INSTRUCTIONS

For Installation and Operation

INTRODUCTION

CAUTION: The equipment covered by this publication must be selected for a specific application and it must be installed, operated, and maintained by qualified persons who are thoroughly trained and who understand any hazards that may be involved. This publication is written only for such qualified persons and is not intended to be a substitute for adequate training and experience in safety procedures for this type of equipment.

The S&C Automatic Control Device—Type UP provides protection of *ungrounded*, wye-connected shunt capacitor banks—including double-wye banks.† It is a solid-state electronic control device of modular construction which detects the loss of individual capacitor units. See Figure 1. 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

† For applications where the source is a delta-connected tertiary transformer winding, a grounded-wye broken-delta voltage-transformer "bank" with shunt resistor—referred to as a high-impedance grounding transformer (normally required for ground-fault detection)—is required to maintain the stability of phase-to-ground voltage relationships for all but fault conditions. Otherwise spurious signal voltages could appear at the neutral of, and result in isolation of, the capacitor bank. However, if the S&C Type UP Automatic Control Device includes the plug-in unbalance compensation module (connected to compensate for both system voltage unbalance and inherent capacitor-bank unbalance), up to 10% unbalance among system phase-to-ground voltages will be automatically compensated for.

Figure 1. S&C Automatic Control Device—Type UP.

Supersedes Instruction Sheet 531-500 dated 2-16-81

the entire bank when a predetermined neutral-to-ground voltage is exceeded.

The Type UP Automatic Control Device incorporates a *gross overvoltage* circuit which functionally 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 short-time delay, when the neutral-to-ground voltage exceeds a field-adjustable level.

An optional plug-in alarm module set (catalog number suffix "-H") may be furnished to provide an alarm signal upon 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.

The Type UP Automatic Control Device, with the precision, flexibility, and compactness of solid-state electronics, offers matchless design features and proven circuits that withstand the rigors of power equipment application.

The Type UP Automatic Control Device utilizes plug-in modules featuring glass-reinforced 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 have contacts of gold-flashed silver-cadmium oxide to ensure long service life.

Metal-oxide surge protectors at critical points in the control circuits provide the optimum in surge protection. 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 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).

The Type UP Automatic Control Device is 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. See Figure 2. 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 (catalog number suffix "-L" or "-M") is available.

The Type UP Automatic Control Device 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.

The Type UP Automatic Control Device may also be furnished in combination with an S&C Automatic Control Device—Type VR, which provides automatic switching of the capacitor bank to regulate system voltage. When this combination is furnished in a weatherproof enclosure, an additional auxiliary, front-access, covered terminal strip is provided, as are additional fuses and fuse blocks. See Figure 3. 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. Refer to S&C Instruction Sheet 531-515 for details on the Type VR Automatic Control Device.

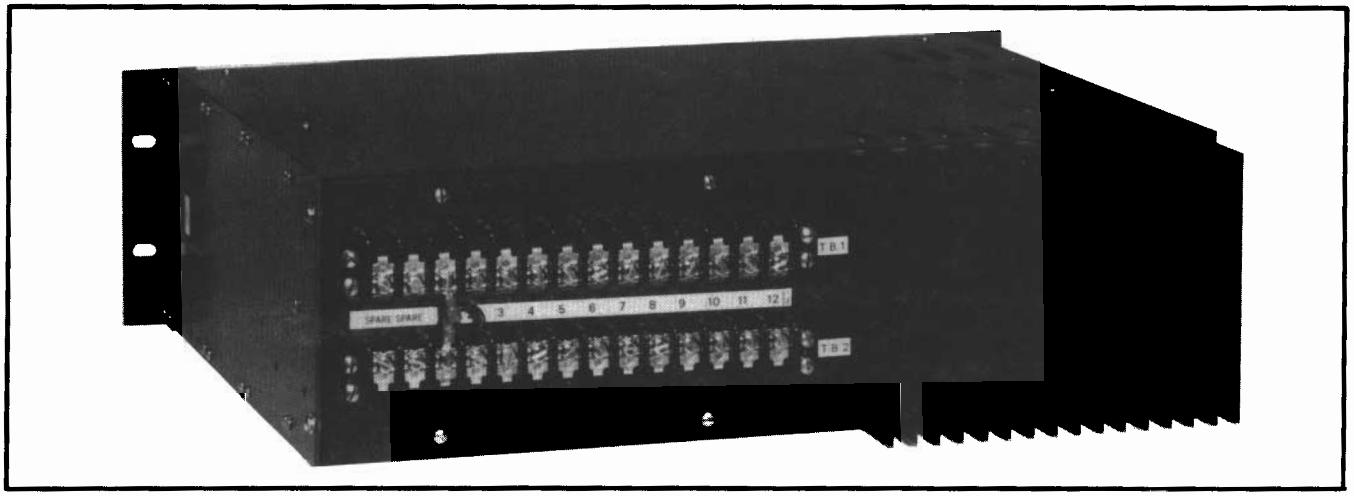

Figure 2. Terminal strips for external control-wiring connections.

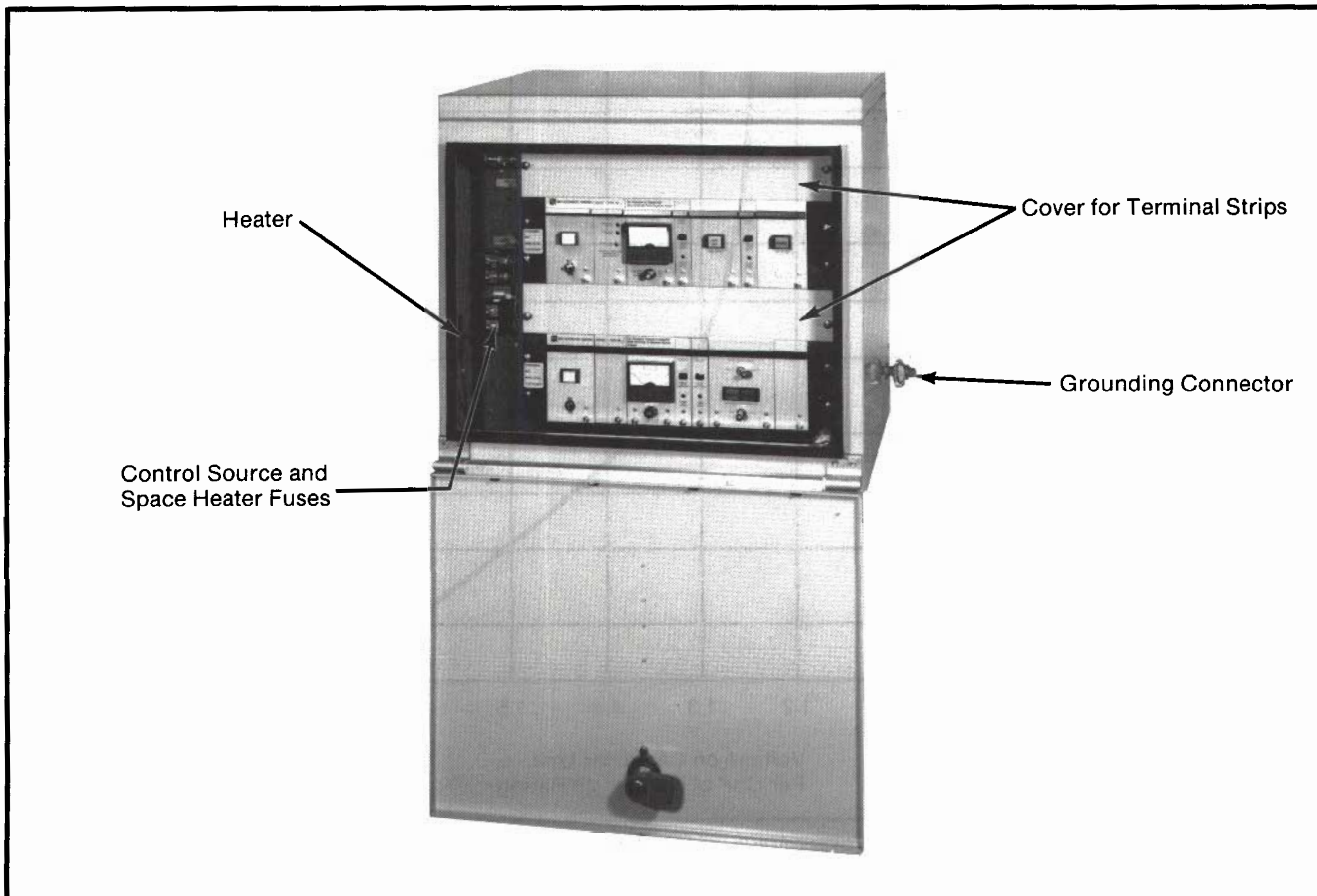

Figure 3. S&C Automatic Control Device—Type UP/VR mounted in weatherproof enclosure.

FUNCTIONAL PERFORMANCE

As failing capacitor units are successively isolated from the same series group by their associated fuses, the voltage applied to the surviving capacitor units in the group increases in discrete steps. Figure 4 indicates permissible capacitor-unit operating time at varying per-unit multiples of capacitor nameplate voltage rating, according to ANSI/IEEE Standard 18-1980, which further states that capacitors shall be capable of continuous operation up to 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 such a recommendation, the ANSI/IEEE data), the entire bank should be removed from service.

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. 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.

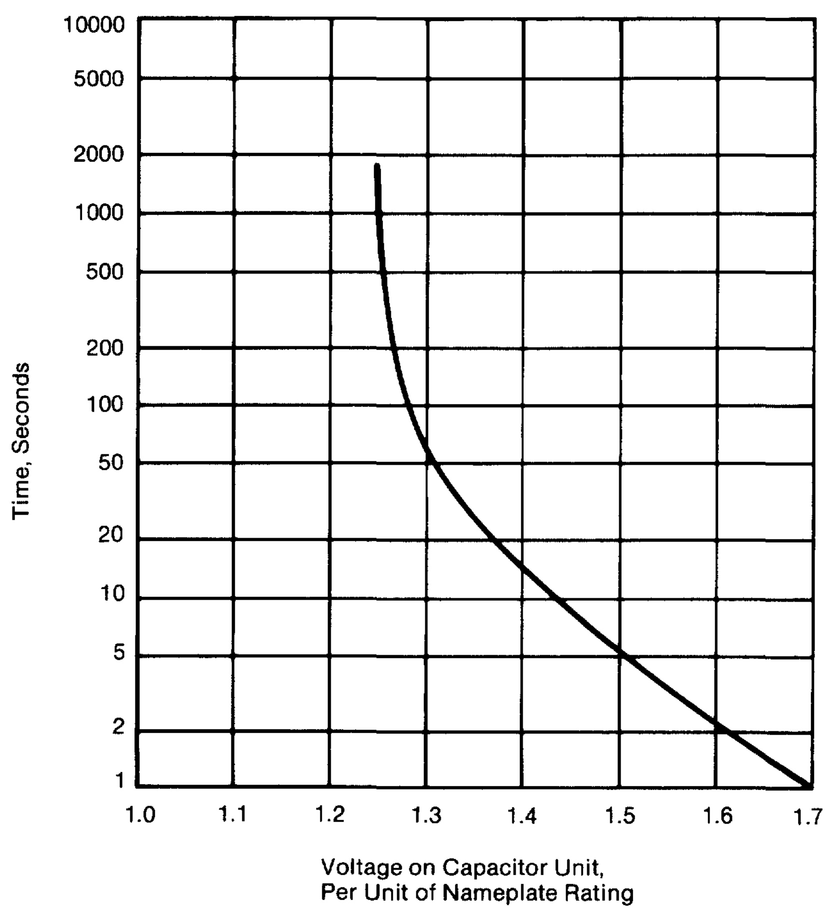

Figure 4. Capacitor-unit power-frequency overvoltage versus time, as permitted by ANSI/IEEE Standard 18-1980, "IEEE Standard for Shunt Power Capacitors," which further states that capacitors shall be capable of continuous operation up to 110% of rated voltage, including harmonics. Note: This curve applies for up to 300 applications of power-frequency overvoltages of the magnitudes and durations illustrated. Capacitor manufacturers may publish different recommendations applicable to their particular units.

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 last-failing capacitor unit before providing a signal to the lockout control module to initiate tripping of the capacitor-bank switching device.

A gross overvoltage circuit responds to faults within the bank producing a neutral-to-ground voltage in excess of a field-adjustable level of 1000 to 5000 volts by initiating isolation and lockout of the capacitor bank after a field-adjustable time delay of 0.5 to 5 seconds.⊕

The Type UP Automatic Control Device may be furnished with an optional 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. 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 (33X) which is actuated through a "b" contact of the capacitor-bank switch-operator auxiliary switch. This auxiliary relay prevents nuisance lockouts of the automatic control device (as well as nuisance activation of the alarm circuit in installations which include the optional alarm module set) resulting from neutral-to-ground voltages of several kilovolts being induced during periods when the capacitor bank has been routinely de-energized.

When required, an optional plug-in unbalance compensation module may be added (along with required additional 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.

§ Factory-set at 10 seconds.

⊕ Factory-set at 2500 volts, for a time delay of 2 seconds.

★ For proper unbalance compensation, the system-derived voltages monitored by the S&C Automatic Control Device must be obtained by means of S&C 30-Volt-Ampere Potential Devices—or voltage transformers—connected to the segment of station bus to which the capacitor bank is tapped. Connecting circuits from the potential devices or voltage transformers to the S&C Type UP Automatic Control Device must be free of variable loads, variable voltage drops, and ground loops so that the voltages monitored accurately represent the magnitude and phase angle of the bus voltages.

General Installation Requirements

To prevent damage to the Type UP Automatic Control Device in the event that surges which exceed factory-tested levels are encountered, S&C's control-circuit fusing recommendations must be followed. The required fuse blocks and fuses are furnished with the control device. If frequent surges in excess of factory-tested levels are anticipated, S&C should be advised as to the severity of the surges so that special recommendations can be made.

In designing the installation, consideration should be given to provision of adequate ventilation for the control device to limit the temperature adjacent to the unit to 160°F maximum. This is particularly important in instances where the control device is installed in a cabinet or where several control devices are installed in close proximity to each other.

Making the Connections

IMPORTANT: The voltmeter module has been calibrated at the factory to provide direct capacitor-bank neutral-to-ground voltage reading for a specific-voltage-rated S&C 15-Volt-Ampere Potential Device connected between the capacitor-bank neutral and ground—as indicated on the label affixed to the back of the module faceplate.

When the optional unbalance compensation module has been specified, it has been calibrated at the factory for a specific-voltage-rated S&C 15-Volt-Ampere Potential Device connected between the capacitor-bank neutral and ground, and for a specific primary-to-secondary voltage ratio S&C 30-Volt-Ampere Potential Device(s) or voltage transformer(s) connected between the station bus and ground—as indicated on the label affixed to the back of the module faceplate.

If other voltage-monitoring devices are utilized, recalibration is required. Refer to the recalibration instructions contained in S&C Reference Drawing RD-3223 for the voltmeter module, or RD-3224 for the unbalance compensation module. The appropriate drawing(s) is furnished as part of the detailed instruction manual which can be ordered for the Type UP Automatic Control Device.

The Type UP Automatic Control Device is equipped with numbered terminal strips for external control-wiring connections at the rear of the device. See Figure 2. Using the connection drawing in the instruction manual furnished with the device, make the following connections:

1. Control source (48 volts dc, 125 volts dc, 120 volts 60 hertz, or 240 volts 60 hertz, as appropriate).
2. Output terminals of the S&C 15-Volt-Ampere Potential Device, having 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

3. Opening circuit of the switch operator.
4. Closing circuit of the switch operator.
5. "b" contact of switch-operator auxiliary switch. This contact should be set to open near the fully closed position of the capacitor-bank switching device.
6. Station ground.
7. Space heater source, where applicable (120 volts 60 hertz or 240 volts 60 hertz).
8. Alarm circuit (optional).

Additionally, if the Type UP Automatic Control Device is equipped with the optional plug-in unbalance compensation module, connections are required to the output terminals of other voltage-monitoring devices as follows:

1. *For detection and compensation of inherent capacitor-bank unbalance only, in applications where the source is grounded*, connection must be made to either:
   a. A single, fully system-voltage-rated S&C 30-Volt-Ampere Potential Device equipped with factory-adjusted calibration device (catalog number suffix "-T"), connected to any phase of the station bus from which the capacitor bank is tapped, or

b. A single voltage transformer, connected to the station bus from which the capacitor bank is tapped—either line-to-line across any two phases or line-to-ground on any phase.

2. *For detection and compensation of inherent capacitor-bank unbalance only, in applications where the source is a delta-connected tertiary transformer winding*, connection must be made to a 1:1-ratio voltage transformer which is then to be connected to any secondary of a high-impedance grounding transformer; the voltage transformer should have a voltage rating equal to the secondary voltage rating of the grounding transformer. (The grounding transformer—which should be connected to the station bus from which the capacitor bank is tapped—maintains the stability of phase-to-ground voltage relationships for all but fault conditions.)

3. *For detection and compensation of inherent capacitor-bank unbalance plus detection and compensation of system voltage unbalance, in applications where the source is grounded*, connection must be made to either:

   a. Three fully system-voltage-rated S&C 30-Volt-Ampere Potential Devices equipped with factory-adjusted calibration device (catalog number suffix "-T"), each connected to a phase of the station bus from which the capacitor bank is tapped, or

   b. Three voltage transformers, connected to the station bus, grounded-wye grounded-wye.

4. *For detection and compensation of inherent capacitor-bank unbalance plus detection and compensation of system voltage unbalance, in applications where the source is a delta-connected tertiary transformer winding*, connections must be made to three 1:1-ratio voltage transformers each of which is then to be connected to a secondary of a high-impedance grounding transformer; the voltage transformers should have a voltage rating equal to the secondary voltage rating of the grounding transformer. (The grounding transformer—which should be connected to the station bus from which the capacitor bank is tapped—maintains the stability of phase-to-ground voltage relationships for all but fault conditions.)

When the unbalance compensation module is used to compensate for system voltage unbalance, it is factory-calibrated in accordance with information furnished at the time of ordering. Such information includes the catalog number of the associated S&C 30-Volt-Ampere Potential Devices, the primary- and secondary-voltage ratings and the turns ratio of the associated voltage transformers, or the secondary voltage rating and turns ratio of the associated grounding transformer, as applicable.

Connecting circuits from the voltage-monitoring devices to the Type UP Automatic Control Device must be free of variable loads, variable voltage drops, and ground loops so that the voltages monitored accurately represent the magnitude and phase angle of the bus voltages. Some possible errors affecting unbalance compensation are:

- Differences in effective voltage ratio among the three S&C 30-Volt-Ampere Potential Devices or the three voltage transformers used to obtain system-derived voltages, as applicable.
- Unbalanced or variable loading of the voltage-monitoring devices used to obtain system-derived voltages. (Station-service transformers are thus not suitable sources for this purpose.)
- Control-wiring voltage drops between the voltage-monitoring devices and the automatic control device. (For example, a 1-ampere current flowing through 1000 feet of number 10 AWG wire will result in a 1-volt drop in the voltage-level signal, which may be sufficient to produce undesirable performance of the protection scheme.) Adequately sized dedicated connecting circuits between the voltage-monitoring devices and the automatic control device will minimize voltage drops.
- Induced voltages in control wiring. Proper shielding is important.
- Ground loops caused by differences in voltage between the grounding points for the capacitor-bank neutral-to-ground voltage-monitoring device and those for the voltage-monitoring devices used to obtain system-derived voltages. Preferably, the secondaries of all the voltage-sensing devices should be grounded at one point—at the control house, as per proposed ANSI C57.13.3, "Guide for the Grounding of Instrument Transformer Secondary Circuits and Cases."

ESTABLISHING THE SETTINGS

Two methods of establishing the capacitor-bank lockout level are given on this and succeeding pages—one utilizing graphs and one utilizing formulas.

Determine Incremental Capacitor-Unit Overvoltage and Capacitor-Bank Neutral-to-Ground Voltage Due to Loss of Successive Capacitor Units—Graphical Method

Step-by-step Procedures

1. Collect installation data, including:
   a. Highest anticipated continuous system line-to-neutral voltage, kv
   b. Nameplate capacitor-unit rating, kv
   c. Number of series groups per phase — S
   d. Number of capacitor units in parallel per series group — P.
2. Using the graph, Figure 5, read per-unit values of V_O—the voltage applied to surviving capacitor units—for a series of steps corresponding to increasing values of F—the number of capacitor units isolated—up to

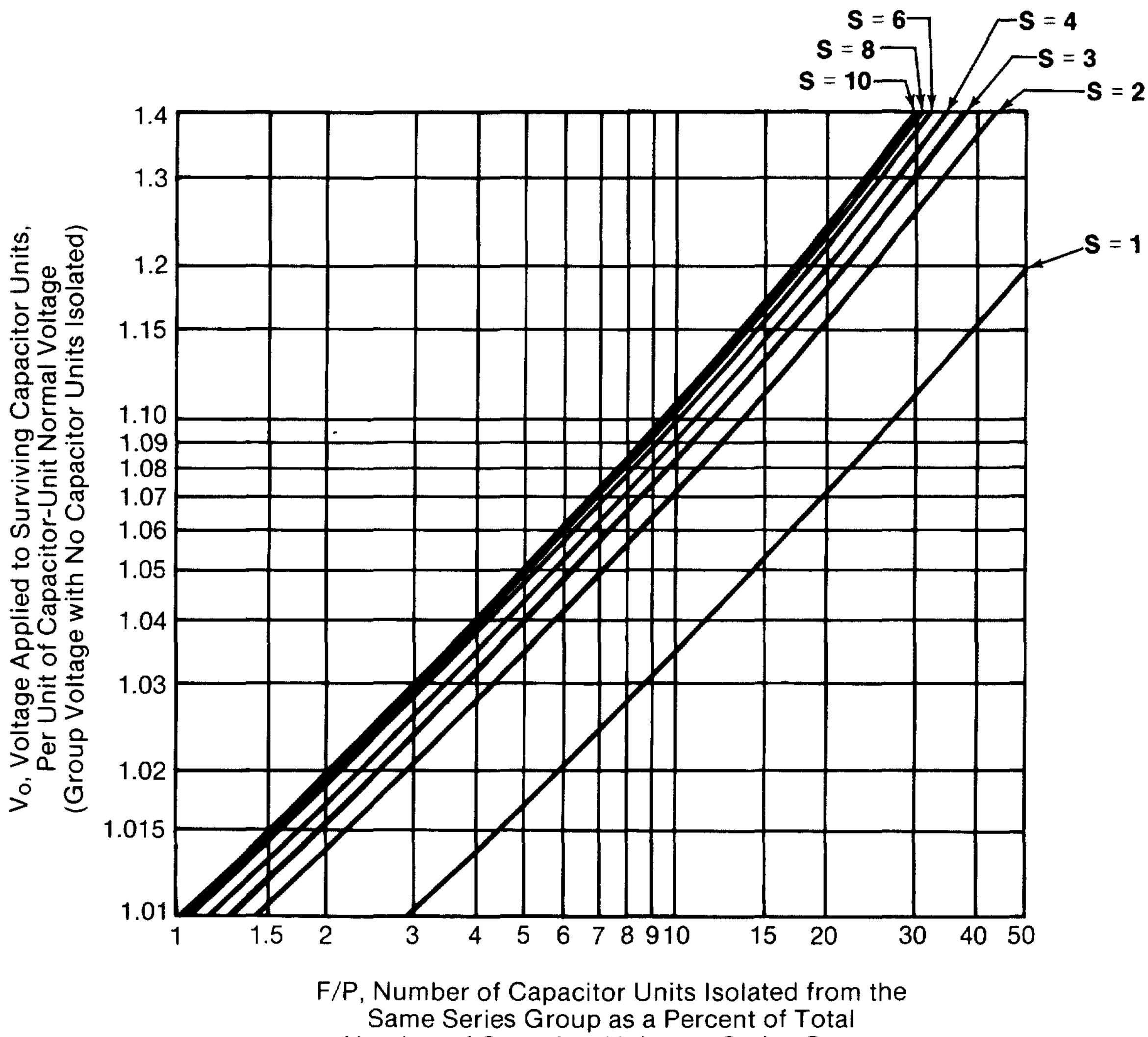

Figure 5. Per-unit voltage applied to surviving capacitor units in a series group versus percentage of capacitor units isolated from the same series group.

and including F_C—the step for which V_O equals or exceeds the capacitor manufacturer's recommended maximum working voltage (generally 1.1 per unit). The step corresponding to F_C will hereafter be referred to as the "critical step."

3. If the capacitor units are operated at other than rated voltage, correct the values read in (2) above by multiplying by the ratio of the "normal" (highest anticipated) applied voltage (all capacitor units operating) to the nameplate voltage rating of the capacitor units.
4. Using the graph, Figure 6, read per-unit values of V_n—capacitor-bank neutral-to-ground voltage—for the same series of steps corresponding to increasing values of F up to and including F_C.
5. Convert the per-unit values of V_n read in (4) above to actual V_n voltage values by multiplying by the highest anticipated system line-to-neutral voltage.

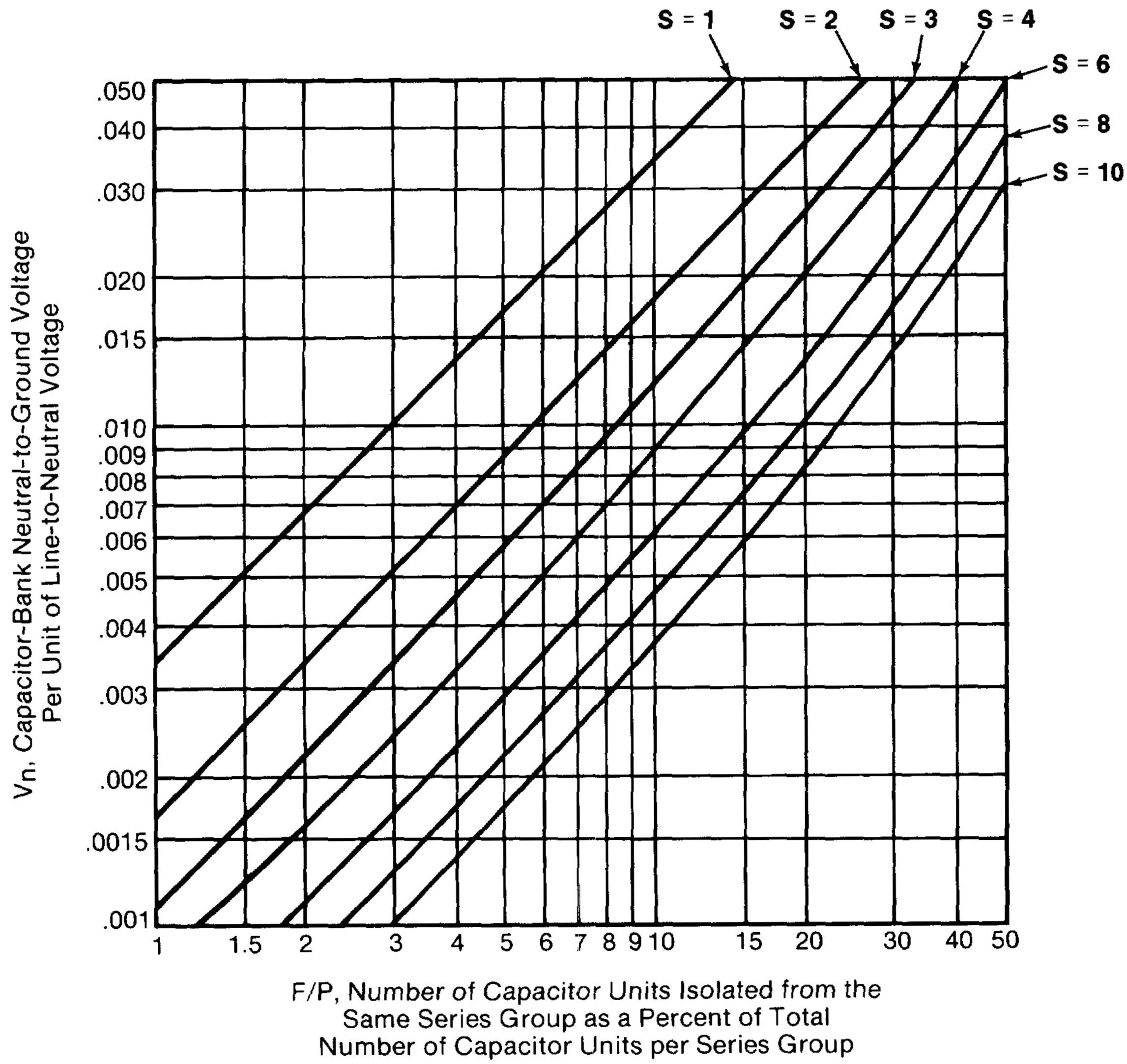

Figure 6. Per-unit capacitor-bank neutral-to-ground voltage versus percentage of capacitor units isolated from the same series group.

6. Determine the desired lockout level—the midpoint between V_n for the critical step, F_c, and V_n for F_{c-1}.

Using the Graphical Method—First Example

1. Installation Data
   a. Highest anticipated continuous system line-to-neutral voltage, kv 20
   b. Nameplate capacitor-unit rating, kv 9.96
   c. Number of series groups per phase 2
   d. Number of capacitor units in parallel per series group 10

2. For F = 1, enter the graph, Figure 5, at 10 on the horizontal scale (1/10 = 10% of capacitor units isolated from a series group). Follow up to a point corresponding to 2 series groups per phase (curve labeled "S = 2") and read V_o = 1.072 per unit on the vertical scale.

   For F = 2, in like manner, enter the graph, Figure 5, at 20 on the horizontal scale (2/10 = 20% of capacitor units isolated from the same series group). Follow up to a point corresponding to 2 series groups per phase (curve labeled "S = 2") and read V_o = 1.16 per unit on the vertical scale. Obviously, F = 2 is the critical step, F_c, if it is desired to limit V_o to 1.1 per unit or less.

3. With an anticipated system line-to-neutral voltage of 20 kv and with 2 series groups per phase, the capacitor units are normally operated at 10 kv. Therefore:

   For F = 1,

   $$V_o = \frac{1.072 \times 10 \text{ kv}}{9.96 \text{ kv}} = 1.076 \text{ per unit}$$

   For F = 2,

   $$V_o = \frac{1.16 \times 10 \text{ kv}}{9.96 \text{ kv}} = 1.16 \text{ per unit}$$

4. For F = 1, enter the graph, Figure 6, at 10 on the horizontal scale (1/10 = 10% of capacitor units isolated from a series group). Follow up to a point corresponding to 2 series groups per phase (curve labeled "S = 2") and read V_n = .018 per unit on the vertical scale.

   For F = 2, in like manner, enter the graph, Figure 6, at 20 on the horizontal scale (2/10 = 20% of capacitor units isolated from the same series group). Follow up to a point corresponding to 2 series groups per phase (curve labeled "S = 2") and read V_n = .038 per unit on the vertical scale.

5. Multiply the values read in (4) above by the system line-to-neutral voltage to convert the per-unit V_n values to actual V_n voltage values. Thus:

   For F = 1,

   V_n = 0.018 X 20,000 volts = 360 volts

   For F = 2,

   V_n = 0.038 X 20,000 volts = 760 volts

6. Determine the lockout level by calculating the midpoint value between V_n for F = 1 and V_n for F = 2, the critical step F_c. Thus, the desired lockout level is

   $$\frac{360 \text{ volts} + 760 \text{ volts}}{2} = 560 \text{ volts}$$

Using the Graphical Method—Second Example

1. Installation Data
   a. Highest anticipated continuous system line-to-neutral voltage, kv 139.44
   b. Nameplate capacitor-unit rating, kv 19.92
   c. Number of series groups per phase 7
   d. Number of capacitor units in parallel per series group 12

2. For F = 1, enter the graph, Figure 5, at 8.33 on the horizontal scale (1/12 = 8.33% of capacitor units isolated from a series group). Follow up to a point corresponding to 7 series groups per phase (interpolate between curves labeled "S = 6" and "S = 8") and read V_o = 1.085 per unit on the vertical scale.

   For F = 2, in like manner, enter the graph, Figure 5, at 16.67 on the horizontal scale (2/12 = 16.67% of capacitor units isolated from the same series group). Follow up to a point corresponding to 7 series groups per phase and read V_O = 1.18 per unit on the vertical scale. Obviously, F = 2 is the critical step, F_C, if it is desired to limit V_O to 1.1 per unit or less.

3. With an anticipated system line-to-neutral voltage of 139.44 kv and with 7 series groups per phase, the capacitor units are normally operated at 19.92 kv, their rated voltage. Therefore, no correction factor need be applied to the values read in (2) above.
4. For F = 1, enter the graph, Figure 6, at 8.33 on the horizontal scale (1/12 = 8.33% of capacitor units isolated from a series group). Follow up to a point corresponding to 7 series groups per phase (interpolate between curves labeled "S = 6" and "S = 8") and read V_n = .0043 on the vertical scale.

   For F = 2, in like manner, enter the graph, Figure 6, at 16.67 on the horizontal scale (2/12 = 16.67% of capacitor units isolated from the same series group). Follow up to a point corresponding to 7 series groups per phase and read V_n = .0093 on the vertical scale.
5. Multiply the values read in (4) above by the system line-to-neutral voltage to convert the per-unit V_n values to actual V_n voltage values. Thus:

   For F = 1,

   V_n = .0043 X 139,440 volts = 600 volts

   For F = 2,

   V_n = .0093 X 139,440 volts = 1297 volts
6. Determine the lockout level by calculating the midpoint value between V_n for F = 1 and V_n for F = 2, the critical step F_C. Thus, the desired lockout level is

$$\frac{600 \text{ volts} + 1{,}297 \text{ volts}}{2} = 949 \text{ volts}$$

Determine Incremental Capacitor-Unit Overvoltage and Capacitor-Bank Neutral-to-Ground Voltage Due to Loss of Successive Capacitor Units—Formula Method

Step-by-step Procedures

1. Collect installation data, including:
   a. Highest anticipated continuous system line-to-neutral voltage, kv
   b. Nameplate capacitor-unit rating, kv
   c. Number of series groups per phase
   d. Number of capacitor units in parallel per series group.
2. Calculate per-unit values of V_O—the voltage applied to surviving capacitor units—for a series of steps corresponding to increasing values of F—the number of capacitor units isolated—up to and including F_C—the step for which V_O equals or exceeds the capacitor manufacturer's recommended maximum working voltage (generally 1.1 per unit). The step corresponding to F_C will hereafter be referred to as the "critical step." Use the formulas:

$$V_O \text{ (volts)} = \frac{(3P)\,(V_{L\text{-}n})}{2F + 3S(P-F)}$$

$$V_O \text{ (per unit)} = \frac{V_O \text{ (Volts)}}{\text{Nameplate voltage rating of capacitor units}}$$

where $V_{L\text{-}n}$ = Highest anticipated continuous system line-to-neutral voltage

S = Number of series groups per phase

P = Number of capacitor units in parallel per series group

F = Number of capacitor units isolated from bank (and from the same series group)

3. For each value of F used in (2) above, calculate the neutral-to-ground voltage, V_n. Use the formula:

$$V_n = \frac{(F)(V_{L-n})}{2F + 3S(P-F)}$$

where V_{L-n}, S, P, and F are defined as in (2) above.

4. Determine the lockout level by calculating the midpoint between V_n for F_c, the critical step, and V_n for F_{c-1}.

Using the Formula Method—First Example

1. Installation Data
   a. Highest anticipated continuous system line-to-neutral voltage, kv 20
   b. Nameplate capacitor-unit rating, kv 9.96
   c. Number of series groups per phase 2
   d. Number of capacitor units in parallel per series group 10

2. For F = 1,

$$V_o\ (\text{volts}) = \frac{(3)\ (10)\ (20{,}000)}{(2)\ (1) + (3)\ (2)\ (10-1)} = 10{,}714 \text{ volts}$$

$$V_o\ (\text{per unit}) = \frac{10{,}714}{9{,}960} = 1.0757 \text{ per unit (or 7.57\% overvoltage)}$$

For F = 2,

$$V_o\ (\text{volts}) = \frac{(3)\ (10)\ (20{,}000)}{(2)\ (2) + (3)\ (2)\ (10-2)} = 11{,}538 \text{ volts}$$

$$V_o\ (\text{per unit}) = \frac{11{,}538}{9{,}960} = 1.1585 \text{ per unit (or 15.85\% overvoltage)}$$

Obviously, F = 2 is the critical step, F_c, if it is desired to limit V_o to 1.1 per unit or less.

3. For F = 1,

$$V_n = \frac{(1)(20{,}000)}{(2)\ (1) + (3)\ (2)\ (10-1)} = 357 \text{ volts}$$

For F = 2,

$$V_n = \frac{(2)(20{,}000)}{(2)\ (2) + (3)\ (2)\ (10-2)} = 769 \text{ volts}$$

4. Determine the lockout level by calculating the midpoint between V_n for F = 1 and V_n for F = 2, the critical step F_c. Thus, the desired lockout level is 563 volts.

Using the Formula Method—Second Example

1. Installation Data
   a. Highest anticipated continuous system line-to-neutral voltage, kv 139.44
   b. Nameplate capacitor-unit rating, kv 19.92
   c. Number of series groups per phase 7
   d. Number of capacitor units in parallel per series group 12

2. For F = 1,

$$V_o\ (\text{volts}) = \frac{(3)(12)(139{,}440)}{(2)(1) + (3)(7)(12-1)} = 21{,}544 \text{ volts}$$

$$V_o\ (\text{per unit}) = \frac{21{,}544}{19{,}920} = 1.0815 \text{ per unit (or 8.15\% overvoltage)}$$

For F = 2,

$$V_o\ (\text{volts}) = \frac{(3)(12)(139{,}440)}{(2)(2) + (3)(7)(12-2)} = 23{,}457 \text{ volts}$$

$$V_o\ (\text{per unit}) = \frac{23{,}457}{19{,}920} = 1.1776 \text{ per unit (or 17.76\% overvoltage)}$$

Obviously, $F = 2$ is the critical step, F_C, if it is desired to limit V_O to 1.1 per unit or less.

3. For $F = 1$,

$$V_n = \frac{(1)(139{,}440)}{(2)(1) + (3)(7)(12-1)} = 598 \text{ volts}$$

For $F = 2$,

$$V_n = \frac{(2)(139{,}440)}{(2)(2) + (3)(7)(12-2)} = 1303 \text{ volts}$$

4. Determine the lockout level by calculating the midpoint between V_n for $F = 1$ and V_n for $F = 2$, the critical step F_C. Thus, the desired lockout level is 951 volts.

Gross Overvoltage Circuit

Calculate the capacitor-bank neutral-to-ground voltage, V_n, resulting from a fault within the capacitor bank which would short out an entire series group. Use the formula:

$$V_n = \left[\frac{1}{3S-2}\right] V_{L-n}$$

where S = Number of series groups per phase
V_{L-n} = Highest anticipated continuous system line-to-neutral voltage

For the first example given under "Determine Incremental Capacitor-Unit Overvoltage and Capacitor-Bank Neutral-to-Ground Voltage Due to Loss of Successive Capacitor Units—Formula Method," the desired gross overvoltage lockout level is the midpoint between V_n for $F = 2$—769 volts—and the value of V_n resulting from shorting out a series group—

$$\left[\frac{1}{(3)(2)-2}\right] 20{,}000 \text{ volts} = 5000 \text{ volts, or}$$

$$\frac{769 \text{ volts} + 5000 \text{ volts}}{2} = 2885 \text{ volts}$$

For the second example given under "Determine Incremental Capacitor-Unit Overvoltage and Capacitor-Bank Neutral-to-Ground Voltage Due to Loss of Successive Capacitor Units—Formula Method," the desired gross overvoltage lockout level is the midpoint between the V_n for $F = 2$—1303 volts—and the value of V_n resulting from shorting out a series group—

$$\left[\frac{1}{(3)(7)-2}\right] 139{,}440 \text{ volts} = 7339 \text{ volts, or}$$

$$\frac{1303 \text{ volts} + 7339 \text{ volts}}{2} = 4321 \text{ volts}$$

Should the calculated gross overvoltage lockout level exceed 5000 volts, the detector should be set at its maximum value.

IS UNBALANCE COMPENSATION NEEDED?

A certain amount of error voltage is always present between the capacitor-bank neutral and ground, due to system voltage unbalance and/or inherent capacitor-bank unbalance resulting from manufacturing-tolerance variations among capacitor units in the bank. Since it is not possible to predict how the two components of the error voltage will combine vectorially, it is important that the magnitude of the error voltage be kept low in relation to the magnitude of the capacitor-bank neutral-to-ground voltage resulting from isolation of one capacitor unit. For example, the error voltage may be additive with respect to the neutral-to-ground voltage resulting from isolation of capacitor units in one phase leg, but subtractive with respect to the neutral-to-ground voltage resulting from isolation of capacitor units in another phase leg.

As a rule, unbalance compensation should be provided if the magnitude of the error voltage approaches 50% of the value of neutral-to-ground voltage calculated for isolation of one capacitor unit. If the capacitor-bank manufacturer can supply an estimate of the per-unit capacitor-bank unbalance between phases, and if the per-unit system voltage unbalance between phases is known, an estimate of the error voltage can be calculated as follows:

$$\text{Error Voltage from Capacitor-Bank Unbalance} = \frac{\left(\begin{matrix}\text{Per-unit}\\ \text{Capacitor-Bank}\\ \text{Unbalance}\end{matrix}\right)\left(\begin{matrix}\text{System Line-}\\ \text{to-Neutral}\\ \text{Voltage}\end{matrix}\right)}{3}$$

$$\text{Error Voltage from System Voltage Unbalance} = \frac{\left(\begin{matrix}\text{Per-unit}\\ \text{System Voltage}\\ \text{Unbalance}\end{matrix}\right)\left(\begin{matrix}\text{System Line-}\\ \text{to-Neutral}\\ \text{Voltage}\end{matrix}\right)}{3}$$

For the two examples given under "Determine Incremental Capacitor-Unit Overvoltage and Capacitor-Bank Neutral-to-Ground Voltage Due to Loss of Successive Capacitor Units—Formula Method," assume a per-unit capacitor-bank unbalance of 0.01 and a per-unit system voltage unbalance of 0.005.

For the first example:

$$\text{Error Voltage from Capacitor-Bank Unbalance} = \frac{(0.01)(20{,}000\text{ volts})}{3} = 66.7\text{ volts}$$

$$\text{Error Voltage from System Voltage Unbalance} = \frac{(0.005)(20{,}000\text{ volts})}{3} = 33.3\text{ volts}$$

In the event that these error voltages are additive, the total error voltage could be as high as 100 volts—28% of the neutral-to-ground voltage resulting from the isolation of one capacitor unit, 357 volts. Thus, the user should forego inclusion of the unbalance compensation module (and the required additional voltage-monitoring devices) unless the need for unbalance compensation is established through field experience. (See Step 11, page 17.)

For the second example:

$$\text{Error Voltage from Capacitor-Bank Unbalance} = \frac{(0.01)(139{,}440\text{ volts})}{3} = 464.8\text{ volts}$$

$$\text{Error Voltage from System Voltage Unbalance} = \frac{(0.005)(139{,}440\text{ volts})}{3} = 232.4\text{ volts}$$

In the event that these error voltages are additive, the total error voltage could be as high as 697.2 volts—a value requiring unbalance compensation since the netural-to-ground voltage resulting from the isolation of one capacitor unit in this example is 598 volts.

Step 1

Place the on-off toggle switch on the power supply module in the *on* position. The presence of control-source voltage will be signified by a lighted indicator.

If an alarm indicator or lockout indicator lamp should light, press the appropriate button to reset the circuit.

Step 2

Choose the appropriate scale for the voltmeter by setting its meter range selector so that the predetermined lockout level will fall in the upper half of the voltmeter scale. Thus, for the examples given under the "Formula Method" on pages 12 and 13, the 0-1000 volt scale should be selected in both cases.

Step 3

Adjust the lockout level by pressing the "push-to-read lockout level" button on the lockout level module while turning the "lockout level adjust" screw to attain the required voltmeter reading.

Step 4

If the optional alarm module set is furnished: Adjust the alarm level by pressing the "push-to-read alarm level" button on the alarm level module while turning the "alarm level adjust" screw to attain the required voltmeter reading. Choose the appropriate meter range as noted in Step 2.

The alarm level setting should be approximately half of the value of the capacitor-bank neutral-to-ground voltage resulting from the isolation of one capacitor unit. Thus, using the examples given under the "Formula Method" on pages 12 and 13, the alarm level settings should be 357 volts/2 = 178 volts, and 598 volts/2 = 299 volts, respectively.

Activation of the alarm circuit upon isolation of one capacitor unit enables the user to choose either to continue operating the capacitor bank—deferring replacement of the failed unit until a convenient time—or to replace the failed unit sooner, thus minimizing the time that surviving capacitor units are exposed to overvoltage and thereby reducing the likelihood that marginal units will fail prematurely.

Step 5

Record, for future reference, the lockout-level and alarm-level settings arrived at in the preceding steps, as indicated on the voltmeter. Note also the voltmeter range selected.

Step 6

Adjust the gross overvoltage circuit neutral-to-ground voltage by setting the 1000-5000 volt single-turn potentiometer located on the lockout control module printed circuit board for the required value. For the examples given under "Gross Overvoltage Circuit" on page 13, gross overvoltage settings should be 2885 volts and 4321 volts, respectively.

LOCKOUT-TIMER ADJUSTMENTS

An important consideration in the application of the Type UP Automatic Control Device is that of coordinating capacitor-bank isolation and lockout with operation of the individual capacitor-unit fuses. It is undesirable for the control to initiate lockout before the fuse for the last-failing capacitor unit has had sufficient time to operate—thereby eliminating any indication as to which capacitor unit was in the process of failing. Generally, coordination will be achieved provided:

1. The lockout and alarm levels are set as described in the foregoing example,
2. The lockout time delay is adequate, and
3. A fusing ratio of 1.25 or less is used for individual capacitor-unit fuses.

Step 7

If other than the factory-set lockout time delay is desired (see SPECIFICATIONS, page 19), set the 1-30 second single-turn potentiometer, located on the lockout level module printed circuit board, for the desired value. The scale on the potentiometer is accurate to ±20%.

Step 8

Adjust the gross overvoltage circuit time delay by setting the 0.5-5 second single-turn potentiometer, located on the lockout control module printed circuit board, for the desired value. The scale on the potentiometer is accurate to ±20%.

The gross overvoltage circuit time delay should be a minimum of 0.5 second‡ *plus* the elapsed time between energization of the capacitor-bank switching device opening circuit and closing of the switching device "b" contact (which is coincident with mechanical parting of the disconnect blades, if an S&C Circuit-Switcher is furnished).

For example, if the capacitor-bank switching device is a 230-kv S&C Circuit-Switcher, the minimum gross overvoltage circuit time delay setting should be 0.5 second plus 0.6 second, or 1.1 seconds total. The elapsed time between energization of the opening circuit and mechanical parting of the disconnect blades can be approximated as 40% of the maximum operating time of the particular S&C Circuit-Switcher used.

Step 9

Record, for future reference, the time-delay settings selected in Steps 7 and 8.

‡ Required to prevent gross overvoltage lockout due to transient system voltage.

FIELD DETERMINATION OF NEED FOR UNBALANCE COMPENSATION

Step 10

Close the capacitor-bank switching device to energize the capacitor bank.

Verify that no capacitor units have been isolated from the capacitor bank (check for blown fuses). The voltmeter should read essentially zero or, at most, 50% of the capacitor-bank neutral-to-ground voltage calculated to result from the isolation of one capacitor unit. Record, for future reference, this voltmeter reading. If the voltmeter reading exceeds 50% of the capacitor-bank neutral-to-ground voltage calculated to result from the isolation of one capacitor unit, it will be necessary to either increase the alarm-level setting or to utilize the optional unbalance compensation module, adjusted as described in Step 11.

ADJUSTMENT OF UNBALANCE COMPENSATION

Step 11

If the voltmeter reading taken in Step 10 exceeds 50% of the capacitor-bank neutral-to-ground voltage calculated to result from the isolation of one capacitor unit, unbalance compensation is required. Assuming that the plug-in unbalance compensation module is installed, calibrated,† and connected, proceed as follows: Turn the "amplitude adjust" screw five full turns clockwise from its fully counterclockwise position. Then turn the "phase-fine adjust" screw three full turns clockwise from its fully counterclockwise position. If the voltmeter reading exceeds the full-scale value, temporarily turn the voltmeter range selector switch to the next higher scale. Next, turn the "phase-coarse adjust" screw to operate the four-position rotary switch (at random) to attain a minimum reading on the voltmeter. Turn the "amplitude adjust" screw to further reduce the voltmeter reading. Turn the "phase-fine adjust" screw to attain a minimum reading on the voltmeter. Return the voltmeter range selector switch to the desired scale. Turn the "amplitude adjust" screw to further reduce the voltmeter reading and then turn the "phase-fine adjust" screw to attain a final minimum reading on the voltmeter. Record, for future reference, this voltmeter reading.

† *The unbalance compensation module is factory calibrated in accordance with information furnished by the purchaser at the time of ordering.*

VERIFICATION OF CALCULATED LOCKOUT AND ALARM LEVELS

Lockout level can be checked as follows:

Step 12

Verify that no capacitor units have been isolated from the bank.

Step 13

De-energize the capacitor bank by opening the capacitor-bank switching device. Then ground the bank, observing established operating procedures and safety precautions. Isolate the number of capacitor units—all in the same series group—previously determined as required to lock out the bank, by removing their respective fuses.

Step 14

Remove the temporary grounds, re-energize the bank, and record the voltmeter reading. If the voltmeter deflection exceeds the lockout-level value, an automatic switching operation will occur to isolate the entire capacitor bank after the timer completes its cycle—as indicated by the "Lockout Indicator" lamp. In any event, de-energize the bank by opening the capacitor-bank switching device as soon as the voltmeter reading has been obtained, to avoid shortening the life of the capacitor units. Verify that no other capacitor units have been isolated.

Note: Following automatic lockout of the capacitor bank, the bank can be returned to service *only after pressing* the "Lockout Indicator" button. This permits closing of the capacitor-bank switching device.

Step 15

De-energize and ground the capacitor bank, observing established operating procedures and safety precautions. Reconnect the fuses which were previously removed to isolate the capacitor units.

Step 16

Repeat Steps 13 through 15 for each of the remaining phase legs of the capacitor bank.

Step 17

Verify that the calculated lockout level is lower than the lowest voltmeter reading obtained in Steps 12 through 16. A calculated lockout level higher than one or two of the voltmeter readings obtained in Steps 12 through 16 indicates that system voltage unbalance and/or inherent capacitor-bank unbalance is creating an error voltage appearing between the capacitor-bank neutral and ground, sufficient in magnitude to obscure the neutral-to-ground voltage resulting from the isolation of successive capacitor units. In this event, either of two actions may be taken:

1. Reduce the lockout-level setting to a value lower than the lowest reading obtained in Steps 12 through 16, with the knowledge that lockout may occur with a lesser number of individual capacitor units removed from service.
2. Install the optional plug-in unbalance compensation module and adjust it as indicated under ADJUSTMENT OF UNBALANCE COMPENSATION.

Step 18

To check the alarm level value (if the optional alarm module set is included), proceed in the same manner described in Steps 12 through 16 with regard to checking the lockout-level value.

MAINTENANCE

No routine maintenance is recommended for the Type UP Automatic Control Device other than an occasional exercising (about once per year) to verify that it is operational. This can be done by temporarily adjusting the lockout level downward until lockout of the capacitor bank occurs.

At installations utilizing an S&C Circuit-Switcher as the capacitor-bank switching device, the associated S&C Switch Operator, Type CS-1A or Type CS-2A, may be conveniently decoupled from the Circuit-Switcher. This capability makes it possible to check out the Type UP Automatic Control Device without actually switching the capacitor bank.

It is advisable, for the first few days after start-up, to compare day-to-day voltmeter readings with those recorded in Step 10 or Step 11. It is possible for changes to occur due to irregularities in the voltage-monitoring devices or to aberrations (developing faults) in the capacitor units themselves. When it has been determined that the capacitor-bank neutral-to-ground voltage is remaining constant, voltmeter readings may be compared at convenient intervals. If a small increase in capacitor-bank neutral-to-ground voltage is then observed, it can be an indication of a failing capacitor unit.

Use the "push-to-read" buttons on the appropriate modules to occasionally check the alarm level (if applicable) and lockout level—as indicated on the voltmeter—against the settings recorded in Step 5.

Finally, it may be prudent to confirm that the time-delay settings, as recorded in Step 9, have not been altered.

SPECIFICATIONS

Automatic Control Device

Catalog Number Suffix	Control-Source Voltage		Current
	Nominal	Operating Range	
A	48 v dc	38 5—56 v dc	1 amp
B	125 v dc	100—140 v dc	1 amp
D	120 v, 60 hz	102—132 v, 60 hz	½ amp
E	240 v, 60 hz	204—264 v, 60 hz	¼ amp

Operating Temperature Range

Ambient adjacent to device . . . . . . -40°F to + 160°F

Neutral-to-Ground Voltage Input Circuit

Normal operating voltage range . . . . . 0 to 10 v, 60 hz
Frequency range . . . . 60 ± 0.3 hertz§
Burden . . . . 1 va maximum

§ For 50-hertz applications, refer to the nearest S&C Sales Office.

‡ For any combination of control-source voltage and ambient temperature within specified range.

System-Voltage Input Circuit (for optional unbalance compensation module)

Voltage range . . . . 60 to 140 v, 60 hz
Frequency range . . . . 60 ± 0.3 hertz§
Burden . . . . 1 va maximum

Neutral-to-Ground Voltmeter

Accuracy . . . . ± 2% of full-scale reading
Ranges . . . . 0-500, 0-1000, 0-2000 volts

Lockout Level Module

Level Detector
Adjustment range . . . . 0 to 2000 volts
Accuracy . . . . ± 1% of setting‡

Time Delay—To Initiate Lockout
Factory setting . . . . 10 seconds
Adjustment range . . . . 1 to 30 seconds
Accuracy . . . . ± 3% of setting‡

SPECIFICATIONS — Continued

Optional Alarm Module Set

Level Detector
- Adjustment range . . . . 0 to 2000 volts
- Accuracy . . . . ± 1% of setting‡

Time Delay—To Initiate Alarm★
- Factory setting . . . . 10 seconds
- Adjustment range . . . . 1 to 30 seconds
- Accuracy . . . . ± 3% of setting‡

Gross Overvoltage Circuit

Level Detector
- Adjustment range . . . . 1000 to 5000 volts
- Accuracy . . . . ± 5% of setting‡

Time Delay—To Initiate Lockout
- Factory setting . . . . 2 seconds
- Adjustment range . . . . 0.5 to 5 seconds
- Accuracy . . . . ± 5% of setting‡

Output-Relay Contact Ratings

Current Carrying
- Continuous . . . . 10 amperes
- 1-Second . . . . 50 amperes

Interrupting . . . . 1.0 ampere at 48 v dc,
0.5 ampere at 125 v dc,
10 amperes at 120 v, 60 hz,
or 5 amperes at 240 v, 60 hz

Approximate Shipping Weight

Type UP Automatic Control Device only . . . . . 26 lbs.
Type UP Automatic Control Device in Weatherproof Enclosure . . . . 186 lbs.
Type UP/VR Automatic Control Device in Weatherproof Enclosure . . . . 212 lbs.

‡ For any combination of control-source voltage and ambient temperature within specified range.

★ Utilizing lockout level module time delay.

Options

Options which have been included with the Type UP Automatic Control Device are signified by the addition of one or more suffixes to the catalog number of the control device, as indicated in the following table:

Item	Suffix Added to Automatic Control Device Catalog Number
Plug-in alarm module set, consisting of one alarm level module and one alarm control module. Provides an alarm signal upon loss of a lesser number of capacitor units than that corresponding to the lockout-level setting.	-H
Plug-in unbalance compensation module. Compensates for system voltage unbalance plus inherent capacitor-bank unbalance,① or for inherent capacitor-bank unbalance only ②	-K
Mounting bezel for flush mounting of Type UP Automatic Control Device.	-L
Mounting bezel for flush mounting of Type UP/VR Automatic Control Device.	-M
Card extender for Type UP Automatic Control Device. Permits positioning of any module for test. Required for field calibration.	-N
Card extender kit for Type UP/VR Automatic Control Device. Permits positioning of any module for test. Required for field calibration.	-P

① Additional connections are required to output terminals of three S&C 30-Volt-Ampere Potential Devices, each equipped with factory-adjusted calibration device (catalog number suffix "-T") and having a system voltage rating equal to the voltage of the system to which the capacitor bank is connected (or three voltage transformers). Note: When an unbalance compensation module is applied with Type UP/VR, any one of these three potential devices (or voltage transformers) may take the place of the potential device or voltage transformer normally required for sensing bus voltage. Specify catalog number of S&C Potential Devices (or primary voltage rating and turns ratio of voltage transformers, plus nominal voltage of voltage-transformer secondary circuit, i.e., whether 115—120 volts or 65.71—69.3 volts). Alternately, where a high-impedance grounding transformer is used for line-to-ground voltage stabilization, connections may be made to the secondaries of the grounding transformer (specify turns ratio and voltage of secondary circuit of grounding transformer), using three 1:1-ratio voltage transformers (furnished by user).

② Additional connections are required to output terminals of one S&C 30-Volt-Ampere Potential Device equipped with factory-adjusted calibration device (catalog number suffix "-T"), and having a system voltage rating equal to the voltage of the system to which the capacitor bank is connected (or one voltage transformer). Alternately, where a high-impedance grounding transformer is used for line-to-ground voltage stabilization, connections may be made to any secondary of the grounding transformer, using a 1:1-ratio voltage transformer (furnished by the user).

Accessories

Item	Catalog Number
Detailed instruction manual for Type UP Automatic Control Device	RD-3355
Detailed instruction manual for Type UP/VR Automatic Control Device	RD-3360

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