S&C BankGuard PLUS® Control
For Substation Capacitor Banks and Shunt Reactors
Application

S&C's BankGuard PLUS Control utilizes flexible, reliable microprocessor technology to:

- Protect substation shunt capacitor banks from overvoltage stress.
- Protect shunt reactors from turn-to-turn faults.

Substation 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—are 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 increases across remaining units in the same series group. This increased voltage can overstress and shorten the life of good capacitor units in the group. As subsequent units fail, their isolation leads to still further voltage increases on remaining units. The result is an accelerating cascade of overvoltages that destroys good capacitor units.

The phenomenon is addressed in IEEE Standard 18-2002, “IEEE Standard for Shunt Power Capacitors.” This standard points out that capacitors are intended to be operated at or below their rated voltage, but should be capable of continuous operation under contingency system and bank conditions, provided that capacitor voltage does not exceed 110% of rated RMS voltage (or the working voltage specified by the capacitor manufacturer). As a point of information, IEEE Standard 1036-1992, “IEEE Guide for Application of Shunt Power Capacitors,” permits higher maximum capacitor voltage—ranging from 130% of rated RMS voltage for 1 minute, to 220% of rated RMS voltage for 6 cycles—for up to 300 applications of power frequency overvoltages.

When the voltage applied to the surviving capacitor units exceeds the manufacturer’s maximum recommended working voltage (or in the absence of a recommendation, 110% of rated RMS voltage), the entire bank should be removed from service.
Thus, medium- to 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.

**Why System and Inherent Capacitor-Bank Unbalance Compensation Is Essential**

In large-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.

**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, voltage relays are sometimes used for sensing isolation of capacitor units. See Figure 1. 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 may also lack a harmonic filter, as is required to prevent sensing errors due to system harmonic voltages. And it 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).

![Figure 1. Voltage relay used for sensing isolation of capacitor units on ungrounded, wye-connected shunt capacitor banks.](image-url)
On grounded, wye-connected shunt capacitor banks, neutral-current and voltage relays are sometimes used for sensing isolation of capacitor units. See Figures 2 and 3, respectively. 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 a 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 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 a 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.

**Figure 2.** Neutral-current relay used for sensing isolation of capacitor units on grounded, wye-connected shunt capacitor banks.

**Figure 3.** Voltage relay used for sensing isolation of capacitor units on grounded, wye-connected shunt capacitor banks.
BankGuard PLUS Control Is the Answer

The S&C BankGuard PLUS Control is more sensitive than conventional voltage relays or neutral current protective arrangements, and can detect the first failed capacitor unit in a capacitor bank. It has the discrimination to disregard spurious transients, and can compensate for system and bank unbalance. This rugged, compact microprocessor-based device utilizes simple software-selectable options for quick setup, and offers design features and proven logic that withstand the rigors of power equipment application.

Protection of Ungrounded Capacitor Banks

The BankGuard PLUS Control provides superior protection of ungrounded, wye-connected and double-wye-connected shunt capacitor banks. See Figure 4. As successive individual capacitor units in a 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 BankGuard PLUS Control—which isolates and locks out the entire bank when a predetermined neutral-to-ground voltage is exceeded.

The BankGuard PLUS Control detects the capacitor-bank neutral-to-ground voltage, as monitored by an S&C 15-Volt-Ampere Potential Device having a system voltage rating indicated in the table on the right.

A digital-filter attenuates 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 the lockout level setting of the BankGuard PLUS Control.

A field-adjustable 0.2- to 30-second time delay is incorporated in the lockout level logic, to assure operation of the fuse associated with the failing capacitor unit . . . before the lockout contacts are activated to initiate tripping of the capacitor-bank switching device. In this way, the failed capacitor unit can be readily located.

Gross overvoltage logic is employed, which bypasses the lockout level and timing-control logic,
to initiate isolation and lockout of the capacitor bank in the event of a flashover of series groups within the capacitor bank. This logic is activated, after a field-adjustable time delay of 0.2 to 5 seconds, by faults producing a capacitor bank neutral-to-ground voltage in excess of a field-adjustable level of 1000 to 5000 volts.

The BankGuard PLUS Control provides an alarm signal upon the loss of fewer capacitor units than that corresponding to the lockout level setting. For many capacitor banks it is practical to activate the alarm upon loss of a single capacitor unit. This is a decided advantage since replacement of the failed capacitor unit can be performed at a convenient, planned time... instead of on an urgent basis, during a lockout resulting from subsequent failure of capacitor units. The BankGuard PLUS Control, further, provides an alarm signal upon loss of control power. The 0.2- to 30-second time delay incorporated in the lockout level logic is utilized to avoid false alarms due to transient disturbances.

The BankGuard PLUS Control incorporates a digital input which is actuated through a contact of the capacitor-bank switch-operator auxiliary switch. This input prevents nuisance operation of the alarm or lockout functions resulting from neutral-to-ground voltages of several kilovolts being induced during periods when the capacitor bank has been routinely de-energized.

The BankGuard PLUS Control also includes an unbalance compensation function. This capability may be used, with the addition of a fully rated S&C 30-Volt-Ampere Potential Device(s) or voltage transformer(s) connected to the station bus, to detect and compensate for the error voltage appearing between the capacitor bank neutral and ground. Error voltage can be 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.

If capacitor-unit manufacturing tolerance variations are of specific concern, a single potential device or voltage transformer is required. If system voltage unbalance is also of concern, three potential devices or voltage transformers are required.

**Protection of Grounded Capacitor Banks**

The BankGuard PLUS Control provides superior 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. See Figure 5. As successive individual capacitor units in a 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 BankGuard PLUS Control—which isolates and locks out the entire bank when a predetermined overvoltage occurs.

The BankGuard PLUS Control utilizes tap-voltage calibration logic which develops the phasor sum of the intermediate tap-point voltages on the three

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**Figure 5. System diagram of BankGuard PLUS Control for protection of grounded shunt capacitor banks.**

Optional S&C 30-Volt-Ampere Potential Device or voltage transformer monitors system line-to-ground voltage for unbalance compensation function.

Operator for capacitor-bank switching device.

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. 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 the square root of 3.

A digital filter is employed 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 setting of the BankGuard PLUS Control.

A field-adjustable 0.2- to 30-second time delay is incorporated in the lockout level logic, to assure operation of the fuse associated with the failing capacitor unit . . . before the lockout contacts are activated to initiate tripping of the capacitor-bank switching device. In this way, the failed capacitor unit can be readily located.

Gross overvoltage and alarm functions are standard and operate in the same manner as described for the ungrounded bank application.

The BankGuard PLUS Control also includes an unbalance compensation function. This capability may be used, with the addition of a fully rated S&C 30-Volt-Ampere Potential Device or voltage transformer connected to the station bus, to detect and compensate for 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.

**Protection of Ungrounded Shunt Reactors**

The BankGuard PLUS Control provides superior 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 these shunt reactors, the most common mode of reactor failure. See Figure 6.

The BankGuard PLUS Control detects the reactor neutral-to-ground voltage, as monitored by an S&C 15-Volt-Ampere Potential Device. A digital filter attenuates harmonics and noise. If 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 BankGuard PLUS Control—which isolates and locks out the shunt reactor.

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**Figure 6.** System diagram of BankGuard PLUS Control applied for protection of ungrounded shunt reactors.
reactor if the neutral-to-ground voltage value set in the lockout function is exceeded.

A field-adjustable 0.2- to 30-second time delay is incorporated in the lockout level logic, to assure that transient disturbances do not initiate nuisance reactor isolation.

Gross overvoltage logic is employed, which bypasses the lockout level and timing-control logic, to initiate isolation and lockout of the reactor in the event of a fault which open-circuits an entire phase winding. This logic is activated, after a field-adjustable time delay of 0.2 to 5 seconds, by faults producing a reactor neutral-to-ground voltage in excess of a field-adjustable level of 1000 to 5000 volts.

The BankGuard PLUS Control includes an unbalance compensation function. This capability may be used, with the addition of a fully rated S&C 30-Volt-Ampere Potential Device(s) or voltage transformer(s) connected to the station bus, to detect and compensate for the error voltage appearing between the reactor neutral and ground. Error voltage can be 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 required.

If reactor phase-winding manufacturing tolerance variations are of specific concern, a single potential device or voltage transformer is required. If system voltage unbalance is also of concern, three potential devices or voltage transformers are required.

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**Specifications**

**Neutral-to-Ground Voltage Input Circuit**
- Normal Operating Voltage Range: 0 to 150 volts
- Frequency Range: 50/60 Hz
- Burden: less than 0.1 VA

**Unbalance Compensation Input Circuit**
- Voltage Range: 10 to 150 volts, 3 phase
- Frequency Range: 50/60 Hz
- Burden: less than 0.1 VA

**Lockout Level**
- **Level Detector**
  - Adjustment Range: 0 to 2000 volts
  - Accuracy: ± 1% of range
- **Time Delay to Initiate Lockout**
  - Factory Setting: 10 seconds
  - Adjustment Range: 0.2 to 30 seconds

**Alarm**
- **Level Detector**
  - Adjustment Range: 0 to 2000 volts
  - Accuracy: ± 1% of range
- **Time Delay to Initiate Alarm**
  - Factory Setting: 10 seconds
  - Adjustment Range: 0.2 to 30 seconds

**Gross Overvoltage Circuit**
- **Level Detector**
  - Adjustment Range: 1000 to 5000 volts
  - Accuracy: ± 1% of range
- **Time Delay to Initiate Lockout**
  - Factory Setting: 2 seconds
  - Adjustment Range: 0.2 to 5 seconds

**Output-Relay Contact Ratings**
- 16 A at 250 Vac
- 0.5 A at 125 Vdc
- 16 A at 24 Vdc

An interposing relay is required if these ratings will be exceeded.

**Control Power Requirements**
- 48–250 Vdc
- 100–240 Vac, 50 or 60 Hz

**Environmental Specifications**
- Temperature: –40°C to +70°C, LCD operates to –20°C
- Humidity: 0–95% (non-condensing)

**Enclosure**
- 17.13” w × 14.68” d × 5.25” h (plus mounting bracket) 19” rack mount
- Painted Aluminum
- Nominal Weight: 11 lbs.
Installation
BankGuard PLUS Control is suitable for mounting in a standard 19-inch relay rack. See Figure 7. 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 device on switchboards, control consoles, or other enclosures, an optional mounting bezel is available.