Disturbance Handling and Efficiency Optimization for SPWM-Three Phase Inverter by Using PID Controller System

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***Abstract*—The importance of studying inverters in electrical systems is highlighted by their role as one of the most important electronic power devices used in numerous applications in industry, as well as in generation, transmission, and distribution, most notably in renewable energy generation systems. An inverter converts direct current power into alternating current power to power loads or connect solar energy sources to the grid. Inverters are built using electronic switches such as thyristors or transistors such as IGPTs and MOSFET transistors. A number of switches are used to build the inverter, depending on the type of inverter, whether single-phase or three-phase. It can also be half-wave or full-wave. The current study proposed a bridge inverter consisting of six electronic switches of the IGBT transistor type arranged in two rows and three columns. To operate the inverter, pulse width modulation (PWM) technology was used to regulate the inverter operation and obtain the required output to supply a three-phase resistive load. In addition, an LC filter was connected to obtain a pure sine wave. Due to the different and variable operating conditions and to overcome disturbances, a conventional control unit was added to improve performance and raise the efficiency of the system. After conducting the proposed tests, the possibility of obtaining an inverter that operates with an efficient system to cover the load requirements under variable operating conditions was verified.**

Keywords—*Disturbance Handling*; *Efficiency Optimization*; *SPWM-Three Phase Inverter; PID Controller System.*

I. Introduction

The demand for energy is of paramount importance and a matter of concern to government institutions, the industrial sector, researchers, academic institutions, companies, and other specialists. Providing energy demand from its sources in a sustainable, safe, less risky, and highly efficient manner requires concerted efforts and knowledge exchange to provide advanced and highly reliable systems. Renewable energy sources of various types are important and of interest to researchers. Solar energy is one of the most important of these sources. When used as a source of electricity generation, the output voltage of the solar source is direct current, while most loads require alternating current. To solve this problem, inverters are employed [1]-[3].

Inverters, both single-phase and three-phase, convert a constant-value direct voltage into a variable-value alternating voltage. Building an inverter requires selecting the type and number of electronic switches, the method of connecting it to the source, and connecting it to the load or grid, in addition to conducting tests to verify its effectiveness. To operate the inverter, a mathematical model and simulation model can be proposed to represent it and analyze its behavior. An appropriate computer simulation can be proposed. An operational condition can be established under simulated conditions suitable for real-time operation. The inverter connects the load and the source to provide the appropriate amount to cover the load [4]-[6].

Simulation allows researchers to conduct tests in less time and modify models more quickly through a simple and inexpensive process. It achieves the goal of identifying the behavior of systems according to a process that suggests different operating conditions. Simulation can enable the construction and design of multiple models, providing the possibility of developing appropriate designs. It is also possible to combine multiple ideas and build suitable models to conduct tests to verify the effectiveness of the system and develop a robust computer-aided methodology to identify the system's capabilities and performance efficiency through behavioral analysis [7]-[9].

Researchers are always striving to provide advanced and advanced research by building and designing highly efficient systems that address operational problems. Due to the diversity of these problems and the changing system disturbances and fluctuations, this requires establishing a foundation by identifying the system's behavior under all speculative operating conditions. When discussing the use of electronic switches to build and design a three-phase inverter to cover an AC load at the specified voltage from an AC source, this requires a conversion process. To obtain an AC waveform, a filter is also required. To address fluctuations and the occurrence of a transient condition, i.e., a potential error, a sensor must be installed to read the output and compare it to the reference value. A control unit is then used to address the error, along with pulse width control technology to regulate the on-off periods of the electronic switches to provide the specified voltage to the load. When the load changes, the control unit helps restore the system to a stable state and delivers better results than when operating without a control unit. The control unit also quickly addresses any waveform distortions in response to address errors resulting from the transient condition [10]-[12].

This simulation presents a three-phase inverter power electronic system to utilize energy resources. Utilizing energy resources using an inverter requires generating trigger pulses to operate the power electronic devices and generate a signal. To generate signals, appropriate circuits using sinusoidal pulse width modulation (PWM) technology are required. Switches operate using electronic switching to change the inverter input voltage from a constant DC current to a variable AC voltage at the inverter output. The possibility of using any type of switch, such as a transistor or thyristor, to construct the inverter can be investigated, in addition to constructing pulse width modulation technology using a simple operational amplifier to provide the switching process through pulse width modulation.

II. Method

Power electronics are important devices that are used in the efficient conversion process within the energy field and play a major and primary role within energy generation sources. It is including renewable sources for generating electrical energy [13]-[16]. Power electronics are of interest to researchers with expertise through reviewing and learning about their use in conversion, distribution, transmission, and connecting them to the grid as well as through control. Among the renewable sources that electronic energy devices are linked to are photovoltaic systems, as well as wind energy systems and batteries as storage units by integrating them with the grid to improve and organize the systems and reduce the resulting losses [17]-[19]. The electronic power devices from which the electronic converter is built consist of semiconductor materials that are injected with impurities that work under certain conditions to conduct electricity. Such as taking silicon and injecting it with phosphorus, which produces a new atom called an n-type that contains a free electron and for a second atom, the same silicon atom is injected with a boron atom, resulting in an atom called a p-type, which has a free hole [20]-[22]. The resulting elements help in electrical conduction. When the two elements are placed close to each other with a neutral area between them because one of them contains positive charges and the other contains negative charges, it is called a p-n junction. All electronic power devices are based on the P-N junction, including the diode thyristor and transistor. An example of a BJT transistor is that it has two types (NPN and PNP). There are two other types of transistors, which are MOSFET transistors and IGBT transistors. MOSFETs are either N-channel or P-channel, while the latter combines a normal BJT transistor and a MOSFET [23]-[25].

Electronics in general deals with power, both small and high power. Electronic circuits that deal with low voltages and currents differ from those that depend on high currents and voltages. When the system requires high values of electrical quantities, power electronic systems are used. We rely on systems in which power electronics are used in applications such as when the available voltage source is an alternating current source while the load is a DC motor, a DC motor type, or any other load such as a DC lamp or a battery charger [26]-[28]. From the previous example, it becomes clear that there is a problem with the difference in the type of source current and the type of required load current. Therefore, it is necessary to think about adding a circuit that converts the type of current from the source current to the required load current. This is called power electronics, which helps in providing the appropriate type and value of the electrical quantities required to cover the load. In the context of the example, we need a circuit to convert from alternating current to direct current, and this circuit is called a rectifier [29]-[31]. The output of the rectifier is either constant or variable. Another example is when there is a DC source and a load that works with the same type, i.e. a DC load that is suitable in terms of the type of supply current. While here there is a need to change the speed of the motor and one of the ways to change the speed requires changing the voltage. When the source voltage is a constant value while the required voltage changes to change the speed, you need to add a circuit that works to provide the required voltage and this circuit is called a DC - DC converter. It is called a chopper and this circuit works to convert a constant electrical quantity into a variable quantity [32]-[34].

An example of this is when the power source is batteries and the load is a DC motor and the required speed is to change, so this requires the presence of a chopper circuit [38]-[40]. It could be a solar energy source that powers a DC motor, and the required speed change also requires the same circuit. There is a third case where the source is DC and the load is an AC motor. This case also requires the addition of a power electronics inverter circuit [35]-[37]. The inverter works to convert the type of current from direct current to alternating current with the possibility of variable the voltage value or frequency. The variable frequency helps in variable the speed of the alternating motor and it can be variable by variable the amplitude, i.e. the voltage value, and it can also be changed by variable the frequency and variable voltage together. The fourth case is when a constant value AC source is available while a variable value AC is required. There is a method that variable the voltage only and is called a voltage controller and there is a second method called a cycle converter that variable the voltage and frequency. From the above, it was identified that there are four types of power electronics, which are electronic power transformers that help change the type of current, the amount of voltage, change the frequency, and obtain a variable source from a constant source [38]-[40].

In the current work, tests are conducted to identify the behavior of the system by proposing the construction and design of a three-phase inverter that converts direct current voltage into alternating current voltage. It is possible to obtain a variable voltage, which allows controlling the inverter output voltage and frequency according to the required and appropriate electrical quantities to cover the loads to simulate real time. The effectiveness of the system is also verified after verifying the possibility of improving performance by using pulse width modulation technology in addition to a traditional PID control unit.

III. Three Phase Inverter with Proportional Integral and Derivative (PID) Controller

A three-phase full-wave or bridge type inverter can be described as consisting of six electronic switches arranged so that a wave can be formed for each phase by two switches and the output is a sine wave with the same value for the three phases of frequency and voltage at a stable and equal load. The mathematical representation of this can be written by equations one to three to show each phase shifted by an angle of 30 degrees [41]-[43].

$$Va(t) = Vm * \sin(wt) \tag{1}$$

$$Vb(t) = Vm * \sin\left(wt - \frac{2 * pi}{3}\right) \tag{2}$$

$$Vc(t) = Vm * \sin\left(wt + \frac{2 * pi}{3}\right) \tag{3}$$

In the current study, the use of a conventional PID controller in a DC to AC converter system using a three-phase inverter was simulated by tracking the error and robustness under different operating conditions. After conducting initial tests of the system, a suitable design for control systems is developed by building a prototype to determine the behavior of the system according to the proposed test cases that suit the real-time operating conditions. To address the disturbances in the system, controllers are added and the best ones are selected, and the optimization results are compared. After conducting the tests, the effectiveness of the system is verified and a stable system is obtained with appropriate accuracy, efficiency and reliability [44]-[45].

The conventional type of controller PI, PD and PID is the most widely used and widespread in most industrial systems. It is considered successful in its use to control and improve the performance of linear systems, but it gives poor and unacceptable performance in non-linear systems. Among the works that have researched and developed solutions to try to address this weakness is the work on developing a conventional self-adaptive controller as well as an adaptive scheduler controller. While others have searched for better ways to address the problems resulting from changing the operating conditions of the system according to theories close to human thinking, i.e. expert controllers such as fuzzy logic and neural networks. The expert is a powerful tool that can be used to design a controller that gives better results than the conventional one. It can give better response speed than the conventional one, while you find that it needs a larger storage unit than the conventional one, and the implementation of the conventional one is easier compared to the expert one. Therefore, in linear systems, the conventional one is preferred, while the expert one is preferred for non-linear systems. The research contributions were first to develop a suitable design for a conventional PID controller and another contribution is to develop the design of the pulse width modulation technique. A simulation procedure was proposed to test the effectiveness of the system as well as to determine the possibility of improvement using controllers and to verify the effectiveness of the control systems in reducing errors and restoring the stability of the system with a relatively high response speed. A three-phase inverter simulation model was proposed and various tests were conducted [46]-[48].

IV. Sinusoidal Pulse Width Modulation (SPWM) Technique

Power electronic converters are linked to electrical power generation systems, including clean and renewable energy systems, as well as to the grid and electrical energy storage systems. Power devices work to convert electrical energy, such as converting a constant voltage to a variable voltage, as well as converting from alternating to direct and vice versa. Pulse width modulation technology is a major axis in reducing harmonics and increasing efficiency, and it is also used to regulate voltage and improve the performance of the work of power electronic converters [49]-[51].

There are many techniques used to open and close electronic switches, including pulse width modulation (PWM). This technique is considered one of the most important techniques that work to change the state of electronic switches used in electronic power converters. It is available in types including SPWM and SVPWM. In it, a sine wave and a triangular wave are used with the frequency of each wave differing from the other, in addition to the presence of a comparator circuit. The comparator input is the sine wave and the triangular wave, and thus a trigger signal or trigger pulses can be generated for electronic switches. In the current work, the SPWM pulse width modulation technique was adopted, the effectiveness of its use in providing the required conversion for a three-phase inverter can be verified by conducting the proposed tests.

Description of pulse width modulation (PWM) technology, a power converter connected to the grid or not connected to the grid consists of one or more sources, some of which are direct current sources and others are alternating current sources. The PWM technology generates a series of pulses that are used to generate an alternating current (AC) output for a three-phase inverter fed from a direct current (DC) source. The voltage and frequency of the inverter output can be regulated according to the switching process by opening and closing electronic switches such as IGBT, which is a type of semiconductor. A tuner can also be added that acts as a filter to modify and shape the inverter output wave, including an LC pass filter [52]-[55].

V. Simulation Model of Three-Phase Inverter with SPWM Control Technique

The first part in this simulation model as show in Fig. 1 under the title input voltage source of inverter include, voltage source type DC with 650 volts. The second is three phase inverter include six switches by using IGBT as show in Fig. 2. In Fig. 3 show the simulation model of three-phase inverter with SPWM control technique that include the three phase load (R=10 ohm) and the three phase LC filter (L= 5e-3H & C= 200e-6F).

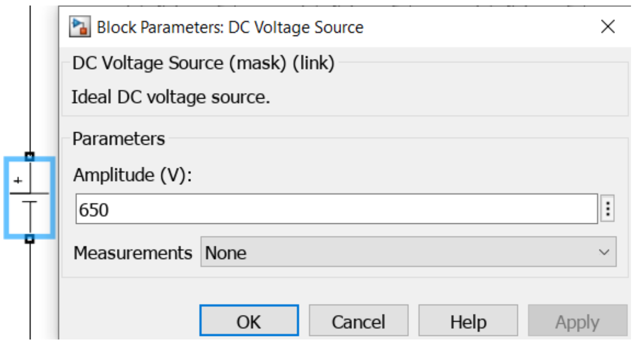
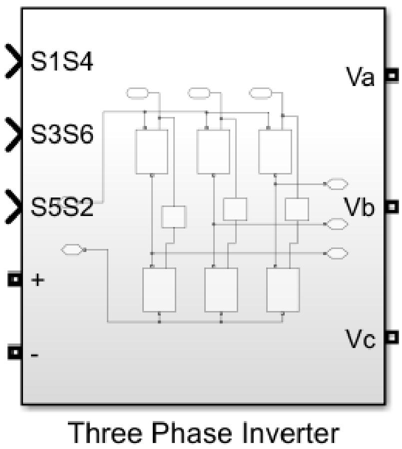
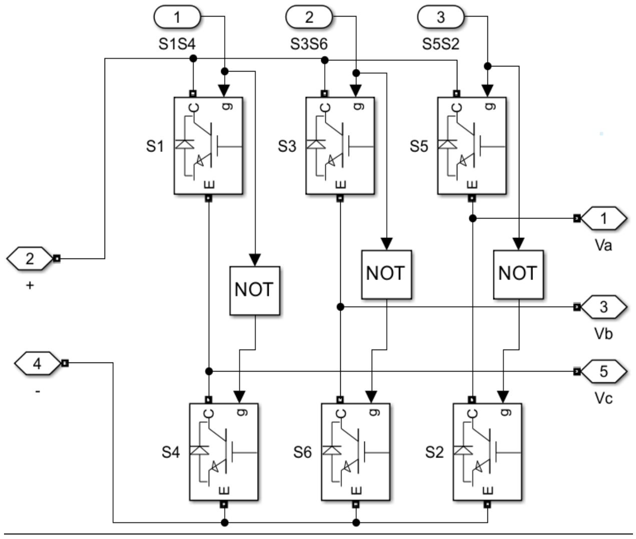


Fig. 1. Input voltage source of inverter



a) Subsystem for three phase inverter



b) Three phase inverter

Fig. 2. Simulation model of Three Phase Inverter

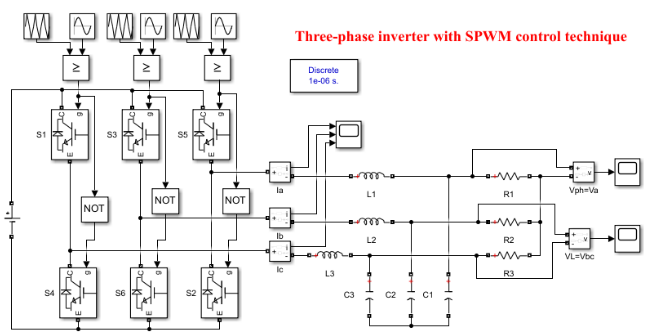
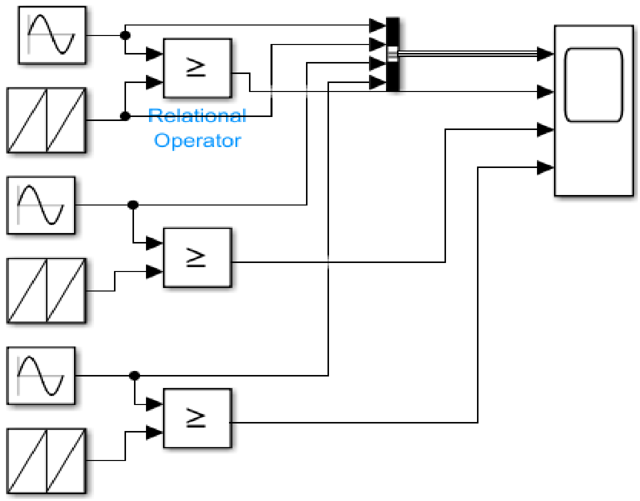


Fig. 3. Simulation Model of Three-phase inverter with SPWM control technique

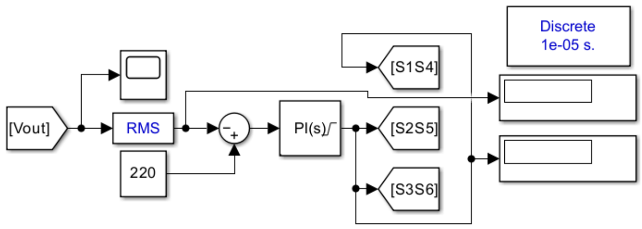
VI. Simulation Model of PI Controller for SPWM-Three Phase Inverter

The first part in this simulation model as show in Fig. 4 under the title controller of inverter include, voltage reference at 220 volts. The second is PI Controller with (Kp= 0.0001, Ki=0.01).

In Fig. 5 show the simulation model of PI Controller for three-phase inverter with SPWM control technique that include the three phase load (R=10 ohm) and the three phase LC filter (L= 5e-3H & C= 200e-6F).



a) SPWM



b) PI Controller

Fig. 4. Simulation model of SPWM and PI Controller

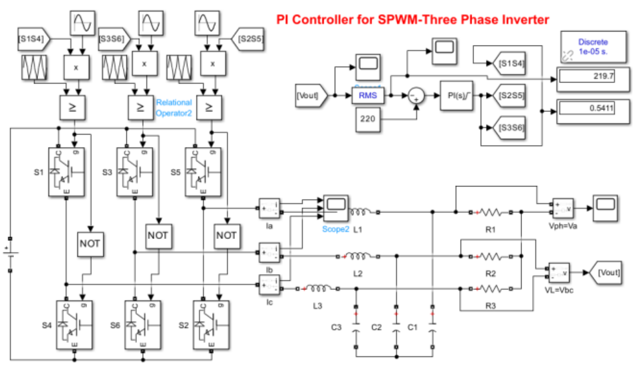


Fig. 5. Simulation Model of PI Controller Three-phase inverter with SPWM control technique

VII. Simulation Result of Three-Phase Inverter with SPWM Control Technique

The system is being simulated using the simulation model in Fig. 3, which represents the first test case, in which sensors were connected to measure electrical quantities, which were represented by measuring the phase voltage on the two ends of the resistive coil of one of the resistors. Another sensor was also placed to measure the line voltage between the ends of two resistors, in addition to connecting a third sensor to measure the current of each of the three phases, as in Fig. 3. The results showed the phase voltage signal as well as the line voltage in addition to the current of the first, second and third phases, as in Fig. 6, Fig. 7, Fig. 8 that show the shape and quantity of the measured reading.

In Fig. 6 shows that simulation waveform input and output of SPWM technique. In Fig. 7 shows that Vph with a run time of 2 s has a start-up value approaching Vph 400 V but a steady-state value of about 310 V. In Fig. 8 shows that

VL with a run time of 2 s has a start-up value approaching VL 600 V but a steady-state value of about 380 V. In Fig. 9 shows that there is a phase difference between the currents flowing in the three phases with an operating time of 2 seconds that includes a starting value of more than 50 amps but its steady value is less than 50 amps, about 45 amps.

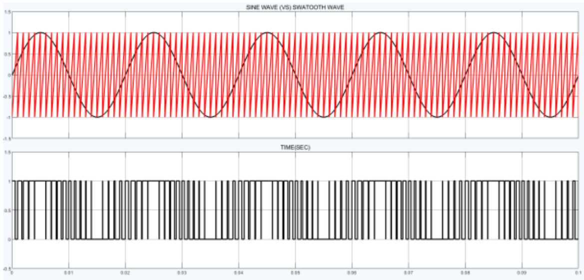


Fig. 6. Simulation result of SPWM technique

Fig. 6 shows the operating period of 0.1 seconds while the sine waveform is one-fifth of the time period, i.e. there are five waves during that period, and from it the frequency of the sine wave can be calculated by dividing the time of one cycle (F = 1/T). In the same way, the time and frequency of the second wave can be known. In the same figure, the trigger pulses can be identified, which are the result of those two waves according to the pulse width modulation technique. The simulation was carried out using the simulation model in Fig. 4(a).

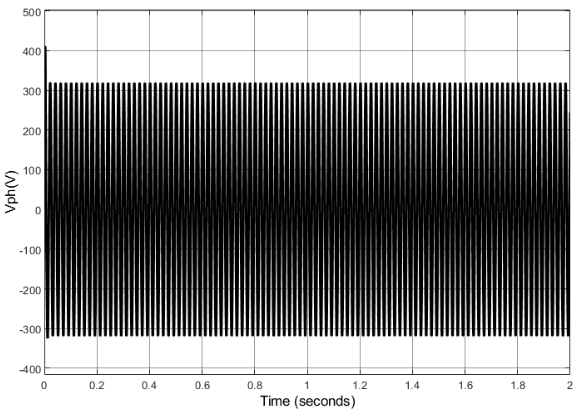


Fig. 7. Simulation result of Three-phase inverter with SPWM control technique for Vph output Load Voltage at (R=10 ohm)

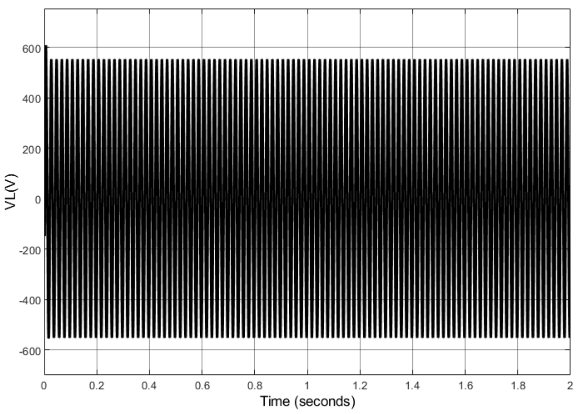


Fig. 8. Simulation result of Three-phase inverter with SPWM control technique for VL output Load Voltage at (R=10 ohm)

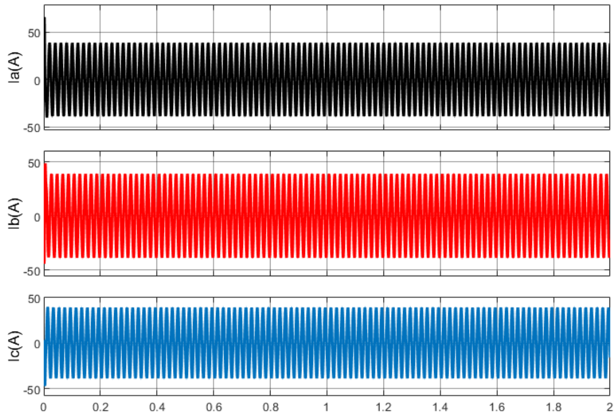


Fig. 9. Simulation result of Three-phase inverter with SPWM control technique for Ia, Ib & Ic output Load current at (R=10 ohm)

VIII. SIMULATION RESULT OF PI CONTROLLER FOR SPWM-THREE PHASE INVERTER

The system is simulated using the simulation model shown in Fig. 5, which represents the second test case in which probes were connected to measure electrical quantities, which consisted of measuring the phase voltage on both ends of the resistive coil of one of the resistors. Other probes were also placed to measure the line voltage between the two ends of the resistors, in addition to connecting third probes to measure the current of each of the three phases, as in Fig. 5. The results showed the phase voltage signal as well as the line voltage in addition to the current of the first, second, and third phases, as in Fig. 10, Fig. 11, Fig. 12, Fig. 13, which show the shape and quantity of the measured reading. In Fig. 10 it is shown that there is a gradual increase in the voltage value Vph with an operating time of 2 seconds that has a starting value close to Vph 50 V but a steady state value of about 180 V. In Fig. 11 it is shown that VL with an operating time of 2 seconds has a starting value close to VL 100 V but a steady state value of about 310 V. In Fig. 12 it is shown that there is a phase difference between the currents flowing in the three phases with an operating time of 2 seconds that has a starting value of more than 5 A but a steady state value of about 20 A. Fig. 13 shows the desired output signal which corresponds to the reference value.

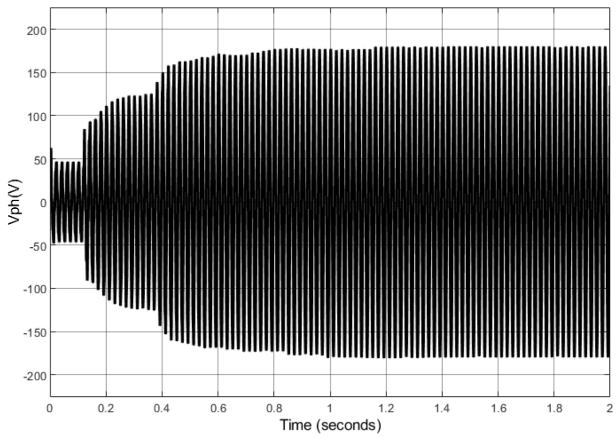


Fig. 10. Simulation result of PI Controller for three-phase inverter with SPWM control technique Vph output Load Voltage at (R=10 ohm)

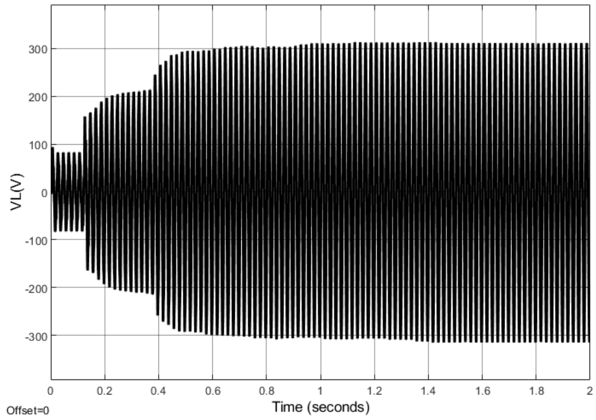


Fig. 11. Simulation result of PI Controller for three-phase inverter with SPWM control technique-VL output Load Voltage at (R=10 ohm)

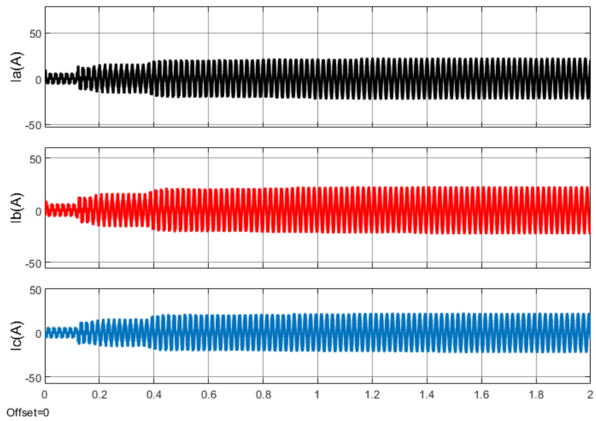


Fig. 12. Simulation result of PI Controller for three-phase inverter with SPWM control technique-Ia, Ib & Ic output Load current at (R=10 ohm)

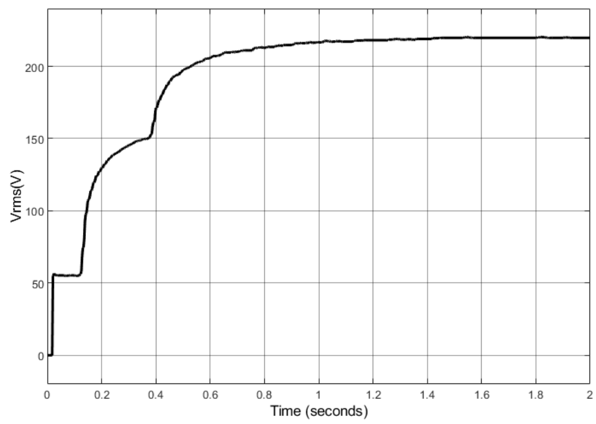


Fig. 13. Simulation result of PI Controller for three-phase inverter with SPWM control technique-Vrms output Load Voltage at (R=10 ohm)

To make the comparison, the harmonic values of the inverter output waves for both current and voltage were taken, which can be drawn in the following figures:

First, the harmonic values of the inverter output waves for both current and voltage with three-phase inverter with SPWM control technique type that show in Fig. 14, Fig. 15, Fig. 16. Second, the harmonic values of the inverter output waves for both current and voltage with of PI Controller for three-phase inverter with SPWM control technique type that show in Fig. 17, Fig. 18, Fig. 19.

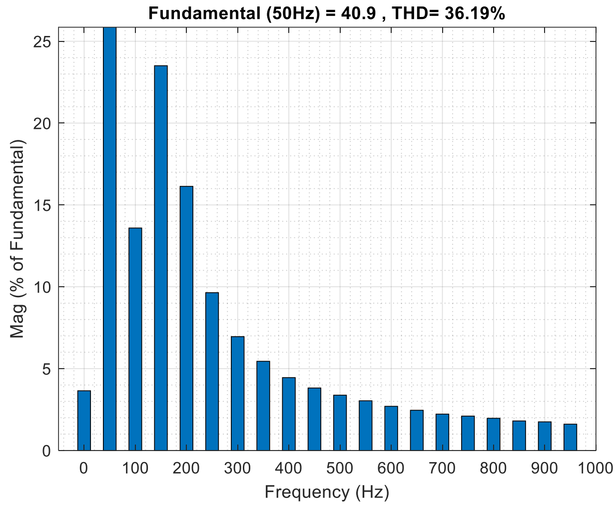


Fig. 14. THD for Current without PI Controller

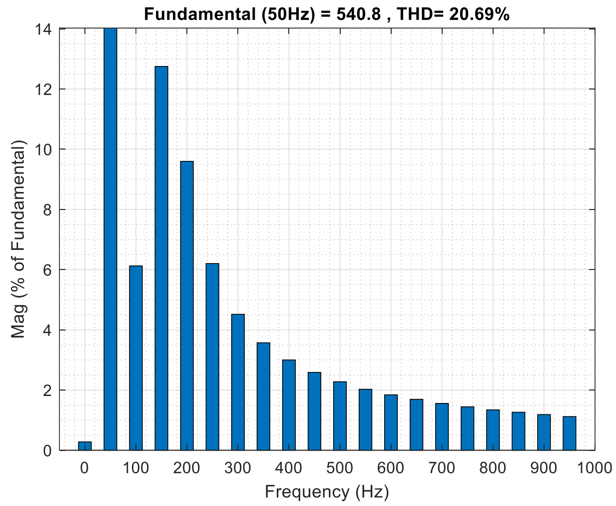


Fig. 15. THD for VL without PI Controller

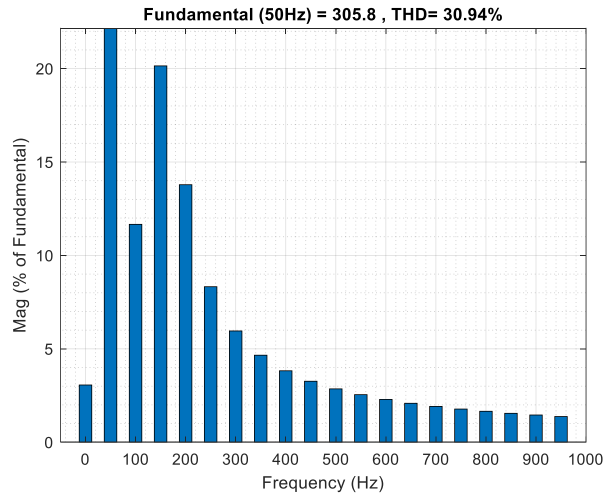


Fig. 16. THD for Vph without PI Controller

Verifying the effectiveness of the system is very important. A reference signal was set that represented the value of the AC voltage of 220 volts. The simulation results showed the possibility of obtaining the required output of a sine wave. The results also showed the difference in the fundamental wave and the total harmonic distortion of the current and voltage waves for the three phases in the case of a stable system when the resistive load is equal to ten ohms with a three-phase filter. The values can be obtained from the table and can be seen in the simulation results. Fundamental and total harmonic distortion without PI control, and with PI control shown in Table I and Table II.

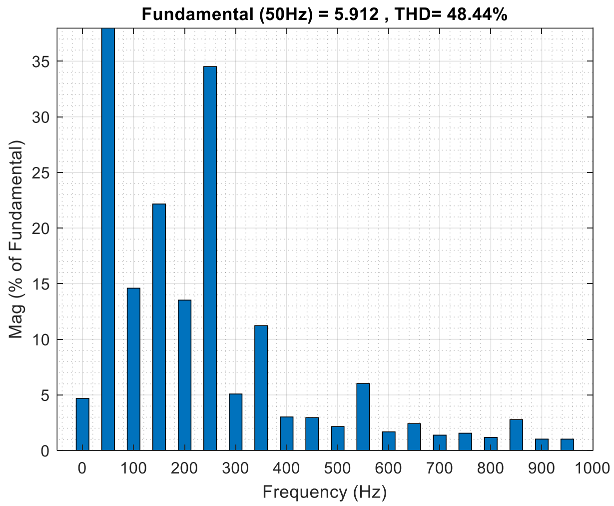


Fig. 17. THD for Current with PI Controller

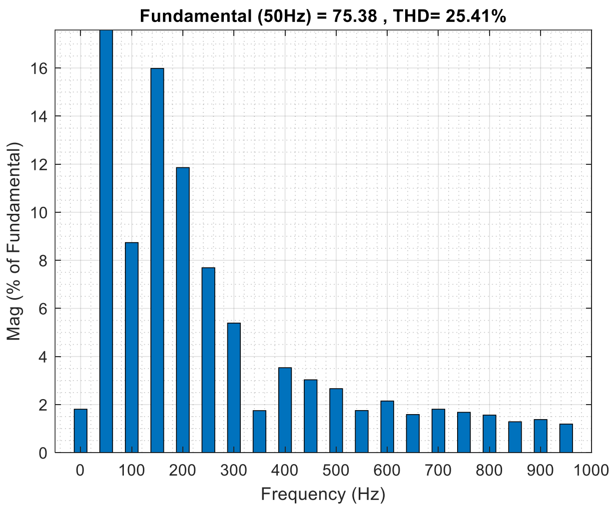


Fig. 18. THD for VL with PI Controller

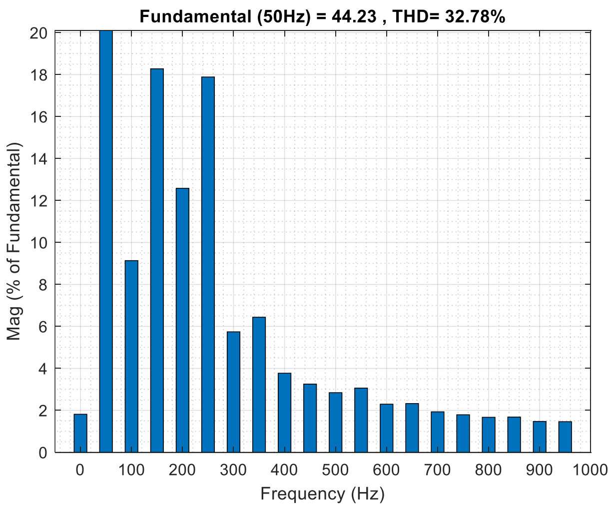


Fig. 19. THD for Vph with PI Controller

TABLE I. FUNDAMENTAL AND TOTAL HARMONIC DISTORTION WITHOUT PI CONTROL

Fundamental (50Hz)	**Total harmonic distortion**		
	Current	***Phase Voltage***	***Line Voltage***
49.9	THD=36.19%		
540.8		THD=20.69%	
305.8			THD=30.94%

TABLE II. FUNDAMENTAL AND TOTAL HARMONIC DISTORTION WITH PI CONTROL

Fundamental (50Hz)	**Total harmonic distortion**		
	Current	***Phase Voltage***	***Line Voltage***
5.912	THD=48.44%		
75.38		THD=25.41%	
44.23			THD=32.78%

IX. CONCLUSION

In the current simulation, we obtained results for the proposed test cases for the inverter's input and output waveforms, representing the source current and voltage and the load current and voltage over the entire operating period to understand the inverter's behavior. The simulation results showed the effectiveness of the proposed system model, and it is recommended for use in practical applications, such as renewable energy systems, power electronics, or industrial automation. A conventional PI controller is presented to improve the performance of a three-phase inverter using simulation and after conducting the proposed tests for two basic test cases. The first test case without PI controller and the fundamental wave and total harmonic distortion were analyzed according to the results obtained from the tests of the proposed model. The test results show the weakening of harmonics which indicates an improvement in THD through its significant decrease. The effectiveness of the system was verified by obtaining an AC waveform of the three-phase inverter output. The system was also optimized and the possibility of obtaining the required output with a reference voltage of 220 V was verified. The results showed the possibility of applying the model in real time. From the first and second tables, the difference between using the system with or without the control unit can be observed, as the simulation results show first that for the current, the factorial is 49.9, while the total harmonic is 36.19%, which is a high percentage because the factorial is high compared to the second case, when there is a control unit, the factorial value is low, 5.912, and the total harmonic percentage is 48.44%, and when calculating it, it is less compared to the other. Where the first without control (49.9, 540.8, 305.8) is higher than the second with the control unit (5.912, 75.38,44.23), and thus the comparison can be made using the remaining values for the phase and line voltage as well.

REFERENCES

[1] L. Meegahapola, A. Sguarezi, J. S. Bryant, M. Gu, E. R. Conde D, and R. B. A. Cunha, "Power System Stability with Power-Electronic Converter Interfaced Renewable Power Generation: Present Issues and Future Trends," *Energies*, vol. 13, no. 13, p. 3441, 2020.

[2] B. K. Bose and F. Wang, "Energy, environment, power electronics, renewable energy systems, and smart grid," *Power Electronics in Renewable Energy Systems and Smart Grid: Technology and Applications*, pp. 1-83, 2019.

[3] P. Megantoro *et al.*, "Modeling The Uncertainties and Active Power Generation of Wind-Solar Energy with Data Acquisition from

Telemetry Weather Measurement," *Results in Engineering*, vol. 25, p. 104392, 2025.

[4] S. W. Shneen, "Advanced optimal for power-electronic systems for the grid integration of energy sources," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 1, no. 3, pp. 543-555, 2016.

[5] M. H. Setiawan, A. Ma'arif, M. S. Saifuddin, and W. A. Salah, "A Comparative Study of PID, FOPID, ISF, SMC, and FLC Controllers for DC Motor Speed Control with Particle Swarm Optimization," *International Journal of Robotics and Control Systems*, vol. 5, no. 1, pp. 640-660, 2025.

[6] J. Shair, H. Li, J. Hu, and X. Xie, "Power system stability issues, classifications and research prospects in the context of high-penetration of renewables and power electronics," *Renewable and Sustainable Energy Reviews*, vol. 145, p. 111111, 2021.

[7] S. W. Shneen and G. A. Aziz, "Simulation model of 3-phase PWM rectifier by using MATLAB/Simulink," *International Journal of Electrical and Computer Engineering*, vol. 11, no. 5, pp. 3736-3746, 2021.

[8] A. Chakraborty, "Advancements in power electronics and drives in interface with growing renewable energy resources," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 4, pp. 1816-1827, 2011.

[9] J. Maza-Ortega, E. Acha, S. Garcia, and A. Gómez-Expósito, "Overview of power electronics technology and applications in power generation transmission and distribution," *Journal of Modern Power Systems and Clean Energy*, vol. 5, no. 4, pp. 499-514, 2017.

[10] S. W. Shneen, Z. B. Abdullah, and H. S. Dakheel, "Design and Implementation of Voltage Source Inverter Using Sinusoidal Pulse Width Modulation Technique to Drive A Single-Phase Induction Motor," *International Journal of Robotics and Control Systems*, vol. 4, no. 4, pp. 1527-1546, 2024.

[11] A. Athwer and A. Darwish, "A review on modular converter topologies based on WBG semiconductor devices in wind energy conversion systems," *Energies*, vol. 16, no. 14, p. 5324, 2023.

[12] M. H. Nguyen and S. Kwak, "Enhance reliability of semiconductor devices in power converters," *Electronics*, vol. 9, no. 12, p. 2068, 2020.

[13] R. Firmansyah, M. A. M. Ramli, and Endryansyah, "Voltage Regulation of Buck Converter in DC microgrid using Energy Valley Optimizer," *2023 Sixth International Conference on Vocational Education and Electrical Engineering (ICVEE)*, pp. 139-143, 2023.

[14] S. W. Shneen, D. H. Shaker, and F. N. Abdullah, "Simulation model of PID for DC-DC converter by using MATLAB," *International Journal of Electrical and Computer Engineering*, vol. 11, no. 5, p. 3791, 2021.

[15] D. Santoso and L. H. Pratomo, "The Voltage Control in Single-Phase Five-Level Inverter for a Stand-Alone Power Supply Application Using Arduino Due," *Journal of Robotics and Control (JRC)*, vol. 2, no. 5, pp. 421-428, 2021.

[16] Y. Zahraoui, M. Moutchou, S. Tayane, C. Fahassa, S. Elbadaoui, and A. Ma'arif, "Synchronous reluctance motor performance improvement using MTPA control strategy and five-level inverter topology," *Journal of Robotics and Control (JRC)*, vol. 3, no. 5, pp. 725-734, 2022.

[17] S. W. Shneen, F. N. Abdullah, and D. H. Shaker, "Simulation model of single phase PWM inverter by using MATLAB/Simulink," *International Journal of Power Electronics and Drive Systems*, vol. 12, no. 1, p. 212, 2021.

[18] L. H. Pratomo, A. F. Wibisono, and S. Riyadi, "Design and Implementation of Double Loop Control Strategy in TPFW Voltage and Current Regulated Inverter for Photovoltaic Application," *Journal of Robotics and Control (JRC)*, vol. 3, no. 2, pp. 196-204, 2022.

[19] T. A. Taha *et al*., "Enhancing Multilevel Inverter Performance: A Novel Dung Beetle Optimizer-based Selective Harmonic Elimination Approach," *Journal of Robotics and Control (JRC)*, vol. 5, no. 4, pp. 944-953, 2024.

[20] A. L. Shuraiji and S. W. Shneen, "Fuzzy logic control and PID controller for brushless permanent magnetic direct current motor: a comparative study," *Journal of Robotics and Control (JRC)*, vol. 3, no. 6, pp. 762-768, 2022.

[21] B. A. Avdeev *et al*., "Overvoltage and Oscillation Analysis for a Full-Bridge Isolated DC-DC Converter," *Journal of Robotics and Control (JRC)*, vol. 5, no. 6, pp. 1764-1771, 2024.

[22] E. S. Oluwasogo and H. Cha, "A Quadratic Quasi-Z-Source Full-Bridge Isolated DC–DC Converter With High Reliability for Wide Input Applications," *IEEE Transactions on Industrial Electronics*, vol. 69, no. 10, pp. 10090-10100, 2022.

[23] Z. Bahij, "DC Microgrid Modeling and Control in Islanded Mode," *Thesis. Rochester Institute of Technology*, 2021.

[24] Z. A. Al-Dabbagh and S. W. Shneen, "Neuro-Fuzzy Controller for a Non-Linear Power Electronic DC-DC Boost Converters," *Journal of Robotics and Control (JRC)*, vol. 5, no. 5, pp. 1479-1491, 2024.

[25] T. Thomas and M. K. Mishra, "Control Strategy for a PV-Wind based Standalone DC Microgrid with Hybrid Energy Storage System," *2019 IEEE 1st International Conference on Energy, Systems and Information Processing (ICESIP)*, pp. 1-6, 2019.

[26] S. Rüstemli, F. Dincer, and M. Almalı, "'Research on Effects of Environmental Factors on Photovoltaic Panels and Modeling with Matlab/Simulink," *Przegląd Elektrotechniczny*, vol. 88, no. 2, pp. 63–66, 2012.

[27] H. S. Dakheel, S. W. Shneen, Z. B. Abdullah, and A. L. Shuraiji, "Evaluation of Voltage/Frequency and Voltage Source Inverter Control Strategies for Single-Phase Induction Motors Using MATLAB Simulation," *Journal of Robotics and Control (JRC)*, vol. 5, no. 6, pp. 1910-1923, 2024.

[28] T. M. Babu, K. Chenchireddy, K. K. Kumar, V. Nehal, S. Srihitha, and M. R. Vikas, "Intelligent control strategies for grid-connected photovoltaic wind hybrid energy systems using ANFIS," *International Journal of Advances in Applied Sciences*, vol. 13, no. 3, pp. 497-506, 2024.

[29] M. Juma, C. J. Msigwa, and B. M. M. Mwinyiwiwa, "Solar Pv Based Maximum Power Point Tracking Embedded Voltage Regulation for Micro-Grid Application," *London Journal of Engineering Research*, vol. 6, no. 06, pp. 552–558, 2019.

[30] S. W. Shneen, A. L. Shuraiji, and K. R. Hameed, "Simulation model of proportional integral controller-PWM DC-DC power converter for DC motor using matlab," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 29, no. 2, pp. 725-734, 2023.

[31] J. Taverne *et al.*, "Design of solar powered charging backpack," *International journal of power electronics and drive systems*, vol. 9, no. 2, pp. 848-858, 2018.

[32] S. A. Razzaq and V. Jayasankar, "Inter-connected AC/DC HMGS power management with 3-phase and 1-phase ILC," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 14, no. 1, pp. 311-319, 2023.

[33] M. H. Setiawan, A. Ma'arif, and I. Suwarno, "Optimal of PID Controller for Enhanced Performance in an AVR System," *2024 IEEE Third International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, pp. 304-311, 2024.

[34] R. T. Ahmedhamdi and S. W. Shneen, "Using position control to improve the efficiency of wind turbine," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 18, no. 6, pp. 3240-3246, 2020.

[35] A. Zagranichny, A. Dukhno, and A. Tsybulia, "Stability of Resonant Inverter with Feedback," *2024 IEEE 7th International Conference on Smart Technologies in Power Engineering and Electronics (STEE)*, 2024.

[36] T. Debela and A. Bhattacharya, "Design and analysis of a DC/AC microgrid with centralized battery energy storage system," *IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society*, pp. 8779-8784, 2017.

[37] D. H. Shaker, "Simulation Model of Single-Phase AC-AC Converter by Using MATLAB," *Journal of Robotics and Control (JRC)*, vol. 3, no. 5, pp. 656-665, 2022.

[38] D. E. Olivares *et al.*, "Trends in Microgrid Control," *IEEE Transactions on Smart Grid*, vol. 5, no. 4, pp. 1905-1919, 2014.

[39] S. W. Shneen and A. L. Shuraiji, "Simulation model for pulse width modulation-voltage source inverter of three-phase induction motor," *International Journal of Power Electronics and Drive Systems*, vol. 14, no. 2, pp. 719-726, 2023.

[40] M. Kumar, "Solar PV Based DC Microgrid under Partial Shading Condition with Battery-Part 2: Energy Management System," *2018 8th IEEE India International Conference on Power Electronics (IICPE)*, pp. 1-6, 2018.

[41] S. W. Shneen, M. A. A. Hussein, J. A. Kadhum, and S. M. Ali, “Application of LFAC {16 2/3Hz} for electrical power transmission system: a comparative simulation study,” *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 17, no. 2, pp. 1055-1064, 2019.

[42] A. Bakundukize, M. Twizerimana, D. Bernadette, B. J. Pierre, and N. Theoneste, “Design and Modelling of PV Power Plant for Rural Electrification in Kayonza, Rwanda,” *Journal of Energy Research and Reviews*, vol. 4, no. 7, pp. 31–55, 2021.

[43] W. Bai, “DC Microgrid optimized energy management and real-time control of power systems for grid-connected and off-grid operating modes,” *Electric power*, 2021.

[44] A. A. Mutlag, M. K. Abd, and S. W. Shneen, “Power Management and Voltage Regulation in DC Microgrid with Solar Panels and Battery Storage System,” *Journal of Robotics and Control (JRC)*, vol. 5, no. 2, pp. 397-407, 2024.

[45] A. El-Shahat and S. Sumaiya, “DC-Microgrid system design, control, and analysis,” *Electronics*, vol. 8, no. 2, p. 124, 2019.

[46] Z. B. Abdullah, S. W. Shneen, and H. S. Dakheel, “Simulation model of PID controller for DC servo motor at variable and constant speed by using MATLAB,” *Journal of Robotics and Control (JRC)*, vol. 4, no. 1, pp. 54-59, 2023.

[47] C. Li, Y. Chen, D. Zhou, J. Liu, and J. Zeng, “A high-performance adaptive incremental conductance MPPT algorithm for photovoltaic systems,” *Energies*, vol. 9, no. 4, p. 288, 2016.

[48] Z. A. Al-Dabbagh, S. W. Shneen, and A. O. Hanfesh, “Fuzzy Logic-based PI Controller with PWM for Buck-Boost Converter,” *Journal of Fuzzy Systems and Control*, vol. 2, no. 3, pp. 147-159, 2024.

[49] K. Gowtham, C. V. Sivaramadurai, P. Hariprasath, and B. Indurani, "A Management of power flow for DC Microgrid with Solar and Wind Energy Sources," *2018 International Conference on Computer Communication and Informatics (ICCCI)*, pp. 1-5, 2018.

[50] Z. A. Al-Dabbagh and S. W. Shneen, “Design of a PID Speed Controller for BLDC Motor with Cascaded Boost Converter for High-Efficiency Industrial Applications,” *International Journal of Robotics and Control Systems*, vol. 5, no. 1, pp. 22-46, 2025.

[51] M. I. Juma, B. M. M. Mwinyiwiwa, C. J. Msigwa, and A. T. Mushi, “Design of a hybrid energy system with energy storage for standalone DC Microgrid application,” *Energies*, vol. 14, no. 18, p. 5994, 2021.

[52] A. N. H. Hamoodi and F. S. Abdulla, “Design and sizing of solar plant for Qayarah general Hospital and simulation with the PV-SOL program,” *NTU Journal of Engineering and Technology*, vol. 1, no. 1, pp. 67–71, 2021.

[53] S. W. Shneen, R. K. Gaber, R. S. Salih, and S. M. Jiaad, “Artificial Neural Network (ANN) Based Proportional Integral Derivative (PID) For Arm Rehabilitation Device,” *Kufa Journal of Engineering*, vol. 16, no. 1, pp. 80-103, 2025.

[54] A. El-Shahat and S. Sumaiya, “DC-Microgrid system design, control, and analysis,” *Electronics*, vol. 8, no. 2, p. 124, 2019.

[55] A. A. Mutlag and S. W. Shneen, “A Comparative Investigation of Hybrid MPPT Methods for Enhancing Solar Power Generation in Renewable Energy Systems,” *International Journal of Electrical and Electronics Research*, vol. 12, no. 3, pp. 991-1000, 2024.