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Abstract

The inverter built in this research is used to convert direct current into alternating current with a size of 3000 watts, which has a DC input voltage of 24 volts. This inverter has a large capacity and can generate enough electricity to run different huge electrical devices or several units at once. It's made utilizing energy-efficient technology to cut down on energy waste during conversion. Furthermore, safeguards such voltage surge and overcurrent prevention guarantee the operational safety of the inverter. This inverter was designed with a 24 Volt DC input and has the primary components in the form of IC3525, IRFB4110 MOSFET, EE55 transformer that converts the 24 volt DC voltage to 350 volt DC, rectifier circuit, 350-12V step down circuit, EGS002 PSW Module to function as a Voltage Regulator and Pulse Width Modulation over Insulated Gate Bipolar Transistor (IGBT), and IGBT YGW40N65F1 for a Current Regulator using 3 mH inductor. The inverter was built using the PWM method and variable loads (resistive load, inductive load and capacitive load), with the aim of evaluating the inverter's ability to handle resistive, inductive and capacitive loads and to see how the inverter responds to load changes dynamically. Based on observations and calculations, higher loads are positively correlated with higher inverter power and efficiency. The inverter has a max output of 664.62 watts and 229 Volt is the output voltage attained. This demonstrates that the EGS002 Pure Sine Wave inverter produces AC voltage of high quality with precise and steady characteristics.

Introduction

Meeting energy needs presents unique issues for Indonesia, a country with a wide size, different geographical circumstances, and a high population spread. Indonesia has a great deal of potential for renewable energy resources. According to the 2019 Indonesian Energy Outlook book, the total potential for new and renewable energy (NRE) is equivalent to 442 GW of electricity generation. In 2018, 8.8 GW of NRE were used to generate electricity, accounting for 14% of the total electricity generation capacity (fossil and non-fossil), for 64.5 GW. Solar energy has the highest NRE potential, at 207.8 GWp. However, Indonesia's solar energy potential does not match its utilization, which is only around 0.07% (Ministry of Energy and Mineral Resources, 2021).[1]

Despite having enormous renewable energy potential, its utilisation is still minimal when compared to conventional power plants that use fossil energy, constrained in funding and energy generated from renewable energy sources is usually in the form of DC (Direct Current) that can be used directly or must be converted into AC current using an inverter.[2] The best inverter is one that can generate pure sine waves, which are identical to the waveform produced by the electrical network.[3] Based on these problems, this research modifies the Pure Sine Wave (PSW) inverter by using the width modulation method and the PWM (Pulse Width Modulation) pulse method. This means that the PWM signal has a fixed wave frequency but the duty cycle varies (between 0% and 100%). PWM switching is the manipulation of the output signal in the on and off state.

Inverters are classified as Pulse Width Modulation (PWM), Modulation Pulse Width Modulation (MPWM), Sinusoidal Pulse Width Modulation (SPWM), or Multiple Sinusoidal Pulse Width Modulation (MSPWM) based on their pulse generator. Inverters use various switching devices, including MOSFET and IGBT switches, each with unique advantages and disadvantages.[4] Inverters also classified by their output waveform: Square Waves (SW), Modified Sine Waves (MSW), and Pure Sine Waves (PSW). [5] This research produces a 3000 Watt 24V H-Bridge Single Phase Pure Sine Wave inverter, with PWM method and Variative loads (Resistive Load,
Inductive Load and Capacitive Load), with the aim of evaluating the inverter's ability to handle resistive, inductive, and capacitive loads and to see how the inverter responds to load changes dynamically.

Research on inverters with pure sine wave output has developed quite significantly, including research by Kunnu Purwanto et al [6] in 2023 which produced an inverter with a maximum power of 500 Watt with focusing on a ferrite core transformer, there was also research by Wafiq Safaroz [7] which produced an inverter with a capacity of 500 watts based on Microcontroller. Other research discusses the comparison of the performance of pure sine wave (PSW) and non pure sine wave (non PSW) inverter types [8] where the PSW inverter is based on the EGS002 module while the non PSW inverter is based on IC 4047. Another study entitled Design of Arduino Uno-based Single Phase Pure Sine Wave Inverter by Muhammad Iskandar et al [9] with an inverter capacity of 1000 Watt, while F. Ronilaya and friends discuss the implementation of Arduino Nano microcontroller for a single phase pure sine wave inverter. [10] Another study is pure sine wave inverters on loads in solar power plant capacity 100 watts peak by Rawi Lastry Rajagukguk and friends.[11] The next research regarding PSW inverter is research by Ahmad Badawi and friends [12] which discusses the use of PIC 18F4550 Microcontroller for highly efficient pure sine wave inverters. The other paper describes a DC-to-AC power converter for low-power hospital equipment. The goal is to efficiently convert a DC power source into a high voltage AC output with low total harmonic distortion and a pure sine wave. The modulation technique used is a bipolar switching scheme. [13]

**Theory**

The inverter circuit in this research is made up of several components, including a 24 Volt battery, IC3525, MOSFET IRFB4110, EE55 Transformer, Rectifier, Step down 350-12V, EGS002, IGBT YGW40N65F1, Inductor, and Variable Loads. This system, which is based on a 3000 watt 24 volt inverter, combines MOSFET components to produce AC voltage output with higher quality and more stable characteristics, including MOSFET IRFB4, IGBT YGW40N65F1, and EGS002 module.

**A. MOSFET IRFB4110**

The IRFB4110 is a power MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) designed for high-current, high-voltage applications. The IRFB4110 mosfet provides high current with a low gate voltage,[14] making it suitable for use in various power electronics systems such as motor controls, power supplies, and solar inverters. Some key features of the IRFB4110 include:

1. Drain-Source (DS) voltage rating of up to 650V, allowing it to handle high voltage levels.
2. Maximum drain current (ID) of up to 42A, making it suitable for high-current applications.
3. Low RDS(ON) value of 0.003Ω (at VDS = 20V), resulting in low power loss and high efficiency.
4. Fast switching capability, with a typical gate charge (QG) of 25nC and a typical drain-source capacitance (Coss) of 280pF, allowing for fast switching times and reduced EMI (Electromagnetic Interference).
5. Thermal resistance (Rth(JA)) of 15°C/W, which helps to dissipate heat generated during operation and prevent overheating.
6. Low gate capacitance (CG) of 35nC, which reduces the amount of gate charge required during switching and helps to reduce EMI.
7. Available in a TO-247 package with a maximum case temperature (Tj(max)) of 175°C, making it suitable for use in high-temperature environments.

Overall, the IRFB4110 is a versatile and reliable MOSFET that offers high performance and reliability in a variety of power electronics applications.

**B. IGBT YGW40N65F1**

Insulated gate bipolar transistors (IGBTs) are widely used in high-voltage and high-power electronics converters due to their high switching frequency, low saturation voltage, and large power capability. [15] The insulated gate bipolar transistor (IGBT) is a fully controllable power semiconductor device capable of switching high voltages and currents. The properties of IGBTs are strongly affected by temperature. It has an impact on the device's electrical properties as well as its reliability.[16] In medium frequency, medium power applications, the Insulated
Gate Bipolar Transistor (IGBT) is a reliable alternative to the power Bipolar Junction Transistor (BJT), Darlington transistor, Metal Oxide Semiconductor Field Effect Transistor (MOSFET), and GTO thyristor.

The YGW40N65F1 is an insulated gate bipolar transistor (IGBT), designed for high-power, high-voltage applications, making it suitable for use in various power electronics systems such as motor controls, power supplies, and solar inverters.[17]

Some key features of the YGW40N65F1 include [18]:
1. Drain-Source (DS) voltage rating of up to 650V, allowing it to handle high voltage levels.
2. Maximum drain current (ID) of up to 40A, making it suitable for high-current applications.
3. Low RDS(ON) value of 0.025Ω (at VDS = 20V), resulting in low power loss and high efficiency.
4. Fast switching capability, with a typical gate charge (QG) of 38nC and a typical drain-source capacitance (Coss) of 380pF, allowing for fast switching times and reduced EMI (Electromagnetic Interference).
5. Thermal resistance (Rth(JA)) of 12°C/W, which helps to dissipate heat generated during operation and prevent overheating.
6. Low gate capacitance (CG) of 35nC, which reduces the amount of gate charge required during switching and helps to reduce EMI.
7. Available in a TO-247 package with a maximum case temperature (Tj(max)) of 175°C, making it suitable for use in high-temperature environments.

Compared to MOSFETs like the IRFB4110, IGBTs like the YGW40N65F1 offer higher current handling capabilities and lower RDS(ON) values at high voltage levels, making them more suitable for certain applications where high power density is required. However, they also have higher gate charge and drain-source capacitance values, which can result in higher EMI and slower switching times compared to MOSFETs.

C. EGS002

The EGS002 PSW is a power MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) manufactured by Infineon. The EGS002 SPWM Driver Board is a PWM inverter driver that requires a filter to produce pure sine wave voltage. Some key features of the EGS002 PSW include [19]:

1. Drain-Source (DS) voltage rating of up to 30V, allowing it to handle moderate voltage levels.
2. Maximum drain current (ID) of up to 2A, making it suitable for low-current applications.
3. Low RDS(ON) value of 0.015Ω (at VDS = 10V), resulting in low power loss and high efficiency.
4. Fast switching capability, with a typical gate charge (QG) of 35nC and a typical drain-source capacitance (Coss) of 240pF, allowing for fast switching times and reduced EMI (Electromagnetic Interference).
5. Thermal resistance (Rth(JA)) of 16°C/W, which helps to dissipate heat generated during operation and prevent overheating.
6. Low gate capacitance (CG) of 15nC, which reduces the amount of gate charge required during switching and helps to reduce EMI.
7. Available in a DPAK package with a maximum case temperature (Tj(max)) of 175°C, making it suitable for use in high-temperature environments.

Compared to other MOSFETs like the IRFB4110 and YGW40N65F1, the EGS002 PSW offers lower voltage and current ratings but lower RDS(ON) values at lower voltage levels, making it more suitable for low-power applications where high efficiency is required. However, its lower voltage and current ratings also limit its suitability for higher power applications compared to other MOSFETs or IGBTs.

Research Methods

This research was conducted in several stages, starting from literature study, hardware development, software development, hardware and software integration, system evaluation containing test result data.

A. Block Diagram System
In the block diagram above, it can be explained that the source used to make a 1-phase full bridge inverter is a battery, battery or power supply of 24V DC. The voltage will be converted into AC voltage. In the process of converting DC voltage into AC voltage using MOSFET to obtain SPWM waves that turn around from switching the mosfet. In the mosfet switching process, the SPWM module driver will then be forwarded to the inverter, the inverter using mosfet has a different signal value. From the output of this inverter in the form of AC voltage which will then enter the step up transformer. This step up transformer serves to increase the voltage from 24V AC to 220V AC. The output of the transformer will be filtered using a capacitor.

B. Block Diagram

In the picture above, the output from the 24 Volt DC battery goes to IC3525. The oscillation frequency in the SG3525 IC control circuit is regulated by the components of the timer resistor (Rt), discharge resistor (Rd), and timing capacitor (Ct).[20]

This IC offers useful features for electric power supply assemblies, including the Soft Star feature that activates when turned on. In addition, this IC controls the circuit’s PWM signal. The SG3525 chip has basic specifications, including : [21]

a) The minimum voltage for IC SG3525 is 8 VDC and a maximum of 35 VDC.
b) Has an internal reference voltage set to 5.1 V + with an accuracy of ±1%.
c) Oscillator that can be changed in value from 100 Hz to a maximum of 500 kHz

The SG3525 IC control circuit is responsible for producing PWM (Pulse Wide Modulation) signals. The SG3525 IC control circuit can adjust frequency and duty cycle. The oscillation frequency value in the SG3525 IC control circuit is regulated by two components connected to pins 5, 6.[22]

The Ferrite cores in EE or UU shapes are commonly used in High Power Electronic Transformer, where the central limb houses both windings. The magnetic circuit required a large DC bias capacity, and EE, UU, or CC cores were appropriate for high-power applications. [23] The EE55 transformer is a high-power electronic transformer that converts the 24 volt DC voltage to 350 volt DC. The EE55 ferrite cores were enlarged using block constructions to generate the high power. The standard transformer design includes an EE core structure with an integrated current doubler, which is well-known in literature. Material and assembly costs are constrained.
The center leg of the E core has twice the magnetic cross-section as the outer legs. This ensures an optimal distribution of core material. Leakage in the core environment can significantly impact component behavior, complicating the design process.

The Rectifier circuit consists of an ES5J Diode is used for two power supplies: powering the EGS002 module after passing through the Step Down 350-12 V, and powering the IGBT YGW40N65F1 with a voltage of 350 Volts.

The output from Step Down 350-12 V goes to EGS002. The EGS002 is a driver board designed for a single phase sine wave inverter. This EGS002 can set frequency configurations of 60 and 50 Hz.[24] EGS002 manages the circuit using an application-specific integrated circuit (ASIC) CMOS EG8010. The IR2110S performs voltage and current protection, temperature sensor, fan control, and indicator functions. EGS002 is an improved version of EGS001, with added protection schemes and liquid display interfacing.[25] It applies to the DC-DC-AC two-stage power converter system.[19] Following the 24VDC voltage is converted to 360VDC at a frequency of 21 KHz, the Pure Sine Wave Inverter EGS002 module converts the voltage to AC 220 Volt 50Hz. EGS002 functions as a voltage regulator and PWM for IGBT. The circuit then involves the IGBT YGW40N65F1 that controls the current through a 3mH inductor. The output will be used for various parameter loading.

C. Schematic Diagram

**Figure 3: Schematic Diagram of the Circuit**

**Stage 1** is the DC-DC Converter Step Up section to increase the low voltage from the battery to a high voltage of 360 Volts DC with a frequency of 21 kHz. Then it will be converted to AC 220 Volt 50Hz at stage 2 with the SPWM module EGS002 (Pure Sine Wave Inverter).

**Stage 2** is the conversion part of the 360V DC high voltage from stage 1 to AC 220 V 50Hz using the EGS002 Pure Sine Wave Inverter module so that it can be used in all 220 Volt home electrical appliances / loads by adjusting the frequency to 50 Hz.
Results and Discussion

The inverter built is a Pure Sine Wave inverter with a power of 3000 Watt 24 Volts. Testing the Characteristics of this 3000 Watt 24 V Inverter using a varied load in the form of Resistive Load Parameters, Inductive Load and Capacitive Load.

**Resistive Loads** are loads that cause resistance to the flow of electric current without causing a phase change between voltage and current. Examples of resistive loads are heaters, incandescent lamps, and other heating elements. Testing with resistive loads aims to observe how the inverter handles loads that are constant and do not change dynamically.

**Inductive Loads** are loads that have inductance components (such as electric motors) that cause phase changes between voltage and current. Testing with inductive loads aims to observe how the inverter handles loads that change dynamically due to the nature of inductance.
Capacitive Load: Capacitive loads are loads that have a capacitance component, such as a capacitor. These loads cause phasing between voltage and current, similar to inductive loads. Testing with capacitive loads aims to observe how the inverter handles loads with capacitive characteristics.

This section may each be divided by subheadings or may be combined. A combined Results and Discussion section is often appropriate. This should explore the significance of the results of the work, don’t repeat them. Avoid extensive citations and discussion of published literature only, instead discuss recent literature for comparing your work to highlight novelty of the work in view of recent development and challenges in the field.

A. Input Power and Output Power Testing

Tests are conducted to determine the inverter's response to dynamic variations in load as well as its capacity to manage resistive, inductive, and capacitive loads. The tests' outcomes can be utilized to enhance the inverter's design, maximize its performance, and make sure it operates correctly in a variety of scenarios.

<table>
<thead>
<tr>
<th>Load</th>
<th>Specification</th>
<th>Battery Input</th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power (W)</td>
<td>Current (A)</td>
<td>V</td>
<td>A</td>
</tr>
<tr>
<td>2 Led’s Lamp (Resistive)</td>
<td>14</td>
<td>0.03</td>
<td>24</td>
<td>35</td>
</tr>
<tr>
<td>1 Heater (Resistive)</td>
<td>700</td>
<td>3.18</td>
<td>24</td>
<td>35</td>
</tr>
<tr>
<td>1 Electric Drill (Inductive)</td>
<td>350</td>
<td>1.59</td>
<td>24</td>
<td>35</td>
</tr>
<tr>
<td>1 Grinding Tool (Inductive)</td>
<td>580</td>
<td>2.63</td>
<td>24</td>
<td>35</td>
</tr>
<tr>
<td>1 cellphone charger (capacitive)</td>
<td>33</td>
<td>0.15</td>
<td>24</td>
<td>35</td>
</tr>
</tbody>
</table>

B. Inverter Efficiency Calculation against Load

Based on the measurement results above, the effect of power factor on inverter efficiency can be calculated using the following equations.

Calculation of Pout (output power) when connected to a load
\[ P_{out} = V \times I \times \cos \theta \] (1)

Calculation of Pin (input power) when connected to the load
\[ P_{in} = V \times I \] (2)

Inverter efficiency is obtained by the formula
\[ \% \eta = \frac{P_{out}}{P_{in}} \times 100 \% \] (3)

<table>
<thead>
<tr>
<th>Loads</th>
<th>Output Power</th>
<th>Input Power</th>
<th>η (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2) 14 Watt LED Lights</td>
<td>V_{out} 220</td>
<td>I_{out} 0.03</td>
<td>13.99</td>
</tr>
<tr>
<td>(1) Heater 700 Watts</td>
<td>V_{in} 209</td>
<td>I_{in} 3.18</td>
<td>1</td>
</tr>
<tr>
<td>(1) Electric Drill 350 Watt</td>
<td>V_{in} 224</td>
<td>I_{in} 1.59</td>
<td>1</td>
</tr>
<tr>
<td>(1) 550 Watt Grinding Tool</td>
<td>V_{in} 229</td>
<td>I_{in} 2.63</td>
<td>1</td>
</tr>
<tr>
<td>(1) 33 Watt Hp Charger</td>
<td>V_{in} 240</td>
<td>I_{in} 0.15</td>
<td>1</td>
</tr>
</tbody>
</table>

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The effect of load on inverter power and efficiency can be seen that the load greatly affects the power and efficiency of the inverter. For example, when the load is added to the resistive load, the inverter efficiency increases to 79.1%. This shows that the inverter works more efficiently when facing higher loads. The Peak Power of the Inverter stands at 664.62 Watts. Peak power indicates the maximum power that can be generated by the inverter under certain conditions.

AC Voltage Stability and Quality can be observed from the AC voltage results with a frequency of 50 Hz and an output voltage level reaching 229 V. This shows that the PSW EGS002 inverter has stable and precise characteristics in generating AC voltage with good quality.

**Conclusion**

The amount of load greatly affects the power and efficiency of the inverter, the inverter will work more efficiently when facing higher loads. As consequence, consider the use of an inverter in accordance with the load that will be applied or connected. Increasing the load capacity can increase inverter efficiency by 70-80%. This inverter was built with a 24 Volt DC input and has the main components in the form of IC3525, IRFB4110 MOSFET, EE55 transformer which converts the 24 volt DC voltage to 350 volt DC, rectifier circuit, 350-12V step down circuit, EGS002 Pure Sine Wave (PSW) Module Driver Board as a Voltage Regulator and Pulse Width Modulation for Insulated Gate Bipolar Transistor (IGBT), and IGBT YGW40N65F1 as a Current Regulator with a 3 mH inductor.

Inverter Peak Power is at 664.62 Watts. The output voltage reaches 229 Volts. This indicates the maximum power that the inverter can produce under specific conditions and the PSW EGS002 inverter has stable and precise characteristics in producing AC voltage with good quality. This inverter is suitable for a variety of tool applications that require electrical power at a frequency of 50 Hz and a voltage range of 220 V. The paper mentions several tool applications, including electric motor drives, household appliances, and cellular charger devices that require stable and precise AC voltage.

**Reference**


