Active noise control in practice: transformer station

H. Buikema
Peutz bv, postbus 66, 6585 ZH, Mook, The Netherlands
F.D. Van der Ploeg
Peutz bv, postbus 66, 6585 ZH, Mook, The Netherlands

Summary
Based on literature and extensive measurements at a specific transformer two concepts regarding acitve noise control have been developed. These concepts have been tested in the Peutz acoustical laboratory, and on site with an experimental setup for active noise control at large transformers. Noise measurements show that a reduction of 5 dB can be achieved in all directions. Additionally, by directing the noise emission, a reduction of 10 dB can be achieved in one specific direction. This experimental project was part of a broader demonstration project regarding the practical application of different types of sensor technology.

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1. Introduction[1]

From literature few examples of application of active noise control in real practical situations are available. Therefore the practical application of active noise control was introduced in the so-called "Sensor City" program. The aim of this program is to stimulate the use of sensors in a broad scope (not only for sound) and in a variety of practical cases, and if possible in combination with each other. This active noise control projects fits within this research program because of the application of sensors for measuring sound and vibration.

2. Aim of the research

The aim of this specific research was to obtain an understanding into the effects of active noise control at large noise sources outdoors and at long distances by the application of specific sensor techniques.
At present, no commercially available active noise control systems designed specifically for large transformers are known.

Origin of transformer noise
The main installations in transformer stations are the transformers themselves. Often so-called three-phase-transformers are used (see figure 2.1). These consist of three coils, each fitted with an iron core.
There are two major sources of transformer noise. The characteristic noise of transformers is caused by magnetostriction: the expansion and contraction within the stacked iron core (laminates) due to the magnetic effect of alternating current flowing through the transformer coils. These extensions and contractions occur twice during each complete cycle of the alternating current flowing through the coil (in Europe 50 Hz). This causes an audible hum. To some extent magnetostriction can be reduced by adequate transformer design, but it cannot be totally eliminated. The other cause of noise are mechanical vibrations. This usually results from vibrations emanating from the core that are transferred to parts of the installation that are attached to it.

In practice, it is a challenge to reduce the noise of a transformer. The transformers are often already equipped with concrete walls on two or three sides. These walls should prevent the transformers being hit by flying debris in case of an explosion of one of the installations. Of course, these walls also act as a sound barrier. If more noise reduction is needed, problems arise.
Often noise from the top side of a tansformator can not be reduced, because of the high voltage power lines. In addition, if the open front side of a

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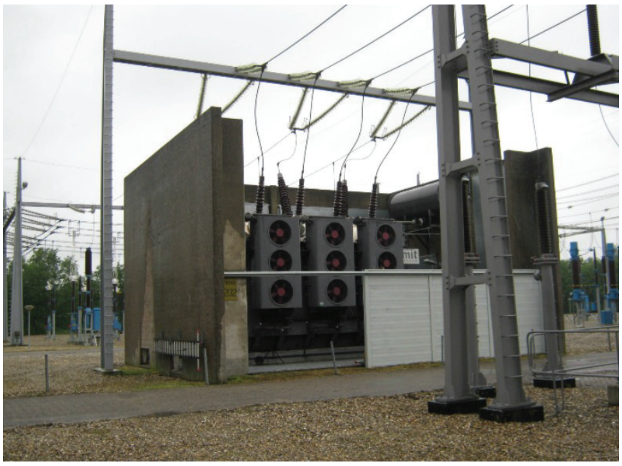
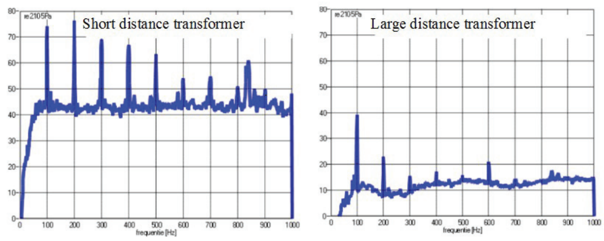
transformer would be provided with a screen, problems may arise regarding the cooling of the transformer and therefore this is often not possible. Therefore, active noise control is an interesting alternative to reduce the noise emission of transformers.



2.1. Transformer

Noise measurements
At a short distance frequencies of 100 Hz and 200 Hz are dominant but also the higher modes (300, 400 and 500 Hz) are clearly present. At a further distance mainly the mode of 100 Hz and – although slightly less - the 200 Hz are dominant. Because of the measurement results at further distance the focus was on reducing noise around 100 Hz.

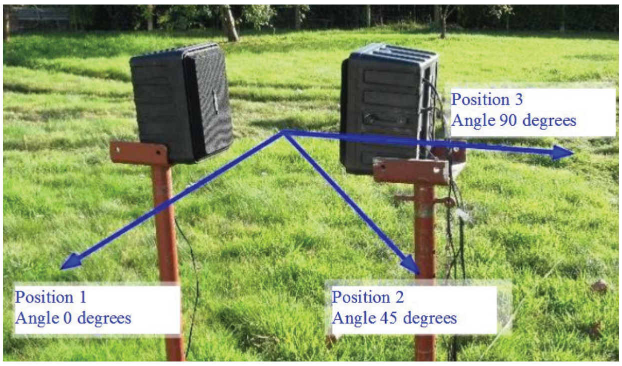


2.2. Measurement in dB(A)

3. Test set-up

General
Based on a close look on the noise characteristics of the specific transformer, literature study and detailed noise measurements of a transformer two concepts of active noise control were designed. At first, both concepts were tested under laboratory conditions in the Peutz laboratory. Then the test was continued in practice at a power station. Because of the spectrum of the noise levels near dwellings at about 100 m distance the focus was on 100 Hz (see figure 2.2).

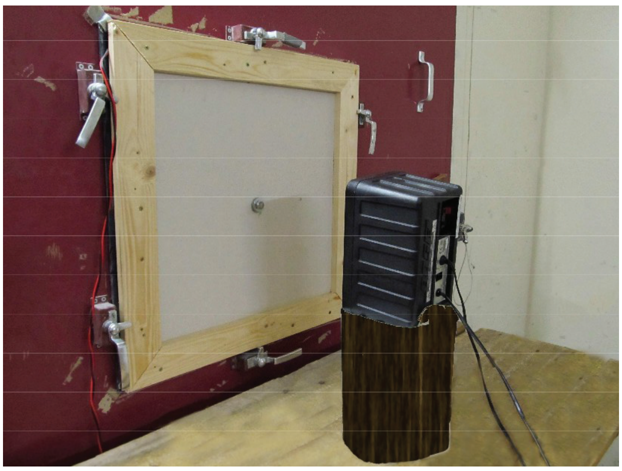
Laboratory tests
The practical possibilities of active noise control were tested with two small loudspeakers, at short distance from each other. Figure 3 shows the practical set-up.



3.1. Test set-up with two identical speakers

Both loudspeakers were connected to a computer by which frequency, phase and amplitude could be regulated. The distance between the loudspeakers was varied, and the noise reduction was measured in three directions. The achieved noise reduction varied between 8 and 13 dB; the latter value if the loudspeakers were facing each other.

In another experiment in the laboratory vibrations were generated in a plasterboard panel by means of an exciter. This plasterboard panel (dimensions 0.45 x 0.45 m, thickness 12.5 mm) was meant to simulate a vibrating part of the transformer. The dimension of this panel was chosen in such a way that the whole panel would vibrate in phase when excited at 100 Hz.
Both a small and a large loudspeaker were placed near this vibrating panel. Figure 3.2 shows the test with the smaller loudspeaker.



3.2. Laboratory set-up with vibrating panel

From these tests it appeared that reduction of the noise emission was possible with both types of loudspeaker, reaching the values that could be achieved theoretically. Reductions of 8 to 9 dB were measured. The tests as described above are not adaptive. In practice, with transformer variations due to changes in load and/or temperature influence the noise emission to the environment. So an adaptive system is required, with a unit that regulates both phase and amplitude. A possible location of the microphone for this purpose is between the vibrating panel and the loudspeaker. The optimal location of the microphone appeared to be at the center between the vibrating panel and the loudspeaker.

4. Test in practice

First concept
For the purposes of the first concept, a number of small loudspeakers are applied at a distance of approximately 30 centimeters from the loudest parts of the housing of the transformer. In figure 4.1 two loudspeakers are shown.

4.1. Speakers at short distance from transformer

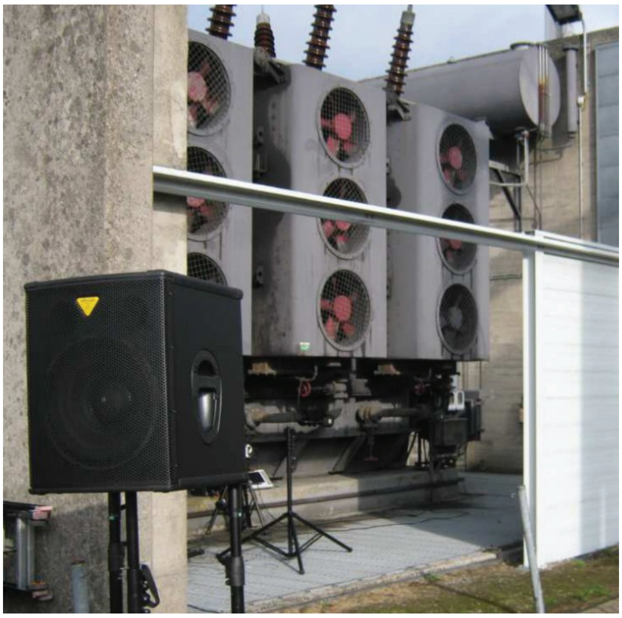
These loudest parts of the transformer are determined based on sound-intensity measurements. These sound-intensity measurements have been performed several times on different days and at different times. It has been found that the location of the loudest parts of the housing does not change either under various conditions and changing load of the transformer. Thus, there is no shift to be seen where other parts of the housing are more important for the noise emission at different times. This allows speakers to be applied at a short distance and at fixed positions from the loudest parts of the transformer.

For the purpose of the test set-up, five loudspeakers were used. Each loudspeaker is driven on the basis of its own vibration sensor and microphone. In the overall arrangement there were five loudspeakers, five microphones and five vibration sensors. Data acquisition cards have been used to digitize the signals from the microphones and vibration sensors.

These digitized signals are the input signals for the control system which is installed on a laptop. Finally the system drives the loudspeakers. Based on the signal from the vibration sensor, the phase and the frequency are determined. This vibration sensor is mounted on the housing of the transformer, at the loud part just in front of the loudspeaker. Important fact is that the system should be able to respond rapidly to frequency changes. It has been found that the frequency of the transformer is not stable but that it fluctuates relatively rapidly in time at around 100 Hz (band width of only about 0.2 Hz). If the system does not respond fast enough beating of the sound arises (the noise cancellation is not offered at the exact same frequency), which makes the noise situation rather more annoying.

The microphone is placed between the casing of the transformer and the loudspeaker. Based on the information from the microphone the volume of the loudspeaker is set. This set-up requires a less quick response because the noise from the casing of the transformer is relatively constant over time and slowly fluctuates around an average value. Since each loudspeaker used is controlled autonomously, the system can easily be expanded with multiple loudspeakers. In practice it has been found that the systems hardly influence each other. Therefore, even if two sound reducing loudspeakers are located at a short distance next to each other, there is no question of mutual influence and this has no effect on the overall sound reduction. In fact, if more loudspeakers are used, the final reduction will be higher.

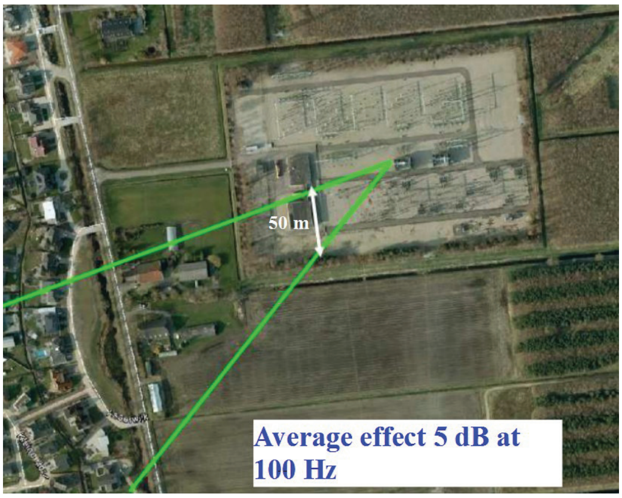
Second concept
The second concept consists of a single loudspeaker located on a stand with a height of approximately 2 m at a distance of about 8 m from the transformer; see figure 4.2.



4.2. speaker at larger distance from transformer

The frequency is determined by the signal from a vibration sensor, mounted on the housing of the transformer. A microphone is placed at a distance of approximately 15 meters from the loudspeaker, in the direction of the nearest dwellings. Based on the signal from this microphone, the phase and volume are set, the target is to minimize the sound pressure level at 100 Hz at the location of this microphone. Based on measurements the area with effective noise reduction by active noise control was determined. It can be argued that such a system is only suitable if a significant "quiet area" is created by active noise control from which one or more dwellings could benefit. A disadvantage of this second concept is that the sound level can increase at other locations.

Results
With the first concept (five small loudspeakers at short distance from the transformer) the obtained reduction at 100 Hz was 3 to 6 dB in all directions. However, more reduction is possible if more loudspeakers are used because more radiating parts of the transformer can be treated by such a system. With the second concept (loudspeakers at further distance) an additional average reduction of 5 dB was obtained at 100 m distance. Measurements were performed in a straight line over a distance of about 50 m with mutual distance of approximately every 3 m; see figure 4.3.



4.3. Average effect of second concept active noise control

The reductions at these positions varied between 3 to 15 dB, on average 5 dB. So reduction is achieved in a significant area and not only at a specific point.

5. Conclusions

Active noise control creates a significant reduction of transformer noise. With the combination of both concepts (loudspeakers at short respectively longer distance from the transformer) a reduction of 10 dB at 100 Hz can be obtained at certain dwellings at about 100 m distance.

6. Acknowledgment

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