

Fuseless Capacitor Bank Protection

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Abstract

The use of fuseless capacitor banks requires subtle changes in the protection approach from the more traditional fused banks. This paper covers the aspects of protecting fuseless capacitor banks of various voltage classes. Comparison of fused versus fuseless capacitor bank protection is discussed, along with examples and insights from Minnesota Power's experiences with fuseless capacitor banks.

Introduction

There are many different VAR and voltage ratings available on power capacitors and many different physical arrangements of power capacitor banks. However, the installations can be grouped into one of three applications - internally fused, externally fused or fuseless. The individual power capacitors are designed uniquely for the application intended and have their own unique failure modes. As a result, protection systems must also be tailored to the application.

All applications of power capacitors require the same basic protection objectives, including system short circuits between phases or to ground within the bank, and element overvoltages, caused by power system overvoltages or by the failure of other elements within the bank. Since the failure modes differ between capacitor types, the performance of protection schemes will also vary. In particular, fuseless capacitors present unique protection considerations.

Capacitor Types

There are three main types of power capacitors, internally fused, externally fused and fuseless. Internally fused capacitors were used extensively in the past when the element technology was all-paper or paper-film. The individual can is constructed from series groups of parallel capacitor elements, each element individually fused within the can (refer to Figure 1a). When an individual capacitor element shorts, the fuse for that element blows, opening the element with minimal overvoltage stress on the remaining elements.

Externally fused capacitors utilize modern all-film element technology. The individual can is constructed from series groups of parallel capacitor elements which are designed to be operated with a common external fuse (refer to Figure 1b). The external fuse will generally not blow for failure of an individual element and the can will continue to operate with a reduced VAR flow and increased voltage stress across the remaining elements within the can. The increased voltage stress usually results in cascaded failure of the remaining elements within the can, ultimately blowing the external fuse.

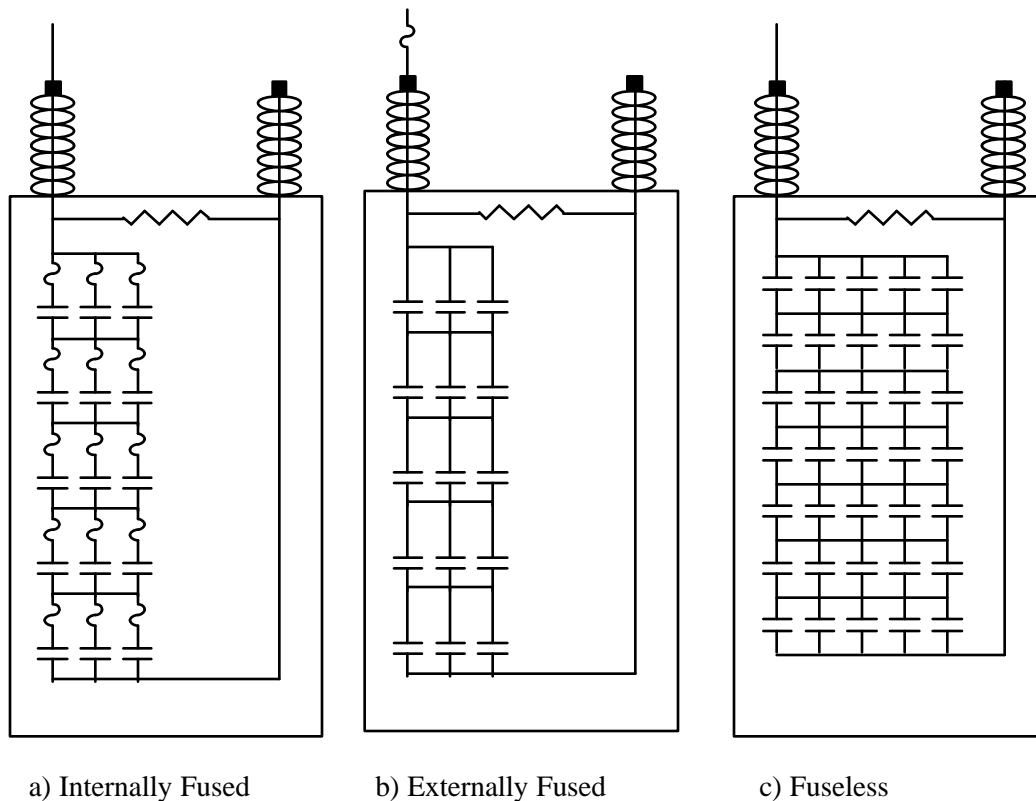


Figure 1: Internal configuration of power capacitors

Fuseless capacitors, like externally fused capacitors, utilize modern all-film element technology and are constructed from series groups of parallel capacitor elements. However, they usually contain more elements than a typical fused capacitor (see Figure 1c). When an individual element shorts, the can continues to operate with a slightly reduced VAR rating. Due to the larger number of series groups within the can and the power wiring methods used, the overvoltage stress on the unshorted groups is smaller than for externally fused capacitors. As a result, cascaded element failures within the same can are not as common.

Typical Capacitor Bank Arrangements

Figure 2 shows a typical high voltage capacitor bank arrangement using externally fused capacitors (note: the discussion of fused capacitor banks will be limited to externally fused). An element failure results in a significant increase in voltage stress on the remaining elements within the can (and a slight increase in voltage stress on the other cans). As a result, a cascaded failure of elements within the same can is common, causing the can fuse to blow. A blown fuse causes a more noticeable increase in voltage stress on the remaining cans. The bank must be removed from service if the voltage stress on the remaining cans becomes high enough to cause cascaded can failure (10% above nameplate is a typical value).

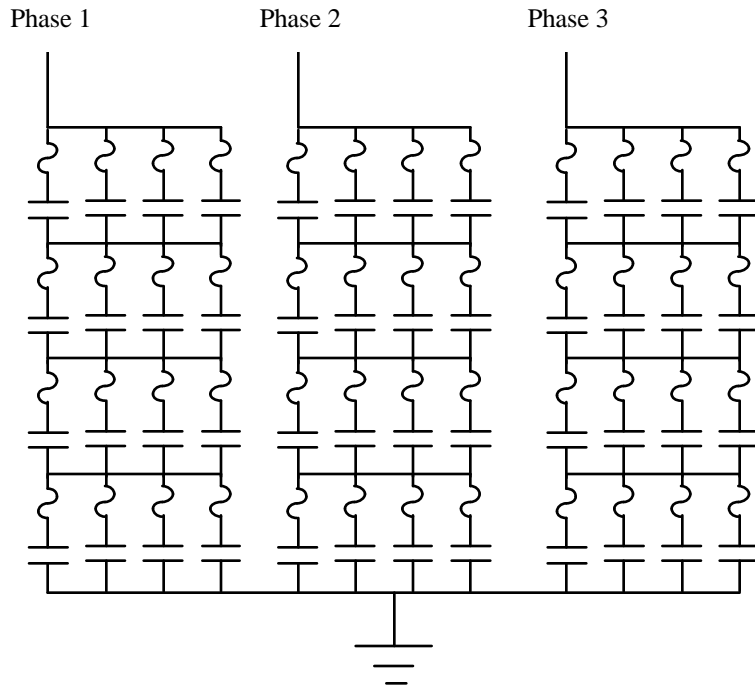


Figure 2: Typical arrangement of an externally fused capacitor bank.

Figure 3 shows a typical high voltage capacitor bank arrangement using fuseless capacitors. In this case, an element failure within a can results in a uniform increase in voltage stress on all the remaining elements in the parallel group. As a result, multiple element failures will occur anywhere in the group, not necessarily within the same can. Again, the bank must be removed from service if the voltage stress on the remaining elements in the group becomes high enough to cause cascaded element failure (10% above nameplate is a typical value).

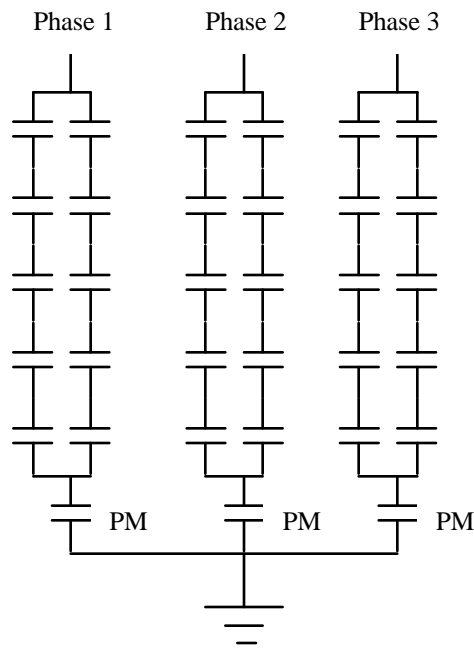


Figure 3: Typical arrangement of a fuseless capacitor bank.

Protection Objectives

The objectives of capacitor bank protection are the same, regardless of the type of capacitors used or the physical arrangements employed. They include short circuit protection for phase and ground faults, overvoltage protection resulting from excessively high power system voltages and overvoltage protection resulting from element failures.

Short Circuit Protection

The failure mode for short circuits (faults) within the capacitor bank is the same for all types of capacitor banks. Consequently, short circuit protection for fuseless capacitor banks is the same as for fused capacitor banks and is generally provided in the form of phase and ground time-overcurrent relaying. Where available, the relaying is generally connected to current transformers located at the capacitor bank breaker. The pick-up of the phase relays should be set above full load with the time delay set to coordinate with other protective devices (bus overcurrent relays, remote zone 2 impedance relays, etc.).

System Overvoltage Protection

Excessively high system voltage can cause capacitor failure, regardless of the type of capacitor. For all types of capacitor banks, protection against overvoltages that are caused by excessively high system voltage is generally provided by a high speed overvoltage relay connected to the substation bus voltage transformers. This relay trips the capacitor bank breaker or vacuum interrupter before capacitor damage can occur. The overvoltage relay pick-up should be set to correspond to a system voltage which results in an unacceptably high (typically 10% over nameplate) can voltage.

Element Failure Related Overvoltage Protection for Fuseless Capacitor Banks

For capacitor banks having more than one series group, failure of individual elements causes the applied voltage to increase on the remaining elements and cans. There are three common methods of detecting can or element failure – voltage differential, neutral overvoltage and neutral overcurrent. All three of these methods can be used on fused and fuseless banks, with varied applications.

When voltage differential is used for a fuseless capacitor bank, the bottom can in each phase is a single element protection module (PM). The voltage differential relay (87V) is connected to look at the difference between the bus voltage and the protection module voltage (see Figure 4). As elements fail within a series group, the phase current will increase and the voltage across the protection module will increase relative to the bus voltage. The difference voltage will become smaller. At the same time, the voltage will increase across the elements within the same series group as the failed elements and, to a lesser degree, across the elements in other parallel groups. This is in contrast to fused banks where failed elements blow fuses, resulting in reduced phase current, reduced tap voltage and an increase in the difference voltage.

In both fused and fuseless capacitor banks, the voltage differential relay provides alarm and tripping functions. The alarm should be set to alert maintenance personnel in advance of a trip so that damaged equipment can be repaired during a scheduled outage. For a fused capacitor bank, this generally means alarming for one blown fuse. On fuseless capacitor banks, the alarm point is not as obvious. Since there is no outward indication of which cans have bad elements, alarming for one failed element may not be useful for maintenance. If the alarm is set for more than one element failed, there is a strong likelihood that several cans will need to be replaced (there is no logical failure mode to suggest that all of the failed elements will be in the same can). Generally accepted practice is to alarm for some number of failed elements that is slightly less (1 or 2) than the trip point.

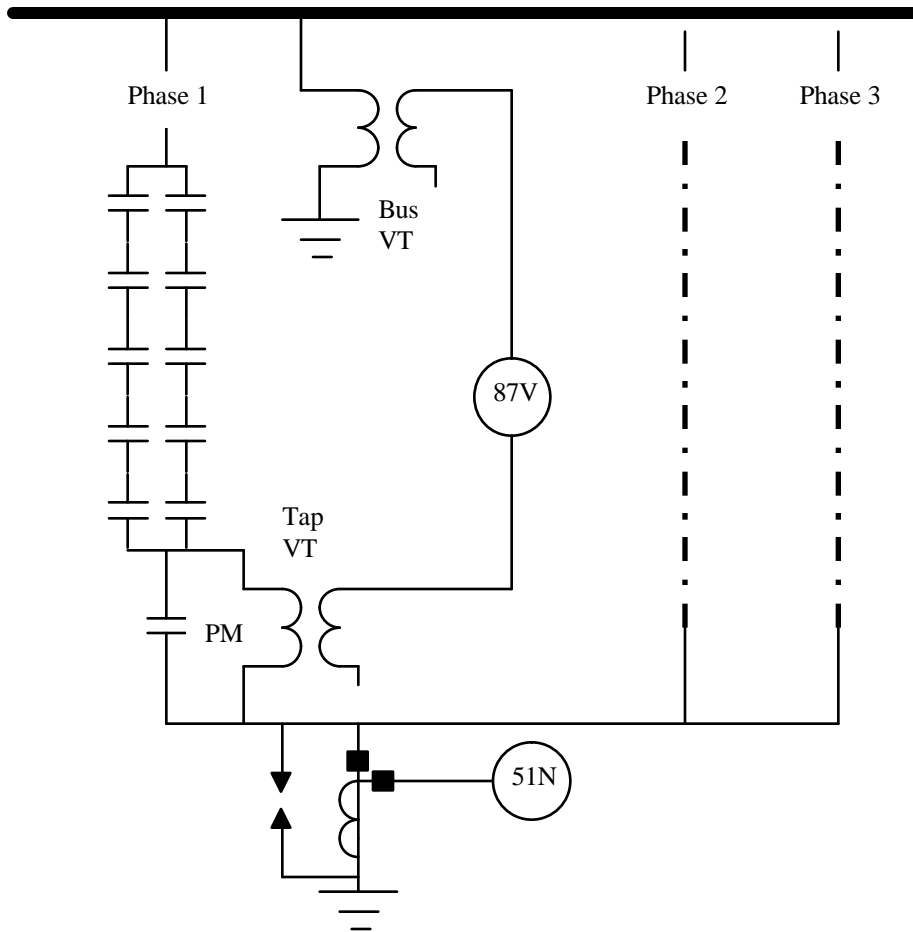


Figure 4: Voltage differential application on fuseless capacitor bank.

Tripping from the voltage differential relay should be set to occur at the point where one more failure (element in the case of fuseless or blown fuse in the case of fused) will result in a voltage stress that exceeds 110% of rating on the remaining elements. Note that, it is important to use nameplate or measured capacitance for the protection modules when performing the voltage differential calculations as a small variable in the protection module impedance results in a significant change in differential voltage. If the voltage differential relay being used has the ability to automatically calculate the nulling factor, it is recommended that this feature be used once the bank is known to contain no bad elements.

Neutral overvoltage relaying can also be used to detect failed elements in both fused and fuseless capacitor banks. In the case of fused capacitor banks, the application is generally limited to ungrounded banks. For fuseless capacitor banks, neutral overvoltage relaying can be applied on grounded wye banks by grounding the bank through a single element protection module (see Figure 5). The neutral overvoltage relay (59N) operates based on the voltage across the protection module. In this application, the voltage across all three phases changes as elements fail within the series groups.

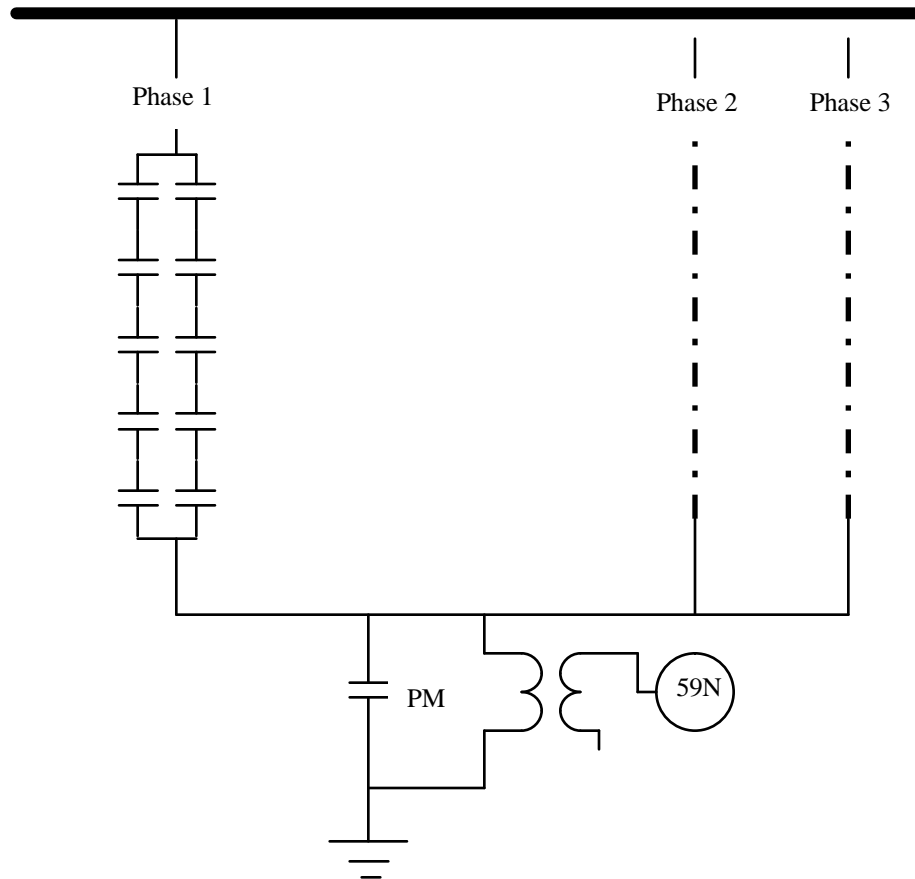


Figure 5: Neutral overvoltage application on fuseless capacitor banks

The setting criteria for alarm and trip are the same for the 59N application as in the case of the voltage differential. However, the calculations for neutral voltage as a function of failed elements uses a wye-delta conversion of the phase impedances to calculate individual phase line currents and associated neutral current/voltage. A disadvantage of the neutral overvoltage application is that it may respond adversely to primary system voltage unbalances.

Neutral overcurrent relaying can be used to detect failed elements in any grounded capacitor bank (51N – Figure 4). On transmission voltage capacitor banks it is generally applied as back-up to a voltage differential application. Since the relay operates on relatively small currents (25 - 50 amps primary), it is generally required to use a low-ratio neutral CT (10:5 or 50:5) with primary protective gaps. The relay can generally be set to provide the same alarm and tripping points as the voltage differential relay. As in the case of the neutral overvoltage relay, the neutral overcurrent application may respond adversely to primary system voltage unbalances.

Conclusions

All of the traditional methods of protecting fused capacitor banks can be applied to fuseless capacitor banks with the same basic objectives. However, a careful understanding of the failure modes of fuseless capacitors is required in order to correctly apply and set the protective relays. Since there is no outward indication of failed elements within fuseless capacitor cans, maintenance and trouble shooting procedures will be different and the relay settings should be designed taking this into account (especially with regard to the failed element alarm).