1. COMBUSTION ENGINEERING RPS SYSTEM DESCRIPTION

1.1 System Configurations

Four generic RPS configurations represent all Combustion Engineering plants. Each plant's RPS closely matches one of these four generic configurations. Among the individual plants, there are only minor variations of hardware and test practices. The most significant of these are noted in the applicable parts of the text. Table 1-1 shows which plants are grouped into the generic designs.

Table 1-1. Combustion Engineering RPS configuration table.

Plant Name	RPS Group
Palisades	1
Fort Calhoun	1
Calvert Cliffs 1, 2	2
Maine Yankee	2
Millstone 2	2
St. Lucie 1, 2	2
Arkansas 2	3
San Onofre 2, 3	3
Waterford 3	3
Palo Verde 1, 2, 3	4

The most important differences between these four RPS configurations are the use of analog or digital core protection calculators and the trip breaker configuration. Table 1-2 shows the four groups and the combinations that define these groups.

Table 1-2. Combustion Engineering RPS group descriptions.

RPS Group	Core Protection Calculator Type	Trip Breaker Configuration
1	Analog thermal margin/low pressure setpoint Calculator	Four trip contactors (relays)
2	Analog thermal margin/low pressure setpoint Calculator	Eight reactor trip breakers
3	Digital core protection calculator	Eight reactor trip breakers
4	Digital core protection calculator	Four reactor trip breakers

1.2 System Segment Description

The Combustion Engineering RPS is a complex control system comprising numerous electronic and mechanical components that combine in the ability to produce an automatic or manual rapid shutdown of the nuclear reactor, known as a reactor trip or scram. In spite of its complexity, the Combustion Engineering RPS components can be roughly divided into four segments—channels, trip matrices, trip breakers/relays/contactors, and rods—as shown in Table 1-3.

Table 1-3. Segments of Combustion Engineering RPS.

RPS Segments				
RPS Group	Channel	Trip Matrices	Trip Breakers/Relays/ Contactors	Rods
1	Four channels (A – D). Each channel includes bistables and instrumentation to measure plant parameters. Thermal margin is calculated with an analog device.	Six trip matrices. Each trip matrix consists of contacts from two channel bistables and four output relays. Each output relay opens a contact in one of four initiation relays (M-1 to M-4). One out of six trip matrices is sufficient to trip the reactor trip switchgear.	Relays M-1 to M-4, also called trip contactors, open contacts in line with the CEDM power supplies.	Rod groups de-energized on successful RPS actuation.
2	Four channels (A – D). Each channel includes bistables and instrumentation to measure plant parameters. Thermal margin is calculated with an analog device.	Six trip matrices. Each trip matrix consists of contacts from two channel bistables and four output relays. Each output relay opens a contact in one of four initiation relays (K-1 to K-4). One out of six trip matrices is sufficient to trip the reactor trip switchgear.	Relays K-1 to K-4 open contacts in line with the eight trip circuit breakers.	Rod groups de-energized on successful RPS actuation.
3	Four channels (A – D). Each channel includes bistables and instrumentation to measure plant parameters. Thermal margin is calculated with a digital device.	Six trip matrices. Each trip matrix consists of contacts from two channel bistables and four output relays. Each output relay opens a contact in one of four initiation relays (K-1 to K-4). One out of six trip matrices is sufficient to trip the reactor trip switchgear.	Relays K-1 to K-4 open contacts in line with the eight trip circuit breakers.	Rod groups de-energized on successful RPS actuation.
4	Four channels (A – D). Each channel includes bistables and instrumentation to measure plant parameters. Thermal margin is calculated with a digital device.	Six trip matrices. Each trip matrix consists of contacts from two channel bistables and four output relays. Each output relay opens a contact in one of four initiation relays (K-1 to K-4). One out of six trip matrices is sufficient to trip the reactor trip switchgear.	Relays K-1 to K-4 open contacts in line with the four trip circuit breakers.	Rod groups de-energized on successful RPS actuation.

There are typically 89 control element assemblies (CEAs) grouped for control and safety purposes into nine banks (five regulating banks, two shutdown banks, and two part-length banks). Typical rod banking is shown in Table 1-4. The trip breakers/ trip contactors interrupt power to the control element assembly drive mechanisms (CEDM). When power is removed, the roller nuts disengage from the lead screw, allowing gravity to insert the control rod assembly.

Table 1-4. Typical rod banking arrangement.

CEA Type	Number of Control Element Assemblies
Shutdown 12-element full length CEA	Shutdown bank A – 16 Shutdown bank B – 20
12-element full length CEA	12
4-element full length CEA	28
4-element part length CEA (not held by the magnetic clutches)	13
Total	89
Total held by RPS	76

The shutdown banks A and B contain approximately 76 percent of the total rod worth and are sufficient to ensure shutdown at the beginning of life and at the end of life of the reactor core. SECY-83-293, Enclosure D, Appendix A. describes a rod failure criterion. In this reference, *rod success* is defined for all PWRs as the insertion of one-half or more of the control rods into the core in a roughly checkerboard pattern. For the purposes of this study, we will require 20 percent, 7 rods total, to fully insert to ensure shutdown. Appendix G presents a range of rod failure criteria and the effect on the overall RPS unavailability.

The shutdown banks A and B contain approximately 76 percent of the total rod worth and are sufficient to ensure shutdown at the beginning of life and at the end of life of the reactor core. Consistent with previous studies, the reported RPS unavailability is based on a rod success criterion of 20 percent. As noted in the statement of considerations (49FR26036) for the ATWS reduction rule (10CFR50.62), the insertion of 20 percent of the shutdown rods is needed to achieve hot, zero power provided that the inserted rods are suitably uniformly distributed. To demonstrate the effect of selecting a different rod success criterion, the overall RPS unavailability was computed for a range of rod failure percentages. The results of this sensitivity study are presented in Appendix G.

1.3 System Operation

The RPS system as shown in Figure 1-1 through Figure 1-3 consists of four identical protective channels. Each protective channel contains between ten and sixteen measurement channels, each capable of initiating protective actions by actuating a bistable. Each bistable includes three relays (included within the bistable component). The relay contacts are in three of the six logic matrices combined with relay contacts from one other channel in a two-out-of-two logic. When both channels trip, the logic matrix de-energizes removing power from the four matrix output relays. The four output relays open contacts supplying power to relays K-1, 2, 3, and 4 (M-1, 2, 3, and 4 in RPS Group 1). The trip parameters are shown in Table 1-5.

Figure 1-4 through Figure 1-8 show the logic of the four RPS-group designs.

1.3.1 Group 1 Trip Contactor Logic

Relays M-1 and M-2 contain contacts that supply ac power to two CRD clutch power supplies on one side of the two clutch power busses. Similarly, relays M-3 and M-4 contain contacts that supply ac power to the CRD clutch power supplies on the opposite side of the two clutch power buses. When the dc power supplies to a clutch power bus on both sides and are de-energized, the magnetic clutch holding coils release the full-length CEAs.

Either relay M-1 or M-2 is sufficient to remove ac power from one side of the CRD clutch power buses. Similarly, either relay M-3 or M-4 is sufficient to remove ac power from the other side of the CRD clutch power buses. Power must be removed from both sides of the CRD clutch buses in order to de-energize the magnetic clutch holding coils and release the full-length rods.

A reactor trip is accomplished by de-energizing the CEDM coils, allowing the shutdown and regulating CEAs to drop into the core by gravity.

1.3.2 Groups 2 and 3 Trip Circuit Breaker Logic

Relays K-1 through K-4 contain contacts that provide actuation of the undervoltage and shunt trips of the eight trip circuit breakers. De-energizing any one trip breaker control relay (K-x) opens one trip path and opens the two breakers controlled by that trip path.

The CEDMs are separated into two groups. The CEDM power supplies in each group are supplied with parallel ac power. The loss of either set does not cause a release of the CEAs. Each power supply source is separated into two branches. Each side of each branch line passes through two trip circuit breakers (each actuated by a separate trip path) in series so that, although both sides of the branch lines must be de-energized to release the CEAs, there are two separate means of interrupting each side of the line.

A reactor trip is accomplished by de-energizing the CEDM coils, allowing the shutdown and regulating CEAs to drop into the core by gravity.

1.3.3 Group 4 Trip Circuit Breaker Logic

Relays K-1 through K-4 contain contacts that provide actuation of the undervoltage and shunt trips of the four trip circuit breakers. De-energizing of any one trip breaker control relay (K-x) opens one trip path and opens the breaker controlled by that trip path.

The CEDMs are separated into two groups, but are supplied ac power from the same parallel power arrangement. The loss of either set does not cause a release of the CEAs. Each side of the branch lines pass through two trip circuit breakers (each actuated by a separate trip path) in series so that, although both sides of the branch lines must be de-energized to release the CEAs, there are two separate means of interrupting each side of the line.

A reactor trip is accomplished by de-energizing the CEDM coils, allowing the shutdown and regulating CEAs to drop into the core by gravity.

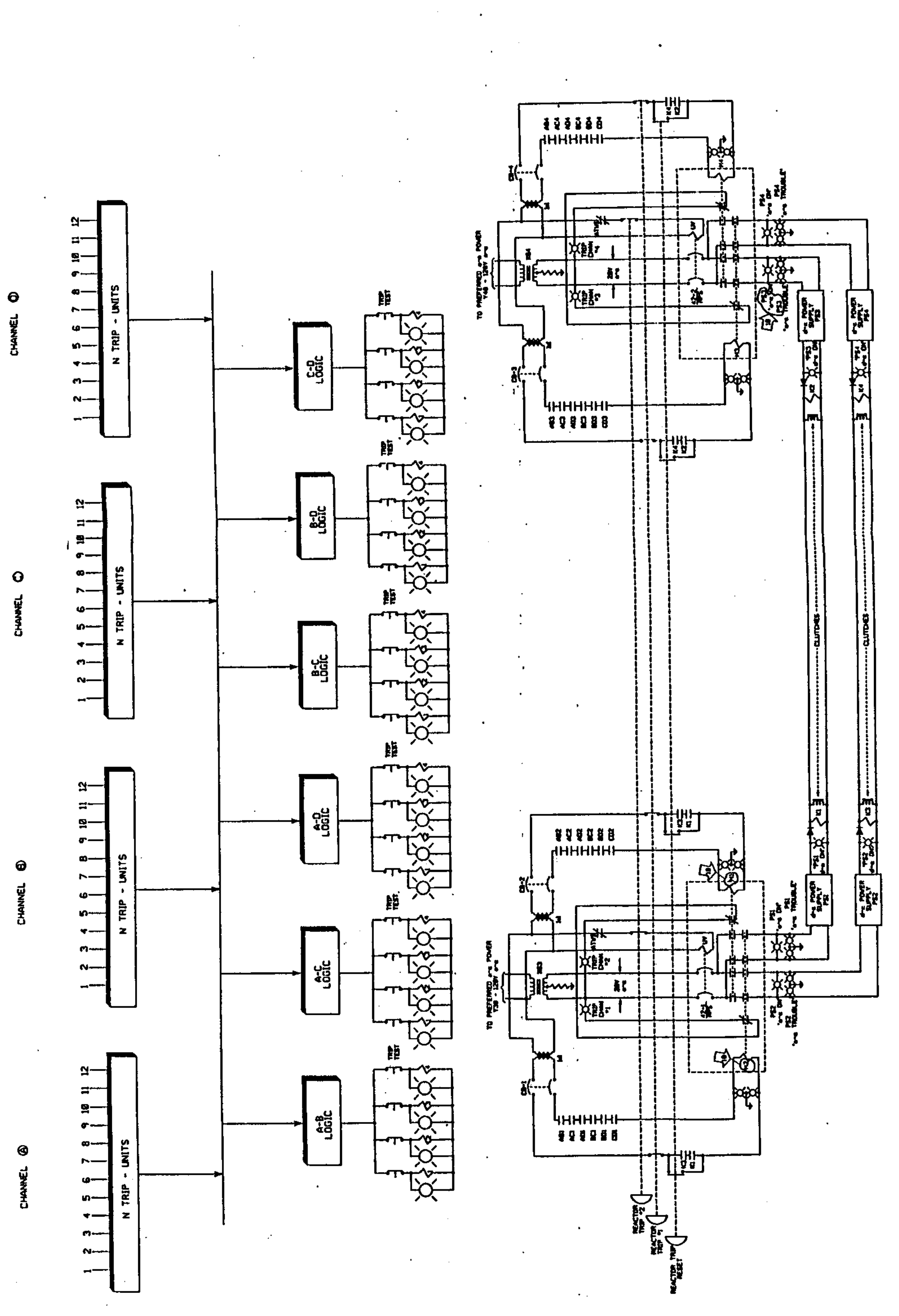

Figure 1-1. Group 1 Combustion Engineering RPS simplified schematic.

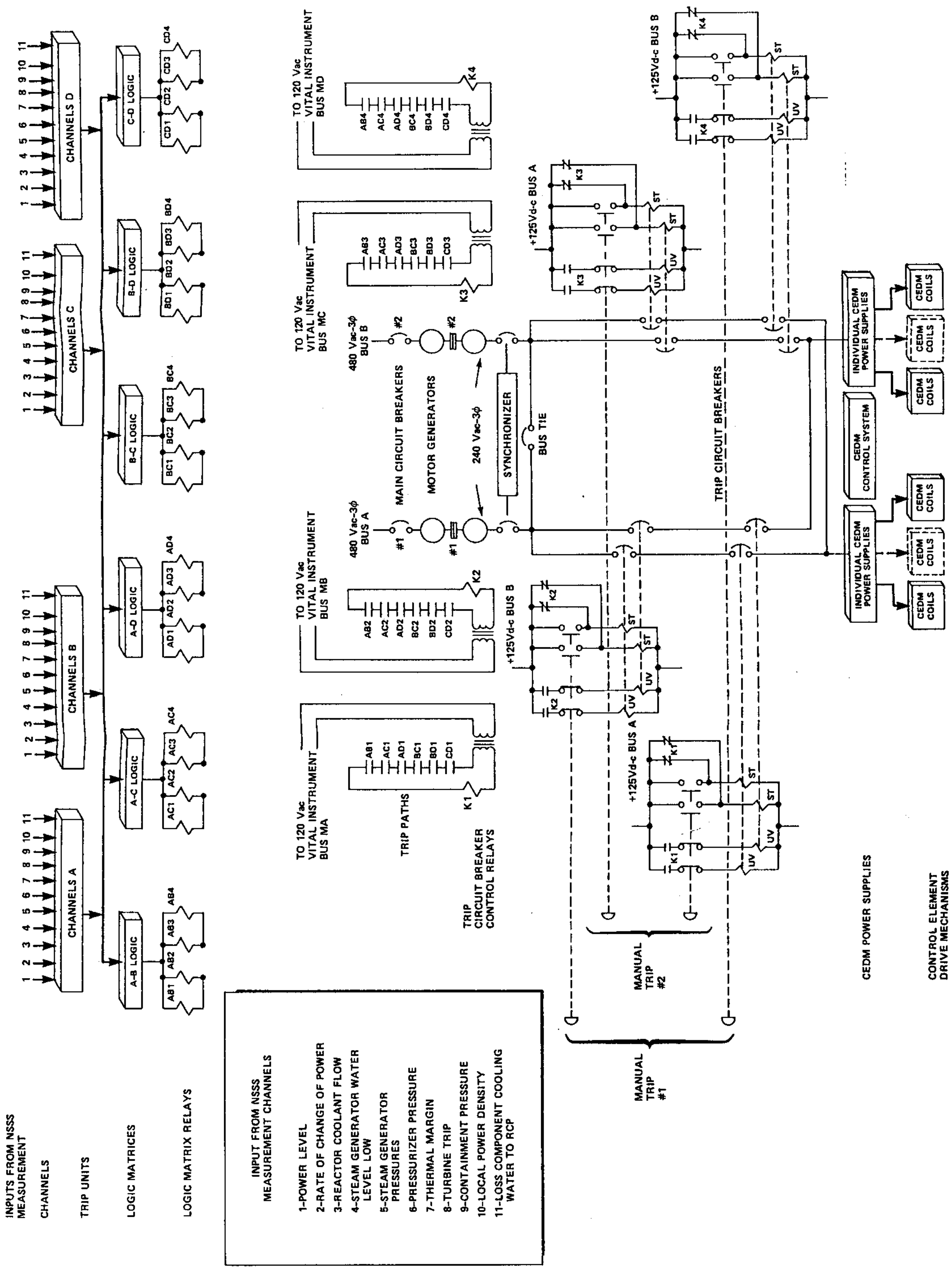

Figure 1-2. Groups 2 and 3 Combustion Engineering RPS simplified schematic.

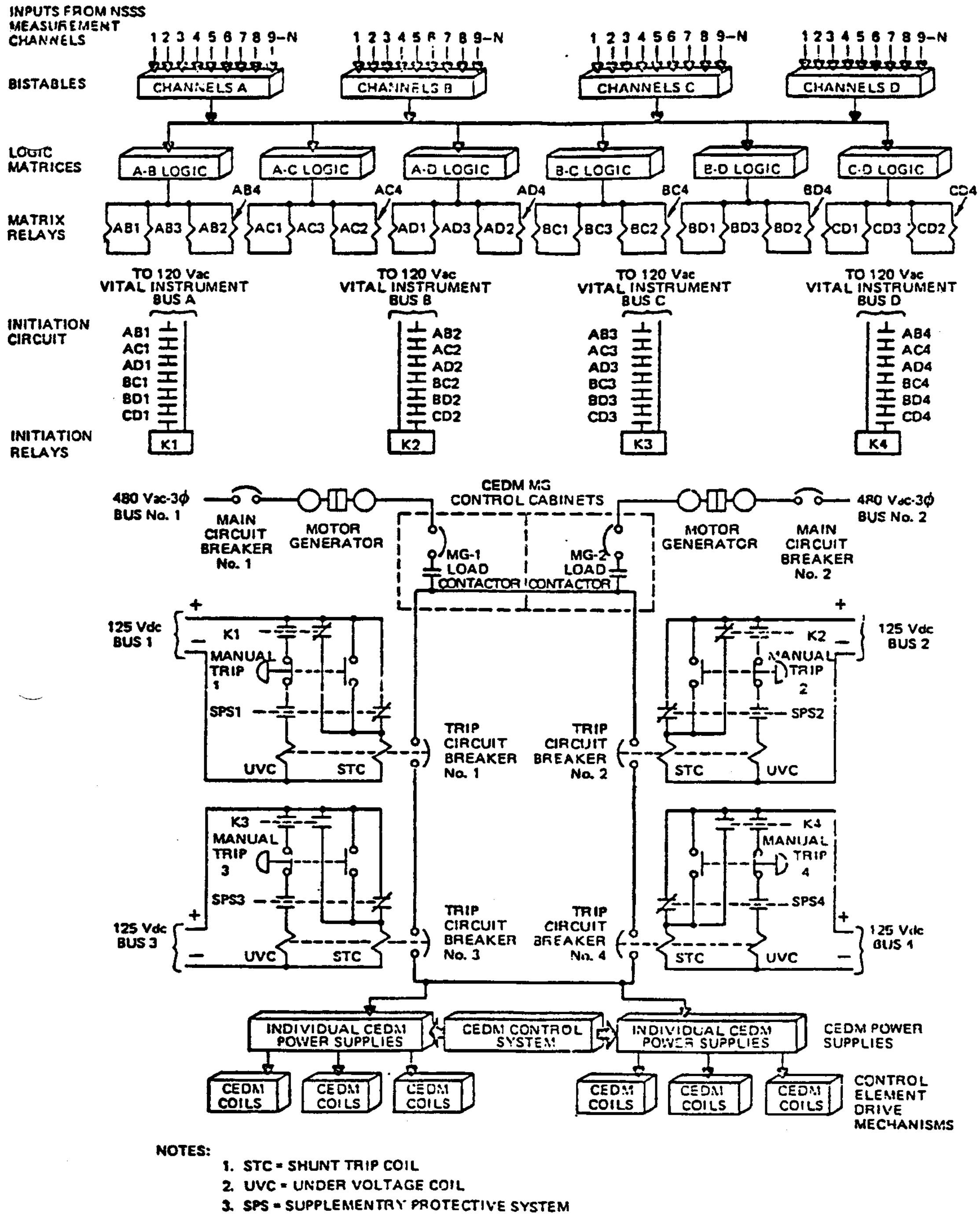

Figure 1-3. Group 4 Combustion Engineering RPS simplified schematic.

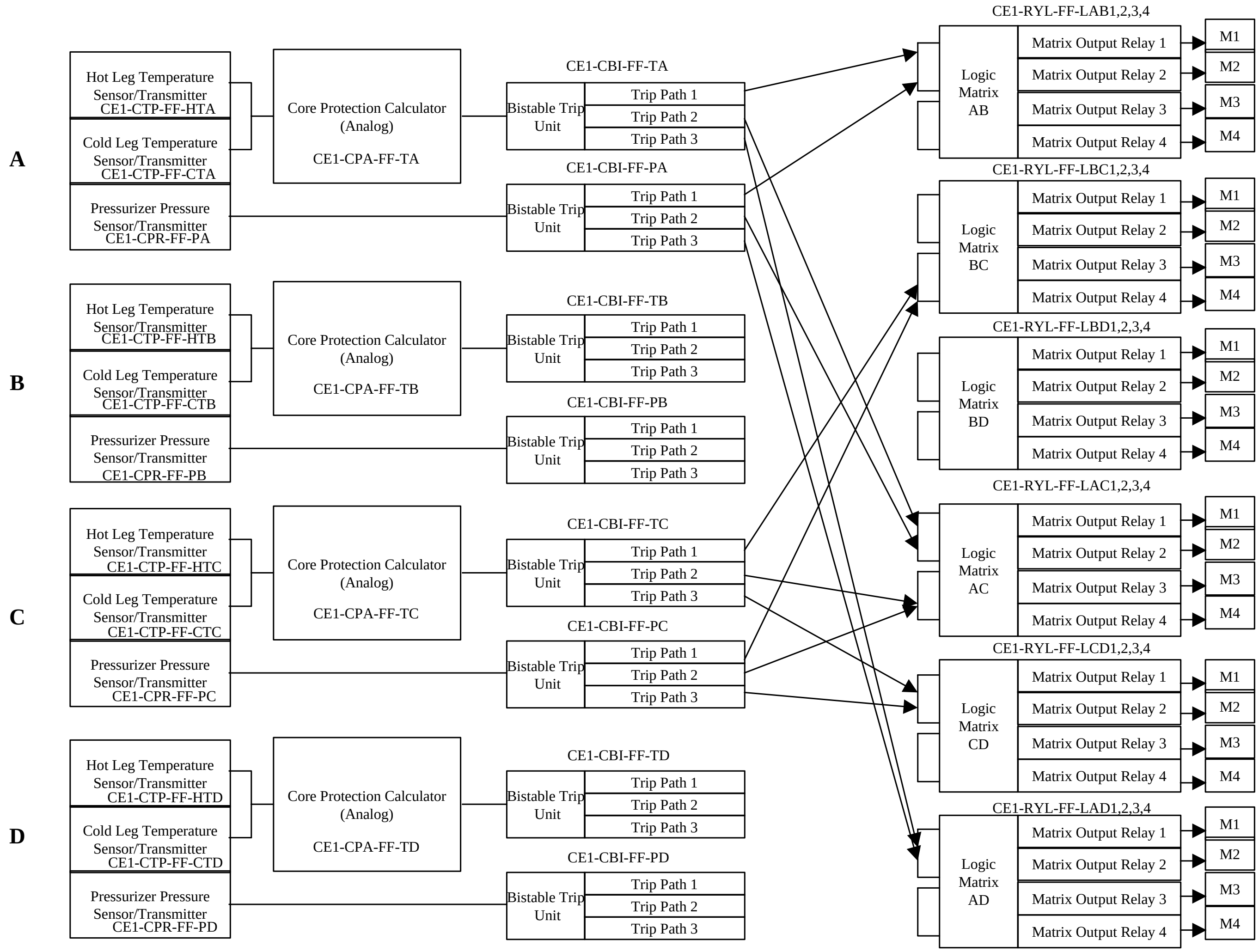

Figure 1-4. Group 1 Combustion Engineering RPS simplified diagram.

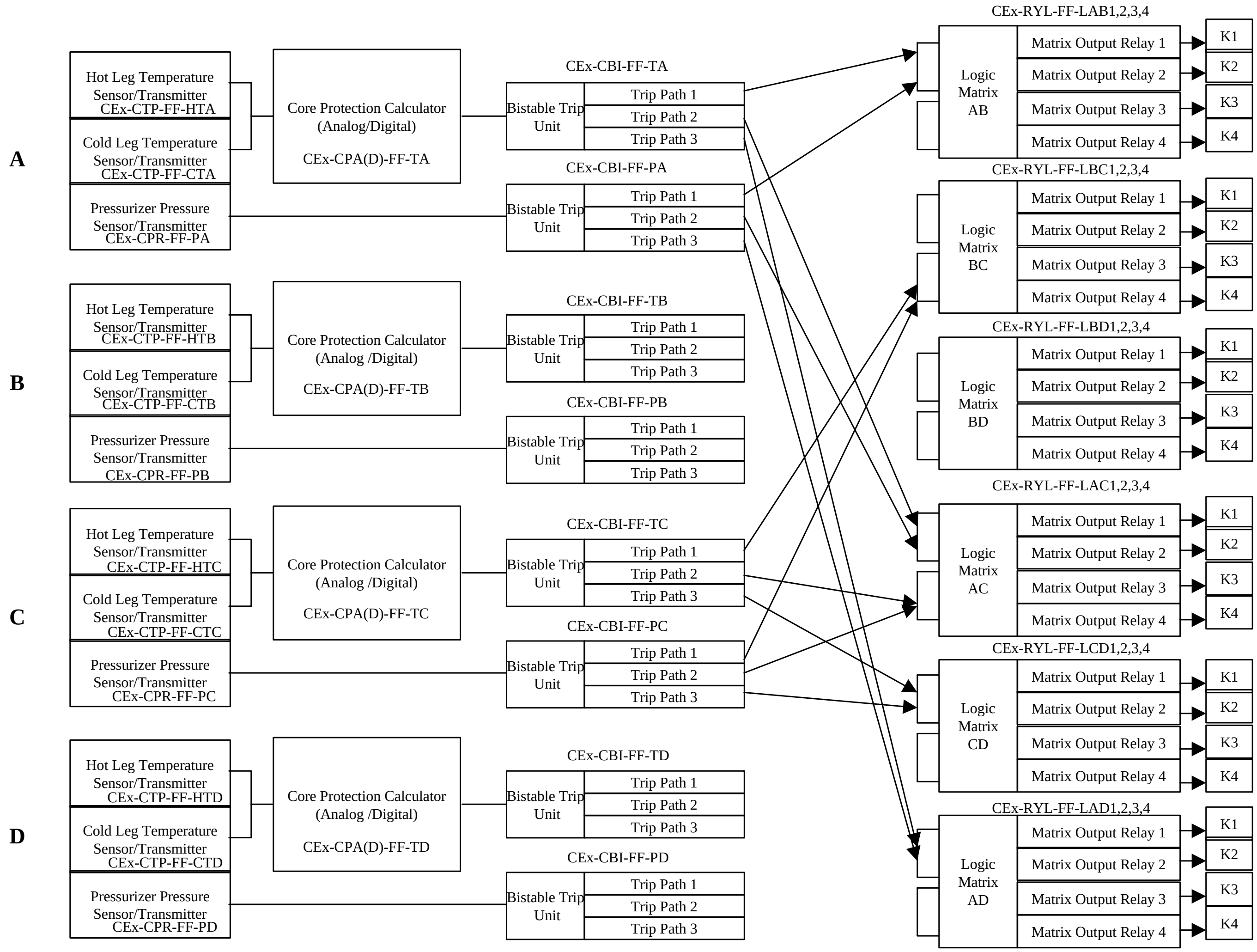

Figure 1-5. Groups 2, 3, and 4 Combustion Engineering RPS simplified diagram.

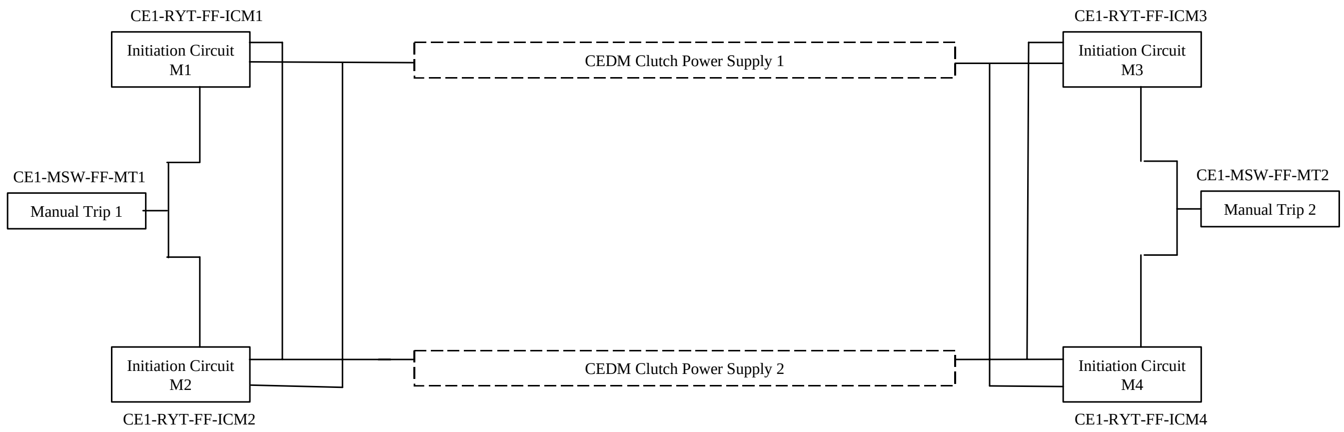

Figure 1-6. Group 1 Combustion Engineering RPS trip contactor and control element assemblies simplified diagram.

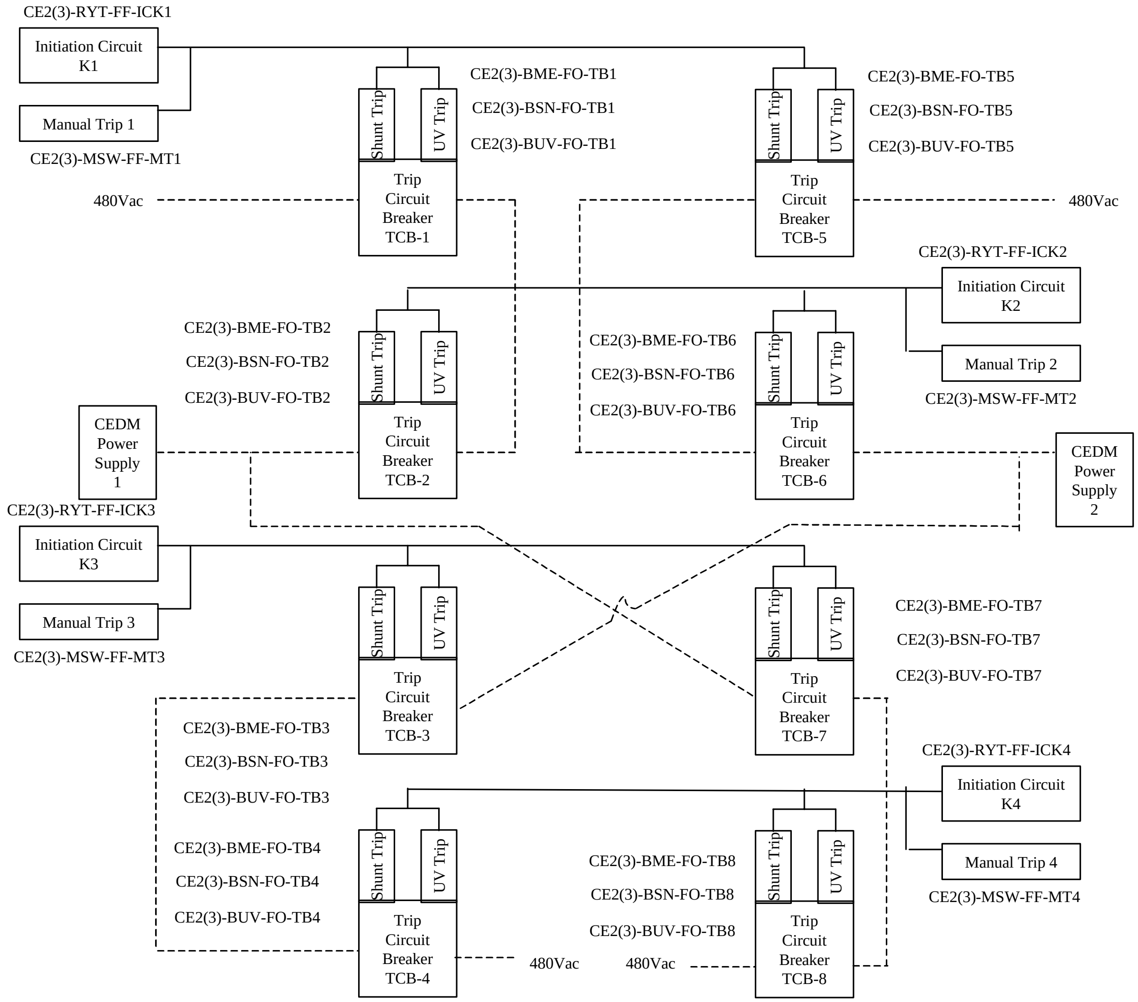

Figure 1-7. Group 2 & 3 Combustion Engineering RPS trip circuit breaker and control element assemblies simplified diagram.

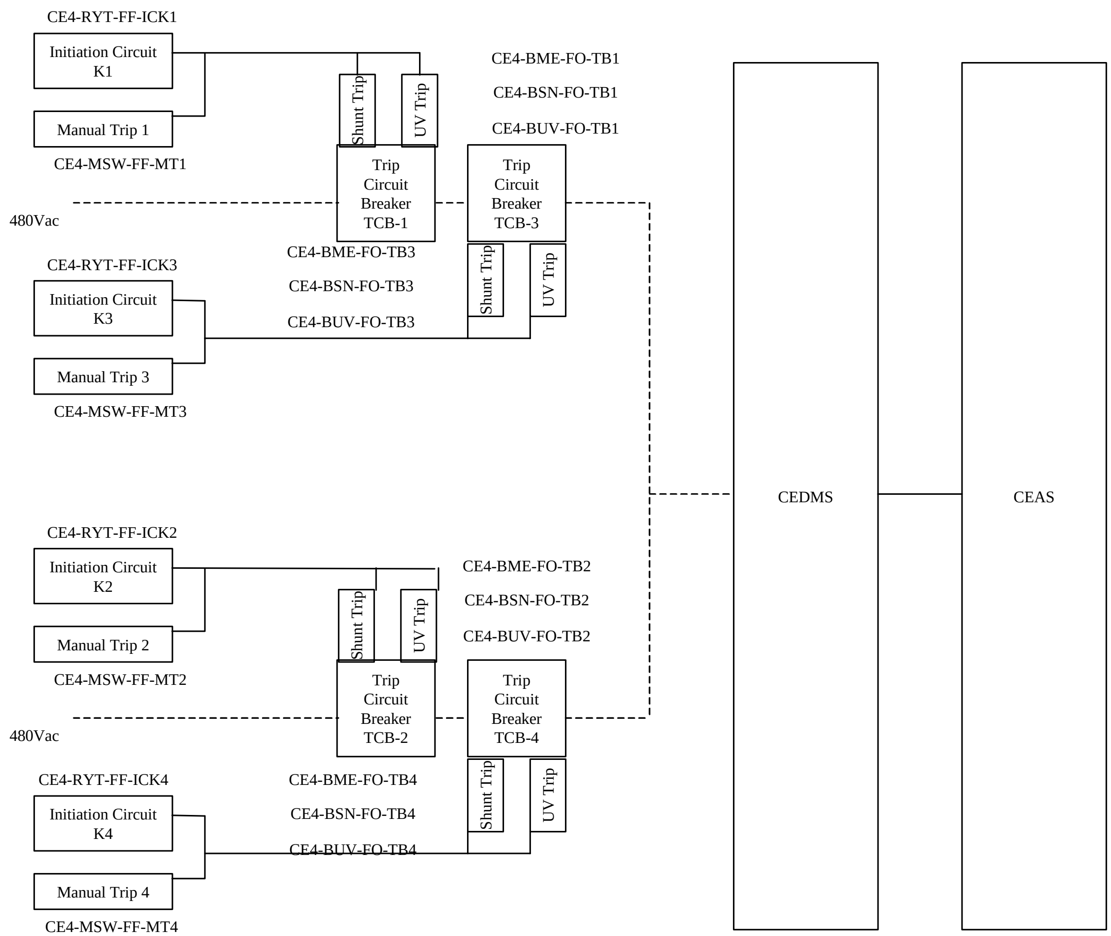

Figure 1-8. Group 4 Combustion Engineering RPS trip circuit breaker and control element assemblies simplified diagram.

Table 1-5. Generic Combustion Engineering RPS trip signals.

Trip Signal	Trip Logic	Purpose of Trip
1. High linear power	2-out-of-4 Coincident	Trip the reactor in the event of a reactivity excursion too rapid to be mitigated by the high-pressure trip without damage.
2. High thermal margin/low pressure [a]	2-out-of-4 Coincident	Two purposes: the thermal margin portion of the trip, in conjunction with the low reactor coolant flow trip, prevents violation of the safety limit on DNB during anticipated transients. The low-pressure portion of the trip functions to trip the reactor in case of a LOCA.
3. High local power density	2-out-of-4 Coincident	Prevent peak local power density in the fuel from exceeding limits.
4. High pressurizer pressure [a]	2-out-of-4 Coincident	Prevent excessive blowdown of the RCS by relief action through the pressurizer safety valves.
5. Low steam generator level	2-out-of-4 Coincident	Protect the reactor coolant system in case of a loss of feedwater and resultant loss in heat sink.
6. Low steam generator pressure	2-out-of-4 Coincident	Protect the RCS from the excessive rate of heat extraction from a steam line break.
7. Low reactor coolant flow	2-out-of-4 Coincident	Protect the core against exceeding departure from nucleate boiling (DNB).
8. High containment pressure	2-out-of-4 Coincident	Assure the trip of the reactor is concurrent with safety injection actuation.
9. Loss of load	2-out-of-4 Coincident	Minimize primary system upset on turbine trip.

a. These two signals are modeled in the RPS fault tree used for this study.