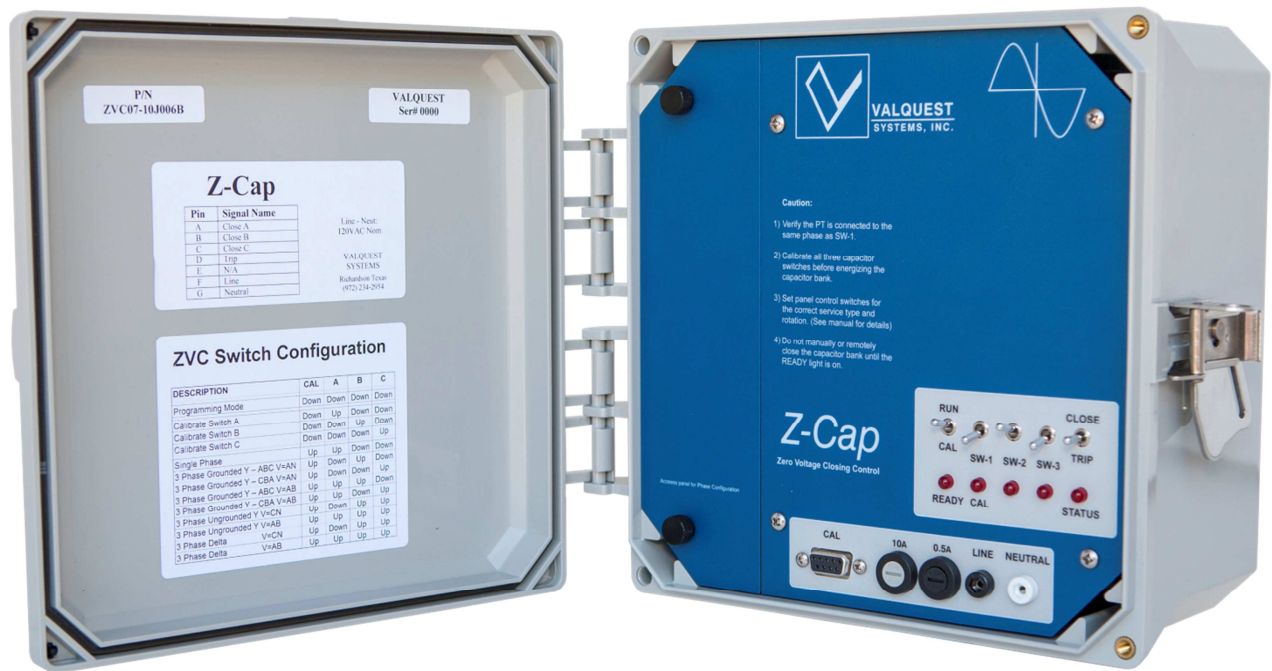


# Z-Cap

## Zero Voltage Closing Control

For Eaton/Cooper ECS ZVC Switches

Switched Capacitor Banks



**Valquest Systems, Inc.**

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# Z-Cap - Zero Voltage Closing Control

Valquest Systems, Inc.

This information herein is sensitive and proprietary to Valquest Systems, Inc.

## Functional Description

### ▪ Zero Voltage Closing

The Z-Cap accepts Close and Trip commands in the form of 120 VAC signals from any external control device such as a PLC or standard capacitor control. Input signals are opto-coupled to insure reliability of the system. The Z-Cap provides a wetting voltage which the controlling device can use if necessary.

When a Close command is received the Z-Cap initiates a separate close operation for each phase. These operations are timed so that each switch's main contacts make initial contact as close to zero crossing as possible. Zero crossing is defined as the time (two per cycle) when the phase conductor is at neutral potential (phase to neutral PT) or when the two phase conductors are at precisely the same potential (phase to phase PT).

### ▪ Constant Close Operation Control Voltage

In order to close the entire bank in a timely manner, each capacitor switch is provided with its own stored energy circuit. These circuits include charged capacitors. The voltage on these capacitors is maintained to within 0.1 volts and is monitored constantly. As long as the capacitor voltage is within tolerance, the "READY" LED will be lit, indicating that the capacitors are charged and ready for operation. A set of dry contacts will also be closed to indicate this condition to the external control unit. The Close sequence cannot be initiated while the capacitor voltages are out of tolerance.

### ▪ Capacitor Temperature Compensation

Because energy storage in a capacitor changes slightly with temperature, close timings change slightly with internal capacitor temperature. The Z-Cap microprocessor constantly monitors the temperature inside the enclosure and adjusts the Close Sequence timings for each phase based on stored energy curves. Time integration is used to allow for the lag between board temperature and internal capacitor temperature.

### ▪ Switch Temperature Compensation

The primary temperature variable which affects Close timing accuracy is the capacitor switch solenoid temperature. The Z-Cap incorporates an exclusive proprietary technique for precisely monitoring this temperature and adjusting the Close Sequence timing accordingly. Valquest Systems is in the process of applying for patents to protect the use this concept and technique.

## Automated Close Time Calibration

Before the control is ready for normal operation each switch circuit must be calibrated. Calibration can be done using switches on the front panel or with a laptop computer. Using a laptop is preferable because it is automatic and allows archiving of calibration data.

For each phase, the user connects the calibration cables to the switch terminal (**without high voltage applied**) and sets the front panel switches to the proper position (see Table 1: Switch Settings). He then starts the calibration sequence using the Z-Cap companion software. The laptop will take each switch through three complete operations during which the precise timings are monitored and stored in the Z-Cap non-volatile memory. This sequencing can also be done from the front panel.

- **Calibration Data Storage**

During calibration the timing parameters for each switch (including reference temperatures) are stored both in non-volatile memory in the Z-Cap. During power losses the Z-Cap will retain these settings.

- **Automatic Close Timing Adjustment**

During every close sequence the Z-Cap uses an exclusive proprietary technique to monitor the motion of each switch solenoid. In conjunction with the calibration data this gives the microprocessor precise information with which to make slight adjustments to the stored timing parameters. This means that over long periods of time the zero voltage closing accuracy will be maintained. Valquest Systems is in the process of applying for patents to protect the use this concept and technique.

- **Switch Status Indication**

The trip circuit is continuously monitored to determine if the capacitor switches are closed or open. This is done without using any auxiliary switches and gives an absolute indication at the "STATUS" LED on the front panel of the bank status. A set of dry contacts also indicates this status to the external control unit.

- **RS-232 Communications**

The control incorporates a 9 pin D type connector to communicate via RS-232 to a laptop with the Z-Cap companion software installed. This software allows the following functions:

- Automated Calibration
- Switch Testing
- Data retrieval
- Digital Close / Trip / Status (optional)

## Control Panel

Refer to Figure 1.

### Switch Settings

Description	Rotation	CPT	Cal	SW-1	SW-2	SW-3
Calibrate Switch 1			Down	Up	Down	Down
Calibrate Switch 2			Down	Down	Up	Down
Calibrate Switch 3			Down	Down	Down	Up
Single Phase	N/A	1-N	Up	Up	Down	Down
3 Phase Grounded Wye	1-2-3	1-N	Up	Down	Up	Down
3 Phase Grounded Wye	3-2-1	1-N	Up	Down	Down	Up
3 Phase Grounded Wye	1-2-3	1-2	Up	Up	Up	Down
3 Phase Grounded Wye	3-2-1	1-2	Up	Up	Down	Up
3 Phase Ungrounded Wye	N/A	3-N	Up	Down	Up	Up
3 Phase Ungrounded Wye	N/A	1-2	Up	Up	Up	Up
3 Phase Delta	N/A	3-N	Up	Down	Up	Up
3 Phase Delta	N/A	1-2	Up	Up	Up	Up

**Table 1**

### Open / Close Switch

The “Open / Close” momentary toggle switch is used during calibration if a laptop is not available. It can also be used for testing purposes. Both this switch and the “Cal” switch are only operational when the calibration cables are connected to the control unit. A jumper in the connector enables them. This insures that the switches will not be accidentally operated under normal conditions.

### LED Indications

Description	READY	SW-1	SW-2	SW-3	STATUS
Capacitor Voltages OK	On				
Calibration Needed Switch 1		On			
Calibration Needed Switch 2			On		
Calibration Needed Switch 3				On	
Switches Closed					On

**Table 2**

In the normal operation mode only the “READY” LED should be lit as an indication that the control is ready to have the closing sequence initiated. The “STATUS” LED will be lit any of the capacitor switches is in the closed position. Two sets of dry contacts are available to send these two bits of information to the controlling device.

## Installation

### ▪ Capacitor Switches

The capacitor switches must be solenoid operated Eaton ECS switches configured for ZVC operation. This means they must be internally wired such that the trip solenoid has a standard micro-switch installed that interrupts the trip signal after the main contacts have opened. The close solenoid must be wired directly to the connector with no interposing micro-switch. See Figure 8 for standard pin connections.

### ▪ AC Power

The Z-Cap works on 120VAC 60 Hz. This voltage is normally supplied from a control transformer. It enters through the seven pin Amphenol connector located on the bottom of the unit (see Figure 2: Power Connector). This transformer provides the power for charging the closing capacitors, the power for tripping the main switches and a reference voltage for calculating the voltage zero cross timing.

In order for the control to operate properly, the primary of this transformer must be wired between neutral and the same phase as the switch that is controlled by the SW-1 closing circuit in the Z-Cap or between the two phases which correspond to the switches being controlled by the SW-1 and SW-2 closing circuits in the Z-Cap (see Table 1: Switch Settings).

### ▪ Control Schemes

There are many command schemes possible. Figure 6 shows two common schemes, one for a PLC and one for an Automatic Capacitor Control being powered from the Z-Cap. Figure 7 shows basic configuration for a Capacitor Control Meter Base and Z-Cap on the same structure.

### ▪ Trip Command

The Trip command is received as a 120 VAC signal on pins B and C of the Control Connector or a dry contact to pins A and B of the Control Connector (see Figure 3: Terminal Block Connections). The signal should last 300 milliseconds and no longer than 2 seconds.

### ▪ Close Command

The Close command is received as a 120 VAC signal on pins D and C of the Control Connector or a dry contact to pins A and D of the Control Connector (see Figure 3: Control Connections). The signal should last 600 milliseconds and no longer than 2 seconds.

### • Status

Switch Status can be read as a dry contact on pins E and F of the Control Connector (see Figure 3: Control Connections).

The dry contact will be closed if any of the capacitor switches are closed. The contact will be open if all of the connected capacitor switches are open.

### • Ready

Ready Status can be read as a dry contact on pins G and F of the Terminal Block (see Figure 3: Control Connections). A closed contact indicates that the closing circuit capacitors are charged and the Z-Cap is ready close the switches.

## Capacitor Bank Configurations

Different cap bank configurations each call for a different set of timing parameters to be stored for zero voltage closing. The configurations can be defined with three characteristics:

- A. Phase rotation (1-2-3 or 3-2-1)
  - B. Grounded Wye, un-grounded Wye or delta
  - C. Phase relation of the voltage reference (CPT connected phase-neutral or phase-phase)
- A delta configuration is handled identically to an un-grounded Wye.
  - The rotation does not need to be known when the configuration is delta or un-grounded Wye.
  - The Z-Cap will always close the switches in order of 1 first, then 2, then 3.
  - In the configurations below the CPT must be connected to the phase(s) connected to the indicated switches.
  - Z-Cap switch connection modifications can be made in the enclosure if necessary.

### Standard Capacitor Bank Configurations:

- **Single phase**  
The control will operate only the switch 1 closing circuit
- **Three phase grounded Wye – 1-2-3 rotation with CPT on 1-N**  
Closes switch 1 at the zero crossing of the reference voltage  
Closes switch 2 at the zero crossing of the reference voltage plus 120 degrees  
Closes switch 3 at the zero crossing of the reference voltage plus 60 degrees
- **Three phase grounded Wye – 3-2-1 rotation with CPT on 1-N**  
Closes switch 1 at the zero crossing of the reference voltage  
Closes switch 2 at the zero crossing of the reference voltage plus 60 degrees  
Closes switch 3 at the zero crossing of the reference voltage plus 120 degrees
- **Three phase grounded Wye – 1-2-3 rotation with CPT on 1-2**  
Closes switch 1 at the zero crossing of the reference voltage plus 30 degrees  
Closes switch 2 at the zero crossing of the reference voltage minus 30 degrees  
Closes switch 3 at the zero crossing of the reference voltage plus 90 degrees
- **Three phase grounded Wye – 3-2-1 rotation with CPT on 1-2**  
Closes switch 1 at the zero crossing of the reference voltage minus 30 degrees  
Closes switch 2 at the zero crossing of the reference voltage plus 30 degrees  
Closes switch 3 at the zero crossing of the reference voltage plus 90 degrees
- **Three phase un-grounded Wye or Delta with CPT on 3-N**  
Closes switch 1 at the zero crossing of the reference voltage  
Closes switch 2 at the zero crossing of the reference voltage plus 90 degrees  
Closes switch 3 at the zero crossing of the reference voltage
- **Three phase un-grounded Wye or Delta with CPT on 1-2**  
Closes switch 1 at the zero crossing of the reference voltage  
Closes switch 2 at the zero crossing of the reference voltage  
Closes switch 3 at the zero crossing of the reference voltage plus 90 degrees

Please refer to Page 5 Table 1: “Switch Settings” for programming the control.

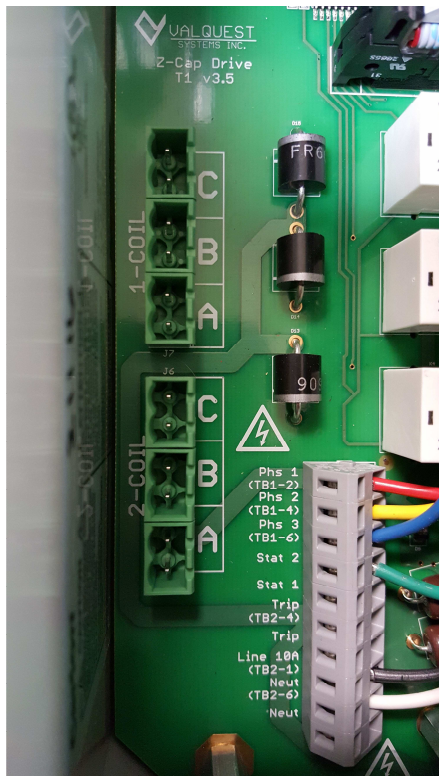
## Z-Cap Configuration

### Modifying Closing Connections

Sometimes capacitor switch wiring is not aligned properly with the transformer for the bank configuration.

- Inside the Z-Cap enclosure, under the access panel, are switch swapping jacks.
- They are labeled A, B and C.
- Because the switch closing order is always 1-2-3, the switches must be connected in positions relative to the transformer as shown in Table 1.
- When the switches are improperly connected, these swapping jacks provide an easy way to set the wiring right.
- Figure 5 shows the Normal (factory wired) setup and 2 examples of modified setups.
- The pictures here show the swapping jacks and how they are connected from the factory.
  
- Figure 5-W1 shows the normal (factory wired) connections.
- Figure 5-W2 shows a situation where the bank has been wired so that the #3 closing circuit is connected to the phase that the transformer is on. The Brown and Orange wire have been swapped in the Z-Cap to correct it.
- Figure 5-W3 shows a situation where the bank has been wired so that the #2 closing circuit is connected to the phase that the transformer is on. The Brown and Red wires have been swapped in the Z-Cap to correct it.
- These corrections are done completely irrespective of the utility's phase references. A B and C have no meaning to the Z-Cap except as it affects phase rotation.

Circular Connector Jacks  
ECS switches use the 2-Coil group



Normal Connections  
A-Brown, B Red, C-Orange

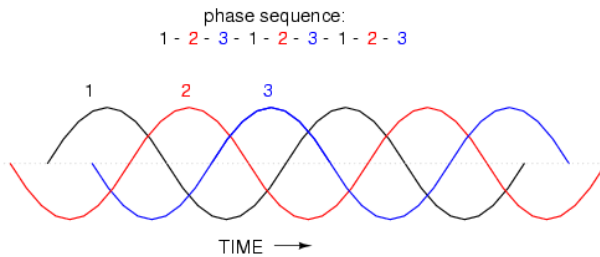


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## Determining Phase Rotation

Phase Rotation is called ABC if B peaks after A and C peaks after B. The opposite is called CBA.



In the case of the Z-Cap it is called 1-2-3 (like the picture). The opposite rotation is 3-2-1. Z-Cap terminology does not use A, B and C to avoid confusion with the utilities' names for the phases.

When the capacitor bank configuration is Grounded Wye, the phase rotation must be known. Assuming that the utility personnel know the phase rotation and can identify the phases, the rotation as it relates to the Z-Cap can be determined.

For instance if Z-Cap circuits are as follows:

- SW-1 connected to Phase A
- SW-2 connected to Phase B
- SW-3 connected to Phase C
- Utility rotation is ABC

Z-Cap rotation is 1-2-3. This is the case shown in Figure 5-W1.

Figure 5-W2 has this same scenario after swapping the brown and orange wires in the Z-Cap. So once again if utility rotation is ABC the Z-Cap rotation is 1-2-3. Of course if utility rotation is CBA then Z-Cap rotation is 3-2-1.

In Figure 5-W3 the phases are not 1 to A, 2 to B, and 3 to C. If utility rotation is ABC then Z-Cap rotation is 2-1-3 which is effectively 3-2-1. If utility rotation is CBA the Z-Cap rotation is 1-2-3.

Many times utility personnel will not know the rotation. Here are some possible methods for determining rotation.

- If a metering point is nearby and the overhead phases can be traced to the test switches in the cabinet it may be possible to use a phase rotation meter or power quality meter to determine the utility's rotation.
- If a set of regulators exists on the line, a phase rotation meter can be used with them. This may require the use of some lengths of wire.
- At the substation: sometimes electronic recloser controls will have the phase rotation as part of their settings. This may require use of a laptop and possibly the manufacturer's configuration software.

It is important to get the Z-Cap rotation right with Grounded Wye banks because otherwise the closing point will be far from zero. This is because the closing angles are 120° apart. So, for instance, if the phase connected to Switch 2 crosses 0 volts 120° after the phase on Switch 1 (rotation = 1-2-3) but Switch 2 closes at 240° after Switch 1, the voltage will be at 0.867 of crest rather than 0.

With Un-Grounded Wye banks and Delta banks it is not necessary to know rotation. This is because there is no current when Switch 1 closes and Switches 2 and 3 close 90° apart. If the rotation is backwards it has the effect of making the requirement -90°. But 90° and -90° are 180° apart.

## Calibration

The control must be calibrated for all three phases (except when operating as single phase) before it can accurately close the switches relative to the zero voltage points. It must also be set for the proper cap bank and voltage sense configuration. Please refer to Table 1: (Switch Settings) to determine how to set the front panel switches for calibration and normal operation.

### Laptop Field Calibration

1. **Make sure that the terminals on all three main capacitor switches are not connected to anything.**
2. Use the Close / Trip switch on the front panel to make sure all switches are in the open position.
3. Connect the Calibration Cables to the Z-Cap Serial Port (DB-9 connector).
4. Connect the two clips on the Calibration Cables to the two terminals of the switch being calibrated.
5. Connect the serial cable from the laptop to the Calibration Cable Connector and start the Z-Cap Companion software.
6. Make sure that **Cooper ECS** switch type is selected.
7. Making sure the indicated serial port is correct, click the **Connect** button.
8. On the **Calibration** tab, select the switch to be calibrated.
9. Click the **Calibrate** button. The laptop will take the control through three complete operations.
10. Move the calibration clips to the next switch and repeat steps 8 and 9 for the other switches.
11. Set the front panel switches to the proper positions based on the bank configuration as detailed in Table 1.

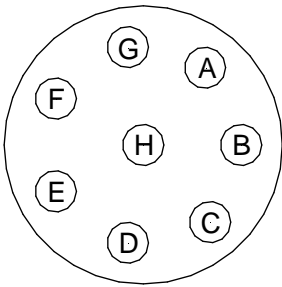
### Front Panel Field Calibration

1. **Make sure that the terminals on all three main capacitor switches are not connected to anything.**
2. Use the Close / Trip switch on the front panel to make sure all the capacitor switches are in the open position.
3. Connect the Calibration Cables to the Z-Cap.
4. Connect the two clips on the Calibration Cables to the two terminals of the switch being calibrated.
5. Set front panel switch Cal to the up position.
6. Set front switch SW-1, SW-2 or SW-3 to the up position corresponding to the switch being calibrated.
7. Set front panel switch Cal to the Down position. This causes the control to enter the calibration mode for the capacitor switch indicated by the SW-1, SW-2 and SW-3 front panel switches.
8. Use the Close / Trip switch on the front panel to initiate a close operation.
9. Observe that the SW-1/Cal light is lit. If it is not lit, the Z-Cap did not get a good read on the switch closure. Inspect the Calibrations Cable connection at the Z-Cap enclosure and at the cap switch.
10. Use the Close / Trip switch on the front panel to initiate a trip operation.
11. Repeat steps 8 and 9 twice more for a total of 3 complete operations.
12. Set front panel switch Cal to the up position.
13. Observe that the Light for the switch being calibrated is not lit. If it is lit, calibration was not done correctly. Repeat steps 6 – 11.
14. Perform steps 4 – 12 for all three capacitor switches.
15. Set switches to the proper positions based on the bank configuration as detailed in Table 1.



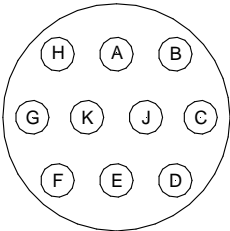
**Figure 1 Front Panel**

## Connections



**Figure 2 Power Connector**

Pin	Signal
A	Close Switch 1
B	Close Switch 2
C	Close Switch 3
D	Trip Switches (All)
E	Line Current
F	Wye Neutral Current
G	120 VAC
H	Neutral



**Figure 3 Automatic Capacitor Control (ACC) Connector**

Pin	Signal	Direction
A	120 VAC	ACC ← Z-Cap
B	Trip Signal	ACC → Z-Cap
C	Trip/Close Common	ACC → Z-Cap
D	Close Signal	ACC → Z-Cap
E	Switch Status	ACC ← Z-Cap
F	Status Common	ACC ← Z-Cap
G	Ready Status	ACC ← Z-Cap
H	Line Current	ACC ← Z-Cap
J	Wye Neutral Current	ACC ← Z-Cap
K	Neutral	ACC ← Z-Cap

Trip and Close commands require 120 VAC Signal for 350 +/- 50 msec.  
Switch and Ready Statuses are dry contacts.

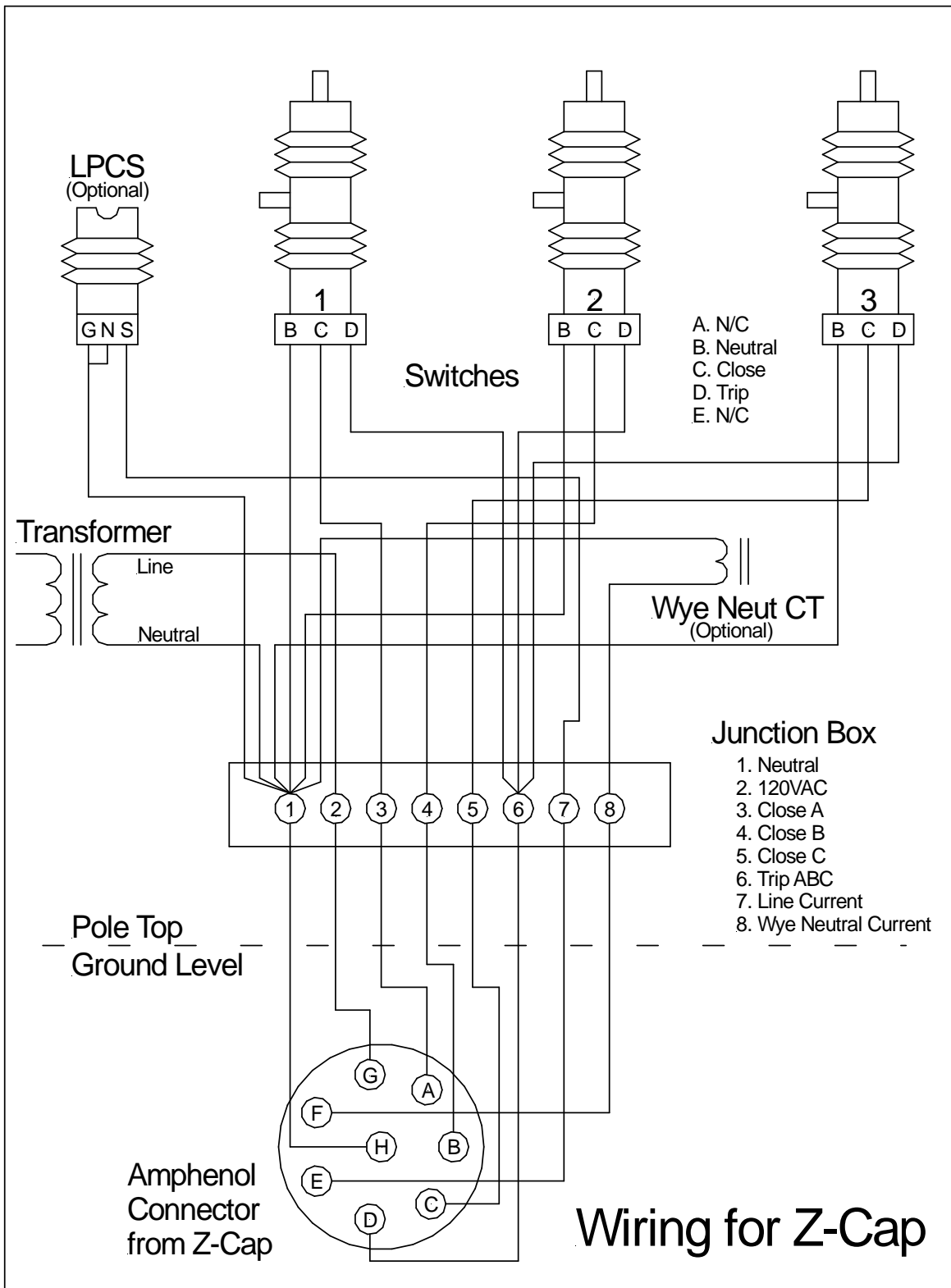
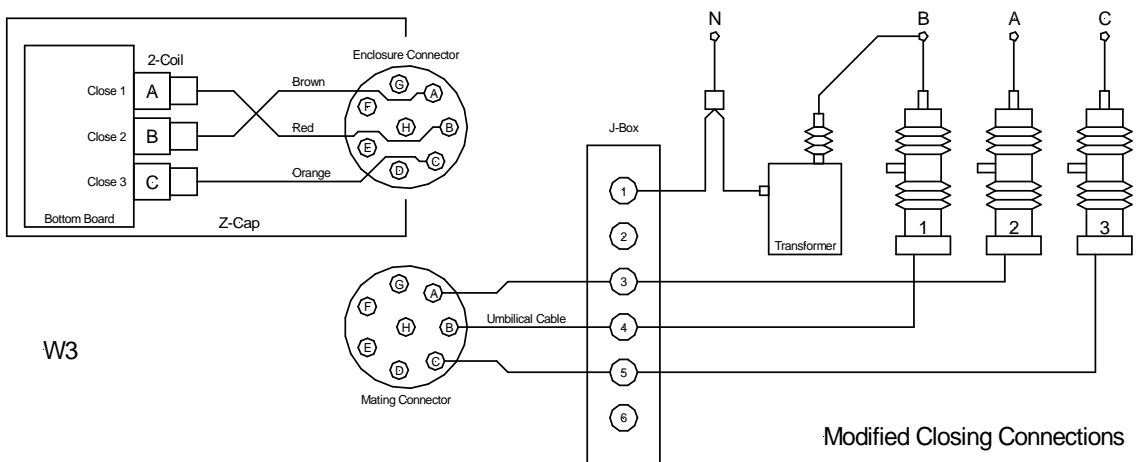
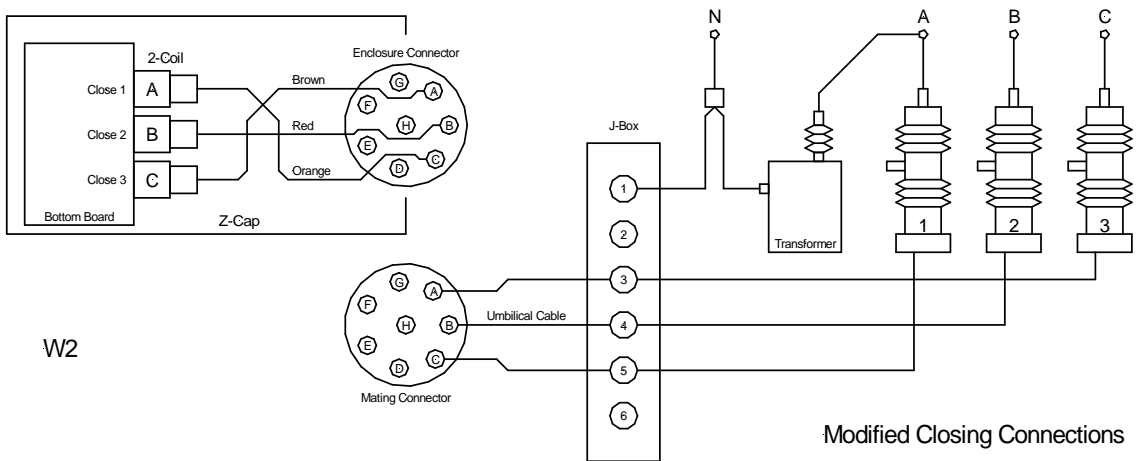
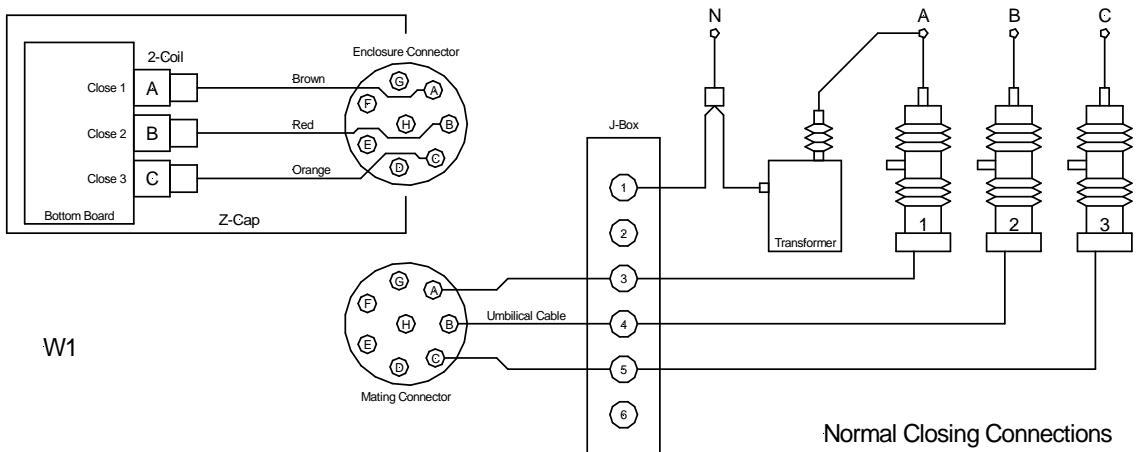


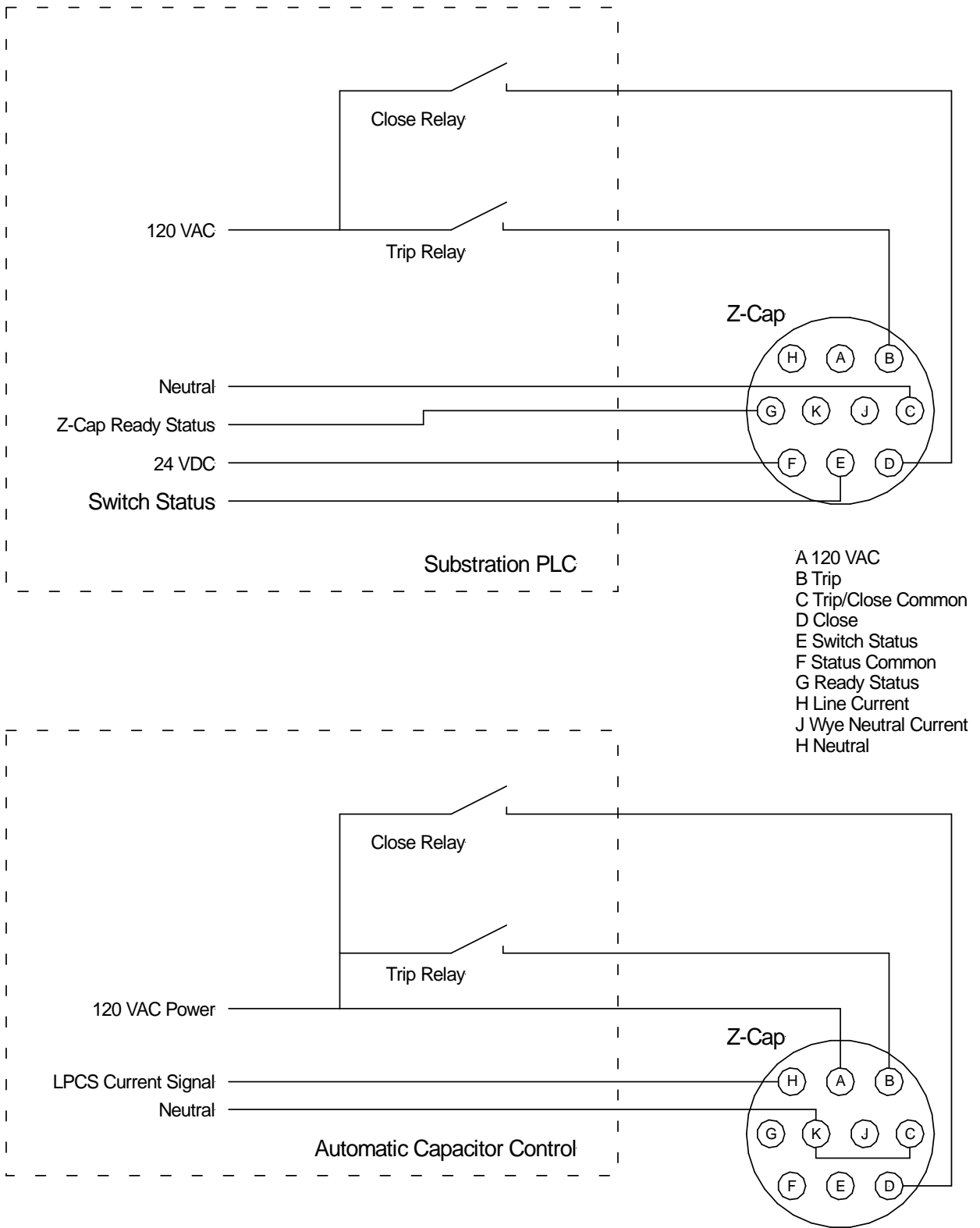
Figure 4 Pole Wiring

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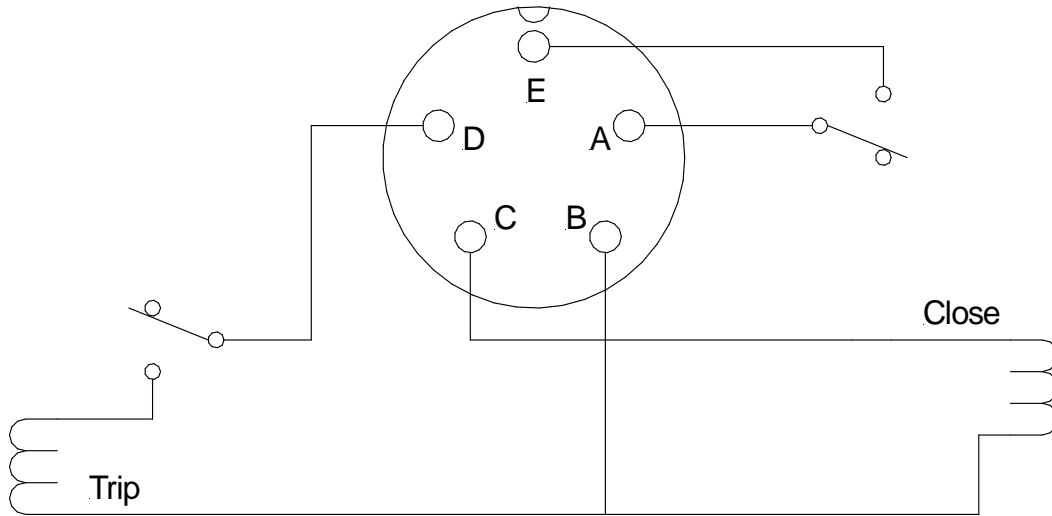
**Figure 5 Closing Connections**

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**Figure 6 Typical Control Schemes**

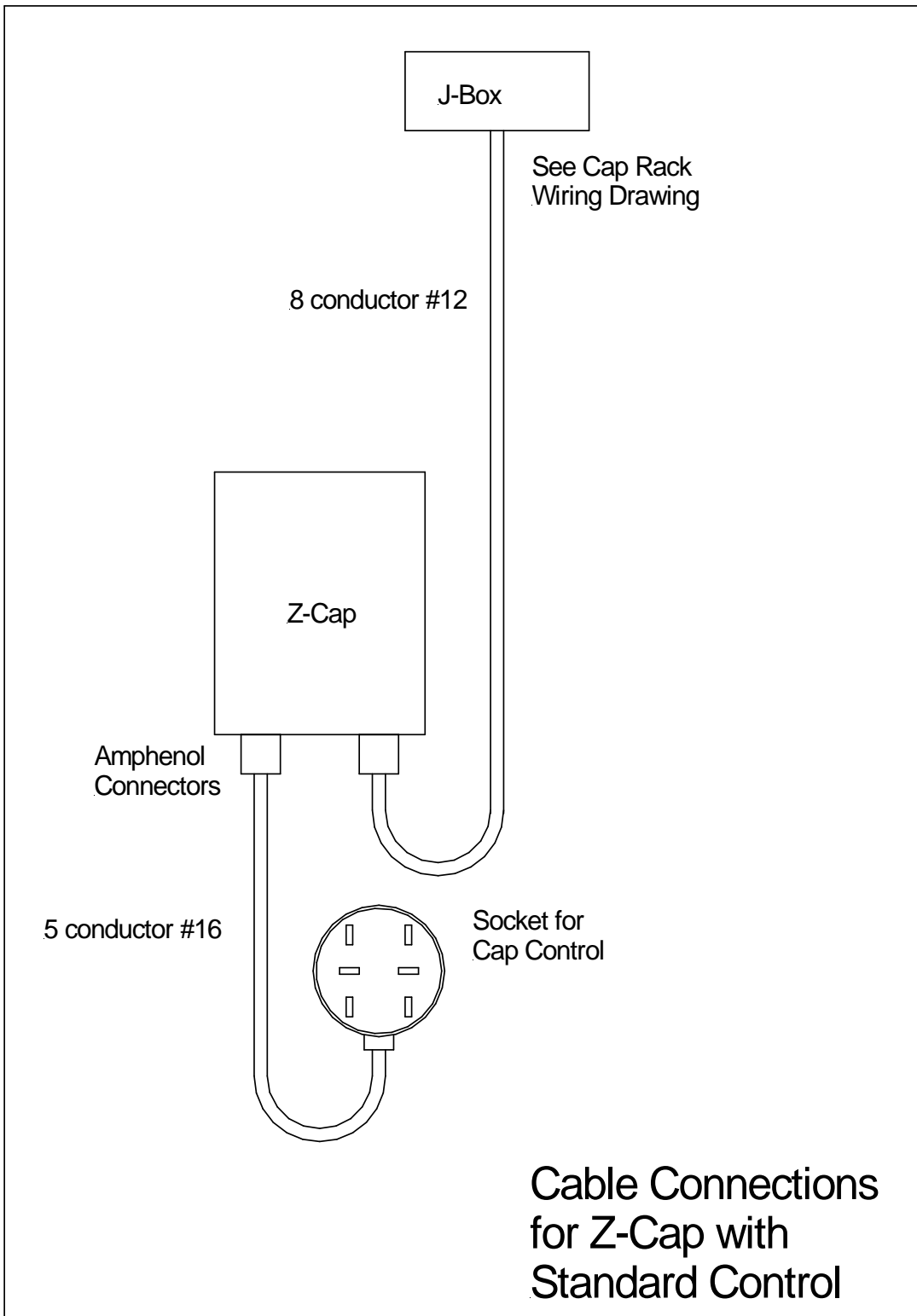
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Eaton ECS ZVC Configuration  
with N.O. Auxilliary Contact  
Switch Shown in Open State

Figure 7 ZVC Switch Connections





**Figure 8      Z-Cap with Standard Capacitor Control**