPT ensures that the Departure from Nucleate Boiling Ratio (DNBR), linear heat rate (kW/ft) and RCS pressure safety limits are maintained during normal operation and AOOs. In conjunction with the engineered safety features actuation system (ESFAS) the consequences of the main steam line break accident and the CEA ejection accidents will be acceptable.

10.1.2.2 High Start-up Rate

The high start-up rate trip is used to trip the reactor when wide range logarithmic power indicates an excessive rate of change. The high start-up rate trip provides a backup to the VOPT to ensure that the DNBR, kW/ft, and RCS pressure safety limits are maintained during start-up conditions. The high start-up rate trip minimizes transients for events such as a continuous CEA withdrawal or a boron dilution event from low power levels.

10.1.2.3 Low RCS Flow

The low RCS flow trip provides protection during the following events:

1. Loss of RCS flow,
2. Loss of non-vital ac power,
3. Reactor coolant pump (RCP) seized shaft and
4. RCP sheared shaft.

The loss of RCS flow and the loss of non-vital ac power are AOOs, and the DNBR safety limit is maintained. The seized RCP shaft and the sheared shaft are accidents that may result in fuel damage.

10.1.2.4 Thermal Margin Low Pressure (TMLP)

The TMLP trip prevents exceeding the DNBR safety limit during AOOs and aids the ESFAS during certain accidents.

The following events require TMLP protection:

1. Excess load (inadvertent opening of an atmospheric steam dump valve),
2. RCS depressurization (inadvertent opening of the spray, power operated relief valves, or pressurizer safety valves),
3. Steam generator tube rupture and
4. Loss of coolant accident.

The first two events are AOOs, and DNBR is maintained. The third and four th events are accidents, and limited fuel damage may occur.

10.1.2.5 Local Power Density (LPD)

The LPD trip ensures that axial peaking, such as that due to axial xenon oscillations, will not cause fuel damage. It ensures that neither a DNBR less than the safety limit nor a peak kW/ft which corresponds to the temperature for centerline fuel melting will occur. This trip is the primary protection against fuel centerline melting.

10.1.2.6 High Pressurizer Pressure

The high pressurizer pressure trip, in conjunction with the pressurizer and main steam safety valves, provides protection against over pressure conditions in the RCS during the following events:

1. Loss of condenser vacuum with a concurrent loss of offsite power,
2. Turbine trip from 102% power,
3. Feedwater system breaks between the steam generator and feedwater inlet check valve,
4. CEA withdrawal and
5. Loss of feedwater flow.

The high pressurizer pressure trip assures that the RCS pressure limit will not be exceeded during AOOs, and in conjunction with the ESFAS, that the consequences of accidents will be acceptable.

10.1.2.7 Low Steam Generator Level

The low steam generator water level trip is required for the following events to help prevent exceeding the RCS design pressure due to a loss of heat sink:

1. Steam system piping failures,
2. Feedwater system pipe breaks,
3. Inadvertent opening of a steam generator atmospheric dump valve,
4. Loss of normal feedwater and
5. Asymmetric loss of feedwater.

The low steam generator water level trip ensures that the DNBR, kW/ft, and RCS pressure safety limits are maintained during normal operations and AOOs and, in conjunction with the ESFAS, the consequences of the steam and feedwater pipe break accidents will be acceptable.

10.1.2.8 Low Steam Generator Pressure

The low steam generator pressure trip provides protection against an excessive rate of heat extraction from the steam generators, which would result in a rapid uncontrolled cool down of the RCS. This trip is needed to shutdown the reactor and assist the ESFAS in the event of a main steam line break.

10.1.2.9 High Containment Pressure

The high containment pressure trip prevents exceeding the containment design pressure following certain loss of coolant accidents, steam line breaks, or feedwater line breaks. It assures a reactor trip prior to, or in conjunction with, accidents, thus assisting the ESFAS.

10.1.2.10 Loss of Load

The loss of load trip is anticipatory for the loss of heat removal capacities of the secondary system following a turbine trip. The loss of load trip prevents lifting of the pressurizer safety valves, PORVs, and the steam safety valves in the event of a turbine generator trip. Thus the trip minimizes the large upsets in RCS pressure and temperature by shutting down the reactor well before the high pressurizer trip set point is reached. Table 10.1-1 summarizes the purposes of all reactor trips.

10.1.3 System Description

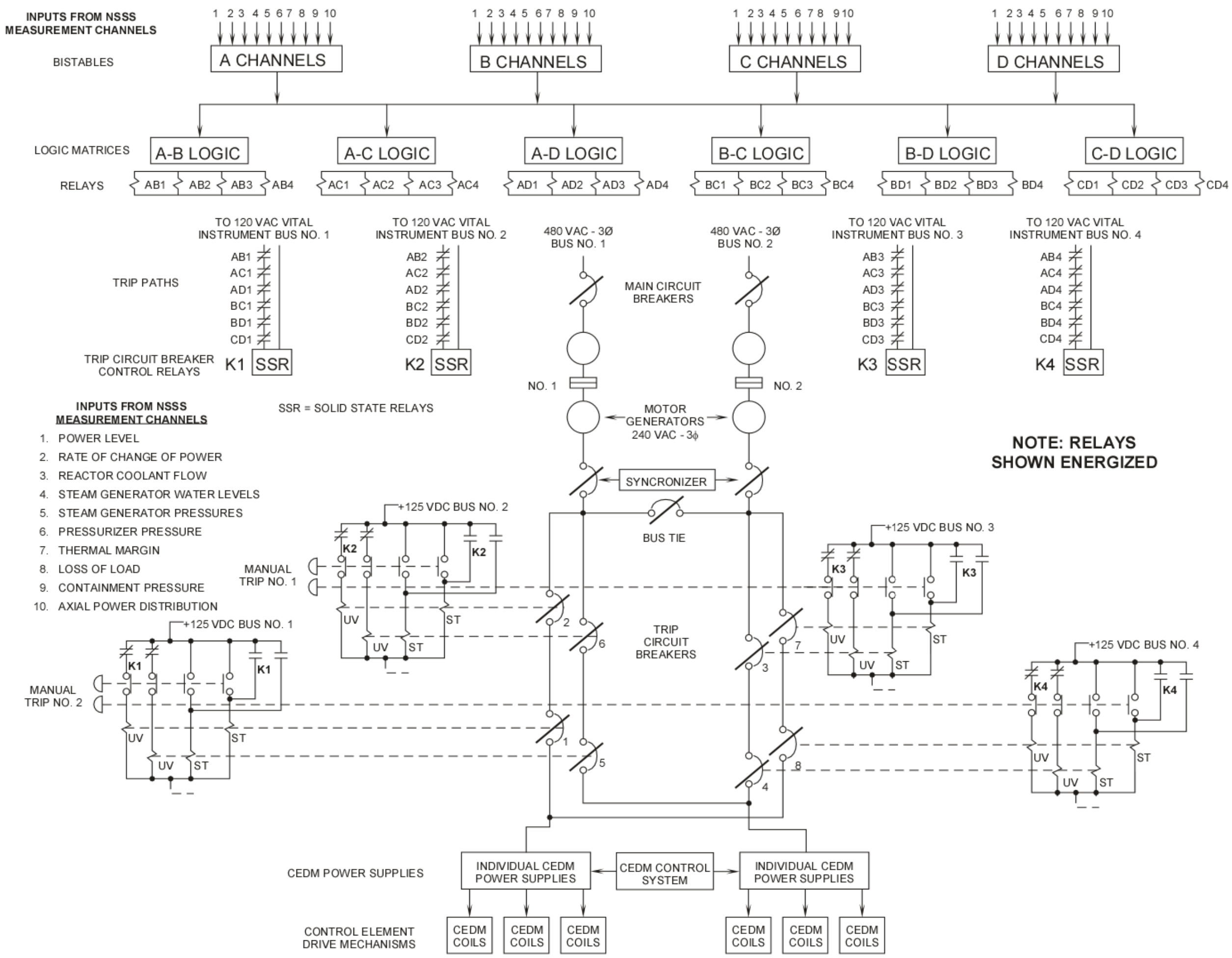


Figure 10.1-1 Simplified Reactor Protection System

As shown in Figure 10.1-1, each RPS channel receives independent inputs of safety related parameters. In each channel, the input signal is compared with its appropriate set point in a bistable. If the parameter is at set point, the bistable de-energizes. When the bistable de-energizes, a signal (in the form of an open relay contact) is sent to the logic matrices. Six logic matrices are required to account for all possible combinations of two-out-of-four channels (AB, AC, AD, BC, BD, and CD).

The logic matrix decides if the two-out-of-four logic for any input parameter is satisfied and, if so, de-energizes its logic matrix relays. When the logic matrix relays de-energize, series contacts in the power supply to the RTB control relays open, resulting in the relays de-energizing.

Two events occur when the RTB control relays de-energize. First, contacts in the RTB’s under voltage (UV) coil open, de-energizing the UV coil and opening the RTB. Second, contacts in the RTB's shunt trip coil close, energizing the shunt trip coil. When the shunt trip energizes, the RTB opens. This action is redundant to the opening of the breaker by the under-voltage coil. When the RTBs open, the coils of the CEA magnetic jack de-energize and the CEAs shutdown the reactor.

A few points should be added to the above discussion. First, the two-out-of-four logic must exist for the same input parameter before a reactor trip will occur. The term coincidence is used to describe this feature. For example, at least two pressurizer pressure transmitters must sense that pressurizer pressure is at or below set point before a reactor trip will occur. One low pressurizer pressure input combined with any other input parameter reaching set point will not trip the reactor. Next, each RTB control relay controls two RTBs. Control relay K1 controls breakers 1 and 5, control relay K2 controls breakers 2 and 6, control relay K3 controls breakers 3 and 7, and control relay K4 control relay controls breakers 4 and 8. Finally, as a minimum, one pair of circuit breakers in each of the supplies must open to de-energize all CEAs. This is called a one-out-of-two logic taken twice.

10.1.4 Component Description

10.1.4.1 Reactor Protection System Sensors

Criterion 24 of 10 CFR 50 requires separation between protection and control systems to prevent a control system failure from affecting the operability of the RPS. Combustion Engineering satisfies this requirement by the use of different detectors for protection systems and control systems. There are no shared inputs between the two electronic systems. In addition, there are four sets of input parameters, one set for each RPS channel. The output of the RPS sensors is supplied to the bistable relay cards in the RPS cabinets.

10.1.4.2 Bistable Trip Unit

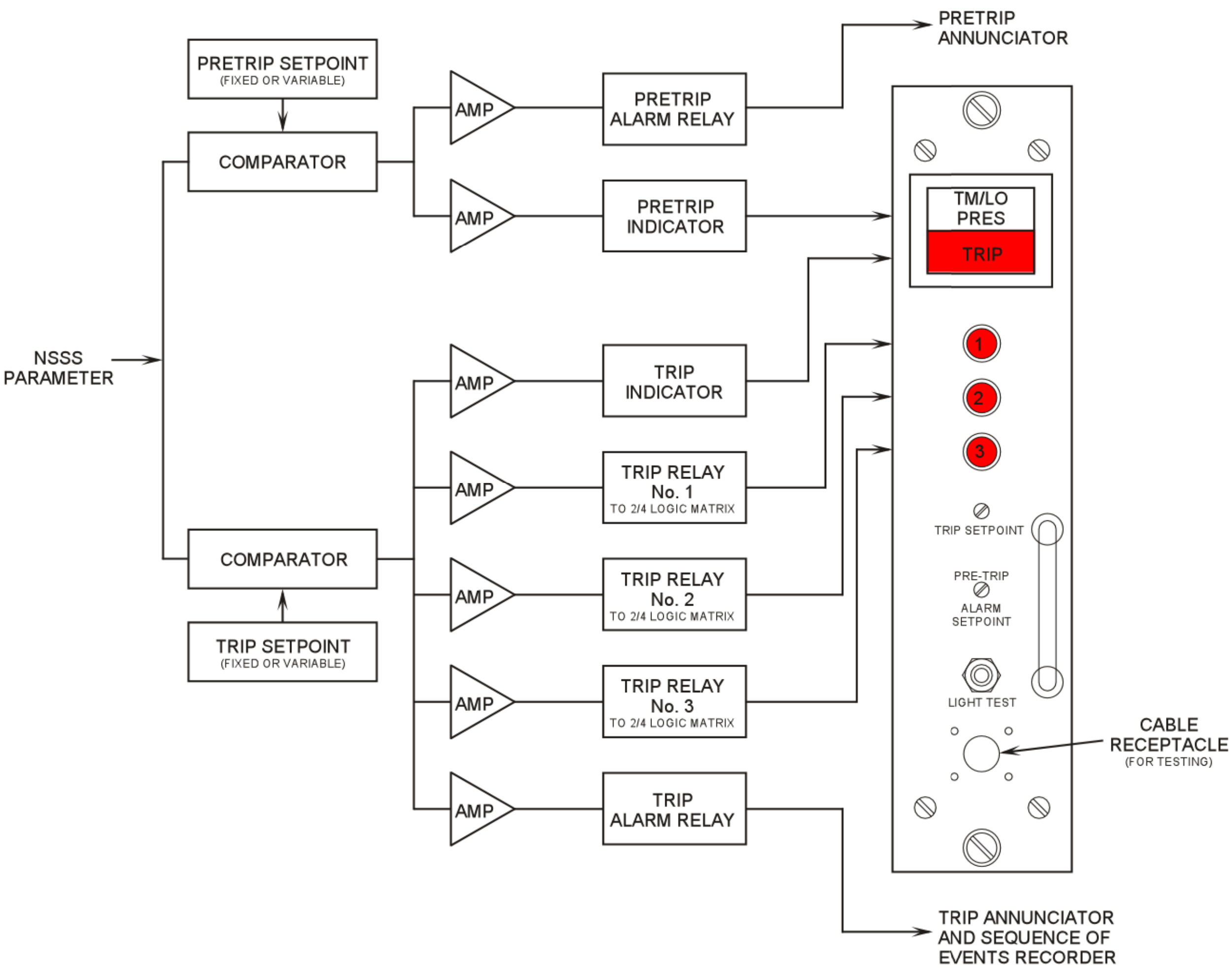


Figure 10.1-2 Bistable Trip Unit

The bistable trip unit (Figure 10.1-2) is used to compare the RPS input parameter with the pre-trip and trip set points and to generate pre-trip and/or trip signals if the pre-trip and trip comparators sense that the input signal equals the set point. There is a bistable trip unit for every trip in each RPS channel. Each bistable trip unit contains seven relays that are maintained in an energized condition by the comparators as long as the input parameter is not at set point. When the parameter equals the set point the comparator output drops to zero and the relays de-energize.

Five of the seven relays are driven by the trip comparator. Three relays are used in the two-out-of-four logic matrices, and the other two relays are used to provide reactor trip annunciation.

To illustrate the uses of the relays in the bistable trip unit, assume that the trip unit shown in Figure 10.1-2 is a channel "C" trip unit. The three relays that are used in the two-out-of-four trip logic operate contacts in the AC, BC, and the CD matrices. The trip indicator relay operates a trip indicator light on the bistable trip unit. The trip alarm relay operates contacts that activate control room annunciators and the computer sequence of events recorder. Bistable trip unit relays contain double coils. One coil operates contacts for logic matrix functions and the other functions as a test coil.

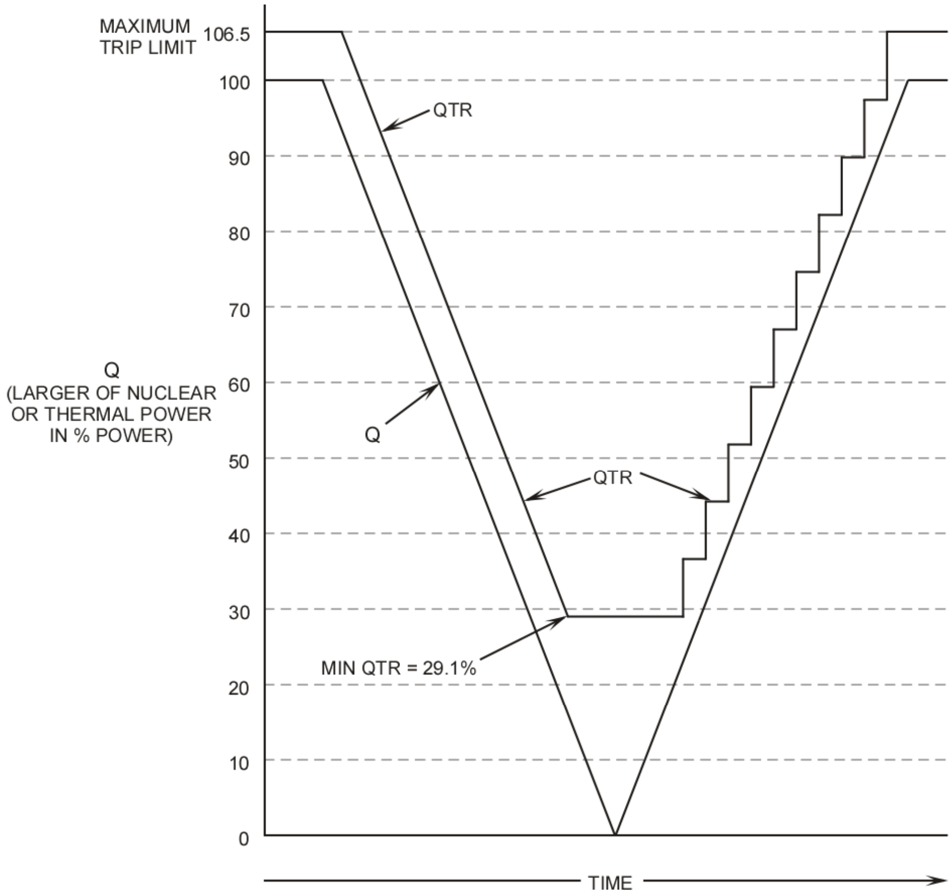


Figure 10.1-3 Variable High Power Trip Operation

One of the bistable trip units, VOPT, has a variable set point that is supplied to the pre-trip and trip comparators. As shown in Figure 10.1-3, the VOPT set point is a function of the highest of nuclear power or ΔT power. The minimum set point for the VOPT is approximately 30%, and the maximum set point is 106.5%. Between these extremes, the set point is manually maintained at 10% above existing power. Set point adjustment is accomplished by four push buttons (one for each RPS channel) located on the main control board.

The manual reset feature is illustrated by the following example. Assume that the plant is operating at 20% power with the VOPT set point at 30% and it is desired to escalate power to 100%. When power reaches 26%, a VOPT pre-trip is generated by the bistable trip unit. When the annunciator alarms the operator presses the push buttons to reset the VOPT setpoint to 40% and the pre-trip set point to 36%. As the power escalation continues, another pre-trip alarm is generated at 36% and the operator presses the push buttons to reset the VOPT set point to 50% and the pre-trip set point to 46%. These actions continue until the VOPT set point has been increased to 106.5%. When power is decreased, the set point automatically tracks downward with the set point remaining about 10% above the existing power.

10.1.4.3 Auxiliary Trip Units

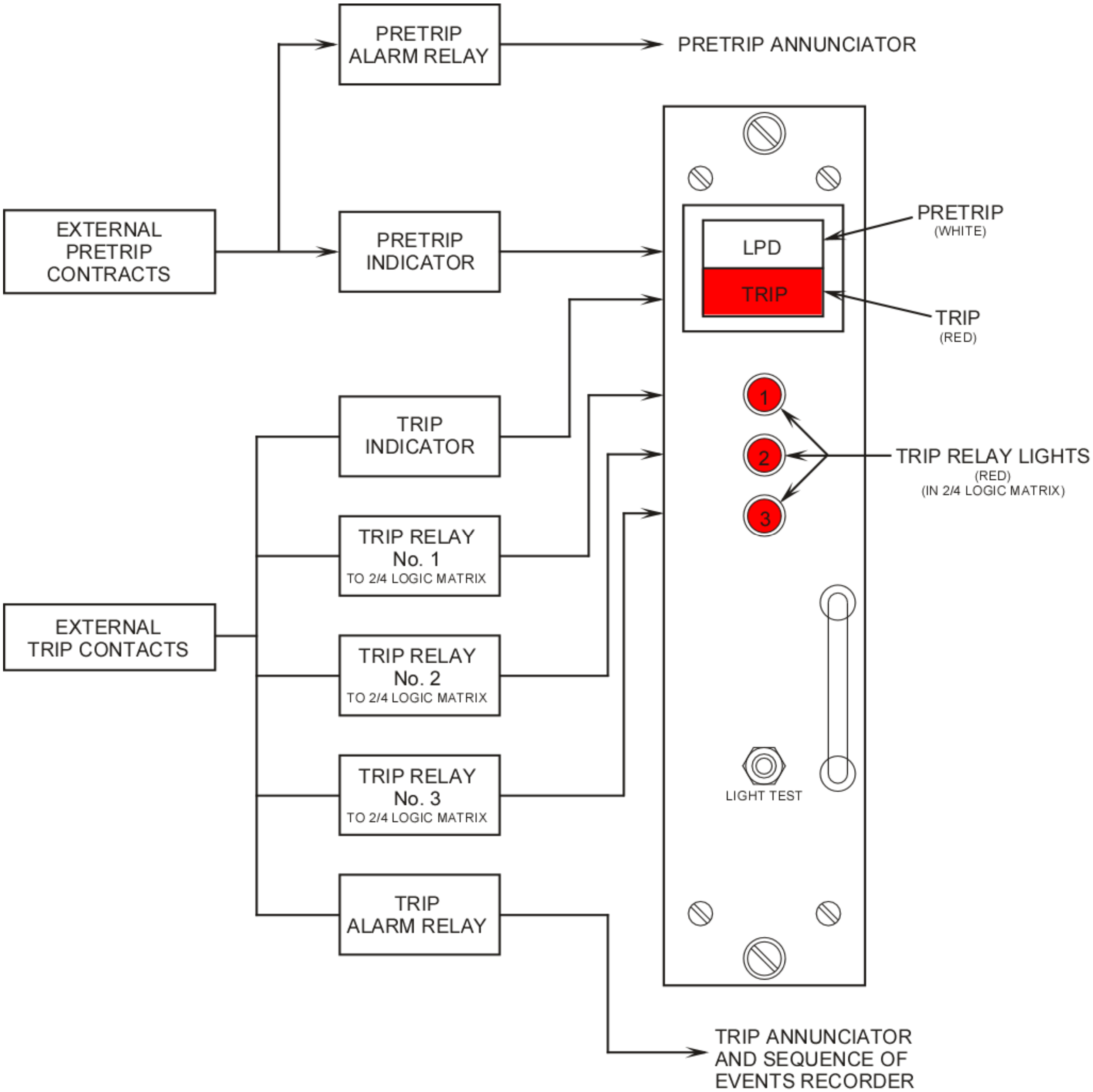


Figure 10.1-4 Auxiliary Trip Unit

The LPD trip and the loss of load trip are implemented by auxiliary trip units instead of bistable trip units. An auxiliary trip unit (Figure 10.1-4) is identical to a bistable trip unit with the exception that the relays are maintained in an energized condition by a normally closed contact. When a pre-trip or trip condition is sensed the contact opens and the relays de-energize. The relay outputs of the auxiliary trip unit are identical to the relay outputs of the bistable trip unit. The auxiliary trip unit relays and the bistable trip unit relays contain double coils, one coil that operates contacts for logic matrix functions and a test coil.

10.1.4.4 Logic Matrices

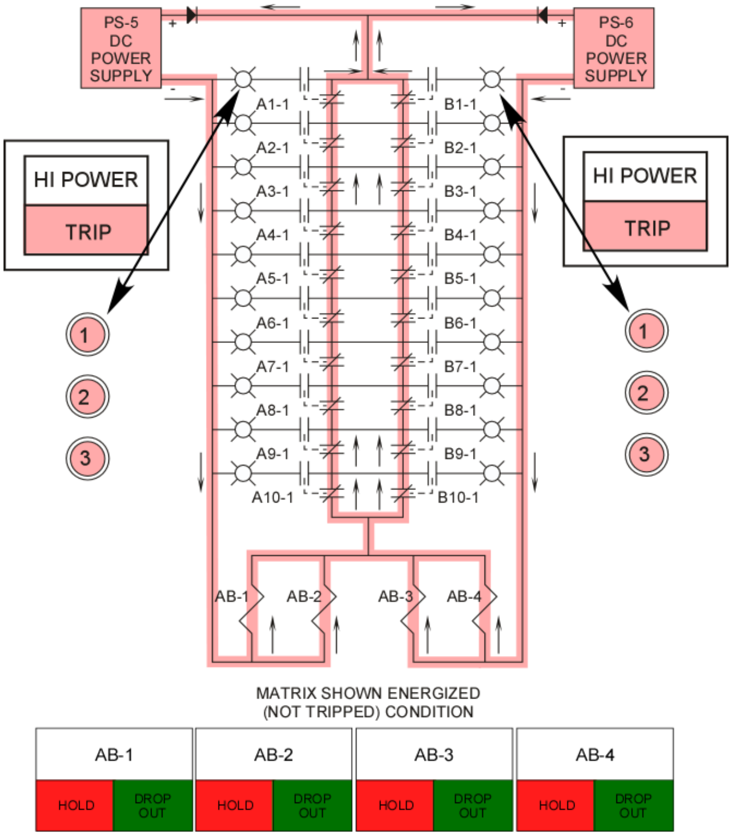


Figure 10.1-5A Coincidence Logic Matrix AB

The logic matrices (Figure 10.1-5) consist of a series-parallel contact network and four logic matrix relays to determine if the two-out-of-four coincidence trip logic has been satisfied.

During normal operation (Figure 10.1-5A), all matrix contacts are closed and the four logic matrix relays are energized. To generate a reactor trip, two parallel contacts must open. When the contacts open, the logic matrix relays de-energize and operate contacts that will open the RTBs. Each logic matrix is powered by redundant dc power supplies. Each of the power supplies is powered from an inverter supplied 120 Vac bus.

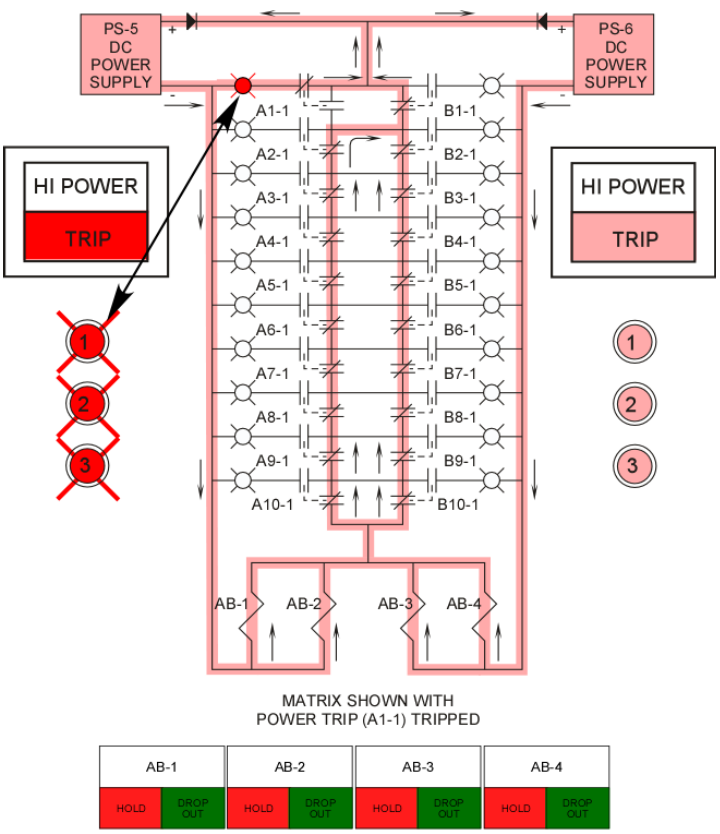


Figure 10.1-5B Coincidence Logic Matrix AB

To illustrate the operation of the logic matrix, assume that the variable overpower as sensed by the “A” channel reaches the trip set point (Figure 10.1-5B). When the trip set point is reached, the comparator in the variable overpower bistable trip unit de-energizes its three trip relays. The de-energizing of the bistable trip relays opens the variable overpower contacts in the AB, AC, and AD matrices and closes a contact in series with the lamp located on the front of the bistable trip unit. All three lamps on the “A” channel variable overpower bistable trip unit will be energized.

As shown in Figure 10.1-5B, power will be supplied to logic matrix relays AB3 and AB4 from power supply 6 (PS6) through the closed B trip relay contacts, maintaining these relays energized. Current will travel from power supply PS5 through logic matrix relays AB1 and AB2, up through the closed “A” trip relay contacts until it reaches the open VOPT contact. Since current cannot flow through the open contact, current will flow through the closed “B” VOPT contact and back to power supply 5. Logic matrix relays AB1 and AB2 will be energized by this current flow.

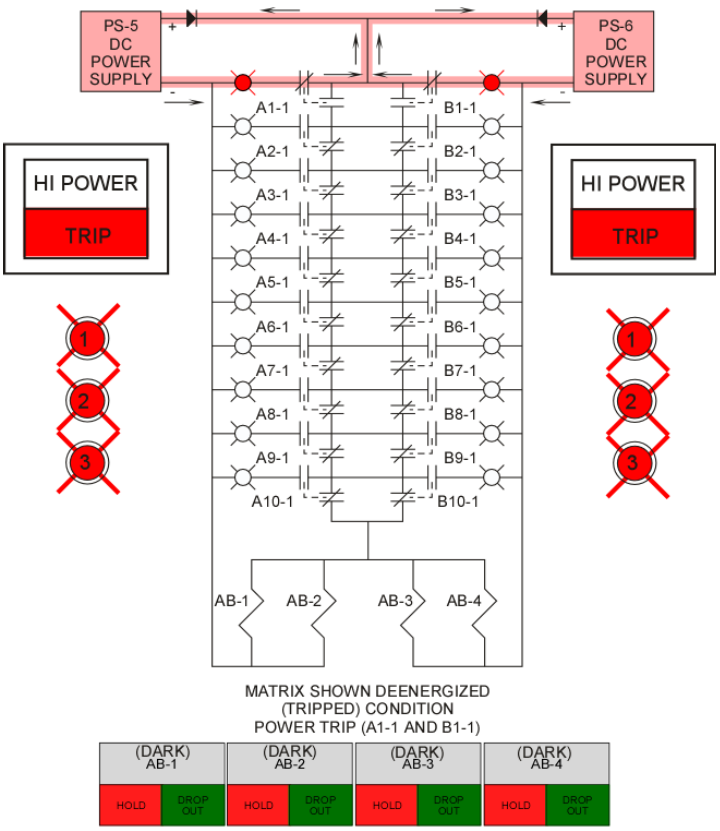


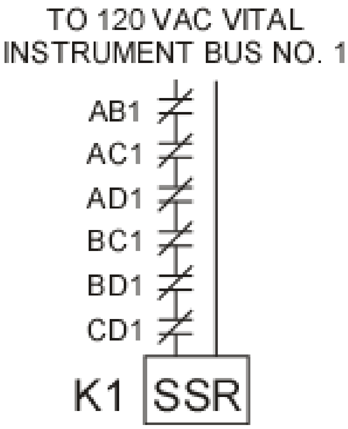
Figure 10.1-5C Coincidence Logic Matrix AB

Now assume that the “B” linear power channel also senses an overpower condition. The”B” channel VOPT bistable trip unit comparator's output will drop to zero and the three trip relays will de-energize. When the relays de-energize, their associated contacts will open in the

AB, BC, and BD matrices. When the “B” VOPT contact opens in the AB matrix (Figure 10.1-5C), current flow from PS6 can no longer maintain logic matrix relays AB3 and AB4 energized. Likewise, the opening of the “B” VOPT contact prevents current from PS5 from flowing through logic matrix relays AB1 and AB2, and the relays de-energize. When the relays de-energize, a series contact in each of the four RTBs control relay circuit opens. The opening of these contacts results in the opening of the RTBs.

As shown in figure 10.1-8, each logic matrix relay contains two coils. One of the coils is used for testing, and the other coil operates contacts in the RTB control relay circuitry.

10.1.4.5 Circuit Breaker Control Relays



There are four RTB control relays, each control relay operates contacts in two RTBs. Each control relay circuit contains six series contacts, one contact operated by a logic matrix relay from each of the six logic matrices. For example, the RTB control relay K1 circuit (Figure 10.1-1) contains the AB1, AC1, AD1, BC1, BD1, and CD1 contacts. Opening any one of the series logic matrix relay contacts de-energizes the RTB control relay and two RTBs will open. The RTB control relay circuitry is also called a trip path. A status panel above the RPS cabinets provides indication of trip path and RTB status.

10.1.4.6 Reactor Trip Circuit Breakers and CEA Power Supplies

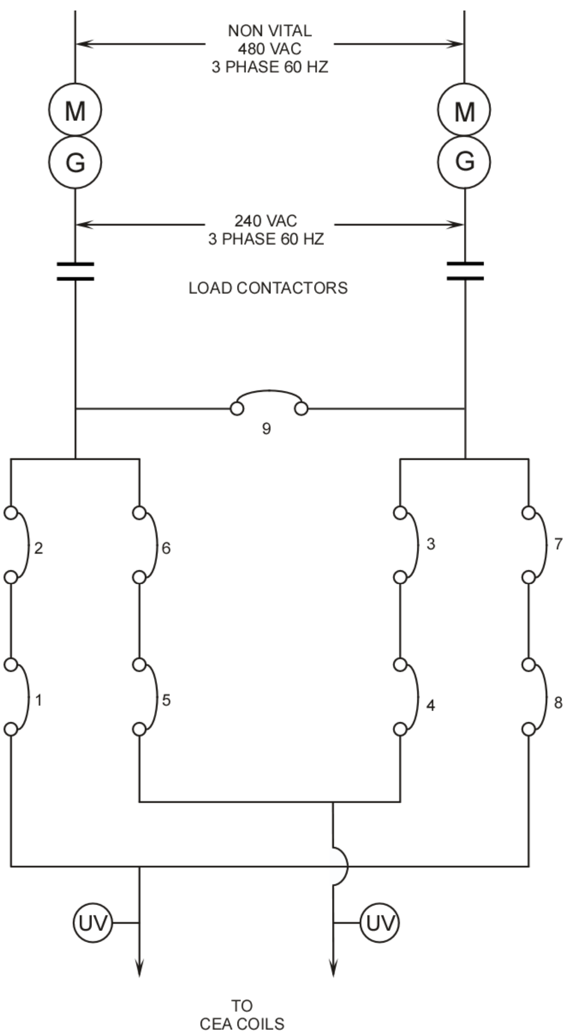


Figure 10.1-6 CEA Power Supply

The coils on the CEA magnetic jack assembly are supplied from two motor-generator (MG) sets (Figure 10.1-6). The MG set motors are powered from non-vital 480 Vac power. The MG set generator has an output of 240 Vac, 60 hz, 3 phase power. Either MG set is capable of providing 100% of the required CEA power; however, both MG sets are normally in service. Power from the MG sets is routed through the MG set output breakers to the CEAs via the RTBs. The MG output breakers are used to synchronize the generators and do not receive a trip signal from the RPS.

Nine RTBs control the MG set power supply to the CEAs. As previously discussed, eight of these breakers (numbers one through eight) are controlled by the trip path relays. Number nine RTB is installed to maintain MG set synchronization regardless of the order of closure of the RTBs. Number nine circuit breaker is not controlled by the RPS.

Under voltage coils monitor the CEA power supply. Should a reactor trip occur, the under voltage coils sense the decrease in supply voltage and provide signals to trip the turbine.

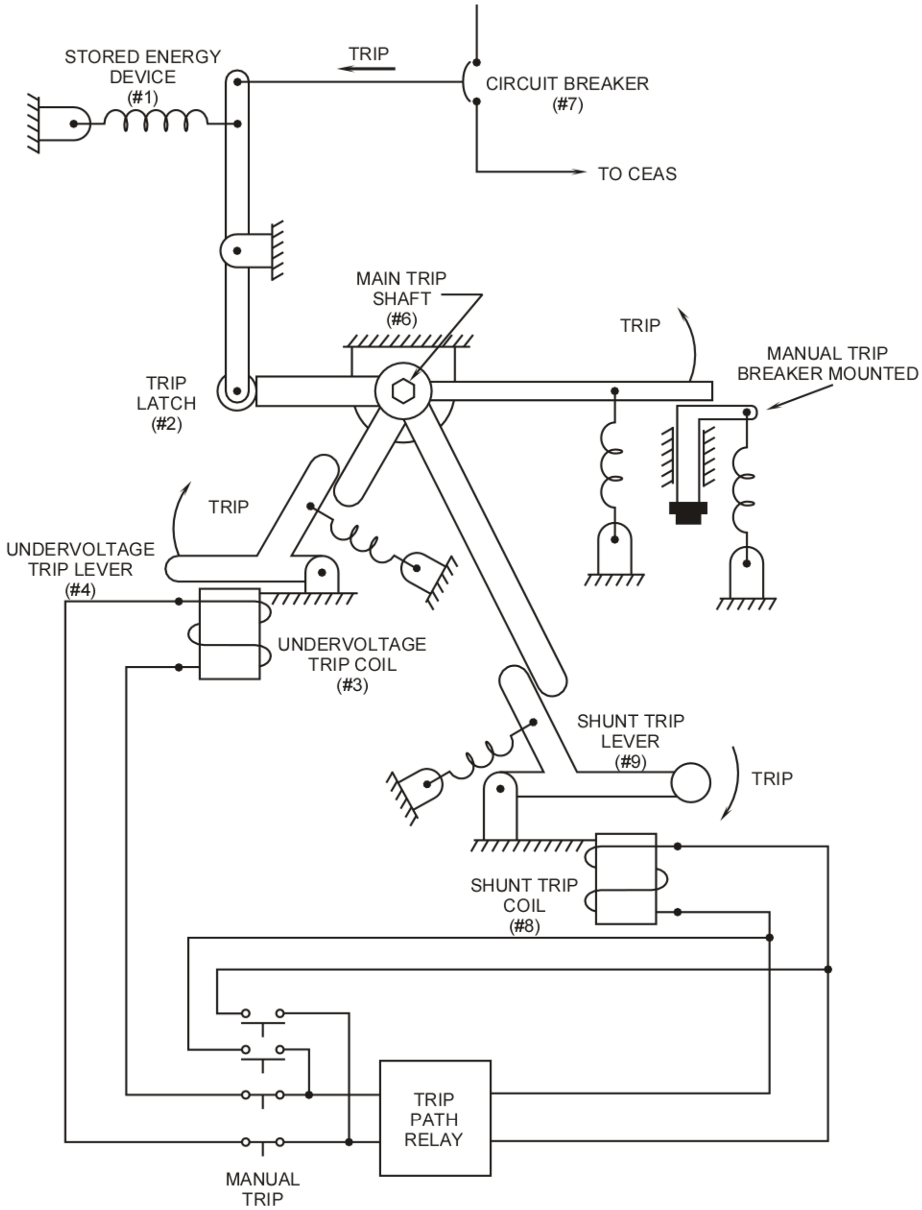


Figure 10.1-7 Reactor Trip Circuit Breaker

Figure 10.1-7 illustrates the mechanical operation of a typical RTB. During normal operations, the RTBs are closed supplying power to the CEAs. The circuit breaker under voltage (UV) coil (#3) is energized and holding the under voltage trip lever (#4). The power to keep the under voltage coil energized is controlled by the RPS.

When a trip signal is sensed through the appropriate logic (2/4), the RPS de-energizes the UV coil (#3) which releases the UV trip lever (#4). The UV trip lever causes the main trip shaft (#6) to rotate counterclockwise. When the main trip shaft rotates, the trip latch (#2) is released allowing the stored energy device (#1) to open the RTB (#7). Of course, opening of the RTBs removes power from the drive mechanisms allowing the CEAs to drop into the core.

The use of the under voltage coil to trip the reactor provides a fail safe feature for the RPS. If a loss of power to the RPS should occur, the UV coils would de-energize and the RTBs would open as described above.

10.1.5 Integrated Operations

The discussion in the following sections (10.1.5.1 and 10.5.1.2) refers to figure 10.1-8 (Reactor Protection System Functional Diagram). This figure, shown de-energized, complies with industry standards and is drawn in the same general format as the process and instrument diagrams found in the plant. All relay contacts that close when a relay is energized, “a” contacts, appear as open contacts, and any relay contacts that open when a relay is energized, “b” contacts, are shown closed. Therefore, if the text states that a contact is closed, it is referring to an energized circuit although the figure shows that same contact as open.

10.1.5.1 Reactor Trip

Using figure 10.1-8, assume that a slow depressurization of one steam generator occurs. This transient will generate a trip signal actuated by either a high containment building pressure or a low steam generator pressure and is chosen to demonstrate the two-out-of-four coincidence trip logic.

As the steam generator depressurizes, steam is released into the containment building and the pressure inside the containment building will increase. When containment building pressure reaches the trip set point, a reactor trip signal is generated. Assume that the “A” RPS channel is the first protective channel to sense the high containment building pressure.

Remember, if a process parameter equals or exceeds a bistable trip set point, the bistable trip unit de-energizes three trip relays. Each trip relay provides an input into a separate logic matrix. In this case when the pressure inside the containment building reaches or exceeds 2.8 psig. The auxiliary bistable trip unit de-energizes three trip relays.

When these trip relays de-energize, their associated logic matrix contacts open. The contacts that open are as follows:

a. The A9-1 contact in the AB matrix
b. The A9-2 contact in the AC matrix
c. The A9-3 contact in the AD matrix

When the trip contacts in the matrix logic open, their associated trip relay lamps energize. Therefore, three trip relay lights energize on the auxiliary bistable trip unit. Although one contact is open in each of the three logic matrices, the logic matrix relays remain energized and the reactor trip circuit breakers remain closed.

Tracing the electrical current flow path from the power supplies, PS-5 and PS-6, through the AB logic matrix, illustrates why a reactor trip has not occurred.

Power supply PS-6 keeps logic matrix relays’ AB-3 and AB-4 energized via the following electrical flow path. Current flows from the PS-6 power supply through logic matrix relays AB-3 and AB-4 to the contact string containing the B1-1 through the B10-1 contacts. Presently all the series contacts on the “B” side of this logic matrix are closed. Therefore, there is not a break in continuity of this circuit and current is allowed to flow back to the positive side of the PS-6 power source.

Meanwhile, power supply PS-5 keeps logic matrix relays’ AB-1 and AB-2 energized via the following electrical flow path. Current flows from the PS-5 power supply through logic matrix relays AB-1 and AB-2 to the contact string containing the A1-1 through the A10-1 contacts. The current flows upward through the closed A10-1 contact and then encounters the A9-1 contact that is open. The current flow back to the positive side of the PS-5 power source is broken, and without an alternate route for the current to flow to the logic matrix relays, AB-1 and AB-2 would de-energize. However, a cross-connect line between contacts A10-1 and A9-1 allows current flow to the “B” series contacts.

With this configuration a current path is available and the PS-5 power source keeps the AB-1 and AB-2 relays energized. Similar power supply paths exist for the AC and the AD logic matrices.

Assume that the “C” channel steam generator pressure transmitter senses a steam generator low pressure condition before a second high containment building pressure condition is sensed. When the “C” low steam generator pressure bistable strip unit de-energizes; its three trip relays de-energize and open the following contacts:

C5-1 in the AC matrix
C5-2 in the BC matrix
C5-3 in the CD matrix

As previously discussed, the associated trip relay lamps on the low steam generator pressure bistable trip unit are energized. In addition, the pre-trip and trip lamps are also energized. The logic matrix for the BC and the CD matrices operate the same as the sequence described for logic matrix AB. However, two contacts are now open in the AC logic matrix A9-2 and C5-1.

Tracing the power supplies, PS-7 and PS-8 through the AC logic matrix, illustrates why a reactor trip has not occurred.

Current flows from the PS-7 power supply through the logic matrix relays AC-1 and AC-2 to the contact string containing the A1-2 through the A10-2 contacts. The current flows upward through the closed A10-2 contact and then encounters the A9-2 contact that is open and blocks the current flow. However, a cross-connect line between contacts A10-2 and A9-2 allows current flow to the “C” series contact string until it encounters open contact C5-1. This open contact prevents current flow and would de-energize the logic relays AC-1 and AC-2 except that between contacts C6-1 and C5-1 a cross-connect exists that allows the electrical current to flow back to the “A” contacts in this string)A5-2 through A1-2) are closed. This provides a current path back to the PS-7 power source and keeps the AC-1 and AC-2 relays energized.

Power supply PS-8 keeps the AC-3 and the AC-4 relays energized with the following current flow path. The electrical current flows through these relays (AC-3 and AC-4), up the “C” series contacts until it reaches the open C5-1 contact. Similar to the previous paragraph, the current flows through the cross-connect over to the “A” series contacts and continues upward and is routed back to the PS-8 power supply.

The logic matrix relays in the AC logic matrix remain energized and the reactor does not trip. As illustrated by this example, any number of

trip inputs may occur within a logic matrix, and since two contacts in parallel are not de-energized at the same time, a reactor trip will not occur.

As the pressure within the affected steam generator continues to decrease, assume that the “D” channel senses a low steam generator pressure. The “D” channel steam generator low pressure bistable trip unit opens contacts in the following matrices:

D5-1 in the AD matrix
D5-2 in the BD matrix
D5-3 in the CD matrix

From a practical standpoint, although three matrices are affected, the important action takes place in the CD logic matrix. When the D5-3 contact opens, two parallel contacts are open in the CD matrix (contact C5-3 was opened earlier). With two parallel contacts open current flow through both contact strings of this circuit is interrupted and the following logic relays de-energize; CD-1, CD-2, CD-3, and CD-4. When these logic matrix relays de-energize, their associated contacts open.

In the lower left portion of figure 10.1-8, a transformer powered from Vital Bus #1 is shown. Notice: directly below and to the left of the transformer is a series of contacts. When the logic matrix relay CD-1 de-energizes, its associated contact (CD-1) opens. This action breaks the continuity of this circuit de-energizing relay K1. When this relay de-energizes, it removes power from the under voltage coils and energizes the shunt trip coils in reactor trip breakers (TCB-1 and TCB-5).

This action, by itself, will not generate a reactor trip because reactor trip breaker pairs (TCB-4 and TCB-8) and (TCB-3 and TCB-7) are still closed. However, as previously stated, contacts' CD-3 and CD-4 are open. Examining the action caused by just one of these contacts (CD-4) shows that, if the CD-4 contact opens, relay K4 de-energizes. When this relay de-energizes, it de-energizes the under voltage coils and energizes the shunt trip coils for reactor trip breakers TCB-4 and TCB-8. Recall that one set of trip breakers, TCB-1 and TCB-5, is already open. Therefore, when these breakers open, all power is lost to the control element drive mechanisms and the control element assemblies fall into the core shutting down the reactor.

As described in Section 10.1.3, only one pair of breakers in each side of the CEDM power supplies must open to cause a reactor trip. In this discussion the pairing of breakers selected was sufficient to trip the reactor.

A subtle thing also occurs with the RPS trip relay lamps during certain events. The trip relay lamps receive power from the same source that supplies the logic matrix relays. It illuminates when a "b" contact closes. This action occurs simultaneously when its associated logic contact opens. If the contacts located above the tripped contacts remain closed, continuity of the circuit is maintained and the trip relay lamps remain lit. Therefore, in this example, when contacts' C5-3 and D5-3 open, power is lost to the high containment trip relay lamps (D9-3). Overall, only the lowest numbered trip relay lamps remain energized following a reactor trip. The result of this action means that a reactor trip "first out" cannot be determined from the Reactor Protection System front panels.

10.1.5.2 Loss of 120 Vac Bus

The design of the RPS is such that the loss of a single 120 Vac vital bus should neither prevent nor cause a reactor trip. Referring to the lower left hand section of figure 10.1-8, assume that a loss of vital bus #1 occurs.

After losing this power source, the K1 relay de-energizes. De-energizing the K1 relay opens the contacts to the under voltage coils and closes the contacts that supply power to the shunt trip coils for reactor trip breakers TCB-1 and TCB-5. Either of these actions opens this pair of reactor trip breakers. A reactor trip does not occur because the reactor trip breaker pairs (TCB-4 and TCB-8) and TCB-3 and TCB-7) are unaffected by the loss of vital bus #1 and remain closed.

Losing this power source (vital bus #1) also affects the following dc power supplies; PS-5, PS-7, and PS-9. Tracing the electrical circuit of the A-B logic matrix, notice that the PS-5 power supply normally keeps logic matrix relays AB-1 and AB-2 energized. However, in this example, this dc power source is lost and these relays de-energize. Once these relays de-energize, their associated contacts AB-1 and AB-2 open. Losing the AB-1 relay in this example has no impact because the K1 relay was lost as a direct result of de-energizing vital bus #1. However, opening the AB-2 contact de-energizes reactor trip relay K2. De-energizing the K2 relay has the similar affect as de-energizing the K1 relay except in this instance reactor trip breakers TCB-2 and TCB-6 open. Opening these two breakers has no additional affect upon the system because these breakers are in series with the previously opened reactor trip breakers.

Despite the electrical fault: a loss of an individual dc power supply, or the loss of an entire vital instrument bus, a reactor trip will not occur. In addition to losing one half (½) of the reactor trip breakers, the loss of power changes the trip logic for the logic matrices affected by that loss of power. For example, if the Channel

“A”, PS-5 power supply was lost, not only do the logic relays AB-1 and AB-2 de-energize, but all the contacts (A1-1 through A10-1) on the left side of the logic matrix open. Operating under these conditions, the logic matrix is aligned so if any single contact opens on the “B” side of the matrix (B1-1 through B10-1), continuity of the circuit is broken, and logic relays AB-3 and AB-4 de-energize. Therefore, with these conditions, a one-out-of-three (1/3) logic exists for the logic matrices affected by the power loss, that is, logic matrix AB, AC, and AD.

10.1.6 RPS Bypasses

10.1.6.1 Trip Channel Inhibit

The trip channel inhibit is provided to remove a trip channel from service during maintenance or testing. When the trip channel inhibit is in effect, the trip logic for that trip is changed to a two-out-of-three logic. As an example, if the low steam generator level trip for “A” steam generator is inhibited in RPS channel “A”, RPS channels “B”, “C”, and “D” will continue to provide steam generator low level trip capability. Any inhibit must be manually initiated and removed at the RPS cabinets.

To inhibit an individual trip function the key for that trip is inserted in the appropriate RPS channel and turned. When the inhibit key is turned contacts in parallel with the bistable trip relay in the logic matrices for the affected trip function are closed. This action inhibits the trip from that channel only.

The inhibit keys are administratively controlled such that no more than one key is available for each of the reactor trips. This RPS design would allow the same reactor trip function to be inhibited in multiple channels if multiple keys were available. Operationally, inhibiting more than one channel for a particular trip function is not allowed by technical specifications.

10.1.6.2 Automatic Bypasses

The operability of the high startup rate, LPD, and loss of load trips are power level dependent. Nuclear instrumentation system bistables provide interlock signals to activate/deactivate these trip functions. The high start-up rate is active when power is greater than or equal to 10^{-4}% (as sensed by wide range logarithmic power) and remains operable until power is greater than or equal to 15% (as sensed by the linear power range safety channel).

At power levels above 15%, feedback from the moderator temperature and doppler coefficients, along with the variable overpower trip provide protection against reactivity excursions and protection by the high startup rate trip is not required. Below 10^{-4}% power, poor counting statistics can lead to erroneous indications; therefore, the high startup rate trip function is automatically bypassed.

The LPD and loss of load trips are automatically bypassed until power, as sensed by the linear power range safety channels, exceeds 15%. Below 15% power, no values of LPD will result in violation of kW/ft limits; therefore, the LPD trip can be safely bypassed.

The 10^{-4}% and 15% power signals used for trip bypassing are channelized. In order to bypass the “A” RPS loss of load trip, power must be less than 15% as sensed by the linear power range safety channel located in the “A” RPS cabinet. Therefore, to ensure that a loss of load trip will not occur, three of the four linear power range safety channels must sense that power is less than or equal to 15%. The above discussion is also applicable to LPD, and if the 10^{-4}% limit is added, the statements apply to all automatically bypassed trips.

10.1.6.3 Zero Power Mode Bypass

The RPS zero power mode bypass feature allows the TMLP and the low RCS flow trips to be bypassed to permit CEA operation during shutdown and cool down evolutions. The zero power mode bypass is manually actuated when it is desired to cool down with the shutdown CEAs withdrawn or when CEA testing is to be performed during shutdown. Cooling down with the shutdown groups withdrawn provides a method of quickly adding negative reactivity to the core should the need arise.

Two conditions must be satisfied for each RPS channel zero power mode bypass:

1. Power, as sensed by the wide range logarithmic power channel must be less than or equal to 10^{-4}%, and
2. A key lock switch, located on the RPS cabinet, must be turned to the bypass position.

When these conditions are satisfied, the bistable trip relays for the TMLP and low RCS flow trip units remain energized by applying a fixed voltage to the relay amplifiers. In addition to blocking the trip functions, the zero power mode bypass also prevents the selection of ΔT power by the TMLP power calculation. An indicating light on the RPS cabinet, labeled ΔT power block is energized to inform the operating staff of this condition. When power is escalated to >10^{-4}%, the TMLP and low RCS flow trip inhibits and the ΔT power block are automatically removed.

10.1.6.4 Low Steam Generator Pressure Bypass

Provisions are made to bypass steam generator pressure during a cool down so that a reactor trip will not occur. Two conditions must be satisfied to bypass the low steam generator pressure reactor trip. First, steam generator pressure must be less than or equal to 785 psia. Next, a key operated bypass switch must be positioned to the bypass position on the RPS. With this trip bypassed, a cool down can proceed without the actuation of a reactor trip. If steam generator pressure exceeds 785 psia, then the low steam generator pressure bypass is automatically removed.

10.1.7 RPS Interfaces

10.1.7.1 CEA Withdrawal Prohibit Interlocks

CEA withdrawal prohibit (CWP) signals are generated by VOPT, high start-up rate, and TMLP pre-trips. The CWP interlock prevents manual or automatic CEA withdrawal causing a greater degradation of these parameters. CWPs have a two-out-of-four logic for each parameter. The TMLP CWP is bypassed if power is less than or equal to 10^{-4}% power.

10.1.7.2 PORV Actuation

The power operated relief valves (PORVs) are opened in conjunction with a high pressurizer pressure trip. Trip unit relays in the high pressurizer pressure trip bistables have contacts in a two-out-of-four coincidence logic that actuate the PORVs. When testing a high pressurizer pressure trip channel, the trip bypass switch energizes a relay whose contacts parallel the trip unit relay and reduces the actuation logic to a two-out-of-three.

10.1.8 RPS Testing

Provisions are made to permit periodic testing of the complete RPS with the reactor at power. These tests cover the trip actions from sensor input, bistable trip relay actuation, logic matrix relay actuation, trip path relay actuation, and finally the opening of the RTBs. These individual tests are described below.

10.1.8.1 Sensor Checks

During reactor operation, the sensors that provide inputs to the RPS are checked by comparing the outputs of all four instruments that measure the same parameter. This is called a channel check. Plant technical specifications require the performance of this check on a periodic basis.

During extended shutdown periods or refueling shutdowns, the sensors are checked and calibrated against known standards.

10.1.8.2 Trip Bistable Tests

Testing of trip bistables is accomplished by manually varying the input signal to the trip comparator (Figure 10.1-2) up or down to the trip set point. Only one bistable is tested at a time and observing the trip action as evidenced by the logic matrix lamps at the bistable trip unit.

Varying the input signal is accomplished by the trip test circuit that consists of a digital voltmeter, test selector switches, and a potentiometer. The bistable to be tested is selected and the test signal is applied. The digital voltmeter may be used to determine the trip set point.

Since the bistable relays are de-energized during the test, the trip function is placed in trip channel inhibit. This test is performed in accordance with technical specifications and is called a channel functional test.

10.1.8.3 Logic Matrix Test

This test is performed to verify proper operation of the six logic matrices. As shown in Figure 10.1-8, the test power supply supplies power to the hold coils of the trip bistable relays (the bistable trip relay has two coils, one that is powered from the comparator, and one powered from the test circuit).

Actuation of the push button applies a test voltage to the test system hold coils of the double coil matrix relays. This voltage will provide the power necessary to hold the relays in their energized position when actuation of the bistable trip relay contacts in the matrix ladder being tested causes the primary matrix relay coils to de-energize.

The logic matrix to be tested is selected using the system channel trip select switch located at the RPS channel cabinets. Then while depressing the matrix hold push button, rotation of the channel trip select switch will release only those bistable trip relays that have operating contacts in the logic matrix under test.

The channel trip select switch applies a test voltage of opposite polarity to the bistable trip relay test coils so that the magnetic flux generated by these coils opposes that of the primary coil of the relay. The resulting flux will be zero, and the relays will release.

Trip action can be observed by illumination of the trip relay indicators located on the front panel and by loss of voltage to the four matrix relays, which is indicated by extinguishing the indicator lights connected across each matrix relay coil.

During this test, the matrix relay hold lights will remain on, indicating that a test voltage has been applied to the holding coils of the logic matrix module under test.

The test is repeated for all six matrices and for each actuation signal. This test will verify that the logic matrix relays will de-energize if the matrix continuity is lost. The opening of the matrix relays is tested in the trip path tests, and is a part of the channel functional test.

10.1.8.4 Trip Path/Circuit Breaker Tests

Each trip path is tested individually by depressing a matrix hold push button (holding the matrix relays), selecting any trip position on the channel trip select switch (opening the matrix), and selecting a matrix relay on the matrix relay trip select switch (de-energizing one of the four matrix relays), causes two RTBs to open. CEDMs remain energized via the other RTBs (Figure 10.1-6).

The drop-out lamps shown on Figure 10.1-8 are used to provide additional verification that the matrix relay has been de-energized, (the AB-1 matrix relay contact energizes the drop-out lamp). Proper operation of the actual trip path matrix relay contacts is verified by the trip path lamp located on the trip status panel.

Proper operation of all coils and contacts is verified by lights on a trip status panel. Final proof of opening of the RTBs is the lack of indicated current through the trip breakers.

The matrix relay trip select switch is turned to the next position, re-energizing the tested matrix relay and allowing the RTBs to be manually reset.

This sequence is repeated for the other three trip paths from the selected matrix. Following this the entire sequence is repeated for the remaining five matrices. Upon completion all twenty four matrix relay contacts and all four trip paths and breakers will have been tested. This test is also a part of the channel functional test.

10.1.8.5 Manual Trip Test

The manual trip feature is tested by depressing one of the four manual trip push buttons, observing a trip of two RTBs, and resetting the breakers prior to depressing the next manual trip push button. This test is performed prior to a reactor startup, unless performed in the previous seven days.

10.1.9 PRA Insights

The purpose of the RPS is to initiate reactor trips to prevent the plant from reaching a safety limit and initiate engineered safety features to mitigate the consequences of an accident. The major RPS PRA concern is an anticipated transient without scram (ATWS). According to the Calvert Cliff's PRA, the ATWS has a core melt frequency contribution of 33%. The dominant accident sequence assumes that a transient (loss of offsite power, loss of feedwater, turbine trip) starts with all the front line systems initially available and proceeds as follows:

1. A valid trip signal is received, and a failure of the reactor trip circuit breakers occurs.
2. The main feedwater pumps trip or runback to a low feedwater flow condition.
3. Primary system failure results due to an over pressure and subsequent core melt.
4. No credit is taken for operator initiation of feed and bleed core cooling, or tripping the reactor.

A failure of the RPS would allow the heat production in the core to continue, while the power conversion system would be removing heat at a reduced rate. The resulting imbalance between the energy removal rate (5%) and the energy production rate (100%) leads to the heatup of the RCS and an increase in system pressure. The magnitude of the pressure increase is determined by the initial power level, heat removal rate, and the net reactivity in the core. The moderator temperature coefficient determines the negative feedback between the temperature rise and resulting power decrease by decreasing the density, or voiding of the primary coolant.

Given that the peak pressure exceeds the service level (3200 psia) limit, various types of system damage have been postulated:

1. If the pressure should exceed 3500 psia, then the reactor vessel head could lift and likely fail to reseat completely.
2. The response of the steam generator tubes is uncertain at these differential pressure and a large number could potentially rupture.
3. Because there is insufficient analysis of the operability of check valves in the primary system for the pressures exceeding the service level limit, there is an assessment that the chemical and volume control and high pressure safety injection systems would be unavailable some significant fraction of the time due to check valves being forced shut and deformed to the point of inoperability. Thus, continued reactor cooling and long term recovery after the system has been over pressurized is questionable, and significant core damage could result from an initiating failure of the RPS.

The risk reduction factor for the RPS is 1.53, and the risk achievement factor is 11,539. The large risk achievement factor is due to the small failure probability of the RPS that is assumed in the PRA. As previously stated, no credit was given for operator actions mitigating this event. Calvert Cliffs has implemented an ATWS procedure which directs the operator to:

1. Trip the reactor manually,
2. Deenergize the motor generator sets (to the CEAs) and
3. Initiate emergency boration.

De-energizing the motor generator sets should bypass any actuation of control circuit failures and result in a successful trip. If done quickly enough, this could result in a reduction in any pressure transient. With appropriate operator training, it may be possible to mitigate this sequence.

The only other ways of reducing this sequence's frequency or mitigating the results appear to involve changes to the plant such as:

1. Reduce the number of transients,
2. Improve RPS reliability,
3. Qualify the RCS and valve operability at higher pressures,
4. Improved analysis to show peak pressure less than current prediction or
5. Change fuel loading so that a more negative MTC is obtained.

10CFR50.62 requires additional safety improvements in the design and operation of light water cooled nuclear powered reactors to minimize the probability of an ATWS event. The requirements are intended to reduce the likelihood of failure of the reactor trip systems to scram the reactor following an ATWS and reduce the consequences should failures occur. The requirements for pressurized water reactors are:

1. Additional equipment, independent of the reactor trip system, to automatically activate the auxiliary feedwater system and initiate a shutdown of the plant turbine under conditions indicative of an ATWS.

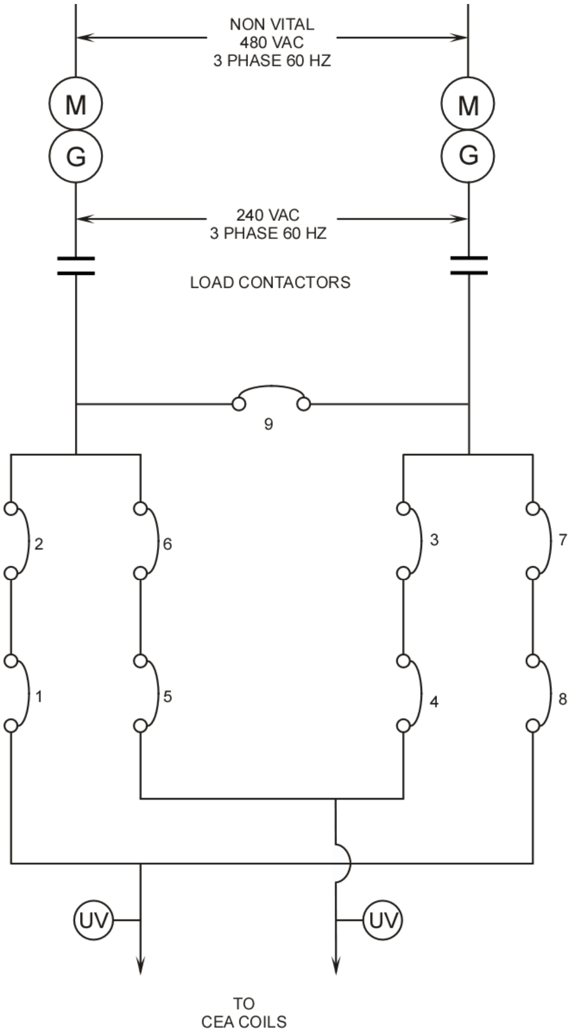


Figure 10.1-6 CEA Power Supply

2. An additional scram system (all of those components of the reactor trip system exclusive of sensors, control element assemblies and their mechanisms) which also is independent of the reactor trip system. Calvert Cliffs has added a diverse scram system to comply with item 2 above. The system utilizes four pressurizer pressure channel instruments that open the load contactors (Figure 10.1-6) on the outtput of the CEDM MG sets when pressurizer pressure exceeds 2450 psia as sensed by at least two of the four transmitters.

10.1.10 Summary

The RPS functions to insure that the fuel cladding and RCS barriers remain intact during anticipated operational occurrences. In addition, the RPS aids the ESFAS in the mitigation of accidents by insuring the reactor is shutdown.

The RPS senses safety related parameters and generates a reactor trip signal if any parameter reaches set point. The RPS has four separate channels and functions with a two-out-of-four logic to trip the reactor. Eight RTBs are controlled by the RPS. These breakers are arranged in two parallel strings with each string consisting of four breakers. The four breakers are arranged in parallel pairs. The trip logic for the circuit breakers is a one-out-of-two for each parallel string.

TABLE 10.1-1 REACTOR TRIP SUMMARY

TRIP	PRE-TRIP SET POINT	TRIP SET POINT	PURPOSE
1. Variable Overpower	104.5%	106.5%	Fuel cladding protection during rapid reactivity excursions
2. High SUR [(1)]	1.5 DPM	2.6 DPM	Startup Protection (backup to VOPT)
3. Low RCS Flow[(2)]	97%	95%	DNBR
4. Low SG Level	47%	37%	Heat Sink Protection
5. Low SG Pressure [(5)]	767 psia	703 psia	Ensures reactor shutdown in the event of a MSLB
6. High Pressurizer [(4)] Pressure	2350 psia	2400 psia	RCS Boundary Protection
7. Thermal Margin Low Pessure [(2)]	50 psia above setpoint	Variable	DNBR
8. Loss of Load [(3)]	No pre-trip	Turbine Trip	Prevents large RCS pressure upsets (lift of PORVs, safeties)
9. High Containment Pressure	No pre-trip	2.8 psig	Ensures reactor shutdown in events requiring safety injection
10. Local Power[(3)] Density (Axial Power Distribution)	Variable	Variable	kW/ft. (Prevent peak local power)

Notes
1. Trip is bypassed below 10^{-4}% and above 15%.
2. Trip is bypassed in zero power mode bypass.
3. Trip is bypassed below 15% power. Trip utilizes an auxiliary trip unit.
4. The pressurizer power operated relief valves are opened by the high pressurizer pressure trip.
5. Trip may be bypassed at 785 psia.

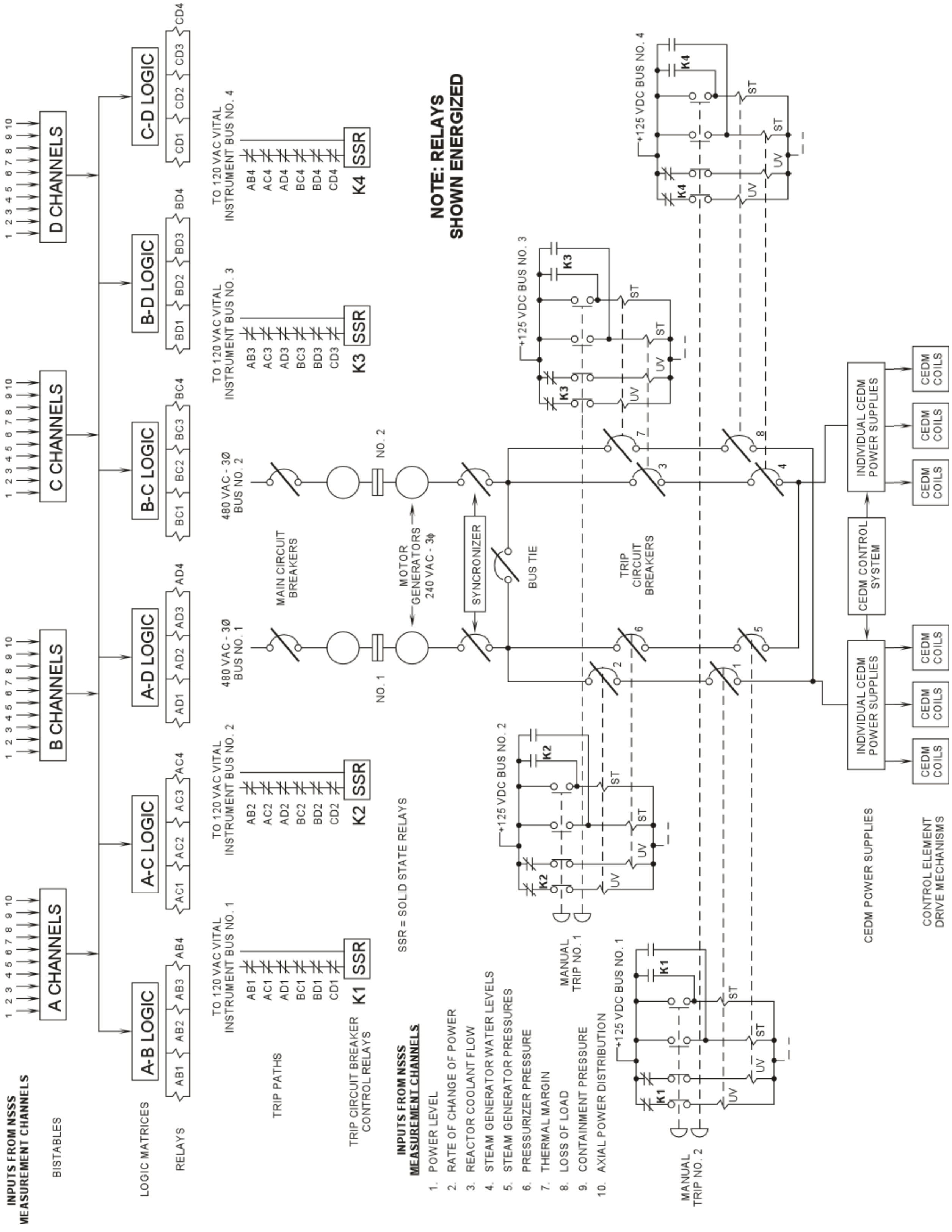


Figure 10.1-1 Simplified Reactor Protection System

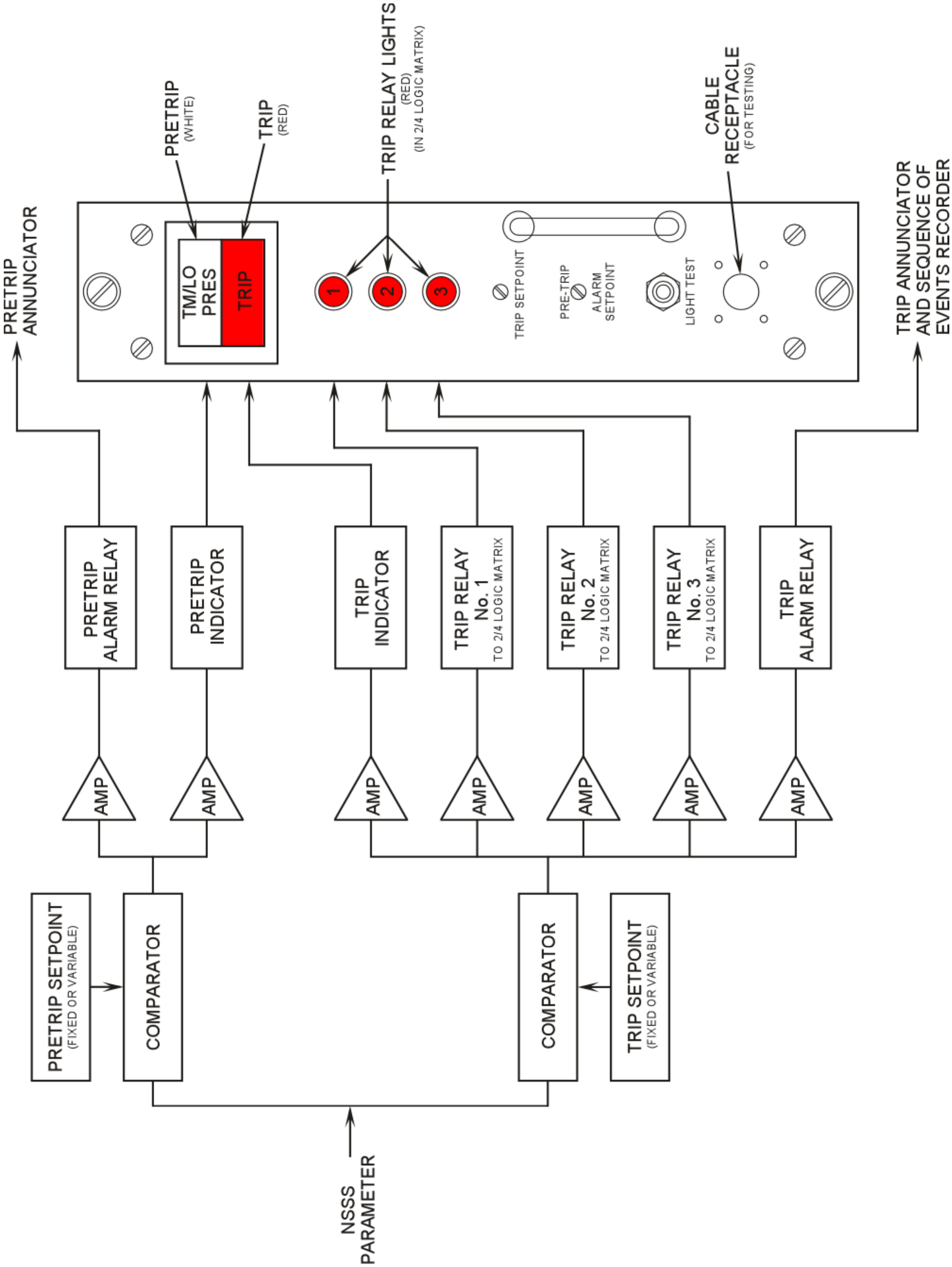


Figure 10.1-2 Bistable Trip Unit

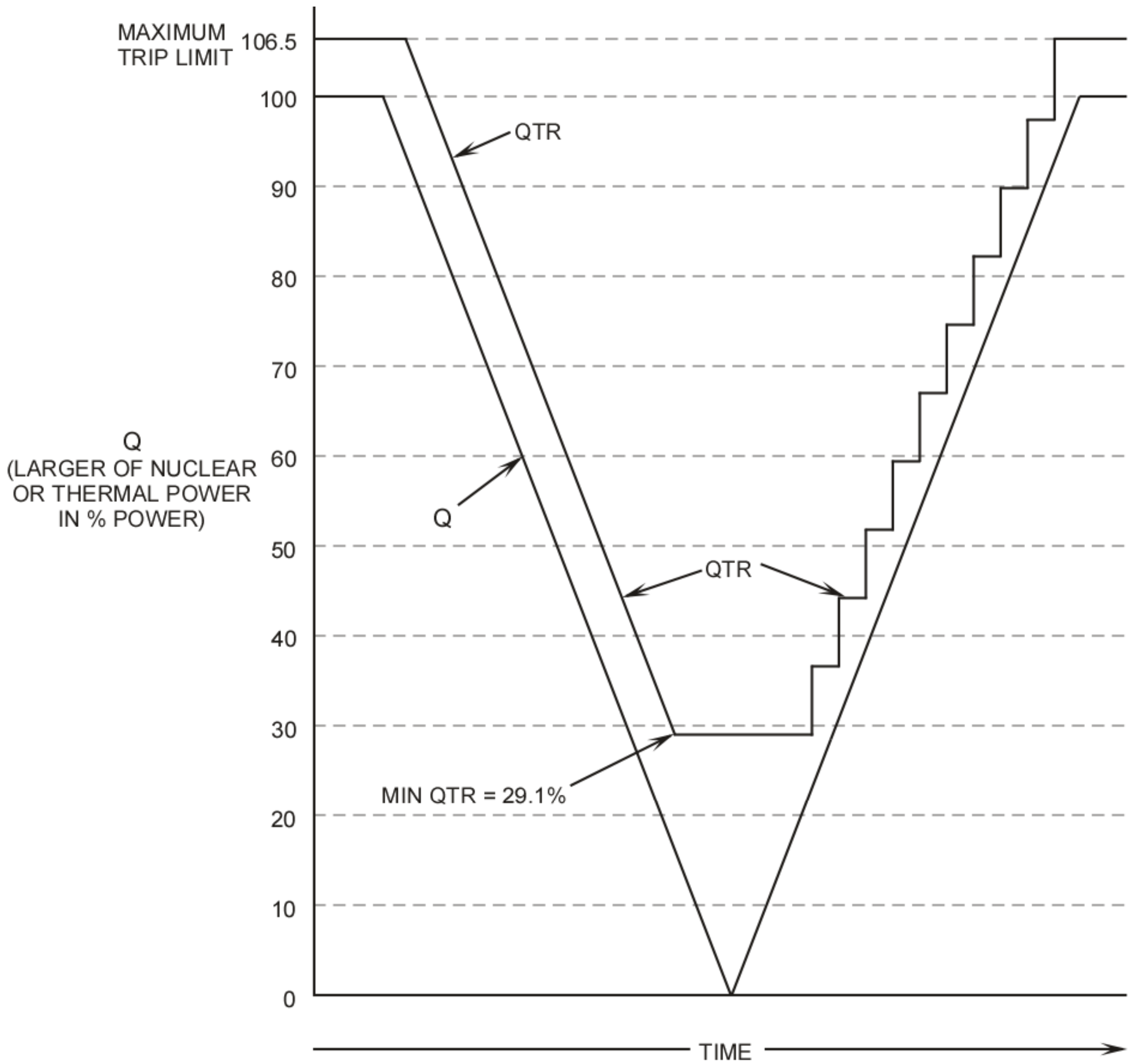


Figure 10.1-3 Variable High power Trip Operation

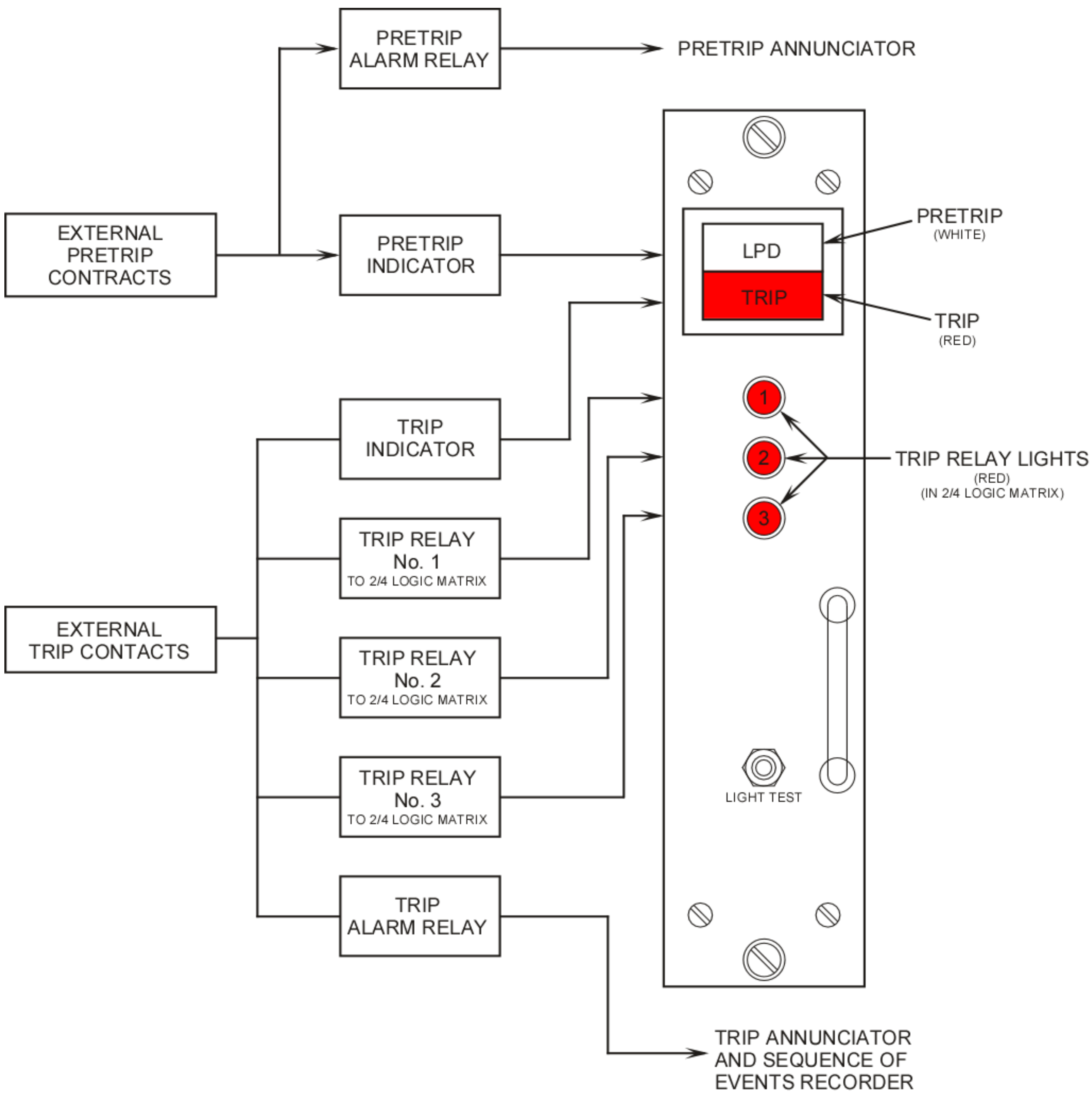


Figure 10.1-4 Auxiliary Trip Unit

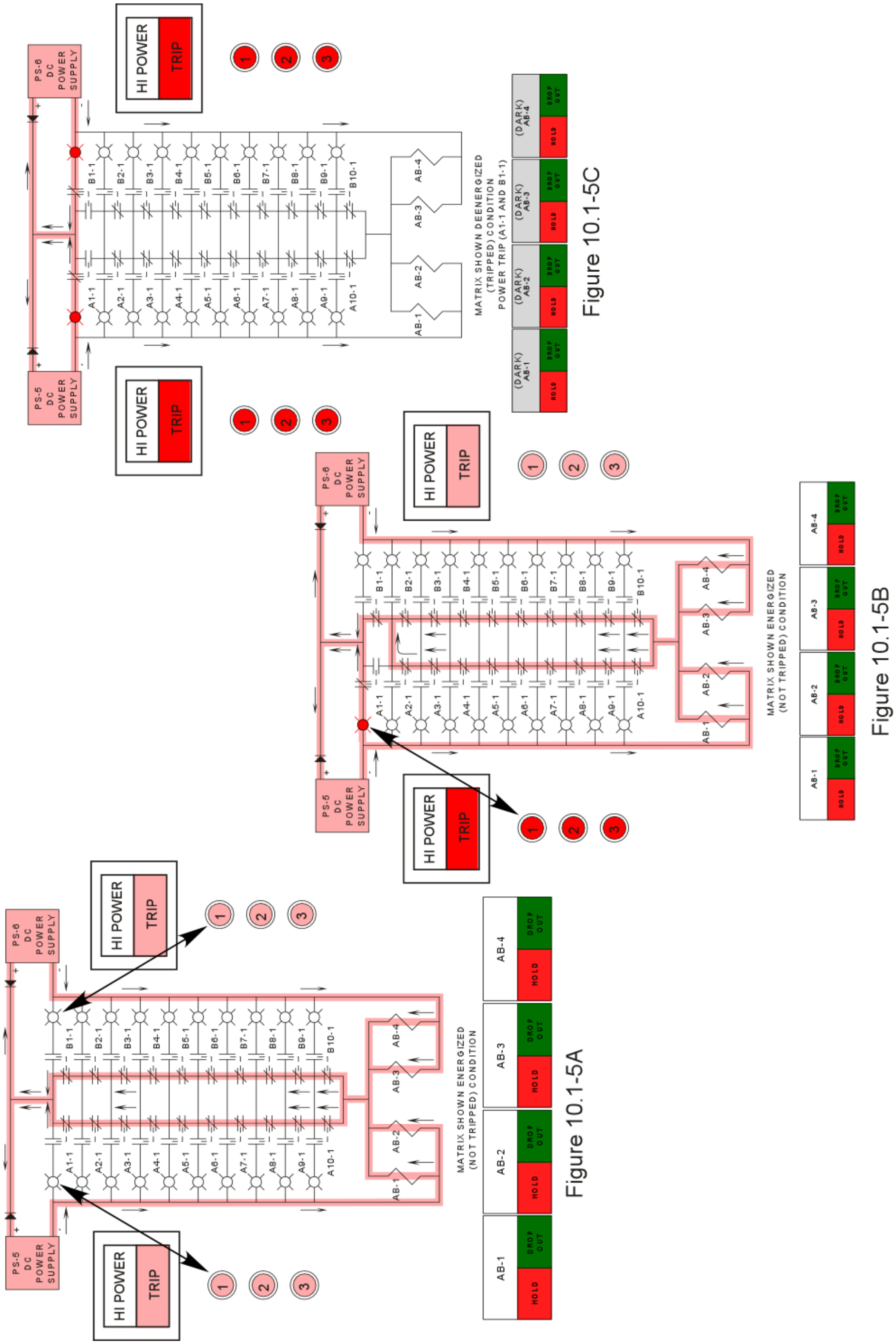


Figure 10.1-5 Coincidence Logic Matrix AB

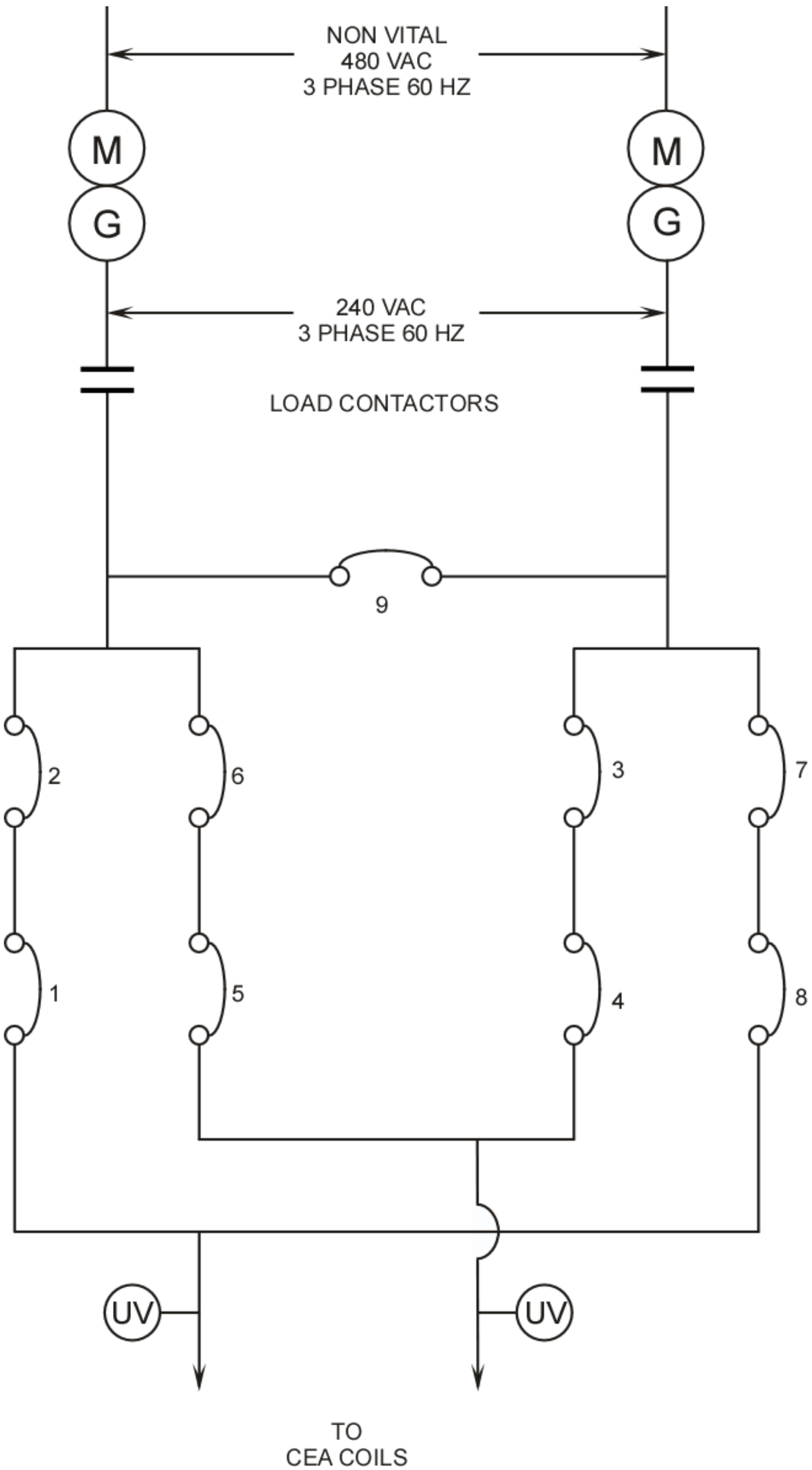


Figure 10.1-6 CEA Power Supply

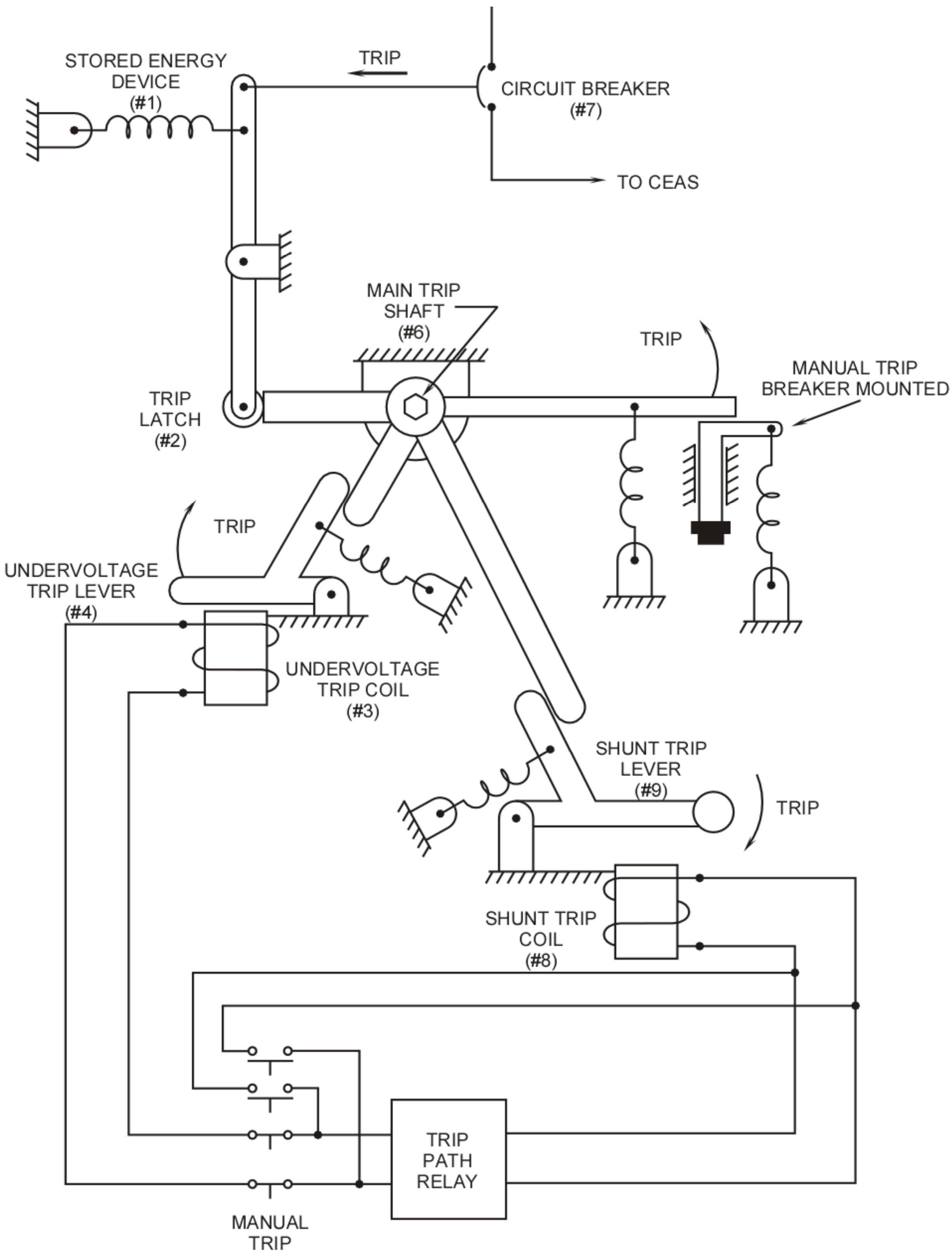


Figure 10.1-7 Reactor Trip Breaker

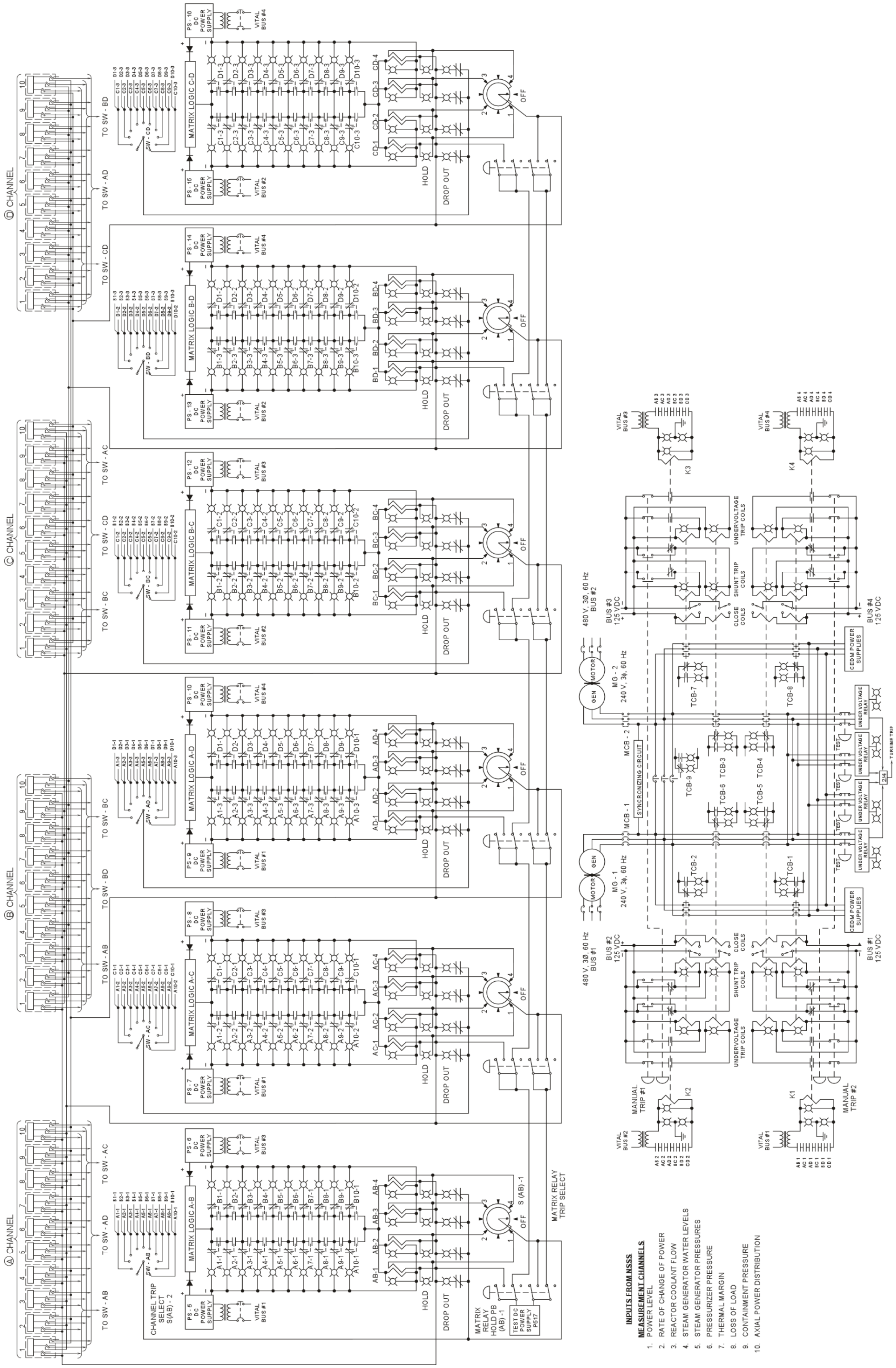


Figure 10.1-8 Reactor Protection System Functional Diagram