National Electrical Manufacturers Association

US G 112-2021

Capacitor Bank Purchasing Specifications Guidance

Disclaimer

The Standards or guidelines presented in a NEMA standards publication are considered technically sound at the time they are approved for publication. They are not a substitute for a product seller's or user's own judgment with respect to the particular product referenced in the Standard or guideline, and NEMA does not undertake to guarantee the performance of any individual manufacturer's products by virtue of this Standard or guide. Thus, NEMA expressly disclaims any responsibility for damages arising from the use, application, or reliance by others on the information contained in these Standards or guidelines.

CONTENTS

Introduction

There are many aspects that must be considered in designing and specifying capacitor banks. The equipment electrical ratings, physical arrangement, and relay protection scheme are intimately intertwined. The bank must be designed to accommodate all applicable devices such as instrument transformers, capacitor switches, protective relays, fuses, and bus-work, along with other devices specific to the application. Capacitor bank protective schemes must be designed and applied to provide the signals required for protective relaying to perform as expected.

This document provides guidance to help engineers draft comprehensive and clear purchasing specifications for capacitor banks. After providing an overview of the relevant Standards, and sections within those Standards, we provide helpful information to assist with cost-impact analysis and considerations for product ratings, rack designs, and bank configurations.

Standards

When drafting purchasing specifications, users should reference several relevant Standards:

IEEE 1036 Application Guide for Shunt Capacitors

Section 5.2.3.1 covers overvoltage-specific capabilities. This is important to protect capacitors from overvoltages beyond their capability. Each overvoltage has an expected number of occurrences per year. Relay protection can be relied on for the longer duration overvoltages, but the short-time occurrences may require surge arrester protection.

Section 5.2.3.2 on overcurrent capability serves as a guide if some type of limitation is needed to prevent excessive discharge currents during switching or closing faults. In addition, it provides suggestions for grounding methods to direct high current transients out of the ground grid. The section also gives some details on switchgear that can be used for capacitor bank switching.

Capacitor Standard IEEE 18 lists capacitor unit capability of operation of 110 % continuous overvoltage. That capability is for contingencies such as temporary overvoltage from fuse operation or element failure, with the expectation that the user will soon correct the overvoltages.

IEEE 18 Capacitor Standard

One key section is section 7.1 Design Tests which determines the unit’s overvoltage and overcurrent capabilities. This section also specifies the major case insulation performance capability. The production tests of Section 7.2 are essentially quality control to ensure that defective units do not get shipped to the customer.

Another key section is 6.9, which provides physical dimensions for substation equipment.
IEEE 18 specifies certain physical dimensions for capacitor units, such as spacing between bushings and the mounting hole spacing. The spacing between bushings determines the maximum unit voltage rating, which is typically 20kV for two bushing units and 25kV for single bushing units. The design maximum altitude is 1800m for normal service conditions. IEEE 18 also specifies that capacitor racks utilize 8” unit-to-unit spacing up to 8kV unit voltage; 9” unit spacing up to15 kV unit voltage; and 11” unit spacing above 15kV. The mounting channel dimensions are also specified.

IEEE C37 Series

IEEE C37.012 is an application guide for Circuit Breakers switching capacitive loads.

IEEE C37.100.2 contains the common requirements for testing capacitive current switching devices.

IEEE C37.99 contains various protection schemes, discusses their strengths and weaknesses, and provides methods for calculating relay settings. These requirements are important because protection needs to be considered in the layout of the bank so that current transformers and/or potential measuring devices can be accommodated, as well as external fuses (when used). The protection method will determine how much selectivity is possible, i.e., targeting where the trouble might be in the bank.

The following table is a "quick reference guide" for where certain requirements are contained in the Standards referenced above:

Item	Reference Standard	Standard clause
Definitions	IEEE 18	3.0
Capacitance tolerance	IEEE 18	5.2
Temperature range	IEEE 18	5.7 and following
Capacitor Unit dimensions	IEEE 18	6.9.1
Unit Mounting dimension	IEEE 18	6.9.1
Bushing details	IEEE 18	6.5 and following
Rack spacing unit to unit	IEEE 18	6.9.5 Table 5
Rack side to side dimensions	IEEE 18	6.9.2 Fig 1
Fuse rail height (externally fused only)	IEEE 18	6.9.2 Fig 1
Rack height (externally fused only)	IEEE 18	6.9.2 Fig 1
Rack drawings externally fused	IEEE 18	6.9.2 Fig 2
Rack drawings fuseless and internally fused	IEEE 18	6.9.2 Fig 3
Unit overvoltage capability AC	IEEE 1036	5.2.3.1 Fig 4
Unit overvoltage capability peak	IEEE 1036	5.2.3.3 Fig 6
Unit overcurrent capability	IEEE 1036	5.2.3.2
Unit transient current capability	IEEE 1036	5.2.3.2 Fig 5
Capacitor bank grounding methods	IEEE 1036	9.1.2 Figs 25, 26
Protection methods general	IEEE 1036	9.3 and following
Protection specific and setting calcs	IEEE C37.99	Full document
Typical voltage and kvar ratings	IEEE 18	**5.4 Table 1
BIL vs Voltage rating	IEEE 18	6.2 Table 2
Type (design) test values	IEEE 18	7.1
Switching issues	IEEE 18	6.2 and 6.3 and following
Switchgear Considerations	IEEE 1036	6.4 and following
Switching device test code	IEEE C37.100.2	Entire doc
Circuit Breaker Considerations	IEEE C37.012	4 and 9 in particular
Bank Protection	IEEE 1036	9.3 and following
Unbalance Protection details	IEEE C37.99	Check table of contents

**these are "typical" but not mandatory. Capacitors are made to order and any reasonable kvar and voltage rating is possible up to the physical limits of the 13.5" wide tank. Ease of handling and weight could drive the maximum kvar rating used.

Cost Considerations

For substation capacitor banks, the capacitor equipment (capacitor units, racks, and elevating structures) represents about 10–15% of the total project cost.

The below table may help put into perspective the initial equipment costs. These informal estimates can guide decisions on items such as capacitor bank voltage rating in comparison to expected maximum system voltage.

Project component	% of total project cost	Future maintenance % project maintenance cost
Capacitor equipment	10	20
Switching equipment	10	40
Protection equipment	10	30
Capacitor equipment assembly	5	0
Switching equipment assembly and commissioning	5	0
Protection equipment assembly test and commissioning	12	0
Site development (grading, drainage, foundations exterior fence) Yard surface (stone)	25	0
Grounding grid	10	5
Control and LV power cabling	13	5
Total	100	100

Capacitive Mvar Required

Usually the size of the bank in Mvar is determined by system or regional planners as the maximum allowable single step size (often determined by the allowable voltage change when switching the bank). For distribution voltages, the allowable voltage change is usually <5%. For transmission banks, the allowable voltage change is usually <2.5%, and for bulk power banks <1.5%)

Choosing a Voltage Rating for the Capacitor Bank

In no case should the voltage rating be lower than the maximum expected usual operating voltage. A higher rating could be considered to promote capacitor bank availability vis-a-vis, lowering the expected failure rate of capacitor units. A higher voltage rating also provides for margin during geomagnetic disturbances and other unusual events.

Since the var output of a capacitor is proportional to its rms operating voltage, users should consider that increasing the voltage rating will require increasing Mvar rating according to the square of the p.u. voltage increase. This increase in Mvar rating is required to obtain the desired Mvar output at the expected operating voltage. If, for example, the voltage rating of the bank is 10% above the required voltage rating, the nameplate Mvar rating of the capacitor bank would have to be increased by 21% over the desired Mvar output.

Physical Arrangement of Stack Racks

Users should allow for capacitor units to fail during the service life of the capacitor bank and, accordingly, make provisions to facilitate their replacement. One such provision is the space required for personnel and equipment to access the failed units.

Unit Size

Usually it is more cost-effective to specify a few large kvar units than many smaller kvar units because fewer units to process results in fewer tanks to produce, fewer bushings, etc. The disadvantage to this, however, is the need to handle the larger, heavier units. Units up to around 600kvar (~100 – 130 lbs.) can be handled in a man lift or bucket truck without additional lifting devices (i.e., cranes).

Rack Configurations

There are 3 basic rack configurations: Edgemount, Upright, and Flat Rack (pancake)

Edgemount (reference IEEE 18, section 6.9)

The most commonly found rack configuration is the Edgemount, where the units are horizontal and sit on the narrow dimension (typically 3” to 7.5” depending on unit kvar rating), and the bushings protrude out to the sides. The distance between mounting channels on opposite sides of the rack is standardized at 36”. The capacitor units can be inserted in and out of position on the mounting channel, and there is no need to lift them in or out of the rack, which facilitates handling, maintenance, and replacement.

Upright (reference IEEE 18, section 6.9)

The second most common rack configuration is Upright, where the units sit vertically with the bushings extending upward. This arrangement has a smaller footprint, but replacing units is more difficult since they need to be lifted upward. Pole-mount capacitor banks are almost exclusively configured this way. Often in the field, entire pole mount banks are replaced as an assembly, and units are changed out at the service center.

Flat Rack (Pancake)

The Flat Rack is not well standardized, but it has the lowest physical profile and lends itself to high voltage banks (up to 550kV) in one stack. The footprint is larger than Edgemount. The units sit on the mounting channels on their broad side with the bushings facing outwards. Flat racks are not amenable to external fuse designs, but they work for either internally fused or fuseless configurations.

Electrical Bank Configurations (IEEE 1036 Section 9.2)

There are three electrical bank configurations used: Externally Fused, Internally Fused, and Fuseless.

Externally Fused (IEEE 1036 9.2.1)

Externally fused bank configurations arrange the capacitor units in series groups of parallel-connected units where each unit has an external fuse (usually an expulsion fuse). For very large banks, currentlimiting expulsion fuses might be used. All capacitor units are internally comprised of capacitor elements connected in series and parallel arrangements to get the voltage rating and capacitance required.

When a fuse clears disconnecting a unit, the series group with the blown fuse will have lower capacitance and thus higher voltage across it than series groups with all fuses intact. This is a contingency where one can take advantage of the 110% “continuous” overvoltage capability. In many banks, the protection is set to trip the bank when the overvoltage on the remaining units in a series group exceeds 110%. The protection needs to be set to detect those conditions where the remaining units experience a voltage level beyond the permitted 110%.

Internally Fused (1036 9.2.2)

A bank with internally fused units can be, and often is, configured the same way as an externally fused bank, though without the external fuses. An internally fused unit has an individual fuse for each element. The elements are configured in series groups of parallel elements. Internally fused units are not self-protecting. Some kind of unbalance protection is needed to trip the bank when elements have an overvoltage beyond 10% or when an excessive quantity of internal fuses is blown. In this sense, an internally fused capacitor is essentially a miniature externally fused capacitor bank within one can.

Fuseless 1036 9.2.3

A fuseless bank is configured in parallel strings of units in series. Each series string will have the full phase to the neutral voltage across it. A unit with failed elements may remain in service indefinitely, as long as the elements do not experience overvoltage beyond 110% of their ratings.

Another characteristic of fuseless banks is that they are typically set to trip when the number of failed elements is equal to or greater than the number of series sections in one full capacitor unit. The protection scheme must be arranged to detect these conditions.

Considerations in Overvoltage Operation—Switchgear Limitation

In considering overvoltage operation, users should recognize that switchgear interrupting ratings are based on the switchgear’s rated maximum voltage. Capacitive current interruption is often one of the first capabilities to disappear on elevating operating voltage. The switching device should not be required to open or close above its rated maximum voltage. If the actual operating voltage exceeds the switching device rated maximum voltage, the switching device operation should be blocked.

A major disadvantage of ungrounded capacitors is the 25% higher recovery voltage stress placed on the switching device. If the switching device does not open the three phases within 4 ms (90 electrical degrees) of each other, the recovery voltage can be over 2 x that of a grounded wye capacitor bank.

Closing

Thank you for taking the time to read this guide and we hope it has been helpful. Please contact Jonathan Stewart (Jonathan.stewart@nema.org) for further information.

§