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A REVIEW ON VARIOUS HARMONIC REDUCTION TECHNIQUES IN TRANSFORMER

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Abstract - Harmonics in transformers have become a critical concern due to the increasing penetration of nonlinear loads, power electronic converters, and renewable energy systems in modern power networks. Excessive harmonic distortion leads to additional copper and core losses, overheating, derating of transformers, reduced efficiency, and compromised power quality. To address these challenges, researchers have proposed a wide range of harmonic mitigation techniques over the past decades. This review paper presents a comprehensive study of various harmonic reduction methods applied in transformers, including design-based approaches such as winding configurations, phase-shifting techniques, and use of K-factor rated transformers, as well as external solutions like passive filters, active filters, hybrid filters, and advanced modulation strategies. The strengths, limitations, and application suitability of each technique are discussed to provide a comparative understanding. Furthermore, the review highlights recent advancements that integrate artificial intelligence and optimization algorithms for adaptive harmonic mitigation. This study aims to guide engineers and researchers in selecting appropriate harmonic reduction strategies for enhancing transformer reliability, efficiency, and service life in power systems.

Keywords: Harmonic distortion, transformer efficiency, power quality improvement, phase-shifting transformers, K-factor rating, passive filtering, active filtering, hybrid filtering, AI-based harmonic mitigation.

1. INTRODUCTION

Transformers play a pivotal role in electrical power systems, ensuring efficient voltage regulation and facilitating power transmission across long distances. Their fundamental purpose is to convert voltage levels up or down to match the requirements of different parts of the system, from generation to distribution to end-users. Traditionally, transformers were designed to operate in environments dominated by linear loads where current and voltage waveforms remained largely sinusoidal. However, the modern power grid has evolved significantly, and so have its challenges.

With the proliferation of power electronics, automation, and industrial drives, the nature of electrical loads has become increasingly non-linear. Equipment such as computers, variable frequency drives (VFDS), rectifiers, electric vehicle chargers, and inverters introduce harmonics into the power system. These harmonics are voltage or current components that exist at frequencies which are integer multiples of the system's fundamental frequency (typically 50 or 60 HZ). As a result, transformers are now frequently subjected to distorted waveforms, which they were not originally designed to handle.

The consequences of harmonic distortion in transformers can be severe. It leads to increased core and copper losses, elevated operating Temperatures, derating of equipment, and potential thermal degradation of insulation materials.

Harmonics can also interact with system impedance and resonance points, causing over voltages and additional stress on components. Furthermore, the presence of harmonics degrades power quality, which is critical in sensitive installations such as hospitals, data centers, and process industries.

Given the importance of maintaining transformer performance and reliability, it has become imperative to implement effective harmonic reduction techniques. These techniques range from transformer design modifications (like delta-wye connections and k-rated windings) to system-level interventions using passive and active filters. With power systems becoming more complex and interconnected, addressing harmonic issues is not only a matter of efficiency but also of safety and regulatory compliance.

This paper provides an in-depth overview of the sources and effects of harmonics in transformers and discusses a variety of mitigation strategies currently used in the field. By analyzing both conventional and advanced harmonic suppression methods, this study aims to support the selection of optimal solutions for different application scenarios.

Types of harmonics in transformers:

- Odd and even harmonics
- Sequence harmonics (in three-phase systems)
- Other classifications
- Transformers harmonics

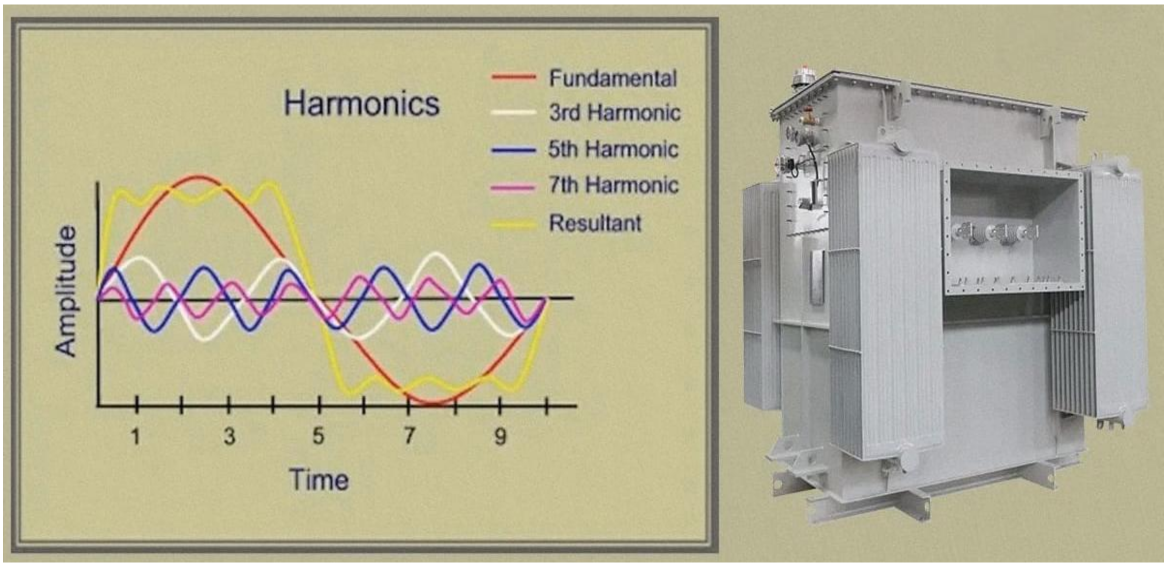

Fig. 1.1 Transformer Harmonics

2. EFFECT OF HARMONIC IN TRANSFORMER

Harmonics in transformers cause increased heating due to additional core and copper losses, leading to reduced efficiency and shorter lifespan. They can also overload the neutral conductor, distort voltage waveforms, and interfere with protection devices. In severe cases, harmonics may cause insulation failure and audible noise.

2.1 Increased Heating and Losses

Harmonics, especially higher-order frequencies, cause additional eddy currents and hysteresis losses in the transformer's core and windings.
These losses increase exponentially with frequency (eddy current losses $\propto f^2$).
Result: overheating, this can reduce insulation life and cause premature failure.

2.2 Reduced Efficiency

Harmonic currents waste energy through increased i^2r losses in the windings and magnetic losses in the core.
Leads to lower power factors and reduced system efficiency.

2.3 Magnetic Core Saturation

Harmonics can distort the magnetic flux waveform, especially even harmonics (like the 2nd), leading to core saturation.
Core saturation increases magnetizing current and can cause excessive noise and overheating.

2.4 Neutral Conductor Overloading

Triplen harmonics (3rd, 9th, 15th) add arithmetically in the neutral wire of a wye system.
This can cause neutral overheating or even melting of the conductor, especially in office buildings or data centers.

2.5 Insulation Stress and Aging

Harmonic-induced heating increases the thermal stress on insulation, accelerating its aging.
Reduces transformer life expectancy significantly.

2.6 Overestimation of Capacity

Transformers not rated for harmonics may appear to handle a load properly (based on KVA), but excessive harmonic current derates actual capacity.
May require k-rated transformers to handle harmonic-rich loads. **Audible noise and vibration**
Harmonics can cause magnetostriction and vibrations in the core, resulting in a humor buzzing sound, especially at multiples of the line frequency.

2.8 Interference with Protection Devices

Harmonics can affect CTS relays, and metering devices, causing false tripping or mis operation of protection systems.

3. HARMONIC REDUCTION TECHNIQUES IN TRANSFORMERS

K-factor rated transformers: designed to withstand high harmonic content by minimizing additional heating.

Special windings and core materials are used to handle the stress caused by harmonics.

Fig. 3.1 K-factor rated Transformers

Phase-shifting transformers: used in parallel with rectifiers to cancel harmonics by creating phase shifts. Typically employed in 12-pulse or 24-pulse systems where the harmonic orders get canceled naturally.

Fig. 3.2 Phase-shifting Transformer

Zig-zag transformers: provide grounding and reduce triple harmonics (3rd, 9th, etc.). Often used in distribution systems to enhance neutral stability and suppress neutral current harmonics.

Fig. 3.3 Zig-zag Transformers

Multi-pulse transformers: multi-winding transformers designed to feed multiples rectifier systems. Reduces low-order harmonics by vector cancellation of harmonic components.

Fig. 3.4 Multi-Pulse transformers

Passive filters: combinations of resistors, inductors, and capacitors connected at transformer input/output to attenuate specific harmonic frequencies. Cost-effective but bulky.

Fig. 3.5 Passive Filters

Active filters: power electronic-based dynamic filters that detect and inject compensating harmonics in real time. They provide precise control but are expensive and complex

Fig. 3.6 Active filters

Magnetic shielding and flux management: advanced core designs and magnetic shielding techniques help minimize leakage flux and flux distortion, thereby reducing harmonic propagation.

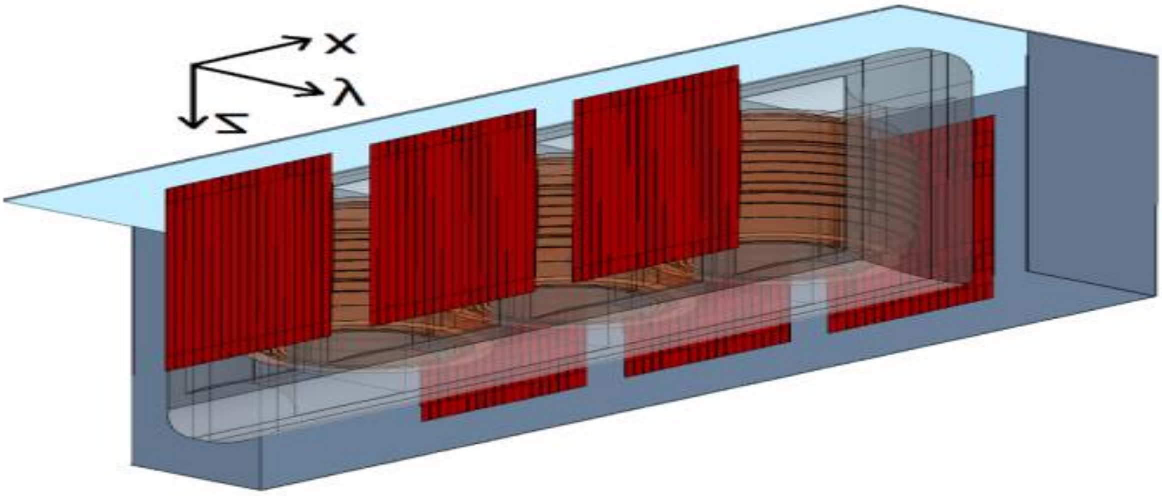

Fig. 3.7 Magnetic shielding and flux Management

4. ADVANTAGES OF HARMONIC REDUCTION IN TRANSFORMERS

Harmonic reduction improves the overall efficiency of transformers by minimizing additional eddy current and core losses caused by distorted waveforms. It reduces unnecessary heating of the transformer windings and core, which helps in maintaining safe operating temperatures.

By lowering thermal stress and minimizing insulation degradation, the operational lifespan of the transformer is significantly extended. It enhances voltage regulation, ensuring a more stable and consistent voltage supply to connected electrical equipment.

Harmonic mitigation helps in complying with international power quality standards like IEEE 519 and IEC norms, avoiding regulatory issues.

It can lead to an improved power factor when harmonics are filtered, particularly in systems that use capacitive compensation. Sensitive electronic devices downstream are better protected from malfunctions or damage caused by harmonic distortions. The transformer operates more quietly with reduced mechanical vibrations and audible noise that are typically induced by harmonics. Maintenance costs are reduced as there is less wear and tear on transformer components due to decreased thermal and electrical stress. Harmonic reduction increases the usable load capacity of the transformer and the entire power system, allowing more efficient utilization of equipment.

CONCLUSION

Transformers, as indispensable components in power systems, face increasing challenges due to the rise of nonlinear loads and associated harmonic distortions. These harmonics, if left unaddressed, can significantly impair transformer performance by causing overheating, insulation degradation, reduced efficiency, and interference with protection and control systems. The consequences are not just technical but also economic, with increased maintenance, reduced equipment lifespan, and potential system failures.

This paper has outlined the nature and impact of harmonics on transformers, highlighting how harmonics arise from modern electronic equipment and how they manifest within power systems. It categorizes the types of harmonics and their specific effects on transformer operation. To counteract these issues, a range of harmonic reduction techniques was discussed—from transformer design enhancements like k-rated and phase-shifting configurations, to system-level solutions such as passive and active filters. Implementing effective harmonic mitigation strategies leads to improved transformer efficiency, enhanced system reliability, longer service life, and better compliance with power quality standards. As the global shift toward smart grids, electric mobility, and renewable energy integration continues, harmonic mitigation becomes increasingly essential. Therefore, selecting the appropriate technique based on load characteristics, system configuration, and cost considerations is critical for sustainable and reliable transformer operation. Ultimately, a proactive approach to harmonic reduction not only protects transformer infrastructure but also ensures a high-performance, resilient power system for the future.

FUTURE SCOPE

With the rising use of nonlinear loads, electric vehicles, and renewable energy sources, harmonic distortion in power systems is expected to increase. Future transformers will need smarter, more adaptive solutions to maintain performance and reliability.

Key areas of future development include:

- Smart transformers with real-time harmonic detection and self-adjusting capabilities.
- Advanced core materials like amorphous alloys to reduce harmonic-related losses.
- Adaptive hybrid filters that respond dynamically to changing load conditions.
- Integration with renewable sources to handle harmonics from solar and wind systems.
- Digital simulation tools and ai to predict harmonic behavior and optimize designs.

These advancements will ensure safer, more efficient, and future-ready transformer systems.

REFERENCES

[1] IEEE std 519-2014 - recommended practice and requirements for harmonic control in electrical power systems.
[2] Bollen, M.H.J. (2000) - understanding power quality problems.
[3] Arrillaga, J. Watson, N.R. (2003) - power system harmonics.
[4] KunderP. (1994) - power system stability and control.
[5] Grady, W.M. (1999). Understanding Power System Harmonics. IEEE Power Engineering Review.
[6] et. al., S. V. . . (2021). Life Extension of Transformer Mineral Oil Using AI-Based Strategy for Reduction of Oxidative Products. Turkish Journal of Computer and Mathematics Education (TURCOMAT), 12(11), 264–271. https://doi.org/10.17762/turcomat.v12i11.5869.
[7] Verma, C., Jangid, R. “Smart Household Demand Response Scheduling with Renewable Energy Resources”, IEEE Third International Conference on Intelligent Computing and Control System (ICICCS-2019), Organized by Vaigai College of Engineering during May 15-17, 2019 at Madurai, India. (Scopus index) DOI: 10.1109/ICCS45141.2019.9065908
[8] M. Halpin, T. A. Short. (2003). Designing Transformers for Nonlinear Load Applications. IEEE Transactions on Industry Application