ONE OPTIMISED NETWORK EQUIPMENT

RATING CAPACITOR BANK COMPONENTS

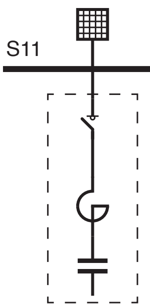
Shunt capacitor banks are expected to operate for many years in harsh electrical and environmental conditions. Conservative designs are therefore preferred from a technical perspective. On the other hand, commercial preference is for least cost designs.

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 IEC 60871 that will result in reliable performance under foreseeable operating conditions.

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

1 Detuned shunt capacitor banks

A detuned filter arrangement may be 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, specifically $V_{N,5}$ = 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.

IEC 60871 requires 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 $I_1 = V_{N,1} \times 1.1/X_{T,1}$ to take into account the continuous fundamental frequency over voltage that may be present at the busbar.

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:

$$V_{C,rating} = \sum_{n=1}^{7} V_{C,n} = 7.93 \text{ kV}$$

Phase-phase voltage rating is therefore $7.93 \times \sqrt{3}$ = 13.73 kV.

$$I_{L,rating} = \sqrt{\sum_{n=1}^{7} I_n^2} = 297 \text{ A}$$

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

2 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 necessary.

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

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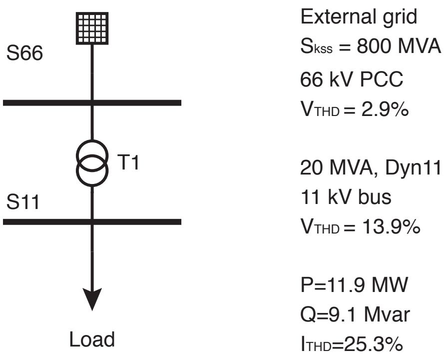
The load is assumed to consist largely of a conventional six-pulse variable speed drive, with contribution at the characteristic harmonic orders of $6(n \pm 1)$.

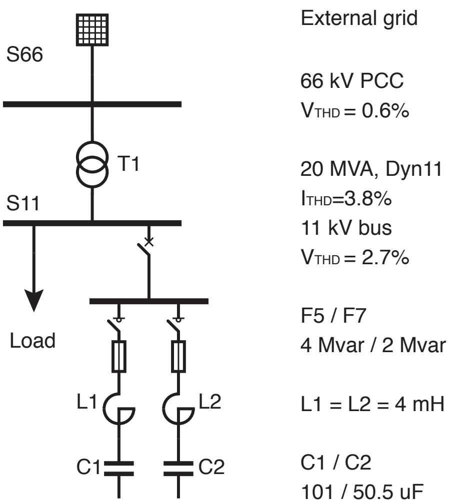


It is assumed that the requirement is for distortion at the PCC and 11 kV busbar to be less than 1% and 3% respectively.

A two-stage harmonic filter tuned to the fifth and seventh harmonics is implemented to improve the situation. The effect of the filter is shown in the graphic opposite.

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.

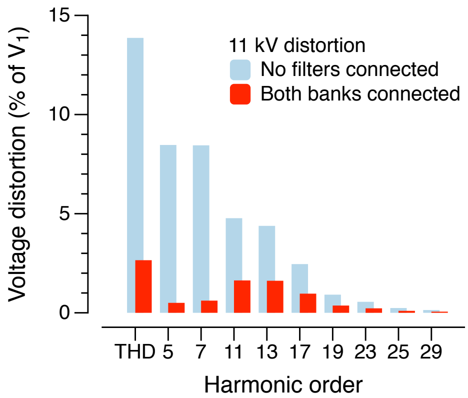
Rating these components follows the same approach as for detuned banks, and takes into account all possible network contingencies to ensure the filter will operate effectively and reliably under all load conditions and under all foreseeable network conditions. With the exception of very simple applications, 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)
F5	4	101	14600	276
F7	4	50.5	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, and in this case the highest voltage rating would be applied to both steps. The number of daily switching operations will influence the step sizes, and the amount of background harmonic distortion will help decide the actual tuning frequency of each stage.

3 Conclusion

Our electricity networks contain many power factor correction systems at all voltage levels. More will be installed for the foreseeable future to ease the pressure on network capacity and defer capital expansion programs. The need for this equipment to be designed correctly is acute if the mooted economic benefits of these systems are to be realised. Ever increasing penetration into the network of photo-voltaic generation places added pressure on network owners to manage voltage levels and harmonic distortion in their networks.

Pressure to reduce costs, particularly life time costs of equipment and the simultaneous requirement to meet onerous network connection standards make it more important than ever before to make sure your equipment is designed safely and optimally.

The design approach for detuned shunt capacitor banks and some of the important topics in tuned filter design presented here demonstrates how Optimised Network Equipment can assist you in designing shunt compensation to ensure reliable performance over many years, at optimal pricing.