Jurnal Teknologi dan Manajemen

ISSN (Print) 1693-2285 ISSN (Online) 2808-9995

Implementation of a Fuzzy Logic Controlled Full Bridge SPWM Inverter for Lighting and Charging Applications

Brainvendra Widi Dionova[1], Muhammad Zidan Regi Permana[1], Devan Junesco Vresdian[1], Legenda Prameswono Pratama[1], Ariep Jaenul[1], Dian Nugraha[2], M. N. Mohammed[3]

[1] *Department of Electrical Engineering, Jakarta Global University, Jakarta, Indonesia*
[2] *Department of Informatics Engineering, Faculty of Engineering and Computer Science, Jakarta Global University, Depok, Indonesia*
[3] *Department of Mechanical Engineering, College of Engineering, Gulf University, Sanad, Kingdom of Bahrain*

ARTICLE INFO

Received : 25 February 2025
Accepted : 26 June 2025
Published : 28 August 2025

KEYWORDS

Fullbridge Inverter, Fuzzy Logic Controller, Microcontroller, SPWM

CORRESPONDENCE

E-mail Corresponding Author:
brainvendra@jgu.ac.id

ABTRACT

As energy sources continue to dwindle, they have garnered significant attention, prompting the government to set a target of at least 31% of Indonesia's total energy consumption coming from renewable sources. This study focuses on developing an inverter, a device that converts direct current (DC) into alternating current (AC), utilizing a 12V/100Ah battery to support a 150-watt AC load. The proposed inverter adopts a full-bridge configuration with single-phase sinusoidal pulse width modulation (SPWM) and incorporates a fuzzy logic controller to ensure stable output voltage. The implementation results indicate that the designed full-bridge inverter produces a steady output aligned with the input from a 12V LiFePO4 battery, as confirmed by data collection which compared the output with and without control, showing that the controlled system yields a more stable output. The testing results of the full-bridge inverter using the SPWM method indicate that the system can produce an AC output voltage of 221–224 V with a frequency of 50 Hz, in accordance with the established standards. In contrast, during testing without control, the output voltage ranged only between 145–147 V with a frequency of 99.18 Hz, which does not meet operational standards. These results clearly demonstrate the effectiveness of the fuzzy controller in maintaining both voltage and frequency stability under varying operating conditions. By accurately adjusting the system response, the fuzzy controller ensures that the inverter consistently delivers output within the desired standard range, thereby enhancing the overall performance and reliability of the system.

1. INTRODUCTION

In the modern era, global energy demand continues to grow. According to the International Energy Agency (IEA), energy consumption worldwide is projected to rise by up to 45% in the coming years, with an average annual increase of 1.6%. Fossil fuels are expected to supply approximately 80% of this demand. This reliance on fossil energy is not only a global concern but also a significant challenge for Indonesia, where fossil fuel consumption accounts for 67% of total energy use, posing a risk to energy security. (Dionova et al., 2023)To mitigate this issue, the government must accelerate the transition to renewable energy to better prepare for uncertainties across various sectors that could impact national energy resilience. This issue remains a key topic of discussion within the Institute for Essential Services Reform (IESR) (Naji Alhasnawi et al., 2024; Raihan et al., 2023; Sen & Ganguly, 2017).

Indonesia has significant potential for renewable energy, with an estimated capacity exceeding 443 GW. Of this total, around 50% comes from solar panels, likely due to Indonesia's geographical location near the equator. This refers to the utilization of heat and sunlight to be converted into electrical energy through the photovoltaic process. Indonesia’s vast renewable energy potential presents a major opportunity, with resources surpassing 443 GW. Notably, solar energy contributes to about half of this potential, largely attributed to the country's strategic position along the equator. This highlights the importance of harnessing solar heat and radiation to generate electricity via photovoltaic technology (Megantoro, 2022;

Paradongan et al., 2024; Wang et al., 2023). The adoption of solar panels as a renewable energy alternative in Indonesia is a strategic choice, considering the country's abundant solar energy potential. On average, Indonesia receives solar radiation of approximately 4.5 kWh/m², enabling a 100 Wp solar panel with a 1 m² surface area and 15% conversion efficiency to generate around 675 Wh of energy. The generated DC electricity can be utilized directly or converted into AC using an inverter for more extensive applications. Harnessing solar panels as a sustainable energy solution in Indonesia is an effective approach due to the country's high solar energy availability. With an average solar radiation of 4.5 kWh/m², a 100 Wp solar panel with a 1 m² surface area and 15% efficiency can produce roughly 675 Wh of energy. This DC electricity can either be used immediately or transf ormed into AC through an inverter to support various energy demands (Dionova et al., 2023; Green, 2019; Hosseinzadeh et al., 2021; Nyamathulla & Chittathuru, 2023; Putra et al., 2024).

The adoption of solar power as a renewable energy source is gaining traction as a reliable alternative for independent electricity generation, reducing dependence on the national grid. Several studies form the foundation of this research, particularly those related to smart home systems. One study explores the use of a pure sine wave inverter powered by a 100Wp solar panel for LED and fan loads. Another focuses on developing a 500W pure sine wave SPWM inverter with fuzzy logic control to enhance DC-to-AC conversion stability. Similarly, research on a 600W full-bridge inverter highlights the benefits of SPWM waveforms, which closely replicate the national grid's sine wave. Additionally, studies on 500W full-bridge SPWM inverters demonstrate their role as backup power sources, protecting electronic devices from sudden power failures (Ferdiansyah et al., 2021; Lastry Rajagukguk et al., 2023; Manamperi et al., 2024; Safaroz, 2023; Syururi, 2022). This research develops a full-bridge SPWM inverter with fuzzy logic control for a solar power system. The system operates with a 12V/100Ah LiFePO4 battery, which supplies DC power to the inverter. The fuzzy logic controller ensures a stable 220VAC output, which is then stepped up to meet household AC power requirements. This research aims to develop a renewable energy generation system for independent lighting and charging applications. The system serves as an alternative power source apart from the national grid, utilizing a full-bridge inverter to convert DC to AC and increase the voltage to 220V to meet the energy needs of lighting and charging stations.

2. METHOD

This research aims to develop a Full-Bridge SPWM Inverter using the Fuzzy Logic Controller method to convert 12V DC into 12V AC. It encompasses the design process, working principles, and testing phases to achieve the desired performance. This research begins by identifying problems, which then lead to the idea of implementing a solution within the university environment. A literature review is conducted to explore previous studies on similar issues. Based on these studies, improvements and direct implementation are carried out specifically in lighting and charging application. After reviewing the literature, the researcher designs the necessary components for the system. Once all components are developed, a Full-Bridge Inverter circuit simulation is conducted using software before testing the actual components. This step helps minimize errors and potential damage during real-world implementation while also serving as an initial data collection phase. Following successful testing, data is gathered for analysis and discussion to evaluate system performance and draw conclusions based on the predefined parameters.

1. Diagram Block

The proposed system derives its energy from a 12V/100Ah battery, which is charged by a 300Wp solar panel, ensuring a sustainable and renewable energy source. The battery's DC output is directed through a Full-Bridge MOSFET circuit and a voltage regulator to maintain stable power delivery. A DC voltage sensor continuously monitors voltage levels, preventing potential damage to components, while the voltage regulator ensures the output remains within the required range for the circuit is depicted in Fig.1.

The current then enters the Full-Bridge Inverter (MOSFET), which, together with a driver circuit, precisely controls the MOSFETs to convert DC into AC power efficiently. An Arduino Nano microcontroller acts as the central control unit, managing operations to achieve the desired output and ensuring system stability. Additional supporting components, such as an LCD for data display, LED indicators for status monitoring, and MOSFET cooling fans to prevent overheating, enhance overall functionality.

The AC output from the MOSFET circuit first passes through an LC filter, which smooths the waveform to minimize distortions, before being directed to a step-up transformer that adjusts the voltage to the required level. Before supplying power to the load, various sensors measure key parameters such as voltage, current, and power consumption to assess system performance and efficiency. The final output is carefully analysed to ensure it meets the design specifications, guaranteeing the system

DOI: 10.52330/jtm.v23i2.428

can reliably supply 150Wh of power for lighting and charging stations for approximately five hours. This setup provides a practical and energy-efficient solution for independent power generation in university environments.

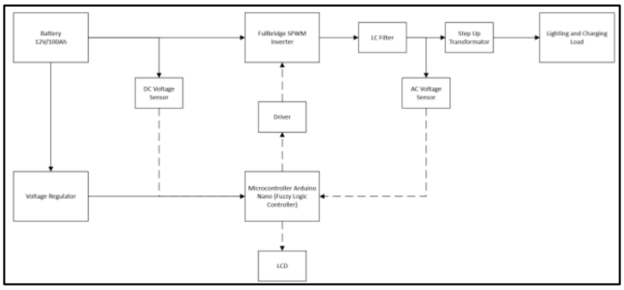


Fig. 1. Block Diagram SPWM Fullbridge Inverter System

2. *Full Bridge Inverter*

An inverter is a device used to convert power by transforming DC (direct current) input voltage into AC (alternating current) output voltage, which can be either fixed or variable is depicted in Fig.2. Inverters are widely used in AC motor speed control systems, uninterruptible power supplies (UPS), and other applications requiring AC power from a battery source. The input voltage for an inverter typically comes from batteries, solar panels, or other DC power sources.

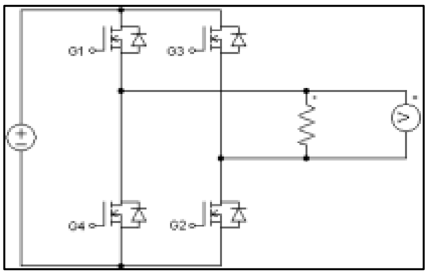


Fig. 2. Single Phase Full Bridge Inverter

Electronic components such as SCR, IGBT, and MOSFET are commonly integrated into inverters to regulate voltage based on operating conditions are shown in Table 1. Based on the conversion method, inverters are categorized into series, parallel, and bridge models. The bridge model is further divided into half-bridge and full-bridge configurations, with the full-bridge model being the preferred choice for the proposed system. An inverter is an electronic device that converts direct current (DC) power into alternating current (AC) power, typically with an output voltage of 220V. The AC power source for the inverter can come from batteries (accumulators), power supplies, or solar panels (Balal et al., 2022; Poorfakhraei et al., 2021).

Table 1. Full bridge Inverter Operating Principle

Condition	VaN	VbN	Active Components
Q1, Q2 ON and Q3, Q4 OFF	Vi/2	- Vi/2	Q1 and Q2 if io>0 D1 and D2 if io<0
Q3, Q4 ON and Q1, Q2 OFF	- Vi/2	Vi/2	D3 and D4 if io>0 Q3 and Q4 if io<0
Q1, Q3 ON and Q2, Q4 OFF	Vi/2	- Vi/2	Q1 and D3 if io>0 D1 and Q3 if io<0
Q2, Q4 ON and Q1, Q3 OFF	- Vi/2	Vi/2	D4 and Q2 if io>0 Q4 and D2 if io<0
Q1, Q2, Q3, Q4 OFF	- Vi/2 Vi/2	Vi/2 - Vi/2	D3 and D4 if io>0 D1 and D2 if io<0

3. *Hardware Spesification Design*

The Hardware Specification Design details the essential components and technical requirements needed to construct the system, ensuring seamless operation and efficiency. The primary hardware includes a 12V/100Ah battery, which serves as the main energy storage unit, and a Full-Bridge SPWM inverter, responsible for converting DC power into AC power. Additionally, an Arduino Nano microcontroller acts as the system's control unit, regulating operations and ensuring stability.

To manage voltage levels effectively, the system incorporates an AC voltage regulator and a DC voltage sensor, both of which help maintain proper voltage output and protect components from fluctuations. An LC filter is integrated to smooth the AC waveform, ensuring a more stable and pure sine wave output. The step-up transformer increases the AC voltage to meet the required power levels for various applications, while the load represents the devices that will utilize the generated electricity, such as lighting systems and charging stations.

Each component is carefully selected based on efficiency, durability, and compatibility, ensuring reliable power delivery and optimal system performance. By integrating these elements, the system is designed to provide a stable and sustainable energy source for independent power applications are shown in Table 2.

Table 2. Hardware Specifications

Components	Specification
Battery	12V/10 Ah
AC Load	Lamps (4 X 15 Watt) Charging (2 x 45 Watt)
DC Voltage Sensor	20 Volt DC
AC Voltage Sensor	PZEM004t (20 Volt AC)
Transformer	Step Up
Filter	LC

The calculation of battery usage has been carefully optimized to maximize efficiency and performance while considering the maximum load the battery can support for 7 hours. The system is designed to supply power to four 15-watt lamps and two 45-watt charging stations, ensuring that total energy consumption remains within the battery's capacity.

To ensure stable power distribution, DC and AC sensors are integrated into the circuit. These sensors precisely monitor voltage levels, helping maintain a consistent energy supply within the required operating range. The collected data is essential for system analysis, enabling real-time monitoring and necessary adjustments to prevent overloads and inefficiencies.

Additionally, an AC filter composed of inductor (L) and capacitor (C) components is implemented to reduce electrical noise and disturbances produced by the Full-Bridge Inverter. By minimizing voltage fluctuations and harmonics, the filter enhances the output waveform quality, ensuring a more stable and cleaner AC power supply for connected loads.

4. *Fuzzy Logic Controller*

In designing fuzzy logic control, several key aspects must be carefully considered to ensure accurate and efficient system operation. These aspects include the membership function, which involves the calculation of error and delta error, as well as the fundamental processes of fuzzification, rule base development, and defuzzification are depicted in Fig.3. Each of these elements plays a crucial role in determining how the fuzzy logic system processes input data and generates the appropriate control response.

The membership function is responsible for defining the degree of truth for input variables. In this case, the input values are derived from the battery output voltage, which directly influences the generated frequency output. The membership function maps these input values into predefined fuzzy sets, allowing the system to interpret them in a way that enables smooth and precise control adjustments.

Fuzzification is the process of converting crisp input values (numerical data) into fuzzy values by associating them with different degrees of membership in defined fuzzy sets. This transformation helps the system handle uncertainties and variations in battery voltage, ensuring a more adaptive response to fluctuations in power supply.

The rule base consists of a set of logical rules that dictate how the fuzzy system responds to different input conditions. These rules are formulated based on expert knowledge or empirical data, ensuring that the inverter operates optimally under varying voltage conditions. The if-then logic structure is commonly used to define relationships between input values (such as error and delta error) and output actions.

Finally, defuzzification is performed to convert the fuzzy output values back into a crisp numerical value that can be used by the control system. This step ensures that the fuzzy logic controller provides a precise and actionable output to regulate the inverter's frequency and voltage.

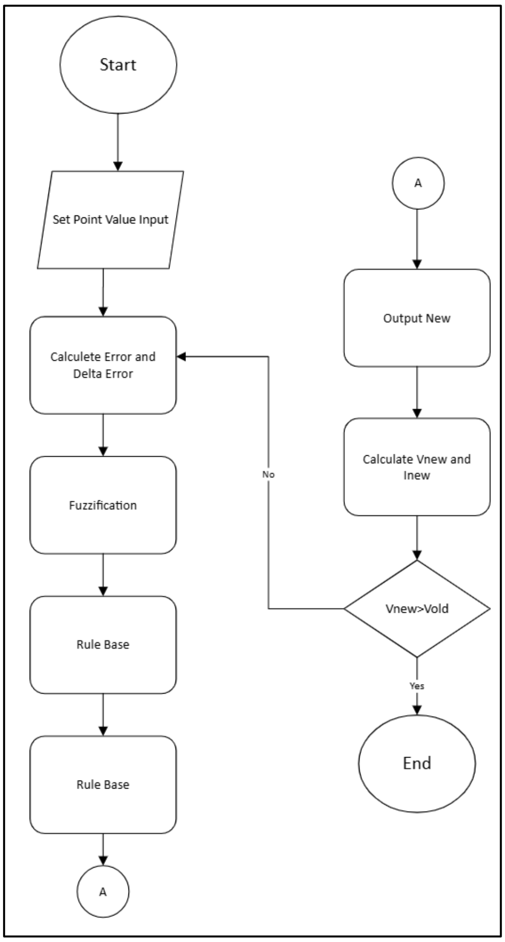


Fig. 3. Full bridge Fuzzy Logic Controller Inverter

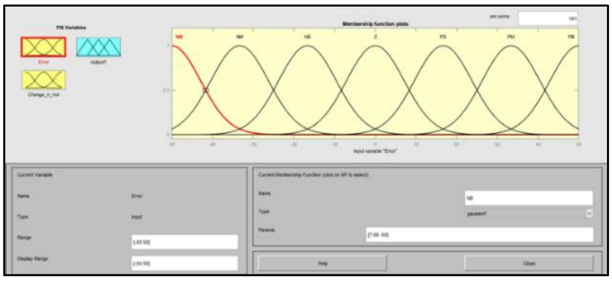
3. RESULT AND DISCUSSION

1. *Fuzzification*

In this process, the input and output values of the inverter will be carefully determined and integrated into the Fuzzy rule base to ensure accurate and efficient system control. The inverter's output parameters, specifically voltage (10–13V) and frequency (–50 to 50Hz), will be used as input variables for the Fuzzy logic system. These input values, consisting of error (the difference between the desired and actual output) and error change (the rate at which the error fluctuates over time), will be analysed and processed within the Fuzzy rule base, as illustrated in Fig.4 and Fig.5. During the fuzzification stage, these crisp numerical input values are converted into fuzzy linguistic variables such as "Low," "Medium," or "High" for voltage, and "Negative," "Zero," or "Positive" for frequency deviation. This transformation is performed using membership functions, typically triangular or trapezoidal, which define the degree to which a specific input belongs to a fuzzy set. By translating precise numerical data into qualitative descriptors, the fuzzification process enables the system to handle uncertainty and imprecision more effectively, essential in dynamic systems like power inverters. The rule

DOI: 10.52330/jtm.v23i2.428

base, consisting of predefined logic rules, then interprets these fuzzy values and generates appropriate control actions. These actions guide the inverter's switching behaviour through SPWM modulation, ensuring that the output waveform remains stable and within the desired parameters.

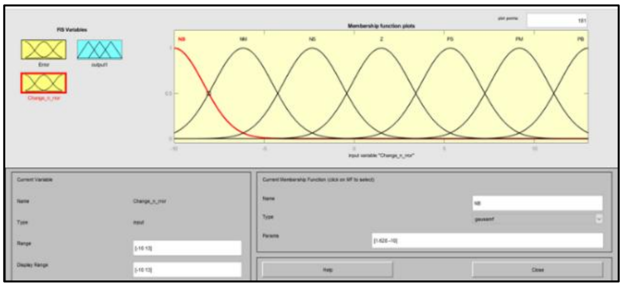


Range [-50 50]

Display Range [-50 50]

Params [7.08 -50]

Fig. 4. Fuzzification Voltage Input



Range [-10 10]

Display Range [-10 10]

Params [1.626 -10]

Fig. 5. Fuzzification Frequency Input

2. *Rule Base*

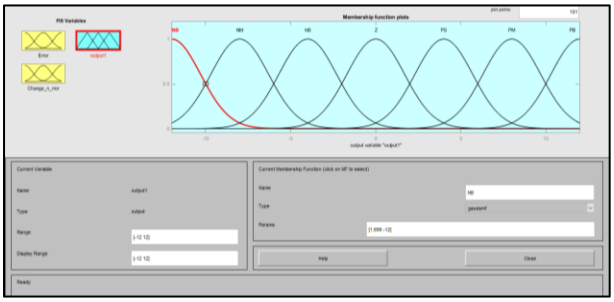
In this process, the possible output values are determined based on the input error and error change within the system. These values are essential for defining the rule base, which serves as the foundation for decision-making in the Fuzzy logic control system. The rule base used in simulation design, implemented through MATLAB software, utilizes a 7x7 matrix, resulting in 49 possible outcomes, as shown in Table 3. Each combination of error and error change is mapped to a specific output response, ensuring that the system can dynamically adjust to variations in input conditions. The construction of the rule base is derived from expert knowledge and heuristic analysis of system behavior under different operating conditions. The 7 linguistic variables used for both input parameters (error and error change) and output include: Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), and Positive Big (PB). This range allows for fine-grained control over the inverter's switching mechanism through SPWM, providing smooth transitions and responsive adjustments. This structured approach enables the Fuzzy logic controller to fine-tune the inverter's performance in real-time, maintaining stable voltage and frequency levels even under fluctuating load or supply conditions. The adaptability and precision of the rule base play a crucial role in achieving high-quality AC output, improving the system's overall reliability and efficiency.

Table 3. Rule Base Design

	u	**Error (e)**						
		NB	NM	NS	ZE	PS	PM	PB
Change of Error (ce)	NB	NB	NB	NB	NM	NS	NS	ZE
	NM	NB	NM	NM	NM	NS	ZE	ZE
	NS	NB	NM	NS	NS	ZE	PS	PM
	ZE	NB	NM	NS	ZE	PS	PM	PB
	PS	NM	NS	ZE	PS	PS	PM	PB
	PM	NS	ZE	PS	PM	PM	PM	PB
	PB	ZE	PS	PS	PM	PB	PB	PB

3. *Defuzzification*

In this process, the desired output values are determined by analyzing error and error change data from the rule base. These values are then processed to generate accurate control responses, allowing the system to adapt effectively to real-time variations. Defuzzification is the final stage of fuzzy inference, where fuzzy outputs are converted into clear control signals for the inverter's switching system. In a Full-Bridge SPWM inverter, this typically involves determining the precise PWM duty cycle needed to regulate voltage and frequency. The Centroid method, commonly used in this process, calculates the center of the aggregated output membership functions to produce a smooth and stable control action essential for generating a sinusoidal waveform that meets electrical standards. As shown in Fig.6 and Fig.7, the system uses defuzzied values to maintain a stable 12VAC output with consistent waveforms. This step effectively translates fuzzy logic into practical, real-time control, enhancing the inverter's stability and performance.



Name output1

Type output

Range [-12 12]

Display Range [-12 12]

Params [1.699 -12]

Fig. 6. Fuzzification Voltage Input

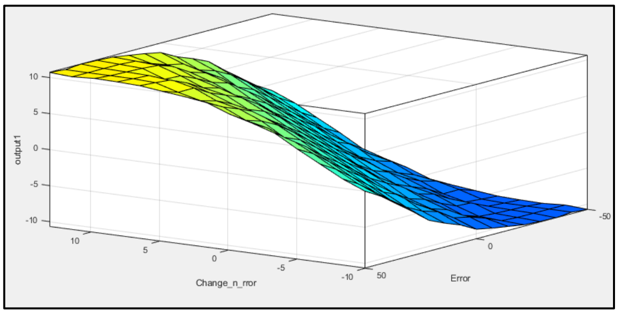


Fig. 7. Output Surface Area

4. *Full Bridge Inverter Simulation*

The following section presents the simulation circuit of the Full-Bridge Inverter, which has been designed in two configurations: open-loop (without fuzzy control) and closed-loop (with fuzzy control). The open-loop simulation, as illustrated in Fig.8, provides an overview of the inverter's performance when no feedback control mechanism is implemented. In this configuration, when a 12V DC input is supplied to the system, the Full-Bridge Inverter generates an output voltage of approximately 11.99V AC. However, due to the absence of a regulation mechanism, the system experiences a voltage drop before the signal reaches the step-up transformer's input. Consequently, the final AC output after transformation does not reach its optimal value, producing only 219V AC instead of the expected 220V AC. This voltage drop indicates that, without a feedback control system, the inverter's performance is less efficient, leading to power losses and voltage inconsistencies.

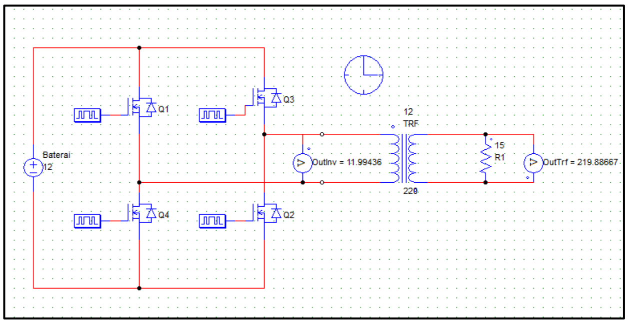


Fig. 8. Full Bridge Open Loop Simulation

The following section presents the simulation of the Full-Bridge Inverter utilizing fuzzy logic control, which plays a crucial role in stabilizing the output voltage and frequency of the inverter, is depicted in Fig.9. The stabilized output is designed to power specifically for charging stations and lighting systems, ensuring a consistent and reliable energy supply. The input source for this Full-Bridge Inverter system is derived from a 12V DC/100Ah LiFePO4 battery, which serves as the primary power storage unit. The inverter then converts this DC input into AC output, which undergoes further regulation through the fuzzy logic control process to maintain stability and optimize performance.

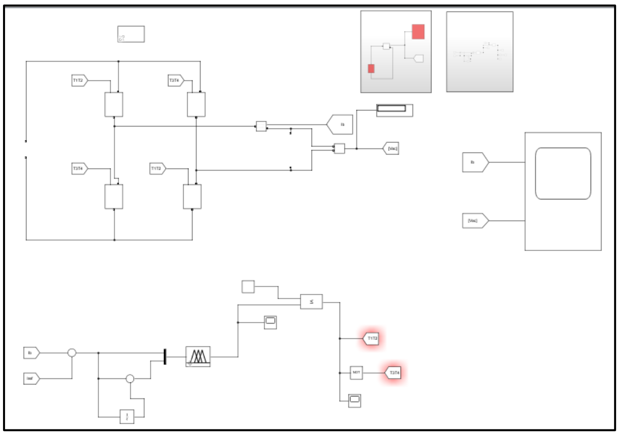


Fig. 9. Full Bridge Close Loop Simulation

5. *Full Bridge Inverter Implementation*

A full-bridge inverter is composed of four electronic switches, typically MOSFETs, arranged in a bridge configuration. These switches are alternately activated in pairs to reverse the current direction across the load, thereby producing an AC voltage at the output. This configuration enables the inverter to generate an AC output voltage with an amplitude nearly twice that of the DC input voltage. Sinusoidal Pulse Width Modulation (SPWM) is a signal modulation technique used to control inverter switches by comparing a sinusoidal reference signal with a triangular carrier signal. This comparison produces pulses of varying widths, allowing the inverter's output to closely resemble a sine wave and reducing harmonic distortion in the AC output. Typically, SPWM signals are generated using microcontroller circuits, dedicated ICs, or analog circuitry. The implementation of the full-bridge inverter with SPWM can be seen in Fig.10.

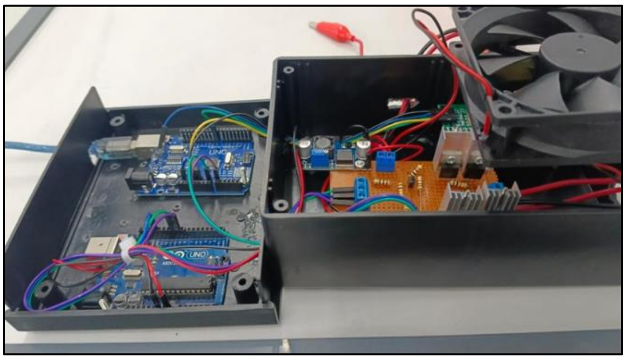


Fig. 10. Full Bridge Hardware Implementation

DOI: 10.52330/jtm.v23i2.428

Table 4. Full bridge Inverter without control and controlled data collection

No	Time (Minutes)	Battery Voltage (V)	Inverter Voltage (V)		Load Current (I)		Frequency (Hz)	
			Without Control	Controlled	Without Control	Controlled	Without Control	Controlled
1.	5	12,63	145	221	0,05	0,36	99,8	50
2.	10	12,63	147	223	0,05	0,36	99,8	50
3.	15	12,63	145	224	0,05	0,36	99,8	50
4.	20	12,59	147	223	0,05	0,36	99,8	50
5.	25	12,59	147	224	0,05	0,36	99,8	50
6.	30	12,59	144	222	0,05	0,36	99,8	50
7.	35	12,59	147	224	0,05	0,36	99,8	50

Based on Table 4, the test results over 35 minutes using a DC battery as the input voltage source compare the output voltage, frequency, and current between the inverter without control and the one with control. The data show that the inverter without a control system only produced an output voltage of 145–147 V, which is significantly below the standard AC voltage of 220 V. In contrast, the inverter equipped with SPWM control consistently generated a stable output voltage in the range of 221–224 V, meeting the required standard. In terms of frequency, the uncontrolled inverter produced a value of 99.18 Hz, far exceeding the standard 50 Hz. Meanwhile, the SPWM-controlled inverter maintained a steady frequency output at 50 Hz. These findings confirm the effectiveness of the SPWM method in enhancing the inverter's performance, making it more reliable and suitable for various electrical applications.

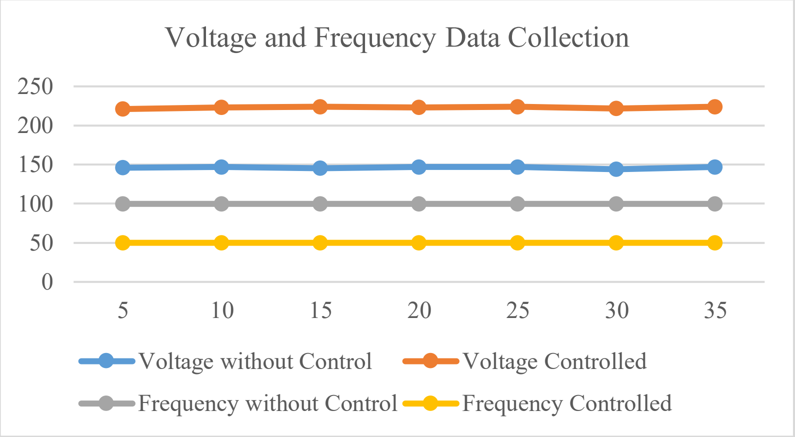


Fig. 11. Full Bridge Hardware Implementation

The graph above on Fig.11 illustrates the measurement results of the inverter's voltage and frequency under two conditions: without control and with control, over several time intervals. In the graph, it is evident that the output voltage of the inverter without control (depicted by the blue line) remains around 145 V, which is significantly below the standard household AC voltage. In contrast, the inverter with control (orange line) maintains a stable output voltage around 220 V, meeting the voltage standards required for both household and industrial applications. Regarding frequency, the output from the uncontrolled inverter (gray line) reaches around 100 Hz, which far exceeds the standard utility frequency of 50 Hz. On the other hand, the inverter with control (yellow line) maintains a very stable frequency at 50 Hz, in line with national standards. The data patterns in this graph confirm that an inverter system with proper control can maintain stable and standard-compliant output voltage and frequency, making it more reliable and safer for use with various electrical loads. Conversely, without control, the inverter output becomes inconsistent and unsuitable for general electrical applications.

4. CONCLUSION

The application of fuzzy logic in Full-Bridge inverter systems has proven effective in maintaining stable output voltage and frequency. Through fuzzification, input values (voltage and frequency) are converted into linguistic variables based on error and error change, enabling fuzzy processing. A 7x7 rule matrix (49 rules) determines appropriate control actions, allowing the system to adaptively respond to input fluctuations. Defuzzification then translates fuzzy results into real control signals to regulate the inverter, ensuring a stable AC output that meets standards. Simulation and implementation results reveal clear differences between uncontrolled and fuzzy-controlled systems. Without control, the inverter outputs around 145–147 V and 100 Hz far from the ideal 220 V and 50 Hz. With fuzzy control, the output stabilizes at 221–224 V and exactly 50 Hz. This shows that the Sinusoidal

Pulse Width Modulation (SPWM) method, enhanced by fuzzy logic, significantly improves inverter performance, making it more reliable for applications like charging stations and lighting systems. In summary, fuzzy logic offers an adaptive and efficient control approach, improving output quality and extending the lifespan of connected equipment.

Author Contribution: All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.

Acknowledgment: The authors would like to express their sincere gratitude to Mandiri House research members for providing the necessary resources and support throughout this research.

Conflicts of Interest: Declare conflicts of interest or state, “The authors declare no conflict of interest.”

REFERENCES

Balal, A., Dinkhah, S., Shahabi, F., Herrera, M., & Chuang, Y. L. (2022). A Review on Multilevel Inverter Topologies. *Emerging Science Journal*, *6*(1), 185–200. https://doi.org/10.28991/ESJ-2022-06-01-014

Dionova, B. W., S, R. J. P., Vresdian, D. J., & Pratama, L. P. (2023). *Evaluation of 300 WP Solar Photovoltaic Panel Performance for Electric Vehicle Charging Station*. *19*(03), 80–84. http://dx.doi.org/10.32497/eksergi.v19i03.5008

Ferdiansyah, I., Sudiharto, I., Sunarno, E., & Muhammad, M. G. (2021). *Desain SPWM Single Phase Full Bridge Inverter pada Sistem Uninterruptible Power Supply 500W*.

Green, M. A. (2019). Photovoltaic technology and visions for the future. *Progress in Energy*, *1*(1), 013001. https://doi.org/10.1088/2516-1083/ab0fa8

Hosseinzadeh, N., Aziz, A., Mahmud, A., Gargoom, A., & Rabbani, M. (2021). Voltage stability of power systems with renewable-energy inverter-based generators: A review. *Electronics (Switzerland)*, *10*(2), 1–27. https://doi.org/10.3390/electronics10020115

Lastry Rajagukguk, R., Damaris Br Bangun, D., Agave Manurung, D., Kurniawan, D., & Agustina Purba, J. (2023). *SINERGI Polmed : JURNAL ILMIAH TEKNIK MESIN KAJIAN INVERTER PURE SINE WAVE TERHADAP BEBAN PADA PEMBANGKIT LISTRIK TENAGA SURYA KAPASITAS 100 WP I N F O A R T I K E L*. *04*(02), 70–78.

Manamperi, I., Ahmad, I., Habibi, D., & Aziz, A. (2024). Optimising grid-forming inverters to prevent under-frequency load shedding with minimal energy storage. *Journal of Energy Storage*, *98*(PB), 112842. https://doi.org/10.1016/j.est.2024.112842

Megantoro, P. (2022). *Peta Pemanfaatan Energi Baru dan Terbarukan di Indonesia*. FAKULTAS TEKNOLOGI MAJU DAN MULTIDISIPLIN.

Naji Alhasnawi, B., Jasim, B. H., Naji Alhasnawi, A., Hussain, F. F. K., Homod, R. Z., Hasan, H. A., Ibrahim Khalaf, O., Abbassi, R., Bazooyar, B., Zanker, M., Bureš, V., & Sedhom, B. E. (2024). A novel efficient energy optimization in smart urban buildings based on optimal demand side management. *Energy Strategy Reviews*, *54*(June). https://doi.org/10.1016/j.esr.2024.101461

Nyamathulla, S., & Chittathuru, D. (2023). *A Review of Multilevel Inverter Topologies for Grid-Connected Sustainable Solar Photovoltaic Systems*.

Paradongan, H. T., Hakam, D. F., Wiryono, S. K., Prahastono, I., Aditya, I. A., Banjarnahor, K. M., Sinisuka, N. I., & Asekomeh, A. (2024). Techno-economic feasibility study of solar photovoltaic power plant using RETScreen to achieve Indonesia energy transition. *Heliyon*, *10*(7), e27680. https://doi.org/10.1016/j.heliyon.2024.e27680

Poorfakhraei, A., Narimani, M., & Emadi, A. (2021). A review of multilevel inverter topologies in electric vehicles: Current status and future trends. *IEEE Open Journal of Power Electronics*, *2*(February), 155–170. https://doi.org/10.1109/OJPEL.2021.3063550

Putra, J. T., Sarjiya, & Setyonegoro, M. I. B. (2024). Modeling of high uncertainty photovoltaic generation in quasi dynamic power flow on distribution systems: A case study in Java Island, Indonesia. *Results in Engineering*, *21*(December 2023), 101747. https://doi.org/10.1016/j.rineng.2023.101747

Raihan, A., Pavel, M. I., Muhtasim, D. A., Farhana, S., Faruk, O., & Paul, A. (2023). The role of renewable energy use, technological innovation, and forest cover toward green development: Evidence from Indonesia. *Innovation and Green Development*, *2*(1), 100035. https://doi.org/10.1016/j.igd.2023.100035

Safaroz, W. (2023). *Rancang Bangun Dan Proteksi Inverter Pure Wave Berbasis*. *11*(3).

Sen, S., & Ganguly, S. (2017). Opportunities, barriers and issues with renewable energy development – A discussion. *Renewable and Sustainable Energy Reviews*, *69*(June 2015), 1170–1181. https://doi.org/10.1016/j.rser.2016.09.137

Syururi, M. A. (2022). *Rancang Bangun Inverter 600 Watt dengan Metode Sinusoidal Pulse Width Modulation*. *11*(3), 147–154.

Wang, X., Gao, X., & Wu, Y. (2023). Comprehensive analysis of tropical rooftop PV project: A case study in nanning. *Heliyon*, *9*(3), e14131. https://doi.org/10.1016/j.heliyon.2023.e14131