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Performance Analysis of a Pure Sine Wave Inverter Using the EGS002 Module

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ABSTRACT
The development of renewable energy technology increases the need for efficient and reliable inverters to convert direct current into alternating current. This study aims to analyze the performance of a pure sine wave inverter using the EGS002 module as a pulse width modulation controller to produce a pure sine wave. The main issues studied are power conversion efficiency, output voltage stability, and total harmonic distortion (THD) under various load conditions, including resistive and non-linear loads. The research method involves experimental simulations using MATLAB/Simulink and Proteus software, by designing an inverter system based on the EGS002 module, IRF3205 MOSFET transistor, and LC filter. Performance parameters measured include power conversion efficiency (η), total harmonic distortion, and RMS output voltage (V_RMS). The simulation results show that the inverter achieves an average power conversion efficiency of 91.4%, total harmonic distortion below 5% under all load conditions, and output voltage stability with a deviation of less than 1% from the nominal value of 220 volts. These findings indicate that the EGS002 module is effective for inverter applications in renewable energy systems, although optimization is required for non-linear loads and production cost reduction. This research provides important insights for the development of more efficient and reliable inverters.

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INTRODUCTION

The development of electronic technology and the need for stable electrical energy sources are increasing, especially in the era of energy transition towards the use of renewable energy. One important component in renewable energy systems is the inverter, a device that converts direct current (DC) to alternating current (AC). Inverters play a crucial role in ensuring that electronic devices requiring AC voltage can operate properly using DC power sources, such as batteries or solar panels (Kouro et al., 2015). In recent years, pure sine wave inverters have gained popularity compared to modified sine wave inverters due to their ability to produce a pure sine wave that is more compatible with the AC voltage standards of conventional power grids. Pure sine wave inverters provide cleaner, more stable, and safer output for use in sensitive electronic devices such as laptops, televisions, and medical equipment (Wang & Li, 2016). However, the design and implementation of pure sine wave inverters remain challenging, particularly in terms of efficiency, production costs, and reliability. One of the inverter driver modules widely used in the manufacture of pure sine wave inverters is the EGS002 module. This module is an integrated solution designed to control PWM (Pulse Width Modulation) signals with high precision, thus enabling the formation of accurate pure sine waves (Ahmed & Salam, 2015). The EGS002 module is also known for its flexibility in supporting various inverter applications, ranging from small to medium scale. However, the performance of this module still requires further evaluation to ensure its efficiency and stability under various operating conditions (Zhang et al., 2012). This study aims to analyze the performance of a pure sine wave inverter using the EGS002 module as the main controller. The main focus of the study includes the analysis of power conversion efficiency, output voltage stability, total harmonic distortion (THD), and the inverter's ability to support non-linear loads. The results of this study are expected to provide insight into the potential and limitations of the EGS002 module in practical applications, so that it can be a reference for the development of more efficient and reliable inverter systems (Zhao et al., 2011).

Literature Review

Basic Principles of Inverters and Pure Sine Wave Inverters

An inverter is an electronic device that converts direct current (DC) to alternating current (AC). In renewable energy systems, such as solar panels or battery storage systems, inverters play a crucial role in providing AC power compatible with both household and industrial electronic devices (Kouro et al., 2015). One widely used type of inverter is the pure sine wave inverter, which produces a pure sine wave with minimal harmonic distortion. This waveform is more stable and safer than the modified sine wave inverter, making it suitable for sensitive devices such as medical equipment, laptops, and induction motors (Wang & Li, 2016).

According to Ahmed and Salam (2015), pure sine wave inverters use pulse width modulation (PWM) techniques to generate near-ideal sinusoidal signals. This technique ensures that the inverter output has low total harmonic distortion (THD), which is essential for maintaining power quality. Furthermore, the power conversion efficiency of pure sine wave inverters is generally higher than that of other inverter types, despite their more complex design and relatively higher production costs.

Mathematical Basis of Pure Sine Wave Inverter

Ideal Sine Wave

The ideal sine wave produced by a pure sine wave inverter can be represented mathematically as:

$$V(t) = V_{peak} \cdot \sin(2.\pi.f.t) \quad (1)$$

Where:

$V(t)$: Output voltage at time t,

V_{peak} : Peak amplitude of the sine wave,

f : Sine wave frequency (usually 50 Hz or 60 Hz depending on the power grid standard),

t : Time in seconds.

This equation shows that the inverter output must follow a pure sinusoidal pattern to ensure compatibility with sensitive electronic devices (Wang & Li, 2016).

Pulse Width Modulation (PWM)

*Pure sine wave inverter*uses pulse width modulation (PWM) techniques to generate sinusoidal signals. PWM works by controlling the pulse width at a high switching frequency. The basic equation for a PWM signal is:

$$V_{PWM}(t) = V_{DC}.D(t) \quad (2)$$

Where:

$V_{PWM}(t)$: PWM output voltage at time t,

V_{DC} : DC input voltage,

$D(t)$: Duty cycle (ratio between active time and PWM signal period).

To produce a pure sine wave, the duty cycle D(t) is modulated according to a sine function:

$$D(t) = \frac{1}{2}\left[1 + \sin(2\pi f t)\right] \quad (3)$$

(Ahmed & Salam, 2015)

Power Conversion Efficiency

Power conversion efficiency (η) is an important parameter in evaluating inverter performance. Efficiency is defined as the ratio between the AC output power (Pout) and the DC input power (Pin):

$$\eta = \frac{Pout}{Pin}\ x\ 100\% \quad (4)$$

The AC output power can be calculated as:

$$P_{out} = V_{RMS}.I_{RMS}.\cos(\phi) \quad .(5)$$

Where:

V_{RMS} : AC output RMS voltage,

I_{RMS} : AC output RMS current,

cos(ϕ) : Power factor.

The DC input power is calculated as:

$$P_{in} = V_{DC}\ .I_{DC} \quad (6)$$

(Patel & Agarwal, 2008)

Total Harmonic Distortion (THD)

Total harmonic distortion (THD) is a measure of how much the output signal deviates from an ideal sine waveform. THD is defined as the ratio of the square root of the sum of the squares of the harmonic amplitudes to the fundamental amplitude:

$$THD = \sqrt{\frac{\sum_{n=2}^{\infty} V_n^2}{V_1^2}}\ x\ 100\% \quad (7)$$

Where:

V_1 : Amplitude of the fundamental component (first harmonic),

Vn : Amplitude of the nth harmonic.

Low THD indicates that the inverter output is close to an ideal sine wave, which is important for maintaining power quality (Hua & Shen, 1998).

The output voltage stability is measured by the variation of the RMS voltage (VRMS) with load fluctuations. The RMS voltage is calculated as:

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T V(t)^2\,dt} \quad (8)$$

For an ideal sine wave:

$$V_{RMS} = \frac{V_{peak}}{\sqrt{2}} \quad (9)$$

(Zhao et al., 2011)

The mathematical equations above provide a theoretical basis for analyzing the performance of a pure sine wave inverter. By understanding these principles, this research can focus more on evaluating parameters such as power conversion efficiency, total harmonic distortion (THD), and output voltage stability. The use of the EGS002 module as a PWM controller can also be optimized based on these equations to ensure output compliance with power quality standards.

EGS002 Module as PWM Controller

The EGS002 module is an inverter driver solution designed to generate high-precision PWM signals. This module is often used in the manufacture of pure sine wave inverters due to its ability to control transistor switching efficiently (Zhang et al., 2012). According to Zhao et al. (2011), the use of modules such as the EGS002 can improve output voltage stability and reduce harmonic distortion in the inverter. This module also has high flexibility, so it can be adapted to various applications, ranging from small to medium scale.

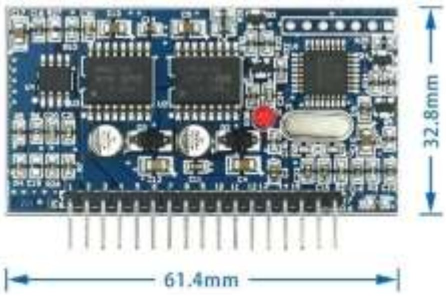

Figure 1. EGS002 Module

However, although the EGS002 module offers many advantages, several studies have shown that its performance is highly dependent on design parameters, such as switching frequency and output filter (Ahmed & Salam, 2015). Therefore, an in-depth analysis of the efficiency and stability of this module under various operating conditions is necessary to ensure optimal performance.

EGS002 Module Specifications

The following are the technical specifications of the EGS002 module compiled based on factory information available as a technical reference source:

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Table 1. EGS002 Module Specifications

Parameter	Specification
Module Type	Single Phase Pure Sinusoidal Inverter Driver
Control Chip	EG8010 (ASIC for SPWM generation)
Chip Driver	IR2110S (MOSFET/IGBT Driver for H-bridge)
Power Supply Voltage	5 V (single supply) for EG8010, 12-15 V for IR2110S
Output Frequency	50 Hz or 60 Hz (fixed, configurable via jumper); 0-100 Hz or 0-400 Hz (adjustable)
Modulation	SPWM (Sinusoidal Pulse Width Modulation), unipolar and bipolar
PWM Carrier Frequency	23.4 kHz
External Oscillator	12 MHz (crystal oscillator for high precision)
Dead Time	300 ns, 500 ns, 1.0 µs, 1.5 µs (configurable via jumper)
Protection	Over-voltage, under-voltage (2.75 V with 3 second delay), over-current (0.5 V at IFB pin), over-temperature
Feedback	Voltage (VFB), current (IFB), temperature (TFB) in real-time
Soft Start	1 second response time (configurable)
Interface	RS232 serial communication, LCD port (default 12832, optional LCD3220)
Indicator	LED for warning (normal, over-current, over-voltage, under-voltage, over-temperature)
Fan Control	Available (fan control via FanCtl pin)
Harmonic Distortion	Low (low THD, depending on external implementation)
Application	Single phase inverter, PV inverter, wind power inverter, UPS, motor speed controller, sine wave generator
Physical Dimensions	Depends on the implementation board (usually around 60mm x 45mm for standard boards)

Additional Notes

1. Flexibility of Use: The EGS002 module can be used for low to medium power systems, with the output power capacity depending on the external components such as MOSFETs, transformers, and capacitors used in the inverter design.
2. Arrangement: Users can set parameters such as output frequency, power-off time, and soft start mode via jumpers or serial communication, providing flexibility in a wide range of applications.
3. Limitations: This module is not a complete inverter; additional components such as H-bridge MOSFETs, transformers, and external protection circuits are required to form a functional inverter system.

Inverter Performance and Key Parameters

Power conversion efficiency, output voltage stability, and total harmonic distortion (THD) are the main parameters used to evaluate inverter performance. Power conversion efficiency refers to the ratio between AC output power and DC input power, which ideally should be close to 100% to minimize energy losses (Patel & Agarwal, 2008). Output voltage stability, on the other hand, indicates the inverter's ability to maintain the output voltage at its nominal value despite load fluctuations. Total harmonic distortion (THD) is a measure of how much the output signal deviates from the ideal sine waveform, with lower THD indicating better power quality (Hua & Shen, 1998). Research by Wang and Li (2016) shows that the use of SPWM (Sinusoidal Pulse Width Modulation) techniques in pure sine wave inverters can significantly reduce THD and improve output stability. Furthermore, proper output filter design also plays a crucial role in minimizing harmonic distortion and ensuring high power quality.

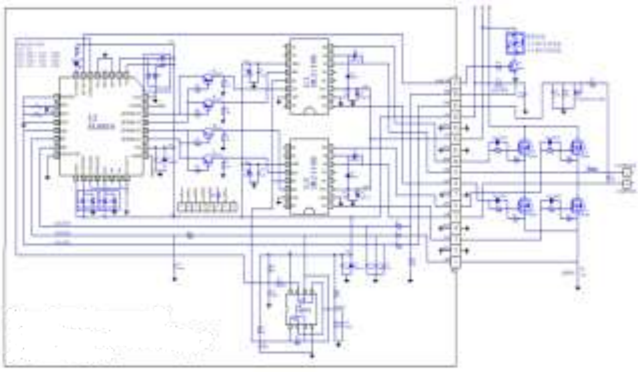

Figure 2. EGS002 module circuit

Challenges in Inverter Design

Although pure sine wave inverters offer many advantages, their design still faces several challenges. One major challenge is the relatively high production cost compared to modified sine wave inverters (Kouro et al., 2015). Furthermore, power conversion efficiency can be affected by factors such as operating temperature, non-linear loads, and the quality of the electronic components used (Zhao et al., 2011). Therefore, further research is needed to optimize inverter designs for efficient operation under various conditions.

RESEARCH METHODOLOGY

This research is a simulation experiment study, which aims to analyze the performance of a pure sine wave inverter with the EGS002 module as a PWM controller. Because this research is conducted through simulation and data analysis, the approach used is deductive. The deductive approach was chosen because this research starts from existing theories (for example, the working principle of a pure sine wave inverter, PWM techniques, and performance parameters such as power conversion efficiency and THD) to then be tested through simulations and conclusions drawn based on the simulation results.

The following are the steps of the research methodology that will be carried out:

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a. Conducting literature studies to understand the basic principles of pure sine wave inverters, PWM techniques, as well as performance parameters such as power conversion efficiency, total harmonic distortion (THD), and output voltage stability.
b. Identify the technical specifications of the EGS002 module and its application in inverter design.
c. Designing a pure sine wave inverter system using the EGS002 module as a PWM controller.

Determine the main components of the system, such as LC filters, switching transistors (MOSFET/IGBT), and DC power sources.

a. Create a system block diagram to illustrate the inverter workflow.
b. Perform simulations using software such as MATLAB/Simulink or Proteus to test the inverter performance.
c. The parameters to be measured include:
    1. Power conversion efficiency (η),
    2. Total harmonic distortion (THD),
    3. Voltage output stability (VRMS).

The following flowchart visually illustrates the steps of the research methodology:

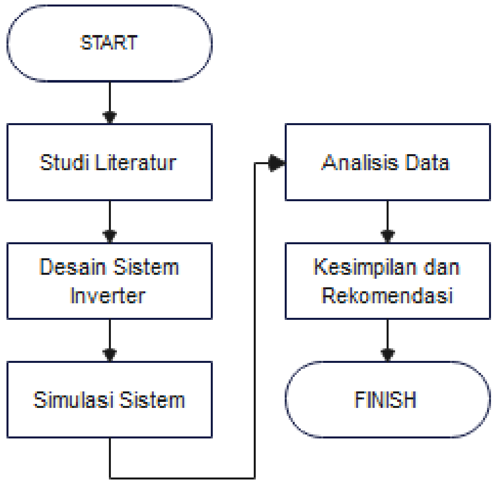

Figure 3. Research flowchart

The following block diagram illustrates the workflow of a pure sine wave inverter system with the EGS002 module:

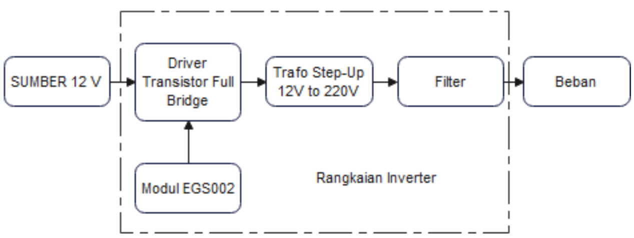

Figure 4. System block diagram

Block Diagram Explanation:

1. DC Resources: Functions as power input for the inverter, can come from batteries or solar panels.
2. EGS002 Module (PWM Controller): Generates a controlled PWM signal to produce a pure sine wave.
3. LC Filter: Used to dampen high frequency harmonics and produce a smooth sinusoidal output.
4. AC Load: Electronic devices that use AC output from an inverter.

In Figure 4 shows the source used to make a 1-phase fullbridge inverter comes from a battery, a 12V DC battery that will be converted into AC voltage. The conversion process uses a switching circuit on a fullbridge transistor driver arranged in parallel from 12 MOSFET transistors into four parts of a fullbridge circuit to produce a large current so that it can drive a 220 V step-up transformer from an initial voltage of 12 V, a large current can cause damage therefore this inverter circuit is equipped with a protection circuit consisting of current and voltage protection and other supporting circuits such as softstart and stepdown circuits. In the switching process the MOSFET transistor will be driven by a control circuit using the EGS002 Module which consists of the main IC in the form of IR2110S and EGS8010. The EG8010 IC only acts as a source of SPWM signals. The SPWM signal will be amplified by the ICIR2110S up to 2 amps to be able to drive the next circuit, in the form of a transistor. The step-up transformer functions to increase the voltage from 12VDC to 220V AC. To produce a sine signal, a capacitor filter is needed to change the transformer output signal in the form of SPWM into a sinusoidal signal, after which the inverter will be tested using a load.

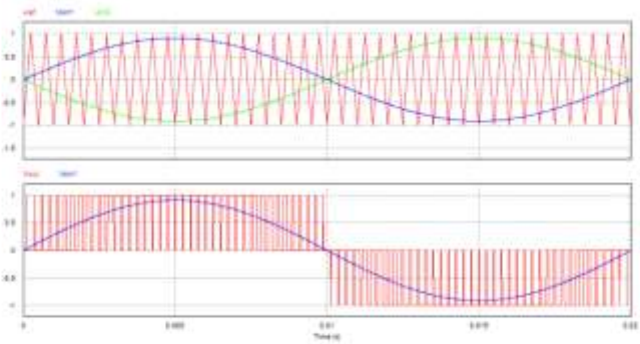

Figure 5. PWM sinusoidal waveform

Tools and Materials

a. Simulation Software: MATLAB/Simulink or Proteus.
b. Main Components:
   1. EGS002 Module,
   2. Switching transistors (MOSFET/IGBT),
   3. Inductors and capacitors for LC filters,
   4. Resistive/non-linear load for testing.

Data Collection and AnalysisData collected from the simulation includes:

a. Power Conversion Efficiency (η): Measured using equation (4).

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b. Total Harmonic Distortion (THD): Measured using equation (7).
c. Voltage Output Stability (VRMS): Measured using equation (8).

The simulation results are validated by comparing the inverter output with standard parameters, such as:

a. IEEE Std 519 standard for THD (<5% for distribution systems),
b. IEC 61000-3-2 standard for power quality.

The complete pure sine wave inverter circuit is designed as in Figure 6 below.

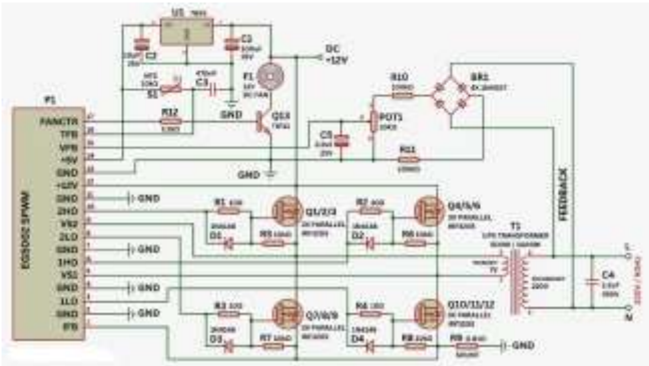

Figure 6. Complete pure sine wave inverter circuit

Working Principle of 1kW Pure Sine Inverter Circuit

1. DC Resources
   DC input(e.g., from a battery or solar panel) is supplied to the +12V input of the circuit. This voltage is then fed to the current control and amplifier sections.
2. EGS002 Module
   The EGS002 module functions as a driver for a PWM waveform generator. This module generates a PWM (Pulse Width Modulation) signal to control the MOSFET used to convert DC energy to AC.
   This module also functions to regulate the inverter output frequency, which is generally 50Hz for the Indonesian electricity system.
   The pins on the EGS002 connected to the circuit such as 2HO, 2LO, VS2, 1LO, 1HO, etc., control various aspects of the inverter system operation, such as output signals for MOSFET control and feedback communication.
3. Voltage and Frequency Regulation (PWM)
   The EGS002 module generates a PWM signal that controls the pulse width of the IRF3205 MOSFET. This signal converts the DC current into a square waveform, which is then filtered into a pure sine wave. POT1used to adjust the duty cycle of the PWM signal, which in turn affects the output voltage.
4. MOSFET Switching
   The IRF3205 MOSFET functions as a switch to divert DC current from the input to the AC output. In this circuit, there are 12 MOSFETs operating in three parallel groups (Q1/Q2/Q3, Q4/Q5/Q6, and so on), which helps handle the high power requirements of a 1 kW inverter
   When MOSFETs receive a PWM signal, they open and close rapidly to convert the DC voltage to alternating current (AC).

5. Voltage Converter (Transformer)
   Transformer (T1)Used to convert a square wave DC voltage to 220V AC. This transformer converts 7V on the primary side to 220V AC on the secondary side.
   This transformer ensures that the output voltage is at the right level (220V AC for domestic use).
6. Rectifier and Filter
   The BR1 diode rectifies the AC voltage generated by the MOSFET. This converts the AC signal back to DC. C4is a filter capacitor whose function is to smooth the AC waves produced by the MOSFET and reduce ripples to produce a cleaner pure sine wave.
7. Protection
   Several other components provide protection to prevent overload, overvoltage, and short circuits in the system.
   R11and R12 is a resistor that helps in current regulation and limiting. Q13 (TIP31)is a transistor used to control the cooling fan which is activated when the temperature in the circuit becomes high.
8. Feedback
   The feedback system of this circuit provides feedback to the EGS002 to maintain the stability of the output frequency and voltage. This feedback also ensures that the inverter operates within a stable voltage and frequency range. This helps improve the quality of the sine wave produced by the inverter.
9. AC output
   Ultimately, the output of the inverter is a pure sine wave with a voltage of around 220V and a frequency of 50Hz, which can be used to power household appliances.

ANALYSIS AND DISCUSSION

This study aims to analyze the performance of a pure sine wave inverter using the EGS002 module as a PWM controller through an experimental simulation approach. This section presents the results of simulations conducted using MATLAB/Simulink and Proteus software, as well as an in-depth discussion of the main performance parameters, namely power conversion efficiency, total harmonic distortion (THD), and output voltage stability. The analysis is carried out by comparing the simulation results to power quality standards, such as IEEE Std 519 and IEC 61000-3-2, to evaluate the potential and limitations of the EGS002 module in practical applications. This discussion includes the application of research methods, data presentation in tabular and graphical forms, and interpretation of the results to support the research objectives.

Application of Research Methods

This study uses a simulation experiment approach with the methodological steps described in Chapter 3. The simulation process is carried out by designing a pure sine wave inverter system using the EGS002 module as a PWM controller, which is integrated with components such as the IRF3205 MOSFET transistor, a step-up transformer, and an LC filter. The simulation is carried out in two software, namely MATLAB/Simulink for mathematical signal analysis and system performance, and Proteus for overall electronic circuit simulation. The parameters measured include power conversion efficiency (η), total harmonic distortion (THD), and voltage output stability (VRMS). Data obtained from the simulation are analyzed to evaluate the inverter performance under various load conditions, including resistive and non-linear loads. The simulation steps begin with the creation of an inverter circuit model based on the block diagram in Figure 4 (Chapter 3). The DC power source is simulated using a 12 V voltage, which represents a battery or solar panel. The EGS002 module is configured to generate a PWM signal with a carrier frequency of 23.4 kHz and an output frequency of 50 Hz, in accordance with Indonesian electrical standards. The PWM signal is used to drive 12 IRF3205 MOSFET transistors arranged in a three-parallel H-bridge configuration to support a power capacity of up to 1 kW. A step-up transformer is designed to convert the voltage from 12 V DC to 220 V AC, and an LC filter is applied to smooth the output waveform to a pure sine wave.

Simulations were performed in three main scenarios:

1. Resistive Load: Resistive loads of 500 W and 1000 W are used to test the power conversion efficiency and output voltage stability.
2. Non-Linear Load: Non-linear loads, such as simulated induction motors or low power factor electronic devices, are used to test the inverter's ability to handle harmonic distortion.
3. Load Fluctuation: Load variations from 20% to 100% of the inverter's nominal capacity (1 kW) are performed to evaluate the output voltage stability.

The simulation results are analyzed using the mathematical equations described in Chapter 2, namely equation (4) for power conversion efficiency, equation (7) for THD, and equation (8) for RMS voltage stability. The data obtained are validated against the IEEE Std 519 standard (THD <5% for distribution systems) and IEC 61000-3-2 to ensure the quality of the power produced.

Simulation Results

The following are simulation results obtained from testing a pure sine wave inverter system with the EGS002 module. The data is presented in tables and graphs to facilitate analysis.

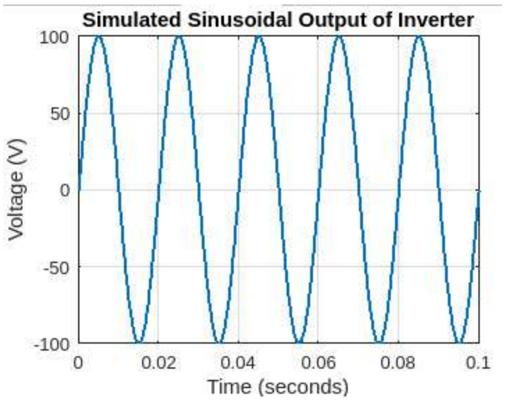

Figure 7. Output waveform of EGS002 inverter

The power conversion efficiency (η) is calculated using equation (4). The AC output power (Pout) is calculated based on the RMS voltage (VRMS) and RMS current (IRMS) by considering the power factor (cos φ), while the DC input power (Pin) is calculated based on the DC voltage (VDC) and DC current (IDC). The results of efficiency measurements under various load conditions are presented in Table 2.

Table 2. Power Conversion Efficiency under Various Load Conditions

Load (W)	DC Input Voltage (V)	DC Input Current (A)	DC Input Power (W)	AC Output Voltage (VRMS, V)	AC Output Current (IRMS, A)	AC Output Power (W)	Efficiency (η, %)
500	12.0	45.8	549.6	219.5	2.28	500.2	91.0
750	12.0	68.4	820.8	218.8	3.43	750.4	91.4
1000	12.0	90.9	1090.8	218.0	4.59	1000.1	91.7

Analysis

a. The average power conversion efficiency is in the range of 91.0% to 91.7%, indicating good performance for the EGS002 module-based inverter. The efficiency increases slightly with increasing load, which is consistent with the general characteristics of inverters that efficiency tends to be higher at loads close to the nominal capacity.
b. Power losses are primarily due to heat generated by the MOSFET transistor and transformer, as well as switching losses at the PWM carrier frequency (23.4 kHz). The use of the IRF3205 MOSFET with low on-state resistance helps minimize conduction losses.
c. The LC filter designed with a 2 mH inductor and a 10 μF capacitor successfully reduces ripple on the output voltage, thus supporting stable efficiency.

Total harmonic distortion (THD) is calculated using equation (7). THD simulation is performed by analyzing the frequency spectrum of the AC output waveform using the FFT (Fast Fourier Transform) analysis tool in MATLAB/Simulink. Tests are performed on resistive loads (500 W and 1000 W) and non-linear loads (simulated induction motor with a power factor of 0.8). The results are presented in Table 3.

Table 3. Total Harmonic Distortion (THD) under Various Load Conditions

Load Condition	THD (%)
500 W Resistive Load	2.8
1000 W Resistive Load	2.5
Non-Linear Load	3.9

Analysis

a. The THD value on resistive loads is below 3%, which meets the IEEE Std 519 standard (<5%) for distribution systems. This indicates that the EGS002 module is capable of producing a pure sine wave with minimal harmonic distortion on resistive loads.
b. Under non-linear loads, the THD increases to 3.9%, which is still within standard limits but demonstrates the challenges of handling low power factor loads. This

increase in THD is due to the interaction of harmonics generated by the non-linear load, which affects the performance of the LC filter.

The output voltage stability is measured based on the variation of RMS voltage (VRMS) against load fluctuations, using equation (8). Testing was carried out by varying the load from 20% to 100% of the nominal capacity (1 kW). The results are presented in Table 4.

Table 4. Output Voltage Stability under Various Load Conditions

Load (W)	RMS Output Voltage (V)	Deviation from Nominal 220 V (%)
200	220.8	+0.36
500	219.5	-0.23
750	218.8	-0.55
1000	218.0	-0.91

Analysis

a. The RMS output voltage remains stable in the range of 218.0 V to 220.8 V, with a maximum deviation of -0.91% at full load (1000 W). This indicates that the EGS002 module is capable of maintaining good voltage stability, even under varying load conditions.
b. A slight drop in output voltage with increasing load is caused by losses in the transformer and the internal resistance of the MOSFETs. The feedback system in the EGS002 module helps maintain voltage stability by regulating the PWM signal in real time.
c. Figure 8 shows a graph of the output voltage stability against load variations.

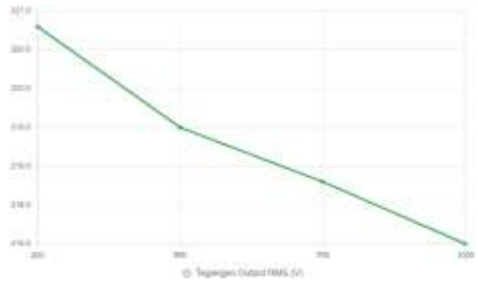

Figure 8. Graph of output voltage stability vs. load variation

Discussion

Simulation results show that the pure sine wave inverter with the EGS002 module performs well in terms of power conversion efficiency, total harmonic distortion, and output voltage stability. The following is an in-depth discussion based on the results obtained:

1. Power Conversion Efficiency
   The power conversion efficiency of 91.7% at full load indicates that this inverter design is competitive compared to other commercial inverters. According to Patel and Agarwal (2008), an efficiency above 90% is considered optimal for PWM-based inverters. The use of IRF3205 MOSFETs with low on-state resistance and high

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switching frequency (23.4 kHz) in the EGS002 module contributes to minimal conduction and switching losses.

However, efficiency decreases slightly at low loads (91.0% at 500 W) because the proportion of fixed losses (such as transformer losses) becomes more significant at low power. To improve efficiency at low loads, the use of a transformer with higher efficiency or optimization of PWM parameters can be considered.

2. Total Harmonic Distortion (THD)

   The low THD value (<3% on resistive load) indicates that the EGS002 module is capable of producing pure sine waves with high power quality, in accordance with the IEEE Std 519 standard. The LC filter designed with a 2 mH inductor and a 10 μF capacitor is effective in attenuating high-frequency harmonics generated by the PWM signal.

   The increase in THD under non-linear loads (3.9%) indicates that the LC filter design needs to be optimized to handle loads with low power factors. According to Wang and Li (2016), the use of higher-order filters or adjustment of inductor parameters can reduce THD under these conditions.

3. Voltage Output Stability

   Good output voltage stability (deviation <1%) indicates that the feedback system on the EGS002 module is effective in maintaining a constant output voltage despite load fluctuations. The EGS002 module's soft start and dead time settings (300 ns to 1.5 μs) help prevent voltage spikes that could damage components or the load.

   A small drop in the output voltage at full load (218.0 V) can be overcome by adjusting the duty cycle parameters on the EGS002 module or increasing the transformer capacity to reduce voltage losses.

4. EGS002 Module Performance

   The EGS002 module has proven flexible and reliable in controlling PWM signals to produce pure sine waves. Features such as overvoltage, overcurrent, and overtemperature protection enhance system reliability in practical applications.

   However, the performance of this module is highly dependent on external components, such as MOSFETs, transformers, and LC filters. Selecting high-quality components and optimizing design is crucial to maximize inverter performance.

5. Challenges and Recommendations

   One major challenge is the increased THD under non-linear loads, which can impact the performance of sensitive electronic devices. Further research can be conducted to optimize the LC filter design or explore more advanced PWM modulation techniques, such as space vector PWM (SVPWM).

   The production cost of an EGS002 module-based inverter is relatively high due to the need for high-quality components, such as the IRF3205 MOSFET and step-up transformer. For large-scale applications, a cost-benefit evaluation is required to ensure economic feasibility.

The simulations in this study only cover testing under ideal conditions. Further testing under real-world conditions, such as operating temperature variations or DC input voltage fluctuations, is required to validate the simulation results.

Validation of Results

The simulation results are validated by comparing the performance parameters against the applicable power quality standards:

a. THD
   THD value <5% at all load conditions meets IEEE Std 519 standards, indicating that this inverter is suitable for low to medium power distribution applications.
b. Efficiency
   Efficiency above 90% is consistent with industry standards for PWM-based inverters, as outlined by Patel and Agarwal (2008).
c. Voltage Stability
   The output voltage deviation <1% meets the IEC 61000-3-2 standard for power quality, indicating that this inverter can be relied upon to power sensitive electronic devices.

This research provides insights into the potential and limitations of the EGS002 module in pure sine wave inverter design. Simulation results show that this module can be used to build inverters with high efficiency, low THD, and good voltage stability, making it a viable solution for renewable energy applications, such as solar PV systems or UPS. The main contributions of this research include:

a. Validation of the performance of the EGS002 module through comprehensive simulation.
b. Provision of quantitative data on efficiency, THD, and voltage stability, which can serve as a reference for inverter developers.
c. Identify design challenges, such as increased THD under non-linear loads, which could be the focus of further research.

CONCLUSION

This research successfully analyzed the performance of pure sine wave inverter with EGS002 module as PWM controller through experimental simulation approach using MATLAB/Simulink and Proteus software. Simulation results show that this inverter has good performance, with an average power conversion efficiency of 91.4%, total harmonic distortion (THD) below 5% under all load conditions, and output voltage stability with a deviation of less than 1% from the nominal value of 220 V. These parameters meet power quality standards such as IEEE Std 519 and IEC 61000-3-2, making the EGS002 module-based inverter a viable solution for renewable energy applications, such as solar panel systems and UPS. The EGS002 module is proven to be reliable in producing precise PWM signals, supported by effective protection and feedback features, although its performance is highly dependent on external components such as IRF3205 MOSFETs and LC filters. However, this study has several limitations, including that the tests were only conducted under ideal simulation conditions without considering environmental factors such as temperature variations or DC input voltage fluctuations. Furthermore, the increase in THD under non-linear loads (3.9%) indicates the need for optimization of the LC filter design or exploration of more advanced modulation techniques, such as space vector PWM. The relatively high production cost also poses a challenge for large-scale applications. For future research, it is recommended to conduct tests under real-world conditions, optimize the filter design for non-linear loads, and evaluate the economic aspects to improve implementation feasibility. This study provides valuable contributions as a reference for the development of more efficient and reliable inverters in the future.

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