1. BABCOCK & WILCOX RPS SYSTEM DESCRIPTION

1.1 System Configurations

Two generic RPS configurations are representative of all Babcock & Wilcox plants. Each plant's RPS closely matches one of these two generic configurations. Among the individual plants there are only minor variations of hardware and test practices and the most significant of these are noted in the applicable parts of the text. These two designs are based on the Davis-Besse RPS design and the Oconee RPS design. Table 1-1 shows which plants are grouped into the generic designs:

Table 1-1. Babcock & Wilcox RPS configuration table.

Plant Name	Design Group
Oconee Units 1, 2, and 3	Oconee
Three Mile Island Unit 1	Oconee
Crystal River Unit 3	Oconee
Arkansas Unit 1	Oconee
Davis-Besse	Davis-Besse

The RPS trips the reactor by removing holding power from the control rod drive motors (CRDMs). Each holding power supply receives dc power from a Main and a Secondary power source. In order to release the rods, both the main and secondary power supplies must be interrupted. This is accomplished by either; opening trip breakers on both power supplies or by removing gating power (gating power controls the operation of the SCRs to move or hold the rods) from the silicon-controlled rectifiers (SCRs).

The most important difference between these RPS configurations is the trip breaker and SCR configurations. The Oconee design uses two ac trip breakers (one on each power supply to all the CRDMs) and four dc trip breakers (each dc trip breaker consists of two dc contacts). The dc trip breakers supply holding power to CRDMs on the safety rod groups 1–4. The four dc trip breakers are arranged so that each breaker supplies one side of the power to two safety rod group CRDM holding power supplies. The diverse electronic trip in the Oconee design removes gating power to the SCRs that provide holding power to the regulating rods.

The Davis-Besse design uses four ac trip breakers (two in series on each holding power supply to the CRDMs). These supply power to the CRDMs of control rod groups 1–8. The Davis-Besse design also provides a diverse electronic trip to all rod groups utilizing the SCRs, which remove gating power to the SCRs that provide holding power to all rods.

1.2 System Segment Description

The Babcock & Wilcox RPS is a complex control system comprising numerous electronic and mechanical components that combine to provide 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 Babcock & Wilcox RPS components can be roughly divided into four segments—channels, trip modules, trip breakers/diverse trip, and rods—as shown in Table 1-2.

Table 1-2. Segments of Babcock & Wilcox RPS.

RPS Group	RPS Segments: Channels	Trip Modules	Trip Breakers/Diverse Trip	Rods
Oconee	Four channels (A–D). Each channel includes instrumentation and bistables to measure plant parameters provide a trip output.	Four trip modules, one for each channel. Each trip module consists of four relays energized by each of the four channels. The relays are configured so that any two-out-of-four will trip its associated breaker(s) or SCR relays.	Two ac breakers and four dc breakers. Each breaker consists of the mechanical portion, the undervoltage device, and shunt trip device. Channels C & D remove gating power from SCRs in rod groups 5, 6, and 7 for the diverse electronic trip.	Rod groups 1–4 de-energized on successful RPS actuation. Rod groups contain 8–12 rods. The diverse electronic trip uses rod groups 5, 6, and 7.
Davis-Besse	Four channels (A–D). Each channel includes instrumentation and bistables to measure plant parameters provide a trip output.	Four trip modules, one for each channel. Each trip module consists of four relays energized by each of the four channels. The relays are configured so that any two-out-of-four will trip its associated breaker or SCR relays.	Four ac trip breakers. Two in series for each CRDM power supply. Each breaker consists of the mechanical portion, the undervoltage device, and shunt trip device. Channels C & D remove gating power from SCRs in Rod groups 1–8 for the diverse electronic trip.	Rod groups 1 – 8 de-energized on successful RPS actuation. Rod groups contain 8–12 rods.

There are typically 69 control rod assemblies grouped for control and safety purposes into eight groups. Four rod-groups function as safety groups, three rod-groups function as regulating rods, and one group serves to regulate axial power peaking. A typical rod grouping is shown in Table 1-3. The trip breakers interrupt power to the CRD mechanisms. When power is removed, the roller nuts disengage from the lead screw allowing gravity to insert the control rod assembly.

One rod group has been shown to maintain the Reactor Coolant System pressure below the ASME Service Condition C limits (approximately 3000 psi) for anticipated transients evaluated by Anticipated Transient Without Scram (ATWS) studies.[i] Consistent with previous studies, the reported RPS unavailability is based on a safety 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 control rods is needed to achieve hot, zero power provided that the inserted rods are suitably uniformly distributed. This is more conservative than the ASME Service Condition C limits. 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.

Table 1-3. Typical rod grouping arrangement.

Group Identifier	Number Of Control Rod Assemblies
Safety Group 1	8
Safety Group 2	12
Safety Group 3	9
Safety Group 4	12
Regulating Group 5	12
Regulating Group 6	4
Regulating Group 7	4
Axial Power Shaping Group 8	8
Total	69

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1.3 System Operation

The RPS system as shown in Figure 1-1 (Oconee) and Figure 1-2 (Davis-Besse) consists of four identical protective channels, each terminating in a trip relay within a reactor trip module. In the normal untripped state, each protective channel passes current to the channel trip relay holding it energized as long as all inputs are in the normal energized (untripped) state. Should any one or more inputs become de-energized (tripped), the channel trip relay in that protective channel de-energizes. Each channel trip relay controls power to one of four trip module relays in its own channel and one in each other channel. When the trip relay de-energizes, each corresponding trip module relay de-energizes, opening two of eight contacts in each trip module. It will take at least one more channel trip relay to complete a trip signal to the breakers.

The channel portion of the RPS, channels A through D, includes many different types of trip signals, as shown in Table 1-4. The trip signals include various neutron flux indications, reactor pressure, temperature, flow, primary containment pressure, and others. Most of the signals involve four sensor/transmitters (or process switches). Shown in the simplified RPS diagrams in Figure 1-3 and Figure 1-5 are sensor/transmitters and trip units associated with the reactor vessel high pressure and high temperature trip signals. (These two signals, along with others, are appropriate for several plant upset conditions, such as main steam isolation valve (MSIV) closure, loss of feedwater, and various losses of electrical loads.) Also shown in the figures are the manual scram switches. The sensor/transmitters are located throughout the plant, while the bistable trip units and relays are located in the RPS cabinets in the control room. A loss of electrical power to a sensor/transmitter or bistable trip unit would result in a trip signal.

The reactor trip modules are given the same designation as the protective channel whose trip relay they contain and in whose cabinet they are physically located. Thus, the protective channel A reactor trip module is located in protective channel A cabinet, etc. The coincidence logic in each reactor trip module controls one breaker in the control rod drive (CRD) power system. Channels C and D also control gating power to SCRs through another set of relays.

1.3.1 Oconee Group Breaker Logic.

Figure 1-1 shows a simplified diagram of the Oconee RPS system and Figure 1-3 shows a functional logic diagram of the Oconee RPS system. The coincidence logic contained in RPS channel A reactor trip module controls breaker A in the CRD. Channel B reactor trip module controls breaker B, channel C reactor trip module controls dc breaker pair C1 and C2, and channel D reactor trip module controls dc breaker pair D1 and D2. In addition, channels C and D control gating power to silicon-controlled rectifiers (SCRs). Breakers A and B control all the 3-phase main and secondary power to the CRDs. Breakers C1, C2, D1, and D2 control the dc power to rod groups 1 through 4. The diverse electronic trip uses relays to remove gating power from SCRs that control the regulating rod groups 5 through 7.

The undervoltage coils of the CRD breakers receive their power from the protective channel associated with each breaker. The manual reactor trip switch is interposed in series between each reactor trip module logic and the assigned breaker's undervoltage coil.

Each reactor trip breaker contains a relay installed with its operating coil in parallel with the existing undervoltage device. The output contacts of these relays control the power to the shunt trip devices. Thus, when power is removed from the breaker undervoltage trip attachment on either a manual or automatic trip signal, the shunt trip attachment is energized to provide an additional means to trip the breaker.

The Oconee electronic SCR trip is shown in Figure 1-4. The electronic SCR trip is a diverse means of interrupting power to the CRDMs. The CRD control system is made up of nine power supplies. Four of these power supplies supply power to the safety rod groups 1 – 4. Four of these power supplies supply power to the regulating rod groups 5 – 7 and the axial shaping rods (group 8). One of the power supplies is the auxiliary power supply, which is used for control of selected rods in place of the group power supplies. The electronic SCR trip removes gating power to the regulating rods (groups 5 – 7) by the trip of channels C and D.

The electronic SCR trip does not remove power from the safety rod groups and instead removes power from the regulating rods. In the case where the trip of the safety rods is unavailable, and the electronic SCR trip functions, all regulating rods (groups 5 – 7, 20 rods) are assumed to be required to insert.

1.3.2 Davis-Besse Group Breaker Logic.

The coincidence logic contained in RPS channel A reactor trip module controls breaker A in the CRD system as shown in Figure 1-2, which shows a simplified diagram of the Davis-Besse RPS system and Figure 1-5, which shows a functional logic diagram of the Davis-Besse RPS system. Channel B reactor trip module controls breaker B, channel C reactor trip module controls breaker C, and channel D reactor trip module controls breaker D. In addition, channels C and D control gating power to SCRs. Breakers A, B, C, and D control all the three phase primary power to the CRDs. SCRs control the gating power to all rod groups as a diverse method of removing power from the CRDs.

The undervoltage coils of the CRD breakers receive their power from the protective channel associated with each breaker. The manual reactor trip switch is interposed in series between each reactor trip module logic and the assigned breaker's undervoltage coil.

Each reactor trip breaker contains a relay installed with its operating coil in parallel with the existing undervoltage device. The output contacts of these relays control the power to the shunt trip devices. Thus, when power is removed from the breaker undervoltage trip attachment on either a manual or automatic trip signal, the shunt trip attachment is energized to provide an additional means to trip the breaker.

The electronic SCR trip is shown in Figure 1-6. The electronic SCR trip is a diverse means of interrupting power to the CRDMs. The CRD control system is made up of nine power supplies. Four of these power supplies supply power to the safety rod groups 1 – 4. Four of these power supplies supply power to the regulating rod groups 5 – 7 and the axial shaping rods (group 8). One of the power supplies is the auxiliary power supply, which is used for control of selected rods in place of the group power supplies. SCRs are also used to control return power from all rod groups.

When Channel C sends a trip signal to trip breaker C, it also sends a trip signal to a group of ten relay coils (channel D functions similarly). The first nine of these coils control gating power to each of the nine power supplies. Both sides of power must be removed to disengage a rod group (e.g., relay C1 and D1 must open to disengage safety rod group 1). The tenth relay coil removes gating power from its corresponding return power SCR.

Table 1-4. Oconee RPS trip signals.

Trip Signal	Trip Logic	Purpose of Trip
1. Over power	2-out-of-4 coincidence	Prevent an inadvertent power increase at power
2. Nuclear over power based on flow and imbalance	2-out-of-4 coincidence	Prevent operation with a departure from nucleate boiling ratio (DNBR) <1.30
3. Reactor coolant pump power	2-out-of-4 coincidence	Redundant to low flow reactor trip
4. Reactor outlet temperature [a]	2-out-of-4 coincidence	Prevent operation with a DNBR <1.30
5. Pressure/Temperature	2-out-of-4 coincidence	Prevent excessive power density
6. Reactor coolant pressure [a]	2-out-of-4 coincidence	Protect integrity of the reactor coolant system (RCS) pressure boundary
7. Reactor building pressure	2-out-of-4 coincidence	Anticipate loss of coolant
8. Main turbine trip	2-out-of-4 coincidence	Minimize primary system upset on turbine trip
9. Loss of main feedwater	2-out-of-4 coincidence	Prevent loss of heat sink

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

1.3.3 Channel Bypass

A channel bypass is provided to allow maintenance and periodic testing to be performed on individual channels. When initiated, the channel bypass prevents the terminating relay of the bypassed channel from de-energizing (tripping). Therefore, when a channel is bypassed, the overall system trip coincidence is two-out-of-three. If two of the remaining three channels trip, all four RPS channels will de-energize their associated CRDM trip channels. The bypass is initiated using key-switches and when one channel is bypassed, an interlock prevents the other channels from being bypassed.

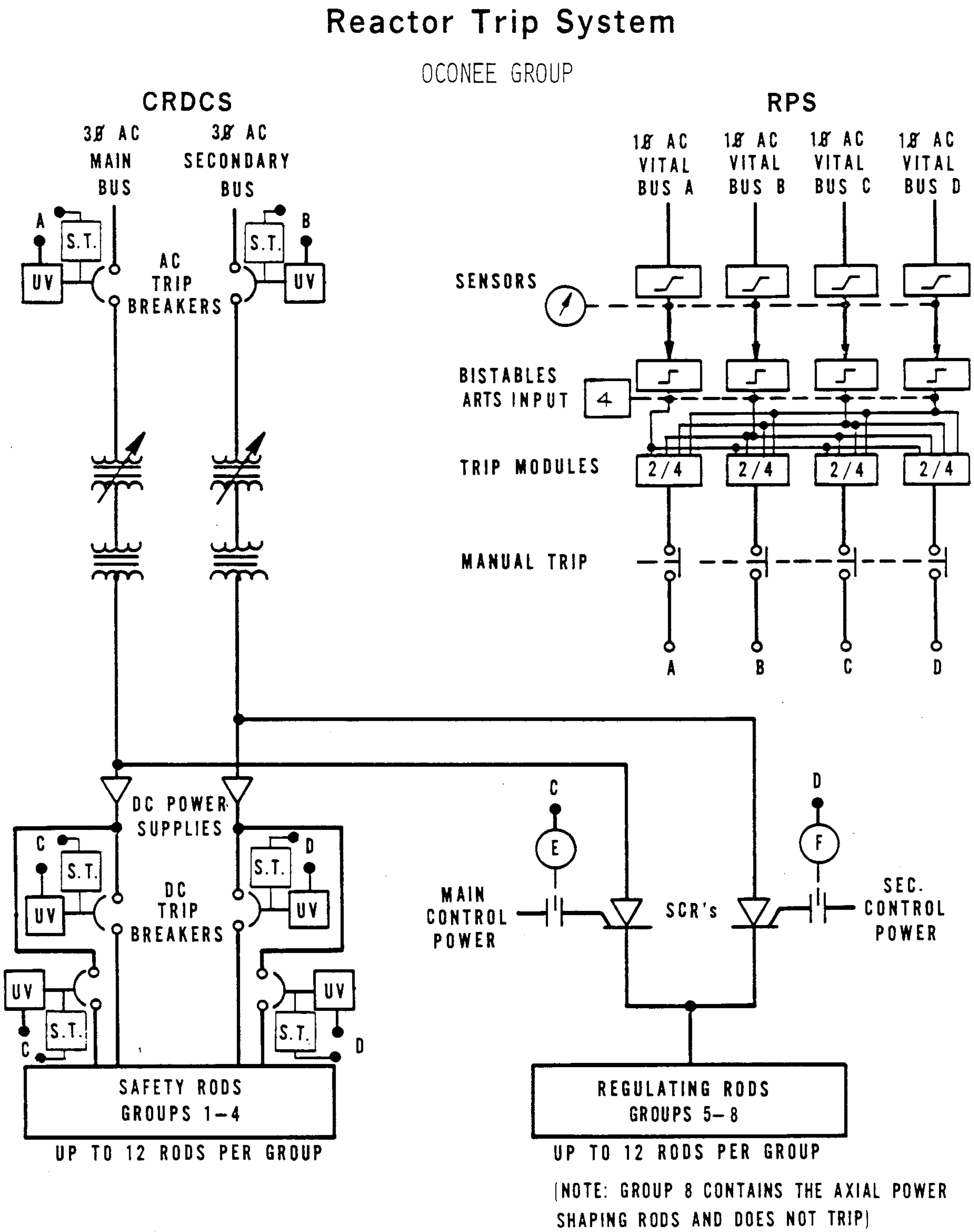

Figure 1-1. Babcock & Wilcox Oconee RPS integrated system diagram.

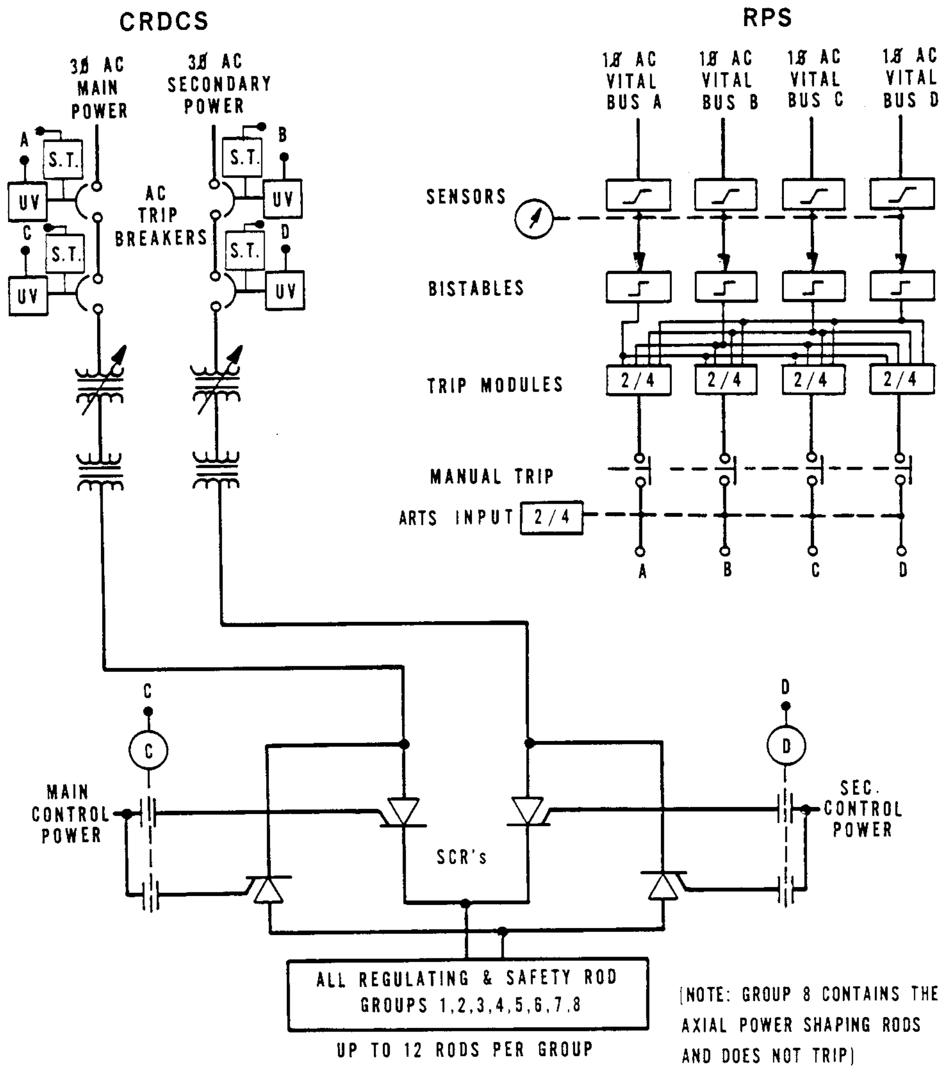

Figure 1-2. Babcock & Wilcox Davis-Besse design RPS integrated system diagram.

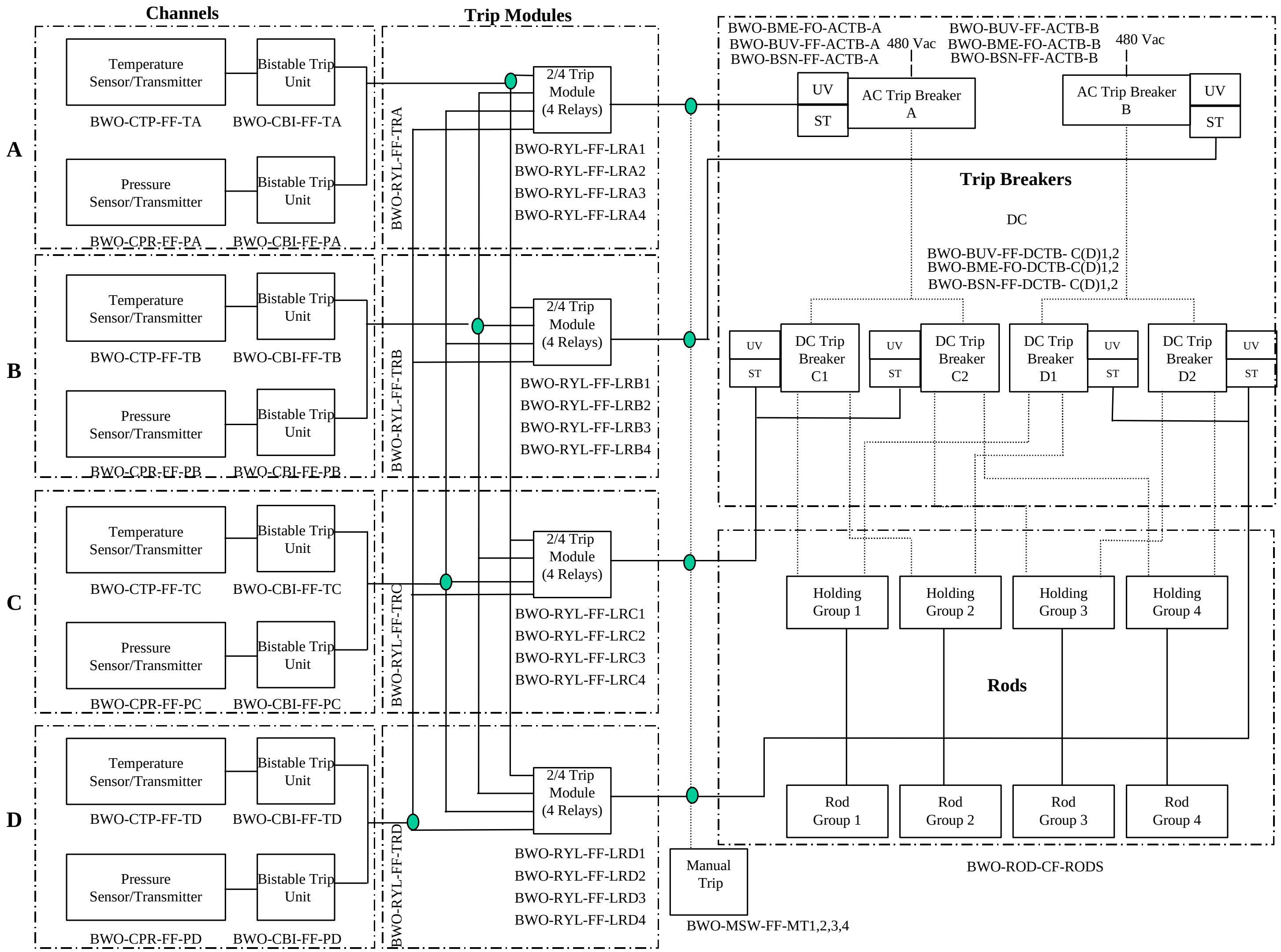

Figure 1-3. Babcock & Wilcox Oconee RPS simplified diagram.

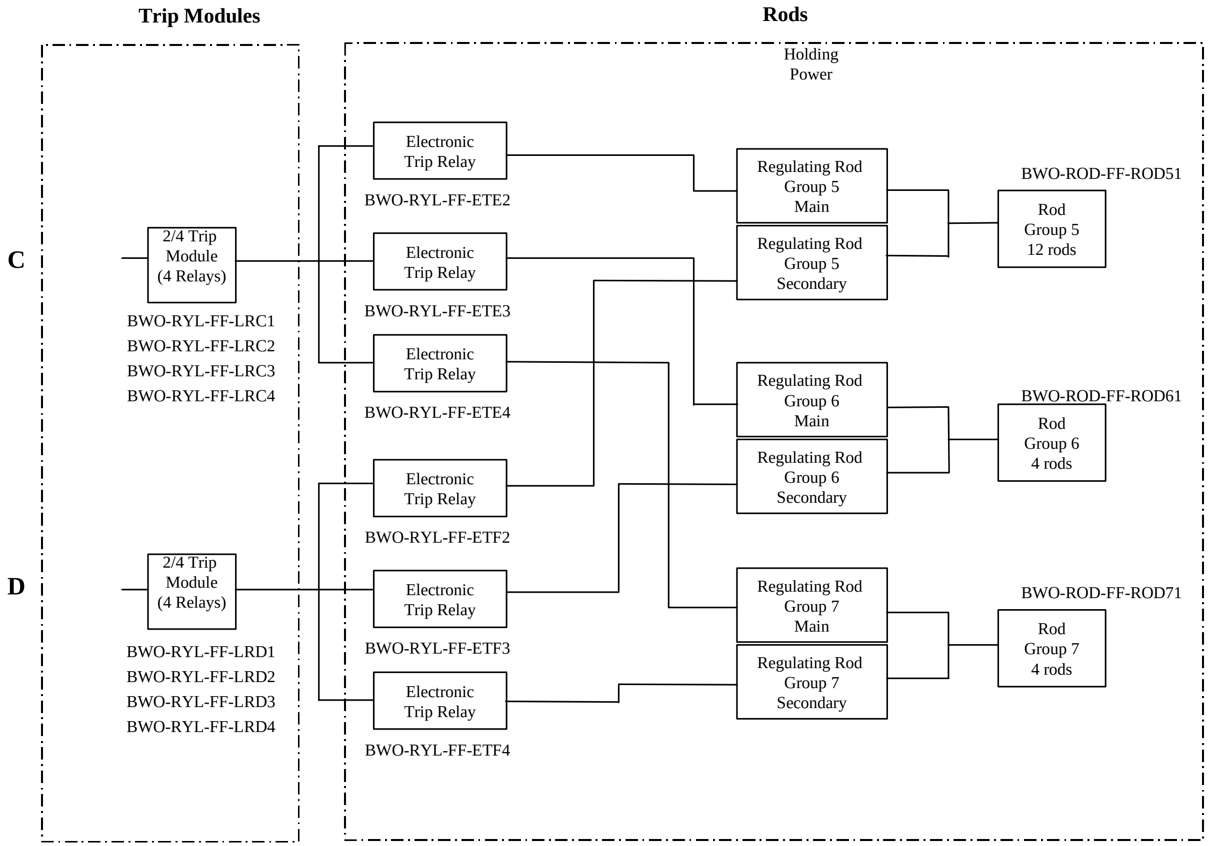

Figure 1-4. Babcock & Wilcox Oconee SCR electronic trip simplified diagram.

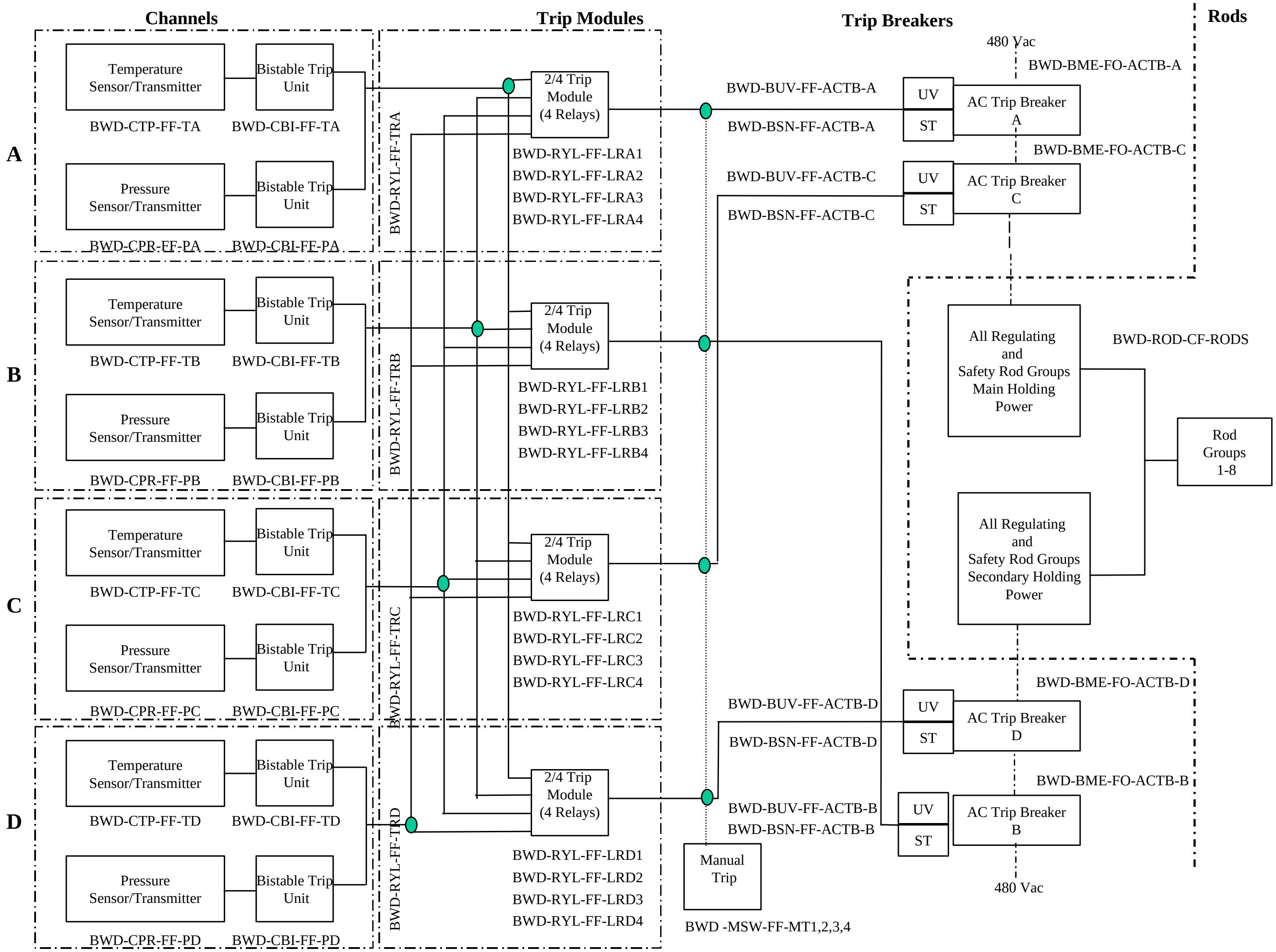

Figure 1-5. Babcock & Wilcox Davis-Besse RPS simplified diagram.

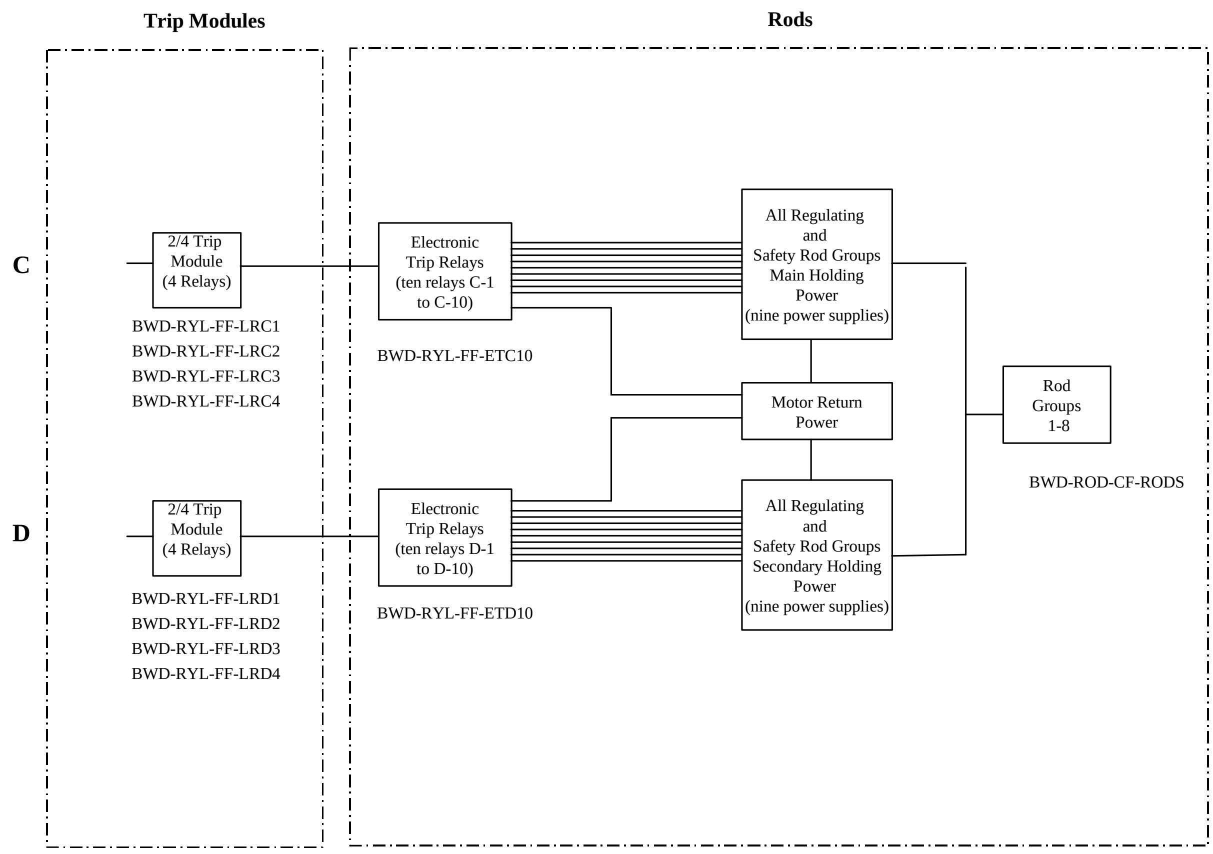

Figure 1-6. Babcock & Wilcox Davis-Besse SCR electronic trip simplified diagram.

i. A.F. McBride, et.al., *Babcock & Wilcox Anticipated Transients Without Scram Analysis*, Topical Report BAW-10099, Revision 1, Babcock & Wilcox, Lynchburg, Virginia, May 1977.