CHINT

Empower the World

White paper

Sustainability and Ester Oil Power Transformers

July 2024

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Introduction

Introduction

In the rapidly evolving landscape of power transmission and distribution, the quest for **efficient, reliable,** and **environmentally friendly** solutions is more pressing than ever. Among the myriad innovations in this field, one technology stands out for its unique blend of performance and sustainability – Ester Oil Transformers.

In this publication, we will delve into the workings of these transformers, their sustainability credentials, and their impact on the energy sector. We will explore the technical aspects, present a case study, discuss the benefits, and look at the future prospects of these transformers, including their role in shaping a sustainable future for energy transmission.

These transformers, filled with **ester oils** instead of traditional mineral oils, represent a significant **leap forward** in transformer technology.

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Understanding Ester Oil Transformers

Understanding Ester Oil Transformers

Transformers are a cornerstone of modern power systems, enabling the efficient transmission and distribution of electrical energy. They work by using **electromagnetic induction** to change the voltage of an alternating current, stepping it up for transmission over long distances, and stepping it down for safe, practical use.

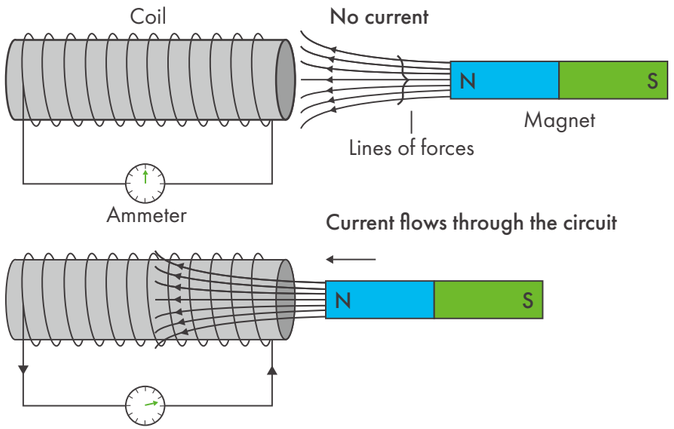

Fig.1 Electromagnetic induction

Traditionally, these transformers have been filled with mineral oil. This oil serves two primary functions: it provides electrical insulation between the transformer's internal components, and it helps to dissipate the heat generated during operation. However, mineral oil has several drawbacks. It is derived from non-renewable sources, it poses environmental risks in the event of a leak or spill, and it can be a fire hazard due to its relatively low flash point.

Ester Oil Transformers represent a significant advancement in transformer technology. Instead of mineral oil, these transformers are filled with ester oils. These oils are derived from renewable sources, such as soybeans or other vegetable oils, making them a more sustainable choice.

Ester oils also have excellent insulating properties, and their higher flashpoint makes them safer to use. In addition, they are biodegradable and non-toxic, reducing the environmental impact in case of leaks or spills.

Retro-filling transformers with natural or synthetic ester fluid to replace mineral oil is a solution that extends the asset life and at the same time optimizes the performance of the transformer.

However, there are some drawbacks to using ester oils, so specifically designed transformers have been developed to mitigate these issues.

The 750kV Ester Oil Transformer is a high-voltage variant of these transformers. The '750kV' refers to the maximum voltage that the transformer can handle. This makes it suitable for large-scale power transmission networks, where high voltage levels are required to transmit power over long distances efficiently.

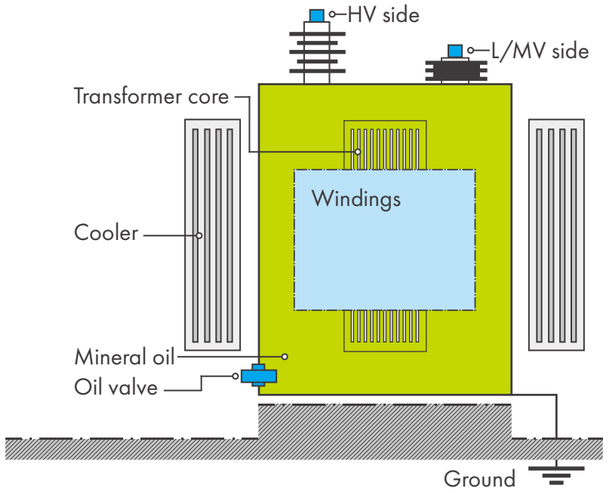

Fig.2 Cross-section of a transformer

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Sustainability of Ester Oil Transformers

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Mineral oil has been frequently used as the insulation liquid in power transformers, improving both **production** and **treatment** at a cost-effective price point.

However, mineral oil is a flammable, explosive fluid: if a transformer leaks mineral oil, it can potentially start a fire. A large fire in a mineral oil transformer not only creates significant damage, but may require expensive cleaning of the surrounding area if the tank has ruptured severely.

In addition, mineral oil is an environmental contaminant, and has the drawback that small amounts of water rapidly degrade its insulating properties.

Ester oils have emerged as a safer, more environmentally friendly alternative to mineral oils in power transformers. The key to their sustainability lies in the unique properties of ester oil.

Derived from renewable sources, ester oil is biodegradable and non-toxic, reducing the environmental impact in case of leaks or spills.

Moreover, ester oil has a high flashpoint – the lowest temperature at which the vapor above the oil sample will momentarily ignite or flash when an ignition source is passed over it – making it less flammable than mineral oil.

This enhances the safety of transformers, particularly in urban or environmentally sensitive locations, and also means that transformers can operate at higher temperatures.

Ester oil can absorb a larger amount of water than mineral oil, permitting the dielectric paper of the transformer to run dryer. This means that using ester oil extends the life of transformer insulation, contributing to longer transformer life and reduced maintenance.

Experimental research has confirmed the beneficial electrical properties and behavior of ester-filled power transformers, which are reflected in a lower and more homogeneous electric field around the transformer's winding wedges.

However, these benefits are accompanied by potential disadvantages – including an increase in load losses, larger masses, manufacturing costs, and larger equipment dimensions – which could potentially hinder their widespread adoption.

These challenges need to be addressed to fully realize the potential benefits of Ester Oil Transformers. Ongoing research and development efforts aim to overcome these challenges and improve Ester Oil Transformers' performance and cost-effectiveness.

Nevertheless, the growing importance of sustainability means that factors such as reducing environmental impacts, increasing safety, and extending transformer lifetime significantly outweigh these drawbacks.

Further development of transformer technology, including innovative design and engineering solutions, may mitigate these disadvantages even further.

CHINT's 750kV Ester Oil Transformer takes the advantages of ester oils to a higher level. Its high voltage rating allows it to be used in large-scale power transmission networks, bringing the benefits of ester oil to a broader range of applications.

Challenges and solutions of ester oil insulation in transformers

	Drawback	Potential solution
Physical and Electrical Dimensions	Using ester fluid insulation in power transformers impacts their physical and electrical dimensions, including higher load losses, impedance, masses, and, consequently, higher manufacturing costs.	The impact on physical and electrical dimensions can be mitigated through careful design and engineering. Moreover, the slightly higher manufacturing costs can be offset by the longer lifespan and reduced maintenance costs of Ester Oil Transformers.
Pour Point and Viscosity	Ester oils have a higher pour point and viscosity than mineral oils, which can affect the cooling efficiency of the transformer.	This can be managed through appropriate transformer design and operation. For instance, maintaining the transformer at a slightly higher operating temperature can ensure the oil remains fluid and effective.
Oxidative Stability	Ester oils may have lower oxidative stability than mineral oils, which can affect the transformer's long-term performance.	This can be addressed through the use of antioxidants and other additives. Regular monitoring and maintenance can ensure the oil remains in good condition over the long term.
Ionization Resistance	Ester oils can increase charge generation compared to mineral oil, but the charge accumulation on the solid surface is not excessive, thus limiting the potential at the solid/liquid interface and associated electrification hazards.	Careful design and operation of the transformer can manage this increase.
Design Changes for High Voltage Levels	At higher voltage levels (>66 kV), it is not always possible to use a mineral oil-designed transformer with an ester fluid. Some design changes may need to be made to accommodate the different chemical makeup of the ester fluid.	While it's true that some design changes may be needed to use ester fluid in high-voltage transformers, these changes can be seen as an opportunity to optimize the transformer design for better performance and efficiency.

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Case Study: CHINT's 750kV Ester Oil Transformer

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To illustrate the benefits of Ester Oil Transformers, we can consider CHINT's 750kV ester-filled transformer. This transformer, **the first of its kind**, was developed as a result of the technical collaboration between CHINT and experts from Cargill, a leading provider of bio-based transformer fluids.

CHINT's 750kV transformer uses Cargill's FR3® fluid, an ester derived from renewable vegetable oils. Developed over five years of laboratory research, this fluid provides excellent cooling and insulating properties, while also being biodegradable and non-toxic. It also offers enhanced fire safety, and extraordinary dielectric properties for ultra-high voltage use.

The transformer design uses a winding structure and main insulation optimization, exit turret simulation improvement, cooling system verification, and other innovative features.

The transformer underwent rigorous testing at the Power Industry Electrical Equipment Inspection and Testing Center of the State Grid Corporation of China. It successfully passed all tests, demonstrating its reliability and performance.

The seven tests to confirm electrical performance were:

- Basic dielectric tests AC. LI, SS, CW
- Testing gaps up to 65 mm and evaluation of Kappeler Curve
- Evaluation of Interfacial Creep
- BDV at low-temperature conditions
- Long gap tests up to 150mm (1800kV) with inhomogeneous field
- Tap Changer testing
- Partial Discharges Inception Voltage

The FR3 fluid also passed all fire safety flammability tests and OECD oral and aquatic toxicity tests.

The development of the 750kV transformer follows many successful cooperative projects between Cargill and CHINT in the 35kV~220kV range, and ushers in a new milestone for transformers. It also raised the application voltage level of FR3 ester to a new height.

FR3 fluid has the highest fire point (360°C) among all K-class fluids for transformers. Furthermore, it has been proven to extend the insulation life of transformers by up to eight times, and reduces the maintenance needed to keep the transformer running at its top output compared to mineral oil-filled transformers.

It has an exceptional ability to remove water that is either generated by the aging of transformer insulation paper or that is present due to the intrusion of moisture into a sealed transformer.

This leads to a much lower paper degradation rate, longer paper lifespan, and longer transformer lifetime.

This case highlights the practical application of Ester Oil Transformers and their potential to revolutionize the energy sector.

The 750kV Ester Oil Transformer strengthens CHINT's offerings and benefits the communities and industries it serves. It reflects CHINT's capabilities in designing complex insulation systems and manufacturing ultra-high voltage transformers, and also verified the feasibility of using ester transformers up to the 750kV voltage level.

CHINT continues to innovate and partner with Cargill for its ester-filled transformers, as both companies push the boundaries of what is possible with more sustainable solutions like ester dielectric fluids.

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Impact and Benefits

Impact and Benefits

Ester Oil Transformers, particularly the 750kV variant, have **far-reaching impacts** on the energy sector and the environment, which can be summarized as follows:

Environmental Impact

Ester oils are derived from renewable sources, making them a sustainable choice for transformer insulation and cooling. In the event of leaks or spills, ester oil is biodegradable and non-toxic, significantly reducing the environmental impact compared to traditional mineral oil. This is particularly important in sensitive environments such as water catchment areas, where a spill could have severe ecological consequences.

Safety and Reliability

Ester oil has a much higher flashpoint than mineral oil; for example, the flashpoint of mineral oil is typically around 160°C, while an ester like FR3 has a flashpoint of 360°C. This makes Ester Oil Transformers less flammable and, therefore, safer, especially in densely populated urban areas. There is a greatly reduced risk of fires that can cause power outages, property damage, and even loss of life.

Using ester oil can also extend the life of transformer insulation, leading to longer transformer lifetimes and improved reliability. This results in fewer power outages and less disruption to consumers and businesses.

Economic Impact

While the initial cost of Ester Oil Transformers may be higher than traditional transformers, the total cost of ownership can be lower when considering factors such as maintenance costs, transformer lifetime, and the potential costs associated with environmental cleanup and fire damage.

Furthermore, the extended life of transformer insulation reduces maintenance requirements and costs, contributing to economic efficiency. Using renewable sources for ester oil production also aligns with global efforts towards sustainability and reducing carbon footprint.

Social Impact

The adoption of Ester Oil Transformers has a number of social benefits. By reducing the risk of fires and power outages, these transformers contribute to the safety and well-being of communities. In addition, by using a renewable and biodegradable coolant, utilities and other transformer owners can demonstrate their commitment to environmental sustainability, enhancing their reputation with customers and stakeholders.

Fig.3 CHINT's 750kV Ester Oil Transformer

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Prospects for the Future

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With a rapidly increasing demand for sustainable solutions in power system infrastructure around the world, the future of Ester Oil Transformers looks highly promising. Companies like CHINT are leading the way with their ongoing **innovation and commitment** to sustainability.

Market Trends

The global power transformer market demonstrates a number of market trends that drive not only demand, but also the type of solution required.

First and foremost, there is a growing demand for electrical energy to meet rising population levels and increased industrialization, particularly in developing regions of the world.

In addition, many developed areas, such as North America and Europe, have aging power infrastructure that requires upgrades or replacements, driving demand for modern transformers.

Many countries are also looking at transitioning to smart power grids, which allow for better energy management and distribution. This requires advanced transformers with improved monitoring and automation capabilities.

The global power transformer market has also witnessed a gradual shift towards renewable energy sources and eco-friendly solutions. This trend is driven by regulatory pressure, consumer demand for sustainable products, and the economic benefits of green technologies. This requires transformers that can handle variable loads while integrating with traditional power grids.

With their environmental and operational advantages, ester oil transformers are well-positioned to capitalize on these trends.

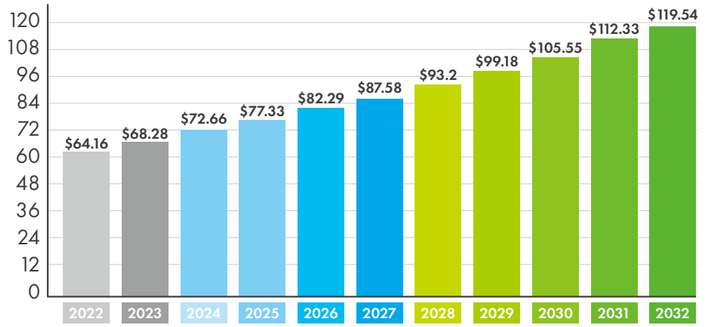
Ester oil transformers use biodegradable and less flammable esters, and so provide environmental and safety benefits that help meet and exceed regulatory standards. Their thermal properties help with efficient cooling and the handling of variable loads typical in renewable energy applications.

Ester oil transformers can be integrated with smart monitoring systems to provide real-time data on performance, which is crucial for smart grid applications.

Their ability to operate efficiently under various loads and conditions enhances grid reliability and resilience.

The longevity and low maintenance requirements of ester oil transformers make them an attractive option for upgrading aging infrastructure, and for creating new projects.

By leveraging these advantages, ester oil transformers can position themselves as a premium, sustainable, and reliable solution in the evolving power transformer market.



(source: www.precedenceresearch.com)

Fig.4 Transformers market size, 2022 to 2032 (USD Billion)

Technological Advancements

Continuous improvements in ester oils and transformer design are likely to lead to even more efficient, robust, and cost-effective solutions, keeping pace with the technological advancements in the power sector.

Research and development efforts are underway to improve the properties of ester oils and optimize transformers' design and manufacturing processes. These advancements could lead to ester oil transformers that are even more efficient, reliable, and environmentally friendly.

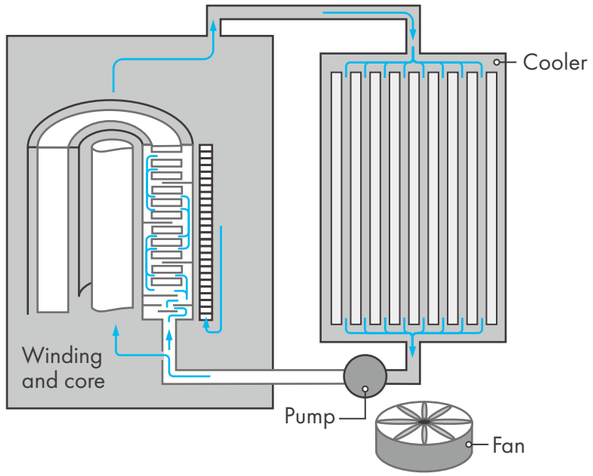


Fig.5 Flow of insulating oil within the cooling system of a typical power transformer

New oil formulations are likely to enhance the biodegradability of ester fluids, making them even more environmentally friendly, while also resulting in better thermal stability, allowing transformers to operate at higher temperatures without degradation.

Optimized cooling systems may improve the efficiency of ester oil insulation, while hybrid solutions combining ester oil with air or water cooling are being researched to enhance overall transformer performance.

It is also probable that enhanced insulating materials will be developed to work alongside ester oils, improving overall dielectric strength and moisture resistance. Innovative transformer designs and the use of high-quality materials will help to reduce losses and improve efficiency.

Deeper integration with smart technologies, such as IoT devices and sensors, will provide real-time data on temperature, moisture levels, and overall performance, enabling predictive maintenance and smarter grid management.

Looking even further forward, incorporating nanotechnology into ester oils could enhance their thermal conductivity and dielectric properties.

These technological advancements will pave the way towards a more sustainable and efficient future for ester oil transformers, not only improving the performance and reliability of transformers, but also aligning with global trends towards renewable energy, smart grid implementation, and environmental sustainability.

Regulatory Landscape

The evolving global regulatory landscape increasingly favors technologies that are safe, efficient, and environmentally friendly. Ester oil transformers are well-positioned to benefit from these trends, offering a sustainable solution that aligns with regulatory goals.

The biodegradable and non-toxic nature of ester oils makes them compliant with increasingly stringent environmental regulations aimed at reducing ecological footprints, and helps utilities and industries to meet their corporate social responsibility targets.

Many countries have committed to sustainability goals and climate action plans, such as the Paris Agreement. Ester oil transformers contribute to these goals by reducing greenhouse gas emissions and environmental contamination.

In addition, as regulations tighten around the use of hazardous materials in general, ester oils present a safer and eco-friendly alternative to conventional mineral oils.

Governments and regulatory agencies increasingly prioritize technologies that enhance public safety and significantly reduce hazards. The inherent safety benefits of ester oil transformers align with these priorities, particularly in urban and industrial settings.

International standards organizations like IEC (International Electrotechnical Commission) and IEEE (Institute of Electrical and Electronics Engineers) are incorporating guidelines that promote the use of eco-friendly transformer fluids. Ester oils often meet or exceed these standards.

Additionally, many governments offer incentives and subsidies for the adoption of green technologies. Ester oil transformers, being environmentally friendly, can benefit from these financial incentives.

Access to green financing options and environmental grants can make the initial investment in ester oil transformers more attractive for utilities and industries, while tax incentives or credits may also be available for companies that invest in sustainable technologies like ester oil transformers.

Finally, the global trend towards harmonizing regulations across countries makes it easier for ester oil transformers to gain acceptance in multiple markets, increasing their adoption as a global solution.

Role of Key Players

Major players in the transformer industry are likely to play a crucial role in the future development of ester oil transformers through their strategies and actions.

Investment in research and development will have a significant impact on both ester fluid innovation and advanced transformer designs. Ester fluids may be developed with enhanced properties such as higher thermal stability, better moisture tolerance, and longer life span. New transformer designs will optimize the use of ester oils, improving overall efficiency and performance.

Large players in the industry will also have the resources to scale up production of ester oil transformers, reducing costs through economies of scale, while implementing stringent quality control measures to ensure reliability and safety, which are critical for gaining market trust.

These key players can leverage their global presence to introduce ester oil transformers in emerging and established markets, forming strategic partnerships with local utilities, governments, and other stakeholders.

CHINT is well-positioned to drive the future of ester oil transformers through innovation, strategic market actions, regulatory advocacy, and sustainability initiatives.

Its commitment to innovation and sustainability, as demonstrated by the development of the 750kV ester-filled transformer, is expected to drive the advancement and adoption of this technology, leading to a more sustainable and efficient power infrastructure globally.

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Conclusion

Conclusion

This white paper has provided a comprehensive overview of ester oil transformers, highlighting their benefits for sustainability, safety, and performance when compared to traditional mineral oils.

The key benefits are:

- Biodegradability
- Non-toxicity
- Excellent insulation
- High flashpoint
- Water absorption

While there are some drawbacks to using ester oils in transformers, these do not outweigh the environmental benefits, and they can also be mitigated through innovative design and engineering solutions.

CHINT's 750kV ester-filled transformer, developed in collaboration with Cargill, a leading provider of bio-based transformer fluids, is a key example of the innovation taking place in this sector.

It is likely to have a far-reaching impact on the energy sector, with benefits for the environment, safety, reliability, economy, and social issues. With increasing demand for energy solutions around the world, emerging market trends are expected to drive greater adoption of ester oil transformers globally.

As the energy sector continues to evolve, the role of sustainable technologies like ester oil transformers becomes increasingly essential. Through their unique blend of performance, safety, and environmental friendliness, ester oil transformers represent a significant step towards a sustainable future for energy transmission.

As the industry moves forward, it is essential to continue exploring and investing in such sustainable technologies.

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