# COMPARATIVE ANALYSIS OF METHODS OF REDUCING ELECTROMAGNETIC EFFECTS OF POWER TRANSFORMERS

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**Abstract** The article provides a comparative analysis of methods for reducing the electromagnetic effects of power transformers and demonstrates the potential for achieving significant improvements by simultaneously employing high-quality insulation, electromagnetic shielding, superior magnetic materials, and optimized load management.

**Keywords:** power transformer, electromagnetic influence, electromagnetic compatibility, isolation, electromagnetic shielding, load optimization.

# СРАВНИТЕЛЬНЫЙ АНАЛИЗ МЕТОДОВ СНИЖЕНИЯ ЭЛЕКТРОМАГНИТНЫХ ВОЗДЕЙСТВИЙ СИЛОВЫХ ТРАНСФОРМАТОРОВ

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**Аннотация** В статье проведен сравнительный анализ методов снижения электромагнитных воздействий силовых трансформаторов и обоснована возможность достижения высоких результатов за счет одновременного использования высококачественных изоляций, электромагнитного экранирования, использования высококачественных магнитных материалов и процессов оптимизации нагрузки.

**Ключевые слова:** силовой трансформатор, электромагнитное воздействие, электромагнитная совместимость, изоляция, электромагнитное экранирование, оптимизация нагрузки.

Power transformers are one of the main devices of modern electrical engineering and energy systems, playing an important role in providing consumers with high-quality electricity. When designing a power supply system, it is essential to consider the adverse effects of power transformers on other components, including electromagnetic interference, energy losses, and overheating. Furthermore, minimizing the electromagnetic effects of power transformers enhances the efficiency of the power supply system and reduces energy losses.

In power transformers, the use of high-quality insulation, electromagnetic shielding of systems, the use of high-quality magnetic materials for the magnetic core, and load optimization play an important role in reducing electromagnetic influences. In order to conduct research aimed not only at improving the technical characteristics of transformers, but also at reducing their negative impact on the environment and identifying the processes of their effective use, we will analyze the most common methods aimed at reducing the electromagnetic effects of transformers, dividing them into 4 large groups (Fig. 1).

*1. Use of high-quality insulation.* The insulation used to mitigate the electromagnetic effects of power transformers must be carefully selected based on the transformer's technical specifications. It should be composed of high-quality dielectric materials and installed following the necessary standards. The types of insulation materials used between different transmission parts of transformers are selected differently depending on the operating conditions, power, and purpose of the transformer. In most cases, transformers use various types of insulation, such as pressed hard paper (cellulose) saturated with

transformer oil resistant to high temperatures (155 °C-180 °C) and voltages (110 kV, 220 kV, 330 kV, 500 kV), synthetically produced special transformer oils (T-1500U, T-1500, TKp, TSp, MVT, GK, VG AGK) with high electrical resistance in the form of liquid, epoxy alloys (resins) in the form of plastics (Table 1).

*Table 1*

| № | Insulating material | Transformer power and application voltage, MVA/kV/kV | | | | |
|---|---|---|---|---|---|---|
| | | **25/10/0.4** | **40/35/10** | **63/110/35** | **100/110/35** | **160/500/110** |
| 1. | Liquid insulation | + | + | + | + | + |
| 2. | Silicone rubber | - | - | + | + | + |
| 3. | Paper-oil insulation | + | - | - | - | - |
| 4. | Cast insulation | + | - | - | - | - |
| 5. | Hard insulation | + | + | + | + | + |
| 6. | Gas insulation | - | + | + | + | + |

According to the results of the analysis, it was established that by using high-quality insulation in power transformers, it is possible to achieve a reduction in energy losses from 5% to 20%.

*2. Electromagnetic shielding.* Installing electromagnetic shields around the transformer helps restrict the spread of magnetic fields into the surrounding environment. Copper foil and magnetic materials (aluminum, brass, copper, permalloy 79NM) with a thickness of 0.5 mm are widely used for electromagnetic shielding. Compared to other techniques, this method is highly effective in reducing electromagnetic interference in adjacent devices. Electromagnetic shielding is carried out by active and passive methods (Table 2).

Active shielding refers to methods that counteract electromagnetic fields by generating an opposing field. Through active shielding, an active counter field is created to minimize or completely eliminate the electromagnetic field, thereby increasing the efficiency of transformers, reducing electromagnetic influences, and eliminating negative electromagnetic influences on devices located near the transformer. To create an opposite field on the screen to the electromagnetic effects arising in the transformer, special sensors are installed to determine the value of the electromagnetic field in it, and the general electromagnetic effect is reduced by creating a field in the opposite phase to the detected electromagnetic field. By applying active shielding technology in transformers, it is possible to save electrical energy and increase the efficiency of the transformer due to the reduction of external electromagnetic influence. Active screening is advantageous over passive screening due to its high efficiency, relatively compact screen dimensions, and the possibility of minimizing electromagnetic fields. **Despite the fact that active screening has a number of advantages over other screening systems, due to the complexity of the design, the need to install complex and high-tech equipment during the installation process, the initial costs of manufacturing and installing such systems are high, and at the same time, an additional source of electrical energy is required to create an opposite electromagnetic field.**

Passive shielding involves reducing electromagnetic fields by adding multiple shielding layers within transformers. Shielding materials used in passive screening (steel, nickel, permalloy 79NM, unsoftened permalloy) have high electromagnetic conductivity and reduce field effects by converting electromagnetic field energy into thermal energy. For the installation of a passive shielding system in power transformers, a layer of copper or aluminum metal coating with high conductivity is installed on the outer body of the transformer. Passive screening is one of the reliable and effective methods of controlling electromagnetic fields in power supply system devices, and by choosing the appropriate material and design during screening, it is possible to reduce electromagnetic impact and further increase the reliability of device operation. This technology can now be widely used in industry and the domestic sphere.

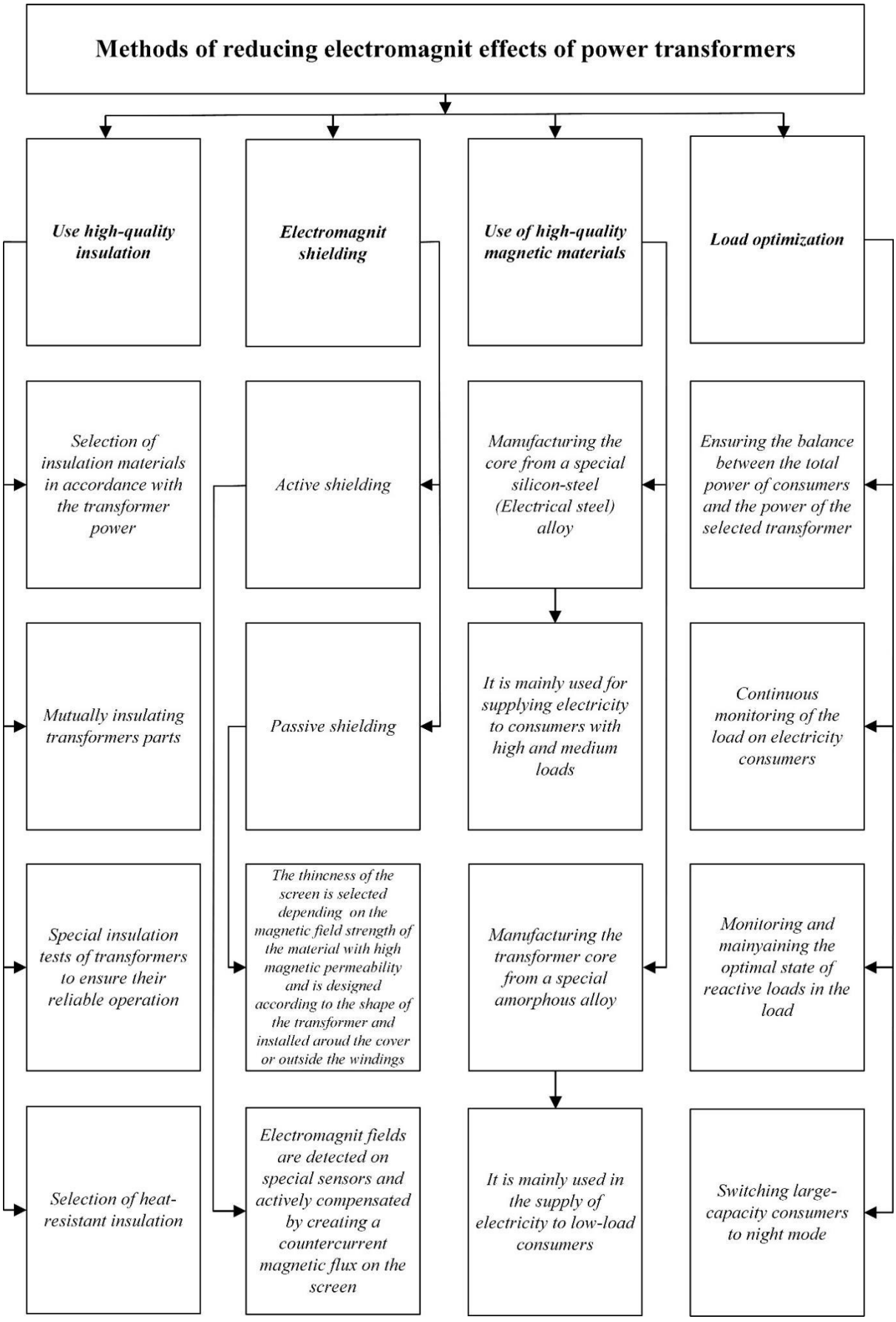



Figure 1. “Classification of methods for reducing the electromagnetic effects of power transformers.”

*Table 2.*

| № | Feature | Active shielding | Passive screening |
|---|---|---|---|
| 1. | Difficulty level | high | low |
| 2. | Efficiency | high | average |
| 3. | In terms of price | high | low |
| 4. | Electricity consumption | required | not required |
| 5. | Repair & Maintenance | complicated | simple |

According to the results of the analysis, it was found that electromagnetic shielding of power transformers can reduce electromagnetic influences by 75-85%.

*3. Use of high-quality magnetic materials.* To reduce the electromagnetic effects of power transformers, increase their efficiency, and reduce energy losses, it is necessary to use high-quality magnetic materials (permalloy, alsifer, magnetically soft materials, silver, copper, aluminum, brass). Transformer cores are typically composed of electrically insulated steel sheets. Transformer cores made of silicon-steel (2-4% silicon) and special amorphous materials have relatively low energy losses due to higher magnetic permeability compared to transformer cores assembled from steel sheets (Table 3). A higher silicon content in transformer core materials reduces electrical resistance and minimizes electromagnetic effects, but if the proportion of silicon in it exceeds the limit, the brittleness of the core increases and the probability of cracking in various areas of the core increases. Amorphous materials are also used in the manufacture of transformer cores. Transformers with a core made of amorphous material are mainly used at low power (transformers with a power not exceeding 5 kVA). When manufacturing a transformer core from an amorphous material, the degree of brittleness of amorphous materials is higher than that of pure steel, which is a more difficult process compared to traditional production. For the preparation of amorphous materials, special equipment is required, i.e., when preparing amorphous materials for a transformer, the heated metal (at a temperature in the range of 1200 °C-1500 °C) must be cooled under special conditions at a rate of $10^6$ °C/sec., the cooling time is approximately $\mathbf{10^{-4}\text{-}10^{-6}}$ sec. Currently, cold-processed steels of grades 3404, 3405, and 3406 and electrical steels with cubic texture and increased silicon content (3% or higher) are mainly used in the magnetic systems of transformers. Materials of this brand are characterized by high working magnetic induction (1.6-2.2 T) and high resistivity (0.4-1.0 μOhm-m).

*Table 3.*

| № | Naming of materials | Magnetic permeability $\mu \cdot 10^3$ | Saturation induction, B (tesla) | Coercive force, $H_c$ (A/m) |
|---|---|---|---|---|
| 1. | Electrical steel | 4÷15 | 1.6÷2.2 | 40÷160 |
| 2. | Amorphous alloy | 100+ | 1.5÷1.8 | 1÷10 |
| 3. | Permalloy | 100÷1000 | 0.6÷1.0 | 0.02÷0.1 |
| 4. | Alcifer | 10÷20 | 1.2÷1.4 | 80÷200 |
| 5. | Ferrites | 10÷100 | 0.3÷0.6 | 100÷4000 |

According to the results of the analysis, it was established that by using high-quality magnetic materials in power transformers, it is possible to reduce electromagnetic losses by 15-30 %.

*4. Load optimization.* Optimizing transformer loads is essential to minimizing electromagnetic effects and maximizing efficiency (ensuring that the transformer load corresponds to the average nominal power and the symmetry of the consumers in the phases). Exceeding or falling below the

nominal load of the transformer leads to a decrease in its efficiency. To optimize the transformer load, it is necessary to thoroughly study the load and constantly monitor the amount of energy. Switching large-capacity consumers to night mode is one of the pressing issues of our time. Because in the daytime mode, as a result of the simultaneous consumption of electricity by the population and large-capacity consumers, the power consumption of power transformers exceeds its nominal value and leads to a decrease in the efficiency of the transformer. (Fig. 2)

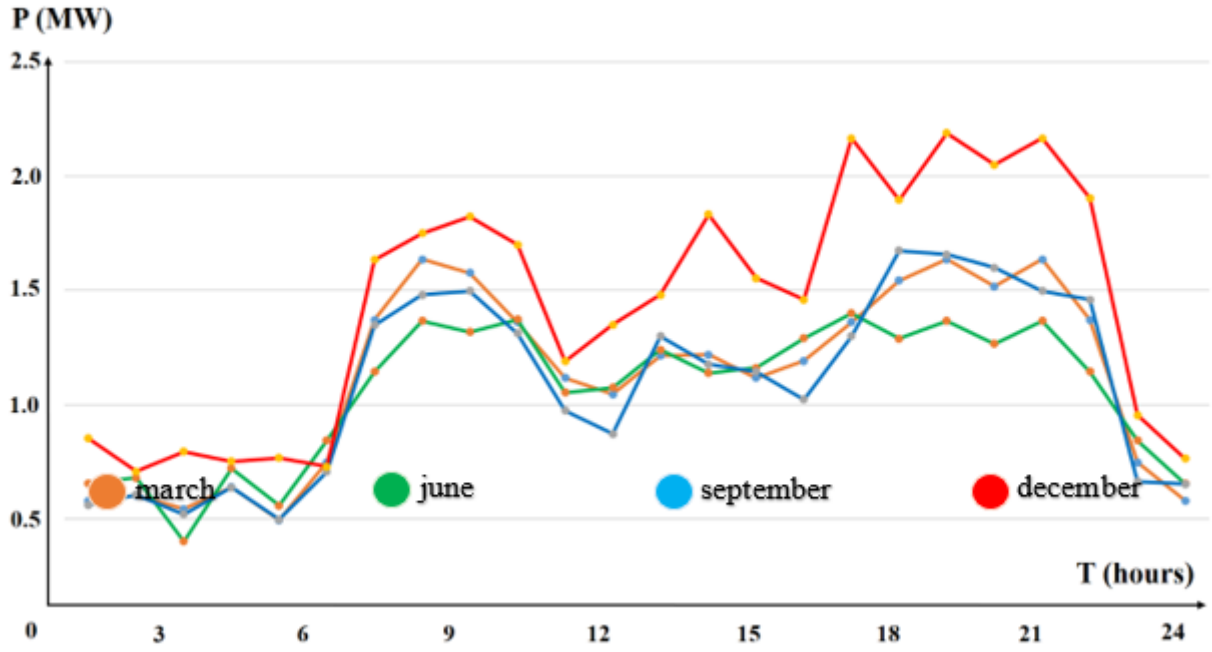



**Figure 2.** Electrical load graph by energy consumption.

In this case, if large-capacity consumers switch to night mode (due to the maximum reduction in electricity consumption by the population in night mode), the power transformers will not be overloaded (their load will be optimized), and thanks to this, the transformer will work more efficiently and their service life will increase.

**Discussion.** The comparative analysis of methods for reducing the electromagnetic effects of power transformers reveals distinct advantages, applications, and limitations for each technique. Below is a synthesis of their effectiveness, applications, and constraints:

**High-Quality Insulation**. Provides a substantial reduction in energy losses, ranging from 5% to 20%. Best suited for transformers operating at high voltages and temperatures, with varied insulation types tailored to specific operational conditions. Performance can degrade over time, requiring maintenance or replacement; initial selection is critical and must match transformer specifications.

**Electromagnetic Shielding**. Achieves a high reduction in electromagnetic influences (75-85%), with active shielding offering superior performance compared to passive shielding. Widely used in industrial and residential settings to mitigate electromagnetic interference in adjacent devices. Active shielding, though efficient, involves high initial costs and complex maintenance requirements, including an additional energy source. Passive shielding is less effective but simpler and more cost-effective.

**High-Quality Magnetic Materials**. Reduces electromagnetic losses by 15-30%, with materials like silicon-steel and amorphous alloys showing significant performance improvements. Primarily used in transformer cores, where reducing energy losses and enhancing efficiency are paramount. Materials such as amorphous alloys are brittle and require specialized manufacturing processes, increasing costs and complexity.

**Load Optimization**. Reduces electromagnetic influences and energy losses by 20-25% while prolonging transformer life. Critical in systems with variable demand, ensuring transformers operate

within optimal load ranges. Requires continuous monitoring and management of loads, with challenges in ensuring compliance during peak usage periods.

**Conclusion.** According to the results of the analysis, it was found that by optimizing the loads in power transformers, it is possible to achieve a reduction in electromagnetic influences and energy losses by 20-25%. Analytical research indicates that the combined application of load optimization, high-quality magnetic materials, electromagnetic shielding, and superior insulation can reduce electromagnetic effects by 50-70% and energy losses by 6-15% on average. While these methods complement one another, their combined effectiveness is not simply additive; once significant reductions are achieved through one approach, the incremental impact of additional methods is relatively small.

**List of used literature**

1. Болтаев О.Т., Ахмедова Ф.А., Исмаилов И.Н. Метод определения электромагнитного взаимодействия различных систем // Международная научная конференция "Научные достижения и инновационные подходы". – 2024. – Т. 4. – Вып. 4. – С. 90–94.

2. Baltag O., et al. Dynamic shielding of the magnetic fields // Advances in Electrical and Computer Engineering. – 2010. – Т. 10. – № 4. – С. 135–142.

3. Болтаев О.Т., Баянов И.Н., Ахмедова Ф.А. Гальванические эффекты гравитационной сети и меры защиты от них // International journal of trends in computer science. – 2021. – Т. 2. – № 1. – С. 3–11.

4. Song W.L., et al. Magnetic and conductive graphene papers toward thin layers of effective electromagnetic shielding // Journal of Materials Chemistry A. – 2015. – Т. 3. – № 5. – С. 2097–2107.

5. Болтаев О.Т., Ахмедова Ф.А., Джаббаров А.Э. О линиях, соединяющих железнодорожный путь с контактной сетью, индукированное напряжение можно определить с помощью компьютерной программы // Central Asian Journal of Mathematical Theory and Computer Sciences. – 2023. – Т. 4. – Вып. 10. – С. 50–54.

6. Keshtkar A., Maghoul A., Kalantarnia A. Magnetic shield effectiveness in low frequency // International Journal of Computer and Electrical Engineering. – 2011. – Т. 3. – № 4. – С. 507.

7. Болтаев О.Т., Ахмедова Ф.А., Нурхонов Б.Ш. Влияние контактной сети на соседние линии и дифференциальные уравнения соседних линий // Emergent: Journal of Educational Discoveries and Lifelong Learning (EJEDL). – 2022. – Т. 3. – Вып. 5. – С. 1–8. DOI: 10.17605/OSF.IO/5QZTM.

8. González M., Pozuelo J., Baselga J. Electromagnetic shielding materials in GHz range // The Chemical Record. – 2018. – Т. 18. – № 7–8. – С. 1000–1009.

9. Болтаев О.Т., Ахмедова Ф.А., Нафасов Н.О. Выражения для определения напряжения, возникающего в соседних линиях в результате воздействия электрического и магнитного полей контактной сети, и их нормативные значения // IEJRD - International Multidisciplinary Journal. – 2022. – Т. 7. – № 2. – С. 8.

10. Takahashi N., Fujiwara K., Takehara J. Basic study on characteristics of magnetic shielding and electromagnetic shielding // WIT Transactions on Engineering Sciences. – 2001. – Т. 31.

11. Болтаев О.Т., Ахмедова Ф.А. Индуцированное напряжение от тяговых сетей и методы снижения его влияния на соседние линии связи // International Journal on Integrated Education. – 2021. – Т. 4. – Вып. 4. – С. 265–271.

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