Comparison of PI and Fuzzy Logic Control for Speed Control of Induction Motor for Marine Application

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Abstract

This work describes the design and development of a Modular Multilevel Inverter (MMI) that uses intelligent ways to manage the Induction Motor (IM) drive in maritime water pumping applications. The suggested inverter has eleven stages and can adjust the speed of an IM drive that is powered by solar photovoltaic panels. Pumping techniques require roughly half of the total energy consumed onboard a ship, according to estimates. In view of this, this study explores and verifies suggested control architecture for a maritime water pumping system with an induction motor (IM) drive and MMI. For better performance, Proportional-Integral (PI) and Fuzzy Logic (FL) based controllers are used to analyze the inverter. A comparison was done in terms of greater robustness in terms of peak overshoot, controller settling time, and inverter Total Harmonic Distortion (THD). The simulations are carried out in MATLAB/Simulink. The results are used to examine controller performance, better inverter output voltage, dependable induction motor speed control, and enhanced power quality through harmonic reduction.

Key words - Total harmonic distortion, field programmable gate array, fuzzy logic controller, induction motor drive, modular multilevel inverter, and proportional-integral.

Introduction

The maritime and shipping industries have made significant efforts around the world to reduce atmospheric emissions and energy usage. Certain guidelines created by the International Convention for the Prevention of Pollution from Ships organization are rigorously observed in the prevention of pollution in the marine environment and unintentional causes [1][2]. Shipping contributes roughly 3% of worldwide CO2 emissions from diesel engines used in marine industries, due to climate change and global greenhouse gas emissions[3].

The use of diesel engines in ships produces greenhouse gases, and CO2 emissions have progressively grown, reaching 8% in 2020[3][4].To address the challenges caused by environmental pollution in the shipbuilding sector, a revolution has proceeded toward the use of solar power to supply clean energy from renewable sources. Despite an ever-increasing global demand for electrical power due to the growing global population, the general desire for solar energy, as well as enhanced inverter power quality, is the need of the hour.[3][4].

Solar power is typically the best option for most suburban and maritime applications since it requires less maintenance, produces less noise owing to the lack of moving components, and takes up less space on ship rooftops. The ship has a solar photovoltaic-based energy system that provides the needed electricity while also implementing an innovative technology to reduce emissions, increase renewable energy efficiency, and improve power stability.

To connect a variety of high-power loads, the solar energy source is combined with a power electronic converter and inverter [5]. A wide spectrum of investigation in contemporary ships has recently been engaged with the use of renewable energy integrated power converters. Voltage digression and frequency variations, which contribute to harmonic distortions, are two major difficulties that arise in power converters [6][7]. An output waveform that looks like a sinusoidal wave may be produced by increasing the number of dc voltage sources on the input side. The outcome is a reduction in total harmonic distortion (THD) and an improvement in output waveform quality, which are the two major benefits of multilevel inverters. Other significant benefits of multilayer inverters are decreased switching losses, less voltage stress on switches, excellent efficiency, and less electromagnetic interference [8-12].

The ship's pumping systems require around 70% of the ship's total electrical energy.[13][14] The proposed research looks at current advances in modular inverters, which are utilized to improve power quality in ships by minimizing harmonics with the help of an intelligent controller.

The variable frequency drive of the ship's seawater cooling pump is powered by the inverter. With proportional integral and fuzzy logic based controllers, the multilevel inverter fed IM drive's performance is evaluated. Due to its improved maximum peak overshoot and stability, the proportional integral controller is employed in the majority of speed control applications. The Fuzzy Logic Controller is the simplest intelligent controller for applications involving induction motor speed control. From daylight to night, the ship's water is continually pumped. Therefore, it is necessary to carefully operate the inverter in order to maintain the beginning current and fixed voltage of an induction motor. The DC motor has been used to originally achieve solar PV water pumping. However, the induction motor has superseded DC motors due to its mechanical simplicity, robustness, dependability, low cost, better efficiency, and reduced maintenance requirements than otherwise[15][16]. There are commutations issues with traditional DC motors. Induction motors are greatly recommended in ships to overcome the limitations of DC motors. The fresh water is properly cooled by the ocean, which pumps sufficiently and meets the requirements. The single phase IM drive used in sustained control systems with MMI topology is the subject of the research project that is being suggested [17]. The induction motor, coupled with the pump, is used for marine seawater pumping applications to ship usage, and the water is used for various purposes every day. The main function of the pump is to suck the water from the sea. This process can be done by both open and closed loop systems. [18-26].

In the simulation research, a solar PV fed MMI powered by an induction motor drive with proportional integral and fuzzy logic based controllers is designed in order to improve the system's overall performance.

The paper is structured as follows: The suggested multilevel inverter is presented in Section II, the proposed topology's control strategy is described in Section III, and the simulation results are reviewed in Section IV.

II. Multilevel Inverter

The architectures of multilayer inverters, which are often employed to create high voltage ac with low voltage rating switches, are developed in [27]. Different modulation strategies, as shown in [28], are used to regulate the multilevel inverter's output voltage. These control methods significantly lower the amount of THD in the inverter output voltage. An enormous number of switching devices are used by a multilayer inverter to provide high staircase output voltage. More dc sources are necessary for the high voltage waveform to be generated. The efficiency of the inverter is decreased because a large number of switching devices results in higher switching losses. In order to increase efficiency, it is therefore required to decrease the switching components. When compared to traditional multilevel inverters, the topologies shown in [29] [30] greatly minimize the number of switching devices. Cascaded H Bridge, flying capacitor, and neutral point clamped multilevel inverters are the three fundamental types of conventional multilevel inverters shown in figure 1. Multilevel inverters have a variety of benefits, which are described in [31].

An H-bridge is a pair of capacitors and switches that provides a distinct input DC voltage for each H-bridge. It is made up of H-bridge cells, each of which may supply one of three distinct voltages (zero, positive DC, and negative DC). When compared to diode clamped and flying capacitor inverters, this form of multi-level inverter has the benefit of requiring fewer components. The inverter is less expensive and heavier than the other two inverters.

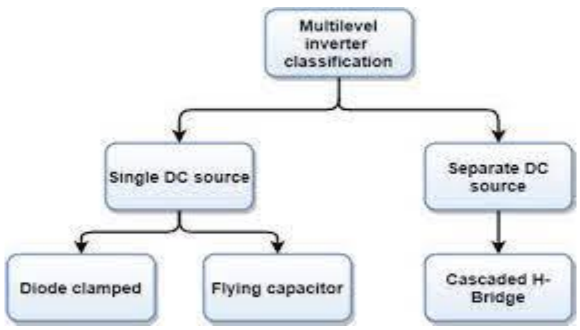

Fig.1. Multilevel inverter topology

As illustrated in Figure 2, the voltage separator at the input end is made up of five numbers of series-connected solar PV modules designated by the letters SPV1, SPV2, SPV3, SPV4, and SPV5.The path of semiconductor devices (both controlled and uncontrolled in nature) marked as S1, S2, S3, S4, S5, D1, D2, D3, D4, and D5 leads to an H-bridge once the input voltage has been separated in this manner (Q1, Q2, Q3, and Q4) Equations (1) and (2) highlight the fact that the symmetrical modular multilevel architecture substantially increases the number of output voltage levels [32].

$$Nlevel = 2S + 1 \qquad (1)$$

$$NIGBT = S + 4 \qquad (2)$$

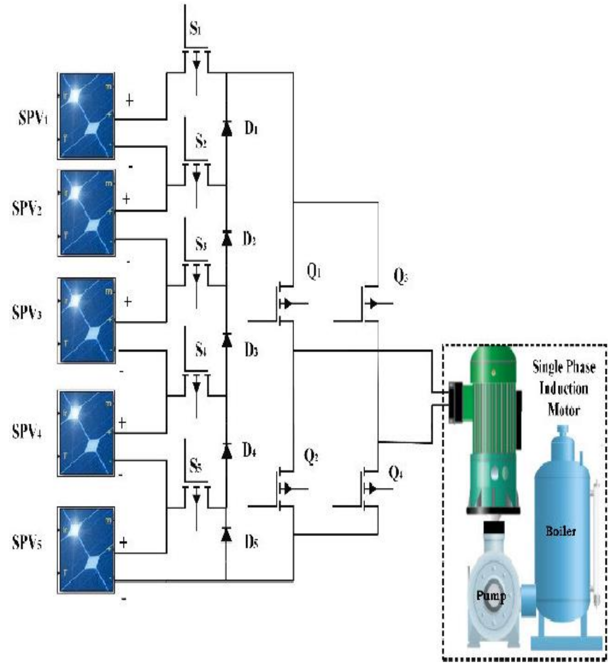

Fig. 3. Control approach of the proposed inverter.

III. CONTROL TOPOLOGY FOR MMI

Figure 3 shows the design of the marine water pumping system's IM drive that is powered by solar PV and uses an MMI. Proportional integral and fuzzy Logic controllers will be used in the suggested architecture to control the MMI. Pulse width modulation is used to operate multilayer inverters and regulate the speed of induction motors, and it controls switching schemes of inverters.

Both controllers use logic control and rule-based approaches to create the modulating signal, which is then compared with the carrier to provide the dynamic pulses necessary for the inverter switches [33],[34]. In the next section results are compared with [35].

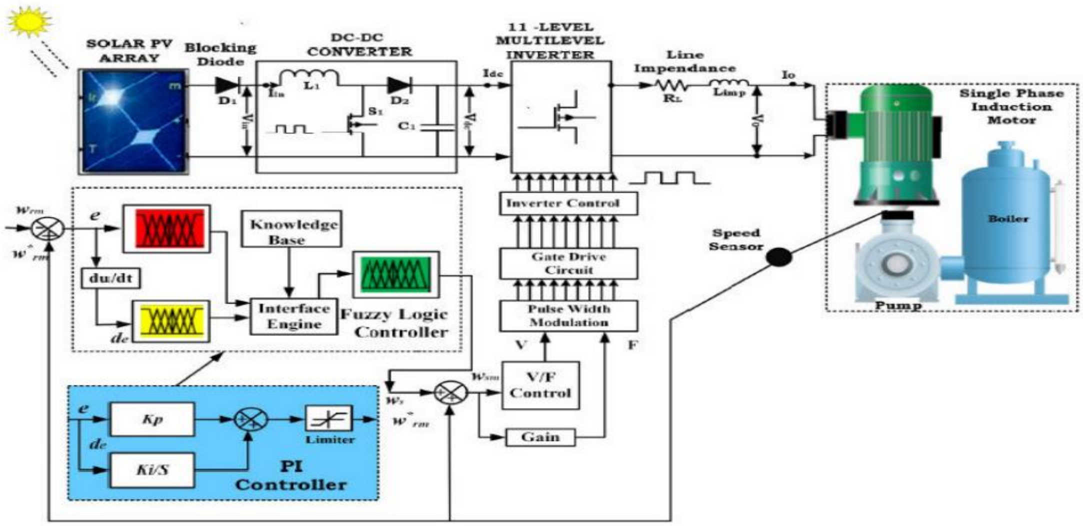

Fig.4.Control approach of proposed multilevel inverter

A. Proportional integral CONTROLLER BASED SPEED CONTROL

The three main methods—trial and error, evolutionary techniques-based searching, Cohen Coon, Lambda tuning, and Ziegler Nichols—are often used to create the PI-based controller. Trial and error is the best choice when comparing different PI controller tuning techniques since it offers a number of advantages for identifying the gain settings and performs better in motor drive applications.

The open and closed control operation with PI controller has several restrictions, such as the stator current exceeds the rated current, slip speed cannot be maintained, and the rotor speed is somewhat modified and less than synchronous speed. These PI controller limitations are mostly brought on by changing operational conditions. FLC circumvents this PI controller constraint.

B. FUZZY LOGIC CONTROLLER

By quickly evaluating the speed controller while combining human thought and rule-based procedures, fuzzy logic controllers are a very effective tool for improving electrical equipment. There are typically three ways to regulate induction motors: (1) the voltage/frequency approach, (2) the flux control method, and (3) the vector control method. Due to its simplicity and high precision, closed loop v/f control is considered to be the best speed control system.

The four essential steps, such as:

(1) Analog fuzzifier produces fuzzy variables from input.

(2) Keeps fuzzy rules

(3) Inference and related rules

(4) Defuzzifier turns actual target into fuzzy variables

Two or more relationship values from the fuzzifier's input variables are included in the fuzzy operator's input. The result is a single truth value. If input 1 is said to show an error, it does so while input 2 represents a changing error. Eight fuzzy subsets of the linguistic variables—of which five are used—are explained as follows:

(1) Negative error speed Big (NB),

(2) Negative error speed Small (NS),

(3) Positive error speed Small (PS),

(4) Positive error speed Big (PB), and

(5) Zero error speed (ZE)

IV. Simulation And Analysis

The simulation model is developed in MATLAB/Simulink 2017 to perform the performance comparison between PI and FL based controllers. The analysis for harmonics reduction under open and closed loop operation is also undertaken.

Simulation

The pump and IM drive are linked, and the intended speed range for the IM drive is 0 to 1000 rpm. In order to achieve the necessary speed, PI has higher overshoot, undershoot, and steady-state error parameters than FLC does. At a reference speed of 1000 rpm, both controllers are tested. It is observed that FLC-based IM drive systems achieve the necessary speed in the shortest amount of time.

The motor starts at 0 seconds and settles at almost 2.3 seconds with the specified speed of 1000 rpm, according to the simulation result using PI controller shown in Figure 4.

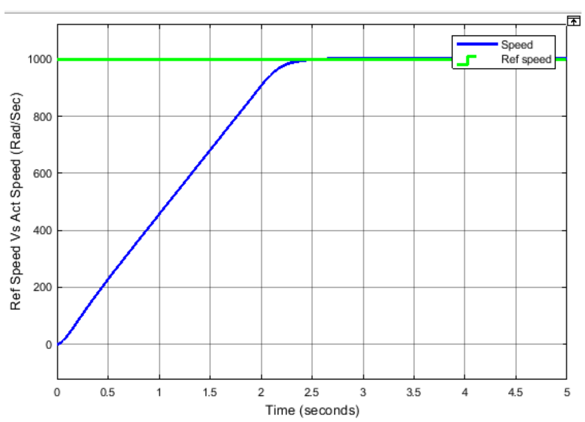

Fig. 4. Speed response of PI controller at 1000 rpm.

As seen in Figure 5, the motor begins at 0 seconds and settles at 0.6 seconds when using the FL controller. The results are compared with respect to optimal gains, and faster setting time. By analyzing the power quality, the Total Harmonic Distortion (THD) with PI controller is 9.60% and with FL controller is 8.67% as shown in Figures 6 and 7 respectively. When monitoring a speed reference, the FLC for motor-fed MMI has a good performance and also has a decreased THD. Figure 9 displays the output voltage of an 11 level inverter. For the maritime application, the suggested IM drive is combined with the water pump system.

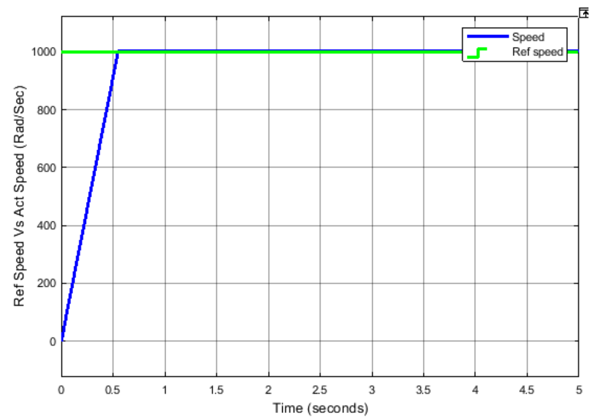

Fig. 5. Speed response of FLC at 1000 rpm.

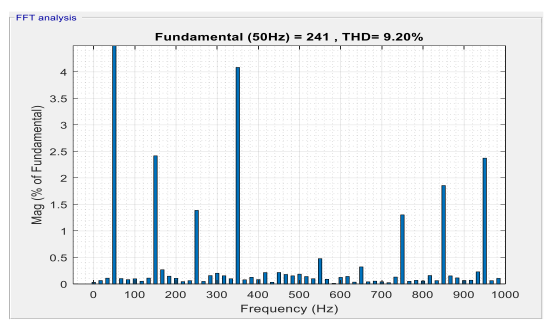

Fig.6. Harmonic analysis with PI controller.

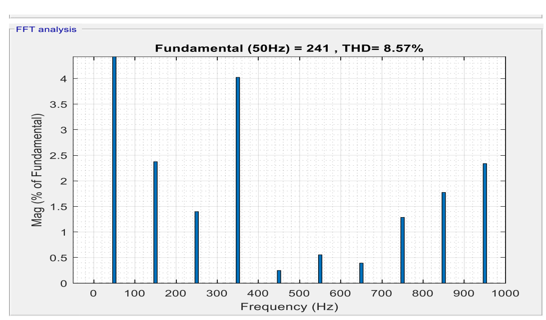

Fig.7. Harmonic analysis with FL controller

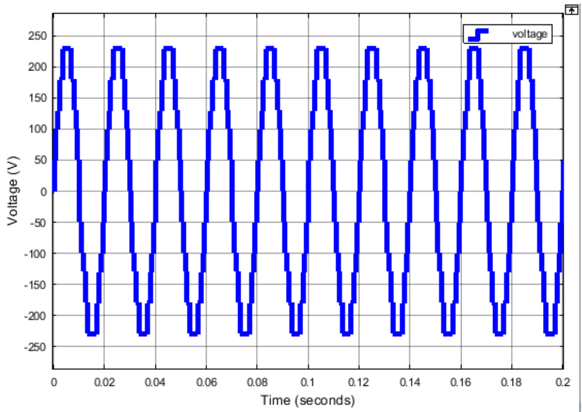

Fig.8. Output voltage waveform of an 11 level inverter

Discussion

In Proportional integral Controller the setting time is 2.3 seconds while in fuzzy logic controller it is 0.6 seconds, so fuzzy logic controller is having faster setting time compared to proportional integral controller. The THD value with Proportional integral is 9.60% and with Fuzzy logic it is 8.67%, so THD is also improved in Fuzzy logic compared to Proportional integral.

Conclusion

Thus by comparing the results , it is concluded that the FLC is significant in decreasing the settling time and improving THD because it would supply high-quality input power to the inverter drive for applications involving marine water pumping. A solar PV fed MMI for speed control of induction motor drive has been examined to investigate its suitability for water pumping system intended for the marine applications. The designed inverter is linked to the solar PV array, which is then supplied to an induction motor. For the controller to produce the best PWM pulses for the inverter switches the motor speed is monitored and feedback is provided. With the help of PI and FL-based controllers, the motor is started gradually and its speed increases to reach the reference speed. The performance of PI and FL controllers for a feasible operation is verified, and results are compared with result obtained in [35].

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