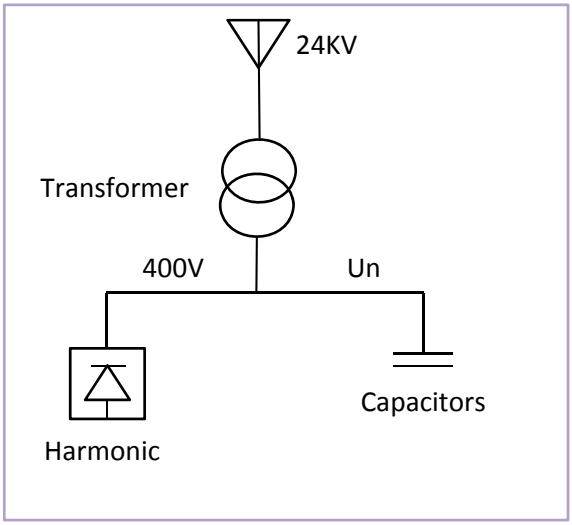
Calculation to choose capacitor units suitable for detuned filter in 3 steps

Example

System voltage is 400 volts and reactive power of capacitor unit is 50kVAR 400V for each step.



Step 1 : induced voltage calculation

We assign Un, U1 and p to be system voltage, the voltage across the capacitor after detuned reactor installation and ratio between impedance of reactor and impedance of capacitor respectively.

When the current is passing through reactor,

$$U1 = Us / (1 - \%p)$$

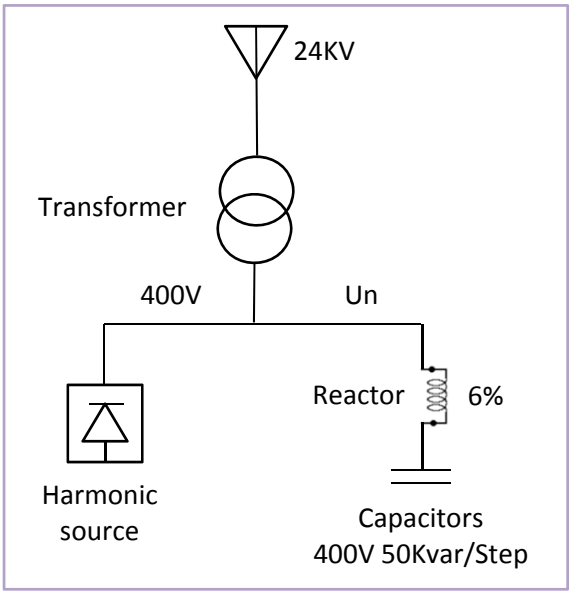
When (Us) is electric system

(p) is % of reactor

And reactive power

$$Q1 = Nc / (1 - \%p)$$

When (Nc) is reactive power of capacitor of system



If you bring 6% reactor connected to capacitor in series and require reactive power of each step equal to 50 kVAR at 400V, you can calculate U1 and Q1 as follows:

- Voltage across the capacitor (U1) = Un / (1 – p)

U1 = 400 / (1 – 0.06) = 426 V ; when p = 6% or 0.06

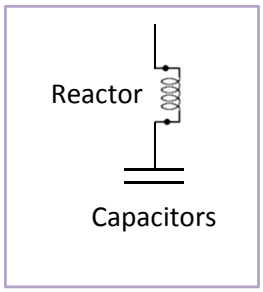
- Reactive power of capacitor (Q1) = Nc / (1 - %p)

Q1 = 50 / (1 – 0.06) = 53 Kvar

Step 2 : Harmonic current flowing to capacitor calculation

The voltage across the capacitor (U2) is occurred from harmonic current flowing to capacitor in the following IEC standard. We will find impedance of capacitor (Xc) after reactor installation and impedance of reactor (XL) at each frequency of each harmonic order. Referring to electrical theory, Xc = 1 / 2¶fC and XL = 2¶fL which C is capacitance of capacitor in Farad and L is inductance of reactor in Henry. Thus, total impedance of detuned filter of each step is | XL – Xc |.

Let's start to calculate impedance of capacitor (Xc) and reactor (XL) for harmonic current calculation.



$Xc = U1^2 / Q2$

$Xc = 426^2 / (53*1000)$

$= 3.42$ Ohms

use detuned reactor 6%

$XL = 3.42 * 0.06$

$= 0.205$ Ohms

After we know value of Xc and XL, we have to calculate impedance of capacitor (Xc) and reactor (XL) on each frequency of each harmonic order. You can find another way to calculate Xc and XL on each frequency if you know that frequency of harmonic order 5th is 250 Hz or 5 x 50Hz. It means frequency of harmonic order 5th is more than fundamental frequency 50Hz about 5 times. If we have a look in formula: Xc = 1 / 2¶fC and XL = 2¶fL which f is frequency of each harmonic order, we will find that if frequency is higher than 5 times, Xc will reduce 5 times and XL will increase 5 times.

As the above mentioned reason, we can calculate impedance of capacitor (Xc) and reactor (XL) on each frequency of each harmonic order as below:

Harmonic order 1st	f = 50 Hz	fundamental frequency 50Hz	Xc1 = 3.420 ; XL1 = 0.205
Harmonic order 3rd	f = 150 Hz	increase 3 times compared with 50Hz	Xc3 = 1.140 ; XL3 = 0.615
Harmonic order 5th	f = 250 Hz	increase 5 times compared with 50Hz	Xc5 = 0.684 ; XL5 = 1.025
Harmonic order 7th	f = 350 Hz	increase 7 times compared with 50Hz	Xc7 = 0.488 ; XL7 = 1.435

As our harmonic limit level indicated in above, U1 = 6%, U3=0.5%, U5=5% and U7=5% We will keep this values to find out harmonic current on each order in later.

Harmonic current at order h $Ih = Uh / (1.732 * | XLh – Xch |)$

when Uh is harmonic voltage

Harmonic order 1st : U1=6% (6% of fundamental)

$I1 = 1.06 * Ic = 1.06 * 72.1 = 76.5$ A

Harmonic order 3rd : U3=0.5%

$I3 = 0.005 * 400 / (1.732 * | 1.14 – 0.615 |) = 2.2$ A

Harmonic order 5th : U5=5%

$I5 = 0.05 * 400 / (1.732 * | 0.684 – 1.025 |) = 33.76$ A

Harmonic order 7th : U7=5%

$I7 = 0.05 * 400 / (1.732 * | 0.488 – 1.435 |) = 12.18$ A

Irms of total harmonic (Is) $= \sqrt{I1^2 + I3^2 + I5^2 + I7^2}$

$= \sqrt{76.5^2 + 2.2^2 + 33.76^2 + 12.183^2}$ = 84.53 A

Thus, maximum current flowing to capacitor unit is 84.53 A. and 6% reactor, which is installed with capacitor, shall be designed to withstand maximum current about 1.05 x Irms.

= 1.05 * 84.53 A = 88.75 A

Step 3 : Maximum voltage across capacitor calculation

Now we know that impedance of 6% detuned reactor is 0.205 ohms and inductance value is 0.653 mH (XL = 2¶fL). Moreover, it will withstand the current about 88.75 A at least. For capacitor unit, it will withstand max. current about 84.53 A.In the next step, we will choose voltage level suitable for 6% detuned filter. At first, we will concern the voltage across the capacitor unit because impedance of capacitor 50kVAR 400V is 3.2 ohms but after reactor installation, the voltage across capacitor and reactive power become 426V and 53kVAR respectively. Therefore, impedance of capacitor will be 3.42 ohms.

$Xc = V^2 / Q$

$= 426^2 / (53*1000)$ = 3.42 Ohm

Since we know value of harmonic current of each order in step 2, we will take those values to find out harmonic voltage across capacitor of each order. Harmonic voltage across capacitor of each order is equal to harmonic current of each order multiplied by impedance of capacitor of each order.

Thus, the harmonic voltage order h $Uh = 1.732 * Ih * Xc / h$

(Xc reduce h times when frequency increase h times compared with fundamental frequency 50Hz)

Harmonic order 1st : U1=6%	I1 = 76.5 A	U1 = 1.732 * 76.5 * 3.42	= 453.2 V
Harmonic order 3rd : U3=0.5%	I3 = 2.2 A	U3 = 1.732 * 2.2 * 3.42 / 3	= 4.35 V
Harmonic order 5th : U5=5%	I5 = 33.76 A	U5 = 1.732 * 33.76 * 3.42 / 5	= 40.0 V
Harmonic order 7th : U7=5%	I7 = 12.18 A	U7 = 1.732 * 12.18 * 3.42 / 7	= 10.3 V

The maximum voltage across capacitor is equal to 453.2 + 4.35 + 40 + 10.3 = 508 V

(system voltage plus induced voltage by reactor and harmonic voltage occurred from harmonic current flowing to capa

We should choose voltage of capacitor more than 508 volts. In Thailand market, there are power capacitor for voltage level 525V. If we choose this voltage level of capacitor, we have to bring this voltage level to find out reactive power. As electrical formula

$Q2 = Q1 \times (V2^2 / V1^2)$ = 53 x ($525^2 / 426^2$) = 80.5 Kvar

Summary

As the mentioned above, if you use capacitor unit 50kVAR for each step at 400V, you will use 6% reactor that impedance of reactor 0.205 ohms or 0.653 mH and withstand max. current about 88.75 A. For capacitor unit for detuned filter, its voltage level shall be more than 508 volts and its reactive power is near 80.5kVAR. (Please be aware of reactive power value of capacitor unit. Because the reactive power is much more or less than the calculated one, it causes reactor will be re-calculated and changed.
Do not forget, impedance of reactor is 6% of impedance of capacitor unit