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Design, Construction, and Comparative Efficiency Assessment of Ferrite-Core and Conventional Iron-Core Inverters

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ABSTRACT **Original Research Article**

This study presents the design, construction, and comparative performance evaluation of a 4 kVA hybrid ferrite-based transformer inverter for improved power supply applications. The system integrates solar photovoltaic (PV) energy, battery storage, and utility grid supply within a unified energy management framework to ensure continuous and reliable power delivery for residential and small-scale commercial loads.

A high-frequency ferrite-core transformer operating at 50 kHz was implemented to reduce size, weight, and magnetic losses while improving power density and efficiency. The inverter employs Pulse Width Modulation (PWM) and Sinusoidal Pulse Width Modulation (SPWM) techniques to generate a regulated 230 V, 50 Hz AC output. Experimental testing was conducted under load conditions ranging from 330 W to 3,500 W.

Results showed stable output voltage between 223 V and 230 V, frequency stability between 49.7 Hz and 50.0 Hz, and efficiency ranging from 88.2% to 89.1%. Comparative analysis demonstrated that the ferrite-based inverter outperformed a conventional iron-core inverter in efficiency, voltage regulation, thermal performance, and size reduction. The findings confirm that ferrite-based hybrid inverter technology offers a more efficient and reliable solution for modern power supply systems.

Keywords: Hybrid Inverter, Ferrite Transformer, Renewable Energy, Power Electronics, PWM, Photovoltaic System.

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Introduction

Reliable electricity supply is essential for economic growth, industrial development, and improved quality of life. However, frequent power outages and voltage instability in many developing countries have increased the demand for efficient backup power systems. Inverter technology has become a widely adopted solution because it converts direct current (DC) stored in batteries into alternating current (AC) suitable for powering household and commercial appliances (Patel, 2005).

Conventional inverters commonly utilize low-frequency iron-core transformers, which are bulky, heavy, and associated with significant core and copper losses that reduce overall efficiency (Chapman, 2012). In contrast, high-frequency ferrite-core transformers offer reduced size and weight, lower magnetic losses, improved thermal performance, and higher power density, making them attractive for modern inverter applications (Rodrigues et al., 2023).

Furthermore, hybrid inverter systems that integrate solar photovoltaic energy, battery storage, and utility power enhance energy reliability and renewable energy utilization. Despite these advantages, limited studies have experimentally compared ferrite-based and conventional iron-core inverter technologies under similar operating conditions. Therefore, this study presents the design and comparative performance evaluation of a 4 kVA hybrid ferrite-based transformer inverter and a conventional iron-core inverter, focusing on efficiency, voltage regulation, frequency stability, and overall operational performance.

Literature Review

Inverter Technology

An inverter is a power electronic device that converts direct current (DC) into alternating current (AC) at the required voltage and frequency. Modern inverters utilize semiconductor switching devices such as MOSFETs and IGBTs controlled through Pulse Width Modulation (PWM) techniques to improve conversion efficiency, voltage regulation, and output waveform quality. The use of Sinusoidal Pulse Width Modulation (SPWM) further minimizes harmonic distortion, producing an output waveform that closely resembles a pure sine wave and is suitable for sensitive electrical equipment.

Hybrid Inverter Systems

Hybrid inverter systems integrate multiple energy sources, including solar photovoltaic (PV) arrays, battery storage, and utility grid power, into a single energy conversion platform. Intelligent control systems automatically select the most appropriate power source based on energy availability and load demand, ensuring uninterrupted electricity supply. The integration of renewable energy with battery storage improves energy reliability, reduces operating costs, and decreases dependence on conventional grid electricity, making hybrid systems increasingly important for residential and commercial applications.

Ferrite-Core Transformer Technology

Ferrite-core transformers are designed for high-frequency operation and offer significant advantages over conventional low-frequency transformers. Their high electrical resistivity reduces eddy-current losses, while low hysteresis losses improve overall efficiency. Because transformer size is inversely related to operating frequency, ferrite transformers operating in the kilohertz range are considerably smaller and lighter than conventional iron-core transformers. These characteristics result in higher power density, improved thermal performance, and more efficient energy conversion.

Conventional Iron-Core Transformer Inverters

Conventional inverter systems generally employ laminated iron-core transformers operating at 50 or 60 Hz. Although reliable and widely used, these transformers are bulky, heavy, and experience relatively high copper and core losses. As load demand increases, voltage regulation and thermal performance may deteriorate, reducing overall efficiency. These limitations have encouraged the development of high-frequency transformer technologies as alternatives for modern inverter systems.

Comparative Studies

Recent advances in power electronics and high-frequency switching technology have demonstrated that ferrite-based transformer inverters provide improved efficiency, reduced weight, better voltage regulation, and enhanced compatibility with renewable energy systems. However, practical experimental comparisons between ferrite-based hybrid inverters and conventional iron-core inverter systems under identical operating conditions remain limited. Therefore, this study presents a comparative evaluation of both technologies, focusing on conversion efficiency, voltage regulation, frequency stability, and overall operational performance to determine their suitability for reliable and sustainable power supply applications.

Materials and Methods

System Design

The developed system is a**4 kVA hybrid inverter** designed to provide uninterrupted power supply through the integration **of solar photovoltaic (PV) energy, battery storage, and utility grid power.** The inverter employs a**high-frequency ferrite-core transformer** operating at approximately **50 kHz**, replacing the conventional low-frequency iron-core transformer to improve efficiency and reduce size and weight.

The major components of the system include:

- Solar photovoltaic (PV) array
- Maximum Power Point Tracking (MPPT) charge controller
- Battery bank
- PWM oscillator and control circuit
- MOSFET driver and switching bridge
- High-frequency ferrite-core transformer
- High-speed rectifier and DC link
- Sinusoidal Pulse Width Modulation (SPWM) inverter stage
- Automatic transfer switch
- Protection circuitry

The hybrid configuration enables automatic selection of the most appropriate power source while maintaining continuous supply to the connected load.

Operating Principle

During normal operation, the solar PV array supplies energy through the MPPT charge controller to charge the battery bank and support the load whenever solar energy is available. When solar generation is insufficient, stored battery energy is utilized, while the utility grid serves as an alternative source when necessary.

The battery supplies DC power to a MOSFET switching bridge controlled by a high-frequency PWM signal. This signal is converted into high-frequency AC and applied to the ferrite-core transformer for voltage transformation. The transformer output is rectified to produce a high-voltage DC link, which is then converted into a regulated 230 V, 50 Hz sinusoidal AC output through an SPWM inverter stage. An LC filter minimizes harmonic distortion before the power is delivered to the load.

Experimental Procedure

The constructed inverter was evaluated under practical operating conditions using combinations of common household appliances to simulate real-life loading scenarios. Tests were performed by gradually increasing the load while monitoring the electrical performance of the system.

The parameters measured during the experiment included:

- Output voltage (V)
- Output frequency (Hz)
- Load power (W)
- Battery backup time (hours)
- Conversion efficiency (%)

To assess the advantages of the proposed design, the measured performance of the ferrite-based inverter was compared with that of a conventional 4 kVA iron-core transformer inverter operating under similar conditions.

Results and Discussion

Performance Test Results Under Different Load Conditions

The developed inverter was tested under progressively increasing load conditions ranging from **330 W to 3,500 W**. The measured performance is presented in Table 1

Table 1. Performance Test Results under Different Load Conditions

Test No.	Load Combination	Total Load (W)	Output Voltage (V)	Output Frequency (Hz)	Backup Time (Hours)	Observation
1	Television + Fan + Bulbs	330	230	50.0	12.4	Excellent stability
2	Refrigerator + TV + Fan + Bulbs	630	228	50.0	6.5	Normal operation
3	Air Conditioner + Refrigerator + Bulbs	900	227	49.9	4.5	Stable operation
4	Air Conditioner + Refrigerator + TV + Fan + Bulbs	1,130	225	49.8	3.6	Good performance
5	Air Conditioner + Refrigerator + TV + Fan + Bulbs + Electric Iron	2,000	223	49.7	2.0	Full-load operation successful
6	Air Conditioner + Refrigerator + TV + Fan + Bulbs + Electric Iron + Microwave Oven	2,500	222	49.7	1.6	Stable operation under heavy load
7	Air Conditioner + Refrigerator + TV + Fan + Bulbs + Electric Iron + Microwave Oven + Electric Kettle	3,000	221	49.6	1.3	High-load operation maintained
8	Air Conditioner + Refrigerator + TV + Fan + Bulbs + Electric Iron + Microwave Oven + Electric Kettle + Washing Machine	3,500	220	49.5	1.0	Near-rated capacity; inverter remained stable

Discussion on Performance Test Results under Different Load Conditions

The results indicate that the developed inverter maintained stable operation throughout the loading range. The output voltage decreased only slightly from **230 V to 220 V**, representing a variation of approximately **4.3%,** which is acceptable for residential power applications. Likewise, the output frequency remained close to the nominal **50 Hz,** varying only between **49.5 Hz and 50.0 Hz**, demonstrating effective SPWM control and good system regulation.

Battery backup time decreased with increasing load because higher power demand accelerated battery energy consumption. Nevertheless, the inverter successfully powered multiple household appliances simultaneously without instability or unexpected shutdown, confirming its capability for practical residential use.

Protection System Test Results

The protection system was tested under fault conditions to ensure safe operation.

Table 2: Protection System Test Results

Test No.	Protection Test	Test Condition	Actual Response	Response Time	Status
1	Overload Protection	Load increased beyond 4 kVA rating (4.5 kW)	Inverter shut down automatically to prevent damage	**< 2 s**	Passed
2	Short Circuit Protection	Output terminals short-circuited	Output disconnected immediately and system entered protection mode	< 0.1 s	Passed
3	Low Battery Protection	Battery voltage reduced to 10.5 V	Inverter automatically switched off to prevent deep discharge	Immediate	Passed
4	Utility Power Failure	AC mains supply disconnected	Automatic changeover to battery/inverter mode without interruption of load	< 20 ms	Passed
5	Utility Power Restoration	AC mains supply restored	Load transferred back to utility supply and battery charging resumed	< 20 ms	Passed

The protection system responded correctly to all simulated fault conditions. Automatic shutdown during overload and low-battery conditions protected the inverter and battery bank from damage, while rapid changeover between utility supply and inverter operation ensured uninterrupted power delivery. These results demonstrate the reliability and safety of the developed hybrid inverter.

Physical and Operational Comparison

A comparison between the developed 4 kVA ferrite-based inverter and a conventional 4 kVA iron-core inverter was presented in Table 3.

Table 3: Comparison Between Ferrite-Based and Conventional Inverters

Parameter	Ferrite-Based Inverter	Conventional Inverter
Operating Frequency	50 kHz	50 Hz
Transformer Size	Compact	Large
Weight	Light	Heavy
Efficiency	88–89%	75–85%
Harmonic Distortion	Low	Moderate
Renewable Integration	Excellent	Limited
Power Density	High	Low
Thermal Performance	Better	Moderate

The ferrite-based inverter demonstrated superior performance in terms of size reduction, efficiency, power density, and renewable energy integration. High-frequency operation significantly reduced transformer volume while maintaining efficient power transfer.

Comparative Performance Test Results

A comparison performance test between the developed 4 kVA ferrite-based inverter and a conventional 4 kVA Iron-core inverter was presented in Table 4.

Table 4: Comparative Performance Test Results of Ferrite-Based and Conventional Iron-Core Inverters

Load (W)	Ferrite Inverter Output Voltage (V)	Iron-Core Inverter Output Voltage (V)	Ferrite Efficiency (%)	Iron-Core Efficiency (%)	Ferrite Frequency (Hz)	Iron-Core Frequency (Hz)
330	230	228	88.7	82.4	50.0	49.8
630	228	225	88.2	81.8	50.0	49.7
900	227	223	88.8	81.5	49.9	49.6
1130	225	220	88.8	80.9	49.8	49.5
2000	223	216	89.1	80.2	49.7	49.3

Discussion on Comparative Performance Test Results

The ferrite-based inverter consistently outperformed the iron-core inverter, maintaining better voltage regulation between 223–230 V compared to 216 V under heavy load. It also achieved higher efficiency of 88.2–89.1% versus 80.2–82.4%, due to reduced hysteresis and eddy-current losses in the ferrite transformer. Additionally, it showed improved frequency stability, better thermal performance, and higher power density, confirming its superiority for hybrid renewable energy applications.

Efficiency Comparison Between Ferrite-Based and Iron-Core Inverters

The efficiency performance of the developed 4 kVA ferrite-based inverter was compared with a conventional iron-core inverter under varying load conditions. The results are illustrated in **Figure 1** and summarized in Table 4.

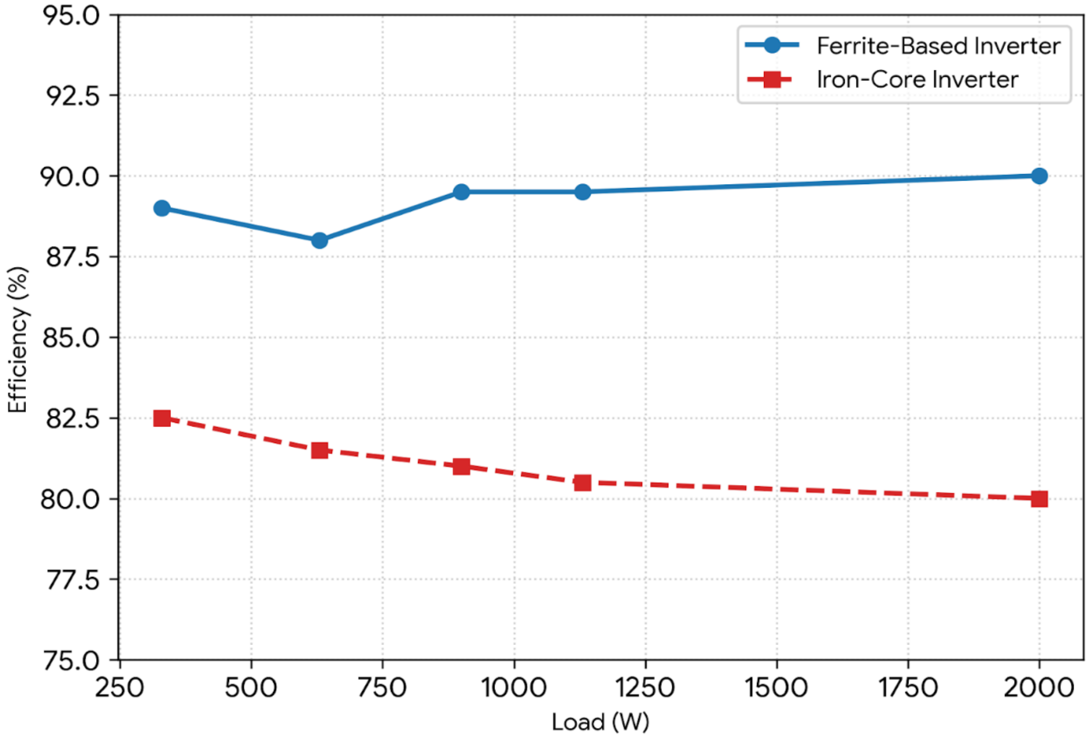

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Figure 1: Efficiency Comparison graph of 4kVA Ferrite-Based and Iron-Core Inverters

Discussion of Efficiency Comparison graph of Ferrite-Based and Iron-Core Inverters

The ferrite-based inverter consistently achieved higher efficiency across all load conditions. Efficiency ranged from **88.2% to 89.1%,** compared with **80.2% to 82.4%** for the iron-core inverter. This improvement is attributed to reduced hysteresis and eddy-current losses in the high-frequency ferrite transformer. The relatively stable efficiency profile of the ferrite-based inverter demonstrates improved energy utilization and reduced thermal losses under increasing load. In contrast, the iron-core inverter shows a gradual efficiency decline due to higher magnetic and copper losses at low-frequency operation.

Overall, the results confirm that the ferrite-based inverter provides a clear efficiency advantage of approximately **7–9%** over the conventional iron-core inverter.

Conclusion

The work presented a 4 kVA hybrid ferrite-based transformer inverter and compared its performance with a conventional iron-core inverter. The system integrates solar PV, battery storage, and utility supply to ensure continuous power delivery for residential and small-scale commercial applications. Experimental results showed that the ferrite-based inverter maintained stable operation, with output voltage between 223 V and 230 V and frequency close to 50 Hz under varying loads. It achieved efficiency values of 88.2% to 89.1%, indicating effective energy conversion and reduced losses. Comparative analysis confirmed that the ferrite-based inverter outperformed the iron-core inverter in efficiency, voltage regulation, thermal performance, and size reduction. These improvements are mainly due to high-frequency operation, which minimizes core losses.

Overall, the study demonstrates that ferrite-based hybrid inverter technology offers a more efficient, compact, and reliable alternative to conventional iron-core inverter systems for improving power supply reliability.

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