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ARTICLE

NOISE GENERATION MECHANISM AND NOISE REDUCTION MEASURES OF HIGH VOLTAGE FILTER CAPACITOR

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ABSTRACT

High voltage filter capacitors are crucial components in power electronic systems, enabling efficient energy transfer while suppressing unwanted noise. However, these capacitors can generate noise that affects the overall performance and reliability of the system. This article explores the noise generation mechanism associated with high voltage. By understanding the underlying noise generation mechanisms and implementing effective noise reduction measures, the performance and reliability of high voltage filter capacitors can be improved in power electronic systems. This article serves as important reference for professionals in the field seeking to mitigate noise issues associated with high voltage filter capacitors and optimize system performance.

KEYWORDS

Filter capacitors, generation mechanism, audible noise, High Voltage Direct Current Transmission (HVDC), reduction measures

1. THE IMPORTANCE OF HIGH VOLTAGE FILTER CAPACITOR NOISE REDUCTION

The importance of high voltage filter capacitor noise reduction in a power system can be understood by considering the impacts on system reliability and equipment protection

1.1 Improving system reliability

(1) Noise generated by high voltage filter capacitors can propagate through the power system and interfere with the operation of sensitive equipment, such as control systems, communication systems, and measurement devices.

(2) Excessive noise can disrupt the proper functioning of these systems, leading to incorrect readings, communication errors, or even system failures.

(3) By reducing noise, the reliability of the power system is improved, ensuring stable and accurate operation of critical components. This helps prevent disruptions, minimize downtime, and maintain overall system performance [1].

1.2 Protecting equipment

(1) High voltage noise can impose stress on equipment, particularly sensitive electronic components, and result in accelerated wear or damage over time. This can lead to premature equipment failures and increased maintenance costs.

(2) Excessive noise can induce voltage spikes or transients that surpass the voltage rating of equipment, causing insulation breakdown, arcing, or component burnout.

By reducing noise in high voltage filter capacitors, equipment is safeguarded from these detrimental effects, prolonging their lifespan and reducing the risk of costly repairs or replacements.

(3) Noise reduction also helps in complying with safety standards and regulations by minimizing the risk of electrical disturbances that could harm personnel or other equipment in the vicinity.

Overall, high voltage filter capacitor noise reduction in a power system is crucial for ensuring reliable and uninterrupted operation, minimizing the risk of equipment failures, and maintaining compliance with safety standards. It helps protect sensitive equipment, extends equipment lifespan, and contributes to the overall stability and efficiency of the power system.

2. THE EVALUATION OF FILTER CAPACITOR NOISE

The evaluation of filter capacitor noise should include two aspects: the assessment of sound power and the evaluation of sound pressure distribution. Sound power is used to evaluate the noise-generating capability of the filter capacitor unit. Sound pressure distribution, on the other hand, is assessed by considering the sound pressure levels in noise-sensitive areas (such as factory boundaries). It is typically used to evaluate the capacitor device or the entire filtering system.

2.1 Sound pressure (P)

Sound pressure is the increase in pressure caused by the presence of sound waves, representing the difference between the pressure in the medium when sound waves are present and the static pressure. It is measured in Pascal (Pa). The electrostatic force F(t) of a capacitor is proportional to the square of the amplitude of the applied current. This force induces vibration of the capacitor casing and leads to the emission of noise. Additionally, the frequency of the vibration and noise is twice the frequency of the power source. The sound pressure level of the noise radiated by the casing vibration is $L_P = 20 1g(p / p_0)$ [2].

In the equation, p_0 represents the reference sound pressure, where p_0 is equal to $2×10^{-5}$ Pa. The variable p represents the sound pressure generated by the casing vibration.

2.2 Sound power (W)

Sound power refers to the amount of acoustic energy propagated through a specified area perpendicular to the direction of sound propagation per unit time. In noise monitoring, sound power refers to the total power emitted by a sound source, representing the acoustic energy radiated outward by the source per unit time. Sometimes, sound power of a source specifically refers to the power within a certain frequency band, in which case the frequency range should be specified [3]. In noise detection, sound power refers to the total power emitted by the sound source. The unit of sound power is watts (W) [4].

3. THE GENERATION PRINCIPLE OF HIGH VOLTAGE FILTER CAPACITOR NOISE

3.1 Thermal noise

High voltage filter capacitors, similar to regular capacitors, generate thermal noise due to the random thermal motion of electrons within the conducting materials. The magnitude of thermal noise is directly related to the temperature and resistance of the capacitor’s conductive materials. In the case of high voltage capacitors, the larger voltage levels can lead to higher power dissipation, resulting in increased temperature and potentially amplified thermal noise.

3.2 Dielectric absorption

Dielectric absorption in high voltage filter capacitors is also a significant factor contributing to noise generation. When a high voltage is applied across the capacitor, the dielectric material stores energy. However, due to the larger voltage levels, the electric field strength within the dielectric can be higher, leading to increased dielectric absorption. This can result in slower discharge and voltage variations when the voltage is removed, contributing to noise [5].

3.3 Partial discharge

In high voltage applications, another factor to consider is the phenomenon of partial discharge. Partial discharge refers to localized electrical discharges that can occur within the dielectric material of the capacitor. These discharges can be caused by imperfections, voids, or impurities within the dielectric, which can lead to rapid voltage changes and subsequent noise generation.

3.4 Electromagnetic Interference (EMI)

High voltage filter capacitors can also contribute to electromagnetic interference (EMI) noise. When the high voltage current passes through the capacitor, it can generate electromagnetic fields, leading to electromagnetic radiation. This radiation can interfere with nearby components or circuits, resulting in noise pickup or coupling.

It’s worth noting that the noise generated by high voltage filter capacitors can be more significant compared to low voltage capacitors due to the increased voltage levels and associated effects. Therefore, careful selection of capacitors with appropriate ratings, such as voltage rating, capacitance stability, and low ESR (Equivalent Series Resistance), becomes crucial to minimize noise in high voltage applications.

4. REDUCTION MEASURE OF HIGH VOLTAGE FILTER CAPACITOR NOISE

Reduction measures for high voltage filter capacitor noise can be categorized into internal noise reduction measures and external noise reduction measures.

4.1 Internal noise reduction measures

Firstly, the principle of internal noise reduction will be introduced, followed by an introduction to the method of internal noise reduction.

4.1.1 Principles of internal noise reduction

CIGRE put forward three principles to reduce the noise:

(1) Increasing capacitor components connected in series: When capacitors are connected in series, the total voltage across the capacitors is divided among them. This reduces the voltage stress on each individual capacitor, including the dielectric stress. By reducing the dielectric stress, the likelihood of noise generation due to mechanical vibrations is also reduced. This method can help minimize the vibration force acting on each capacitor, resulting in reduced noise levels.

(2) Improving mechanical damping: Mechanical damping refers to the ability of a material or structure to dissipate vibrations or oscillations. By enhancing the mechanical damping properties of the capacitor component package, you can increase its stiffness. This helps dampen mechanical vibrations and reduces the likelihood of noise generation. Compact packaging of the capacitor components can enhance the overall mechanical damping characteristics, which contributes to noise reduction.

(3) Considering resonant frequency while designing the capacitor: Resonant frequency is an important consideration in capacitor design for noise reduction. When the natural frequency of a capacitor coincides with an external excitation frequency, resonance can occur, leading to increased vibration amplitudes and noise generation. By carefully designing the capacitor to have a resonant frequency outside the expected operating frequencies or by using damping techniques to shift the resonant frequency away from the operating range, the risk of noise due to resonance can be minimized [6].

4.1.2 Internal noise reduction specific methods

Researchers have proposed and designed a low-noise power capacitor based on a composite micro-perforated panel sound absorption structure, targeting the main noise frequencies of the capacitor. The proposed low-noise structure exhibits good sound absorption performance for mid-to-low-frequency noise. However, this structure can only reduce noise within specific frequency bands and lacks parameterization. For exported capacitor products, there is a significant amount of harmonic generation in high-voltage transmission systems, which primarily produces noise in the high-frequency range [7]. The applicability of this method does not meet the requirements of capacitor manufacturers [8].

In addition, WU Peng, et al. have studied the sound absorption characteristics of CSC (Composite Silicon Carbide) components and developed a low-noise capacitor structure based on the CSC design. This structure controls a wider vibration frequency range compared to regular capacitors, resulting in a reduction of more than 10 dB in sound pressure level at the bottom [9]. However, the rubber components of the structure are prone to aging and wear, which may lead to internal fluid leakage, posing safety risks for capacitor products [10].

Furthermore, researchers have achieved good vibration reduction by incorporating corrugated tube dampers between the core of the capacitor and the capacitor housing. The damping effect is particularly significant at the bottom of the capacitor, with a noise reduction of up to 7-9 dB. Corrugated tube dampers effectively reduce noise at the bottom of the capacitor. However, the long-term reliability of this structure during operation is difficult to verify, and there are potential safety concerns, making it challenging to implement in practical engineering applications.

4.2 External noise reduction measures

Currently, the main strategy for external noise reduction in capacitors is to add damping structures on the bottom and top surfaces. By designing a double-bottom low-noise capacitor, where a sealed air cavity is welded to the bottom of the capacitor, experimental results have shown that the noise level at the bottom is reduced by 8-15 dB compared to regular capacitors. This structure is currently considered an effective method for reducing bottom surface noise [11].

5. CONCLUSION

Currently, research on the generation principle of capacitor noise is still limited, and the fundamental mechanism behind its noise generation and the construction of a physical model for vibration and noise transmission have not been fully revealed. Cox, through practical measurements, discovered that the frequency of vibration and noise on the capacitor casing is equal to the frequency of electrostatic forces between the capacitor plates. Based on this analysis, it is concluded that electrostatic forces act as the excitation source for capacitor vibration and noise. However, it should be noted that Cox's analysis of the capacitor casing modes is a simplified approach. The capacitor casing can be viewed as a structure, and its modal parameters can be obtained through calculations or experiments [12]. However, the premise of the above conclusion is that there are no residual charges on the dielectric film of the capacitor. Therefore, there is still a lack of research on the residual charges on the dielectric film interface and the internal vibration mechanism of the capacitor component. If a more comprehensive modeling of the noise generation mechanism of transformers can be achieved, it will facilitate the further refinement of noise reduction measures for capacitors, thereby further reducing the noise level [13].

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