Calculation Method for Audible Noise in High Voltage Power Capacitor

Power capacitors are commonly used as part of AC or DC harmonic filters and for reactive power compensation in HVDC (=> HVDC Components) and FACTS substations. In these applications the audible noise generated by the stacks of power capacitors is a potential concern to the compliance with restrictive noise levels as well as for the other equipment installed within a substation. Would not be the best solution avoiding noise or being able to calculate the sound level early enough before the construction phase begins? Now Siemens has developed a calculation method based on existing standards for a whole capacitor bank to evaluate possible noise levels in the design phase of a project. The power capacitors can belong to one of the noisiest sources in a substation reaching high noise levels up to 100 dB(A) which is similar to a compressed air hammer. In addition to the high noise levels, difficulties with the assessment and control of the noise generated by the capacitors arises from the frequency spectrum, which is composed of several pure (single frequency) tones up to the kilo-Hertz (kHz) range. This means for the development of the sound - calculation method several influencing factors/terms of conditions have to be considered.

Design of the high voltage power capacitor

The power capacitor is internally constituted of aluminium foil (electrode) and polypropylene film (dielectric) wound and compacted forming a laminated unit of rectangular shape called capacitor element. Several elements are stacked and electrically connected forming the capacitor. A simplified representation of a segment of an element is shown in figure 1.

![Fig. 1 – (a) Representation of the laminated stack of foils which composes the capacitor: the aluminium – al - and the polypropylene - PP. (b) representation of electrostatic forces.](http://www.siemens.com/FACTS) ![http://www.siemens.com/HVDC]
How is the noise generated?

Electrostatics forces arise in the charged capacitor causing an attraction of the electrodes and consequently a compressive strain in the dielectric.

In the case of time dependent voltages (harmonic voltages) generated by for example switching operations; the forces can produce mechanical vibration on the capacitor elements and consequently output of acoustic waves to the environment. The amplitude of the acoustic waves are proportional to the intensity of the harmonic voltages and the mechanical response of the capacitor unit, i.e., how much it vibrates and irradiates acoustic energy at a given frequency under the action of the electrostatic forces.

The right picture illustrates a typical noise emissivity of an 800 kVAR capacitor unit — harmonic forces at the vicinity of 1000 Hz should be avoided since the capacitor are very efficient in converting vibration into noise at these frequencies! This characteristic noise emissivity of the capacitor depends on the constructive parameters such as reactive power, capacitance, electrical stresses, size and that constitute the challenge of designing a low noise capacitor.

Determination of sound power

The determination of the sound power of a capacitor bank is not a simple task as field measurements are not representative due to the variation of load, network and environmental conditions or unprecise due to restrictions for safety reasons. In laboratory conditions, on the other hand, it is nearly impossible to simulate a real condition as present in a capacitor bank.

In our chosen method the sound power is determined by a combination of sound intensity measurements of a single capacitor unit, and corresponding calculations. The measurements for a single capacitor unit are conducted at a reduced load, that is, at reduced voltage levels and a single harmonic frequency at a time. The sound power of a unit is then calculated by extrapolating the measured sound levels to the nominal load and adding the contribution of each capacitor unit in the bank, usually hundreds of units. Typically the sound power of capacitors filter banks range between 70 to 90 dBA (ref 10^{-12}W) similar to a car driving past, but can reach up to 100 dBA comparable to a compressed air hammer for large HVDC filters.
Noise assessment

In the designing of a substation, the assessment of the audible noise is of great importance to the project. This task comprises the use of a suitable model for the sound propagation from the source to the receiver, where topology, ground types, atmospheric conditions and obstacles to the noise propagation are included. The sources are characterized by their sound power level, geometry and sound directivity, whereby the latter is sometimes omitted in the modelling of sources but in the case of the capacitor banks it must be included in order to create a representative acoustic model. The Siemens calculation method for noise assessment is based on the following international regulations:

- **ISO1996 – Description, measurement and assessment of environmental noise**
  A methodology for the environmental noise assessment and guidance on predicting the potential annoyance response of a community to long-term exposure can be found in the international standard *ISO1996 – Description, measurement and assessment of environmental noise*. For example a penalty may be added to the continuous noise levels generated by the capacitors bank due to its tonal characteristics. The tonal content of the capacitor bank is composed of sound harmonics from 50 Hz up to 5 kHz, depending on the harmonic voltages spectrum.
  It is important to notice that the noise assessment is subjected to local regulations; therefore it may differ from the mentioned international standard.

- **ISO9613 – Attenuation of sound during propagation outdoor**
  The computation of the sound levels can be carried out with the method described in the international standard *ISO9613 – Attenuation of sound during propagation outdoor*. The method called ray-tracing breaks down sources into finite-size sources and calculates the individual contribution to a given point (receiver). Attenuation due to distance, atmospheric absorption, soil absorption, reflections and diffraction may be taken into account.

Summary

Now the developed calculation method for audible noise in high voltage power capacitors based on international standard and under consideration of electrical and mechanical constrains as well as local environmental conditions offers the opportunity to evaluate the possible noise level in the design phase of a project. This is the first step forward to improve the equipment design of the power capacitors in order to reduce the noise level in the environment.