ANFIS Control for Solar PV fed Modular Multilevel Inverter for Marine Water Pumping Applications

V.Shalini Rubi[1], Dr. R. Kiranmayi[2], Sri K. Nagabhushanam[3], N. Swathi[4]

[1] *PG-Scholar, Department of EEE, JNTUA College of Engineering (Autonomous) Ananthapuramu, India.* *shalinirubi3824@gmail.com*
[2] *Professor, Department of EEE, JNTUA College of Engineering (Autonomous) Ananthapuramu, India.* *kiranmayi0109@gmail.com*
[3] *Assistant Professor (Adhoc), Department of EEE, JNTUA College of Engineering (Autonomous) Ananthapuramu, India.* *knneee.eee@jntua.ac.in*
[4] *Assistant Professor (Adhoc), Department of EEE, JNTUA College of Engineering (Autonomous) Ananthapuramu, India.* *nswathi.eee@gmail.com*

Abstract: In this paper, we show our work developing and implementing a Modular Multilevel Inverter (MMI) for intelligent Induction Motor (IM) drive control. Pumping water from the sea is the primary focus of these methods. It has been suggested that an eleven-stage inverter could be used to regulate the speed of a photovoltaic solar-powered IM drive. It is estimated that pumps account for roughly half of a ship's total energy consumption. Therefore, the purpose of this study is to investigate and assess the proposed control design for an induction motor (IM) drive and MMI-based marine water pumping system. The primary motivation behind this design was to reduce the complexity of the controller. Controllers based on Proportional-Integral (PI), Fuzzy Logic (FL), and Adaptive Network-based Fuzzy Interference System (ANFIS) are tested alongside the inverter to see how well they improve performance. The Total Harmonic Distortion (THD) of inverters, controller settling times, and peak overshoot have all been compared to identify the most robust option. In order to establish which of these elements is superior, this comparison was performed. The suggested control scheme's novel feature is the design and integration of a marine-specific MMI, IM drive, and intelligent controller for use in marine water pumping applications.

Keywords: Modular Multilevel Inverter, Induction Motor, Proportional- Integral and Fuzzy Logic, ANFIS controller

1. INTRODUCTION

In recent years, modular multilevel inverter, or MMI, systems that are supplied by solar photovoltaic panels have grown more popular because to their effectiveness and durability. These systems are commonly used in marine water pumping applications, where they offer a sustainable and cost-effective solution for water supply in remote areas. However, the effectiveness of such systems is very sensitive to the control method used.

Adaptive Neuro-Fuzzy Inference System (ANFIS) control is a promising technique for controlling the operation of MMI systems. ANFIS combines the strengths of fuzzy logic and neural networks to provide a powerful and flexible control strategy. It can effectively handle nonlinearities and uncertainties in the system, making it an ideal choice for controlling the complex operation of solar PV fed MMI systems.

In this project, we will explore the use of ANFIS control for solar PV fed MMI systems in marine water pumping applications. We will develop a control algorithm based on ANFIS and evaluate its performance through simulation studies. The aim of this project is to improve the efficiency and reliability of solar PV fed MMI systems for use in pumping seawater, and to promote the use of sustainable energy solutions in remote areas.

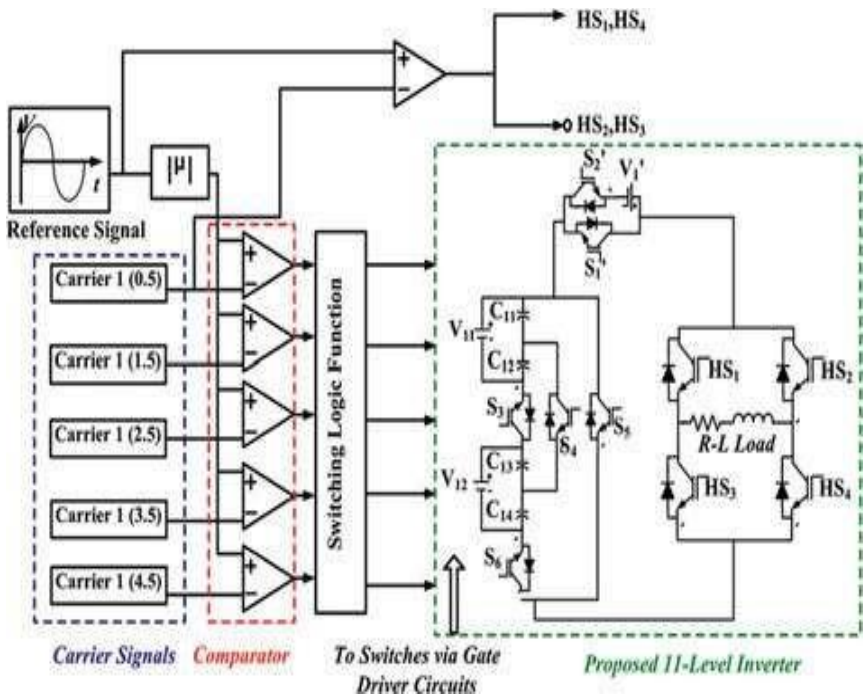

Figure 1: The planned 11-level inverter is seen in this schematic.

UNFCCC and IMO created standards to decrease ship CO2 emissions (IMO). The depletion of conventional energy sources is contributing to both a worldwide energy shortage and environmental degradation. By 2020, diesel-powered vessels will release 8% more greenhouse gases and carbon dioxide than they did in 2010 [3, 4]. After years of struggling with pollution, the shipbuilding sector is now getting a clean slate thanks to solar electricity. Solar energy adoption and the creation of more efficient inverters are two significant concerns [3, 4]. The energy crisis worsens as conventional sources of fuel become depleted. The greenhouse effect causes global warming as a result of this. By 2100, we may expect a global average temperature increase of 3 to 6 degrees Celsius [4, 5]. Solar power is attractive for ships since it is easy to install, requires minimal maintenance, and has a tiny footprint. Solar photovoltaics improve the efficiency of renewable energy sources, lessen pollution, and stabilise electricity. Both a power converter and an inverter are part of a solar energy system [6]. Recently, ships have been experimenting with integrated power converters that can draw electricity from renewable sources. Voltage drift and frequency fluctuations [7, 8] lead to harmonic distortions. Seventy percent of a vessel's electrical energy goes into pumping [9, 10]. Harmonic distortion is a problem with the ship's converter. We'll have a look at the state of the art modular inverter, which uses an intelligent controller to lessen harmonic distortion and boost ship power quality. Here, we present a cascaded symmetric multilevel module with the ability to generate negative voltages. See Figure 1 for a solar-powered inverter with smart regulation. VFD is used to power the ship's seawater pump. When used to an IM drive powered by several inverters, a comparison is made between PI and FLC controllers. For the most part, PI controllers are employed in situations where speed regulation is required because of their better peak overshoot and constancy. One of the simplest commutators is the frequency-locking commutator (FLC) speed controller for induction motors. Recirculating the ship's water supply at all times. When an induction motor is turned on, the inverter regulates the first surge of current and voltage.

To rephrase, DC motors suffer from poor commutation. These issues do not affect ships that use induction motors. The cooling effect of salt water on fresh water is a double win. The research recommends using MMI topology for single-phase IM marine water pumping motors. The sun and the weather determine the actual pace at which time passes. By changing the inverter's switching frequency, the speed of an induction motor may be modified. The PWM controls on the FL controller allow for this. In the model, a solar PV generator provides power to a hybrid IM drive with PI and FL regulators. The SPARTAN3E500 FPGA controller generates electrical impulses for use in inverters and converters. It offers IM drive controllers based on PI and FL for use in marine water pumping systems. The

SPARTAN3E500 FPGA controller was used to create a real-time MMI- fed IM drive. Improving power quality by comparing the performance of FL and PI regulators. This article provides an examination of MMI.

2. LITERATURE SURVEY

[1] B. B. Panigrahi, S. Sahu, and S. S. Meher, "Control strategies for solar photovoltaic fed multilevel inverter: A review," International Journal of Renewable Energy Research, vol. 6, no. 3, pp. 1243-1257, 2016. This paper provides an overview of different control strategies for solar photovoltaic fed multilevel inverters, including traditional methods and intelligent control techniques such as fuzzy logic and neural networks. It highlights the advantages and limitations of each method and presents future research directions for improving the performance of solar PV fed multilevel inverters.

[2] A. F. Zobaa, A. M. E. Al-Sumaiti, and J.M. Bakhashwain, "Adaptive neuro-fuzzy inference system (ANFIS) based maximum power point tracking (MPPT) for photovoltaic systems," Published in 2013 on pages 752-758 of the International Journal of Electrical Power & Energy Systems. In order to maximize the efficiency of solar installations, this research suggests an ANFIS-based MPPT algorithm. The algorithm's objective is to accomplish rapid and accurate monitoring of the highest power point while accounting for the nonlinear and dynamic features of PV systems. The simulation results show that the suggested algorithm outperforms the more common MPPT methods.

[3] S. Sahoo, S. R. Mohanty, and A. K. Panda, "Fuzzy-logic-based control of modular multilevel converter for grid integration of renewable energy sources," IEEE Transactions on Industry Applications, vol. 51, no. 1, pp. 663-673, 2015. In order to facilitate the integration of renewable energy sources into the grid, a modular multilevel converter (MMC) is proposed here, with its control approach based on fuzzy logic. The suggested control approach may compensate for MMC system nonlinearities and perform high-quality power conversion despite these systemic flaws. The suggested control mechanism is shown to be superior to the status quo in simulation results.

[4] S. Sahu, B. B. Panigrahi, and S. S. Meher, "Adaptive neuro-fuzzy based MPPT control of photovoltaic fed cascaded multilevel inverter," Energy, vol. 97, pp. 220-231, 2016. This paper proposes an ANFIS-based MPPT control strategy for a photovoltaic-fed cascaded multilevel inverter. The proposed strategy has the capability to deal with the nonlinear and dynamic features of the PV system and achieve fast and accurate MPPT. Simulation results demonstrate the effectiveness of the proposed strategy in comparison with conventional MPPT techniques.

[5] G. Abdelsalam, A. M. Massoud, S. Ahmed, and P. Enjeti, "High-performance adaptive perturb and observe MPPT technique for photovoltaic-based microgrids," IEEE Transactions on Power Electronics, vol. 26, no. 4, pp. 1010-1021, 2011. In this paper, we provide a maximum power point tracking strategy for solar-powered microgrids that uses an adaptive perturb and observe approach. The proposed approach is effective in measuring the maximum power point, even under changing conditions. The simulation results demonstrate that the proposed technique outperforms conventional MPPT methods.

3. METHODOLOGY

MODULAR MULTI LEVEL CONVERTER

High-voltage direct current (HVDC) transmission systems and other high-power applications employ Modular Multi-Level Converters (MMCs). It consists of a series of identical sub-modules, each consisting of a half-bridge circuit connected to a capacitor. These sub- modules are connected in series to form the converter.

The MMC is capable of producing high- quality output voltages with low harmonic distortion, which makes it suitable for use in high-power applications where the quality of the power output is important. It also has the ability to operate at high voltages and currents, which makes it suitable for use in HVDC transmission systems.

The control of an MMC is more complex than that of other power converters, as it involves the control of multiple sub-modules. However, this complexity can be reduced by using advanced control algorithms such as model predictive control or cascaded control.

Inverter:

Inverters convert DC to AC. Solar power, UPS, and electric cars employ inverters. They are an essential component in systems that use batteries or other DC sources and need to produce AC power for use in home appliances, power tools, and other devices. Inverters can produce a range of AC waveforms, including sinusoidal, square, and modified square waves, depending on the application requirements. They can be designed to operate at different power levels, from a few watts to megawatts.

Multilevel Inverter:

MMLI multilayer inverters produce a staircase-like AC waveform from several DC voltages. Multiple capacitors and power electronic switches in sequence generate a high-quality output voltage waveform with minimal harmonic distortion.

The MMLI outperforms two-level inverters in power efficiency, EMI, and voltage. The MMLI may also be scaled up or down to match power needs.

The MMLI converts solar PV panel DC electricity into AC power for the marine water pump in the ANFIS management system. The ANFIS control system adjusts the switching frequency and modulation index of the MMLI based on the solar PV input power and the load demand to optimize its performance.

The MMLI used in the ANFIS control system for marine water pumping applications is designed to withstand harsh marine environments, including saltwater corrosion and high humidity. It is also highly reliable and requires minimal maintenance, making it an ideal choice for remote marine water pumping applications.

Figure 2: Multilevel Inverter

SYSTEM CONFIGURATION AND OPERATION STRATEGY

ANFIS Control for Solar PV-fed Modular Multilevel Inverter for Marine water pumping applications:

- **Solar PV array:** The solar PV array is used to generate DC power from sunlight. The output DC voltage of the solar panels is fed to the input of the inverter.
- **Modular multilevel inverter:** The modular multilevel inverter converts DC solar panel electricity into AC water pump power. The inverter operates by switching a series of power electronic devices to produce a stepped output voltage waveform that approximates a sine wave.
- **Water pump:** The inverter's AC electricity drives the water pump, which pumps sea water for different uses.

- **ANFIS control:** ANFIS (Adaptive Neuro- Fuzzy Inference System) is a type of intelligent control system that combines the capabilities of neural networks and fuzzy logic to provide precise and adaptive control. ANFIS control is used to optimize the performance of the inverter andmaximize the efficiency of the system. The ANFIS controller receives inputs from the solar PV array and the load and adjusts the output voltage of the inverter to maximize power transfer and efficiency.

The operation strategy of the system involves optimizing the performance of the inverter and maximizing the power transfer efficiency. The ANFIS controller continuously monitors the output of the solar PV array and the load and adjusts the output voltage of the inverter to match the load requirements. The ANFIS controller uses a combination of neural network and fuzzy logic algorithms to adaptively adjust the inverter output voltage and minimize power losses. This results in a more efficient system that can operate at higher power levels while maintaining stability and reliability.

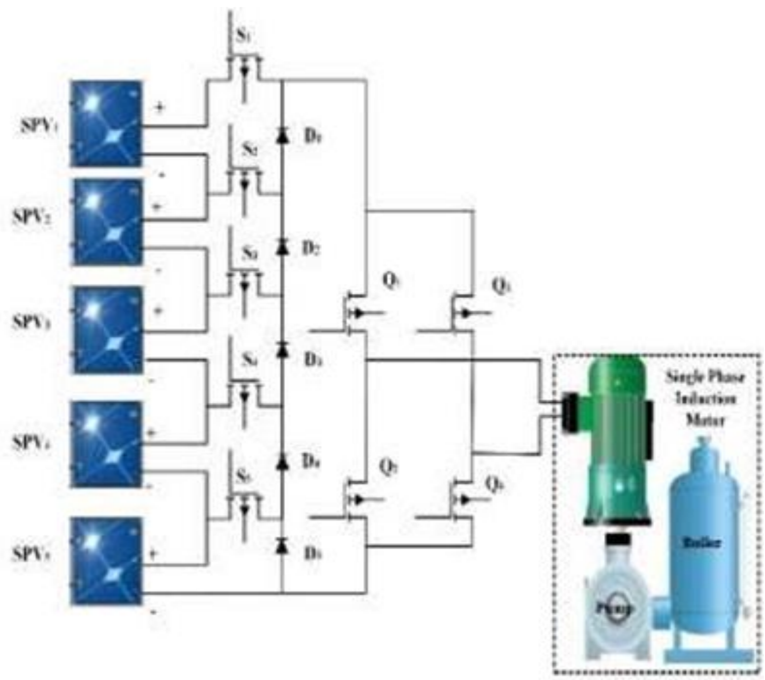

Figure 3: Proposed multilevel inverter.

DESIGN OF AN INDUCTOR (L)

The inductor is typically used in combination with capacitors to create a low-pass filter that attenuates the high-frequency harmonics present in the output voltage waveform of the inverter. The value of the inductor is chosen based on the switching frequency of the inverter and the load requirements.

The design process for the inductor involves the following steps:

- ✓ **Determine the switching frequency of the inverter:** The switching frequency of the inverter is the rate at which the power electronic devices switch on and off to create the output voltage waveform. The switching frequency is typically in the range of 1 kHz to several kHz, depending on the design of the inverter.
- ✓ **Determine the load requirements:** The load requirements refer to the power and voltage requirements of the load that the inverter is driving. The load requirements are used to determine the maximum current that will flow through the inductor.
- ✓ **Calculate the inductance value:** The inductance value is calculated using the following formula:

$$L = V / (\Delta I / \Delta t) \quad (1)$$

Where L is the inductance in henries, V is the DC voltage input to the inverter, ΔI is the change in current in amps, and Δt is the time interval in seconds.

- ✓ **Choose a suitable core material and size:** The core material and size are chosen based on the required inductance value and the maximum current that will flow through the inductor. The core material should have low losses at the operating frequency of the inverter to minimize power losses.

DESIGN OF A CAPACITOR

The following equation calculates the capacitor capacitance needed in an ANFIS control system for Solar PV-fed Modular Multilevel Inverter for marine water pumping:

$$C = (I\_load \times T) / V\_ripple \quad (2)$$

Where C is the capacitance in farads, I_load is the load current in amperes, T is the ripple time in seconds, and V_ripple is the maximum allowable ripple voltage.

The load current can be determined from the specifications of the pumping system, while the maximum allowable ripple voltage would depend on the sensitivity of the system to

fluctuations in voltage. The ripple time can be calculated as:

$$T = (2 \times \pi \times L) / V\_out \quad (3)$$

Where L is the inductance of the output filter and V_out is the output voltage of the inverter.

The inductance of the output filter can be calculated based on the desired cutoff frequency and the capacitance of the capacitor. The cutoff frequency can be selected based on the requirements of the pumping system.

Once the capacitance value is calculated using the above equation, a suitable capacitor with a suitable voltage rating and low ESR can be selected for the application.

It is important to note that this equation provides an approximation and that the actual capacitance value may need to be adjusted based on practical considerations and system performance during testing.

MULTILEVEL INVERTER DESIGN

Designing a multilevel inverter for an ANFIS control system for a Marine water pumping solar PV-fed modular multilevel inverter would require a few considerations. One approach to designing such an inverter is by using a cascaded H-bridge topology. The following equation can be used to determine the DC voltage source required for this topology:

$$V\_dc = N \times V\_out + V\_margin \quad (4)$$

Where V_dc is the DC voltage source required, Cascaded H-bridge topology has N H-bridge cells, V_out is the desired output voltage of the inverter, and V_margin is a margin added to account for voltage drops and losses in the system.

The output voltage and H-bridge cell switches' voltage ratings determine the number of cells needed. The switches must be able to handle the DC voltage source and the peak voltage of the output waveform.

The modulation technique used in the ANFIS control system would also need to be considered when designing the multilevel

inverter. The modulation technique would determine the number of output levels required and the switching frequency of the H-bridge cells.

It is important to note that the actual design of the multilevel inverter would require additional considerations, such as selecting appropriate switches, gate drivers, and protective circuitry. It is recommended to consult with a qualified engineer or expert in the field for detailed guidance on designing a multilevel inverter for this application.

WATER PUMP DESIGN

Designing a water pump system for an ANFIS control system for a Marine water pumping solar PV-fed modular multilevel inverter would require a few considerations. One important factor to consider is the required flow rate, which can be determined using the following equation:

$$Q = A \times v \tag{5}$$

Where Q is the flow rate in cubic meters per second, A is the cross-sectional area of the pipe in square meters, and v is the fluid velocity in meters per second.

The intended flow rate and fluid velocity define the pipe cross-sectional area, which would depend on the pumping system's requirements and the piping system's layout.

Another important factor to consider is the required head or pressure, which can be determined using the following equation:

$$H = (P\_out - P\_in) / (\rho \times g) \tag{6}$$

Where H is the head or pressure in meters, P_out is the output pressure of the pump in pascals, P_in is the input pressure of the pump in pascals, ρ is gravity's acceleration in metres per second squared, and is fluid density in kilogrammes per cubic metre.

The output and input pressure values would depend on the system's requirements and the piping system's layout, while the fluid density would depend on the type of fluid being pumped.

Once the flow rate and head or pressure values are determined, an appropriate pump with the required flow rate and head or pressure capabilities can be selected for the application. The pump selection would also depend on the specific application requirements, such as the type of fluid being pumped, the operating temperature range, and the environment.

It is important to note that these equations provide approximations and that the actual design of the water pump system would require additional considerations, such as selecting appropriate pump components and protective circuitry. It is recommended to consult with a qualified engineer or expert in the field for detailed guidance on designing a water pump system for this application.

4. CONTROL TOPOLOGY FOR MMI

The control topology for an ANFIS control system for a Solar PV-fed MMIs for marine water pumping vary on the application. However, the following control topology can be used as a general guideline:

- **MPPT Controller:** A Maximum Power Point Tracking (MPPT) controller is used to track the maximum power point of the solar PV panel and regulate the DC voltage output to ensure the inverter operates at the maximum power point.
- **DC-DC Boost Converter:** The MMI uses a DC-DC boost converter to raise the solar PV panel's DC voltage.
- **Modulation Strategy:** A modulation strategy is used to control the switching of the power semiconductor devices in the MMI. The Phase-Shifted Carrier (PSC) modulation strategy is commonly used for MMIs.
- **ANFIS Controller:** Based on the inverter output voltage and current, an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller adjusts the modulation approach. The ANFIS controller can use a variety of control techniques, such as PID control or MPC,

to adjust the modulation strategy to ensure that the inverter output meets the desired specifications.

- **Protective Circuitry:** Protective circuitry, such as overcurrent protection and overvoltage protection, is included to ensure safe and reliable operation of the inverter.

- **Water Pump Control:** A control system is included to regulate the speed of the water pump based on the output of the inverter. This control system can use a variety of techniques, such as PID control or model-based control, to regulate the speed of the pump and maintain the desired flow rate and head.

It is important to note that the above control topology is a general guideline and the specific requirements of the application may require modifications to the topology.

SPEED CONTROL USING A PI-BASED REGULATOR

An ANFIS control system powered by solar panels may use a PI controller equation for speed regulation, as shown here:

$$u(t) = Kp * e(t) + Ki * \int e(t)\, dt \quad (7)$$

Where:

- u(t) is the control signal (output) that adjusts the motor torque to regulate the speed of the water pump.
- Kp is the proportional gain of the controller.
- Ki is the integral gain of the controller.
- e(t) is the error signal, which is the difference between the setpoint speed and the actual speed of the water pump.

The error signal can be calculated using the following equation:

$$e(t) = Wref - Wact \quad (8)$$

Where:

- “Wref” is the reference speed of the water pump.
- Using a speed sensor, we may determine the water pump's real speed, denoted by the symbol "Wact.".

The values of Kp and Ki can be determined using various tuning methods, such as Ziegler- Nichols method or trial-and-error method, to achieve the desired performance specifications. The tuning process involves adjusting the values of Kp and Ki to achieve parameters like settling time, overshoot, and steady-state error that you want to see when measuring response speed.

The PI controller is typically implemented using a digital signal processor (DSP) or a microcontroller, and the control signal is applied to the inverter to adjust the output voltage and frequency. The ANFIS controller can be used to adjust the modulation strategy of the inverter based on the feedback signals from the inverter output, such as the output voltage and current, to ensure that the inverter output meets the desired specifications.

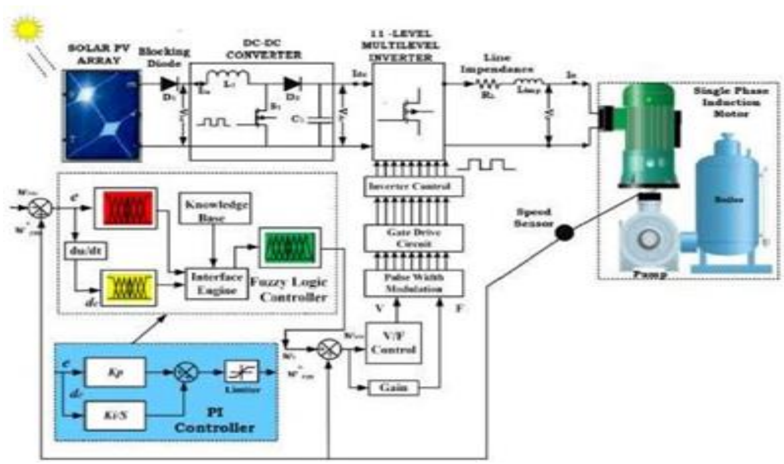

Figure 4: Control approach of the proposed inverter.

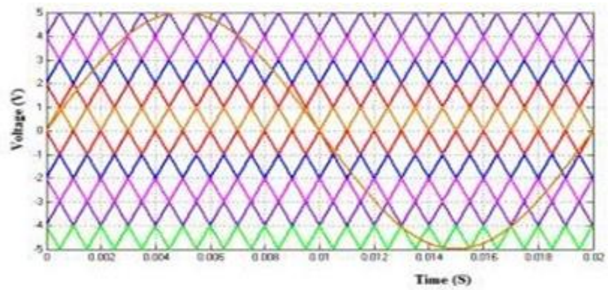

Figure 5: APOD control signal.

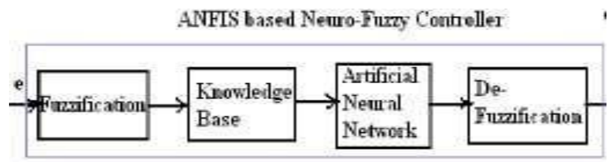

Figure 6: ANFIS based Neuro-Fuzzy Controller

ANFIS stands for Adaptive Neuro-Fuzzy Inference System, which is a popular type of fuzzy logic controller (FLC). It combines fuzzy logic and neural networks' benefits to create a controller that can learn from input- output data and adjust its parameters to improve performance.

Fuzzy inference and neural networks make up an ANFIS-based neuro-fuzzy controller. Linguistic rules convey expert knowledge and produce data-driven judgments in the fuzzy inference system. The neural network learns the parameters of the fuzzy inference system using a hybrid learning algorithm that combines backpropagation and least-squares estimation.

The ANFIS-based neuro-fuzzy controller can be used in various control applications, such as temperature control, speed control, and position control. It is particularly useful when dealing with complex and nonlinear systems, where traditional controllers may not be effective.

The main advantage of ANFIS-based neuro- fuzzy controllers is their ability to adapt to changing environments and learn from experience. This makes them highly suitable for control applications that involve uncertain or dynamic systems. However, they can be complex and require significant computational resources to train and operate.

APOD stands for Amplitude and Phase Optimum (APO) Distortion (D) control signal. It is a type of control signal used in power electronics applications, such as inverter control, to minimize the output voltage distortion.

The APOD control signal is used to adjust the magnitude and phase of the reference signal

applied to the modulator of the inverter. The aim is to minimize the distortion of the output voltage waveform while maintaining the required output voltage level.

The APOD control signal can be implemented using a closed-loop feedback control system, where the distortion of the output voltage is measured and used to adjust the amplitude and phase of the reference signal. The controller can be based on a Proportional-Integral (PI) or a Proportional-Resonant (PR) control strategy, depending on the application requirements.

The APOD control signal may also be accomplished using a feedforward control technique, in which the output voltage distortion is predicted ahead of time using information about the load current and the inverter settings, and the amplitude and phase of the reference signal are adjusted accordingly.

Overall, the APOD control signal is a useful tool for minimizing output voltage distortion in power electronics applications, which can improve the performance and efficiency of the system.

FUZZY LOGIC CONTROLLER

Decisions are made by a Fuzzy Logic Controller (FLC) depending on information provided by the user. Unlike traditional control systems that rely on precise mathematical models, FLCs use linguistic rules and fuzzy sets to handle uncertainty and imprecision in the input data.

A fuzzifier, rule set, and inference engine make up the FLC's core functionality. The fuzzifier converts the input data into linguistic variables, which are then mapped to fuzzy sets. The rule base contains a set of if- then rules that define the relationship between the fuzzy sets of the input variables and the output variables. The inference engine uses these rules to determine the appropriate output based on the input data.

The FLC can be used in a variety of control applications, such as speed control, temperature control, and power control. In each case, the FLC takes in input variables, such as speed, temperature, or power, and

outputs a control signal that adjusts the system to achieve the desired output.

The FLC is particularly useful in situations where the mathematical model of the system is not well-defined, or when the input data is uncertain or imprecise. It can also handle non- linear systems and systems with multiple inputs and outputs, making it a versatile tool for control engineering.

Overall, the FLC is a powerful tool for control engineering that can handle uncertainty and imprecision in input data, making it a valuable addition to any control system.

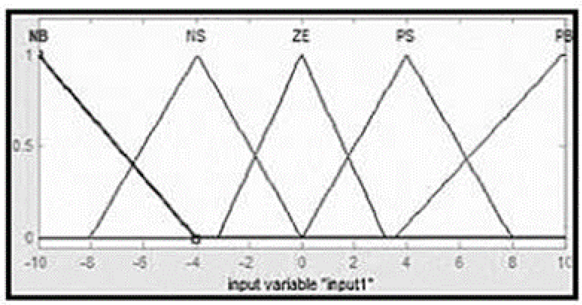

Figure 7: Allocation of range for subsets. TABLE 1. Fuzzy rules.

e/ce	NB	NS	ZE	PS	PB
NB	ZE	NS	NB	NB	NB
NS	ZE	NS	NB	NS	NB
ZE	PB	PS	ZE	NS	NB
PS	PB	PS	PS	ZE	NS
PB	PB	PB	PB	PS	ZE

The fuzzy operator takes relationship values from the fuzzifier input variables. One result is true. As expected, Input 2 reports the problem. Five of the eight fuzzy subsets in linguistic variables are used:

- Negative error speed Big (NB)
- Negative error speed Small (NS)
- Positive error speed Small (PS)
- Positive error speed Big (PB) and
- Zero error speed (ZE)

For the sake of argument, let's say the result is NS; for values between 0.341 and 0.3416, all rule-based membership functions will continue to operate normally. Figure 5 depicts the 0.1 NB, 1.0 PB, 0.66% PS, and 0.5 ZE outputs. The values that can be used as input are as follows: NB = -1600; NS = -8.06; ZE = -3.2; PS = -0; 4; 8; and PB = -3.52; 9.92; 1550. The

speed-control logic's rule matrix is displayed in Table 1.

Nine semiconductor switches (S1-S5) are paralleled with four H bridge switches (Q1- Q4) to form the 11-level MMI. Fuzzy logic is used to do a comparison between the bipolar triangle and sine waves, which results in the PWM. The pulses from S1–S5 regulate the inverter, and those from Q1–Q4 regulate the volume.

Figure 6 depicts the complete design of the FLC structure determined by the inverter's switching pattern produced by the switching pulse generator. There is intentional design of the input fuzzification membership (IN1-IN6)

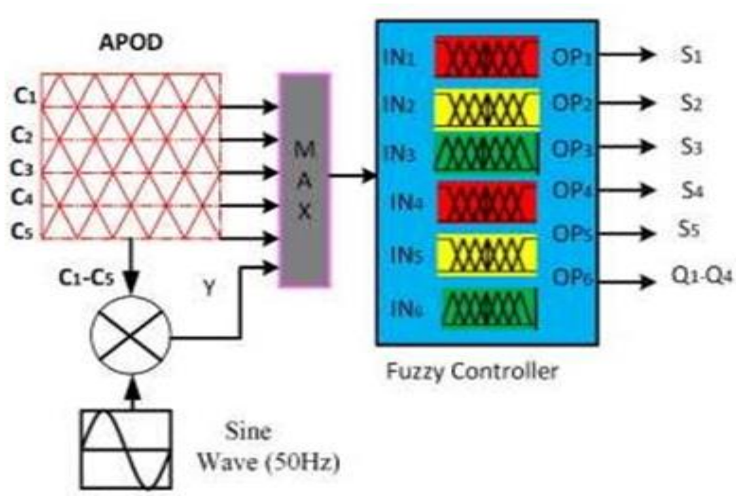

Figure 8: FLC controller switching pulse generation structure

Having a magnitude range of (1, 0, 1) for switching. Positive numbers from 0 to 1 indicate the first quarter cycle, while positive numbers from 90 to 180 represent the second quarter cycle. Negative one indicates the third (180-270) and positive zero the fourth (270-360) quarterly cycles. Then, in the defuzzification step, six membership functions are constructed utilising fuzzy rules to provide the desired outcome. In this article, we show how we

designed and built two controllers specifically for use with water pumps. Voltage and frequency control the inverter. Induction motors have their speeds adjusted using the voltage and frequency (v/f) approach.

ANFIS CONTROLLER

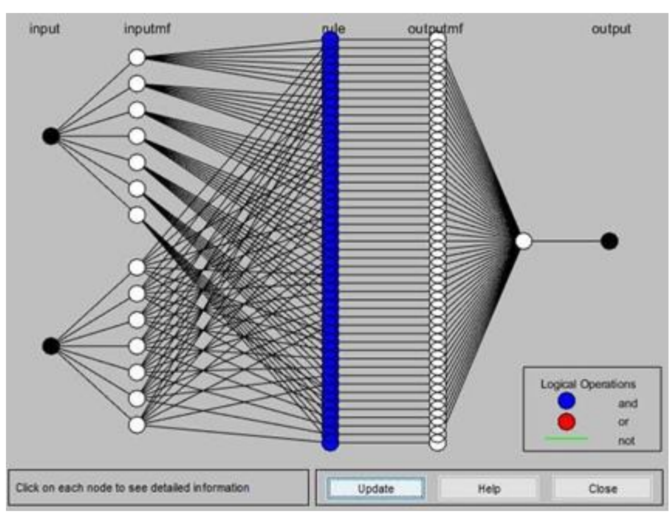

Figure 9: ANFIS structure TABLE 2 ANFIS rules

E/CE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

5. RESULTS & DISCUSSION

Simulation results:

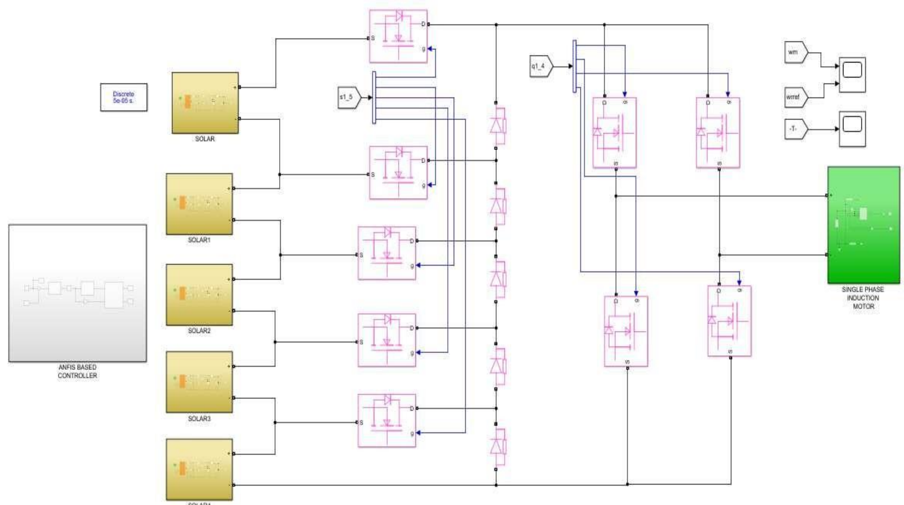

Figure 10: Proposed Simulink

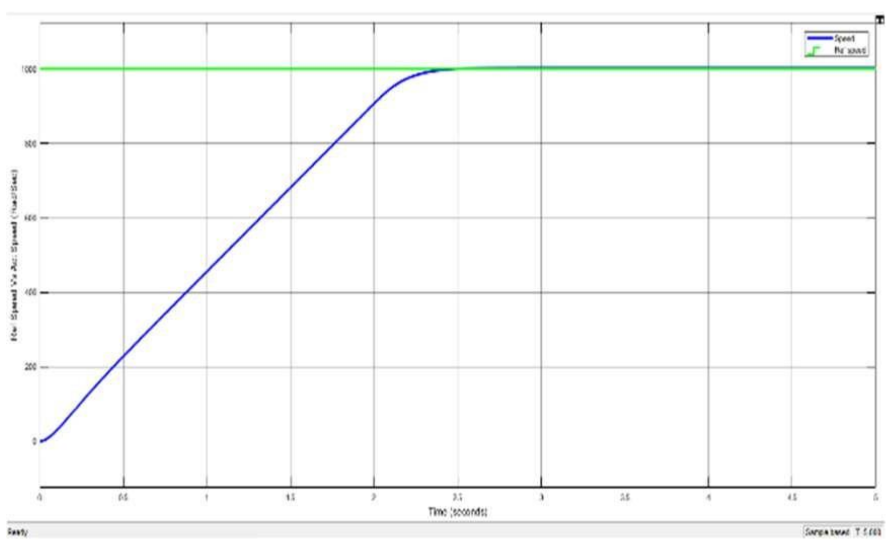

Figure 11: Speed response for using PID controller

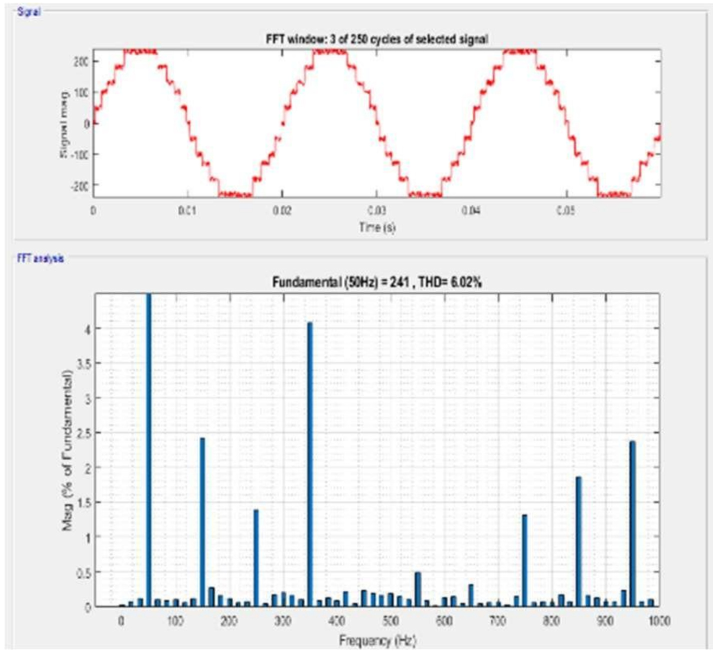

Figure 12: PID harmonics

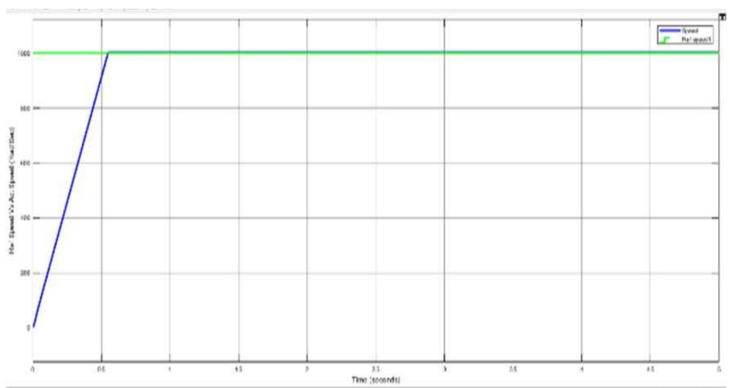

Figure 13: Speed response for using FUZZY controller

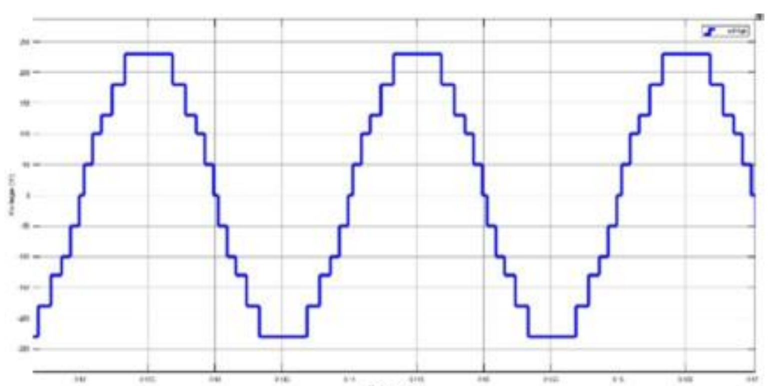

Figure 14: Constant Voltage

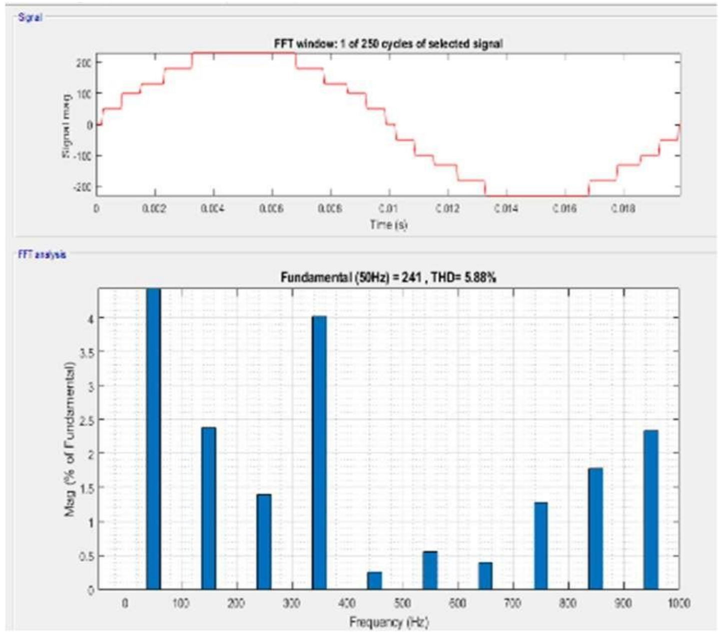

Figure 15: FUZZY harmonics

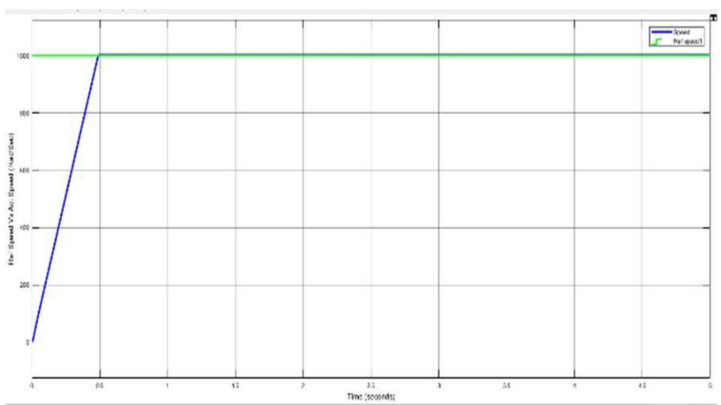

Figure 16: Speed response for using ANFIS controller

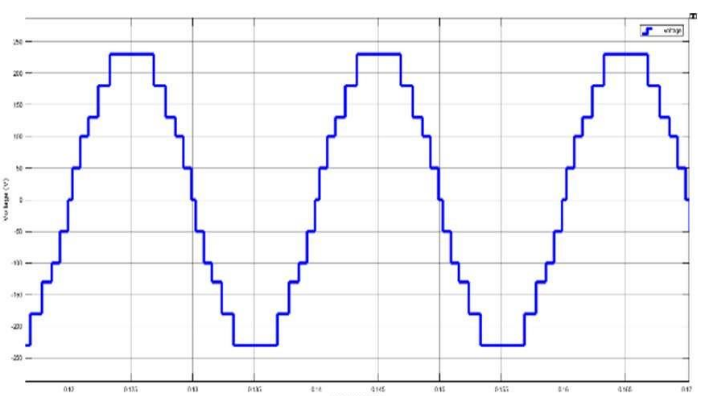

Figure 17: Constant Voltage

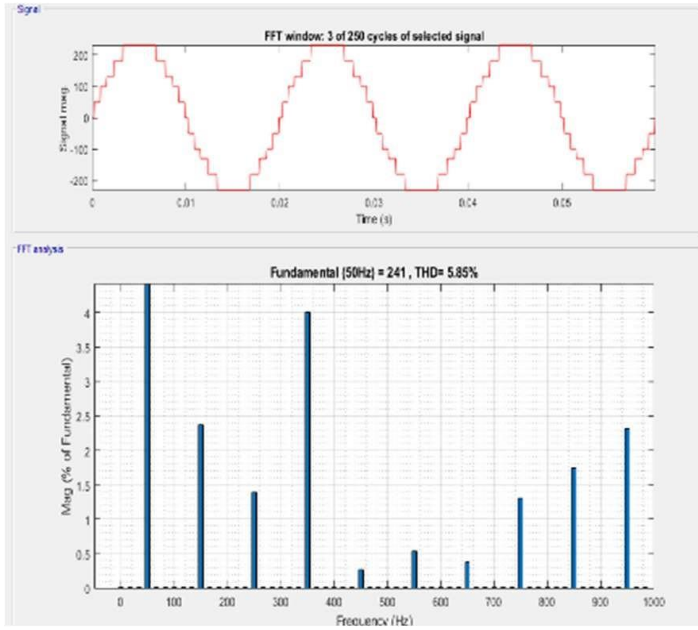

Figure 18: ANFIS harmonics

6. CONCLUSION

The proposed work is relevant because it seeks when the marine water pumping inverter driving power system has to be improved. The steady-state and dynamic behaviours of a solar PV-fed MI for speed control of an induction motor drive have been analysed to determine the system's viability as a maritime water pumping system. The suggested inverter links the solar PV array to an induction motor. The controller gets information about the motor's speed and uses it to create the most effective pulse width modulation (PWM) signals for the inverter's switches. PI, FL, and ANFIS controllers start the motor gradually and raise its speed to the reference speed. Simulation is used to test and evaluate the capabilities of PI, FL, and ANFIS controllers in the context of a realistic operational scenario. According to the findings, the ANFIS-based controller outperforms the PI controller and the FI controller in terms of settling time and harmonics reduction. The most noticeable consequences of the proposed control system are a decrease in steady-state error while regulating the speed of the induction motor and an increase in harmonics at the output of the multilayer inverter. DC microgrids have source, converter, load, controller, and grid. Conventional use defines a microgrid as a community-owned and - operated power system that provides electricity to nearby residential areas. All of the specified DC microgrid components are present and operational in the proposed setup. A key challenge for the future will be making accurate predictions about energy production and use.

7. REFERENCES

[1]. H. Lan, Y. Bai, S. Wen, D. C. Yu, Y.-Y. Hong, J. Dai, and P. Cheng, ''Modeling and stability analysis of hybrid PV/diesel/ESS in ship power system,'' Inventions, vol. 1, no. 5, pp. 1–16, 2016, doi: 10.3390/inventions1010005.

[2]. S. G. Jayasinghe, L. Meegahapola, N. Fernando, Z. Jin, and J. M. Guerrero, ''Review of ship microgrids: System architectures, storage technologies and power quality aspects,'' Inventions, vol. 2, no. 4, pp. 1–19, 2017, doi: 10.3390/inventions2010004.

[3]. R. Kumar and B. Singh, ''Single stage solar PV fed brushless DC motor driven water pump,'' IEEE J. Emerg. Sel. Topics Power Electron., vol. 5, no. 3, pp. 1337–1385, Sep. 2017, doi: 10.1109/JESTPE.2017.2699918.

[4]. S. Shukla and B. Singh, ''Single-stage PV array fed speed sensorless vector control of induction motor drive for water pumping,'' IEEE Trans. Ind. Appl., vol. 54, no. 4, pp. 3575–3585, Jul./Aug. 2018, doi: 10.1109/TIA.2018.2810263.

[5]. C.-L. Su, W.-L. Chung, and K.-T. Yu, ''An energy-savings evaluation method for variable-frequency-drive applications on ship central cooling systems,'' IEEE Trans. Ind. Appl., vol. 50, no. 2, pp. 1286–1297, Mar./Apr. 2014, doi: 10.1109/TIA.2013.2271991.

[6]. B. Singh, U. Sharma, and S. Kumar, ''Standalone photovoltaic water pumping system using induction motor drive with reduced sensors,'' IEEE Trans. Ind. Appl., vol. 54, no. 4, pp. 3645–3655, Jul./Aug. 2018, doi: 10.1109/TIA.2018.2825285.

[7]. A. Dolatabadi and B. Mohammadi-Ivatloo, ''Stochastic risk-constrained optimal sizing for hybrid power system of merchant marine vessels,'' IEEE Trans. Ind. Informat., vol. 14, no. 12, pp. 5509–5517, Dec. 2018, doi: 10.1109/TII.2018.2824811.

[8]. H.-L. Tsai, ''Design and evaluation of a photovoltaic/thermal-assisted heat pump water heating system,'' Energies, vol. 7, no. 5, pp. 3319–3338, May 2014, doi: 10.3390/en7053319. 88532 VOLUME 9, 2021

[9]. A. Alexander Stonier et al.: FL Control for Solar PV Fed MMI
[10]. M. G. Yu, Y. Nam, Y. Yu, and J. Seo, ''Study on the system design of a solar assisted ground heat pump system using dynamic simulation,'' Energies, vol. 9, no. 4, pp. 1–17, 2016, doi: 10.3390/en9040291.
[11]. S. V. Giannoutsos and S. N. Manias, ''A systematic power-quality assessment and harmonic filter design methodology for variable-frequency drive application in marine vessels,'' IEEE Trans. Ind. Appl., vol. 51, no. 2, pp. 1909–1919, Mar. 2015, doi: 10.1109/TIA.2014.2347453.
[12]. C. Gnanavel and S. A. Alexander, ''Experimental validation of an eleven level symmetrical inverter using genetic algorithm and queen bee assisted genetic algorithm for solar photovoltaic applications,'' J. Circuits, Syst. Comput., vol. 27, no. 13, pp. 1–23, 2018, doi: 10.1142/ S0218126618502122.
[13]. R. Thangaraj, T. R. Chelliah, M. Pant, A. Abraham, and C. Grosan, ''Optimal gain tuning of PI speed controller in induction motor drives using particle swarm optimization,'' Log. J. IGPL, vol. 19, no. 2, pp. 343–356, Apr. 2011, doi: 10.1093/jigpal/jzq031.
[14].
[15]. M. S. Zaky and M. K. Metwaly, ''A performance investigation of a four-switch three-phase inverter-fed IM drives at low speeds using fuzzy logic and PI controllers,'' IEEE Trans. Power Electron., vol. 32, no. 5, pp. 3741–3753, May 2017, doi: 10.1109/TPEL.2016.2583660.
[16]. R. E. Geneidy, K. Otto, P. Ahtila, P. Kujala, K. Sillanpää, and T. Mäki-Jouppila, ''Increasing energy efficiency in passenger ships by novel energy conservation measures,'' J. Mar. Eng. Technol., vol. 17, no. 2, pp. 85–98, May 2018, doi: 10.1080/20464177.2017.1317430.
[17]. A. A. Stonier, ''Design and development of high performance solar photovoltaic inverter with advanced modulation techniques to improve power quality,'' Int. J. Electron., vol. 104, no. 2, pp. 174–189, Feb. 2017.

DOI: https://doi.org/10.15379/ijmst.v10i4.2241