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**PRIOR TO ENERGIZING A PREVIOUSLY-FAILED CAPACITOR BANK, THE "CAPACITOR BANK TROUBLESHOOTING SEQUENCE GUIDE" (Section V) MUST BE COMPLETED!**

**FIGURES**

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## -) SAFETY

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This is a safe-use guide for the described equipment. Only qualified personnel should proceed. Keep these instructions available to all Substation personnel. ***Read these instructions carefully before proceeding. Otherwise, serious injury or equipment damage could occur.*** **FOLLOW ALL DTE & MIOSHA SAFETY REGULATIONS.**

**FRC/PPE**

— **WEAR ALL NECESSARY FLAME RESISTANT CLOTHING (FRC) & PERSONAL PROTECTIVE EQUIPMENT (PPE) WHILE PERFORMING ANY PROCEDURES IN THIS ARTICLE.**

— **ALL JOBS ON POWER EQUIPMENT REQUIRE MINIMUM OF CATEGORY 2 FRC.**

— **EQUIPMENT ENERGIZED TO ≥ 600-V MIGHT REQUIRE HIGHER FRC CATEGORY. REFER TO DTE ENERGY ELECTRICAL SAFETY STANDARDS.**

— **THIS WORK REQUIRES SAFETY GLASSES WITH SIDE SHIELDS OR GOGGLES.**

## -) SCOPE & RESPONSIBILITY

[top]

A) This article provides ***instructions*** unique to this class of circuit breaker.

B) ***Qualified maintenance personnel*** must perform these procedures (adjustment, testing, and inspection) as scheduled. Additionally, they will perform any other necessary maintenance – with prior approval, if required, from the equipment engineer.

C) Circuit breaker testing results must fall within all ***established testing values***. Any deviations must be resolved with equipment engineer and/or manufacturer.

**DANGER**

1) **BEFORE TESTING OR WORKING ON CIRCUIT BREAKER OR MECHANISM, *EQUIPMENT MUST BE PROTECTED* AGAINST ALL SOURCES OF POTENTIAL & STORED ENERGY BY ENSURING THE FOLLOWING:**

**— ALL DISCONNECTS ARE OPEN, OR OUTSIDE PROTECTION IS PROVIDED IF NEEDED**

**— BREAKER IS COMPLETELY DE-ENERGIZED**

***[IF APPLICABLE]***
***ON SPRING-TYPE MECHANISMS, SPRINGS MUST BE DISCHARGED, & CIRCUIT BREAKER MUST BE OPEN & RACKED OUT***

***[IF APPLICABLE]***
***ON PNEUMATIC & HYDRAULIC MECHANISMS, PRESSURE SUPPLY VALVE IS CLOSED & PRESSURE DRAIN VALVE IS OPEN***

**— REQUIRED BARRIERS & TAGS ARE IN PLACE**

2) **IF A FAULTY CONDITION ARISES DURING ANY INSPECTIONS / PROCEDURES, THE NECESSARY *REPAIRS OR ADJUSTMENTS* MUST BE PERFORMED BEFORE PROCEEDING.**

3) **REVIEW ALL *MANUFACTURER'S WARNINGS* AND CAUTIONS.**

4) **PRIOR TO APPLYING TEST POTENTIAL, ENSURE ALL *PERSONNEL ARE CLEAR* OF EQUIPMENT BEING TESTED.**

5) **DO *NOT* HI-POT OR INSULATION-RESISTANCE TEST (MEGGER) ANY *SOLID STATE DEVICES*.**

6) **PRIOR TO ANY FUNCTIONAL TESTS, VERIFY THAT OPERATION OF *AUXILIARY SWITCHES* — CONNECTED IN CONTROL CIRCUITS OF OTHER SYSTEMS — WILL NOT ENDANGER PERSONNEL AND EQUIPMENT OUTSIDE BREAKER OR EQUIPMENT BEING TESTED.**

**DANGER**

**PRIOR TO ENERGIZING A PREVIOUSLY-FAILED CAPACITOR BANK, THE "CAPACITOR BANK TROUBLESHOOTING SEQUENCE GUIDE" (Section V) MUST BE COMPLETED!**

## -) QUICK REFERENCE (Equipment/Special Tools, Documentation)

[top]

- Equipment/Special Tools

  1) conductivity tester

2) insulation resistance tester (Megger) (500-2500-V)

3) multi-meter

4) scale (6-inch)

5) step-transformer

6) test leads – various

7) timing device

8) variac rectifier set

# I) CAPACITOR CELLS – FAILURES & BLOWN FUSES

[top]

**WARNING**

**DIELECTRIC LIQUIDS & CAPACITOR CELLS:**

**— PERSONNEL MUST WEAR OIL-IMPERVIOUS GLOVES (STOCK NO. 981-0014) & COVER-ALL GOGGLES (STOCK NO. 981-0190) WHEN WORKING WITH LEAKING CAPACITOR CELLS, DIELECTRIC-SPLASH CLEANUP, OR ANY OTHER POSSIBLE DIELECTRIC-LIQUID CONTACT.**

**— CHECK GLOVE INTEGRITY BEFORE EVERY JOB.**

**— AFTER COMPLETING JOB, WASH HANDS & FACE WITH WARM WATER & SOAP.**

**— ANYTHING THAT COMES IN CONTACT WITH DIELECTRIC SPLASH MUST BE SEALED IN A CLAMP-TOP DRUM CONTAINER & SENT TO SALVAGE-WSC.**

**- THIS INCLUDES RAGS, CLOTHES, STONES, DIRT, & LEAKING, RUPTURED, OR PUNCTURED CAPACITOR CELLS.**

**- DEFECTIVE CAPACITOR CELLS SENT TO SALVAGE-WSC MUST BE PROMPTLY FOLLOWED BY A MEMO TO THE "INSULATION COORDINATOR" STATING LOCATION, CAPACITOR CELL MAKE, CATALOG NO., SERIAL NO., kVAR RATING, VOLTAGE LEVEL, REASON FOR SCRAPPING, & REMOVAL DATE.**

[top]

A) *See Section II: CAPACITOR-CELL FUSES-MAINTENANCE to if cell, fuse, or both need replacement.*

B) Refer to ***"Maintenance Letter 346"*** for proper reporting of failed capacitor cells.

C) If replacement capacitor cells or fuses are unavailable, capacitor banks MUST be ***balanced*** to avoid overvoltage on remaining banks. *See Section VI: CAPACITOR BANK BALANCING.*

# II) CAPACITOR-CELL FUSES – MAINTENANCE

*(back)*

*[top]*

## -) SCOPE

A) Defective or Blown ***Fuse Element***
Substation Operator will change a defective or blown fuse element in a capacitor cell, as soon as conditions permit, to restore service.

B) Defective ***Capacitor Cell***
Substation Operator will submit an OFW to Substation Maintenance to replace a defective capacitor cell and its fuse element.

## 1) CAPACITOR CELL INSPECTIONS

*[top]*

A) Capacitor Bank ***Problems***

- Capacitor-bank problems usually occur in one of its individual capacitor cells.

B) Capacitor-Cell ***Fuse***

*[top]*

- Each capacitor cell within a capacitor bank is typically fused (fuse-protected). If a capacitor-cell disturbance occurs, the fuse should blow, which disconnects capacitor cell from capacitor bank.

***[NOTE]***
***Some capacitor-bank installations are non-fused.***

C) Visual ***Inspections***

*[top]*

Other common problems are caused by corroded or fatigued fuse elements. Therefore, Substation Operator will visually inspect all components of a capacitor bank that is shut down for maintenance. This includes the following:

1) Fuses and Fuse Connections

- Replace fuse if any of the following are found:
  - i) loose, frayed, corroded, or otherwise deteriorated components
  - ii) melted or broken-open links
  - iii) deteriorated horn fiber (from moisture entering open end of fuse tube)
  - iv) swollen horn-fiber insert (impedes ejection of tail from fuse tube)
  - v) horn fiber used as insect nest
  - vi) swollen fuse tubes (in some McGraw-Edison cells) (compromises integrity of outside Bakelite tube)

2) Capacitor Cells

   a) Remove any wildlife nesting (e.g., bird or wasp nests) during shutdown.

   b) Submit an OFW for Substation Maintenance to replace a capacitor cell if any of the following are found:
      - i) broken, cracked, or chipped cell bushings
      - ii) leaking, bulging, ruptured, punctured, charred, or otherwise damaged cells

3) Electrical Connections

   - Submit an OFW for Substation Maintenance to inspect/repair connections if any of the following are found:
     - o loose or corroded connections

4) Capacitor Rack and Support Insulators

   - Submit an OFW for Substation Maintenance to make repairs if any of the following are found:
     - o tracking, arcing, cracked, chipped, or broken rack components or insulators

## 2) CAPACITOR CELL TESTING *(see Figures 11 & 12)*

*[top]*

A) After capacitor bank is shut down and properly protected *(see Article 405)*, Substation Operator will test capacitor cell for proper ***capacitance*** before replacing its fuse element.

B) This testing is done with a hand-held, battery-operated ***Fluke Multi-Meter*** – set to ***"Capacitance Tester"*** – as follows:

1) Insert test leads into Fluke Multi-Meter. *(see Figure 11)*.

- RED TEST LEAD goes into the "Volts, Ohms, Diode Test" receptacle.

- BLACK LEAD goes into the "Common Terminal."

2) Turn rotary switch to capacitance setting: "**Ω /⊣⊢**"

3) Press and hold down YELLOW KEY for two (2) full seconds. "**μF"** will appear on LCD screen.

4) Connect multi-meter lead probes across terminals of capacitor cell with blown fuse. LCD screen will display "**OL"** momentarily, then, will automatically switch back to "**μF**."

5) Record capacitance reading, and compare it with the acceptable capacitance value, listed in *TABLE 01: CAPACITANCE VALUE RANGES FOR POWER SHUNT CAPACITORS*.

6) If capacitance value is WITHIN acceptable range *(from Table 01)*, install new fuse in capacitor cell.

7) If capacitance value is OUTSIDE of acceptable range, do NOT install new fuse in capacitor cell. Submit OFW to Substation Maintenance for defective capacitor cell replacement.

### 3) FUSE REPLACEMENT *(see Figures 13, 14, & 15)*

*[top]*

A) If performing a blanket replacement of all ***fuse tubes***, old tubes will be sent to, and inspected at, Maintenance Headquarters to salvage any that are re-usable.

- Salvageable fuse tubes are characterized by the following:
  - fuse link must freely slip out of tube when held vertically with the ferrule down
  - fuse-tube's insides must be perfectly smooth
- Fuse LEADERS (LINKS) are NOT salvageable – their tails were custom-cut for each location and likely will not fit other locations

B) Wherever a capacitor cell has caused its ***fuse element*** to blow, replace BOTH components.

C) When a capacitor ***cell blows its fuse*** – and the cell appears normal – Substation Operator will test cell for defect.

**⚠ NOTICE**

**SUBSTATION OPERATOR WILL SUBMIT AN OFW TO SUBSTATION MAINTENANCE FOR DEFECTIVE CELL REPLACEMENT.**

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D) After determining that a capacitor cell is NOT defective, Substation Operator will replace ***defective fuse unit*** as follows:

1) Perform required switching and protective procedures to shut down capacitor bank.

2) Unscrew fuse tube, and remove defective unit.

3) Check for fuse tube obstruction from mud daubers, dirt, moisture swelling, etc. Clear any obstruction.

4) Ensure replacement fuse tube and leader (link) are proper size *(see Section III, 2, D)*.

5) Do NOT cut fuse tube to shorten it. They are sized according to capacitor-cell voltage rating.

6) Feed new fuse leader (link) through fuse tube.

   - Check for, and reject, any leader (link) damaged by crimps, bends, or frayed leader wire.

7) Ensure that fuse's knurled bolt is tight and its washer is in place *(see Figure 15)*.

8) Screw fuse tube back onto its rack.

9) Remove jamb nut from bushing terminal.

10) Remove fuse clamp.

11) Remove defective fuse leader (link), if it is still present.

12) Bend flipper spring up toward fuse-tube end so that it is ≤ one (1) inch from tube.

   - Visually inspect flipper-spring integrity *(see Section III, 1 regarding discontinued old-style GE flipper spring – with bracket – which must be replaced).*

     - o When a fuse blows, an improperly installed or poorly designed flipper spring can cause "leader whipping" (a swinging faulted leader, which could contact –

or arc with – neighboring fuse leaders (links) or capacitor cells, possibly causing a "domino" effect of multiple capacitor-cell failures and fires).

13) Feed fuse leader (link) through eye-end of fuse spring.

14) Wrap fuse leader (link) – clockwise – around terminal bushing.

- Ensure that leader (link) is not binding with flipper.

15) Replace fuse clamp.

16) Replace jamb nut, and tighten it.

17) Cut off any excess fuse leader (link).

# III) CAPACITOR-CELL FUSES – PRODUCT INFO

[top]

## 1) FUSE SPRINGS – GE: OLD (DISCONTINUED) & NEW

(back)

A) ***OLD GE capacitor-cell fuse spring*** – identified by a bracket supporting the flipper spring *(see Figure 16)*

- **Old GE capacitor-cell fuse springs must be replaced.**

B) ***NEW GE capacitor-cell fuse spring*** (used since 1984) – has NO bracket supporting the spring *(see Figure 16)*

## 2) PRODUCT INFO

[top]

### A) Capacitor Bank – 13.2-kV; 6-mVAR Max.; 200-kVAR Capacitor Cells; Current-Limiting Fuses

1) Capacitor Cells – 200-kVAR; 7.62-kV (2-bushings)

- Edison Stock # 666-9174

- Approved Manufacturers: GE (Cat. # 58L107WC70); Cooper Power Systems (Cat. # CUM00011Y1 – includes capacitor cell and current-limiting fuse)

2) Current-Limiting Fuses

- Edison Stock # 666-9106

- Approved Manufacturer: Cooper Power Systems (8.3-kV; 40-A); Type NXC (Cat. # FA5J40)

**B) Capacitor Bank – 24-kV; 18-mVAR Max.; 100-kVAR Capacitor Cells; Expulsion Fuses**

[top]

1) Capacitor Cells – 100-kVAR; 6.9-kV

- Edison Stock # 666-9016
- Approved Manufacturers: GE (Cat. # 54L316WC70); Cooper Power Systems (Cat. # CUM00011Y2 – includes capacitor cell and current-limiting fuse)

2) Fuse Tubes

- Edison Stock # 666-9020
- Approved Manufacturers: GE (Cat. # 115A1615G41); Cooper Power Systems (Cat. # CCM149B1)

3) Fuse Flipper Springs

- Edison Stock # 666-9019
- Approved Manufacturer: GE (Cat. # 248A6954G1)

4) Fuse Links – 25-kV

- Edison Stock # 703-0123

**C) Capacitor Bank – 24-kV; 18-mVAR Max.; 200-kVAR Capacitor Cells; Expulsion Fuses**

[top]

1) Capacitor Cells – 200-kVAR; 6.9-kV

(back)

- Edison Stock # 666-9040
- Approved Manufacturers: Cooper Power Systems (Cat. # CUM00011Y3 – includes capacitor cell and fuse link)

**Recommendation**
Try to stock only the above-listed brands, for the following reasons:

- tight clearances between fuse and top of capacitor-cell bushing
- all capacitor cell sizes vary between manufacturers

Failed 200-kVAR capacitor cells – while still under warranty – are returned to, and replaced by, the manufacturer. When manufacturer replacements arrive, send them back to the Maintenance Headquarters that originally handled the failed cells. That Maintenance Department should then place these replacement cells in same-make capacitor banks.

2) Fuse Tubes

- Edison Stock # 666-9020
- Approved Manufacturers: GE (Cat. # 115A1615G41); Cooper Power Systems (Cat. # CCM149B1)

3) Fuse-Flipper Springs

a) Horizontal Mounting

- Edison Stock # 666-9053
- Approved Manufacturer: GE (Cat. # 248A6954G1)

b) Vertical Mounting

- Edison Stock # 666-9019
- Approved Manufacturer: GE (Cat. # 248A6954G1)

4) Fuse Links – 40-kV

- Edison Stock # 703-0124

### D) Capacitor Bank – 24-kV; 36-mVAR Max.; 200-kVAR Capacitor Cells; Current-Limiting Fuses

*(back)*

*[top]*

1) Capacitor Cells – 200-kVAR; 6.9-kV

- Edison Stock # 666-9995
- Approved Manufacturers: Cooper Power Systems (Cat. # CUM00011Y4 – includes capacitor cell and current-limiting fuse) *(see Section III, 2, C, 1 for replacement policy)*

2) Current-Limiting Fuses

- Edison Stock # 666-9106

- Approved Manufacturer: Cooper Power Systems (8.3-kV; 40-A); Type NXC (Cat. # FA5J40)

3) All capacitor banks rated at 24-kV; up to 36 mVAR – except McGraw-Edison capacitor banks – may be equipped with either ***Westinghouse CLXP or COL fuses***. These cells have a current-limiting fuse and expulsion link, in-series. Whenever these fuses are blown or damaged, replace entire unit with an NXC current-limiting fuse.

## E) Capacitor Bank – 40-kV; 18-mVAR Max.; 100-kVAR Capacitor Cells; Expulsion Fuses

*[top]*

1) Capacitor Cells – 100-kVAR; 12-kV
   - Edison Stock # 666-9014
   - Approved Manufacturers: GE (Cat. # 54L301WC70); Cooper Power Systems (Cat. # CUM00011Y6 – includes capacitor cell and fuse link)
2) Fuse Tubes
   - Edison Stock # 709-0096
   - Approved Manufacturers: GE (Cat. # 31F2807G1); Cooper Power Systems (Cat. # FN3Y2C)
3) Fuse-Flipper Springs
   - Edison Stock # 666-9019
   - Approved Manufacturer: GE (Cat. # 248A6954G1)
4) Fuse Links – 15-kV
   - Edison Stock # 703-0127

## F) Capacitor Bank – 40-kV; 18-mVAR Max.; 200-kVAR Capacitor Cells; Expulsion Fuses

*[top]*

1) Capacitor Cells – 200-kVAR; 12-kV
   - Edison Stock # 666-9039
   - Approved Manufacturers: Cooper Power Systems (Cat. # CUM00011Y7 – includes capacitor cell and fuse link) *(see Section III, 2, C, 1 for replacement policy)*

2) Fuse Tubes

- Edison Stock # 709-0096
- Approved Manufacturers: GE (Cat. # 31F2807G1); Cooper Power Systems (Cat. # FN3Y2C)

3) Fuse-Flipper Springs

- Horizontal Mounting
  - Edison Stock # 666-9053
  - Approved Manufacturer: GE (Cat. # 248A6954G2)
- Vertical Mounting
  - Edison Stock # 666-9019
  - Approved Manufacturer: GE (Cat. # 248A6954G1)

4) Fuse Links (25-kV)

- Edison Stock # 703-0123

**G) Capacitor Bank – 40-kV; 36-mVAR Max.; 200-kVAR Capacitor Cells; Current-Limiting Fuses**

*[top]*

1) Capacitor Cells – 200-kVAR; 12-kV

- Edison Stock # 666-9996
- Approved Manufacturers: Cooper Power Systems (Cat. # CUM00011Y8 – includes capacitor cell and current-limiting fuse) *(see Section III, 2, C, 1 for replacement policy)*

2) Current-Limiting Fuses

- Edison Stock # 666-9122
- Approved Manufacturer: Cooper Power Systems (15-kV; 25-A); Type NXC (Cat. # FA6J25)

4) All 40-kV capacitor banks rated up to 36mVARS — except Cooper Power Systems banks — may be equipped with either Westinghouse CLXP or COL fuses. Whenever these fuses are blown or damaged, replace entire unit with an NXC current-limiting fuse.

### H) Capacitor Bank – 40-kV Fuseless

[top]

1) Capacitor Cells – 400-kVAR; 12-kV
   - Edison Stock # 666-9992
   - Approved Manufacturers: Cooper Power Systems (Cat. # CEP99205A1)
2) Capacitor Cells — 500-kVAR; 12-kV
   - Edison Stock # 666-9991
   - Approved Manufacturers: Cooper Power Systems (Cat. # CEP99169A1)
3) Capacitor Cells — 550-kVAR; 12-kV
   - Approved Manufacturers: Cooper Power Systems (Cat. # CEP06095A1)

## IV) BANKGUARD CAPACITOR RELAYING – 59-N (aka 59-N BCR)

[top]

### -) SCOPE *(see Figures 05 & 06)*

A) ***59-N bankguard capacitor relaying*** (59-N BCR) is designed to reduce voltage disturbances on the DTE Energy sub-transmission system, with the goal of preventing catastrophic equipment failure.

B) The most common 59-N bankguard capacitor relaying (59-N BCR) scheme consists of a ***voltage-sensing potential device*** installed between the 40-kV capacitor-bank neutral bus and the substation ground mat.

C) When the potential device *(see Figures 05 & 06)* senses a trouble-indicating neutral-bus voltage, it energizes a ***lockout relay (LOR)***, which isolates the capacitor bank and locks out the capacitor switcher.

### 1) OPERATIONS

[top]

This bankguard relaying scheme engages when ***neutral-bus voltage*** reaches a certain value: the equivalent of four (4) capacitor cells failing on one (1) phase.

A) In most substations, when this value is detected, the 59-N BCR energizes its 1_ _94 ***LOR***, which trips and locks out the capacitor switcher.

- In these installations, a diode is installed within the 40-kV circuit breaker. This prevents breaker from tripping if the problematic neutral-bus voltage value is caused by a capacitor failure.

B) In substations where ***fault capacity exceeds 30-kA***, the 1_ _94 LOR will do the following:

1) Trip the 40-kV trunk or tie-line circuit breaker.

2) Lockout the capacitor switcher.

3) Allow trunk or tie-line circuit breaker to reclose.

C) Two ***other possible substation events*** could generate a voltage difference between ground and capacitor neutral bus:

1) A fault could occur within substation ground mat, elevating the potential of that ground.

- This is rare, and sufficient relay protection would be cost-prohibitive.
  The protection provided by such a scheme yields the same results as the 59-N bankguard relaying scheme; every protected capacitor in the affected area would be isolated.

2) Trouble could arise on equipment connected to capacitor bank, creating voltage spikes that could rupture capacitor cells.

a) When capacitor-bank-connected equipment fails, the capacitors should automatically drain through faulted equipment. But this is NOT guaranteed, and subsequent reclosures can prompt capacitor-cell failures to cascade.

b) Therefore, whenever any capacitor-bank-connected equipment energizes its own protective relay to trip the circuit breaker, it also energizes the 59-N BCR LOR to isolate capacitor bank. The affected circuit breaker then completes its normal reclosing cycle.

## 2) ALARMS

[top]

A) The 59-N BCR scheme and the 1_ _94 LOR are alarmed separately. Whenever the 59-N BCR picks up and isolates the capacitor switcher, there should be ***TWO (2) alarms*** to acknowledge.

1) A 59-N operation is indicated by the ***RED LAMP*** mounted to face of bankguard relay panel. Reset it by pushing button also mounted on panel.

2) Alarm switch for 1_ _94 LOR is located on switchboard panel. Acknowledge by engaging the toggle-switch.

B) If ***protective relays*** on trunk or tie-line initiate a capacitor-switcher lockout, a circuit-breaker alarm AND a 1_ _94 alarm will be generated. However, the trunk or tie-line circuit breaker may remain closed upon capacitor-switcher's reclosure. This would cancel one of the alarms.

### 3) PROTECTION

[top]

Since the 59-N BCR system contains a potential device, a ***secondary switch*** is installed on the device. This secondary switch is located within the capacitor-switcher control compartment – OR – within a weatherproof box mounted (below) the potential device, inside the capacitor fenced enclosure. **This secondary switch is considered a protective tagging point.**

**NOTICE**

**— THE RED INDICATING LAMPS LOCATED ON THE 59-N BCR PANEL ARE SELF-CONTAINED UNITS.**

**— SUBSTATION OPERATOR WILL SUBMIT A "FIVE (5)-DAY URGENT OFW" IF THIS LAMP NEEDS REPLACEMENT.**

## V) CAPACITOR BANK TROUBLESHOOTING SEQUENCE GUIDE

(back)

[top]

**DANGER**

**PRIOR TO ENERGIZING A PREVIOUSLY-FAILED CAPACITOR BANK, THIS "CAPACITOR BANK TROUBLESHOOTING SEQUENCE GUIDE" (Section V) MUST BE COMPLETED!**

### 1) FUSED 24-kV & 40-kV

[top]

A) Inspect for, and note, capacitor-cell ***blown fuses*** and capacitor-cell ***bulges***.

B) Inspect for, and note, ***YELLOW TARGETS*** and/or ***RED TARGETS*** on capacitor switcher.

C) Then, follow this ***troubleshooting sequence***:

1) If *Step 1* issues (blown fuses, bulged cells) are found, follow *Step 4: Capacitor Banks Diagnosis Sequence (below)*.

2) If *Step 2* issues (targets on switcher) are found, follow *Step 5: Switcher Diagnosis Sequence (below)*.

3) If *Step 1* AND *Step 2* issues are found, follow *Step 4: Capacitor Banks Diagnosis Sequence AND Step 5: Switcher Diagnosis Sequence, in-parallel (below)*.

D) Capacitor Banks ***Diagnosis Sequence***

[top]

**1) Verify that "Red Tag Protection" has been applied.**

2) Do the following:

a) Determine and record capacitor-cell voltage rating: _____________

b) Determine and record capacitor-cell kVAR rating: ______________

c) Count capacitor cells on lower rack and upper rack of each phase, and record results, (below).

***[NOTE]***
*Most capacitor banks are balanced top-to-bottom; some are balanced left-to-right.*

| | XΦ | YΦ | ZΦ |
|---|---|---|---|
| No. of upper cells | ______________ | ______________ | ______________ |
| No. of lower cells | ______________ | ______________ | ______________ |
| Total per phase | ______________ | ______________ | ______________ |

d) From Table 01 *(below)* determine and record capacitor-cell capacitance range.

Min. ________ µf     Max. ________ µf

e) Determine (and record) the phase-capacitance range by multiplying total number of cells per phase by the min. and max. capacitance-cell values.

(back)

f)

Total cells per phase ____________ x Min. ________ µf = __________ µf

Total cells per phase ____________ x Max. ________ µf = __________ µf

[top]

3) Measure and record capacitance on each phase.

XΦ ____________ µf

YΦ ____________ µf

ZΦ ____________ µf

4) Compare individual values obtained in *Step C*.

   a) Value variations should be < half (1/2) of an individual cell's capacitance.

   b) Each phase measurement must fall within the min./max. range established in *Step V, 1, 4, B, v. (phase-capacitance ranges)*.

      i) If these criteria are met, skip to *Step 5: Switcher Diagnostic Sequence.*

      ii) If these criteria are NOT met, continue with *Step E*.

5) Measure and record the capacitance of each rack *(which will total six (6) measurements)*. The protective grounds by the switcher must be temporarily removed.

X1Φ ______________ µf    X2Φ ______________ µf

Y1Φ ______________ µf    Y2Φ ______________ µf

Z1Φ ______________ µf    Z2Φ ______________ µf

6) Compare individual values obtained in *Step E*.

[top]

   a) Value variations should be < half (1/2) of an individual cell's capacitance.

   b) Each rack measurement must fall within 50% of the min./max. range established in *Step V, 1, 4, B, v. (phase-capacitance ranges)*.

      i) If these criteria are NOT met, verify continuity of each capacitor-cell fuse.

         - If a blown fuse is found, measure the cell capacitance.

            - If cell capacitance is within range, replace fuse.

            - If cell capacitance is NOT within range, replace cell AND fuse.

ii) Re-check *Step F* bulleted requirements. If these criteria still are NOT met after replacing any blown fuses/bad cells, measure capacitance of each individual capacitor cell for acceptance.

E) ***Switcher*** Diagnosis Sequence

- Refer to Job procedures:
  - 350-015: S&C Circuit Switchers, Vertical & Center Break Models 34.5-kV through 345-kV

    **— OR —**

  - 350-017: Southern States Cap Switcher 72

## 2) FUSELESS 24-kV & 40-kV

[top]

A) Inspect for, and note, capacitor-cell ***bulges***.

B) Inspect for, and note, ***YELLOW TARGETS*** and/or ***RED TARGETS*** on capacitor switcher.

C) Then, follow this ***troubleshooting sequence***:

1) If *Step 1* issues (bulged cells) are found, follow *Step 4: Capacitor Banks Diagnosis Sequence (below)*.

2) If *Step 2* issues (targets on switcher) are found, follow *Step 5: Switcher Diagnosis Sequence (below)*.

3) If *Step 1* AND *Step 2* issues are found, follow *Step 4: Capacitor Banks Diagnosis Sequence AND Step 5: Switcher Diagnosis Sequence, in-parallel (below)*.

D) Capacitor Banks ***Diagnosis Sequence***

[top]

**1) Verify that "Red Tag Protection" has been applied.**

2) Do the following:

a) Determine and record capacitor-cell voltage rating: _____________

b) Determine and record capacitor-cell kVAR rating: ______________

c) From *Table 01* *(below)* determine and record capacitor-cell capacitance range.

Min. ________ µf Max. ________ µf

d) Determine (and record) the phase-capacitance range by dividing total number of cells per phase by four (4), then multiplying the result by the min. and max. capacitance-cell values.

Total cells per phase _____________ x Min. ________ µf = __________ µf

Total cells per phase _____________ x Max. ________ µf = __________ µf

[top]

3) Measure and record capacitance on each phase.

XΦ ____________ µf

YΦ ____________ µf

ZΦ ____________ µf

4) Compare individual values obtained in *Step C*.

a) Value variations should be < half (1/2) of an individual cell's capacitance.

b) Each phase measurement must fall within the min./max. range established in *Step V, 2, 4, B, v. (phase-capacitance ranges)*.

i) If these criteria are met, skip to *Step 5: Switcher Diagnostic Sequence.*

ii) If these criteria are NOT met, continue with *Step E*.

5) Measure and record the capacitance of "strings" (i.e., groups of capacitor cells in-series). Number of strings could vary depending on capacitor bank size. *See Figure xx* to identify strings and measurement points on a typical 24/40-kV - 18 mVAR fuseless capacitor bank (18 strings, 6 strings per phase).

X1Φ ______________ µf X2Φ ______________ µf

X3Φ ______________ µf X4Φ ______________ µf

X5Φ ______________ µf X6Φ ______________ µf

Y1Φ ______________ µf Y2Φ ______________ µf

Y3Φ ______________ µf Y4Φ ______________ µf

Y5Φ ______________ µf Y6Φ ______________ µf

Z1Φ ______________ µf Z2Φ ______________ µf

Z3Φ ______________ µf Z4Φ ______________ µf

Z5Φ ______________ μf      Z2Φ ______________ μf

6) Determine the average for values obtained in *Step E*. All individual string values should be within ± 0.2 μf of each average.

7) If the average values do not fall within ± 0.2 μf of each average, measure the capacitance of each cell for acceptance.

E) ***Switcher*** Diagnosis Sequence

- Refer to Job procedures:
  - 350-015: S&C Circuit Switchers, Vertical & Center Break Models 34.5-kV through 345-kV

    **— OR —**

  - 350-017: Southern States Cap Switcher 72

**Table 01 – Capacitance Value Ranges for Power-Shunt Caps**

[top]

| UNIT VOLTAGE RATING (kV) | UNIT POWER RATING (kVAR) | CAPACITANCE VALUE RANGE (MICROFARAD)* MINIMUM | MAXIMUM |
|---|---|---|---|
| 6.9 | 100 | 5.54 | 6.49 |
| 6.9 | 200 | 11.09 | 12.97 |
| 6.9 | 500 | 27.72 | 32.43 |
| 7.62 | 200 | 9.09 | 10.64 |
| 12.0 | 100 | 1.83 | 2.14 |
| 12.0 | 200 | 3.67 | 4.29 |
| 12.0 | 400 | 7.33 | 8.58 |
| 12.0 | 500 | 9.16 | 10.72 |
| 12.0 | 550 | 10.08 | 11.75 |

***** Capacitance value ranges are based on -0% to +15% manufacturing tolerance, with temperature compensation from -20 degrees Celsius to +40 degrees Celsius.

(back)

*(see Figure 17 – Strings and Measurement Points)*

# VI) CAPACITOR BANK BALANCING

(back)

[top]

## -) SCOPE

Follow these guidelines for balancing capacitor banks.

## 1) BALANCING

[top]

If more than one (1) capacitor-cell ***fuse is found blown*** on one (1) phase – resulting in an imbalance – Substation Operator will de-energize capacitor bank and keep it out-of-service until failed fuses are replaced.

**However …**
Under certain system conditions, the System Supervisor may require the capacitor bank to remain in-service, for voltage support, before replacement parts are available. If so, Substation Operator must ***balance the capacitor bank*** to avoid overvoltaging remaining banks.

### A) *13.2-kV BANKS*

[top]

- Wye-ungrounded connection
- Ratings vary from 3-mVAR to 6-mVAR.
- 200-kVAR capacitor cells
- Each bank contains three (3) phases.
  - Each phase contains one (1) group.
    - Each group contains capacitor cells connected in-parallel.
- **BALANCING REQUIRES EACH PHASE GROUP TO CONTAIN SAME NUMBER OF FUNCTIONING CELLS CONNECTED IN-PARALLEL.**

### B) *24-kV & 40-kV BANKS*

[top]

- Outdoor rack-type construction
- Wye-grounded – OR – wye-ungrounded connection
- Ratings vary from 4.8-mVAR to 30-mMVAR.

  - 4.8-mVAR banks use 100-kVAR capacitor cells.
  - 30-mVAR banks use 200-kVAR capacitor cells.

- Each bank contains three (3) phases.
  - Each phase contains two (2) racks (in an upper/lower OR right/left configuration) connected in-series.
    - Each rack contains capacitor cells connected in-parallel.

- **BALANCING REQUIRES EACH RACK – OF ALL THREE (3) RACK CONFIGURATIONS (PAIRS) – TO HAVE SAME NUMBER OF FUNCTIONING CAPACITOR CELLS CONNECTED IN-PARALLEL.**

  ***[NOTE]***
  ***A few small-size capacitor banks contain only one (1) rack per phase.***

  - Each bank contains three (3) phases.
    - Each phase contains one (1) rack.
      - Each rack contains two (2) sides connected in-series.
        - Each side contains capacitor cells connected in-parallel.

- **BALANCING REQUIRES EACH SIDE – OF ALL THREE (3) RACKS – TO HAVE SAME NUMBER OF FUNCTIONING CAPACITOR CELLS CONNECTED IN-PARALLEL.**

**1) WYE-UNGROUNDED** *(see Figures 01 & 02)*

*[top]*

a) **Upper Rack In-Series with Lower Rack** *(see Figure 01)*

- To balance 24-kV or 40-kV ungrounded capacitor banks, each rack (upper and lower) of all three (3) phases must contain same number of capacitor cells, connected in-parallel.

b) **Left-Side Rack In-Series with Right-Side Rack** *(see Figure 02)*

- To balance 24-kV or 40-kV ungrounded capacitor banks, each rack (left-side and right-side) of all three (3) phases must contain same number of capacitor cells, connected in-parallel.

c) **One Side of Small Bank In-Series with Other Side of Small Bank**

- To balance 24-kV or 40-kV ungrounded capacitor banks, each small bank (both sides or groups) of all three (3) phases must contain same number of capacitor cells, connected in-parallel.

**2) WYE-GROUNDED** *(see Figures 03 & 04)*

*[top]*

Since each phase of 24-kV or 40-kV grounded capacitor banks can be independently balanced, the number of connected capacitor cells per phase can be unequal without causing an overvoltage condition.

a) **Upper Rack In-Series with Lower Rack** *(see Figure 03)*

- To balance 24-kV or 40-kV grounded capacitor banks within each phase, the number of capacitor cells on lower rack must equal number of capacitor cells on upper rack.

b) **Left-Side Rack In-Series With Right-Side Rack** *(see Figure 04)*

- To balance 24-kV or 40-kV grounded capacitor banks within each phase, the number of capacitor cells on left-side rack must equal number of capacitor cells on right-side rack.

### 2) GENERAL

*[top]*

A) When balancing a capacitor bank, Substation Operator will completely remove ***disconnected (blown) fuse element*** – or secure it – to prevent its contact (aka ***“leader whipping”***) with capacitor-bank frame, another fuse, or another capacitor cell.

B) On capacitor banks containing current-limiting fuses, Substation Operator will conduct a ***continuity check*** of ALL limiters following a blown-fuse replacement or a capacitor-bank balancing operation. Defective current limiters cause voltage imbalances on in-service capacitor cells.

C) ***Fuseless*** capacitor banks cannot be balanced.

## VII) CAPACITOR (aka “SHUNT CAPACITOR”) THEORY & OPERATION

*[top]*

### 1) PURPOSE

Capacitors (aka “shunt capacitors”) are installed throughout the DECO electrical system. When installed near an inductive load, capacitors improve voltage regulation and allow additional equipment capacity. Therefore, system-load capacity is increased.

**Here’s how:**

A) Induction motors, transformers, and other inductive equipment draw a ***line current*** greater than the actual power they consume. This happens because the ***magnetizing current*** in the circuit (produced as the magnetic fields build up and collapse within each cycle) reaches its maximum value one quarter of a cycle LATER than the voltage wave does (***LAGGING the impressed voltage by 90°***).

B) Capacitors draw a current that reaches their maximum value one quarter of a cycle SOONER than the voltage wave does (***LEADING the impressed voltage by 90°***).

C) Therefore, ***capacitor current is 180° out-of-phase*** (exactly opposite) with the magnetizing current supplied by inductive equipment (motors, transformers, etc.). So when a load comprising inductive AND capacitive equipment is connected to a line, the magnetizing current (between capacitor and generator) is reduced by the capacitor-current level.

D) *(See Figure 10)* As shown, if ***E*** is the direction of the voltage, ***Ip*** is the current supplying the useful power, and ***Im*** is the magnetizing current, then ***Il*** is the line current (produced by ***"graphic addition"***). As a result, ***Il*** is greater than ***Ip*** by the current amount needed to supply useful power.

E) Consider a capacitor drawing current ***Ic*** – and an equal but opposite current ***Im***. If these two were now connected in-parallel, ***Ic*** and ***Im*** would balance out, and the ***total line current*** would coincide with ***Ip*** in magnitude and direction.

1) The power current ***Ip*,** multiplied by voltage, equals "true power" ***(kW)***.

2) The line current ***Il*,** multiplied by voltage, equals "apparent power" ***(kVA)***.

3) The ratio of true power to apparent power ***(kW : kVA)*** is the "power factor" of the circuit.

**Capacitors are connected to the system during heavy-load periods. This produces the following effects:**

A) ***Raises power factor*** of load and system as a whole.

- Amount of power-factor improvement depends on amount of reactive load and amount of connected capacitance.

B) Causes voltage to ***rise at the load***.

- Amount of voltage increase depends on amount of reactive drop and amount of connected capacitance.

**To obtain optimum voltage regulation, capacitors are connected to, AND disconnected from, the DTE Energy electrical system by automatic switchgear.**

- This ***switchgear*** can be controlled automatically (by time clocks or VAR controllers), OR can be controlled manually by Substation Operator.

**Because amount of magnetizing current *(identified as "Im" in Figure 10)* is reduced, more load-carrying capacity becomes available.**

- Indeed, if ***Ic*** should exceed ***Im***, load would contain a leading power factor, causing voltage to rise.

- This can cause transformers, lines, etc., to have a greater load AFTER capacitor is online than before it was connected.

**On the DTE Energy system, capacitor use is frequently manipulated by System Supervisor to maintain 24-kV and 40-kV buss voltage while incoming transmission lines are out-of-service during light-load periods.**

## 2) CONSTRUCTION & CONNECTIONS

*[top]*

A) Capacitor ***Cells***

1) Each capacitor-bank cell contains two (2) bushings (13.2-kV metal-enclosed cap banks and fuseless) or one (1) bushing (24-kV and 40-kV fused cap banks). In all cases bushings are insulated from their case and connected to special thin-foil paper layers.

    - The paper layers are infused with refined mineral oil – OR – synthetic chlorinated biphenyl.

        - Neither is flammable or explosive.

2) With fused capacitor banks, each capacitor cell's source side is fused with an indicating-type high-voltage power fuse.

B) Capacitor ***Bank Installations***

*[top]*

- On Westinghouse, GE, and Cooper (McGraw-Edison) capacitor-bank installations, individual capacitor cells are supported by an ***insulated rack***. *(see Figure 09)*

    - This rack is energized from the parallel series combination's midpoint.

C) Capacitor ***Discharge***

*[top]*

3) Capacitors retain a dangerous charge even after their energy source has been removed.

- **Therefore, it is mandatory that capacitor-bank installations be discharged before any work is performed on them.**

4) As shown in *Figure 08*, upon removal of energy source, entire capacitor bank will discharge down to a 50-volt level within five (5) minutes.

5) As a further safeguard, all three (3) capacitor-bank phases – and the insulated rack – are grounded by ground switches – OR – a set of removable grounding leads, which Substation Operator must install before any capacitor equipment work is performed.

## 3) OPERATING INFORMATION

*[top]*

A) A capacitor may retain ***above-normal operating voltages*** after disconnection from the line.

- These voltages are dependent upon the voltage-wave resting point when circuit breaker was opened.

B) Therefore, whenever a ***capacitor is de-energized***, wait at least five (5) minutes before re-energizing it.

- Otherwise, excessive capacitor voltage may damage equipment connected to the bus.

C) Whenever a capacitor is connected to a bus, the ***current surges*** two (2) to three (3) times normal during first 1/4 to 1/2 cycle.

*[top]*

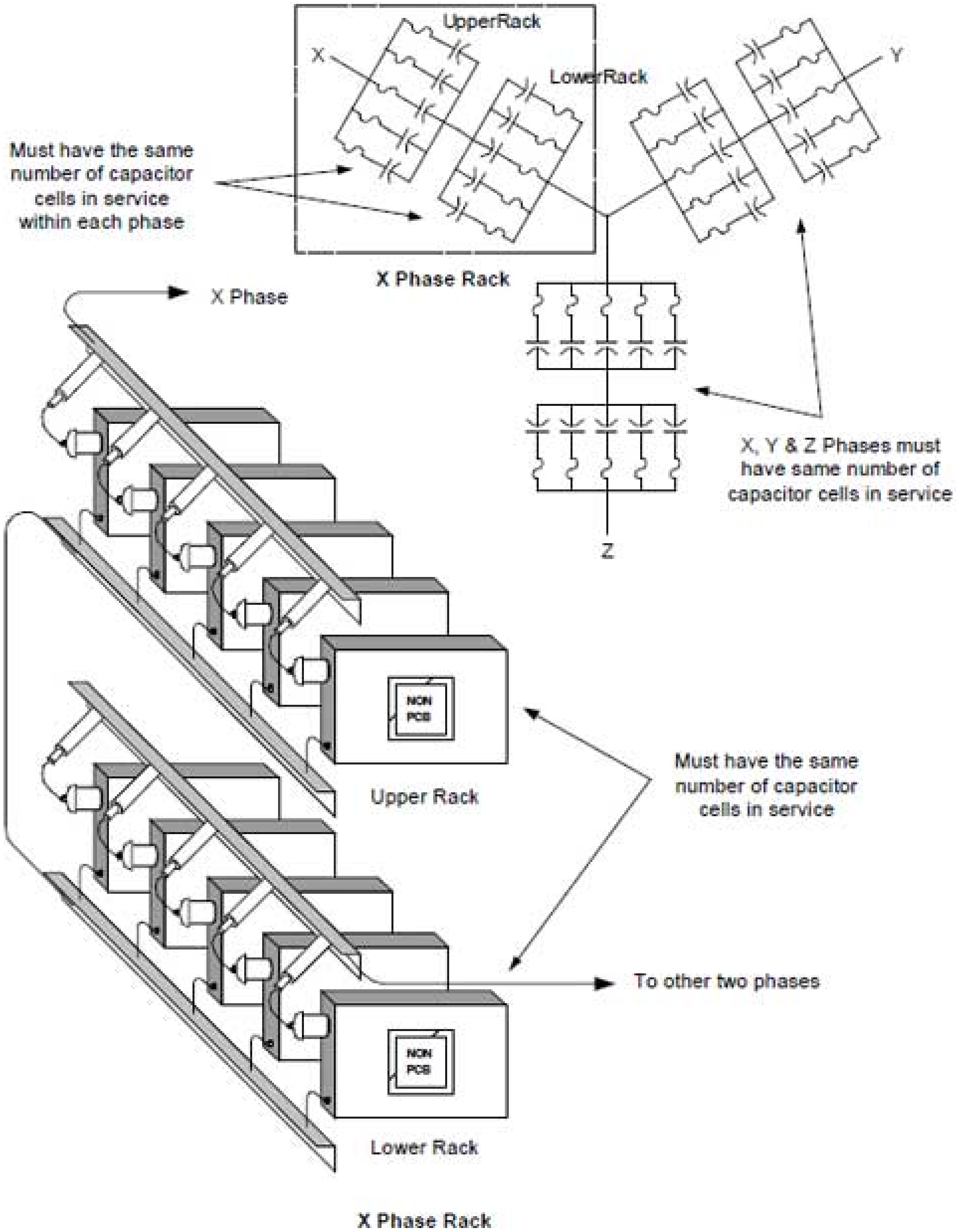



**FIGURE 1**
**Wye-Ungrounded Capacitor Bank**
**Upper Rack in Series with Lower Rack**

**Figure 01 — Wye-Ungrounded Capacitor Bank – Upper Rack In-Series with Lower Rack**
*(back)*

*[top]*

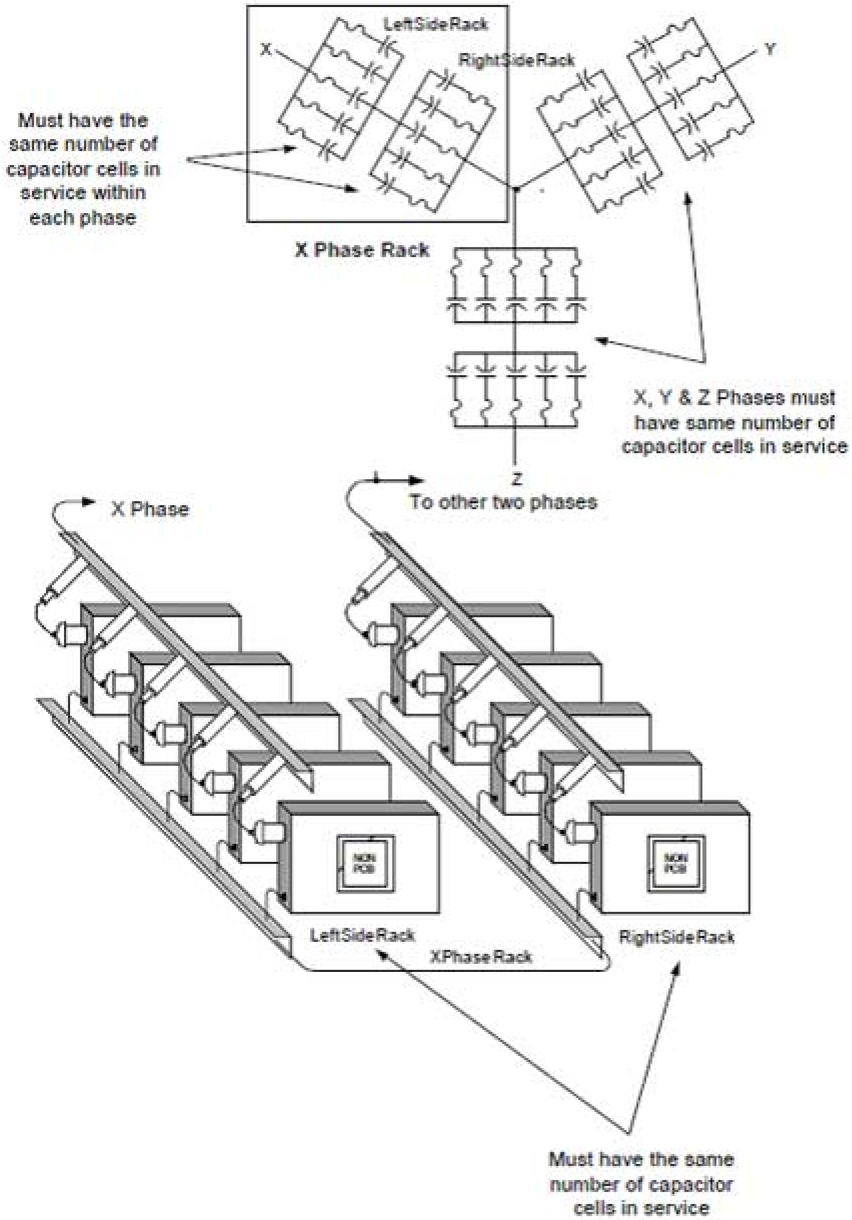



**FIGURE 2**
**Wye-Ungrounded Capacitor Bank**
**Left Side Rack in Series with Right Side Rack**

**Figure 02 — Wye-Ungrounded Capacitor Bank – Left-Side Rack In-Series with Right-Side Rack**
*(back)*

*[top]*

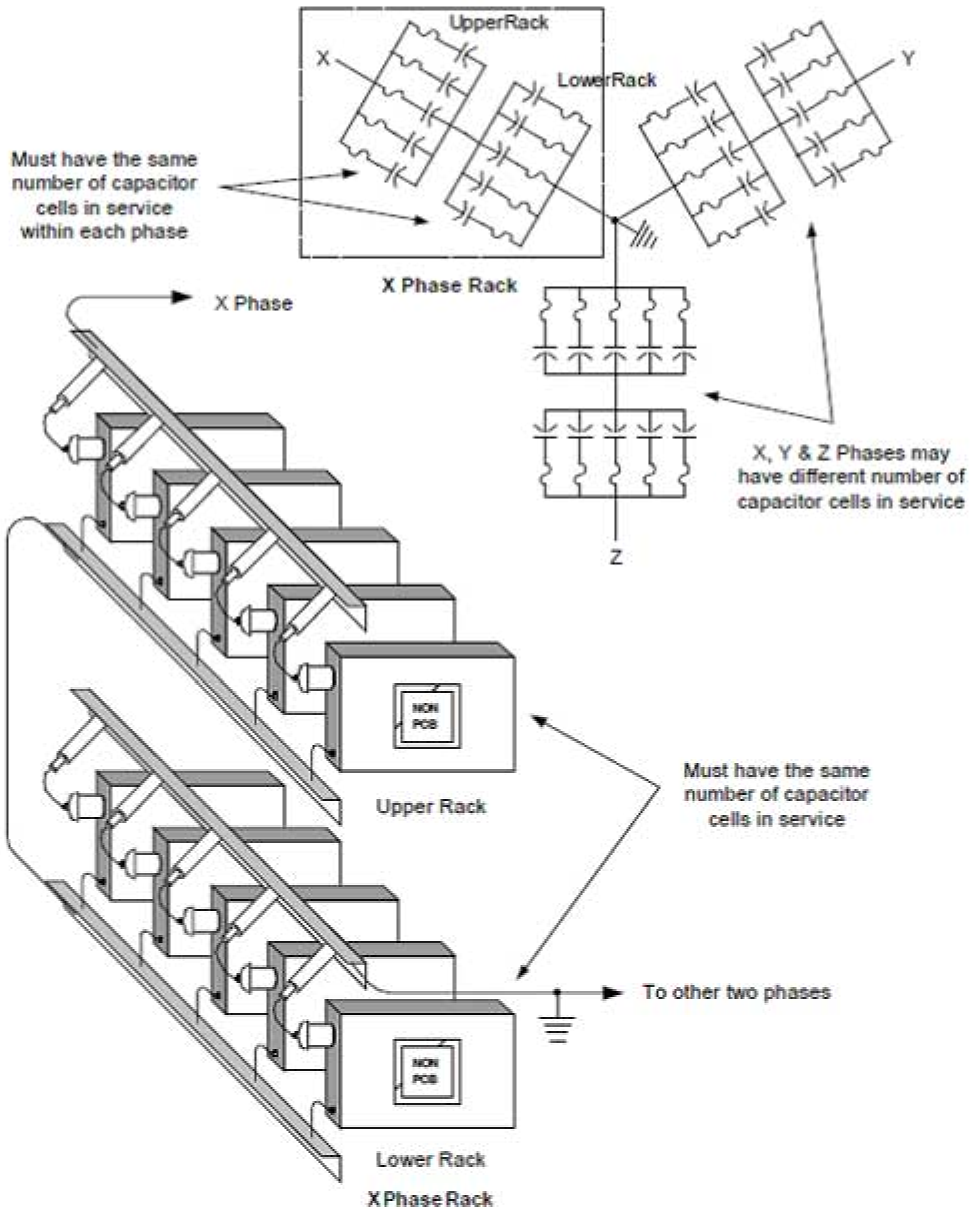



**FIGURE 3**
**Wye-Grounded Capacitor Bank**
**Upper Rack in Series with Lower Rack**

**Figure 03 — Wye-Grounded Capacitor Bank – Upper Rack In-Series with Lower Rack**
*(back)*

*[top]*

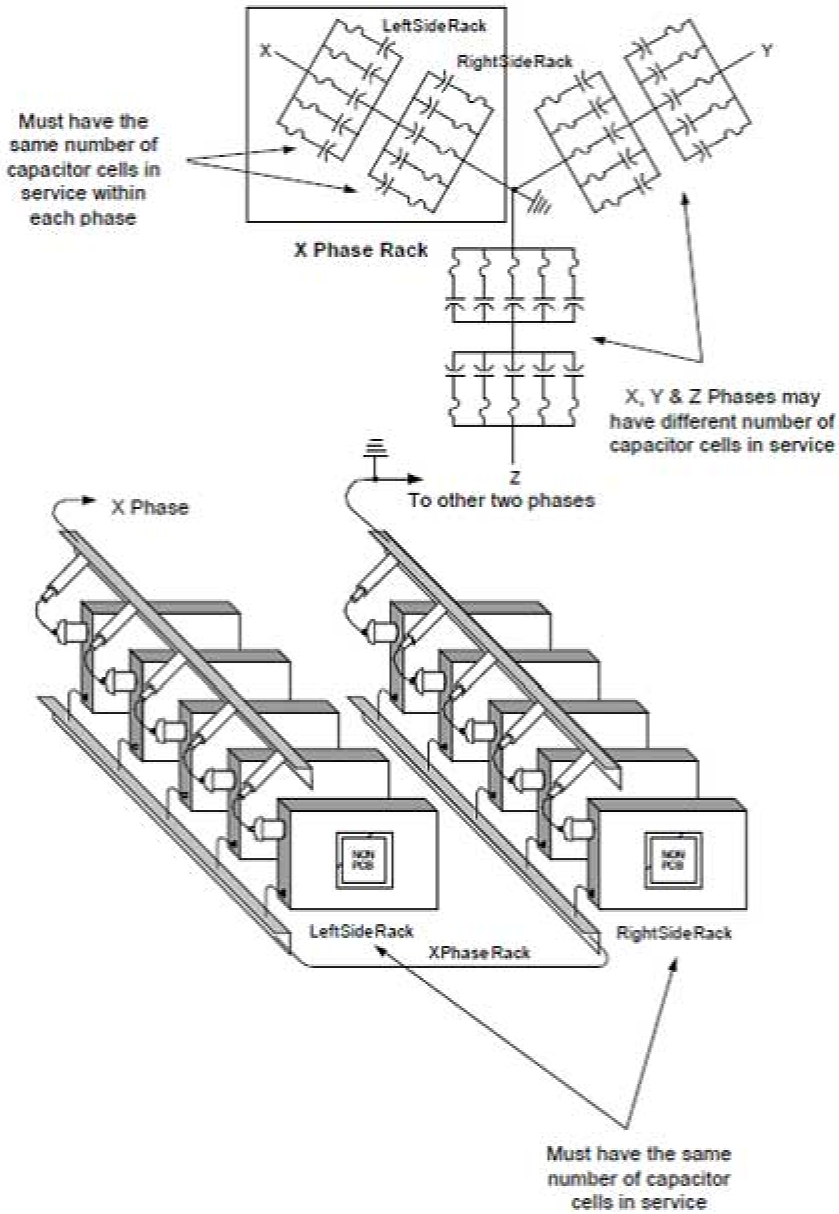



FIGURE 4
Wye-Grounded Capacitor Bank
Left Side Rack in Series with Right Side Rack

**Figure 04 — Wye-Grounded Capacitor Bank – Left-Side Rack In-Series with Right-Side Rack**
*(back)*

*[top]*

**Figure 05 — Voltage-Sensing Potential Device**

*(back)*

*[top]*

**Figure 06 — Lockout Relay (LOR)**
*(back)*

*[top]*

Construction and Connections (Continued)

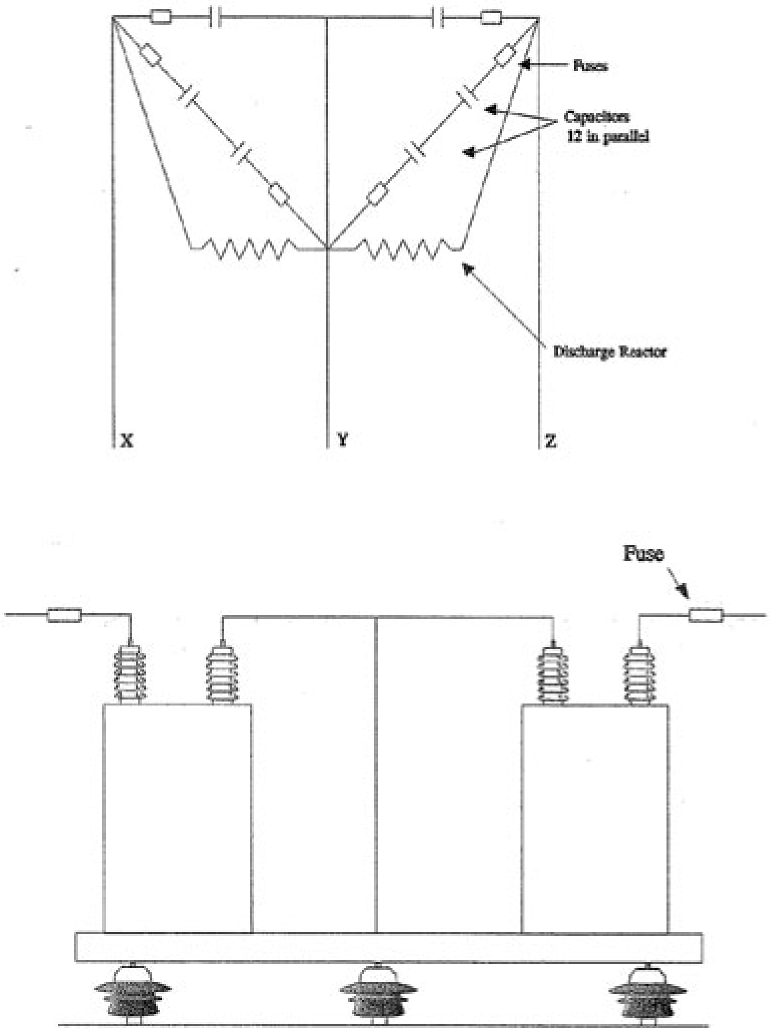



**Figure 07 — Fuses, Construction, & Connections**
*(back)*

*[top]*

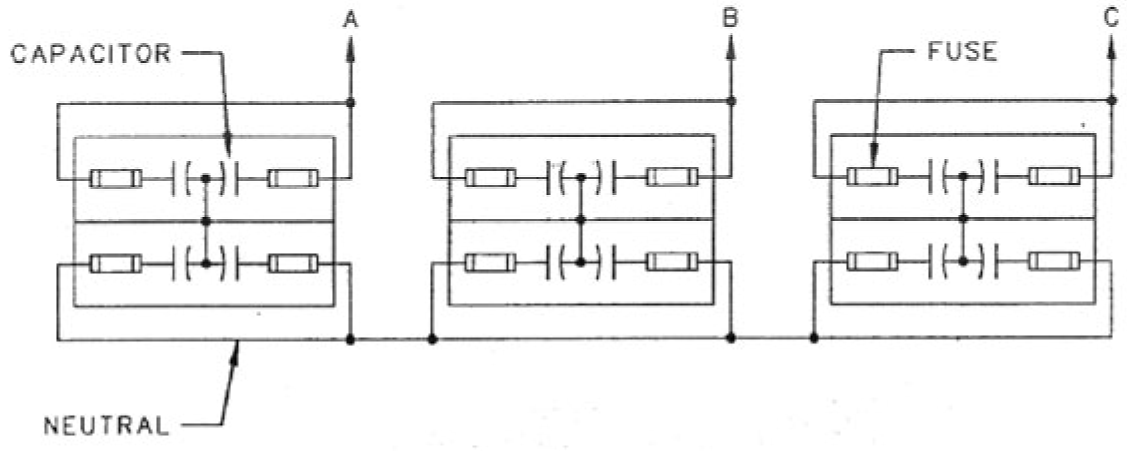



**Figure 08 — Capacitor Bank Group & Fuses**
*(back)*

*[top]*

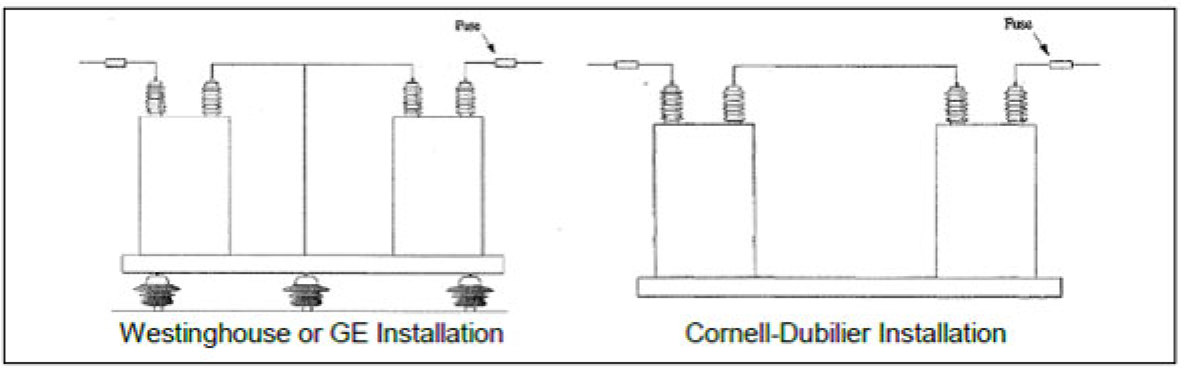



**Figure 09 — Capacitor Bank Installations**
*(back)*

*[top]*

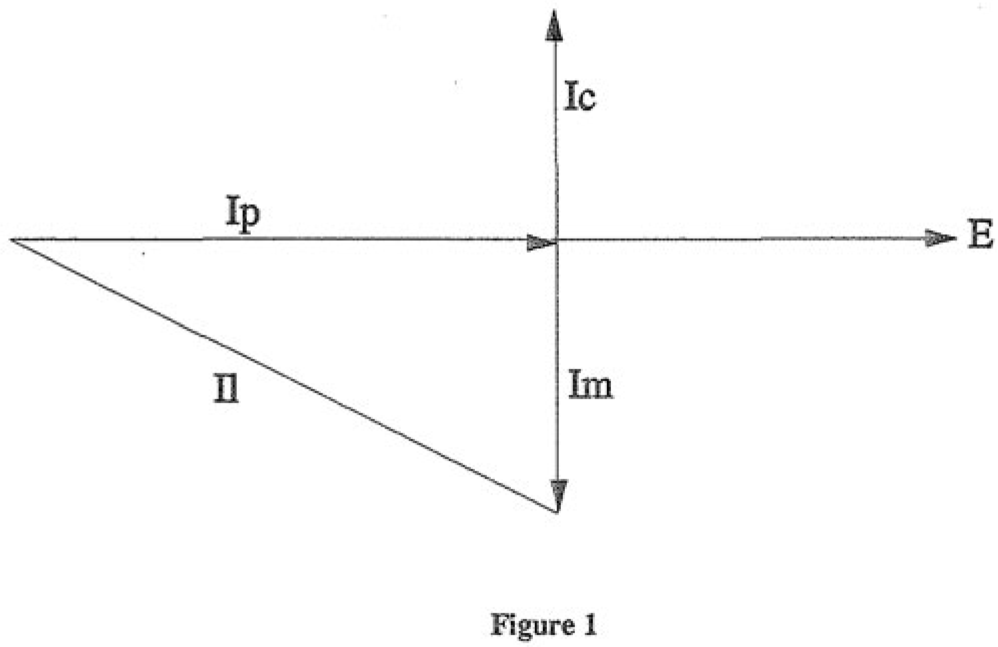



**Figure 10 — Current Flow**
*(back)*

*[top]*

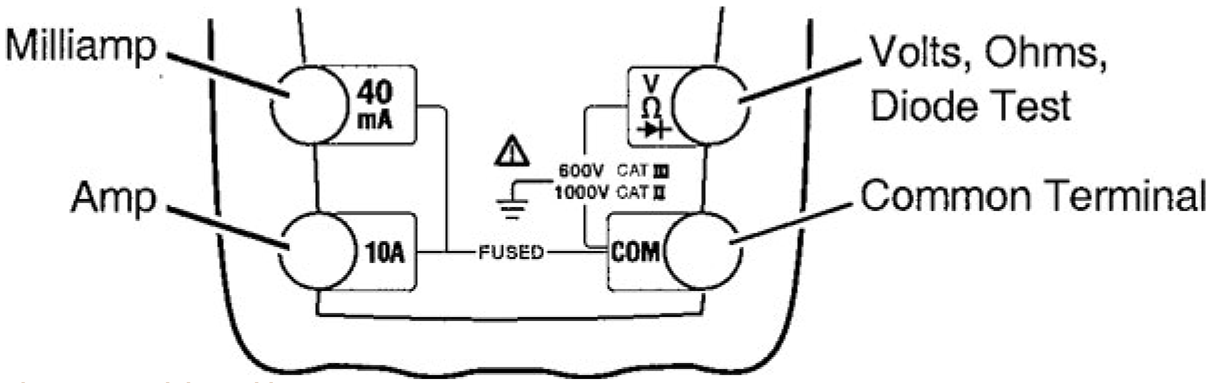



**Figure 11 — Fluke Multi-Meter**
*(back)*

*[top]*

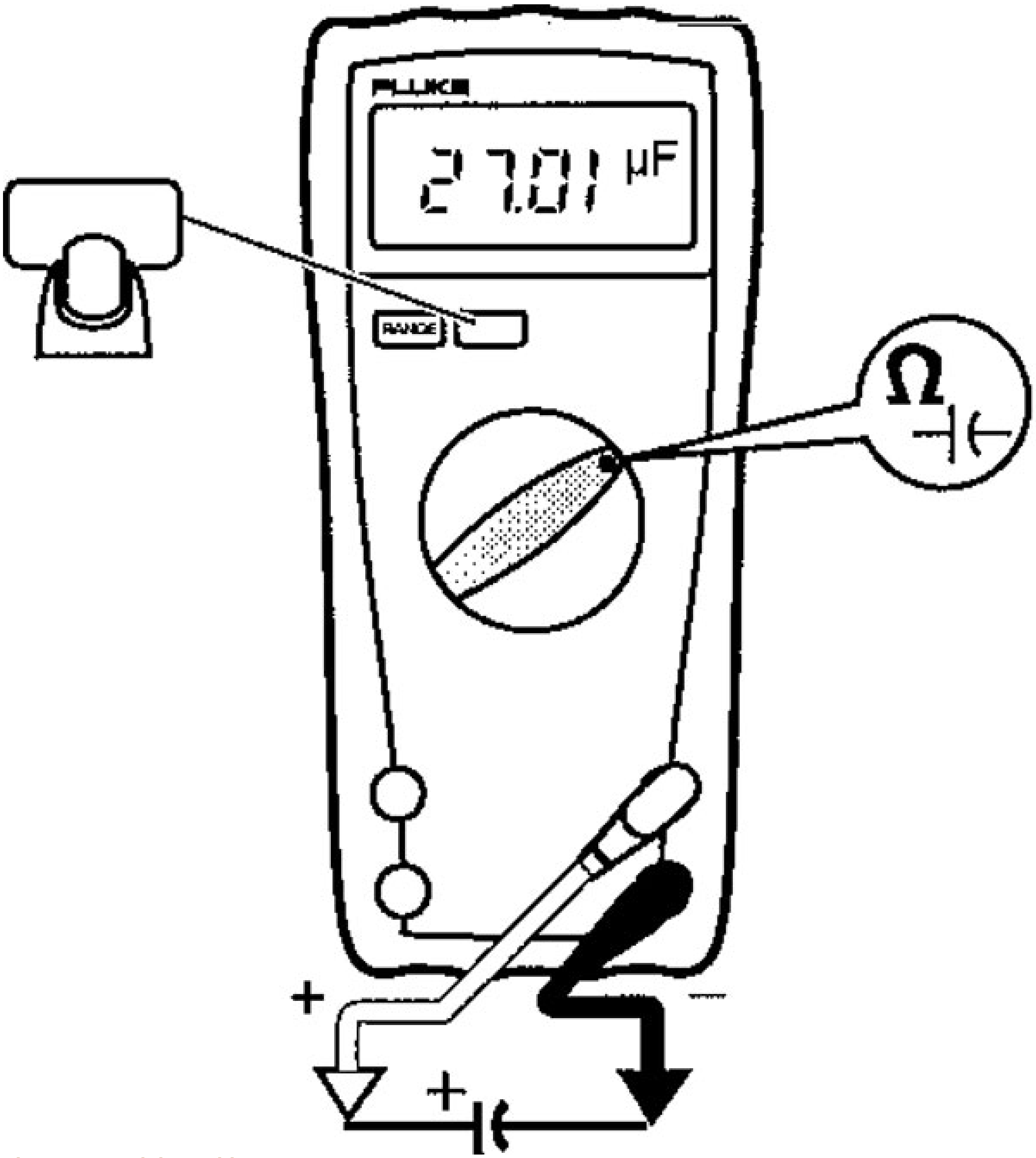



**Figure 12 — Fluke Multi-Meter**
*(back)*

*[top]*

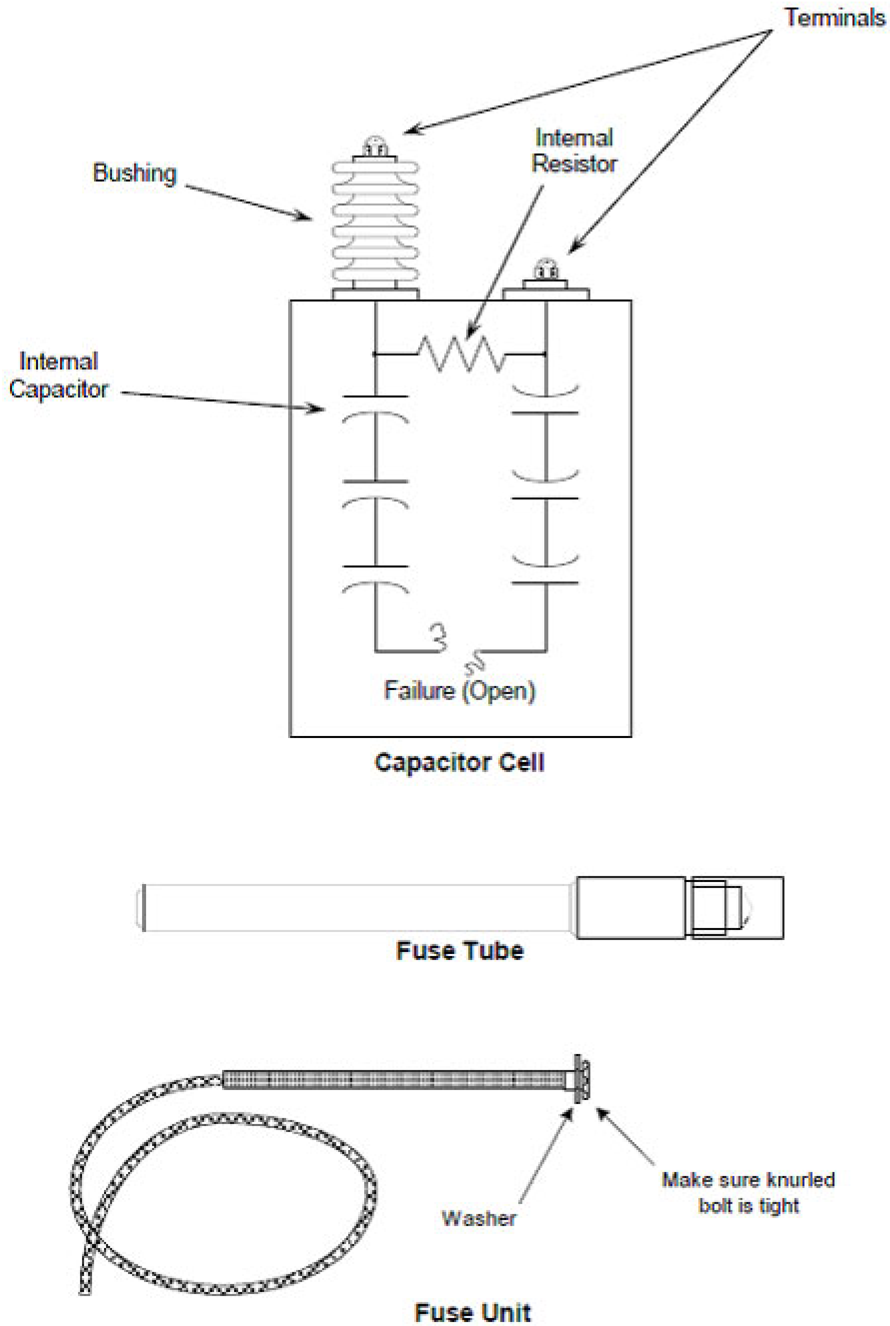
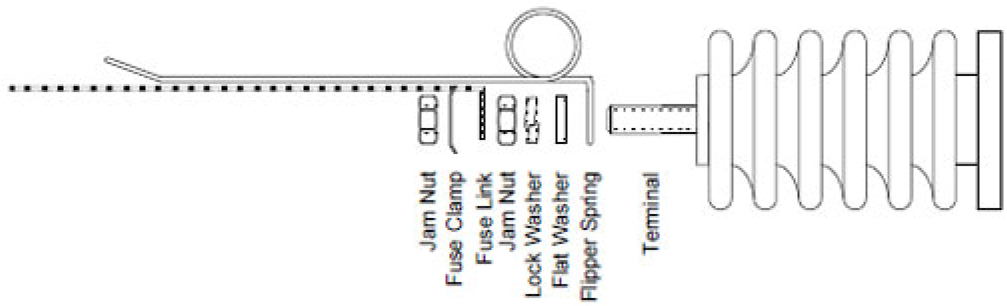



**Figure 13 — Fuse Element Components**

*(back)*

*[top]*

### Horizontal Bushing Assembly



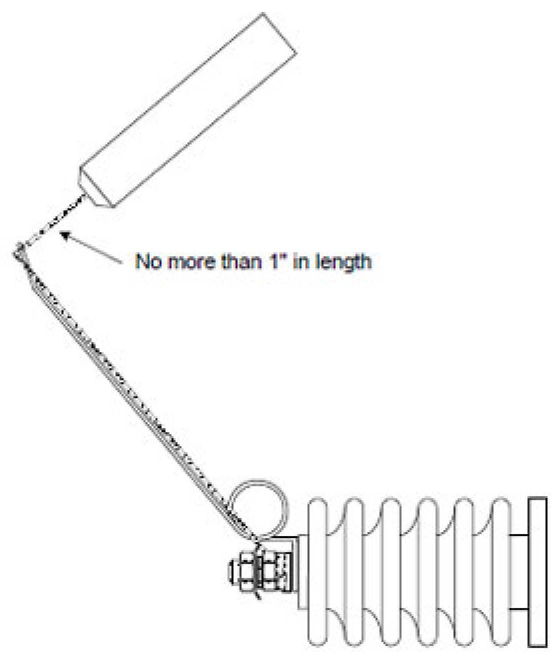




**Figure 14 — Fuse Element – Horizontal Bushing Assembly**
*(back)*

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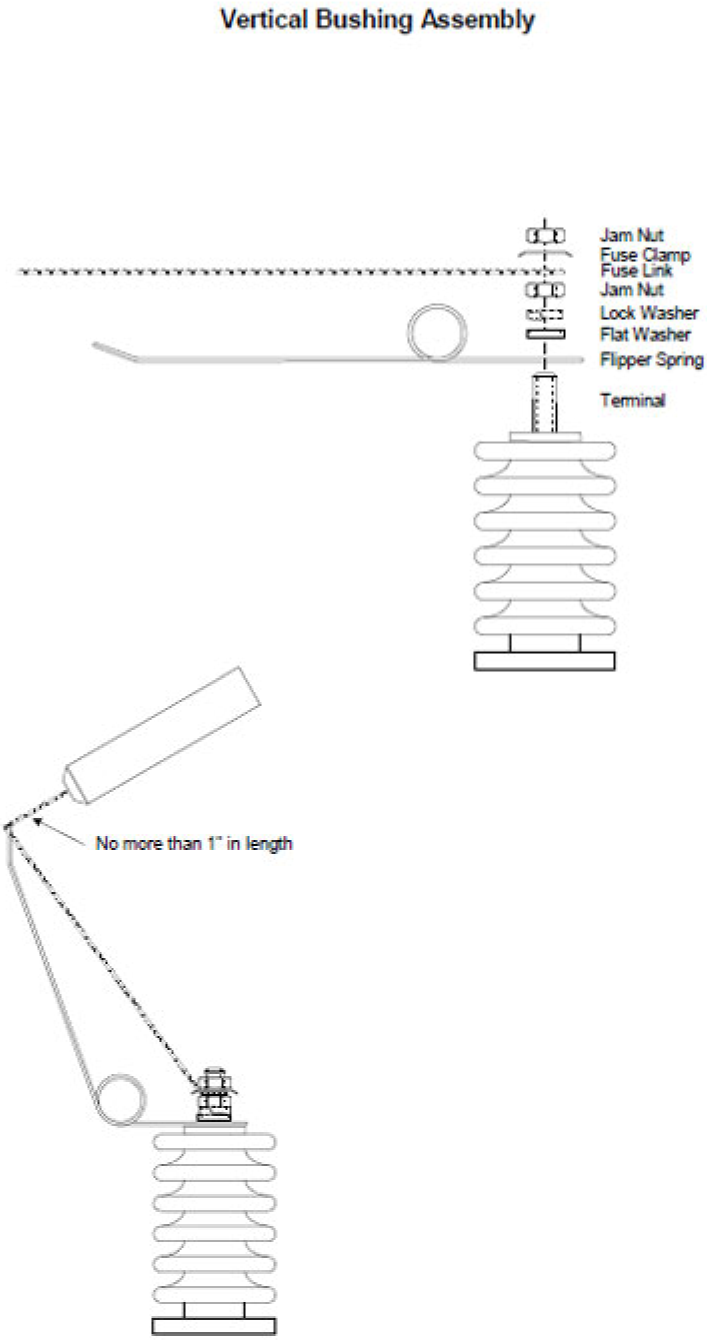


**Figure 15 — Fuse Element – Vertical Bushing Assembly**

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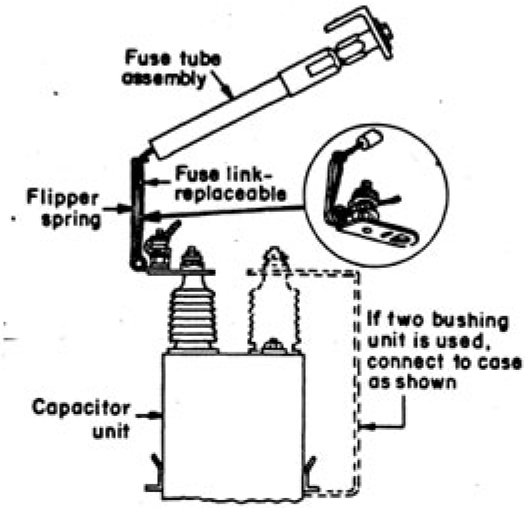
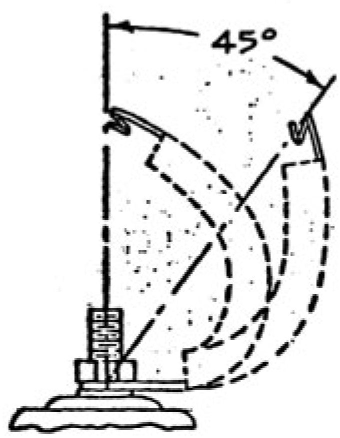



Old Style Spring
(To Be Replaced)




New Style Spring

Identification of
General Electric Capacitor Fuse Springs

**Figure 16 — Springs – Old and New Style**

*(back)*

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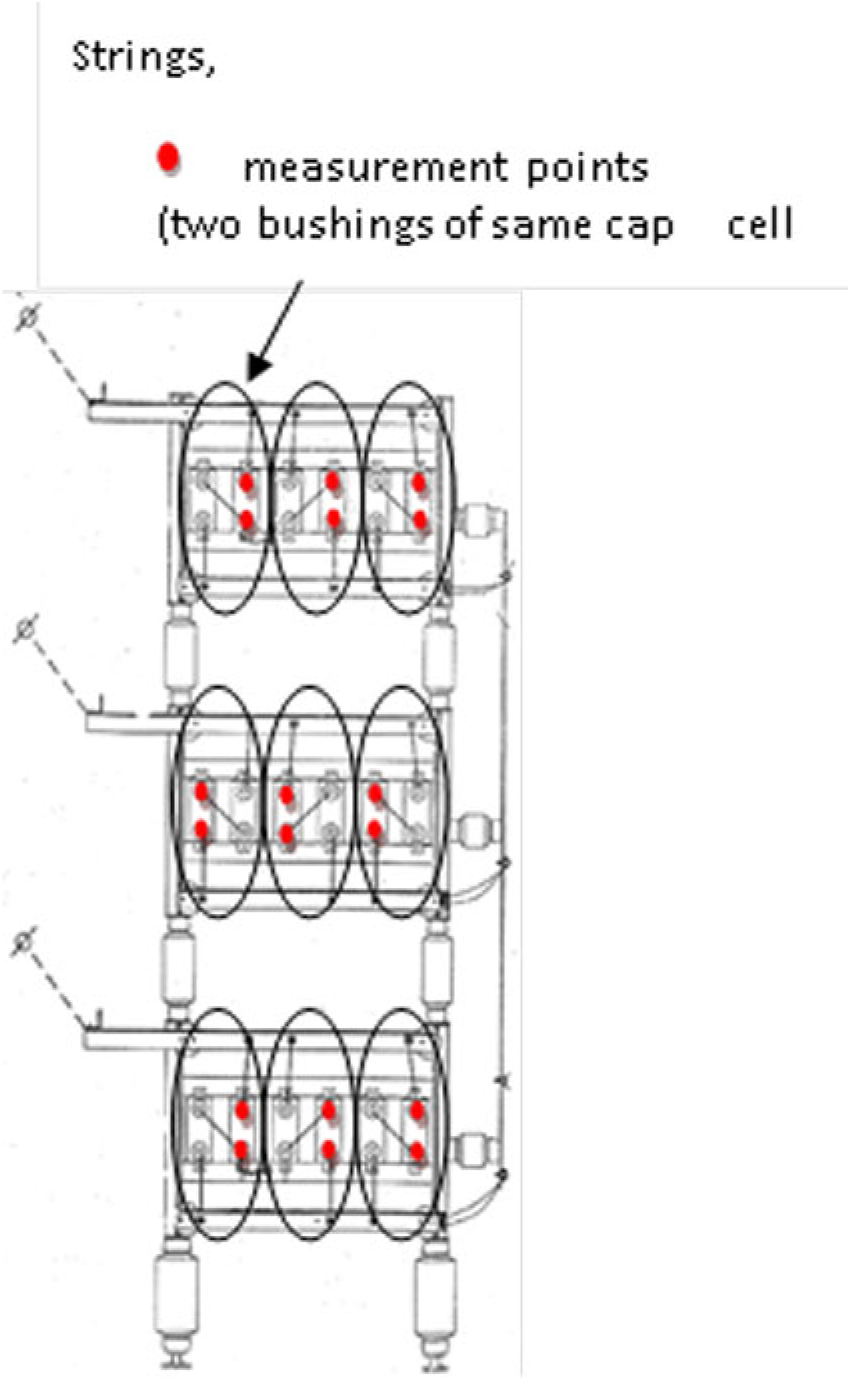


**Figure 17 — Strings & Measurement Points**
*(back)*

*[top]*