Cable Selection for Medium Voltage Capacitor Banks and Harmonic Filter Banks

Introduction

This document presents the fundamental aspects of cable and conductor selection for connecting pad mounted shunt capacitor and harmonic filters to industrial, commercial and utility power systems, with voltages of 2.4 kV to 34.5 kV. Information on cable selection and the use of stress cones is provided. The proper selection of these items can decrease installation time, material cost, and subsequently, the total installed costs of the capacitor or harmonic filter bank installation.

Background

Medium and high voltage pad mounted capacitor banks are most commonly connected to the power system by insulated cable. For 2400 volt and 4160 volt systems, this cable can be either shielded or non-shielded. For systems above 4160 volts, the cable must be shielded in accordance with the requirements of the National Electric Code (NEC).The termination of shielded cable must be done with stress relief cones and must be done at all terminating points.

Some pad mounted capacitor and harmonic filter banks may not require medium voltage cable if they are supplied with a bushing entry option. For these banks, bare, or 600 volt conductor may be used. Northeast Power Systems, Inc. (NEPSI) recommends 600 volt conductor be used, since the thin, 600 volt layer of insulation will tend to protect the copper (if copper wire is used) from corrosion. The 600 volt insulated conductor should be rated for outdoor use and should be treated as a bare conductor. When installing this conductor, it is important that the phase-to-phase and phase-to-ground clearance requirements of the NEC (Table 710-33 of the NEC) be met. The conductors should also be suitably supported so they cannot swing together from forces due to faults, wind or other acts of nature.

The choice of 600 volt conductor, for banks with bushing entry, is simple. Determine the size of conductor from Table 1 and source a conductor rated for outdoor use. The choice of medium voltage cable, on the other hand, is a bit more complicated and is the primary topic of this document. There are a host of options and considerations that cannot be fully presented, but the major options and considerations are as follows:

Table 1 – Major Considerations

Voltage and insulation level	Type of insulation
Type of shield	Jacket
Choice of stress relief cone	Conductor Size

An understanding of the above considerations, may be all that is necessary in choosing the right cable for your installation.

Voltage and Insulation Level

The Cable should be rated at the phase-to-phase voltage level of the capacitor or harmonic filter bank. In addition to the voltage rating, the insulation level of the cable must be chosen. The cable insulation level is dependent upon the overcurrent protection and grounding method of the system at which the bank is being applied. The description of each insulation level is described below. A conservative approach, when in doubt, is to choose the 133% or 173% insulation level.

100% Insulation Level
Cables in this category should be used on circuits which are provided with relay protection such that a ground fault condition will be cleared as quickly as possible, but in any case within 1 minute. This insulation level is applicable to the great majority of cable installations which are on grounded neutral systems.

133% Insulation Level
Cables in this category should be used on installations where the clearing time requirements of the 100% level cannot be met but there is adequate assurance that the faulted section will be cleared within one hour. This insulation level may also be used when greater insulation strength (higher reliability), than is provided by the 100% level thickness, is desired.

173% Insulation Level
This level is to be used when the time required to de-energize a faulted section is indefinite, or when the circuit is of a resonant grounded type.

Type of Insulation

There are a host of options available when it comes to choosing the type of insulation. The prominent types in use today include: TRXPLE, XLPE, EPR and HMWPE insulation. Surveys have indicated that HMWPE cable is seldom used, while TRXLPE, and EPR insulation seem to be the preferred type.

Shield

Shielded cables are required for voltages above the 5kV level, and are optional at the 4160 volt and 2400 volt level. The shield controls the electrical stress between the conductor and ground and it provides protection against water penetrating into the conductor insulation. Complete cable shielding consist of two parts: the first is a non-metallic semiconducting layer - either taped or extruded over the insulation - which totally encloses the cable, and second, is a metallic conductor of one of several types which serves to provide a solid bond between the semiconducting layer and the metallic shield. The metallic shield can take several forms: flat strap concentric neutral, round wire concentric neutral, wire shield, tape shield and corrugated tape shield. The choice of shield is primarily dependent upon the fault current carrying capability of the shield. In general, concentric neutral shields are not required for capacitor bank applications. Corrugated tape shield typically have higher fault handling capabilities

than tape and wire shields and are a good choice for capacitor or harmonic filter bank installations.

Conductor Ampacity

The conductor ampacity should be chosen based on the requirements of the NEC.In addition to the NEC requirements, consideration should be given to future capacitor or harmonic filter bank expansion, and the added duty requirements from harmonics for harmonic filter banks.The tables on the last page of this document show kvar capabilities for different size bare conductors and MV-90 cable at industry standard voltage levels.These tables provide a conservative conductor sizes that should work for most installations.

The cable ampacity shown is actually based on the table with the lowest ampacity rating for high voltage conductors in Tables 310-69 through 310-84.The kvar ratings have 25% derating factor to account for overvoltages and harmonics.The actual tables and derating factors of the NEC should be consulted for unusual applications.As much as a 30%-40% derating factor could apply for elevated ambient temperatures or unventilated cable tray installations. In addition, for cable tray installations, a 1/0 or larger conductor is required per the NEC.

In general, 5 kV cable is not available in sizes less than #4 AWG and 15kV cable is not available in sizes smaller than #2 AWG.This fact alone, in many cases, will determine the conductor size requirements.

Jacket

The jacket of medium voltage cable serves several functions.

1. Provide mechanical protection for the cable.

2. Provide a barrier against ingress of moisture which could harm the cable insulation or shield material.

3. Provide some electrical insulation between the shield and ground.This would become important on cable systems in which only one side of the shield cable is grounded.

4. For direct buried cables a semiconducting jacket may provide to limit the shield to ground voltage.

The choice of jacket mainly lies in the type of application. For applications involving direct burial, cable tray, and direct sunlight, the cable jacket should be marked and listed for the application.

Stress Relief Cones

As discussed above, when shielded conductor is used, stress relief cones must be used. A stress relief cone as shown in figure 1, provides a means of reducing and controlling the electrical stresses where the cable shield system is ended, just short of the point of termination.

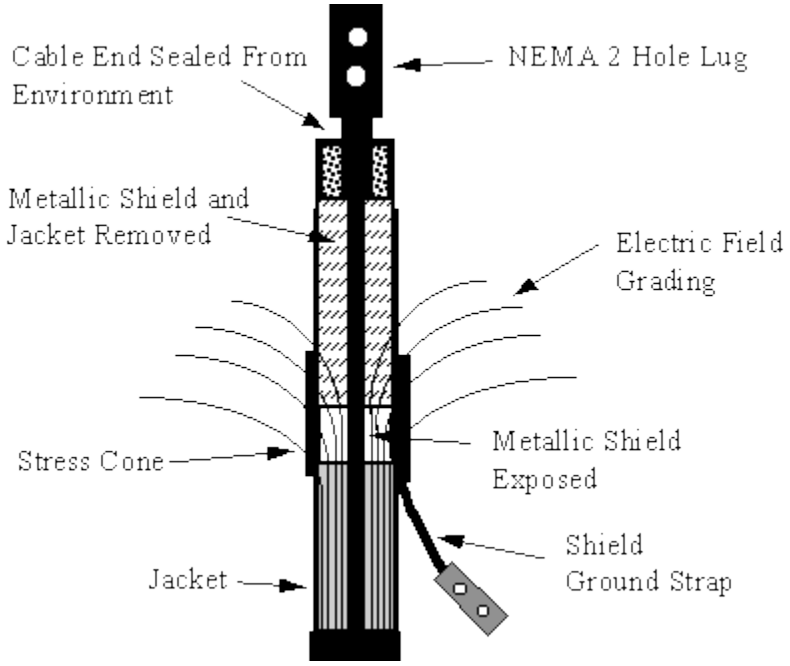


Figure 1 - Typical Stress Relief Cone Shown Electric Field Grading

There as three classes of terminations as listed below.

Class 1
This class of termination is commonly used outdoors and provides the following:

1. Some form of electric stress control for the cable insulation shield termination.

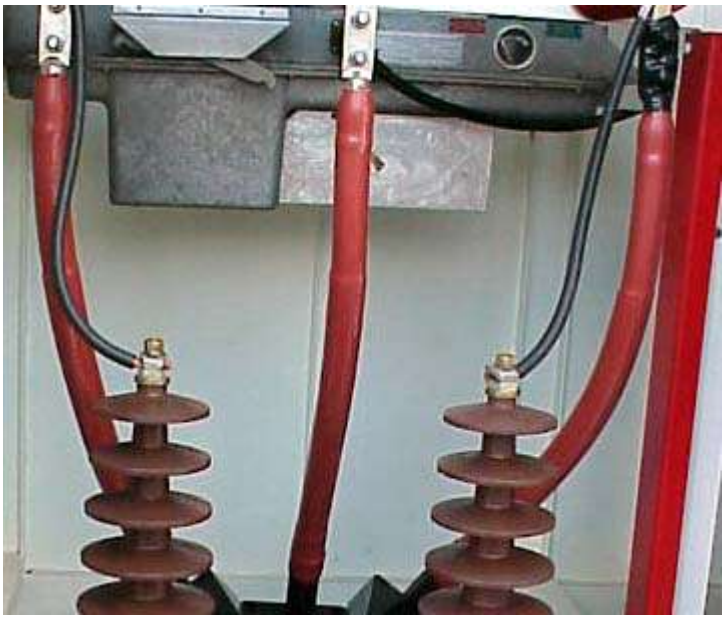
2. Complete external leakage insulation (sheds to increase creepage distance) between the medium voltage conductor and ground.

3. A seal to prevent the entrance of the external environment into the cable.

Class 2
These terminations are the same as class one terminations, except there is no seal (Item 3 in the Class 1 category above) from the external environment. This type of termination would typically be used indoors or outdoors when equipped with rain shields or special outdoor insulation.

Class 3
A class 3 termination provides electric stress control only (only the first item in the class 1 category above). This class of terminations used primarily used indoors.

The termination classes described above are available as pre-molded, cold shrinkable and heat shrinkable forms. Elastimode, 3M, Joslyn, and Raycem are major suppliers. Generally, cold shrinkable are the simplest to install and require no heat. Typically, an hour is required for each termination. A considerable amount of time is required to prepare the ends of the cable. Workmanship in preparing the cable ends is very important. In addition to the benefits of easy installation, many of the heat shrinkable and cold shrinkable terminations are as flexible as the cable they are being placed around. This flexibility helps in minimizing the required termination clearance. See NEPSI tech note on cable terminations for further information on bending radius and termination clearance.



Picture above shows a 34.5kV Raychem heat shrinkable termination installed in the incoming compartment of a 10 MVAR 34.5kV Harmonic Filter Bank.

SHIELDED AND UNSHIELDED COPPER CONDUCTOR

AWG	APPROXIMATE AMPACITY	MAXIMUM THREE PHASE KVAR AT INDICATED VOLTAGE						
		2.4KV	4.16KV	4.8KV	6.9KV	12.47KV	13.2KV	13.8KV
8	52	160	277	320	460	831	880	920
6	69	212	368	424	610	1103	1167	1220
4	91	280	485	560	805	1454	1539	1609
2	125	384	666	769	1105	1998	2114	2211
1	140	431	746	861	1238	2237	2368	2476
1/O	165	507	880	1015	1459	2637	2791	2918
2/O	190	584	1013	1169	1680	3036	3214	3360
3/O	220	677	1173	1353	1945	3516	3721	3891
4/O	255	784	1359	1569	2255	4075	4313	4510
250	280	861	1493	1722	2476	4474	4736	4952
350	350	1076	1866	2153	3095	5593	5920	6190
500	425	1307	2266	2614	3758	6792	7189	7516
750	525	1615	2799	3229	4642	8390	8881	9284
1000	590	1815	3145	3629	5217	9428	9980	10434

CONSERVATIVELY BASED ON INSULATED THREE CONDUCTOR COPPER CABLE IN ISOLATED CONDUIT IN AIR BASED ON CONDUCTOR TEMPERATURE OF 90C. ALL OTHER CABLE TYPES AND APPLICATIONS SHOULD HAVE HIGHER KVAR CAPABILITY.

BARE COPPER CONDUCTOR

AWG	APPROXIMATE AMPACITY	MAXIMUM THREE PHASE KVAR AT INDICATED VOLTAGE						
		2.4KV	4.16KV	4.8KV	6.9KV	12.47KV	13.2KV	13.8KV
6	80	246	426	492	707	1278	1353	1415
4	105	323	560	646	928	1678	1776	1857
3	120	369	640	738	1061	1918	2030	2122
2	140	431	746	861	1238	2237	2368	2476
1	165	507	880	1015	1459	2637	2791	2918
1/O	195	600	1040	1199	1724	3116	3299	3448
2/O	225	692	1199	1384	1990	3596	3806	3979
3/O	260	800	1386	1599	2299	4155	4398	4598
4/O	300	923	1599	1845	2653	4794	5075	5305
250	340	1046	1813	2091	3006	5433	5751	6013
300	375	1153	1999	2307	3316	5993	6343	6632
350	420	1292	2239	2583	3714	6712	7105	7427
400	455	1399	2426	2799	4023	7271	7697	8046
500	515	1584	2745	3168	4554	8230	8712	9107

TABLE IS CONSERVATIVELY BASED ON 60 C CONDUCTOR AND SHOULD BE GOOD FOR ALL TYPES OF COPPER CONDUCTOR. THIS TABLE CAN ONLY BE USED FOR BANKS WITH BUSHING ENTRY.

Notes to above tables:

1. Ampacity based on Table 310-75, 5 kV cable.

2. Ampacity of cable based on zero shield current (only one side of shield grounded).

3. Kvar ratings based on 74% of conductor rating (This is not a requirement for capacitors above 600 volts, but has been adopted in these tables to account for voltage rise, harmonics, and manufacturing tolerances.

4. Where cable trays are used - Single conductor cable shall be No. 1/0 or larger and shall be of a type listed and marked on the surface for use in cable tray. Cables may require a derating of 30% for covered trays. Check Article 318-13 of the NEC for more detail.

5. Increased burial depth beyond 36" may require a derating of 6% per increased foot. Check notes for tables 310-69 through 310-86 of the NEC for more detail.

6. The tables and text in this document are for information purposes only, and Northeast Power Systems or any affiliation thereof, cannot be held liable for their correctness.

Picture of Medium Voltage Cable from the Okonite Company.

Key to attached picture:

A: Uncoated, Okopact (Compact Stranded) Copper Conductor

B: Strand Screen-Extruded Semiconducting EPR

C: Insulation-Okoguard EPR

D: Insulation Screen-Extruded Semiconducting EPR

E: Shield-5 Mil LCS Copper Tape

F: Jacket-Okolon

Northeast Power Systems, Inc.
66 Carey Road
Queensbury, New York 12804
Phone: 518-792-4776
Fax: 518-792-5767
E-mail: sales@nepsi.com
Website: www.nepsi.com