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DESIGN OF A SOLAR PV-FED MODULAR MULTILEVEL INVERTER FOR MARINE WATER PUMPING USING FUZZY LOGIC CONTROL

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ABSTRACT
The design and implementation of a Modular Multilevel Inverter (MMI) to control the Induction Motor (IM) drive using intelligent techniques for marine water pumping applications is presented in this paper. The proposed inverter has eleven levels and can control the speed of an IM drive powered by solar photovoltaic. Pumping schemes in an onboard ship are estimated to consume nearly half of the total energy. Taking this into consideration, this paper investigates and validates a proposed control design with reduced complexity for a marine water pumping system using an induction motor (IM) drive and MMI. Inverter performance is improved through the use of Proportional-Integral (PI) and Fuzzy Logic (FL) based controllers. A comparative study has been made with respect to better robustness in terms of peak overshoot, settling time of the controller and Total Harmonic Distortion (THD) of the inverter. Simulations are undertaken in MATLAB/Simulink implementation is conducted.

INTRODUCTION
The maritime and shipping industries have made significant efforts around the world to reduce atmospheric emissions and energy consumption. Certain rules framed by the International Convention for the Prevention of Pollution from Ships organization (MARPOL) [1], [2] are strictly followed in the prevention of pollution in the marine environment and accidental causes. Shipping contributes approximately 3% of global CO2 emissions from diesel engines used in marine sectors due to climate change and global greenhouse gas emissions [3].The marine shipping diesel engines emit 2.8% carbon dioxide (CO2), 15% nitrogen oxides (NOX), and 13% sulphur oxides (SOx), which are the most significant pollutants in the atmosphere. The United Nations Framework Convention on Climate Change (UNFCCC) and the International Union for the Conservation of Nature (IUCN). Aside from the growing global energy crisis caused by the depletion of conventional energy sources, it also plays a significant role in the emission of harmful pollutants into the air and water. The use of diesel engines in ships emits greenhouse gases, and CO2 emissions are gradually increasing, reaching 8% by 2020 [3], [4]. To address the problems caused by environmental pollution in the ship industry, a revolution began with the implementation of solar power to provide clean power from green energy sources. Despite an ever-increasing global demand for electrical power due to an increasing global population, the overall desire for solar energy, as well as improved power quality of an inverter, is critical. The depletion of conventional energy sources is causing the global energy crisis to worsen. However, it also causes the greenhouse effect, which contributes to global warming. The temperature of the Earth's surface is expected to rise by 3 to 6 degrees Celsius by the end of the century [4], [5]. Solar power is typically the best choice for most suburban and marine applications because it requires less maintenance, produces less noise due to the lack of moving parts, and takes up less space on ship rooftops. The solar photovoltaic energy system is implemented in a ship to deliver the required power while incorporating a novel technique to reduce emissions, boost renewable energy efficiency, and improve power stability.
To interface various high power loads, the solar energy source is integrated with a power electronic converter and an inverter [6]. Recently, a broad range of exploration in modern ships has been involved

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with the association of renewable energy integrated power converters. Voltage digression and frequency deviations, which cause harmonic distortions, are two critical issues that occur in power converters [7, 8]. The ship's pumping systems consume approximately 70% of total electrical energy [9], [10]. In ship power electronics, the converter is a critical component used for the propulsion of motor drives systems, but it suffers greatly from harmonics. The proposed research looks into recent advances in modular inverters, which are used to improve power quality in ships by reducing harmonics with the help of an intelligent controller. The paper describes a novel symmetric multilevel module based on the cascade category that does not require any additional circuit to generate negative voltage levels. Figure 1 depicts a solar-fed eleven-level inverter with intelligent control techniques aimed at improving performance parameters for marine applications.

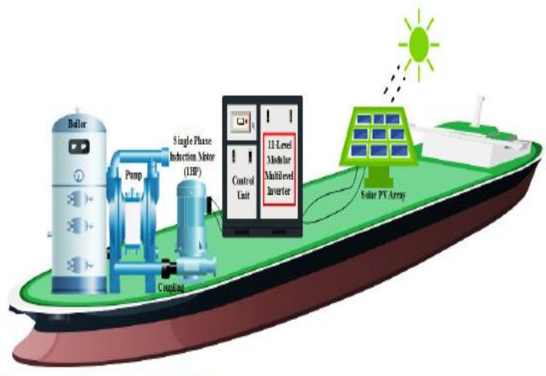

FIGURE 1. Schematic diagram of the proposed 11-level inverter.

The inverter is used to power the variable frequency drive of the ship's seawater cooling pump. With PI and FLC-based controllers, the performance of the multilevel inverter-fed IM drive is investigated. Because of its superior maximum peak overshoot and stability, the proportional - integral (PI) controller is used in the majority of speed control applications. The FLC is the most basic intelligent controller for controlling the speed of induction motors. The ship's water is continuously pumped from morning to evening. As a result, the starting current and fixed voltage of an induction motor must be appropriately maintained by controlling the inverter. Commutation issues plague conventional direct current motors. In order to overcome the disadvantages of DC motors, induction motors are highly preferred in ships. The seawater pumps adequately and meets the requirements for proper fresh water cooling. The proposed research work is concerned with a single phase IM drive for marine water pumping, which is implemented in sustained control methods using MMI topology [11].

LITERATURE SURVEY

1. Design and evaluation of a photovoltaic/thermal-assisted heat pump water heating system,'' Energies, vol. 7, no. 5, pp. 3319–3338, May 2014,

The design, modeling, and performance evaluation of a photovoltaic/thermal-assisted heat pump water heating (PVTA-HPWH) system are presented in this paper. The cooling effect of a refrigerant improves both the PVT efficiency and the coefficient of performance (COP) of the HPWH system. In the MATLAB/Simulink environment, the proposed model was created by considering the reciprocal energy exchange between a PVT evaporator and an HPWH system. Furthermore, the PV electricity meets the HPWH's power consumption needs through a model-based control methodology. A real-world field test is used to assess system performance. The results demonstrated the proposed PVTA-HPWH system's power autonomy with higher PVT efficiency and COP.

2.A systematic power-quality assessment and harmonic filter design methodology for variable-frequency drive application in marine vessels(2015)

High fuel costs in the maritime industry encourage the use of variable-frequency drives (VFDs) for energy-saving applications. However, the introduction of such nonlinear loads into the vessel's power distribution network causes harmonics, which can be dangerous if not predicted and controlled. A systematic power-quality assessment and monitoring methodology is proposed in this paper to calculate VFD contribution to voltage distortion at the point of common coupling (PCC), taking into account the source short-circuit capacity and the existing vessel's power system harmonics. The design and sizing of appropriate harmonic attenuation filters, including ac and dc chokes and frequency-tuned passive filter options, is done in accordance with voltage harmonic distortion limits set by marine classification societies. The effectiveness of the proposed power-quality analyzing procedure is evaluated through a real practical example, which includes harmonic filter design for VFD retrofit application to fan and pump motors that operate constantly during sea-going operation in a typical tanker vessel. Power-quality field measurements obtained via an on-board harmonic monitoring platform confirm that total voltage harmonic distortion and individual voltage harmonics at PCC are kept below 5% and 3%, respectively, demonstrating that the design complies with relevant marine harmonic standards even in the worst operating conditions.

3.“Experimental validation of an eleven level symmetrical inverter using genetic algorithm and queen bee assisted genetic algorithm for solar photovoltaic applications,’’ 2018,

This paper describes an 11-level symmetrical inverter with fewer semiconductor switches designed for solar photovoltaic (PV) applications. The proposed Multilevel Inverter (MLI) relies heavily on the genetic algorithm (GA) and queen bee assisted genetic algorithm (QBAGA). When compared to conventional MLI, the proposed symmetrical MLI topology uses fewer semiconductor devices. The modulation index threshold related to the decrease in the number of inverter output voltage levels, on the other hand, is greater than the MLI. The goal of this paper is to use optimization algorithms to find the optimal modulation index (ma) value in order to achieve the maximum power point (MPP) from a solar PV array.

In order to eliminate harmonics, an 11-level symmetrical inverter is considered, and its optimal modulation index (ma) is calculated. Total harmonic distortion (THD) is used to estimate the quality of an inverter's output voltage, implying an improvement in power quality. The simulations are performed in MATLAB/Simulink, and the experimental prototype is built with a processor based on a field programmable gate array (FPGA). The simulation and experimental results show that the absence of filter components results in lower THD, demonstrating the effectiveness of the proposed system.

4.‘‘A Metaheuristic optimization approach for tuning of fractional-order PID controller for speed control of sensor less BLDC motor,’’

This paper describes a novel Bat Algorithm (BA) method for governing the rotor speed of a sensor less Brushless Direct Current (BLDC) motor that is based on optimal tuning of a Fractional-Order Proportional Integral Derivative (FOPID) controller. The BA is used to create a novel optimization algorithm that can generate five degrees of freedom parameters for the FOPID controller, namely (Formula presented.), (Formula presented.), (Formula presented.), and (Formula presented.). The desired speed control and robust performance are obtained by using the FOPID closed loop speed controller in conjunction with BA for optimal tuning. The time domain specifications of a dynamic system for unit step input to a FOPID controller for speed response, such as peak time ((Formula presented.)), percentage of overshoot (PO), settling time ((Formula presented.)), and rise time ((Formula presented.)). The simulation results are compared with Artificial Bee Colony (ABC) optimization method and Modified Genetic Algorithm (MGA) for evaluation of transient and steady state time domain characteristics. The proposed BA-based FOPID controller optimization technique is more efficient in improving the transient characteristic performance and reducing steady state error.

5.‘Assorted carrier-variable frequency-random PWM scheme for voltage source inverter,(2017)

This study presents an assorted carrier-variable frequency random pulse width modulation (AC-VF-RPWM) method in which a new type of mixed carrier wave is proposed for a three-phase voltage source inverter-fed induction motor drive. This study has focused on the reduction of acoustic noise where a deterministic PWM strategy is replaced with a proposed RPWM. Inverted sine carrier, sine carrier and triangle carrier are used to compare with the reference sinusoidal wave to generate the pulse

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(lead and lag) positions. The two groups (lead and lag) each with three pulse positions are randomly selected and it aims at dispersing the harmonic voltage over a wide band area. The linear feedback shift register-based random bit generation algorithms are used to select the three pulse positions from the lead and lag groups. In addition, a frequency modulator converts the carriers into a randomized frequency, which will give more potency to the randomization process. The results of co-simulation and experimental evaluation that the proposed method could provide harmonic power spectra of the voltage and current spreading over a much broader band area, as compared with the conventional schemes. In addition, Xilinx XC3S500E FPGA device synthesis results are presented.

PROPOSED SYSTEM

The proposed inverter has eleven levels and can control the speed of an IM drive powered by solar photovoltaic. Pumping schemes in an onboard ship are estimated to consume nearly half of the total energy. Taking this into consideration, this paper investigates and validates a proposed control design with reduced complexity for a marine water pumping system using an induction motor (IM) drive and MMI. Inverter performance is improved through the use of Proportional-Integral (PI) and Fuzzy Logic (FL) based controllers. A comparative analysis was performed in order to improve robustness in terms of peak overshoot and settling time of the inverter controller. Simulations are carried out using MATLAB/Simulink.

The schematic circuit diagram of proposed 11 level MMI inverter circuit is configured in figure 2.

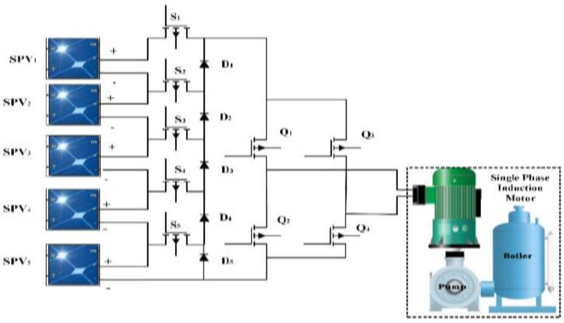

Fig.2. Proposed 11 level MMI circuit.

CONTROL TOPOLOGY FOR MMI

Figure 3 depicts the structure of a solar PV-fed IM drive for a marine water pumping system using an MMI. The proposed topology uses PI and FL-based controllers to control the MMI. PWM governs an inverter's switching schemes, which are used in conjunction with intelligent control techniques to operate a multilevel inverter and control the speed of an induction motor. The v/f control scheme is used in Alternate Phase Opposition Disposition (APOD) under the category of multicarrier PWM methods by varying the voltage, frequency, and reference. Both controllers use logic control and rule-based techniques to generate the modulating signal, which is then compared to the carrier to generate the dynamic pulses required by the inverter switches [16], [17]. The performance of IM with PI and Fuzzy controllers in open loop and closed loop operation at constant and variable loads is investigated. The sections that follow describe the design and implementation of PI and FL-based controllers for improving the performance of an IM drive in conjunction with MMI.

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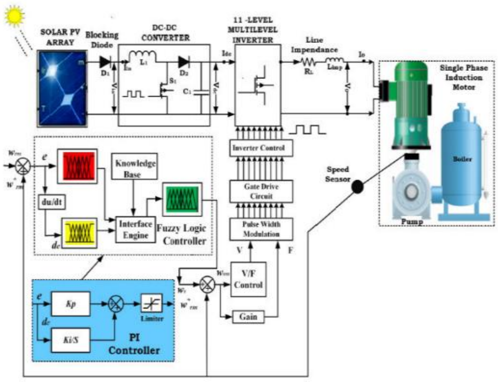

FIGURE 3. Control approach of the proposed inverter.

A.PI CONTROLLER BASED SPEED CONTROL

The PI-based controller is typically implemented using one of three methods: trial and error, evolutionary techniques-based searching, Cohen Coon, Lambda tuning, or Ziegler Nichols. When comparing various methods for PI controller tuning, the trial and error method is chosen due to its numerous advantages in detecting gain parameters and improved performance in motor drive applications.

The open and closed control operation with the PI controller has some limitations, such as the rotor speed being slightly modified, which is less than the synchronous speed, the stator current exceeding the rated current, and slip speed being insufficient. These PI controller drawbacks are most noticeable when operating conditions change. FLC overcomes the PI controller's limitation.

B. FUZZY LOGIC CONTROLLER

The fuzzy logic controller is a highly efficient tool that is used to improve the electrical apparatus by evaluating the speed controller while incorporating human thinking and rule-based protocols. In general, there are three methods for controlling induction motors: (1) voltage/frequency method, (2) flux control method, and (3) vector control method. In comparison to other speed control methods, the closed loop v/f control method is the best because of its simplicity and accuracy. The proposed FL controller is intended to solve two major tasks: (1) estimating induction motor speed and (2) reducing speed error using a rules-based system while also degrading harmonics. The FL controller features two inputs and one output. The error and change in error speed are considered as input and the modulating signal is taken as the output. FL controller mainly follows the four necessary steps, such as: (1) Analog fuzzifier converts input into fuzzy variables (2) Stores fuzzy rules (3) Inference and associated rules (4) Defuzzifier converts the fuzzy variables into actual target.

SIMULATION RESULTS

A. SPEED TRACKING PERFORMANCE AND HARMONICS ANALYSIS OF INVERTER The IM drive connected to the pump should have a speed range of 0 to 1000 rpm. When comparing PI to FLC, the parameters such as overshoot, undershoot, and steady-state error are higher in PI. Both controllers are tested at 1000 rpm, which is the reference speed. It should be noted that the FLC-based IM drive system achieves the desired speed in the shortest amount of time.

Using pi controller:

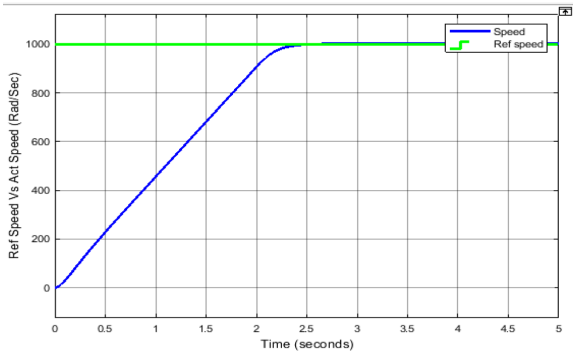

Figure 4. TI Controller

Using fuzzy logic controller:

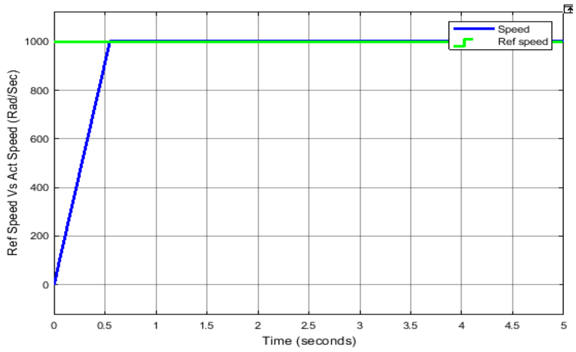

Figure 5. Fuzzy logic controller

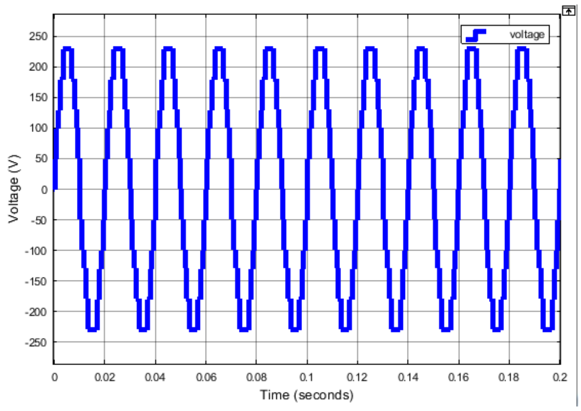

Figure 6. 11 Level voltage

CONCLUSION

The proposed work is important because it will provide high-quality input power to inverter drives used in marine water pumping applications. To investigate its suitability for water pumping systems intended for marine applications, a solar PV fed MMI for speed control of induction motor drive was examined at steady state and dynamic behaviours. The proposed inverter connects the solar PV array, which is then fed to an induction motor. The controller receives feedback from the motor speed sensor in order to generate optimal PWM pulses for the inverter switches. With the help of PI and FL-based controllers, the motor is started gradually and the speed is increased to achieve the reference speed. The performance of the PI and FL controllers for a feasible operation is validated and compared in simulation and experiment. When compared to the PI controller, the results show that the FL-based controller has a faster settling time and lower harmonics. The proposed control scheme has the primary effect of reducing the steady-state error of induction motor speed control and deteriorating harmonics at the output voltage of a modular multilevel inverter. Table 3 illustrates a comparative analysis on the number of semiconductor switches required for the design of MMI along with those inverters available in the literature when considering the number of components required for the proposed MMI. The major components of a power supply are the source, converter, load, controller, and grid.

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