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Fuzzy Logic Control for Solar PV fed Modular Multilevel Inverter towards Marine Water Pumping Applications

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ABSTRACT The paper presents the design of Modular Multilevel Inverter (MMI) to control the Induction Motor (IM) drive using intelligent techniques for marine water pumping applications. The proposed inverter is of eleven level and has the ability to control the speed of an IM drive which is fed by solar photovoltaic's. It is estimated that the energy consumed by pumping schemes onboard ship is nearly 50% of the total energy. Considering this fact, the paper investigate and validates the proposed control design with reduced complexity intended for marine water pumping system employing an induction motor (IM) drive and MMI. The analysis of inverter is carried out with Proportional-Integral (PI) and Fuzzy Logic (FL) based controllers for improving the performance. A comparative analysis 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 to show the effectiveness of the proposed scheme. Simulations are undertaken in MATLAB/Simulink and the detailed experimental implementation in real time with Field Programmable Gate Array (FPGA). The results thus obtained are utilized to analyze the controller performance, improved inverter output voltage, reliable induction motor speed control and power quality improvement by reduction of harmonics. The novelty of the proposed control scheme is the design and integration of MMI, IM drive and intelligent controller exclusively for marine water pumping applications.

INDEX TERMS Field Programmable Gate Array, Fuzzy Logic Controller, Induction motor drive, Modular Multilevel Inverter, Proportional-Integral, Total Harmonic Distortion.

I. INTRODUCTION

In worldwide, considerable efforts been taken by the maritime and shipping industries to deteriorate the level of atmospheric emissions and consumption of energy. The deterrence of pollution in the marine environment and accidental causes are strictly followed by certain rules which are framed by International Convention for the Prevention of Pollution from Ships organization (MARPOL) [1-2]. The climate change and global greenhouse gas emissions shipping contribute about 3% of global CO_2 emissions from diesel engines involved in marine sectors [3].

The marine shipping diesel engines emits 2.8% of Carbon dioxide (CO_2), 15% of Nitrogen Oxides (NO_X), 13% of Sulphur Oxides (SO_x) which are the most significant gases involved to pollute the atmosphere. The United Nations Framework Convention on Climate Change (UNFCCC) and the International Maritime Organization (IMO) thoroughly investigated and framed the rules and regulations for the reduction of CO_2 emissions by the shipping industry.

In addition to the growing global energy crisis caused by the depletion of conventional energy sources, it also involve to a great extent in the emission of harmful pollutants in air and water. The usage of diesel engines in the ship emits greenhouse gas and CO_2 emissions are gradually increased, and it is strongly expected to reach 8% in the year 2020 [3-4].

To overcome the problems faced due to environmental pollution in the ship industry, a revolution progressed towards the implementation of solar power to provide clean power from green energy sources. Inspite of an ever-increasing global demand for electrical power owing to the increasing worldwide population, the overall desire for solar energy along with improved power quality of an inverter are the need of the hour [3-4].

The depletion of conventional energy sources causes the growing global energy crisis. However, it also results in the greenhouse effect leading to global warming. The temperature of the earth surface is expected to increase by 3ºC to 6ºC within the end of this century [4-5].

Solar power is usually the best choice for most of the suburban and marine applications as it requires lesser amount of maintenance, offer noise free operations due to the absence of moving parts and occupies less space at rooftops in the ship. The solar photovoltaic's based energy system is implemented in ship which delivers power incorporating a novel technique to decrease emissions, to augment the renewable energy efficiency, and also to perk up the stability of power.

The solar energy source is integrated with a power electronic converter and inverter to interface multifarious high power loads [6]. Recently, a wide range of exploration in the modern ship is engaged with association of renewable energy integrated power converters. The two critical issues occurred in power converter are voltage digression and frequency deviations which leads to harmonics distortions [7-8].

The pumping systems in the ship consume approximately 70% of overall electrical energy [9-10]. In ship power electronics, converter is a major block used for the propulsion of motor drives systems but suffers a lot with the setback on harmonics. The proposed work investigates the recent developments in modular inverter, which is used to improve power quality in the ship by reducing harmonics with aid of an intelligent controller.

The paper presents a novel symmetric multilevel module established on cascade category which does not require the necessity of any additional circuit to create negative voltage levels. A solar fed eleven level inverter with intelligent control techniques aimed to attain improved performance parameters for marine applications is shown in Figure 1.

The inverter is used to power the variable frequency drive of the seawater cooling pump mounted on the ship. The performance of the multilevel inverter fed IM drive is examined with PI and FLC based controllers. The proportional - integral (PI) controller is used in the majority of the speed control applications due to its better maximum peak overshoot and stability. The FLC is the simplest of all the intelligent controllers for induction motor speed control applications. The water is continuously pumped from morning to evening in the ship. Hence, the starting current and fixed voltage of an induction motor is to be maintained appropriately by controlling the inverter.

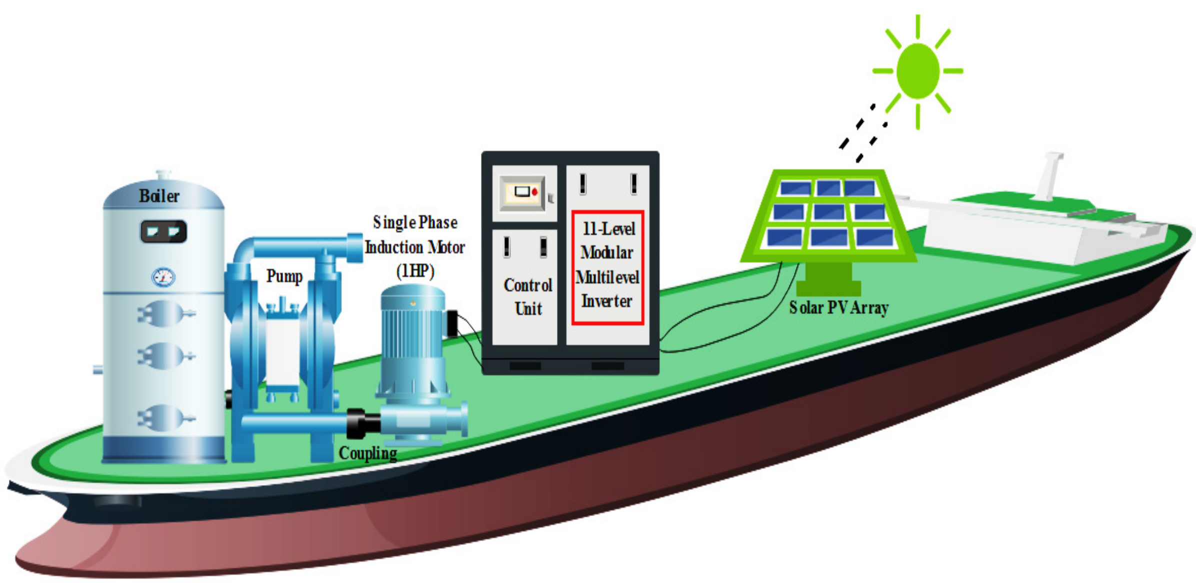

Figure 1. Schematic diagram of the proposed 11-level inverter

Conventional DC motors have commutation problems. To overcome the drawback of DC motor, induction motor is highly preferred in the ship. The seawater pumps adequately and satisfies the needs for the proper cooling of the fresh water. The proposed research work deals with single phase IM drive for marine water pumping, which is implemented with MMI topology in sustained control methods [11].

The real-time implementation of speed control is governed by maximum solar power extraction in the atmospheric conditions. Besides, the switching frequency is gradually varied from the inverter is to control the speed of an induction motor. This is achieved by the optimized Pulse Width Modulation (PWM), which is generated with aid of modulating signal generated for a FL controller in enhancing the power quality.

The simulation study involves the design of solar PV fed MMI powering an IM drive with PI and FL based controllers to enhance the overall performance of the system. The prototype model is developed with SPARTAN3E500 FPGA controller which generates the necessary pulses for both inverter and converter involved in the system.

The contributions made in the paper are illustrated as below:

- Investigating the performance of PI and FL based controllers to IM drive system for marine water pumping
- Implementation of MMI fed IM drive in real time using SPARTAN3E500 FPGA controller
- Comparative analysis of FL and PI based controllers towards the performance improvement in improving power quality

This paper mainly focuses on the performance analysis of MMI. The formulation of the paper is as follows: Section II provides the system configuration and operation strategy, Section III details the control approach for proposed topology, Section IV analyzes the simulation results and Section V mulls over the experimental setup and discussions.

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II. SYSTEM CONFIGURATION AND OPERATION STRATEGY

The PV array with a maximum power capacity of 150W at Standard Test Conditions (STC) (1000W/m^2, 25ºC) is considered in accordance with the rating of IM drive coupled water pump. The operating power capacity of the PV array is selected such that it can run the motor pump system with aid of modular multilevel inverter [11-12].

II.1. PV Array Design

A 10W solar PV module is made up of 36 cells (36 cells x 0.588 V = 21.6 V_{oc}) connected in series. The specifications are: Maximum power (P_{max}) = 10W_p, V_{oc} = 21.6V and I_{sc} = 0.659 A. The maximum voltage and current of a module is V_{mp} = 17V and I_{mp} = 0.588A ($P_{max} = V_{mp}$ x I_{mp}=17 x 0.588= 9.96W).

A 20W solar module with 72 cells associated in series is utilized as an input source. The specifications are: Maximum power (P_{max}) = 20W_p, V_{oc} = 21.5V and I_{sc} = 1.24 A. The maximum voltage and current ratings of a module at V_{mp} = 17.5V and I_{mp}=1.143A ($P_{max} = V_{mp}$ x I_{mp} = 17 x 1.14=19.8W).

The two different ratings of 10W and 20W cited above are connected in series and parallel to achieve the maximum power capacity of 150 W (5 x 10 = 50W, 5 x 20 = 100W) at STC.

The current equation of solar cell given in equation (1) has four indefinite constraints (I_L, I_0, R_s and α) that has to be dogged before attaining the V-I characteristics of the PV cell [13-14].

$$I = I_L - I_D = I_L - I_0 e^{\left(\frac{V+iRs}{\alpha}\right)} - 1 \quad (1)$$

A. Estimation of Light Current (I_L)

A scheme to estimate the light current I_L is expressed as,

$$I_L = \frac{\varphi}{\varphi_{ref}}[I_{L,ref} + \mu_{I,SC}(T_C - T_{C,ref})] \quad (2)$$

B. Estimation of Saturation Current (I_0)

The expression for saturation current is expressed as,

$$I_0 = I_{0,ref}\left(\frac{T_{C,ref}+273}{T_C+273}\right)^3 \exp\left[\frac{e_{gapNs}}{q\alpha_{ref}}\left(1-\frac{T_{C,ref}+273}{T_C+273}\right)\right] \quad (3)$$

During the reference condition the saturation current can be evaluated as,

$$I_{0,ref} = I_{L,ref}\exp\left(-\frac{V_{oc,ref}}{\alpha_{ref}}\right) \quad (4)$$

C. Determination of TVTC Factor

The Thermal Voltage Timing Completion (TVTC) factor (α) is the task of temperature and expressed as,

$$\alpha_{ref} = \frac{2V_{mp,ref} - V_{oc,ref}}{\frac{I_{sc,ref}}{I_{SC,ref} - I_{mp,ref}} + \ln\left(1-\frac{I_{mp,ref}}{I_{SC,ref}}\right)} \quad (5)$$

$$\alpha = \frac{T_C+273}{T_{C,ref}+273}\alpha_{ref} \quad (6)$$

D. Determination of series Resistance (R_s)

The series resistance is determined as,

$$R_s = \frac{\alpha_{ref}\ln\left(1-\frac{I_{mp,ref}}{I_{SC,ref}}\right) + V_{OC,ref} - V_{mp,ref}}{I_{mp,ref}} \quad (7)$$

II.2. DC-DC Converter Design

An intermediate DC-DC converter in the solar photovoltaic conversion system is set to operate at maximum power for providing symmetric input to MMI. Equation (8) shows the relationship between input voltage and output voltage of DC-DC boost up converter with respect to duty cycle.

$$V_{out} = \frac{V_{in}}{1-D} \tag{8}$$

A. Design of an Inductor (L)

The following steps given from Equations (9)-(10) illustrate the design of an Inductor required for the system.

$$L_1 = \frac{V_{in} * (V_{out} - V_{in})}{\Delta I_L * f_s * V_{out}} \tag{9}$$

$$\Delta I_L = (2\% - 4\%) * I_{out(max)} * \frac{V_{out}}{V_{in}} \tag{10}$$

$$\Delta I_L = (0.03) * 5 * \frac{24}{12} = 0.3$$

$$L_{b1} = \frac{12 * (24-12)}{0.3 * 3 \times 10^3 * 24} = 0.65$$

B. Design of a Capacitor

The following steps given from Equations (11)-(12) illustrate the design of a Capacitor required for the system.

$$C_1 = \frac{I_{(out)} * D}{f_s * \Delta V_{out}} \tag{11}$$

$$\Delta V_L = (2\% - 4\%) * V_{out(max)} * \frac{I_{out}}{I_{in}} \tag{12}$$

$$\Delta V_L = (0.03) * 24 * \frac{5}{10} = 0.36$$

$$D = \frac{V_{out}}{V_{in} + V_{out}} = \frac{12}{36} = 0.67$$

$V_{out(max)}$ is the maximum voltage delivered by the PV module under STC.

II.3. MULTILEVEL INVERTER DESIGN

The voltage separator at the input end is composed of five numbers of series connected solar PV modules denoted with SPV_1, SPV_2, SPV_3, SPV_4, and SPV_5 as shown in Figure 2. The input voltage thus separated is then transmitted to the route comprises of semiconductor devices (both controlled and uncontrolled in nature) denoted as S_1, S_2, S_3, S_4, S_5, D_1, D_2, D_3, D_4, and D_5 and finally leads to a H-bridge (Q_1, Q_2, Q_3, and Q_4). Equations (13) and (14) point outs that the symmetrical modular multilevel topology significantly increases the number of output voltage levels [15].

$$N_{level} = 2S+1 \tag{13}$$

$$N_{IGBT} = S+4 \tag{14}$$

2.4 WATER PUMP DESIGN

The water pumping system comprises of IM drive along with centrifugal pump which is used for marine applications. Pump affinity law is considered as a reference for the design of centrifugal pump. In accordance to it, the load torque is directly proportional to the speed square as given in (15).

$$T_L = K_p \times \omega_r^2 \tag{15}$$

$$K_p = \frac{9.94}{(2 \times \pi \times 24)^2} = 0.00043712\ \mathrm{Nm/(rad/sec)^2}$$

III. CONTROL TOPOLOGY FOR MMI

The structure of the solar PV fed IM drive for marine water pumping system employing an MMI is shown in Figure 3. The proposed topology is to control the MMI using the PI and FL based controllers. The switching schemes of an inverter are governed by PWM with aid of intelligent control techniques to operate multilevel inverter and control the speed of an induction motor.

The v/f control scheme is employed by varying the voltage, frequency along with the reference in Alternate Phase Opposition Disposition (APOD) under the category of multicarrier PWM methods. The five different triangular carrier waveforms (each out phase of 180^0) are compared with the one sinusoidal reference waveform to generate the required PWM pulses as shown in Figure 4.

The logic control and rule based techniques for both the controllers intend to generate the modulating signal which is then compared with the carrier to generate the dynamic pulses required for the inverter switches [16-17]. The performance of IM with PI and Fuzzy controllers at constant and variable loads in open loop and closed loop operation are analyzed.

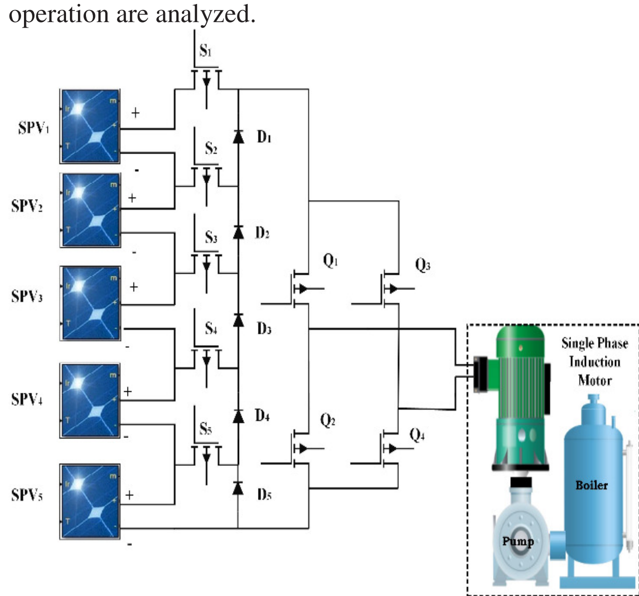

Figure 2. Proposed multilevel inverter

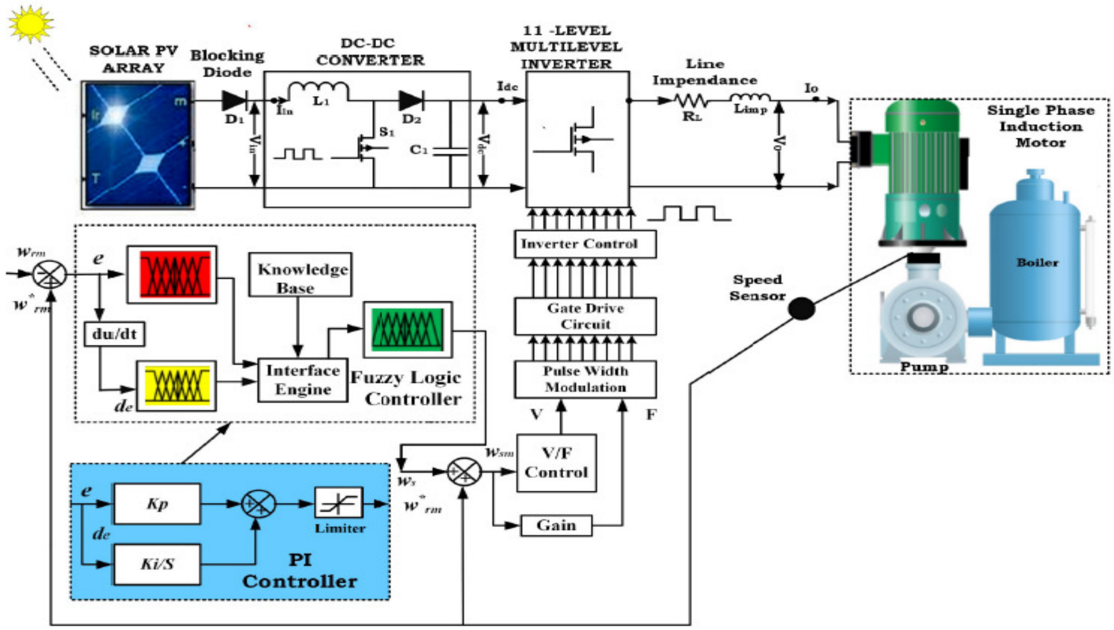

Figure 3. Control approach of the proposed inverter

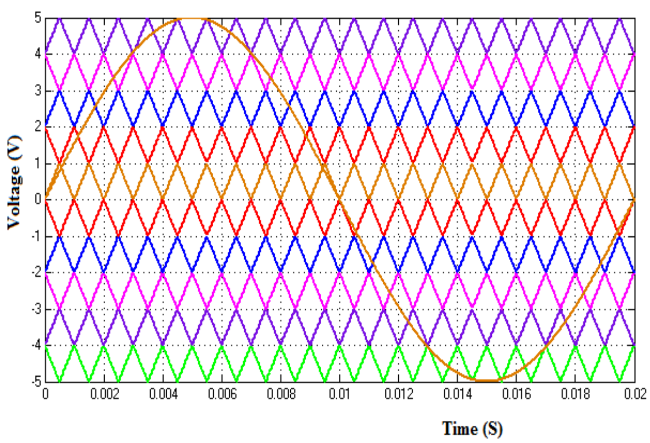

Figure 4. APOD control signal

The following sections describe the design and implementation of PI and FL based controllers in improving the performance of an IM drive operating along with MMI.

A. PI CONTROLLER BASED SPEED CONTROL

The PI based controller is generally implemented with any of the three different methods such as trial and error, evolutionary techniques based searching, Cohen Coon, Lambda tuning and Ziegler Nichols. In comparison of various methods for PI controller tuning, trial and error method is nominated due to its several benefits in detecting the gain parameters and better performance in motor drive applications.

Typically, the comparator compares the actual (ω_{rm}) and reference (ω_{rm}*) speed and the error ($\omega_{e(n)}$) thus obtained is used for tuning the parameters K_p and K_i. The error equation ($\omega_{e(n)}$) is given by,

$$\omega_{e(n)} = \omega_{rm} - \omega_{rm}* \quad (16)$$

$$\Delta\omega_{e(n)} = \omega * e^{-\omega_{re(n-1)}} \quad (17)$$

The trial and error method mainly focused on two essential parameters in calculating the proportional and integral gain for motor drive applications. The numerical value of K_p and K_i attained from trial error method are 50 and 2, respectively. The objective of the PI controller is to minimize the error to enhance the driving performance.

The objective of the closed loop PI controller has the superior performance while controlling the speed of an induction motor at constant torque. The proposed inverter (S_1, S_2, S_3, S_4, and S_5) and (Q_1, Q_2, Q_3, and Q_4) switches are controlled by the v/f method. The switches S_1 to S_5 controls and operates the inverter while the other switches Q_1 to Q_4 convert the polarity changes of the inverter. The output of the inverter with constant v/f is fed into IM drive.

The open and closed control operation with PI controller has some limitations such as the rotor speed is slightly modified which is less than synchronous speed, stator current exceeds the rated current and slip speed cannot be maintained. These drawbacks of a PI controller mainly occur with fluctuating operative conditions. This limitation of the PI controller is overcome by FLC.

B. FUZZY LOGIC CONTROLLER

Fuzzy logic controller is a most efficient tool which is used to enhance the electrical apparatus through its fastness to evaluate the speed controller incorporating human thinking and rule based protocols. Generally, three methods are available for the control of induction motors namely, (1) voltage/frequency method, (2) flux control Method and (3) Vector control method. In comparison with the speed control methods, closed loop v/f control method is characterized as best due to its simplicity and good accuracy.

The proposed FL controller is intended to solve the two important main tasks: (1) estimating induction motor speed and (2) reducing error in speed using the rules based system and also deteriorating the harmonics.

The FL controller is designed with 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

The input to the fuzzy operator has two or more relationship values from fuzzifier input variables. The output is a single truth value. If input 1 is declared to indicate the error means it while the input 2 indicates the changing error. The linguistic variables contain eight fuzzy subsets in which five subsets are used which are described 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)

If suppose the output is NS, it values up to 0.3416 such that the entire rule based membership functions work along with it. The output of the NB is 0.1, PB is 1, PS is 0.66 and ZE is 0.5 as illustrated in Figure 5. The input linguistic values range are NB=-1600,-10,-4, NS=-8.06,-3.96, 0.02646, ZE=-3.2, 0, 3.2, PS=0, 4, 8 and PB=3.52, 9.92,1550. Table 1 shows the rule matrix based the logic to control the speed.

The 11 level MMI has 9 semiconductor switches (S_1-S_5) switches which are connected in parallel to (Q_1-Q_4) H bridge switches. The bipolar triangular and sine wave is compared to generate the PWM based upon the fuzzy rules. The pulses for S_1 –S_5 are inverter control pulses and Q_1 to Q_4 are level control pulses.

FLC structure is fully designed by switching pattern of the inverter using switching pulse generator as shown in Figure 6. The input fuzzification membership is designed (IN_1-IN_6) with switching magnitude range of (-1, 0, 1). Positive range from 0 to 1 represents the first quarter cycle (0º-90º) and second quarter cycle (90º-180º) respectively. Similarly, the negative range from -1 to 0 represents the third quarter cycle (180º-270º) and fourth quarter cycle (270º-360º). Later, in defuzzification, six membership functions are developed based on fuzzy rules to obtain the desired output.

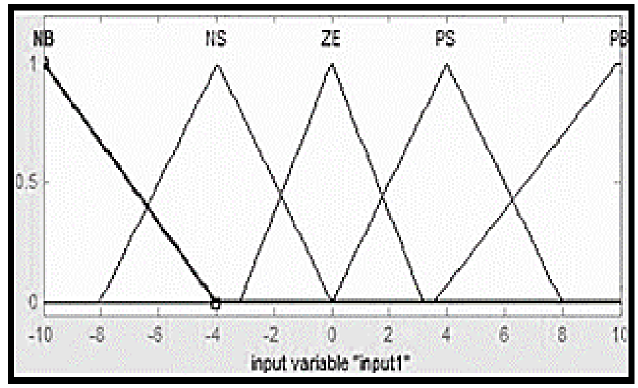

Figure 5. Allocation of range for subsets

TABLE .I 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

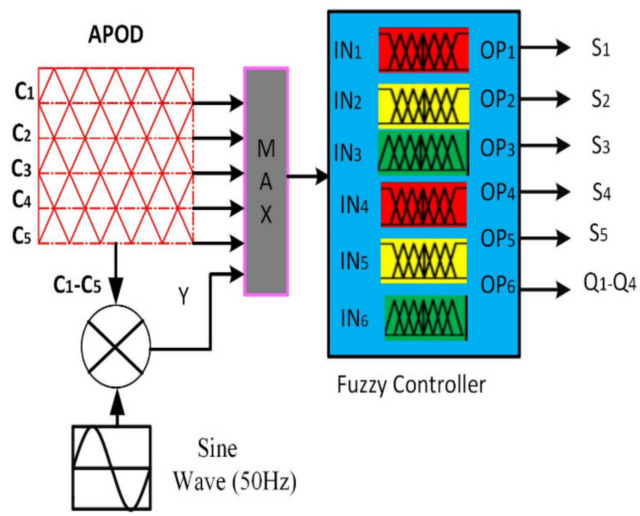

Figure.6 FLC Controller Switching Pulse generation structure

The paper illustrates the design and development of two controllers for water pumping application. The voltage and frequency are used to control the inverter. The speed of induction motor is controlled by v/f method.

IV. SIMULATION AND ITS ANALYSIS

The simulation model is developed in MATLAB/Simulink 2013 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.

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A. Speed tracking performance and harmonics analysis of inverter

The IM drive connected with the pump is desired to reach the speed from 0 to 1000 rpm. To reach the desired speed, the parameters such as overshoot, undershoot and steady-state error are higher in PI when compared to FLC. Both controllers are examined at the reference speed of 1000 rpm. It is noted that FLC based IM drive system reaches the desired speed with the minimum time period.

The simulation result with PI controller is shown in Figure 7 point outs the motor starting at 0s and the motor speed is settled nearly 2 sec with the set speed of 1000 rpm. Using the FL controller, motor starts at 0s and settles at 0.5sec as shown in Figure 8.

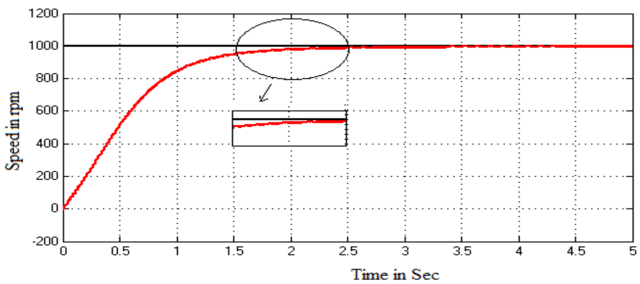

Figure 7. Speed response of PI controller at 1000 rpm

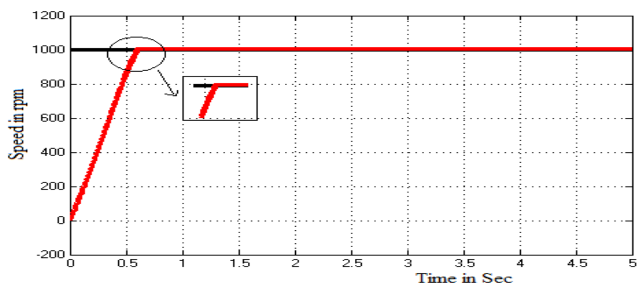

Figure 8. Speed response of FLC at 1000 rpm

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 10.44% and with FL controller is 5.67% as shown in Figures 9 and 10 respectively. The FLC for motor fed MMI provides a good response under the tracking of speed reference and also lower THD. The output voltage of inverter an 11 level inverter is shown in Figure 11. The proposed IM drive is integrated with the water pump system for the marine application.

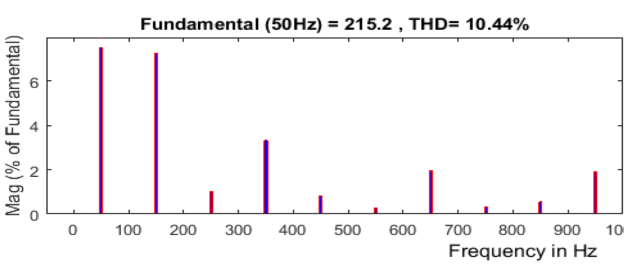

Figure 9. Harmonics analysis of PI Controller

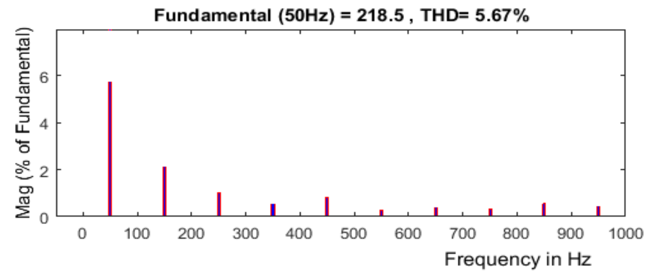

Figure 10. Harmonics analysis of FL Controller

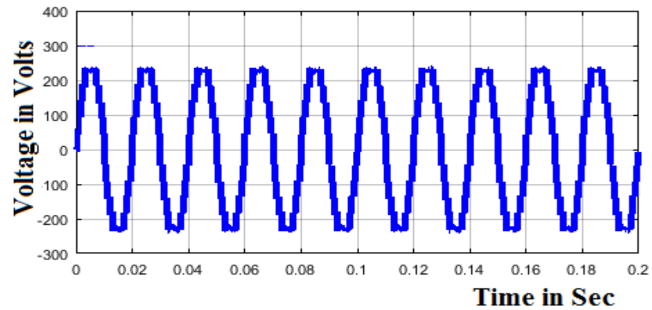

Figure 11. Output voltage waveform of an 11 level inverter

V. EXPERIMENTAL ANALYSIS

The experimental setup consists of the solar PV array connected with the modular multilevel inverter with rated power. The 150W solar PV module specifications are given in Table II. The entire hardware setup is shown in Figure 12 along with the entire components involved and its associated output voltage waveform of improved power quality.

TABLE .II HARDWARE SPECIFICATIONS FOR SOLAR PV

Module specification	$10W_p$	$20W_p$
Maximum Power (P_{max})	10W	20W
Solar PV Open circuit Voltage (V_{oc})	21.6V	21.5A
Solar PV short circuit current (I_{sc})	0.659A	1.24V
Solar PV voltage at MPP (V_{mp})	17V	17.5V
Solar PV current at MPP (I_{mp})	0.588A	1.143A
Maximum reverse current	1A	1A

The proposed inverter has been evaluated by practical implementation in real time control using FPGA Spartan - 6 controllers considering the motor of 1.1 kW rating. The IM is fed by MMI using nine MOSFETs switch with gate drive board as shown in Figure 12.

Figure 12.Experimental setup

The motor currents are measured using the speed sensor and feedback is sent to the controllers which produces the PWM pulse to operate inverter. The performances of PI and FL controllers are tested and the results are compared for both simulation and experimental setup. The results ensured that the FL controller shows the fast settling time compared with PI controller. The two controllers are tested for the speed variations from 0-1000 rpm. The PI controller shows the settling time at 0.2 sec while FL controller settles at 0.09 sec as exposed in Figure 13.

The induction motor coupled with the pump is used for marine application of seawater pumping to ship usage and clean the water every day at an average of around 50 liters used for various purposes. The main work of the pump is to suck the water from the sea. This process can be done by both open and closed loop system [22-30]. The developed system also reduces the THD as illustrated in Figures 14 and 15. The corresponding inverter output voltage is depicted in Figures 16.

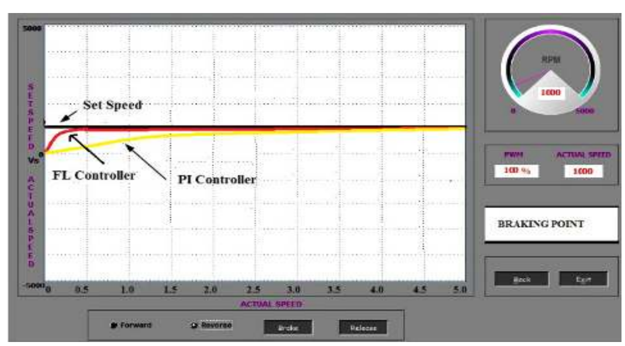

Figure 13.Speed response of PI-FL controller proposed inverter

The VHDL coding for synthesized devices of SPARTAN3E500 FPGA at 50MHz is performing a major role in Xilinx project navigator [23]. The FPGA is mainly focused on three important parameters, such as: (1) to reduce the size of the program area of the controller (2) to increase the speed of the controller and (3) to reduce the power dissipation.

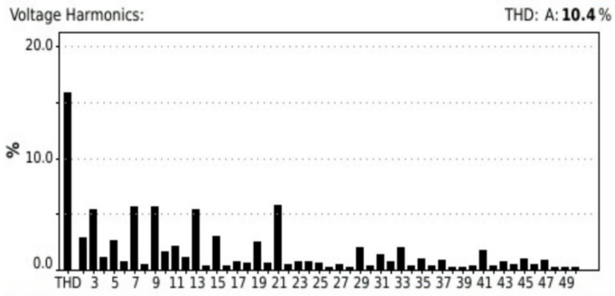

Figure 14.Harmonics analysis with PI Controller

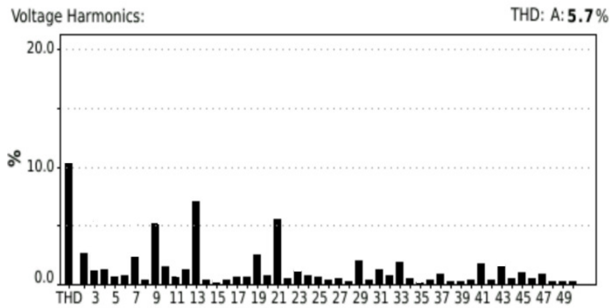

Figure 15.Harmonics analysis with Fuzzy Controller

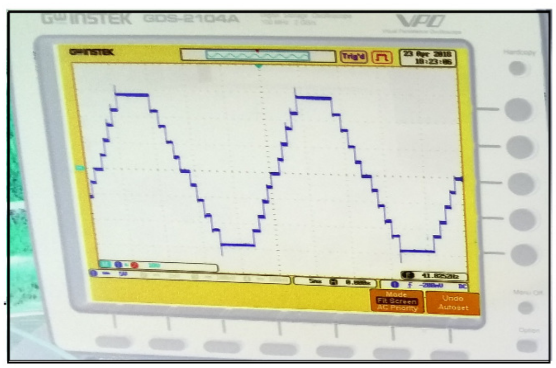

Figure 16.Output voltage waveform of MMI

The hardware description design and functionality tool of Modelsim6.3f is used as shown in Figure 17. A 17.50Hz clock divider, 2.4 kHz frequency is used to generate the PWM pulses for the switches Q_1 - Q_4 and Q_2 - Q_3. The five different triangular carriers (C_1-C_5) are compared with the sinusoidal wave at 50Hz fundamental frequency to generate the PWM pulses for S_1 to S_5 based on the switching pattern.

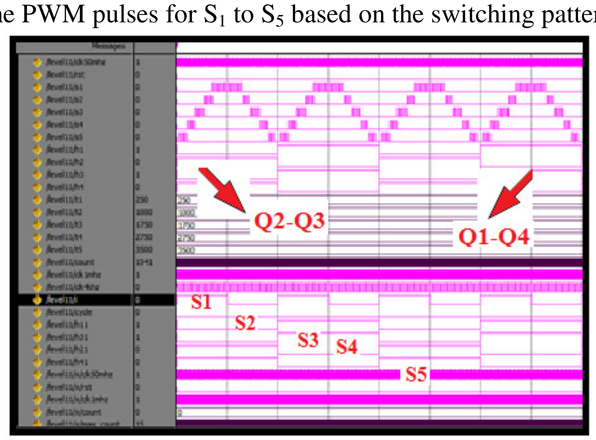

Figure17. Model sim 6.3f based switching pulse for inverter switches

VI. CONCLUSION

The relevance of the proposed work is to provide high quality of input power to the inverter drive pertaining to marine water pumping applications. A solar PV fed MMI for speed control of induction motor drive has been examined at steady state and dynamic behaviors to investigate its suitability for water pumping system intended for the marine applications. The solar PV array is connected with the proposed inverter when is then fed to an induction motor. The motor speed is sensed and feedback is given to the controller for generating optimal PWM pulses for the inverter switches. The motor is started gradually and the speed is increased to achieve reference speed with aid of PI and FL based controllers. The performance of PI and FL controllers for a feasible operation is verified and results are compared in both simulation and experiment. The results ensure that the FL based controller provides fast settling time and reduced harmonics when compared with the PI controller. The main impact of the proposed control scheme is to reduce the steady-state error of the induction motor speed control and deteriorate harmonics at the output voltage of modular multilevel inverter.

On considering the number of components required for the proposed MMI, the Table III illustrates the comparative analysis on the number of semiconductor switches required for the design of MMI along with those inverters available in the literature.

The source, converter, load, controller and grid are the major components of a DC microgrid. A microgrid is normally referred as a standalone autonomous system to generate power by the community and for the community regions. In the proposed system, the entire component cited for DC microgrid is present and performs its function effectively. The appropriate estimation of power generated and power used is the future scope.

TABLE .III COMPARATIVE ANALYSIS

Ref.No	Number of Sources	Number of Switches	Number of Level
18	3n+1	5n+6	6n+3
19	2n+2	4n+6	4n+3
20	4n+2	4n+6	8n+5
21	4n	12n	16n+1
Proposed	**n**	**n+4**	**2n+1**

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