Trends and New Products in Capacitors

May 11, 2023

Powering Business Worldwide

Capacitors on the Power System

- Power Capacitors are the simplest and lowest cost source of leading vars.
- Modern All-Film Power Capacitors are virtually maintenance free.
- Most installations on the distribution system

Powering Business Worldwide

Why on the Distribution System?

- Vars are Required by Loads
  - Nearly All Loads are on Distribution System
- Vars have Two Sources:
  - Generators
  - Capacitors
- Capacitors Supply Local Support that Relieve Duty on the Distribution, Transmission, and Generation Systems.

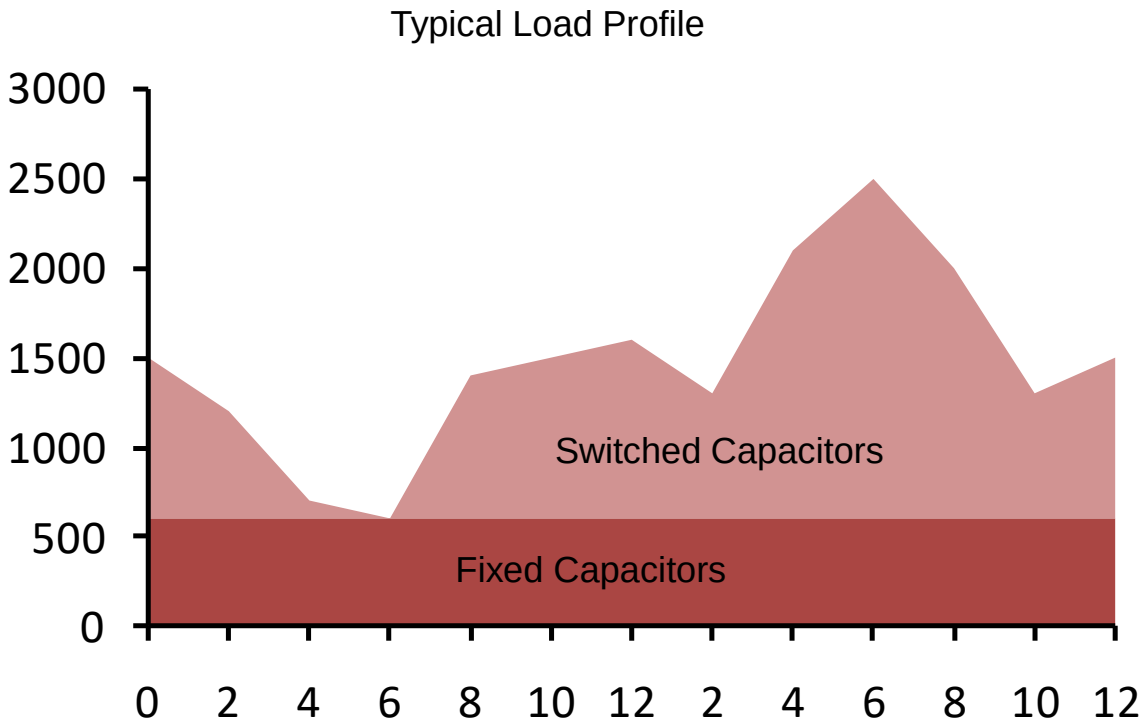
Powering Business Worldwide

Capacitor banks on the Distribution System are the most **Economical** and most **Efficient** source of Vars

Why on the Distribution System?

- Shunt capacitor should be installed on the system as near as possible to the load where the Vars are needed.
- Approximately 75% of the Var requirements for the complete system comes from the consumer's load.
- The remaining 25% is needed to supply the var requirements of the power system itself.
- A common practice in the United States is to install sufficient unswitched capacitors in pole-top installations. on distribution feeders to correct the light-load power factor to unity or slightly leading. Install fixed banks to support 2/3 of the base load and the other 1/3 as switched.

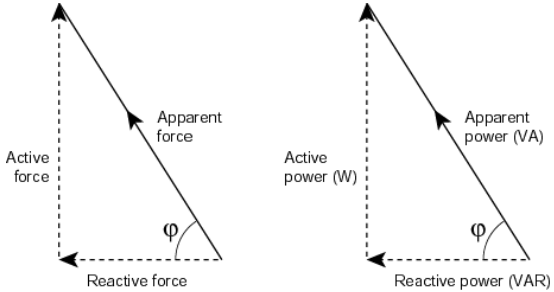
Load Profile

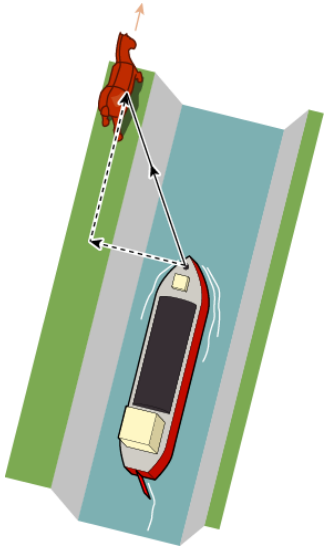


Powering Business Worldwide

Horse & Boat Example

- **The fact that the horse is not walking straight in front of the boat, does not influence the work it has to do to pull the boat. But without compensation by the rudder, the boat will be pulled towards the bank of the canal.**
- **<u>Consequences:</u>**
  - **•The fact that the rope is pulling at the <u>flank</u> of the horse and not straight behind it, limits the horse's capacity to deliver work**
  - **•The turned <u>rudder</u> leads to extra losses**



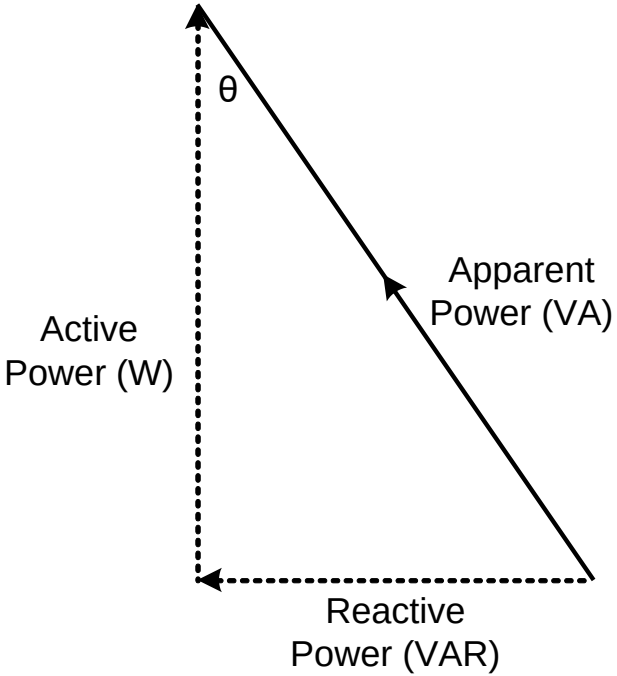


<u>"Volts-Amps-Reactive" aka: "VAR"</u>

- **Reactive Power (VAR) is needed to provide rotational magnetism in motors, but does not actually provide Active Power (Watts)**
- **Reactive Power adds to the total Apparent Power (VA) that must be supplied by generators (flank offset) and creates excess losses in power lines and transformers (rudder drag)**
- **Instead of drawing VARs from the generator through the lines and transformer, capacitors can provide VARs locally (balancing force right at front of ship)**

Powering Business Worldwide

Power Factor



Power Factor = Cosine θ

$$\text{Power Factor} = \frac{\text{Active Power}}{\text{Apparent Power}}$$

Typical Loads

LOAD	TYPICAL PF
Incandescent Lamps	1.0
Fluorescent	0.95 - 0.97
Synchronous Motors	1.0 to 0.80 Leading
Squirrel Cage Motors	0.75 - 0.90
Induction Motors	0.55 - 0.85
Arc Furnace	0.65 - 0.70
Power Converter	0.50 - 0.90

Product Line Introduction

Powering Business Worldwide

Emerald Road Facility – Greenwood, SC


Internally fused capacitor units


Unfused capacitor units


Capacitor switches


Metal-enclosed capacitor banks


Mobile capacitor banks


Open air capacitor banks


Pole-mounted capacitor banks

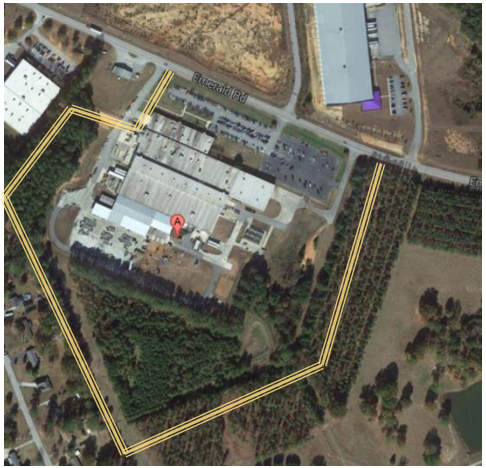

Special capacitor applications


CM52 advanced deadfront network protector


VisoVac customized solutions fault interrupter


VisoVac padmount fault interrupter


Legacy network protectors



1520 Emerald Road, Greenwood, SC 29649 USA.

- Plant Constructed in 1972
- Production started in 1973 as part of McGraw-Edison.
- Transitions to Cooper Power Systems in 1985.
- Merged with Eaton Corporation in 2012, Network Protector Integration in 2013.

- 216,000 ft^2 on 35 Acre Site.
- 250+ Employees
- ISO 9001 Compliant Facility

Primary Components

Capacitor Units

- Internally Fused
- Unfused (Standard, Heavy, Extreme Duties)

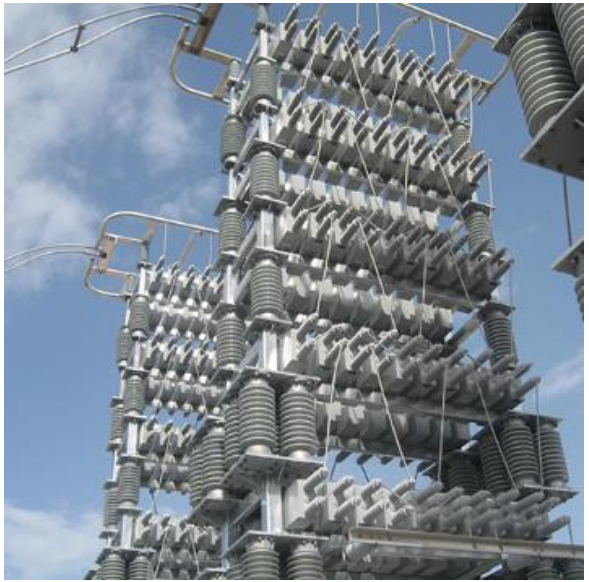
Capacitor Switches

- ECS & TriSync – Vacuum
- NR – Oil

Powering Business Worldwide

Capacitor Banks Types

Pole-Mounted Capacitor Banks



Open Air Capacitor Banks

Capacitor Banks Types (Cont.)

Metal Enclosed Capacitor Banks

Mobile Capacitor Banks

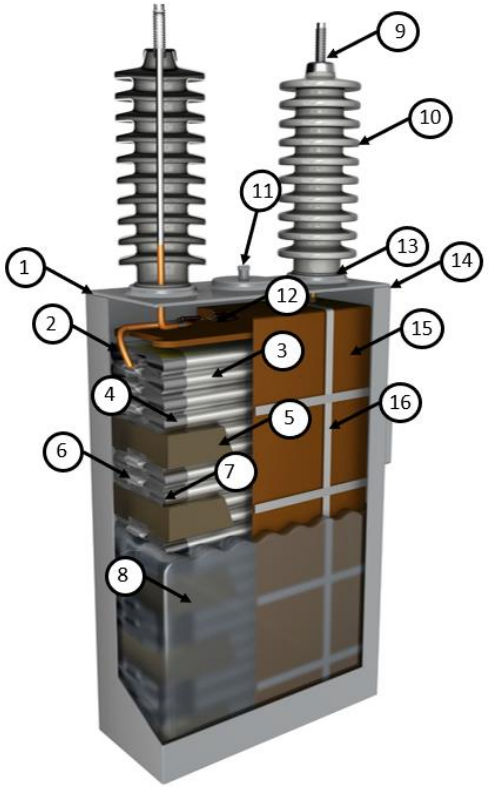
Powering Business Worldwide

Capacitor Unit Overview

Powering Business Worldwide

Capacitor Unit – Construction Overview

1. Stainless-steel tank
2. Continuous lead wire
3. Surface-altered film
4. Extended-foil Construction
5. Internal separation
6. Mechanical crimp
7. Laser cut edge
8. Dielectric fluid / impregnation

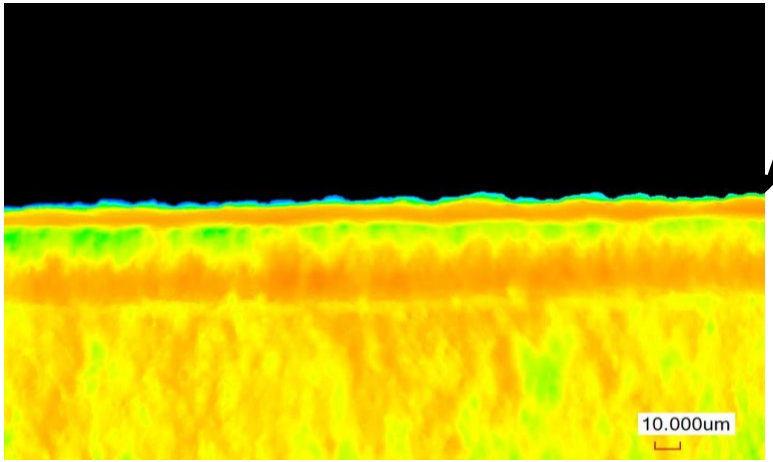


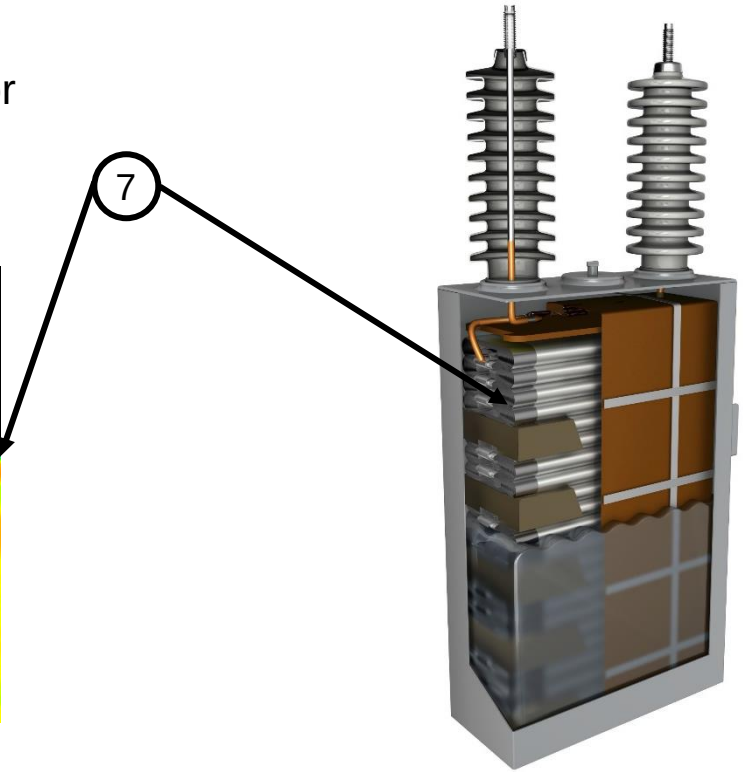
9. Terminal cap
10. Porcelain bushings
11. Impregnation fill tube
12. Discharge resistors
13. CapSeal™ bushing bond
14. MIG seam weld
15. Major insulation
16. Composite banding

Powering Business Worldwide

7) Laser Cut Foil

Grants superior DIV (Discharge Inception Voltage) characteristics under all operating conditions. Allows for reduced size, lower fluid content and lighter weight designs.

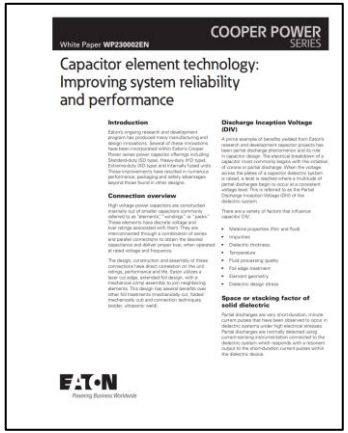




Powering Business Worldwide

Foil Edge Treatment

Significantly increased Discharge Inception Voltage (DIV) to the highest design margin in the industry.


COOPER POWER SERIES

White Paper WP230002EN

Capacitor element technology: Improving system reliability and performance

Introduction

Connection overview

Discharge Inception Voltage (DIV)

Space or stacking factor of solid dielectric

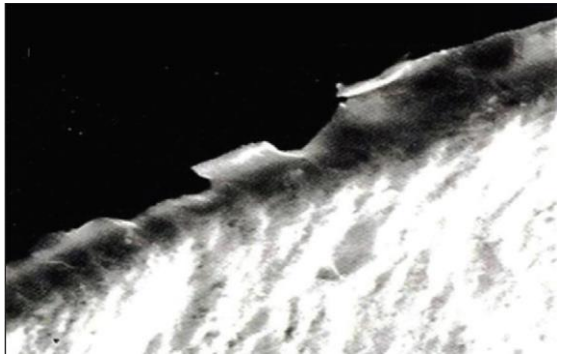
EATON

Powering Business Worldwide

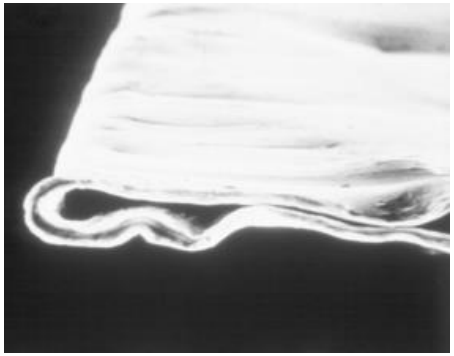
[White Paper Link]

Summarizing element technology and techniques.

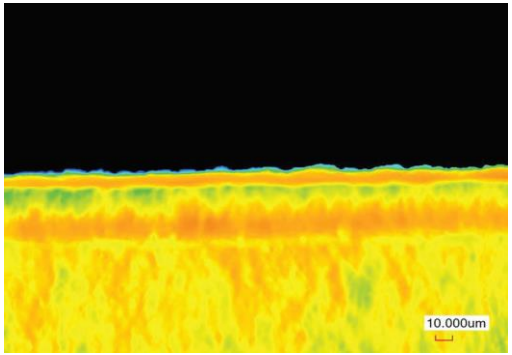
Mechanically Slit



Folded Foil



Laser Cut



EATON

Powering Business Worldwide

One vs Two Bushing Capacitor

One bushing capacitors may be used when connecting terminals to a common node.

Example:

Grounded Wye Distribution Racks

Two bushing capacitors must be used for all other applications.

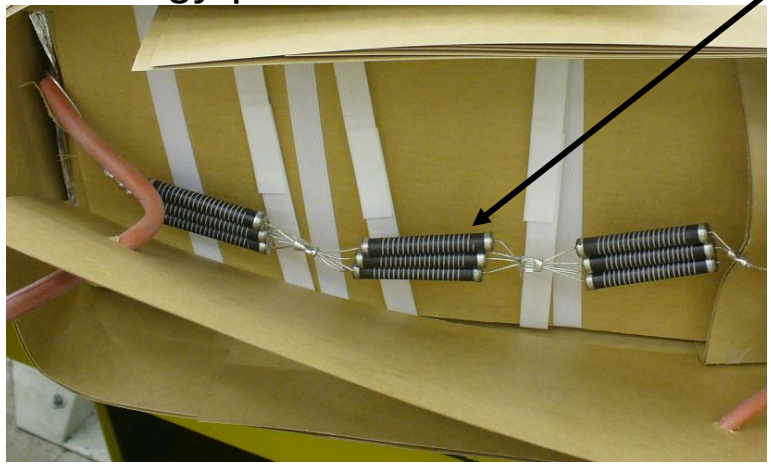
Example:

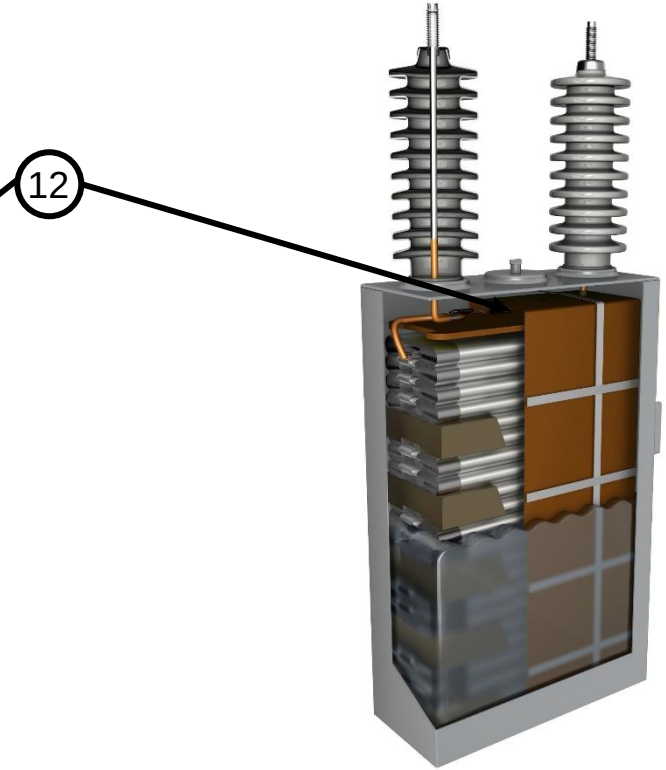
Fuseless Capacitor Banks

Powering Business Worldwide

12) Discharge Resistors

Lathe-trimmed, thick film resistive elements on high-durability ceramic cores assure long mechanical and electrical life. Used to safely dissipate stored energy prior to maintenance actions.

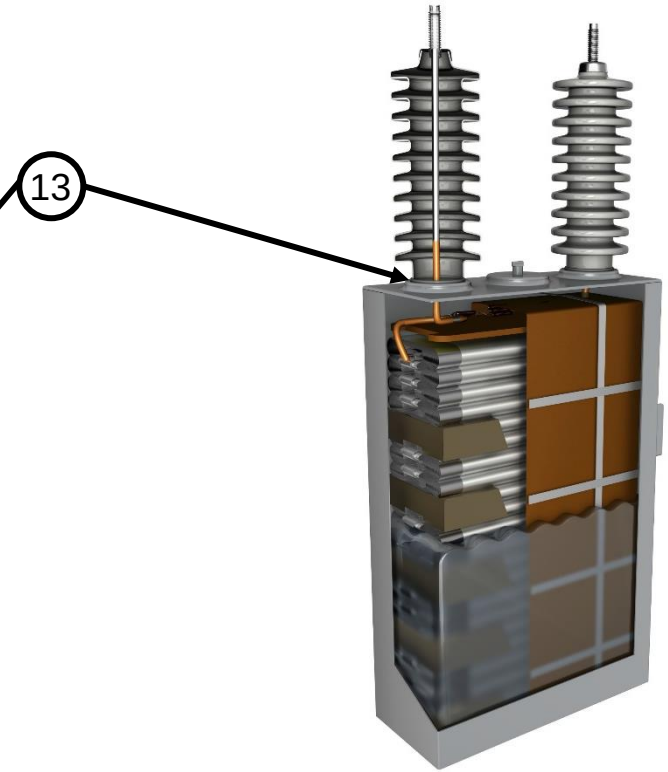




Powering Business Worldwide

13) CapSeal™ Bushing Bonding

Patented molecularly bonded bushing at terminal caps and tank cover assure leak-free hermetic seal without the need for a gasket by means of an adhesive bonding. A revolutionary technique provides improved durability and process control.



Duty Comparison

	Standard Duty (SD)	Heavy Duty (HD)	Extreme Duty - Cold (XDC)	Extreme Duty - Base (XDB)	Extreme Duty - Hot (XDH)
Maximum Fault Current (kA)	10	10	15	15	15
Upper Ambient (°C)	55	55	40	55	75
Lower Ambient (°C)	-40	-40	-50	-40	0
Continuous RMS Overvoltage	110% rated	125% rated	125% rated	125% rated	125% rated
Peak Overvoltage	120% rated	135% rated	135% rated	135% rated	135% rated
Performance testing Std 18-2012	N/A	meets @ -40°C	meets @ -50°C	meets @ -40°C	meets @ 0°C

- *Note – Wildfire Mitigation is a unit upgrade that can be applied to any duty rating. This addition will increase the maximum fault current to 20kA, all remaining ratings are unchanged.*

Powering Business Worldwide

Extreme Duty Capacitor Product Breath

Powering Business Worldwide

Extreme-duty Evolution

Extreme-duty design has been optimized for application needs. Remaining product ratings are unchanged.

Extreme-duty Cold (XDC type)

- Ambient Operating Temperature – **-50°C to +40°C**

Extreme-duty Base (XDB type)

- Ambient Operating Temperature – **-40°C to +55°C**
  - Consistent with SD and HD products

Extreme-duty Hot (XDH type)

- Ambient Operating Temperature – **0°C to +75°C**

Powering Business Worldwide

Extreme-Duty Hot (XDH) – Product Overview

Validation testing currently underway IEC 60871-2:2014 Aging Test at 75°C Ambient

Extreme-Duty Hot (XDH) Capacitor Units are designed for ambient temperature applications up to **75°C**.

Legacy capacitor unit designs are designed to IEEE 55°C. Which historically have required customers in high heat application to oversize banks and derate product, or design large & costly cooling systems.

High Ambient Units follow legacy build techniques utilized in Extreme Duty (XD) deigns, additional design optimization including:

- Propriety material changes including thickness and composition
- Packing optimization to control losses as related to unit surface area
- High current terminal caps for lower temperature rise implications
- Larger gauge or double lead wires to run cooler.

Wildfire Mitigation

Wildfire Mitigation designs offer the highest level of protection and lowest fire risk available in the industry.

Wildfire Mitigation upgrades are available with all Eaton capacitor unit duty offering.

These units are designed for application in remote areas where maintenance is challenge or areas with higher risk of fire events.

Each unit construction includes feature making their designs the most robust available, resulting in a maximum fault current of 20 kA.

Unit Features Include

- Increase in bushing creepage
- Double mechanical crimps
- Oversized terminal leads
- Increase in enclosure thickness
- CapSeal epoxy bushing bonding
- Increase in major insulation layers

Powering Business Worldwide

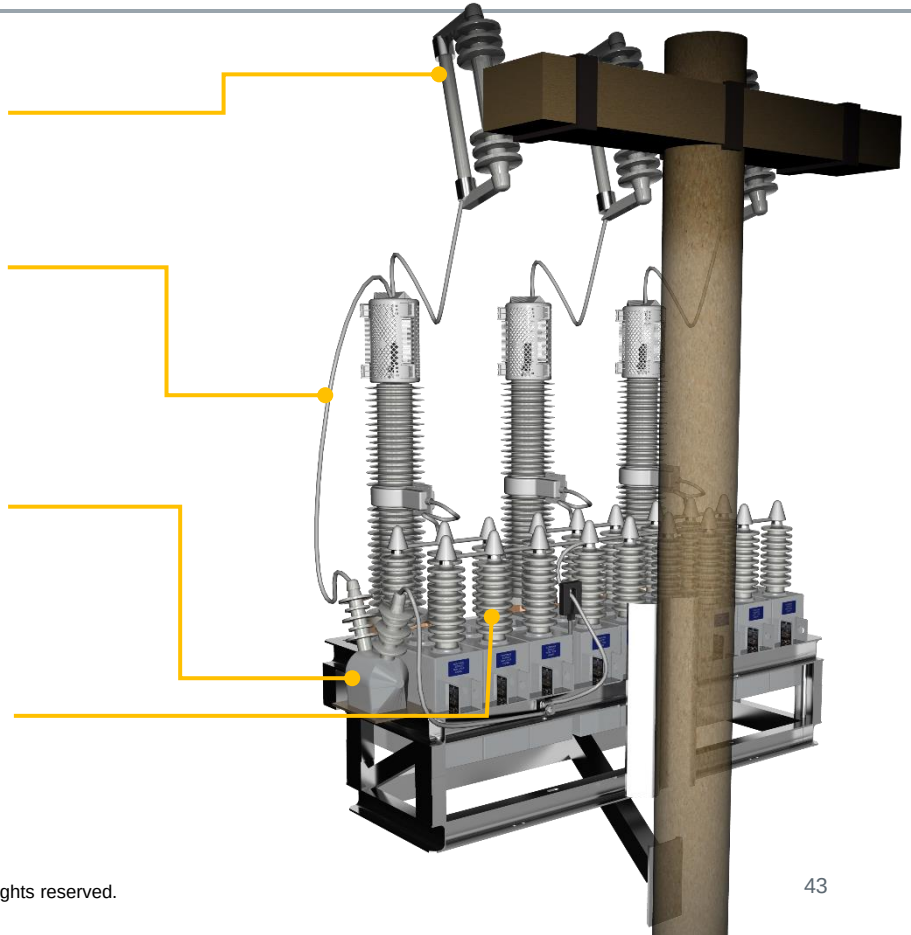
Wildfire Mitigation Pole Mounted Bank Design

Current Limiting Fuse – Protects the bank from overloads and secondary fault events. Features current limiting line protection with no gas, sparks or debris emitted during fuse operation.

Wire Insulation – All wiring features increased wire gauge size to run cooler and protective sleeving/insulation to prevent the risk of a shorting event.

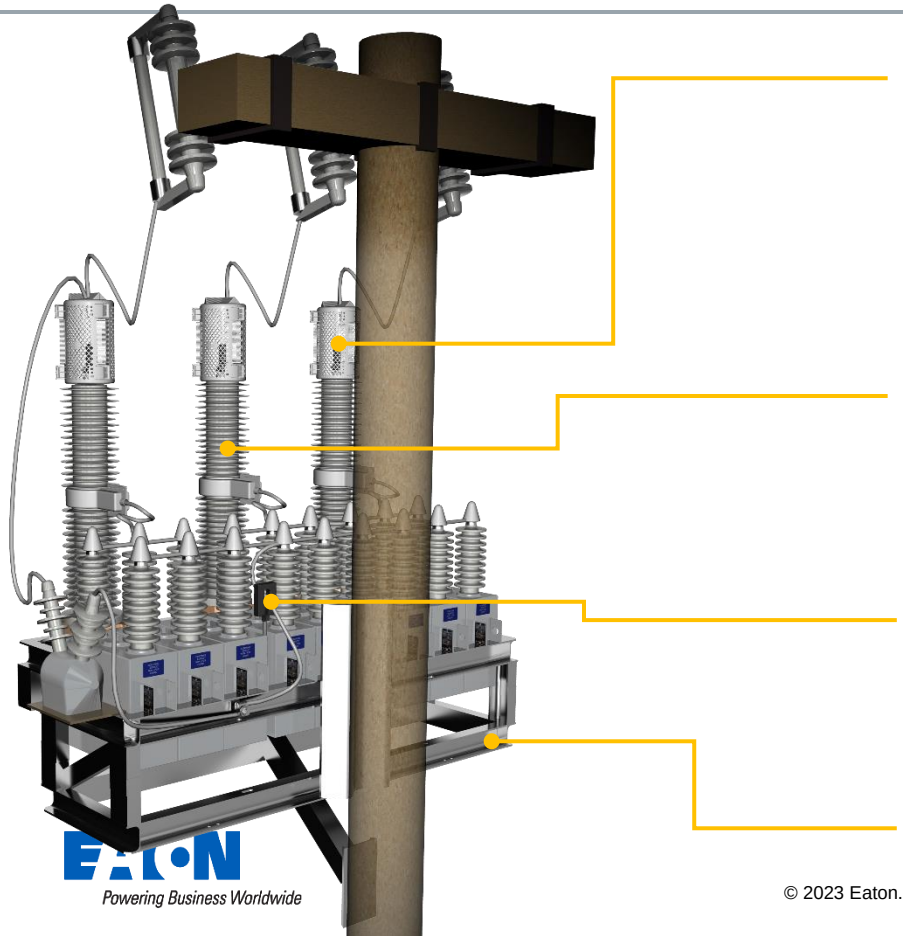
Dry Type Transformer – Utilizes an oil free design with low maintenance and increased application life. Prevent risk of leaking oil and fluid ignition failures.

Wildfire Mitigation Capacitor Units – Available in QTY 3, 6, 9 and 12 unit banks. Each unit features the performance and design benefits described previously.



Powering Business Worldwide

Wildfire Mitigation – Unit Construction



Wildlife Protection – All wire terminations points include guards and covers to reduce potential animal caused failure modes – nesting, ingesting materials, direct contact shorts, etc. Design are compliant with IEEE Std. 1656.

Vacuum Capacitor Switch – 3 phase TriSync switch (shown) or 1 phase Edison Capacitor Switch (ECS). Each phase utilizes a single vacuum bottle with permanent magnet solenoid mechanism. No maintenance required, and no risk of oil leaking.

Neutral Sensor – Used to measure imbalance between bank phases. This allows for repeatable monitoring of capacitor units' heath and proactive maintenance options.

Light Weight Frame – Constructed of high strength 6061-T6 aluminum alloy. Frame is free standing, with integrated lifting and mounting provisions for rapid installation.

Powering Business Worldwide

Capacitor Switch Overview

Powering Business Worldwide

Capacitor Switches

Configurations:

- Oil - NR Switch 1ø
- Vacuum – Edison Capacitor Switch (ECS) 1ø
- Vacuum – TriSync™ Capacitor Switch (ECS) 3ø
- 3ø Zero-Voltage Closing (ZVC) control

Applications:

- Open Air Substation Capacitor Banks
- Pole Mounted Racks
- Metal-Enclosed Capacitor Banks
- Mobile Capacitor Banks
- Distribution Capacitor Switching – IVVC/CVR
- Other 200 A & 400 A Load Switching

NR Oil Capacitor Switch – Single Phase

Voltage Rating:

15 kV

25 kV

BIL Ratings:

95 kV

125 kV

Continuous Current Rating:

200 A (15 kV)

60 A (25 kV)

Features:

- Motor Operated
- 120/240Vac Control Voltage
- Visual Position Indicator
- 5 & 6 Pin Receptacle Options

Powering Business Worldwide

Edison Capacitor Switch (ECS) – Single Phase

Voltage Rating:

15 kV 25 kV

38 kV

BIL Ratings:

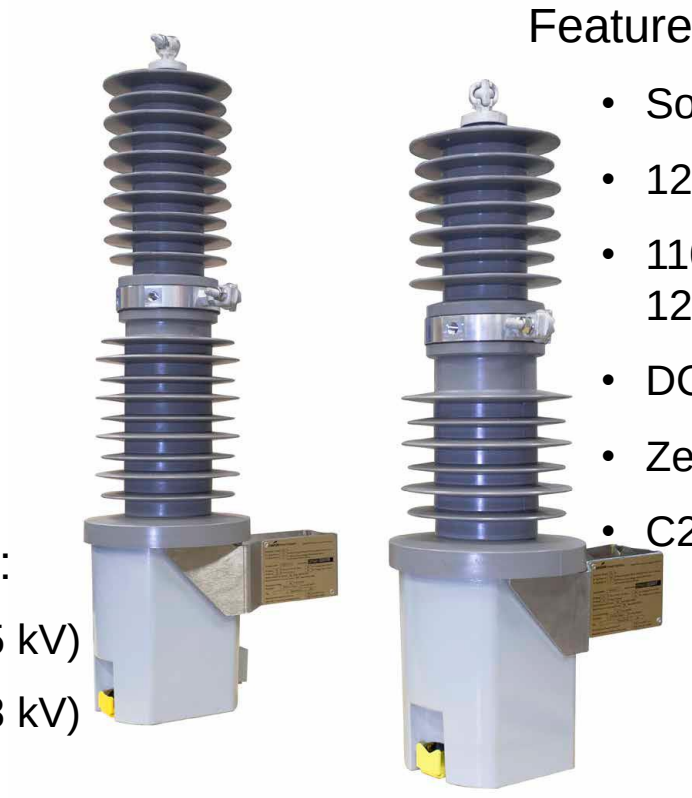
95 kV 125 kV

150 kV 200 kV

Continuous Current Rating:

200 A (15.6 kV & 25 kV)

400 A (15.6 kV & 38 kV)



Features:

- Solenoid Operated
- 120/240Vac Control Voltage
- 110Vdc, 115Vdc, 120Vdc, 125Vdc, 135Vdc
- DC Pulse
- Zero Voltage Closing Capable
- C2 Restrike Class

Powering Business Worldwide

TriSync™ Capacitor Switch – Three Phase

Voltage Rating:

15 kV 25 kV

38 kV

BIL Ratings:

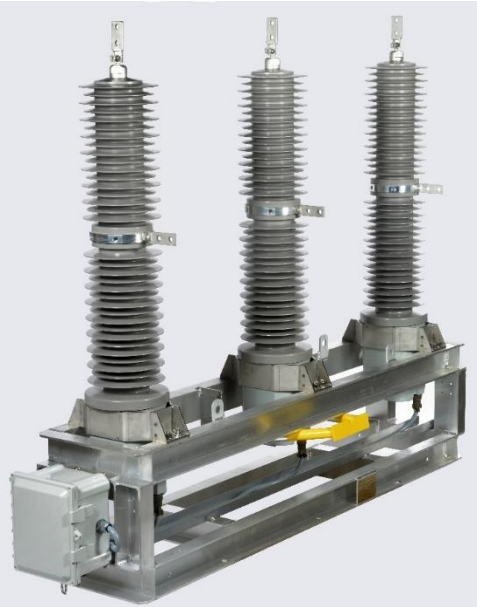
110 kV 150 kV

200 kV

Continuous Current Rating:

200 A (15.6 kV & 25 kV)

400 A (15.6 kV & 38 kV)

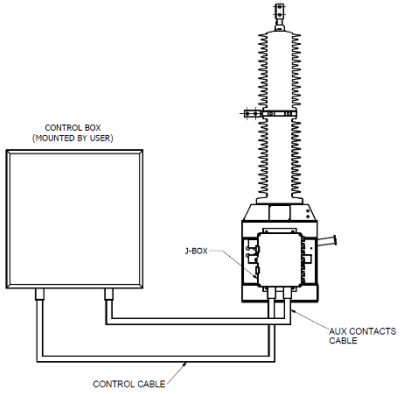


Features:

- Solenoid Operated
- 120/240Vac Control Voltage
- 110Vdc, 115Vdc, 120Vdc, 125Vdc, 135Vdc
- DC Pulse
- Zero Voltage Closing Capable
- C2 Restrike Class
- 50,000 Operations
- Mechanical Gang Open
- External Control Box for Control and Aux Connections

Powering Business Worldwide

TriSync™ Control Box



TriSync Control Box houses the switch control modules and is available with a variety of controller options including Cooper Power Systems CBC-8000, jaw mount provision for off the shelf capacitor control, and Valquest Z-Cap control for use in ZVC applications.

- Box allows customer to mount in convenient accessible locations for easy operation and maintenance.
- Cables are available in variety of lengths with male and female connectors for quick installation.
- 12 pin receptacle is used for power and functional operation
- 10 pin receptacle for use in switching auxiliary equipment.

Capacitor Switch Recovery and Restrike

Pole Discrepancy	Recovery Voltage (p.u.)
≤ 90 electrical degrees (Simultaneous operation)	2.5
Both of the other 2 poles delay opening	3.0
One of the other 2 pole delays opening	4.1

Recovery Voltage Across First Pole to Clear

Class	Probability of Restrike	Max Number of Restrikes in 1200 Operations	Classification Description
C2	0.2%	2	“Very low”
C1	2.0%	24	“Low”
C0	>2.0%	≥25	“Moderate” to “high”

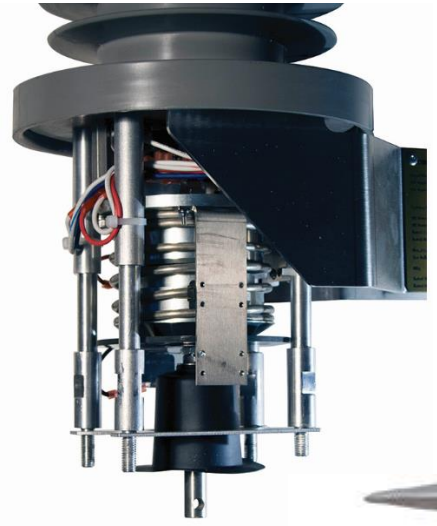
Restrike Classification of Capacitor Switches
Per IEEE Std C37.66™

Powering Business Worldwide

Vacuum Switch - Feature Summary

Direct Drive, Permanent Magnet Solenoid Operated

- Simple, linear drive design
- No cams, linkages, or struts to fail or break
- No electronic circuit boards or relays
- Low control power operating requirements across full temperature range
- Zero Voltage Closing for ambient temperatures ranging from -50C to +60C



Superior Hydrophobic Properties with Cycloaliphatic Epoxy Bushings

- Less surface wetting
- Alternating shed design improves flashover performance
- High creep versus porcelain for improved performance in contaminated environments
- Designs per IEC 60815 for “Very High Pollution Severity” class are available

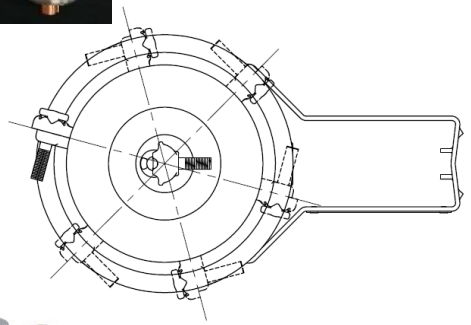
Powering Business Worldwide

Vacuum Switch - Feature Summary (Cont.)

Vacuum Interrupter
- Field-proven, high quality Eaton® vacuum interrupter
- Specifically designed for capacitor switching
- Fully encapsulated in solid dielectric material for effective heat transfer and maintenance free operation

FlexConnect™ Patented Terminal Ring Design
- Allows for 360 degree termination of load (in 60 degree increments)
- Eliminates need to break seal in order to rotate switch body to accommodate installation requirements
- Allows for multiple terminals by simply adding another terminal clamp

Non-metal Tank Design
- Fiberglass reinforced polyester
- Prevents corrosion
- Integrated rain shield and hot stick guide for the trip handle



Powering Business Worldwide

Capacitor Switch ANSI/IEEE C37.66 Ratings

ANSI/IEEE C37.66

Rated Current 200 A to 600 A

Operating Duty Test (1200 operations)

Test voltage:

- Simultaneous Opening: 0.87 x V_{LLMax}
- Non-simultaneous Opening: 1.2 x V_{LLMax}

Rated Voltage (kV)	BIL (kV) External / Open Gap
15.0	95/95
15.5	95/95
15.5	110/95
15.5	110/110
27.0	125/95
27.0	125/125
27.0	150/125
38.0	150/125
38.0	150/150
38.0	200/150
38.0	200/200