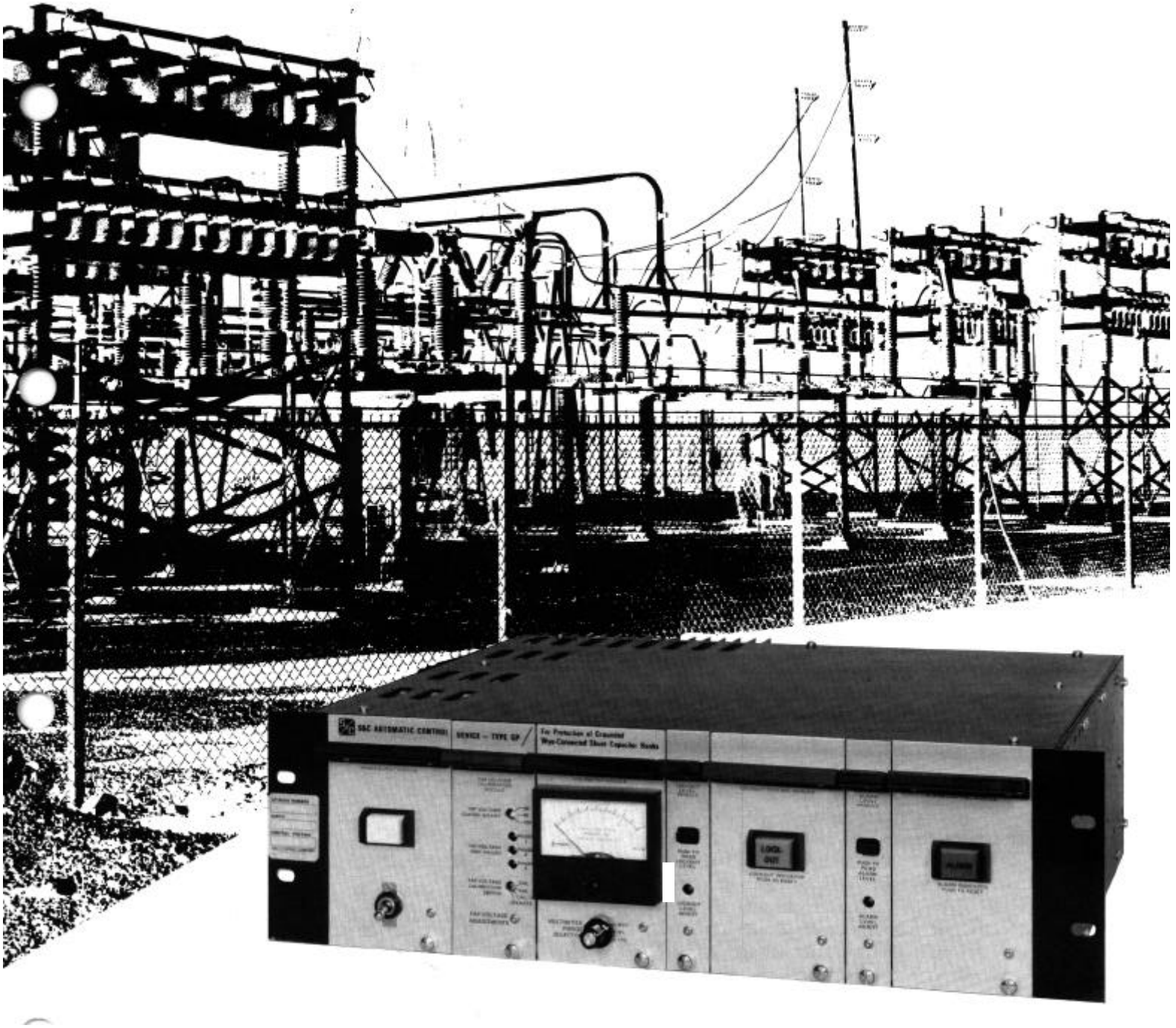

S&C Automatic Control Devices
Types UP, GP, VR, and UPR

For Capacitor Banks and Shunt Reactors

New Publication ©1986

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S&C ELECTRIC COMPANY • Chicago
S&C ELECTRIC CANADA LTD. • Toronto

Page 1 of 18
October 27, 1986

APPLICATION AND OPERATION

These field-proven reliable solid-state electronic controls

- Protect large-sized shunt capacitor banks from overvoltage stress and provide automatic bank switching for system-voltage regulation, and
- Protect shunt reactors from turn-to-turn faults.

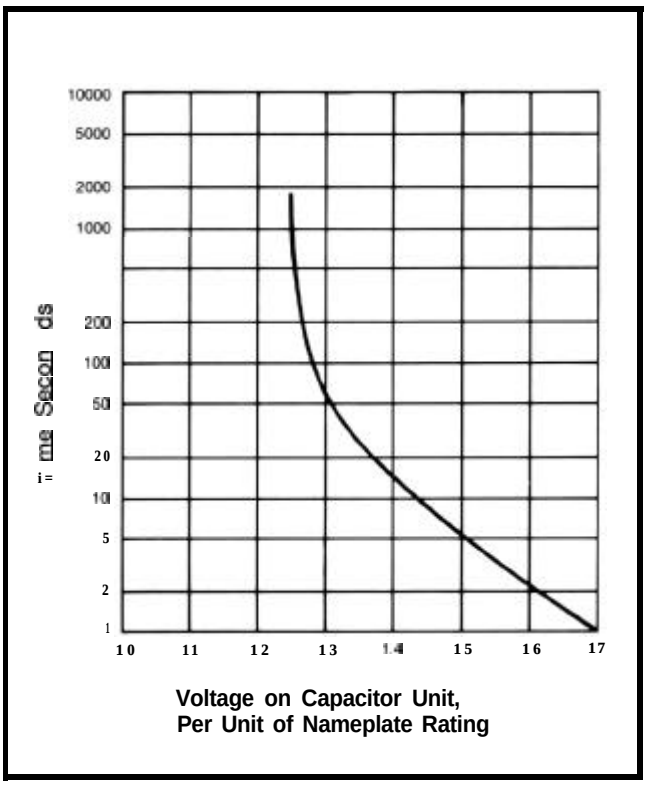
Large-Sized Capacitor Banks Need Sophisticated Overvoltage Protection

Medium- to large-sized wye-connected shunt capacitor banks commonly utilize twofold protection against short circuits. Individual capacitor units are protected by fuse links that clear internal faults, reducing the probability of case ruptures. And the bank-plus the system-is protected against major faults by the bank protective device, such as power fuses or an S&C Circuit-Switcher.

But when a fuse link operates to isolate a failed capacitor unit, the voltage across remaining units in the same series group increases. This increased voltage can overstress and shorten the life of the other good capacitor units in the group. As subsequent units fail, their isolation leads to still further voltage increases on remaining units. The result: an accelerating cascade of overvoltages that destroys good capacitor units.

This phenomenon is addressed in ANSI/IEEE Standard 18-1980, "IEEE Standard for Shunt Power Capacitors." The standard specifies a curve, shown at right, which indicates permissible capacitor-unit operating time at varying per-unit multiples of capacitor nameplate voltage rating. (The standard further states that capacitors shall be capable of continuous operation to at least 110% of rated voltage, including harmonics . . . most capacitor manufacturers publish similar data, which may permit higher working voltages.) When the voltage applied to the surviving capacitor units exceeds the manufacturer's maximum recommended working voltage (or in the absence of a recommendation, the ANSI/IEEE data), the entire bank should be removed from service.

Thus, large-sized capacitor banks need a third form of protection: A sophisticated control device having the sensitivity to detect isolation of the first failed unit in a capacitor bank-and alarm upon isolation of that unit, to enable the user to replace it before additional failures occur-but with the discrimination to disregard system and inherent bank unbalances and spurious transients, as well as harmonics.



Capacitor-unit power-frequency overvoltage versus time, as permitted by ANSI Standard 18-1980; see text. This curve applies for up to 300 applications of power-frequency overvoltages of the magnitudes and durations indicated.

Why System and Inherent Capacitor-Bank Unbalance Compensation Is Essential

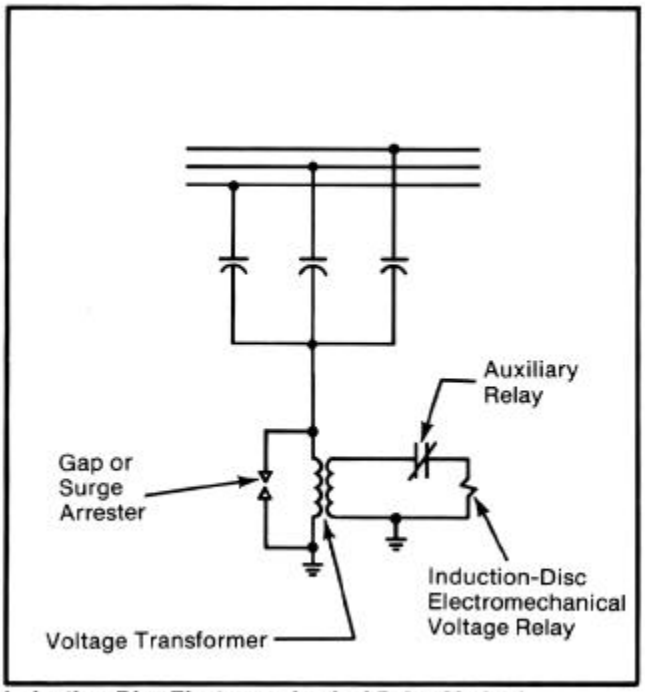
In larger-sized capacitor banks, extraneous voltages can introduce significant errors in-or even overpower – the voltage signal created by loss of individual capacitor units. For example, a fixed error voltage may be present due to capacitor-bank inherent unbalance resulting from manufacturing-tolerance variations among individual capacitor units, or due to system voltage unbalance resulting from nontransposition of overhead lines. A variable error voltage may also be present due to system load unbalance resulting from changing load conditions, although this error voltage is usually only significant in very-large-sized, transmission-voltage-level capacitor banks. Compensation for these extraneous voltages is thus crucial to ensure proper operation of the capacitor-bank control device.

Capacitor-bank inherent unbalance can usually be minimized through costly and time-consuming measurement and relocation of capacitor units. The effect of fixed system voltage unbalance is not as readily remedied. A capacitor-bank control device should thus be conveniently adjustable to compensate for both of these sources of extraneous voltage, so that it has the capability to detect and respond to a single faulted capacitor unit.

Electromechanical Voltage Relays and Neutral Current Relays Are Inadequate

Capacitor-protection schemes assembled from general-purpose relays provide only marginal performance . . .

On ungrounded, wye-connected shunt capacitor banks, induction-disc electromechanical voltage relays are sometimes used for sensing isolation of capacitor units. But this protection method has some severe limitations: the associated voltage transformer must have a voltage rating equal to the actual system voltage, in order to withstand the short-term overvoltages experienced during routine capacitor-bank switching and during faults. Such a transformer, however, provides inherently poor sensitivity to isolation of a single capacitor unit because of its high turns ratio. Further, to alarm upon isolation of a single capacitor unit-to enable the user to replace the failed capacitor unit before additional failures occur-a second voltage relay is required. This method also lacks an harmonic filter, as is required to prevent sensing errors due to



Induction-Disc Electromechanical Relay Method

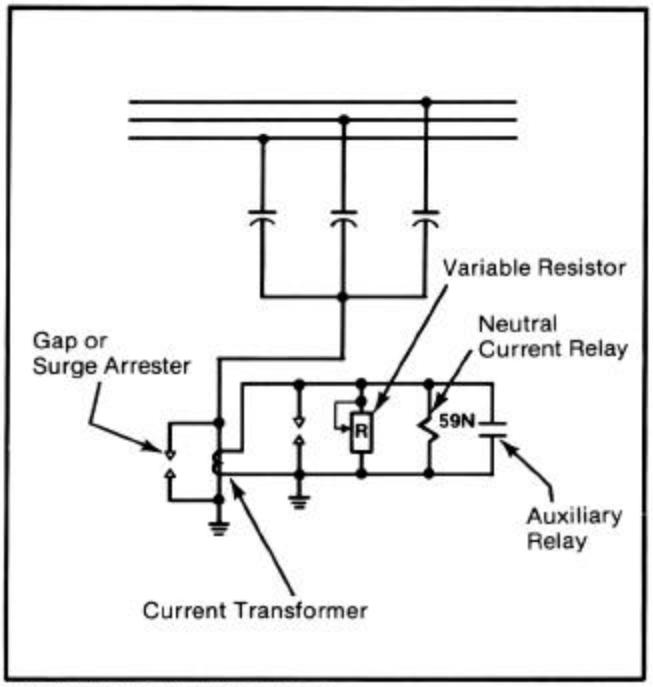
APPLICATION AND OPERATION — Continued

system harmonic voltages. And, this method provides no compensation for system or inherent capacitor-bank unbalances, which can be quite significant in larger-sized capacitor banks and can cause false operations resulting in lockout of the capacitor bank or, conversely, no operation when one is necessary.

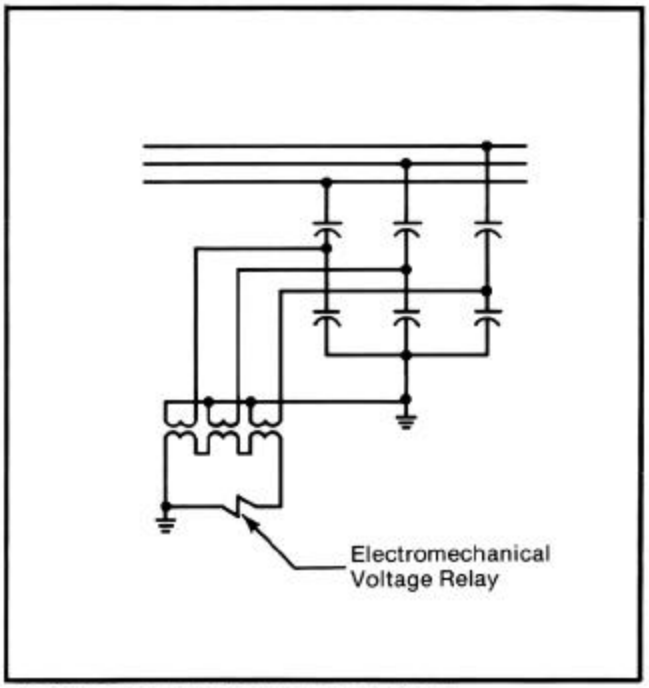
On grounded, wye-connected shunt capacitor banks, neutral-current and electromechanical voltage relay schemes are sometimes used for sensing isolation of capacitor units. But again, these techniques have some significant limitations.

In the neutral-current relay scheme, the current transformer associated with the neutral current relay must have a high ratio in order to withstand the momentary charging currents flowing between neutral and ground during routine capacitor-bank switching and during faults. Such a transformer provides inherently poor sensitivity to isolation of a single capacitor unit. A high-ohmic-value burden resistance is also required so that the neutral current relay can withstand these charging currents. Further, to alarm upon isolation of a single capacitor unit, a second relay must be furnished. This method too lacks an harmonic filter, as is necessary to prevent sensing errors due to system harmonic voltages. And again, this method provides no compensation for system or inherent capacitor-bank unbalance.

The electromechanical voltage relay method, on the other hand, provides excellent sensitivity in grounded capacitor-bank applications. But it also has some significant drawbacks: A second relay is required to alarm upon isolation of a single capacitor unit. This method also lacks an harmonic filter, as is necessary to prevent sensing errors due to system harmonic voltages. And, once again, this method provides no compensation for system or inherent capacitor-unit unbalance which can cause false operations.



Neutral Current Relay Method



Electromechanical Voltage Relay Method

S&C Automatic Control Devices Are the Answer

The S&C Type UP Automatic Control Device, for protection of *ungrounded,* wye-connected shunt capacitor banks, and the S&C Type GP Automatic Control Device, for protection of *grounded,* wye-connected shunt capacitor banks, have the sensitivity to detect the first faulted unit in a capacitor bank-but with the discrimination to disregard system and bank unbalance and spurious transients. These compact solid-state electronic devices, illustrated and described on pages 6 through 9, overcome the inadequacies of electromechanical voltage relays and neutral current relays. Each utilizes rugged modular construction for quick set-up and simple addition of field-installable options, and offers matchless design features and proven circuits that withstand the rigors of power equipment application.

The Type UP and Type GP controls may each be applied with the S&C Type VR Automatic Control Device, a companion solid-state electronic control device to regulate system voltage. The Type VR Automatic Control Device is available separately or in an integrated assembly with a Type UP or Type GP Automatic Control Device. These devices are illustrated and described on pages 10 through 13.

And for protection of *ungrounded,* wye-connected shunt reactors, the S&C Type UPR Automatic Control Device is available. This solid-state electronic device, illustrated and described on pages 14 and 15, detects turn-to-turn faults in the windings of such reactors and isolates and locks out the reactor when a predetermined reactor neutral-to-ground voltage is exceeded.

Other S&C Automatic Control Equipment Available

S&C manufactures a comprehensive line of capacitor protective devices . . . there are devices suitable for even-larger capacitor banks, as well as smaller ones.

For very-large-sized, *grounded,* wye-connected transmission-voltage-level capacitor banks, variable system voltage unbalance can be of major concern. The S&C Automatic Control Device-Type GPS is recommended for such applications since it is inherently immune to the effects of variable system voltage unbalance, as well as fixed system voltage unbalance. This device, further, possesses the high selectivity essential for preventing unnecessary removal of the capacitor bank from service-an especial concern in very-large-sized capacitor banks where the probability of encountering an occasional capacitor-unit failure is high, but where loss of the entire bank capacity would seriously affect power system performance. To provide this selectivity, the Type GPS Automatic Control Device incorporates a unique multiple-alarm-level detection system.

For small- to medium-sized capacitor banks, on the other hand, the extra features offered by Type UP, Type GP, and Type GPS Automatic Control Devices-such as unbalance compensation and alarm options-may not be economically justifiable or needed. For these applications, the S&C Bankgard™ Relays-Type LUC and Type LGC are available. The Type LUC Bankgard Relay is designed for *ungrounded* capacitor-bank applications; the Type LGC Bankgard Relay is designed for *grounded* capacitor-bank applications. Refer to the nearest S&C Sales Office for complete details on these other S&C capacitor-bank protective devices.

APPLICATION AND OPERATION — Continued

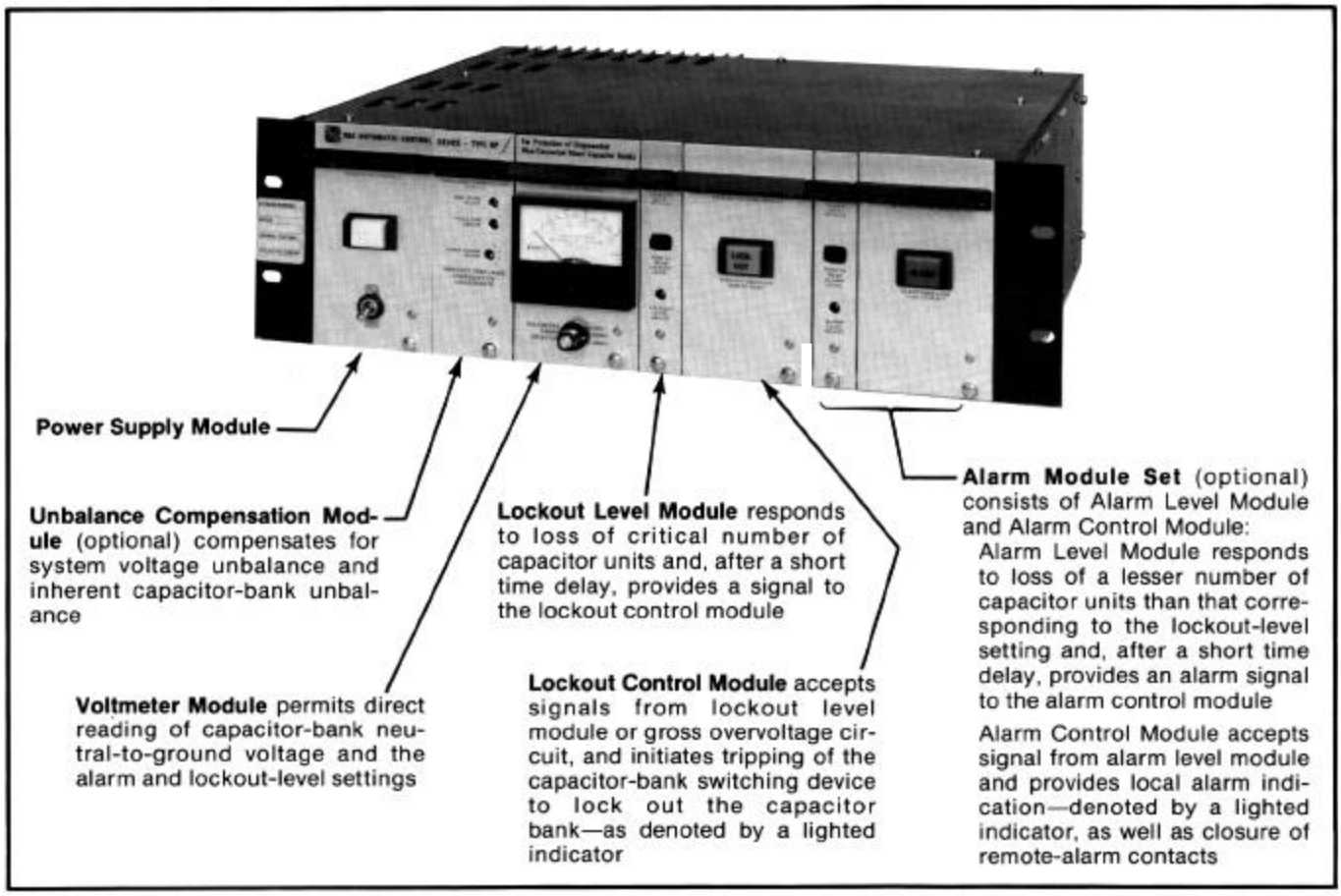
Type UP Automatic Control Device

The S&C Automatic Control Device-Type UP provides protection ***of*** *ungrounded,* wye-connected shunt capacitor banks-including double-wye banks-by detecting the loss of individual capacitor units. As successive individual capacitor units in a series group of a capacitor bank are isolated from the bank by their respective fuses, the surviving capacitor units in the group are protected against cascading voltage overstress by automatic switching-initiated by the Type UP Automatic Control Device-which isolates and locks out the entire bank when a predetermined neutral-to-ground voltage is exceeded.

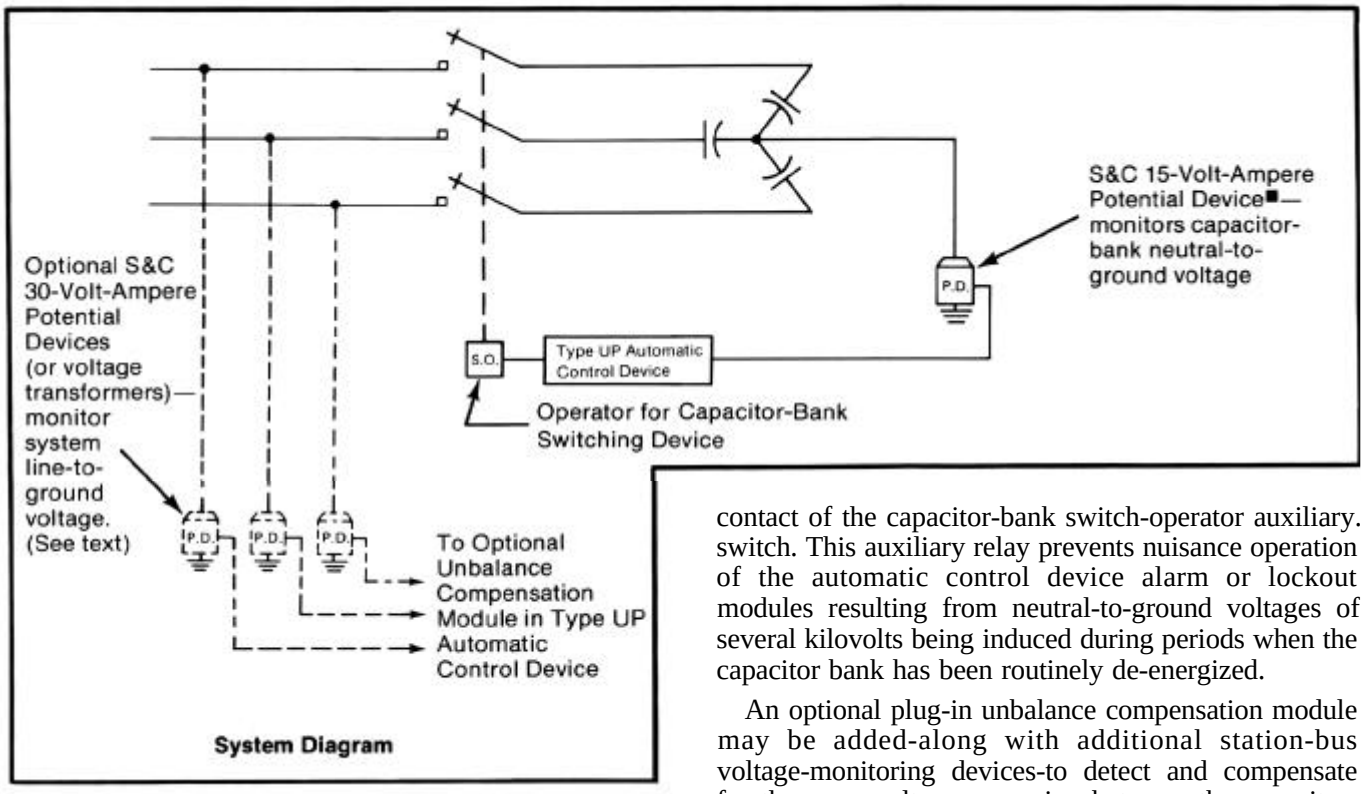
The Type UP Automatic Control Device utilizes a voltmeter module which detects the capacitor-bank neutral-to-ground voltage, as monitored by an S&C 15-Volt-Ampere Potential Device. A narrow-bandpass filter is employed in this module to attenuate harmonics and noise. Since predictable discrete increases in capacitor-bank neutral-to-ground voltage result from the isolation of successive capacitor units, a specific value may be selected for adjusting the lockout level module of the Type UP Automatic Control Device.

A field-adjustable 1- to 30-second time delay is incorporated in the lockout level module, to assure operation of the fuse associated with the capacitor unit before providing a signal to the lockout control module to initiate tripping of the capacitor-bank switching device. In this way, the failed capacitor unit can be readily located.

A gross overvoltage circuit is employed which bypasses the lockout-level and timing-control circuits and initiates isolation and lockout of the capacitor bank in the event of a flashover of series groups within the



S&C Automatic Control Device-Type UP.



System Diagram

capacitor bank. This circuit is activated, after a field-adjustable time delay of 0.5 to 5 seconds, by such faults producing a capacitor-bank neutral-to-ground voltage in excess of a field-adjustable level of 1000 to 5000 volts.

The Type UP Automatic Control Device may be furnished with an optional plug-in alarm module set, which provides an alarm signal upon the loss of a lesser number of capacitor units than that corresponding to the lockout-level setting. For many capacitor banks it is quite feasible to activate the alarm upon loss of a single capacitor unit-a decided advantage since replacement of the failed capacitor unit can be accomplished at a convenient, planned time, instead of on an urgent basis during a lockout resulting from subsequent failure of capacitor units, The alarm module set, further, responds to loss of control power to the Type UP Automatic Control Device and provides an alarm signal. The 1- to 30-second time delay incorporated in the lockout level module is also utilized here to avoid false alarms due to transient disturbances.

The Type UP Automatic Control Device incorporates an auxiliary relay which is actuated through a contact of the capacitor-bank switch-operator auxiliary. switch. This auxiliary relay prevents nuisance operation of the automatic control device alarm or lockout modules resulting from neutral-to-ground voltages of several kilovolts being induced during periods when the capacitor bank has been routinely de-energized.

An optional plug-in unbalance compensation module may be added-along with additional station-bus voltage-monitoring devices-to detect and compensate for the error voltage appearing between the capacitor-bank neutral and ground caused by system voltage unbalance and/or inherent capacitor-bank unbalance resulting from manufacturing-tolerance variations among capacitor units in the bank. Such error voltage can otherwise cause false operations resulting in lockout of the capacitor bank or, conversely, no operation when one is necessary.

■ The potential device should have a system voltage rating as follows:

Nominal Source Voltage, Kv	Potential-Device System Voltage Rating, Kv, Nominal
below 23	23
23	23
34.5	23
46	23
69	34.5
115	69
138	69
161	138
230	138

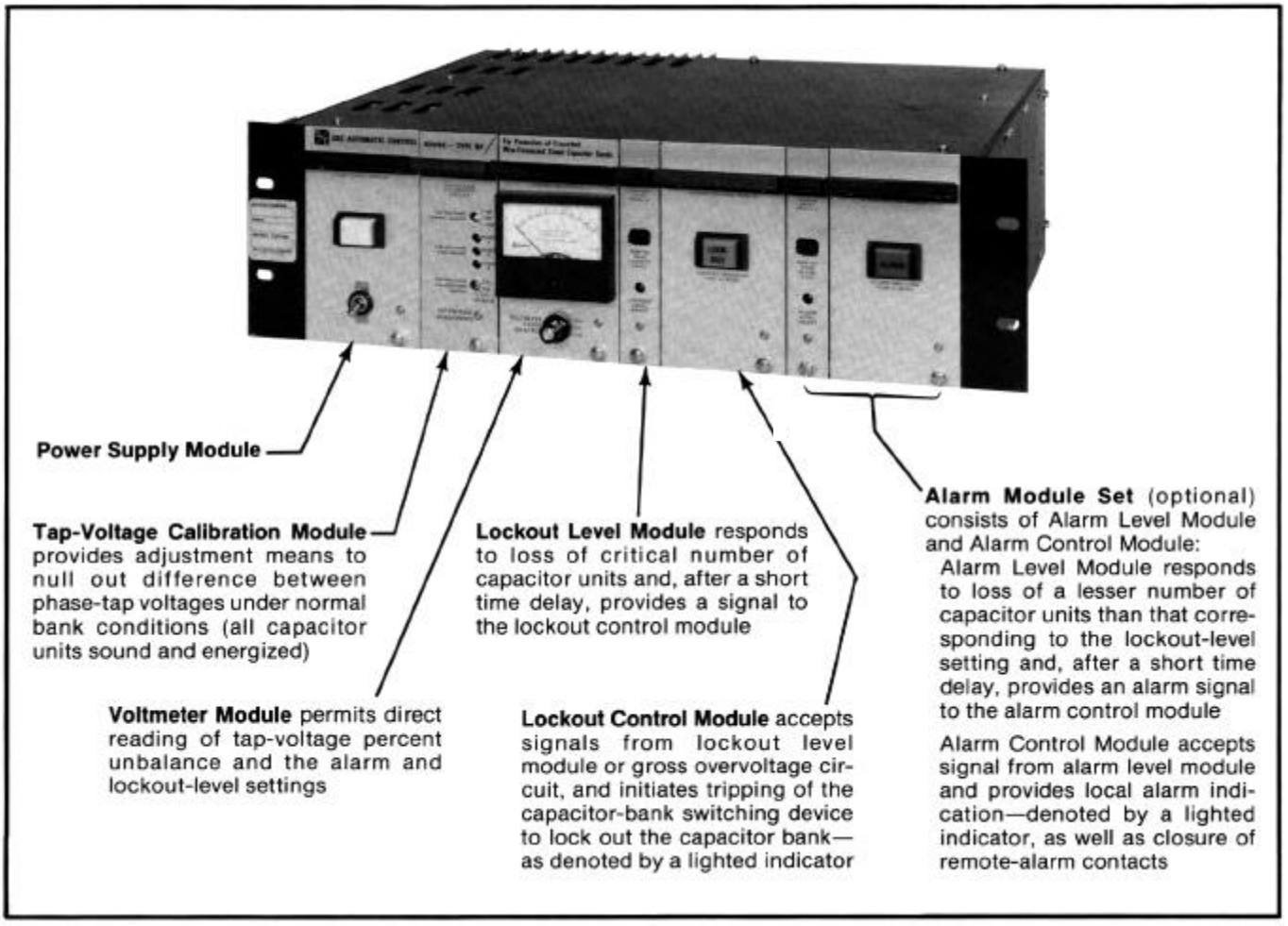
APPLICATION AND OPERATION — Continued

Type GP Automatic Control Device

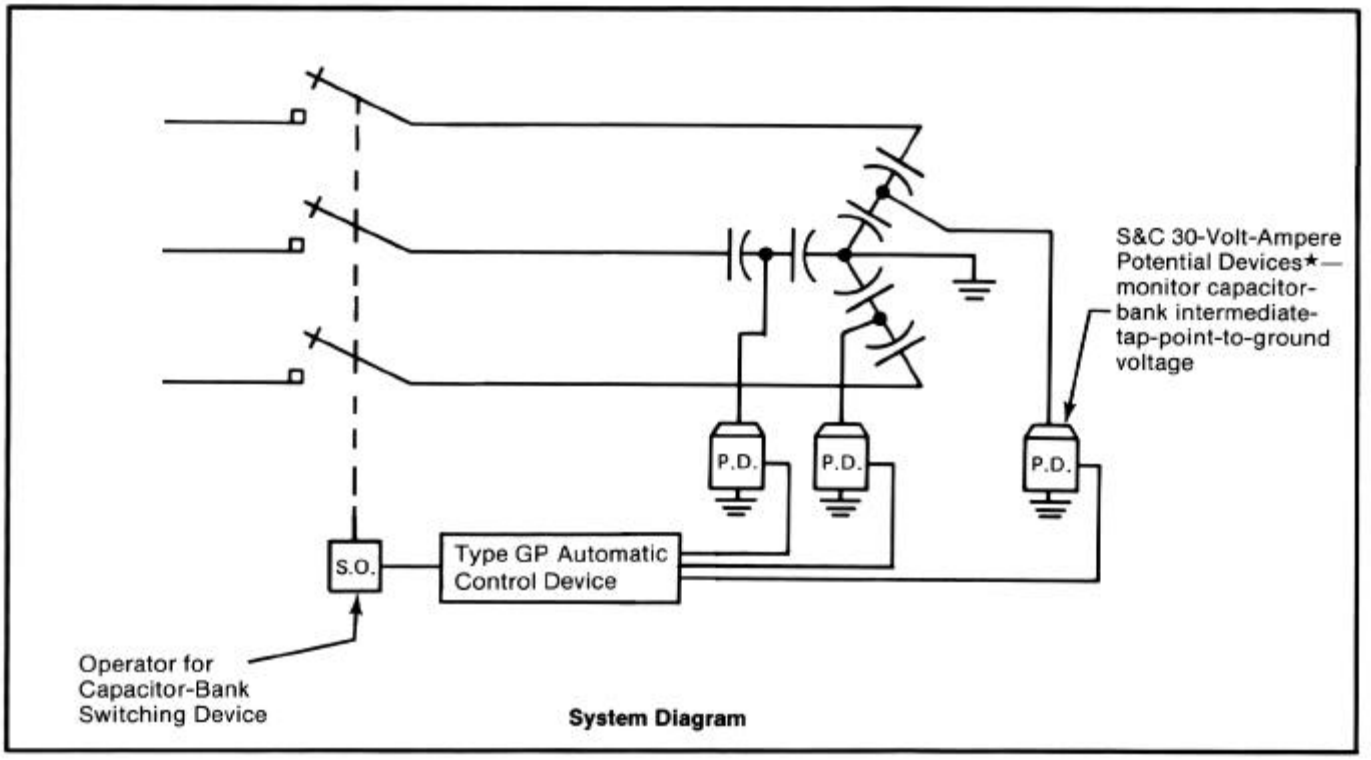
The S&C Automatic Control Device-Type GP provides protection of *grounded,* wye-connected shunt capacitor banks, consisting of two or more series groups per phase, by detecting the loss of individual capacitor units. As successive individual capacitor units in a series group of a capacitor bank are isolated from the bank by their respective fuses, the surviving capacitor units in the group are protected against cascading voltage overstress by automatic switching-initiated by the Type GP Automatic Control Device-which isolates and locks out the entire bank when a predetermined overvoltage occurs.

The Type GP Automatic Control Device utilizes a tap-voltage calibration module which develops the phasor sum of the intermediate tap-point voltages on the three phase legs, as monitored by S&C 30-Volt-Ampere Potential Devices, and provides an adjustment means for eliminating the effects of inherent capacitor-bank unbalance (resulting from manufacturing-tolerance variations among capacitor units in the bank) and fixed system voltage unbalance. A narrow-bandpass filter is employed in this module to attenuate harmonics and noise. Since predictable discrete increases in tap-voltage percent unbalance result from the isolation of successive capacitor units, a specific value may be selected for adjusting the lockout level module of the Type GP Automatic Control Device.

A field-adjustable 4- to 30-second time delay is incorporated in the lockout level module, to assure operation of the fuse associated with the capacitor unit before providing a signal to the lockout control module to initiate tripping of the capacitor-bank switching device. In this way, the failed capacitor unit can be readily located.



S&C Automatic Control Device- Type GP.



System Diagram

A gross overvoltage circuit is employed which bypasses the lockout-level and timing-control circuits and initiates isolation of the capacitor bank in the event of a flashover of series groups within the capacitor bank. This circuit is activated, after a field-adjustable time delay of 0.5 to 5 seconds, by such faults producing a capacitor-bank tap-voltage percent unbalance in excess of a field-adjustable level of 5 to 20%.

The Type GP Automatic Control Device may be furnished with an optional plug-in alarm module set, which provides an alarm signal upon the loss of a lesser number of capacitor units than that corresponding to the lockout-level setting. For many capacitor banks it is quite feasible to activate the alarm upon loss of a single capacitor unit-a decided advantage since replacement of the failed capacitor unit can be accomplished at a convenient, planned time, instead of on an urgent basis during a lockout resulting from subsequent failure of capacitor units. The alarm module set, further, responds to loss of control power to the Type GP Automatic Control Device and provides an alarm signal. The 4-to 30-second time delay incorporated in the lockout level module is also utilized here to avoid false alarms due to transient disturbances.

The Type GP Automatic Control Device incorporates an auxiliary relay which is actuated through a contact of the capacitor-bank switch-operator auxiliary switch. This auxiliary relay prevents nuisance operation of the automatic control device alarm or lockout modules resulting from excessive tap-voltage percent unbalance being induced during periods when the capacitor bank has been routinely de-energized.

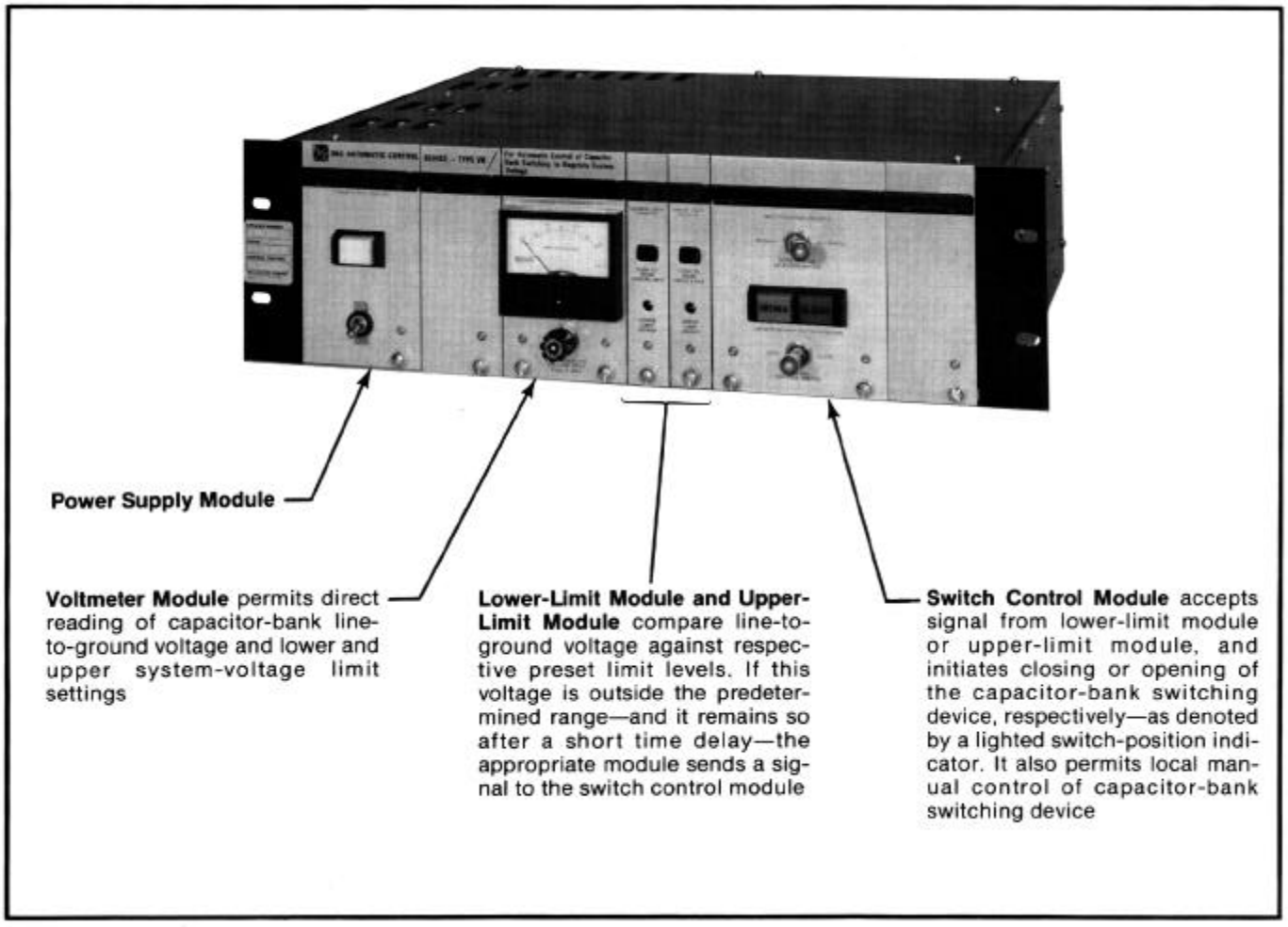
★ Each potential device should have a system voltage rating at least equal to the voltage appearing between the intermediate tap points and ground multiplied by $\sqrt{3}$.

APPLICATION AND OPERATION — Continued

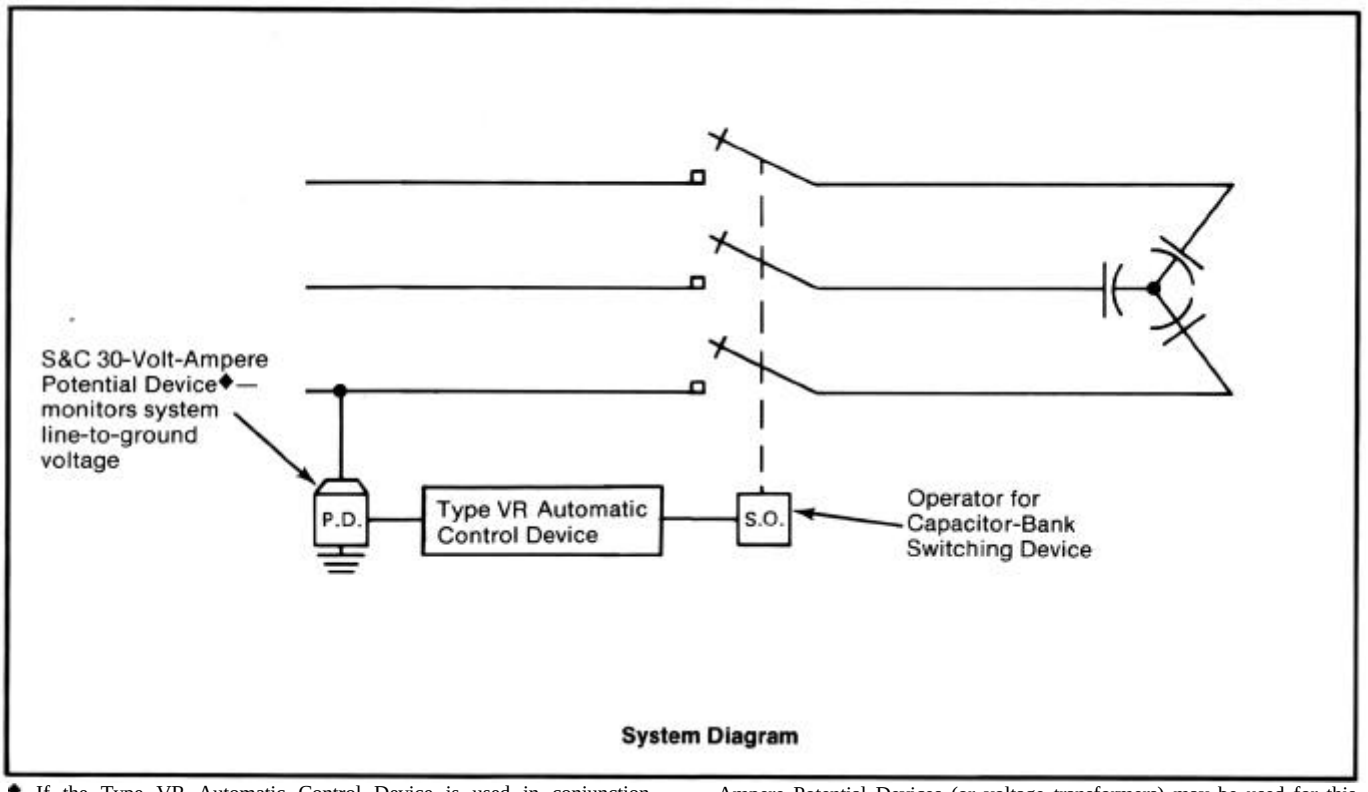
Type VR Automatic Control Device

The S&C Automatic Control Device-Type VR provides automatic control of capacitor-bank switching to regulate system voltage. It utilizes a voltmeter module which detects system line-to-ground voltage, as monitored by an S&C 30-Volt-Ampere Potential Device. This voltage is compared with limits preset on the lower-limit module and upper-limit module. If the voltage is outside the predetermined range, a signal is sent to the switch control module to either close or open the capacitor-bank switching device, as appropriate.

A field-adjustable 10- to 450-second time delay is incorporated in each limit module, to prevent unwanted switching operations in response to system transients. To further guard against undesirable capacitor-bank switching operations, a blocking circuit is employed which prevents closing operations whenever system voltage drops below 33% of its nominal value; another circuit sends an opening signal to the capacitor-bank switching device in the event control power is lost to the Type VR Automatic Control Device.



S&C Automatic Control Device–Type VR.



System Diagram

◆ If the Type VR Automatic Control Device is used in conjunction with a Type UP Automatic Control Device equipped with optional unbalance compensation module, any one of the associated S&C 30-Volt-Ampere Potential Devices (or voltage transformers) may be used for this purpose.

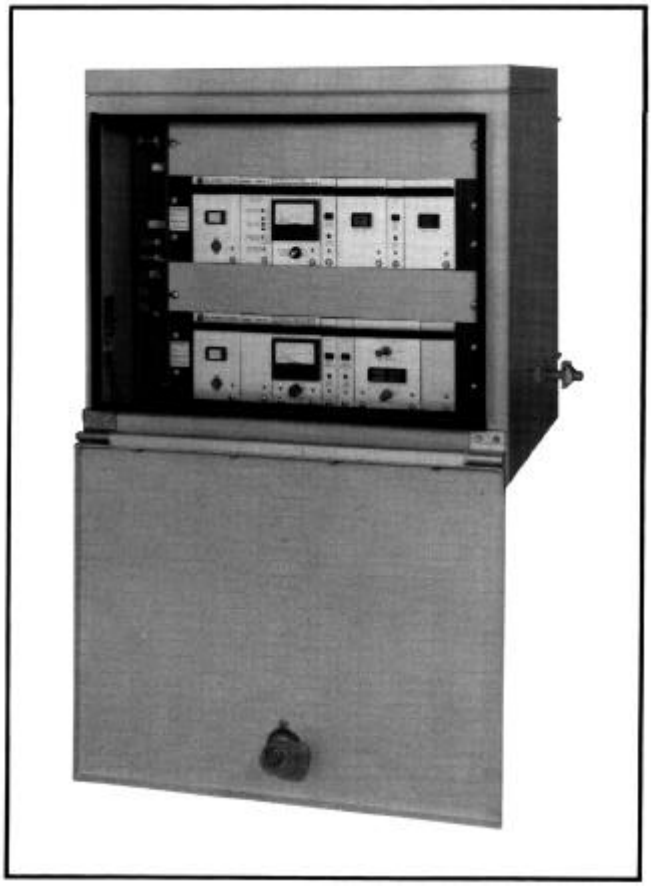
APPLICATION AND OPERATION — Continued

Type UP/VR and Type GP/VR Automatic Control Devices

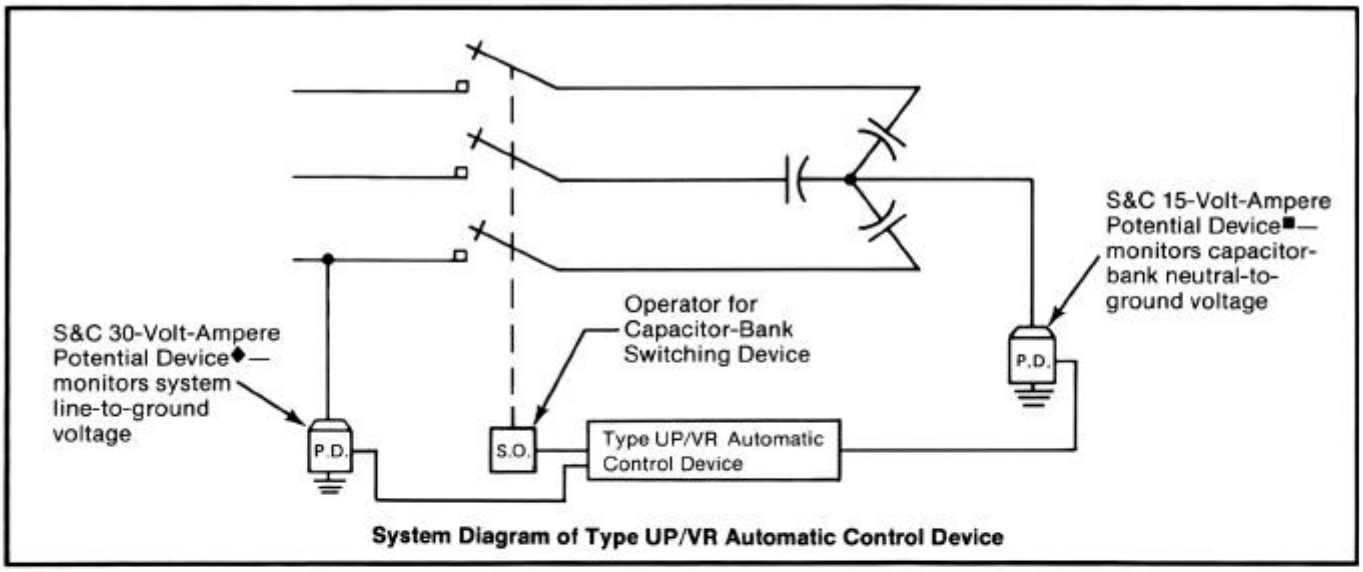
The S&C Automatic Control Device-Type UPNR incorporates the Type UP and Type VR control devices in an integrated assembly to provide protection of *ungrounded,* wye-connected shunt capacitor banks in addition to automatic switching of such capacitor banks to regulate system voltage.

The S&C Automatic Control Device-Type GP/VR similarly incorporates the Type GP and Type VR control devices in an integrated assembly to provide protection of *grounded,* wye-connected shunt capacitor banks in addition to automatic switching of such capacitor banks to regulate system voltage.

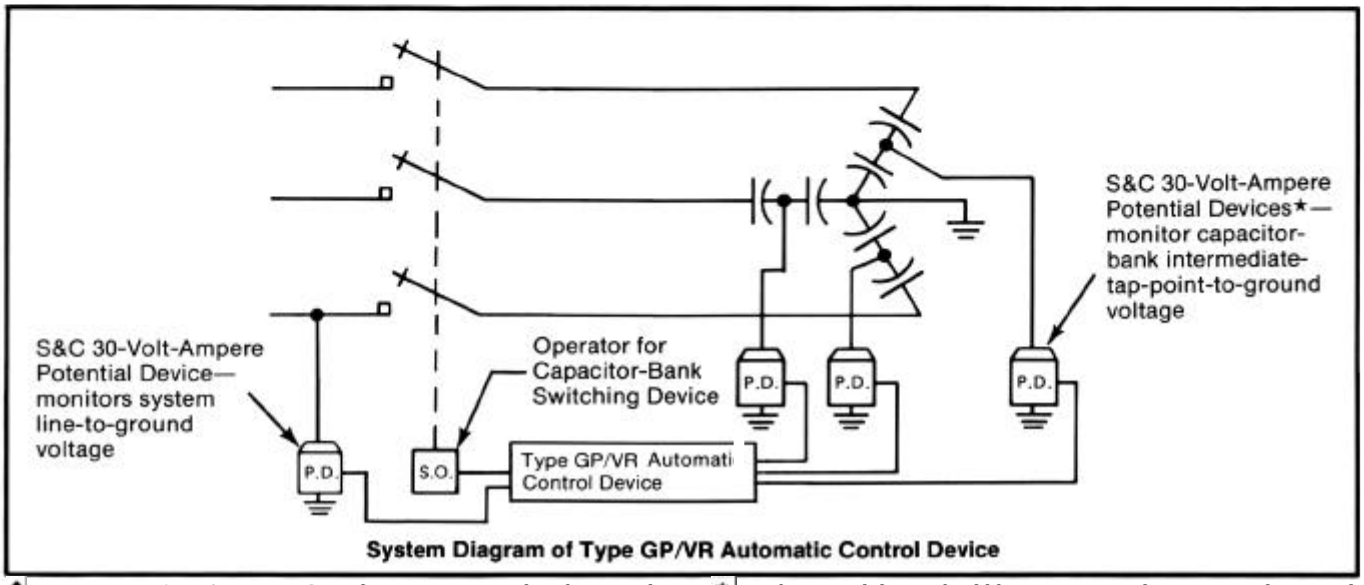
In each instance, the two control devices are interconnected to coordinate their functions, to prevent capacitor-bank energization if loss of capacitor units in the bank has caused a lockout.



S&C Automatic Control Device-Type GP/VR, in weatherproof enclosure.



System Diagram of Type UP/VR Automatic Control Device



System Diagram of Type GP/VR Automatic Control Device

◆ For Type UP/VR Automatic Control Devices equipped with optional unbalance compensation module, any one of the associated S&C 30-Volt-Ampere Potential Devices (or voltage transformers) may be used for this purpose.

■ The potential device should have a system voltage rating as follows:

Nominal Source Voltage, Kv	Potential-Device System Voltage Rating, Kv, Nominal
below 23	23
23	23
34.5	23
46	23
69	34.5
115	69
138	69
161	138
230	138

★ Each potential device should have a system voltage rating at least equal to the voltage appearing between the intermediate tap points and ground multiplied by $\sqrt{3}$.

APPLICATION AND OPERATION — Continued

Type UPR Automatic Control Device

The S&C Automatic Control Device-Type UPR provides protection of *ungrounded*, wye-connected shunt reactors-either three-phase reactors or three-phase banks of single-phase reactors-by detecting turn-to-turn faults in the windings of such shunt reactors, the most common mode of reactor failure.

The Type UPR Automatic Control Device utilizes a voltmeter module which detects the reactor neutral-to-ground voltage, as monitored by an S&C 15-Volt-Ampere Potential Device. A narrow-bandpass filter is employed in this module to attenuate harmonics and noise. When a turn-to-turn fault occurs in one of the phase windings, the shunt reactor is protected from further damage by automatic switching-initiated by the S&C Type UPR Automatic Control Device-which isolates and locks out the shunt reactor when the predetermined neutral-to-ground voltage value set on the lockout level module is exceeded.

A field-adjustable 0.3- to 4-second time delay is incorporated in the lockout level module, to assure that transient disturbances will not initiate a nuisance reactor isolation.

Power Supply Module

Unbalance Compensation Module (optional) compensates for system voltage unbalance and inherent reactor unbalance

Voltmeter Module permits direct reading of reactor neutral-to-ground voltage and the alarm and lockout-level settings

Lockout Level Module responds to turn-to-turn winding fault and, after a short time delay, provides a signal to the lockout control module

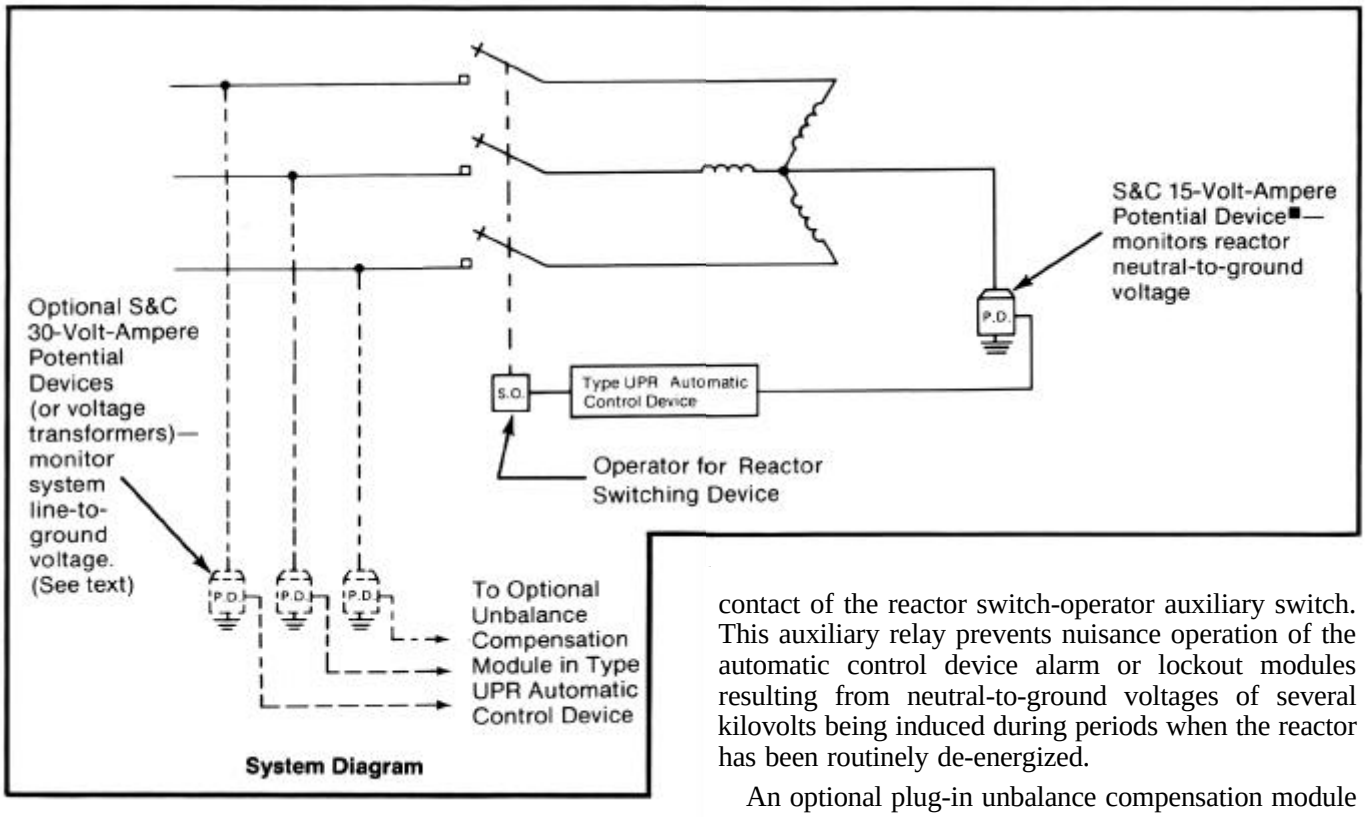
Lockout Control Module accepts signals from lockout level module or gross overvoltage circuit, and initiates tripping of the reactor switching device to lock out the reactor—as denoted by a lighted indicator

Alarm Module Set (optional) consists of Alarm Level Module and Alarm Control Module:

Alarm Level Module responds to a reactor-to-neutral voltage level less than that for which automatic switching is desired and, after a short time delay, provides an alarm signal to the alarm control module

Alarm Control Module accepts signal from alarm level module and provides local alarm indication—denoted by a lighted indicator, as well as closure of remote-alarm contacts

S&C Automatic Control Device-Type UPR.



System Diagram

A gross overvoltage circuit is employed which bypasses the lockout-level and timing-control circuits and initiates isolation and lockout of the reactor in the event of a fault which open circuits an entire phase winding. This circuit is activated, after a field-adjustable time delay of 0.5 to 5 seconds, by such faults producing a reactor neutral-to-ground voltage in excess of a field-adjustable level of 1000 to 5000 volts.

The Type UPR Automatic Control Device may be furnished with an optional plug-in alarm module set, which provides an alarm signal when the reactor neutral-to-ground voltage exceeds a predetermined level less than the lockout-level setting. The alarm module set, further, responds to loss of control power to the Type UPR Automatic Control Device and provides an alarm signal. A field-adjustable time delay of 0.3 to 4 seconds is incorporated in the alarm level module to avoid false alarms due to transient disturbances.

The Type UPR Automatic Control Device incorporates an auxiliary relay which is actuated through a contact of the reactor switch-operator auxiliary switch. This auxiliary relay prevents nuisance operation of the automatic control device alarm or lockout modules resulting from neutral-to-ground voltages of several kilovolts being induced during periods when the reactor has been routinely de-energized.

An optional plug-in unbalance compensation module may be added-along with additional station-bus voltage-monitoring devices-to detect and compensate for the error voltage appearing between the reactor neutral and ground caused by system voltage unbalance and/or inherent reactor unbalance resulting from manufacturing-tolerance variations among the phase windings. Such error voltage can otherwise cause false operations resulting in lockout of the reactor or, conversely, no operation when one is necessary.

■ **The potential device should have a system voltage rating as follows:**

Nominal Source Voltage, Kv	Potential-Device System Voltage Rating, Kv, Nominal
below 23	23
23	23
34.5	23
46	23
69	34.5
115	69
138	69
161	138
230	138

CONSTRUCTION

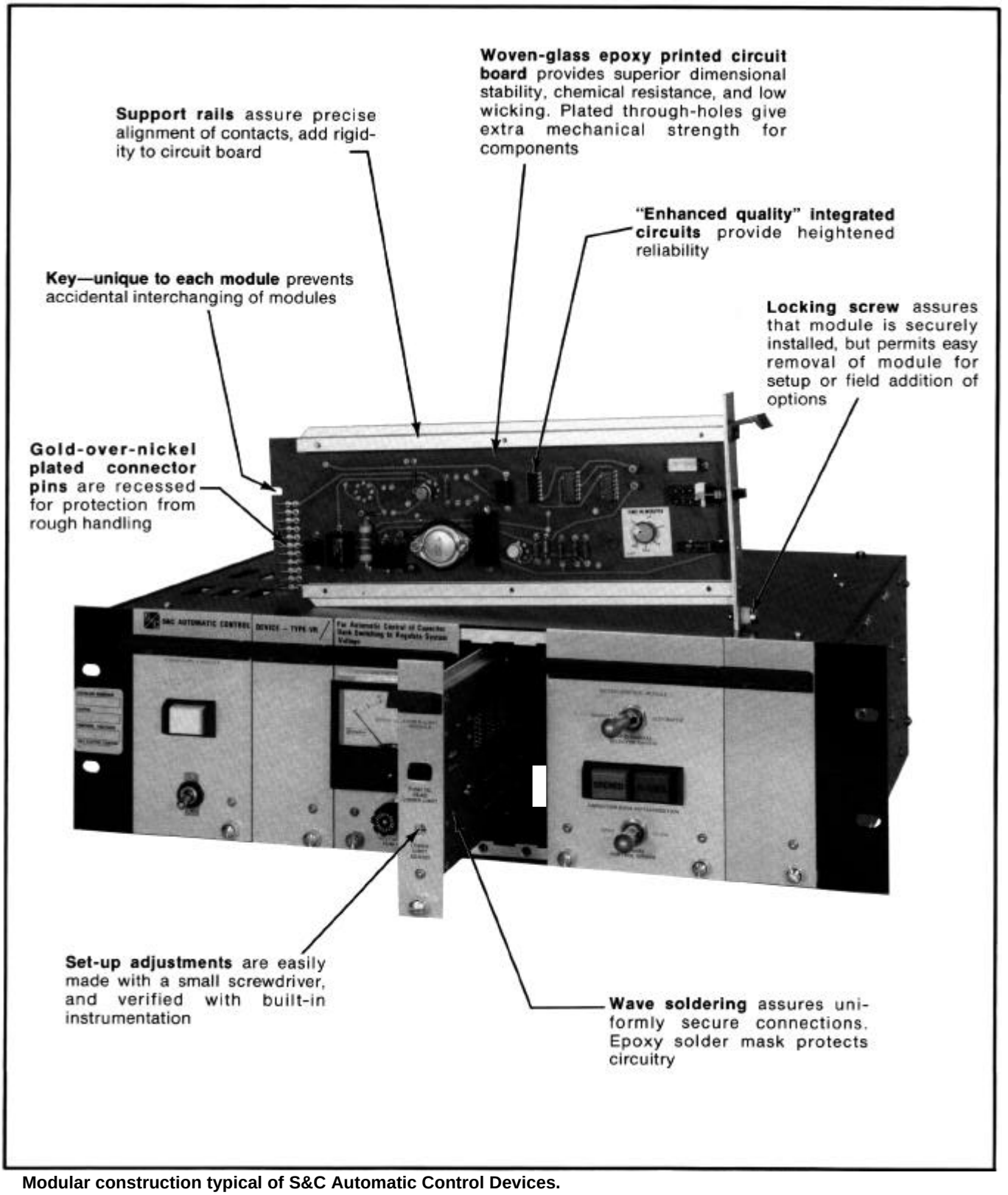
S&C Automatic Control Devices utilize plug-in modules featuring woven-glass epoxy circuit boards, with all components applied at levels well below MIL-STD guidelines to minimize component stress, power-supply requirements, and internal heating. "Enhanced quality" integrated circuits and gold-over-nickel plated connector pins and receptacle contacts are used throughout for increased reliability. Voltage-sensing input circuits are transformer isolated and output circuits are relay isolated; these relays are dustproof and have contacts of gold-flashed silver-cadmium oxide to ensure long service life.

Varistors are used at all external connection points in the control circuits to suppress transient voltages. S&C's unique surge-control techniques have been field proven through years of successful application in hostile utility-substation environments. The capability of every S&C electronic device to withstand voltage surges is confirmed by two factory quality-check tests: The ANSI Surge Withstand Capability Test (ANSI Standard C37.90a, 1974); plus a much more severe (5-kv, 3.75-joule) capacitive-discharge test specially developed by S&C to duplicate or exceed voltage surges measured in EHV power substations. The specified surges are applied at all terminals of the device. Additional factory tests include a 60-hertz dielectric test; screening procedures with the device energized-including vibration, temperature-cycling, and maximum-operating-temperature tests; and functional tests both before and after the screening tests.

S&C Automatic Control Devices are suitable for mounting in a standard 19-inch relay rack. External control-wiring connections are made to numbered terminal strips at the rear of the device. Customer-installed fuses and fuse blocks for the control source are provided. For flush-mounting of the control device on switchboards, control consoles, or other enclosures, an optional mounting bezel is available.

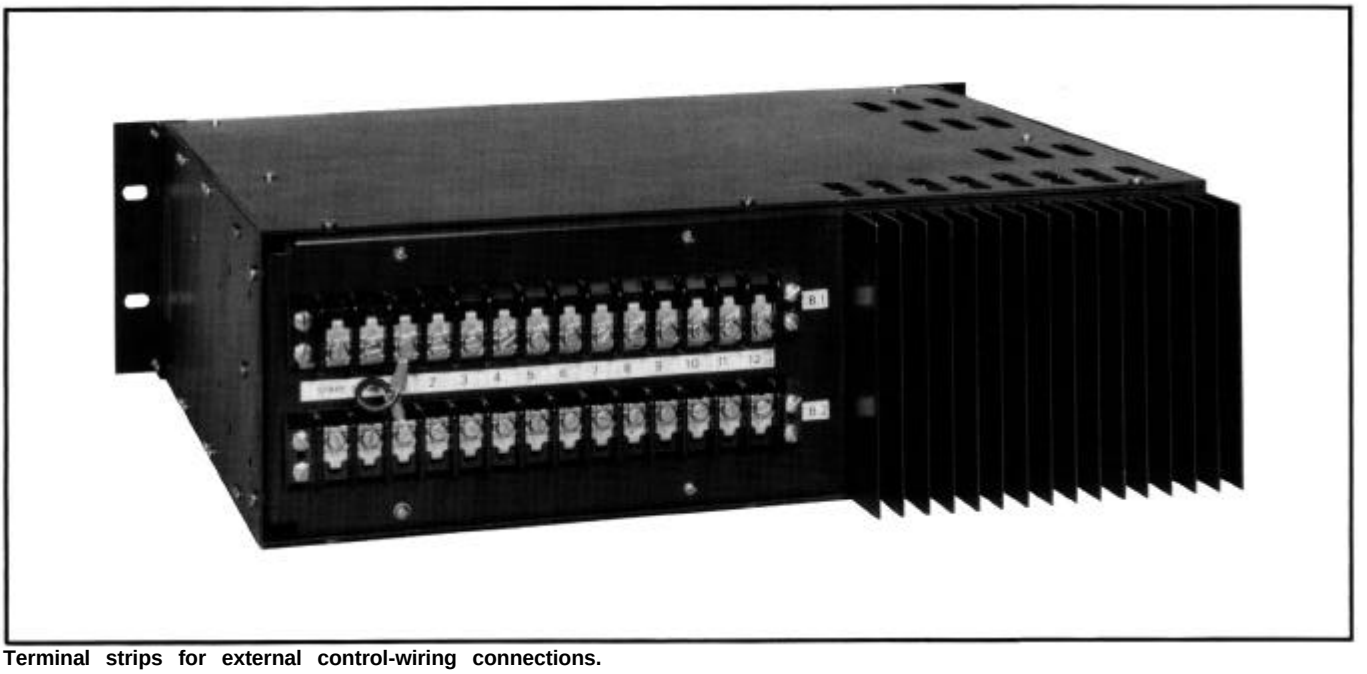
S&C Automatic Control Devices may be furnished in a weatherproof enclosure suitable for mounting on a substation structure. In this instance, a prewired, auxiliary, front-access, covered terminal strip is provided, in addition to a space heater suitable for 120-volt ac or 240-volt ac operation. The space heater is controlled by a nonadjustable 90°F thermostat. Factory-installed fuses and fuse blocks for the control source and for the space heater are included. External connections to the automatic control device are made through a conduit-entrance plate located at the bottom of the enclosure.

When a Type UP or Type GP Automatic Control Device is furnished in combination with a Type VR Automatic Control Device in a weatherproof enclosure, an additional auxiliary, front-access, covered terminal strip is provided, as are additional fuses and fuse blocks. All necessary interconnections are prewired. Further, if the combination is furnished for 125-volt dc control-source voltage (catalog number suffix "-B"), the weatherproof enclosure is supplied with an exhaust fan controlled by a nonadjustable 120°F thermostat.

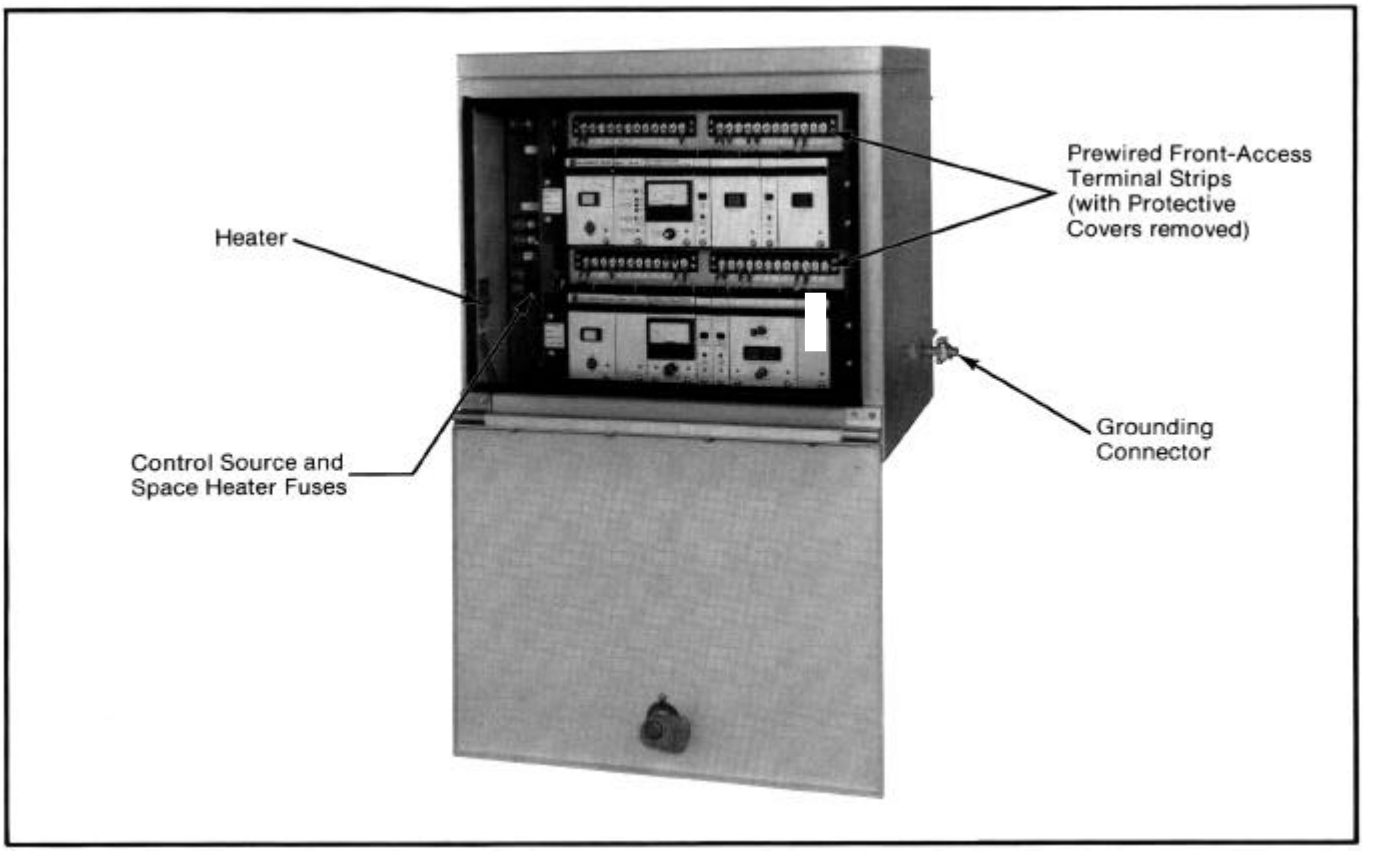


Modular construction typical of S&C Automatic Control Devices.

CONSTRUCTION — Continued



Terminal strips for external control-wiring connections.



S&C Automatic Control Device-Type GP/VR mounted in weatherproof enclosure.