APPLICATION NOTE

COMPONENT RATINGS IN SHUNT CAPACITOR BANKS

Introduction

Shunt capacitor banks are expected to operate for many years in harsh electrical and environmental conditions. Conservative designs are therefore preferred from a technical perspective. On the other hand, commercial preference is for least cost designs.

This note reviews the requirements for capacitor voltage rating and reactor current rating in two common situations. The purpose is to determine component ratings according to the requirements of standards such as AS 2897 and IEC 60871 that will result in reliable performance under all operating conditions.

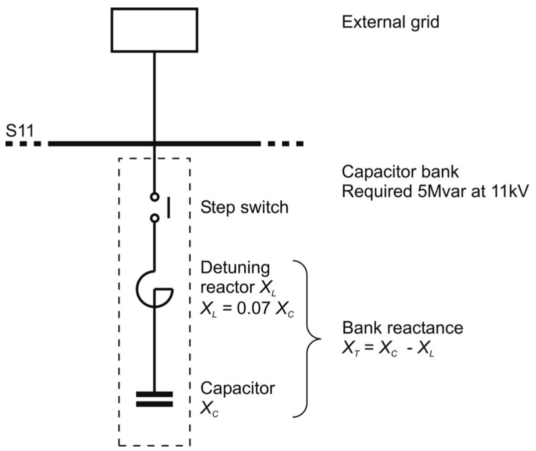
The first situation involves a detuned capacitor bank in the presence of known background harmonic distortion. In the second situation a harmonic filter reduces the harmonic distortion produced by a non-linear load.

Detuned shunt capacitor banks

A detuned filter arrangement is selected to simplify the bank design or because there is no need to reduce harmonic distortion levels significantly. The design approach assumes that network conditions with the bank connected are known, or that values published as worst case figures in network distribution codes are to be used.

In this example, a capacitor bank with nominal output Q_N of 5 Mvar at nominal voltage V_N of 11 kV is required. The decision has been made to make use of a 7% detuned bank. The busbar voltage can be expected to operate at 10% above nominal voltage for substantial periods, including the voltage rise as a result of the capacitor bank.

It is assumed that the voltage total harmonic distortion V_{THD} = 5%. For the purposes of this example, it is assumed that this arises from 5th and 7th harmonic voltages only where $V_{N,5}$ = 4% and $V_{N,7}$ = 3%, in percentage of the fundamental frequency nominal voltage.



The total bank reactance can be calculated from the nominal reactive power requirement of the bank at nominal voltage, $X_T = V_N^2/Q_N$ .This value and the relationships indicated in the figure above result in values of capacitance 122.3 µF and inductance of 5.8 mH.

Note that the combination of inductor and capacitor is capacitive at frequencies less than the tuning frequency of 189 Hz, and inductive at frequencies greater than 189 Hz. Resonance between the capacitor bank and the network impedance is therefore impossible above this tuning frequency.

AS 2897 and IEC 60871 require that the voltage rating of the capacitor be determined as the arithmetic sum of fundamental and harmonic voltages.

The fundamental frequency voltage across the bank is determined by considering the current I_n flowing through the bank at 50 Hz, and then using the capacitor reactance $X_{C,50}$ at 50 Hz to determine the voltage across the capacitor, $V_{C,1} = I_1 \times X_{C,1}$, where $I_1 = V_{N,1} \times 1.1/X_{T,1}$.

The current at each harmonic is determined in a similar fashion, as $I_n = V_{N,n}/X_{T,n}$ and $V_{C,n} = I_n \times X_{C,n}$.

n	$V_{N,n}$ (V)	$X_{T,n}$ (Ω)	I_n (A)	$V_{C,n}$ (V)
1	12100	24	287	7512
5	440	4	65	339
7	330	9	21	78

These results lead directly to the required voltage rating of the capacitors and the current rating of the reactor:

$$V_{C,rating} = \sum_{n=1}^{\infty} V_{C,n} = 13.7\ \text{kV} \quad \text{and} \quad I_{L,rating} = \sqrt{\sum_{n=1}^{\infty} I_n^2} = 297\ \text{A}$$

The rated output of the capacitor bank at rated voltage is 7.25 Mvar.

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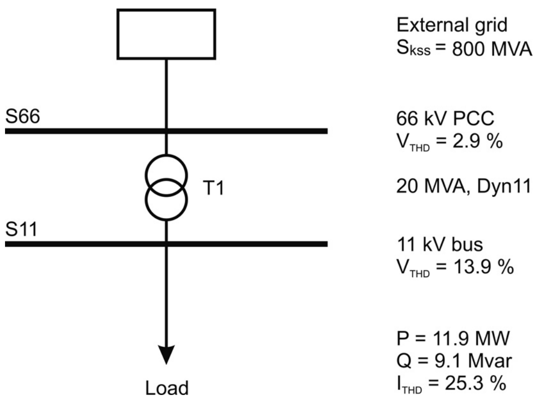
Tuned shunt capacitor banks

Rating components in tuned capacitor banks (i.e. harmonic filters) is somewhat more complex because the capacitor bank must be designed within the context of the network and harmonics to be filtered. An understanding of the operating modes of the network and practical limitations of capacitor and reactor design is vital.

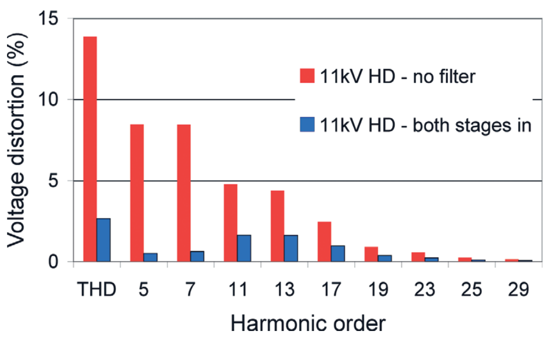
Tuned filters are generally installed to reduce the effect of non-linear loads in an installation. The non-linear load in the network below causes unacceptably high levels of voltage distortion inside the facility and at the point of common coupling.



Assume that distortion at the PCC and plant busbar should be less than 1% and 3 % respectively.
A two-stage harmonic filter tuned to the fifth and seventh harmonics is implemented to improve the situation.

In this case, the correct rating of the filter components depends on the amount of harmonic current distortion produced by the load and to be absorbed by the filter, network background harmonic distortion and component tolerances.

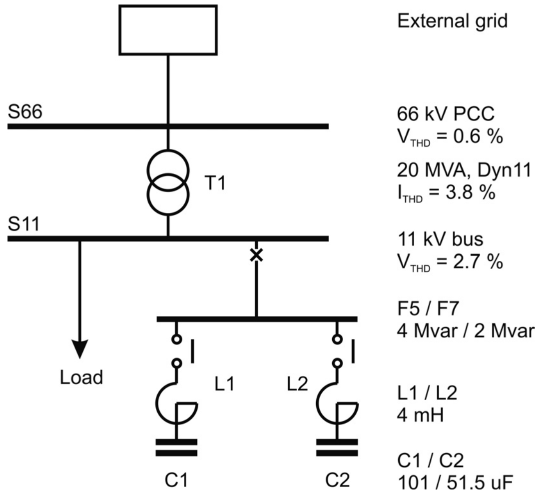
Rating these components follows the same approach as for detuned banks, and takes into account all possible network contingencies to ensure the filter will operate effectively and reliably under all load conditions and under all foreseeable network conditions. With the exception of very simple applications, this cannot be done without a harmonic impact study.



In this case, the arithmetic sum of voltages across the capacitor and current through the reactors are expected to be as follows:

Filter	*L* (mH)	*C* (μF)	V_C (V)	I_L (A)
5th	4	101	14600	276
7th	4	51.5	14300	154

These figures include provision for fundamental frequency voltage levels, and can be used as minimum component ratings.



Practical considerations also influence component ratings. It is desirable to use the same capacitor unit in each filter stage, so the highest voltage rating would be applied to all steps. The number of switching operations per day will influence the step sizes, and the amount of background harmonic distortion will help decide the actual tuning frequency of each stage.

Conclusion

A formal design approach for detuned shunt capacitor banks was presented, and some important topics in tuned filter design were introduced. Nokian Capacitors can assist you in designing shunt compensation to ensure reliable performance over many years, at optimal pricing.

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