IMPROVING THE ENERGY EFFICIENCY OF ELECTRICAL SYSTEMS USING HIGH FREQUENCY POWER TRANSFORMERS

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ABSTRACT: Energy efficiency in homes is becoming increasingly important in the context of growing concerns about climate change and rising utility costs. This practice involves using modern technologies to reduce energy consumption without compromising comfort or functionality. Introducing automation systems and energy consumption control can bring significant financial benefits and reduce environmental impact. In this paper, we explore how IoT and Home Assistant can be used to improve energy efficiency in a home.
This work provides a detailed introduction to Home Assistant, an open-source platform for home automation that allows centralized control of smart devices through a unified interface. Initially developed by Paulus Schoutsen in 2013, it supports a wide variety of devices and protocols, including Wi-Fi, Zigbee, Z-Wave, and MQTT, facilitating interoperability between different technologies. Home Assistant runs locally, ensuring user data privacy and security.

Key words: transformers, design, magnetic core, energy efficiency

1. INTRODUCTION

The electrical transformer is a static device consisting of two or more magnetically coupled windings, used to change the values of electrical quantities of alternating current power (voltage and current), keeping the frequency constant. The working principle of the transformer is based on the phenomenon of electromagnetic induction, and in order to achieve an efficient magnetic coupling, the windings are placed on a ferromagnetic core. At frequencies above 10 kHz, transformers can be constructed without a ferromagnetic core.

Electric transformers can be classified according to their purpose, having the following main categories:

1. Power Transformers:
- Three-phase and Single-phase: Used for the transport and distribution of electricity at the level of voltage and power requested by consumers.
2. Special Transformers:
- Used in specific applications such as electric furnaces (electric arc, induction) and welding equipment.
3. Measuring Transformers:
- Intended for measuring current and voltage.
4. Transformers for Power Electronics:
- Used in applications involving the conversion and control of electrical energy.
5. Impulse micro-transformers:
- Used in low power electronics such as integrated circuits.

Power electronics deals with the transformation by static switching of the average value (in direct current), the amplitude (in alternating current) and the frequency of voltage and electric current. These fast processes require energy storage elements such as inductors and capacitors. Electrical transformers play a crucial role in galvanic separation and voltage amplitude modification.

Transformers are often integrated into switch-mode converters to provide DC isolation between the input and output of the converter. When the input of the converter is connected to the AC mains, isolation is achieved by means of a 50 Hz or 60 Hz transformer. A major advantage of using transformers in converters is that their size and weight decrease in proportion to the operating frequency. By integrating the transformer into the converter, it can operate at the switching frequency of the converter (from tens to hundreds of kHz), which leads to significant improvements in its performance.

2. HIGH FREQUENCY POWER TRANSFORMERS

High-frequency power transformers (IPIF) have become essential components in various fields of modern electronics due to their ability to transfer power efficiently and quickly at frequencies much higher than those used in traditional power networks.

These devices are designed to operate in frequency ranges from a few kilohertz (kHz) to even a few megahertz (MHz), enabling superior performance in power conversion systems such as switch mode power supplies (SMPS), chargers wireless, telecommunications equipment and more. The use of high frequencies in power transformers presents significant advantages over conventional transformers, especially in terms of reduced size and weight, energy efficiency and fast response to load variations. These characteristics make them ideal for applications that require high power density and portability, such as electronic equipment, transportation systems, and space technology. However, operation at high frequencies also brings significant challenges to the design and use of IPIF transformers.

These include the need for advanced materials for the magnetic core and conductors usable at high frequencies, as well as design optimization to minimize energy losses and parasitic effects such as skin effect and losses due to proximity currents. A power transformer has become an indispensable component in power electronics. It is used to perform some important functions, such as: voltage transformation, electrical isolation and sound filtering between the primary and secondary terminals. The ideal power transformer should efficiently and instantaneously transfer the external current source to its external load. The conventional power transformer usually operates at a frequency of 50 or 60 Hz. The construction of these transformers consists of 2 or more windings around a heavy and bulky core. Although it is simple to build and implement, it is the most voluminous and expensive of the power supply systems. To solve the cost and size problems, the high frequency power transformer was introduced.

A comparison between the conventional and the high frequency transformer can be seen in the figure below.

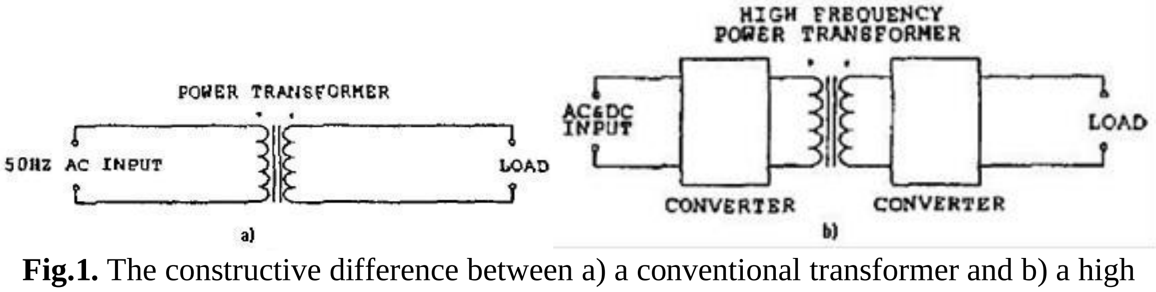

Fig.1. The constructive difference between a) a conventional transformer and b) a high frequency transformer

2.1.Principle of Operation

IPIF transformers work on the principle of electromagnetic induction, similar to traditional transformers. However, at high frequencies, advanced technology is used to minimize energy losses and unwanted effects such as:

1. **The film effect:** At high frequencies, the current tends to concentrate on the surface of the conductors. This necessitates the use of thinner or specially shaped conductors to reduce losses.

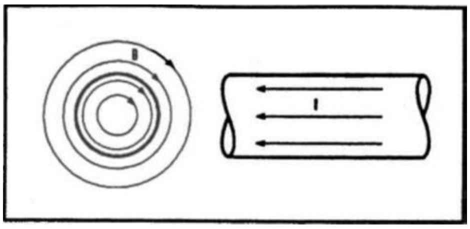

Fig.2. Low frequency insulated conductor

2. Core Losses: Cores used at high frequencies are made of low-loss materials such as ferrites, which allow the transformer to operate efficiently.

3.Magnetic Coupling: IPIF transformers have a tighter magnetic coupling to maximize energy transfer between the primary and secondary windings.

2.2. Types of IPIF Transformers

High frequency power transformers can be classified into several categories depending on their applications:

1.Transformers for switching power supplies (SMPS): These transformers are used to adjust the voltage and current in power supplies that operate by fast switching.

2.Transformers for industrial applications: These are used in welding equipment, electric furnaces and other applications that require high power and precise control.

3.Telecommunications transformers: Used for signal isolation and adaptation in transmission and reception equipment.

4.Micro-transformers: Used in low power

Although IPIF transformers have many advantages, there are also challenges associated with their use:

1.Design complexity: Designing transformers at high frequencies requires advanced knowledge and specialized tools to minimize losses and ensure performance.

2. High Costs: The advanced materials and technology required to manufacture these transformers can lead to higher production costs.

3. Proximity Effects: At high frequencies, proximity effects can affect transformer performance, requiring additional design measures to minimize them.

IPIF transformers are used in various fields, including:

1. Wireless charging equipment: These use high-frequency transformers to efficiently transfer power between coils.

2. Power supplies for electronic equipment: Used in laptops, mobile phones and other electronic devices to convert the supply voltage.

3. Telecommunication systems: Used in base stations and transmission equipment to adapt electrical signals.

4. Automotive: Used in energy management systems and vehicle electrification applications.

3. DIMENSIONING OF TRANSFORMERS

The sizing of high-frequency power transformers (IPIF) is a complex process that requires special attention to specific design parameters, given that they are used in applications that require high efficiency and stable performance. Here are the essential steps for sizing high-frequency power transformers, highlighting the application requirement

1. Assessment of Power Requirements

• Rated Power (S): It is essential to determine the total power that the transformer must deliver, expressed in kilovolt-amperes (kVA). This is based on the analysis of the connected load and system requirements.

• Active Power (P): Active power is relevant in the calculation of efficiency and must be correlated with the power factor of the load.

2. Setting the Tensions

Although IPIF transformers have many advantages, there are also challenges associated with their use:

$$I_{intrare} = \frac{S}{U_{intrare}} \quad (2)$$

$$I_{iesire} = \frac{S}{U_{iesire}} \quad (3)$$

These values are essential for sizing conductors and windings.

3. Calculation of Current

• Input Current (InputInput) and Output Current (Output: These values are calculated based on apparent power and voltages, using the formulas:

Hysteresis Loss and Eddy Current Losses: These losses are significant at high frequencies. It is important to evaluate these losses to determine the efficiency of the transformer.

Efficiency: Calculate the efficiency of the transformer, wanting a value of 90% or more:

$$\eta = \frac{P_{iesire}}{P_{intrare}} x100 \quad (4)$$

4. Evaluation of the Operating Frequency

Frequency (f): It is a critical parameter, because the characteristics of the

• Input Voltage (U_{input}): This is the voltage to which the transformer will be connected (eg: 230 V).

• Output Voltage (U_{output}): The desired voltage at the output of the transformer (eg: 24 V).

•Transformation Ratio (n): It is important to calculate the transformation ratio, which influences the dimensions of the windings:

$$n = \frac{U_{int}}{U_{ies}} \quad (1)$$

materials used in the transformer core are influenced by the operating frequency (ex: 20 kHz, 50 kHz, 100 kHz or more). Ferrite cores are preferred for higher frequencies due to low losses.

5. Analysis of Losses and Efficiency

Hysteresis Loss and Eddy Current Losses: These losses are significant at high frequencies. It is important to evaluate these losses to determine the efficiency of the transformer.

Efficiency: Calculate the efficiency of the transformer, wanting a value of 90% or more:

$$\eta = \frac{P_{iesire}}{P_{intrare}} x100 \quad (4)$$

6. Thermal Considerations

Another important aspect is the management of the heat generated by losses in the transformer. The proper sizing of the transformer must include:

• Calculation of losses: Losses in the core (ferromagnetic losses) and losses in the windings (ohmic losses) are taken into account.

• Cooling system: You can opt for natural or forced cooling, depending on the size and power of the transformer. It is important that the operating temperature is kept below a certain threshold to prevent material damage.*

7. Physical and Mechanical Dimensions

The physical dimensions of the transformer must be optimized to ensure

8. Mechanical Characteristics

• Mechanical Structure: The mechanical design must ensure the stability and

• Shielding and Shielding: It is important to include electromagnetic shielding to

9. Materials Used

• Core Materials: The choice of transformer core materials is crucial.

Ferrite cores are common for high frequencies because they offer better performance compared to silicate steel cores. • Conductors: It is important to use conductors that minimize skin effect losses at high frequencies. Multifilament

10. Norms and Standardization

• Compliance with international standards (eg: IEC, ANSI) is essential to ensure the safety, reliability and efficiency of transformers.

11. Testing and Validation

After sizing and manufacturing the transformer, it is essential to carry out tests to validate the performance:

• Electrical tests: Checking voltages, currents and transformation ratio.

proper mounting and efficient operation. This includes:

• Case shape and dimensions: These must allow adequate heat dissipation and accessibility for maintenance.

• Insulation: Insulating materials must be selected based on operating voltages and environmental conditions.

resistance of the transformer, especially at high frequencies where vibrations can be more pronounced.

protect the transformer from external interference.

• Thermal tests: Evaluation of thermal behavior under load conditions.

• Insulation tests: Ensuring that the insulation meets the standards required for transformer safety and reliability

reduced, which has a positive impact on the environment.

Homes with smart automation systems are often more attractive to buyers and can command higher prices in the real estate market. Automation can increase the property's value, reflecting current market trends that favor modern technology and sustainability.

Smart systems add an extra level of security and comfort, making the home more appealing to both residents and potential buyers. Remote control of devices and monitoring through smart security cameras are just a few examples of functionalities that bring direct benefits to homeowners.

5. CONCLUSIONS

High frequency power transformers play a vital role in modern technology, having essential applications in various fields. Although associated with specific challenges, their advantages in terms of efficiency, small size and performance make them indispensable in electronics and engineering. Continued research and development in this area will help improve the performance and expand the use of IPIF transformers in the future.

Sizing high frequency power transformers involves a detailed assessment of design parameters and specific application requirements. This process ensures not only optimal operation of the transformer, but also maximum energy efficiency andincreased durability under varied operating conditions. Collaboration with specialist engineers and adherence to design standards are essential to the success of this activity. Sizing high frequency power transformers is a complex process involving a number of calculations and design considerations. Through the correct selection of materials, the determination of the appropriate parameters and the appropriate testing, efficient and reliable transformers adapted to the specific requirements of modern applications can be made. This not only optimizes performance, but also contributes to improving the energy efficiency of electrical systems.

Advantages of Using Transformers

1. Energy Efficiency: Transformers can reduce voltage or current demands on transistors and diodes within the converter, thus improving energy efficiency and reducing production costs.
2. Multiple Outputs: By using multiple secondary windings, each with a corresponding transformation ratio, multiple DC outputs can be obtained to suit different voltage requirements.
3. Flexibility in Design: Choosing an appropriate transformation ratio allows optimizing the operation of the converters, thus ensuring a balance between performance and costs.

The electrical transformer is an essential element in modern electrical systems, having diverse applications in the field of electrical energy transmission and distribution, as well as in power electronics. Through its integration into converters, the transformer contributes to increasing the efficiency, flexibility and performance of electrical systems.

Advantages of IPIF Transformers

High frequency power transformers offer numerous advantages:

1. Reduced dimensions: Due to high frequencies, the size of the magnetic core can be considerably reduced, which allows the construction of more compact equipment.
2. Energy efficiency: These transformers have lower energy losses due to the use of advanced materials and optimized design.
3. Quick Response: The ability to operate efficiently at rapid load variations makes them ideal for applications that require a quick response.
4. Galvanic isolation: Provides electrical separation between input and output circuits, which is essential for equipment safety.

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