Capacitor bank protection design considerations

George Gao, Senior Application Engineer–Capacitors, Eaton

Michael Gresko, Capacitor Specialist, Eaton

Duc Nguyen, Application Engineer–Capacitors, Eaton

Gordon Pettersen, Product Manager–Capacitors, Eaton

Capacitor banks provide an economical and reliable method to reduce losses, improve system voltage and overall power quality. This paper discusses design considerations and system implications for Eaton's Cooper Power™ series externally fused, internally fused or fuseless capacitor banks.

Capacitor unit construction

First, let's take a look at capacitor unit construction, which is essential to gain a better understanding of protection schemes. Eaton capacitor unit designs can be divided into two classifications:

- Unfused (including externally fused and fuseless)
- Internally fused

Both unfused and internally fused capacitor units are constructed from smaller capacitors, commonly referred to as elements or packs. These elements each have an individual voltage and kilovolt amps reactive (kvar) rating. These elements are connected in series and parallel combinations to achieve the required voltage and kvar rating of the unit.

The basic capacitance calculation for each element in the capacitor is:

C = Capacitance

K = Dielectric constant

t = Distance between plates (in.)

A = Overlapping plate area (in.^{2})

Each element can be designed to achieve the desired capacitance value by adjusting the distance between the plates (t) or area of the plates (A). This is optimized through a winding mechanism that wraps layers of polypropylene film (dielectric) and aluminum foil (plates) together within an automated machine. This winding process compresses the high-strength dielectric polypropylene film to reduce element thickness and minimize the distance between conductive plates. These elements are formed with a variety of customized parameters—including material length, compression, material layers, material width, material thickness, number of turns, and more—to achieve the required ratings.

When interconnected, multiple elements combine to function as a single capacitor unit. This combination of elements is typically referred to as a module and is shown in Figure 1.

Figure 1. Internal module and element connections are pictured.

Powering Business Worldwide

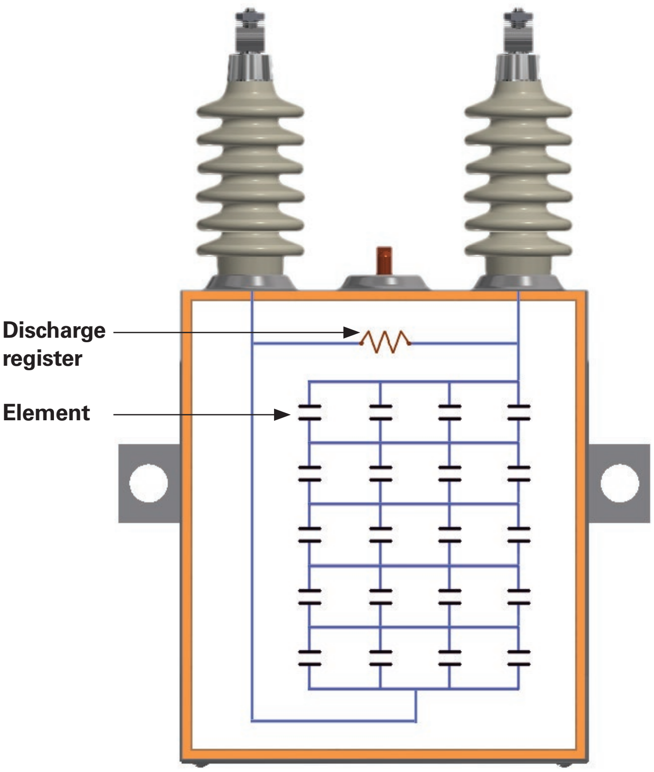

Figure 2. Internal arrangement of elements in an unfused capacitor unit.

Table 1. Comparison of capacitor designs

	Standard duty	Heavy duty	Extreme duty
Continuous RMS overvoltage	110% of rated voltage	125% of rated voltage	125% of rated voltage
Peak overvoltage	120% of rated RMS voltage	135% of rated RMS voltage	135% of rated RMS voltage
Maximum fault current handling	10,000 A	10,000 A	15,000 A
Ambient operating temperature	-40° C to +55° C	-40° C to +55° C	-50° C to +55° C
Performance test per IEEE Std 18-2012	N/A	Meet @ -40° C	Meet @ -50° C
BIL ratings	95, 125, 150, 200 kV BIL	95, 125, 150, 200 kV BIL	95, 125, 150, 200 kV BIL
Application	Previous standard - utility transmission and distribution application	Current standard for improved electric power system reliability	Industrial power systems, harmonic filter applications
kvar ratings	50 - 800 kvar	50 – 800 kvar	50 - 600 kvar
Voltage ratings	2400 – 22800 V	2400 – 22800 V	2400 – 22800 V
Routine tests	Standard	Standard	Special

Unfused unit construction

Today's capacitors are far more advanced than historical models. Historically, kraft paper was used as a dielectric; so, a failed element required prompt removal from service to minimize the likelihood of capacitor unit rupture. The modern all-film capacitor exhibits what is known as a fail-safe failure mode. When the polypropylene dielectric fails, the energy in the resulting small arc punctures many layers of the thin film and foil. The arc causes the film layers to recede allowing many layers of the aluminum foil electrodes to touch and weld together, forming a stable joint, which exhibits low resistance. This stable weld joint can carry the full capacitor unit rated current indefinitely and without gassing.

The discharge resistor (shown in the upper portion of Figure 2) dissipates stored energy after the unit is de-energized and is designed to enhance safety during maintenance activities. The resistor also discharges trapped DC voltage on the capacitor bank before re-energization can occur. Personnel should follow proper safety measures, and ensure the bank is properly discharged before re-energization.

Eaton provides industry-leading capacitor unit designs used across applications, including standard duty (SD), heavy duty (HD) or extreme type (XD); Table 1 provides a comparison of capacitor unit designs.

Standard-duty capacitors are designed to the IEEE 18-2002 standard and are typically used in utility transmission and distribution applications, whereas heavy-duty capacitors are designed to the IEEE 18-2012 standard for applications where higher reliability is needed. Heavy-duty capacitors are more resistant to the impact of higher transients, harmonics and voltage excursions than standard-duty capacitors. Extreme-duty capacitors are designed for the most extreme harmonic environments and should be considered for application on systems with unknown contingencies (including industrial applications).

Duty type selection is one of many considerations. Although it is possible to achieve similar overvoltage capability by selecting a higher rated SD-type unit (e.g. using an 8320 V SD type verse a 7200 V HD or XD type), some features may be limited: cold temperature (-50**°** C) performance, 15 kA fault current handling, specialized routine testing.

Selecting the unit type affects capacitor unit internal design (e.g. # of series groups). Since some unbalance protection schemes (i.e. fuseless bank designs) consider these factors for things like unbalance detection, it is not always possible or recommended to mix unit types.

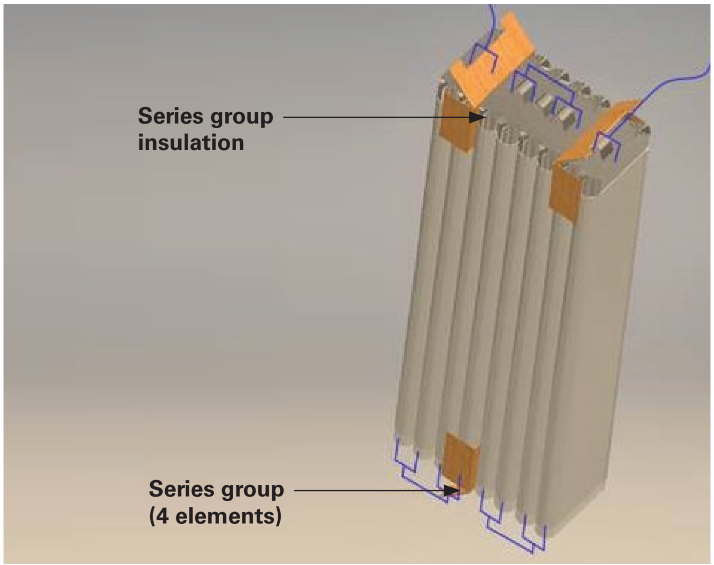

Figure 3. Illustration of the internal module used in unfused unit construction.

With unfused unit construction (illustrated in Figure 3), elements are combined in parallel to form a series group, and the series groups are connected (in series) to complete internal connections.

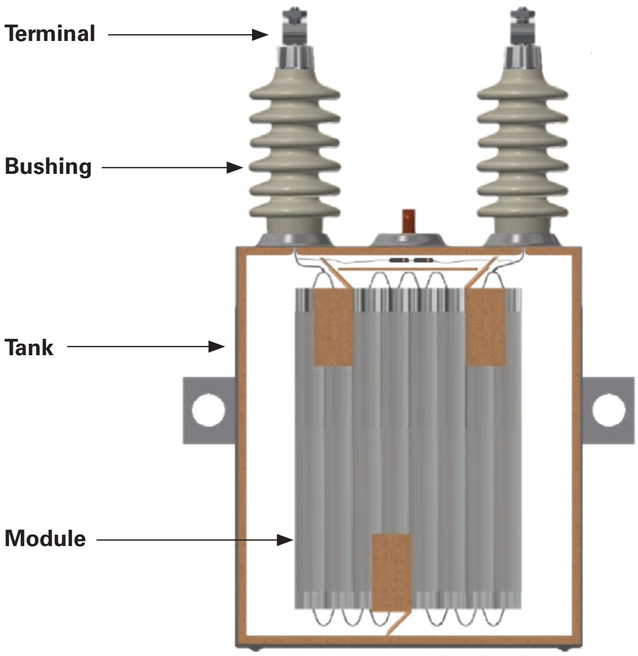

Figure 4. Unit assembly illustration.

Figure 4 illustrates unit construction after the module is inserted and the tank cover/bushing assembly is completed. To complete the assembly, the module is surrounded with major insulation–to prevent shorting to enclosure—and all air is removed from the assembly and replaced with a dielectric fluid.

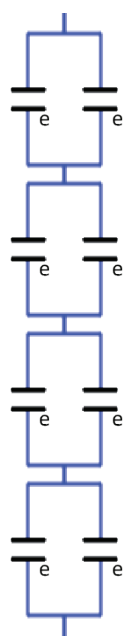

Figure 5. Simplified electrical diagram of an unfused unit.

For example illustrated in Figure 5, there are two elements per series group and a total of four series sections. The number of series groups vary with the unit voltage rating, and the number of parallel elements varies with the unit kvar rating.

Internally fused unit construction

Internally fused capacitors protect each element with its own fuse. With this design, individual elements that fail are isolated, and there is no need to remove the entire unit from service. This design was created at a time when tank rupture failures were common; today, this historic failure mode is virtually eliminated through material and construction advances.

Internally fused units use similar element construction, paper insulation and connection techniques, while incorporating dedicated fuses to protect individual elements. In this design, a fuse is simply a piece of wire specifically selected based on the internal design of the unit to melt under fault conditions. Because each element is protected with a fuse inside the capacitor unit, the I2R loss is much higher (e.g. 50% higher) compared to unfused unit construction.

Modern-day capacitors exhibit relatively low losses overall, and with proper design, the additional losses are not a major concern. That said, the additional heat generated by internal fuses may prevent use in certain situations and will shorten the capacitor unit life (compared to unfused units).

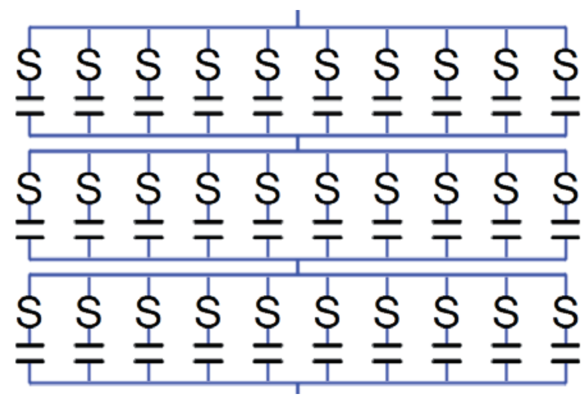

Figure 6. Simplified electrical diagram of internally fused unit.

Figure 6 shows 10 elements per series group with a total of three series groups, and each element protected with its own fuse.

Bank protection

Capacitor banks are composed of many individual capacitor units electrically connected to function as a complete system. Units are connected in series to meet required operating voltage, and in parallel to achieve the required kvar (graphically represented in Figure 7). Capacitor banks require a means of unbalance protection to avoid overvoltage conditions, which would lead to cascading failures and possible tank ruptures.

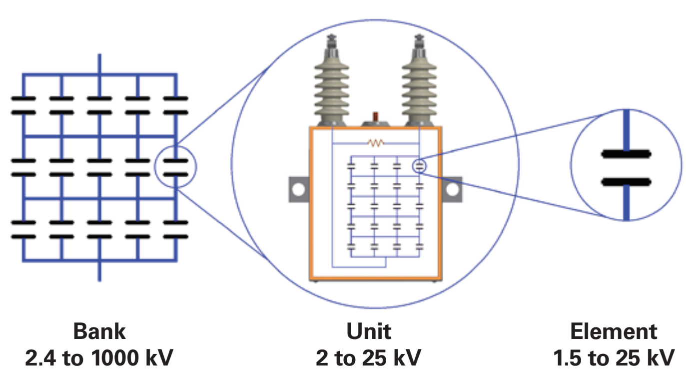

Figure 7. Bank connection at bank, unit and element levels.

Bank protection strategy consists of:

- Fusing selection (external or internal)
- Proper bank design and arrangement (proper number of units in series and parallel, or isolation of fuseless strings)
- Unbalance detection

The primary protection method uses fusing. When properly applied, fuses will protect the bank from cascade failure by removing failed elements or units from service. Secondary protection is provided through unbalance detection, which will alarm and remove the bank from service when the trip set point is reached. Each protection strategy delivers specific benefits.

Capacitor bank protection strategies

Externally fused protection schemes

Externally fused bank technology is the oldest protection strategy for capacitor banks. As the name implies, each unfused (fuseless) capacitor unit is protected with a fuse external to the capacitor (typical construction is illustrated in Figure 8). Externally fused banks use current-limiting or expulsion-type fuses.

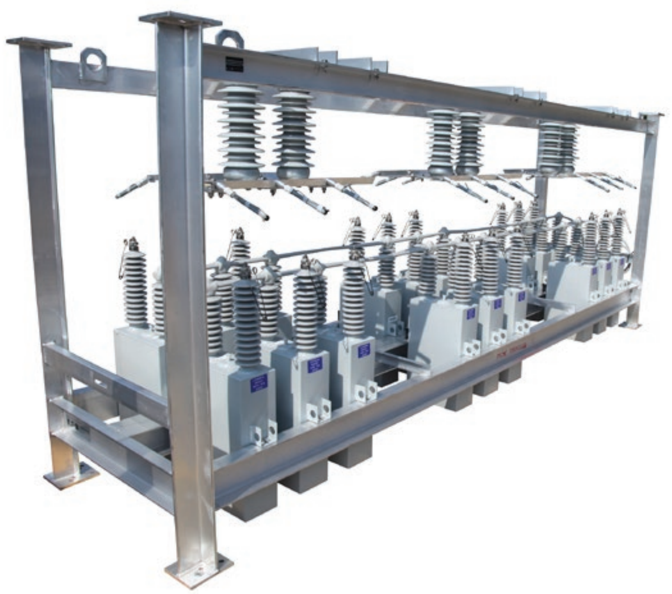

Figure 8. Vertically mounted externally fused bank with expulsion fuses.

Like the internal unit construction, the bank interconnects individual capacitor units in series and parallel combinations to achieve the desired voltage and kvar ratings. When a capacitor unit fails due to a short circuit, the resulting current is multiples of its rated current, and is likely to eventually exceed the unit's thermal and mechanical limits. A fuse is essential to isolate the failed unit in time and avoid a tank rupture or other catastrophic failure.

Bank stability, parallel stored energy, and bank cost are critical considerations to determine whether an externally fused, internally fused or fuseless bank is the best option.

Bank stability is achieved when a single fuse operation does not result a single unit exceeding 110% of its rated value. If the 110% threshold is exceeded, the bank is considered at risk and should be removed from service. In other words, a bank should generally be designed to accommodate at least one fuse operation and still stay operating within the continuous rating, and below the 110% overvoltage limit. After the first fuse operation, it is desirable for an unbalance protection scheme to alarm operators of the condition. It is standard practice to provide an unbalance alarm after the first fuse operation and remove the bank from service after subsequent fuse operations, or when the voltage on any remaining capacitor unit exceeds 110% of its rated value.

The following formulas can be used to determine the allowable number of units that can be removed without increasing the voltage more than 110% across the remaining units in that series group (or section).

Single grounded wye: $\boldsymbol{F = \frac{NS}{S-1}\left(1 - \frac{V_T}{SV}\frac{100}{\%V_R}\right)}$

Single ungrounded wye: $\boldsymbol{F = \frac{3NS}{3S-2}\left(1 - \frac{V_T}{SV}\frac{100}{\%V_R}\right)}$

Split ungrounded wye: $\boldsymbol{F = \frac{6NS}{6S-5}\left(1 - \frac{V_T}{SV}\frac{100}{\%V_R}\right)}$

The following formulas can be used to determine the minimum number of units which must be placed in parallel to maintain a specific overvoltage with a known number of units out.

Single grounded wye: $\boldsymbol{N = \frac{V(\%V_R)(S-1)F}{SV(\%V_R)-100V_T}}$

Single ungrounded wye: $\boldsymbol{N = \frac{V(\%V_R)(3S-2)F}{3(SV(\%V_R)-100V_T)}}$

Split ungrounded wye: $\boldsymbol{N = \frac{V(\%V_R)(6S-5)F}{6(SV(\%V_R)-100V_T)}}$

Where:

F = Number of units removed from a series section

V_R = Voltage on remaining units in that group

V_T = Applied line-to-neutral voltage

V = Rated voltage of capacitor units

S = Number of series sections per phase

N = Number of parallel units per series section

Table 2. Minimum number of units in parallel per series section per phase

# series section	Grounded wye	Ungrounded wye	Split ungrounded wye (units per wye section)
1	–	4	2
2	6	8	7
3	8	9	8
4	9	10	9
5	9	10	10
6	10	10	10
7	10	10	10
8	10	11	10
9	10	11	10
10	10	11	11
11	10	11	11
12	11	11	11

Another important consideration is the total energy stored in the parallel connected capacitors for each series section. This in determines the maximum kvar allowable per series section and the proper unit kvar rating when designing the bank.

When a capacitor short circuits and before the fuse operates, the energy stored (total kvar) in the parallel connected units will discharge through the failed capacitor and its fuse. Consequently, it is imperative to ensure that such an event will not lead to unit tank rupture or fuse failure, by limiting this total stored energy and the resulting outrush currents from the parallel units. By considering the energy capability (joule rating) of the capacitor unit and its fuse, the maximum allowable kvar per series section can be calculated.

Each combination of external fusing and capacitor unit design has a defined maximum energy rating capability. This is the maximum amount of energy that the equipment can withstand without unit rupture or fuse operation failure. Considering the equipment energy ratings, and the application and operating conditions, the following equations can be used to determine the maximum parallel kvar allowed per series section or group.

$$E = \frac{CV_{peak}^2}{2}$$

Where**:**

E = Energy stored in the capacitor in joules

C = Capacitance in farads

V_{peak} = Peak voltage in volts

Where:

Q = Reactive power output in vars

ω = 2πf where f = 60 or 50 Hz

C = Capacitance in farads

V_{rated} = Rated rms voltage in volts

The all-film dielectric design capacitor unit has a withstand energy limit up to 30 kilojoules (kJ), which may allow up to 9300 kvar in parallel per series section when used with expulsion fuses. When the parallel energy exceeds the limitation of the expulsion fuse or fuse/capacitor combination, several solutions are possible:

- Redesign the bank to reduce the parallel kvar energy
- Use current-limiting fuses, which have higher energy capability of approximately 50 kJ or more
- Reconfigure as a fuseless or internally fused capacitor bank

Capacitor banks rated 38 kV-LL and below can often be designed with a single series section and with all the capacitor units in one common block frame. Capacitor banks at higher voltages (e.g. 46 kV-LL or above) and MVAr ratings (20 MVAr or above) usually need to be arranged with two or more series sections.

When multiple series sections are required, each phase must be located in its own individual frame(s).

If only one or two frames are required for each phase, it is possible to stack the frames in a phase-over-phase arrangement (e.g. each phase stacked on top of each other). This phase-over-phase arrangement is also called a 3S arrangement.

For the higher voltage and MVAr bank designs, requiring more than six frames, the frames are usually arranged side-by-side (referred to as 1S arrangement) with each phase in its own stack, or multiple stacks.

The following guidelines typically provide the most compact and cost-effective designs for externally fused banks:

- Minimize the structure and height by minimizing the number of series sections in the bank
- Maximize the kvar rating of each capacitor unit by minimizing the number of units in parallel
- Avoid current-limiting fuses

Externally fused banks are field proven (the North American standard) and provide important benefits:

- Visual indication of fuses (reduced maintenance time)
- Lower unit losses and temperature rise (compared to internally fused units)
- Reduced cost (compared most internally fused designs)
- Simpler unbalance relaying

For example, an externally fused, 24 MVAr @ 34.5 kV-LL, ungrounded wye capacitor bank impacts parallel energy, bank stability and design as follows:

- Single wye option: Considering that 8000 kvar per phase exceeds the parallel energy capability for a single series section, select a two series section design. This results in 4000 kvar parallel per series section. Referencing Table 2, a minimum of eight parallel-connected units are needed per series section for bank stability. Therefore, each phase consists of 16 units (two series and eight parallel), and 48 total units for a three-phase bank. Each unit should be rated 9.96 kV for two series sections per phase (19.92 kV/2). Dividing 24 MVAr by 48 units, results in a unit rated kvar of 500 kvar, which can be manufactured and fused, and the bank design is complete.
- Split Wye option: Considering that 8000 kvar per phase exceeds the parallel energy capability for a single series section, select a two series section design. With the split wye design, this results in four series sections, with 2000 kvar parallel per series section. Referencing Table 2, a minimum of seven parallel-connected units are needed per series section for bank stability. Therefore, each phase consists of 28 units (two series and 7+7 parallel), and 84 total units for a three-phase bank. Each unit should be rated 9.96 kV for two series sections per phase (19.92 kV/2). Dividing 24 MVAr by 84 units, results in a unit rated kvar of 286 kvar, which can be manufactured and fused, and the design is complete.

Table 3 can be used to determine the number of series sections and voltage rating of the capacitor units based on the bank system voltage (not valid for internally fused designs).

Table 3. System voltage series section summary

System voltage	Series sections				
	1	2	3	4	5
4160	2,400	–	–	–	–
4800	2,770	–	–	–	–
7200	4,800	–	–	–	–
12,470	7,200	–	–	–	–
13,280	7,620	–	–	–	–
13,800	7,960	–	–	–	–
23,000	13,280	–	–	–	–
24,900	13,800	–	–	–	–
34,500	19,920	9,960	–	–	–
46,000	–	13,280	6,640	–	–
69,000	–	19,920	13,280	9,960	--
115,000	–	–	22,100	–	13,280

Internally fused protection strategy

The criteria for fusing externally or internally for capacitor banks are similar. In the both cases, fuse operations cause an increase in the voltage applied to the remaining elements or units in parallel with the failed element (or unit). For external fusing, it is possible to operate and remove shorted units from service fast enough to prevent tank rupture and damage to the remaining units. For internal fusing, it is also possible to operate and remove failed elements from service fast enough to prevent damage to the remaining elements and to coordinate with the unbalance detection scheme. Figure 6 depicts the internal elements and fuse arrangement for internally fused unit. The design of internally fused capacitor banks is simple and typically employs larger kvar capacitor units with fewer capacitors in parallel and more in series compared with an externally fused capacitor bank.

Most of the complexity of an internally fused capacitor bank is in the construction of the capacitor unit, so there are fewer considerations in the design of an internally fused bank, when compared to an externally fused bank. Bank stability is like that of externally fused bank, except the overvoltage condition needs to be considered for both the element and unit levels when a fuse operates. It is standard practice to provide an unbalance alarm when an internal fuse operation results in an overvoltage on the remaining elements in the series section of 135% of rated voltage. The bank will trip when the overvoltage on the remaining elements in the series section exceeds 150% of rated voltage, or the voltage across any capacitor unit exceeds 110% of rated unit voltage. Since internal fuses are hidden from view and most units contain at least 20 but can have as many as 100 elements, detecting one or two failed elements in a large internally fused capacitor bank requires very sensitive unbalance relaying equipment.

Parallel energy has typically been viewed as a non-issue for internally fused capacitor banks because the current limiting fuses are commonly used. However, fuse sizing/rating must still be considered when designing the unit to ensure fusing selection is appropriate to handle discharge energy into the shorted element through its fuse. The impedance in the series section is small, therefore the discharge current is high and the fuse operates quickly. Because the impedance of the internal series section is so small compared to the impedance of the discharge path of the entire series section of capacitors, the energy from the other capacitors in parallel does not come into play in the operation of the internal fuse.

Unlike an unfused unit, an internally fused unit tends to fail in open circuit manner. When an element fails, the internal fuse operates (opens) to isolate the failed element from the circuit. There are, however, some atypical modes of failure that can result in a terminal-to-terminal short circuit in an internally fused capacitor unit, including:

- Flashover of a bushing due to pollution, animals, or debris
- Internal major insulation failure
- Internal discharge resistor failure

Figure 9 shows an arrangement of capacitors with only two capacitor units placed in parallel. This design greatly reduces the energy discharged into the failed capacitor and minimizes the chance for a catastrophic failure of the bank in cases of atypical failure modes listed above.

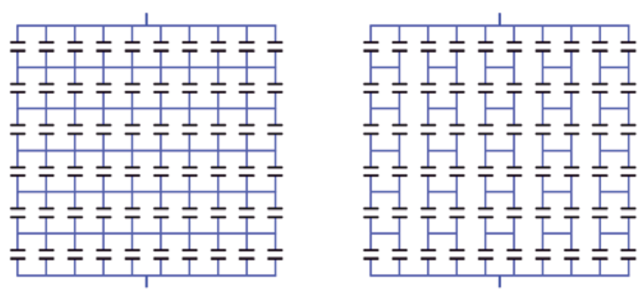

Figure 9. Alternative configuration example.

Internally fused banks provide important benefits, including:

- Smaller footprint than externally fused banks
- Ability to isolate single element failures
- Reduced parallel energy concerns
- No need to coordinate external fuses to tank rupture curves

When designing internally fused capacitor banks, the most cost-effective design is generally achieved by utilizing the largest kvar capacitor that can be manufactured.

Design an internally fused, 24 MVAr @ 34.5 kV-LL, ungrounded wye capacitor bank:

Taking into consideration that the largest internally fused unit design is 750 kvar and 12 kV maximum, the maximum unit voltage limitation requires at least a two series section design. A 24 MVAr design requires at least 32 units, due to 750 kvar limitation.

Since there are three phases, and two series sections per phase, the number of units per phase must be a multiple of six (12 in this case). The bank requires the use of 12 units per phase and 36 total units, which results in rated unit kvar of 24000/36=667 kvar.

- Single wye option: two series sections with six parallel-connected units per series section. Each phase consists of 12 units or 36 units for a three-phase bank. Each unit should be rated 9.96 kV and 667 kvar.

OR

- Split wye: two series sections with three+three parallel-connected unit per series section. Each phase consists of 12 units or 36 units for a three-phase bank. Each unit should be rated 9.96 kV and 667 kvar.

Fuseless protection strategy

For a fuseless bank, capacitor units are only connected in series (illustrated in Figure 10); they are never placed in parallel like an externally or internally fused capacitor bank. Therefore, when analyzing a fuseless capacitor bank, the number of internal series sections is an important consideration. An internal series section is one of the series sections of parallel connected elements inside of a capacitor unit. Fuseless capacitor banks are constructed of one or more strings of series-connected capacitor units.

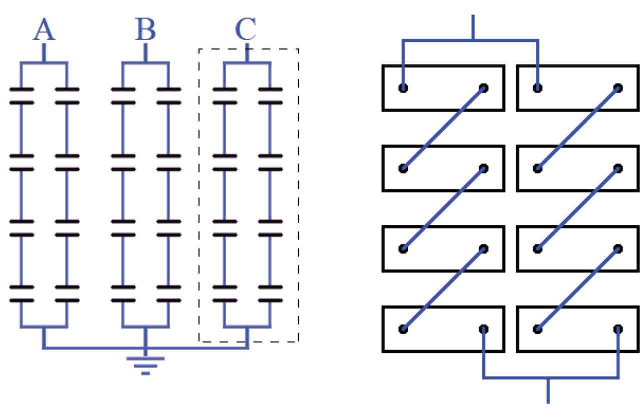

Figure 10. Fuseless capacitor bank connection schematic.

Because fuseless capacitors units are never connected directly in parallel, parallel energy is not a relevant factor and nor is it a concern for fuseless banks. This also makes it simpler than internally or externally fused banks with fewer design considerations. Bank stability for a fuseless capacitor bank is similar to that of an externally fused capacitor bank and defined by shorted series sections, internal to individual capacitors. The voltage on the remaining series sections in the string should not exceed 110% of its rated voltage. For example, if there are four capacitor units in series and each unit has eight series sections, then there is a total of 32 series sections in the string. If one series section shorts, the voltage increase across the remaining series sections is 32/31 of the previous value, or about 3.2% higher.This is well below the 110% threshold; however subsequent failures could lead to the removal of the bank from service.

The current in a string should be limited to provide sufficient safety margin for any stable weld joints in shorted elements. This safety margin allows for the effects of maximum system voltage, frequency, capacitance tolerance, unbalance due to internal series group failures and harmonics. The minimum number of strings is calculated as followed:

Where:

S_{min} = Minimum number of strings

I_{phase} = Nominal phase current in amperes

I_{string} = Maximum string current allow. This is manufacturer dependent.

While fuseless capacitor banks can be applied at any voltage, the most cost-effective design is typically achieved by using the largest kvar capacitor that can be manufactured (the system voltage is most often ≥ 46 kV-LL). For bank stability, the overvoltage on the remaining series sections in a string with several shorted series sections should not exceed 110% of rated voltage. This can be economically achieved at bank rated voltages of 46 kV-LL and higher. Similarly to an internally fused capacitor bank, the lowest cost is generally achieved by using the largest kvar unit possible.

The key benefits associated with fuseless banks include:

- Reduced costs (compared to typically externally or internally fused types)
- No parallel energy concerns and no need to coordinate fuse TCC
- No spurious fuse operations
- Less substation space required
- Simplicity

Designing a fuseless, 18 MVAr @ 69 kV-LL, grounded wye capacitor bank:

Taking into consideration that the largest fuseless unit design is 800 kvar and 22.8 kV maximum, the maximum unit voltage limitation requires at least two series connected units in the fuseless string.

Considering the 800 kvar unit limitation, a minimum of 18 MVAr/800 kvar = 23 units is required.

Since there are three phases, and if two series sections per phase, the number of units per phase must be a multiple of six (24 in this case). The bank design requires the use of eight units per phase and 24 total units, which results in rated unit kvar of 18000/36=750 kvar.

- Single wye option: four fuseless strings with two series-connected units per fuseless string. Each phase consists of eight units, or 24 units for a three-phase bank. Each unit should be rated 19.92 kV and 750 kvar.
- Split wye option: 2+2 fuseless strings with two series-connected units per fuseless string. Each phase consists of eight units, or 24 units for a three-phase bank. Each unit should be rated 19.92 kV and 750 kvar. Each unit would be manufactured with a minimum of 10 internal series sections. With two units connected in series, there would be a total of 20 series elements in the fuseless string. This ensures bank stability, as when a single element shorts, the remaining overvoltage is 20/19=1.05, less than 1.1 or 110%. The bank would need to trip offline if two elements in the same fuseless string short (i.e. 20/18=1.11 or 111%, which is higher than 110%).

Capacitor bank design schemes

When designing a capacitor bank, many factors must be taken into consideration: rated voltage, kvar needs, system protection and communications, footprint and more. These factors govern the selection of the capacitor units to be used, along with proper grouping of these units. Capacitor banks voltage ratings may range from 4160 volts through 800,000 volts and are comprised of standard single-phase capacitor units which are available in 50 through 800 kvar ratings from 2400 through 22,800 volts. One or more capacitor units are connected in series to make up the required voltage and are connected in parallel in each series group to get the desired total bank kvar.

Figure 11 shows the most cost-effective fusing option based on bank MVAr and rated voltage. Please note this manufacturer specific and a general guide that can change over time.

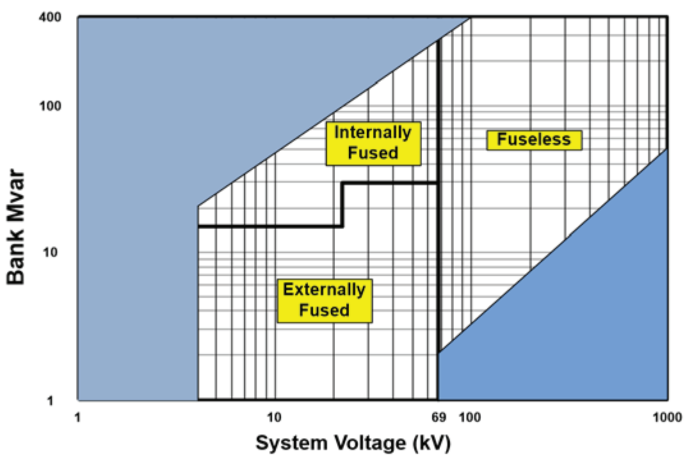

Figure 11. Optimal fusing option.

While this paper provides an overview for some considerations, it is not a complete analysis for every aspect that must be reviewed selecting the type of capacitor bank for each application. Design guidelines vary from one manufacturer to another with respect to design margin and capability, and this paper specifically addresses Eaton capacitor technology.

Contact Eaton regarding any questions on how to select unit type for any new or existing banks and applications. Visit Eaton.com for more information on power capacitors.

About the authors

George Gao is a senior application engineer with Eaton's Capacitor Group. George graduated from Mississippi State University with a M.S. in electrical engineering. George has been with Eaton's capacitor group for 14 years in various engineering and marketing roles serving the international OEMs and international markets. George previously worked as an electrical engineer for American Superconductor and Southern Company in engineering research and support for three years prior to his current role with Eaton. George currently plays a major role in marketing for designing and providing quotations and technical support for the full line of medium voltage capacitor products for international customers, consultants and distributors.

Michael Gresko is a capacitor specialist with Eaton's Capacitor Group. Michael graduated from Drexel University with a B.S. in electrical engineering. Michael has been with Eaton's Capacitor Group for 23 years in various engineering and marketing roles serving the utility and industrial markets. Michael previously worked as an electrical engineer for General Electric in engineering support for five years prior to his current role with Eaton. Michael currently plays a major role in marketing for designing and providing quotations and technical support for the full line of medium voltage capacitor products for commercial and industrial customers, consultants and distributors.

Duc Nguyen is an application engineer with Eaton's Capacitor Group. He has been with Eaton for more than three years after spending over 10 years in the utility industry as a system/design engineer. He is primarily responsible for providing quotations and technical support for switches and capacitor bank products in the commercial and industrial and international markets. Duc holds a BS in electrical engineering from University of South Carolina and is a licensed engineer in SC.

Gordon Pettersen is the product manager for Eaton's Capacitor Group. Gordon graduated from Clarkson University with a B.S. in mechanical engineering and a minor in mathematics. After college, Gordon joined General Electric's Edison Engineering Development Program (EEDP). Following graduation from the EEDP, he worked primarily as a blower and motor engineer for locomotive and drill applications. In 2014, Gordon joined Eaton as an engineering manager for low- and medium-voltage busway products and 2018 transitioned to the power capacitor team. In his current role, Gordon is responsible for a variety of sales and marketing functions, as well as training and contract analyst teams.

Eaton
1000 Eaton Boulevard
Cleveland, OH 44122
United States
Eaton.com

Eaton's Power Systems Division
2300 Badger Drive
Waukesha, WI 53188
United States
Eaton.com/cooperpowerseries

Printed in USA
Publication No. WP230005EN/MJ
August 2021