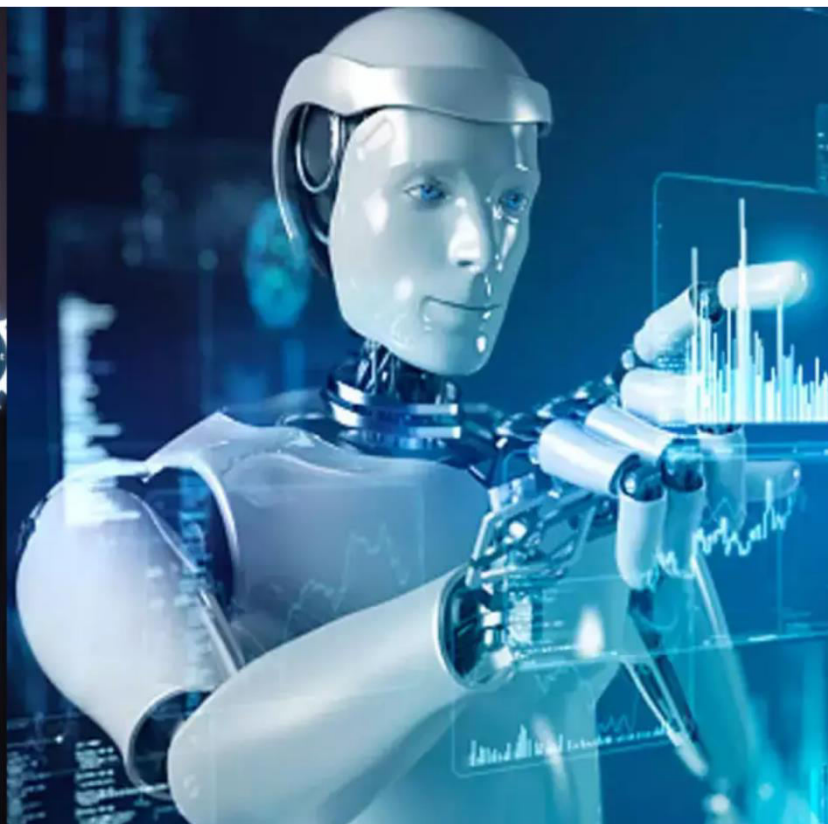




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Performance Analysis of 3 ϕ IM Drives using MMC Fed PV System

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ABSTRACT: The growing requirements for sustainable and eco-friendly solutions are becoming more apparent as concerns about environmental impact continue to grow, and adequate power sources are attracting immense interest in renewable energy in motor drives. The performance of a three-phase induction motor (IM) of 20HP running on a 13-level Modular multi-level converter (MMC) fed by a photovoltaic (PV) system is investigated in this work. While PI-based Field Oriented Control (FOC) with two-stage current control guarantees exact speed control and circulating current suppression, a P&O MPPT algorithm optimizes solar power extraction efficiency, and it is improved by a discrete 3phase PWM approach by lowering the losses. The performance criteria, including PV power/voltage/current, MMC voltage/current, motor speed, and torque, are observed in MATLAB/Simulink with 3.25% THD in MMC phase voltage improvements are less than 5% to satisfy the IEEE 519. The results show MMC's fit for Electrical vehicles, industrial automation, and grid-connected renewable systems.

KEYWORDS: Modular Multilevel Converter (MMC), Induction Motor (IM), Field-Oriented Control (FOC), PI Controller, P&O MPPT, PV System, Two-Stage Current Control, Discrete PWM, Total Harmonic Distortion (THD).

I. INTRODUCTION

The transition towards sustainable and energy-efficient motor drives has increased the need for renewable energy-powered electrical drives. Among eco-friendly resources, harnessing solar energy is commonly used because of its scalability, accessibility, and eco-friendly qualities [1]. It is difficult to integrate the circuitry of PV array systems with induction motor (IM) drives due to challenges like power intermittency, voltage fluctuation, and optimizing efficiency. To address such problems, Modular Multilevel Converters (MMCs) emerge as the very efficient replacement for the traditional two-level and three-level inverters. The benefits offered by MMCs include enhanced voltage scalability, reduced switching losses, enhanced power quality, and low Harmonic Distortion (THD) [2]. All these benefits render MMC-fed motor drives suitable for industrial drives, electrical vehicles (EVs), and grid-connected renewable systems [3]. Though PV-fed IM drives have a strong advantage, several problems do arise that need to be solved. They are: Unstable PV Power output means the variability of solar irradiance affects motor performance, necessitating an effective solar energy utilization stability policy by MPPT [4]. High THD and circulatory currents mean the conventional inverters induce large harmonics, which can lead to heating losses and torque ripples in IMs [5]. Conventional Control methods cannot deliver dynamic performance in PV-fed MMC systems because they are ineffective to control Speed and torque in PV-fed MMC systems, so advanced control methods are required [6]. This paper's purpose is to design a high-performance MMC-fed induction motor drive powered by a PV system, overcoming the challenges through the Perturb & Observe (P&O) MPPT Algorithm with PWM to the DC converter of PV circuitry, which provides maximum solar energy output and stable power supply [7]. PI-based field-oriented Control (FOC) system improves the regulation of speed and torque substantially, resulting in improved performance in applications and mainly controlling the speed as much as the user required in uniformly [8]. MMC, PV, and IM have no isolation, and they are interconnected, and also, components in MMC are connected in series or cascaded fashion which can cause or allow the circulatory currents, Two-Stage Current Control can eliminate these in this mechanism which efficiently eliminates the occurrence of circulating currents, resulting in a system efficiency improvement [9]. Along

with this, the Discrete 3-phase PWM Modulation with feedback of the above control systems minimizes switching loss and THD, improving motor drive stability and eliminating the DC components in MMC output 3-phase voltages [10]. In this paper usage of a 13-level MMC for PV-fed IM drives with improved power quality and efficiency is done [11]. Along with the control systems integration methods like PI-FOC, two-stage current control, and discrete PWM lead to dramatically improved motor drive performance that is exceptional compared to conventional methods [12], with the detailed analysis of Detailed THD testing, the result of which is a low THD of 3.25%, that guarantees high power quality [13]. These all are represented in the MATLAB/Simulink-based performance analyzed by simulation for PV Voltage, Current, Power, MMC 3 phase Voltage and Current [14] and 20 HP 3 phase induction motor characteristics Speed/Time, Torque / Time is observed.

II. PROPOSED CONFIGURATION

The proposed system circuitry integrates connections of a PV array, an MMC, and an induction motor (IM), all governed by a proposed control system. The PV array contains photodiode circuitry that converts solar energy into DC power, which the MMC transforms into a multilevel AC waveform to efficiently drive the IM. The control system ensures maximum power tracking, stable converter operation, and precise motor performance, optimizing energy conversion and system reliability.

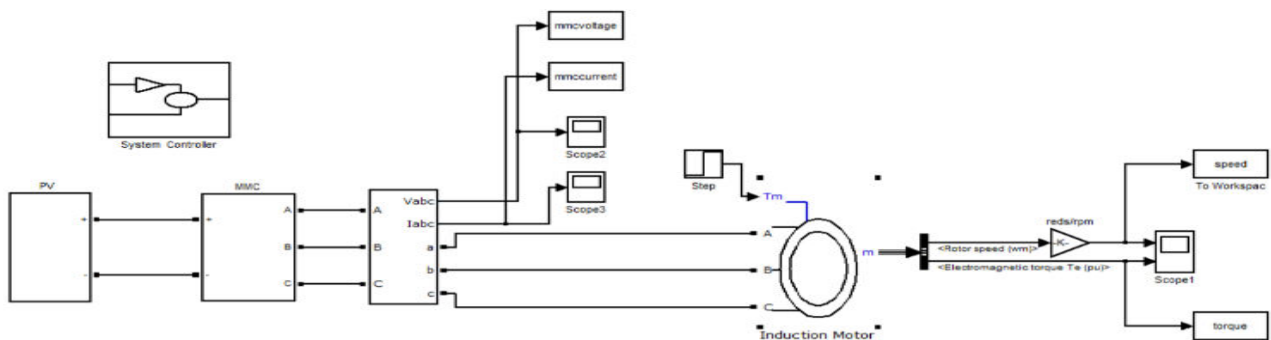


Fig 1: Proposed System Configuration

A PV system generates DC electricity from solar radiation based on the photovoltaic effect. The electrical characteristics of a solar cell are defined by the Shockley diode equation. The PV circuitry in the proposed system, where the irradiance and temperature magnitude fed to PV array and its output is connected to DC-DC converter with P&O MPPT with PWM for switching and controlling the variable output of PV.

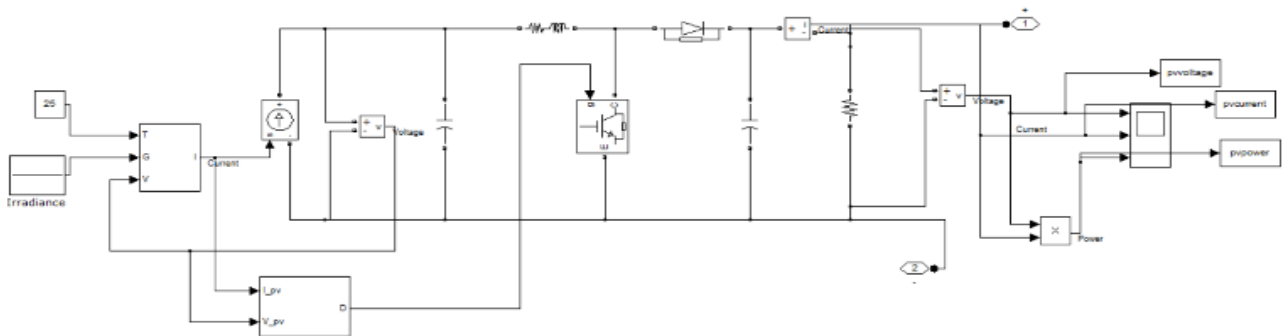


Fig 2: Photo Voltaic Plant

The MMC serves as the primary power conversion unit, transforming DC power from the PV arrays connections into a multilevel AC output. The proposed circuitry consists of 13 levels means 12 submodules. Each submodule, comprising of power switches and capacitors, enables precise control, reducing voltage stress and harmonic distortion while

improving efficiency. Operating at 461V AC and ~50A, the MMC utilizes PWM control to regulate switching and optimize power delivery.

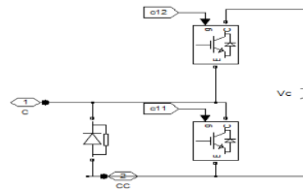


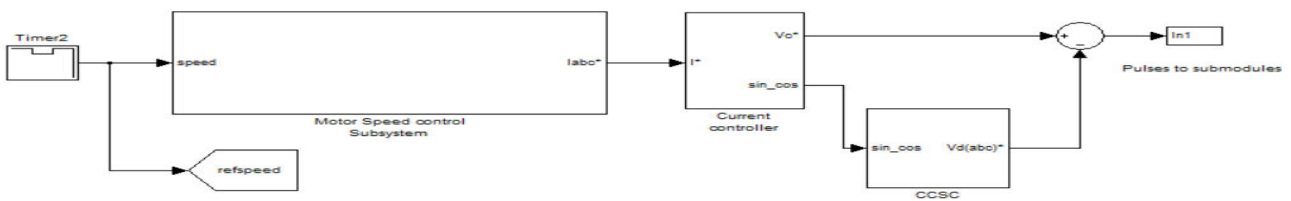
Fig 3: MMC submodule in 13-level 3 phase MMC

The three-phase output from the Modular Multilevel Converter (MMC) powers an induction motor, which acts as the mechanical load. The motor utilizes Field-Oriented Control (FOC) and a PI controller for precise speed management. Real-time monitoring of critical parameters, including rotor speed, electromagnetic torque. Additionally, techniques like optimized PWM are employed to minimize torque ripple, resulting in smoother and more efficient motor operation. The parameter equations of the induction motor help to ease in controlling IM parameters, and it will help in designing a motor speed control system. Torque of rotor fluxes and Speed of load torque and inertia.

The control system ensures coordination among the PV, MMC, and IM subsystems. The MPPT algorithm adjusts duty cycles to harvest maximum available power from solar panels. Two-stage current limit control prevents the MMC from taking an excess of current. A closed-loop PI-based FOC strategy regulates speed, and discrete PWM with feedback of speed control and current limit control generate pulses to all submodules.

Fig 4: Overall Control System

III. PROPOSED METHODOLOGY



P&O MPPT is a widely utilized method to extract the maximum power from solar power systems. It achieves this by changing the voltage at which it is operating and then searching for the power variation to determine the duty cycle of the DC-DC converter. The P&O MPPT algorithm adjusts the switching based on real-time power and voltage variations to track the maximum power point (MPP). It calculates power using system voltage and current, then determines whether to increase or decrease the duty cycle accordingly while keeping it within defined limits for optimal performance [16],[17].

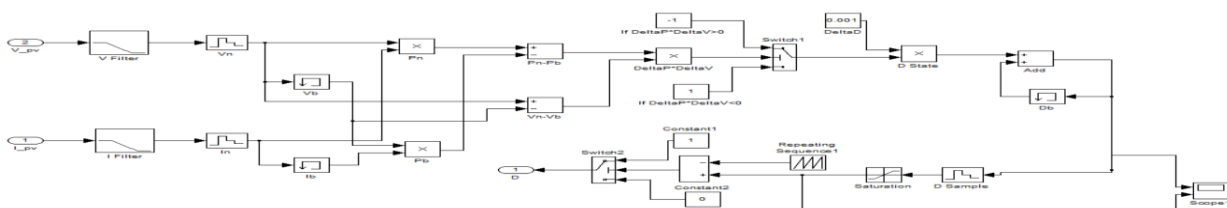


Fig 5: Perturb & Observe MPPT system

The control system consists of a stage current control strategy where these dual stages are connected through Sin_Cos of two stages. The Sin_Cos of the first stage becomes the input of Sin_Cos of the second stage. The voltage and current. The system applies Park transformation to transform three-phase (abc) voltages and currents into dq0 components for control. The PI controller controls dq-axis currents for better dynamic response and steady-state performance. Decoupling terms take care of cross-coupling effects to enhance the accuracy of control. Inverse Park transformation transforms dq0 values to abc signals for system operation. The method enhances current control dynamics and stability in power electronics. [3,4,6,7,9,10,11,12].

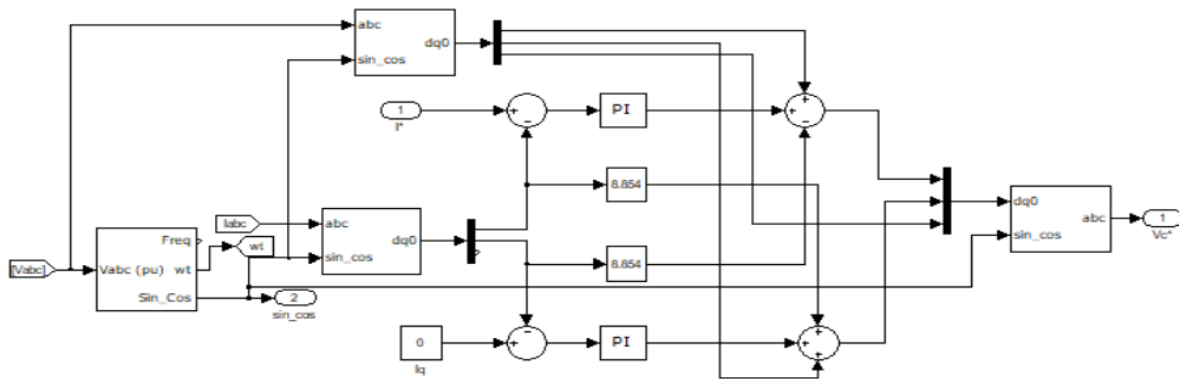


Fig 6: First stage current control

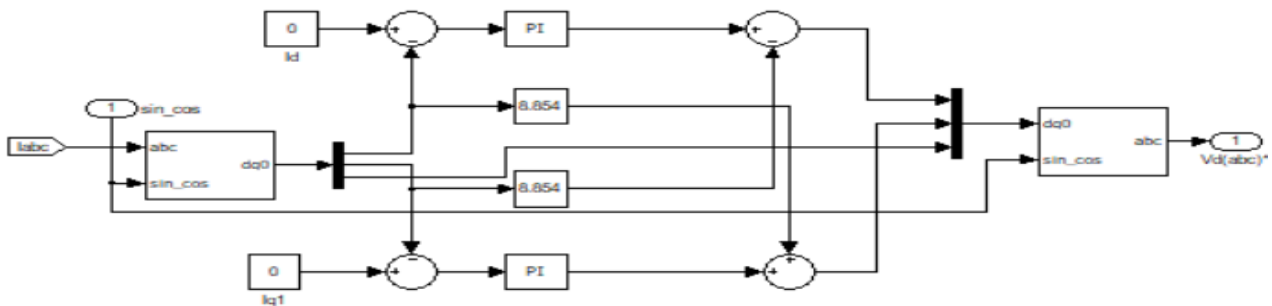


Fig 7: Second Stage current control

Three-phase discrete PWM is used in MMC switching to control motor drive operation and remove DC components. Switching operations are guided by control signals from a dual-stage current controller and a motor speed control system [1,2]. Accurate tracking is ensured by the inner current loop, while the speed controller creates dq-axis current references [3, 5]. Inverse Park transformation, $V_{ref,abc}$ modulate PWM signals, improving capacitor voltage balance and lowering harmonics [10,14]. This approach ensures robust speed tracking, as validated by [7][10]. The flux calculation and ABC to dq transformation blocks process motor currents into dq coordinates and where θ is the rotor electrical angle. The dq current controller refines i_d and i_q based on the reference values, where $e_d = i_d^* - i_d$ and $e_q = i_q^* - i_q$ are dq axis current errors [4][9][12]. The reference speed (ω^*) is set by external inputs. Measured speed (ω) is fed back for closed-loop correction. The output of this speed control is fed to dual stage current control, and the dual stage current control output is fed to MMC switching as a control signal using 3 phases discrete PWM for MMC [5][6][14]. This ensures high efficiency, reduced THD, and enhanced control dynamics, aligning with the principles in [3][5][15].

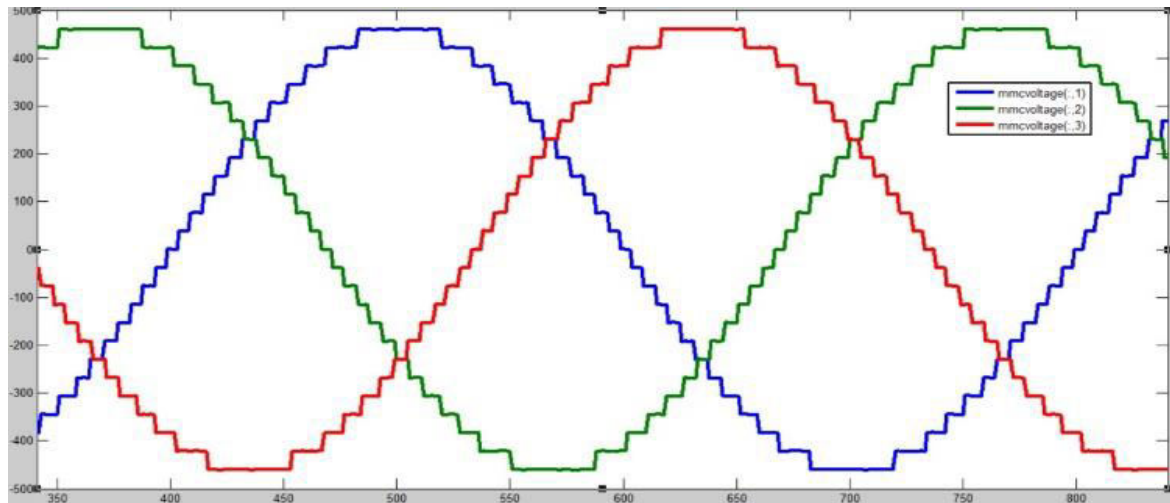


Fig 11: Simulation of 13-level 3-phase Modular Multilevel Converter RYB Voltages

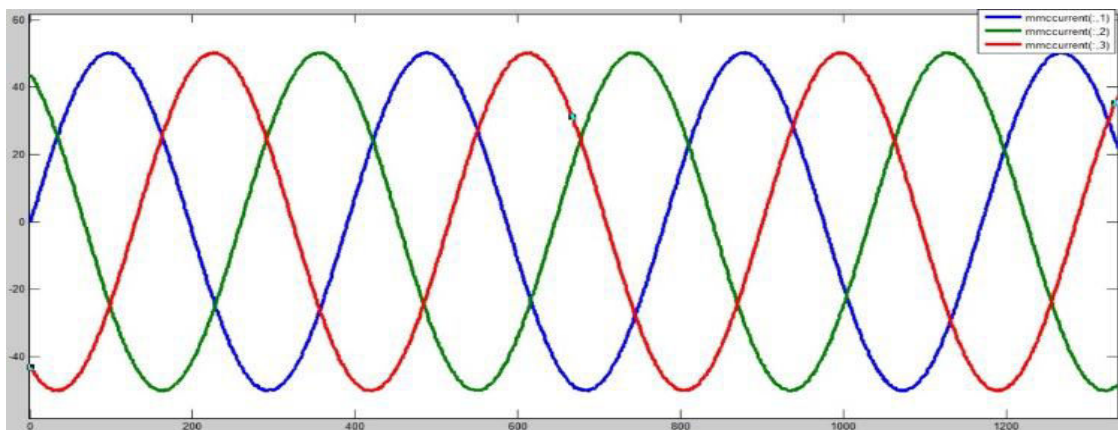


Fig 12: Simulation of 3 phase Currents in 13 level Modular Multilevel Converter

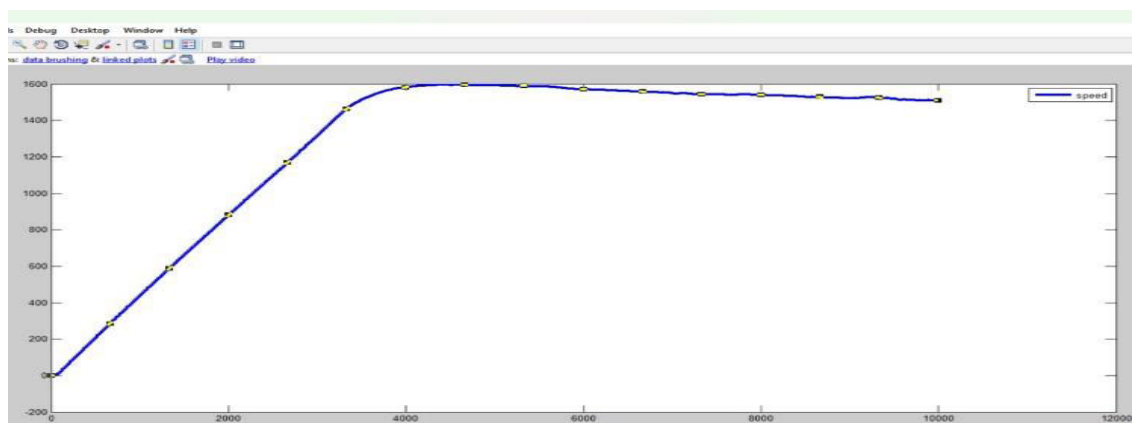


Fig 13: Simulation of Speed/time of 3 phase Induction Motor in Proposed System

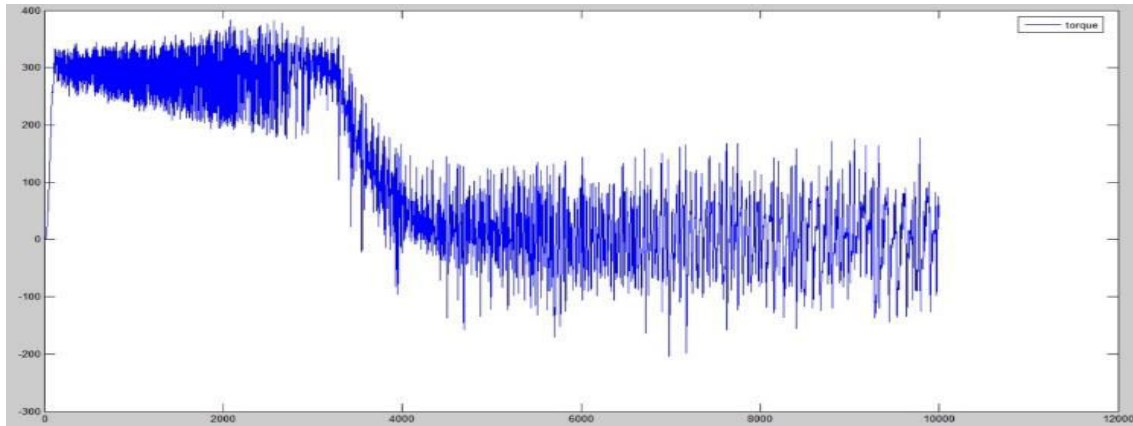


Fig 14: Simulation of Torque/time of 3-phase Induction Motor in Proposed System

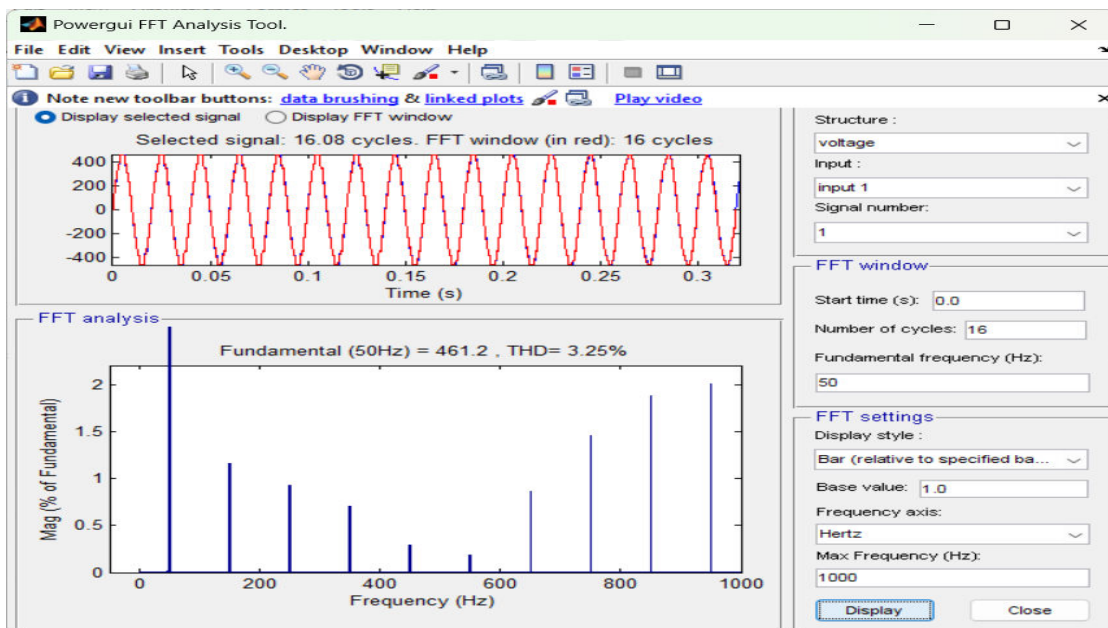


Fig 15: THD of Proposed System Voltage

Key Simulation Results of The Proposed System:

Parameters	Value
PV Voltage	490v
PV Current	58A
3 phase 13 level MMC Voltage	461V
3 phase 13 level MMC Current	50A
3 phase Inductor Motor Power Rating	20HP
THD % of Proposed System Voltages	3.25%

V. CONCLUSION

The designed proposed system, i.e., photovoltaic fed to 13 level 3 phase Modular Multilevel Converter (MMC)-based 3phase induction motor (IM) drive system was successfully simulated and designed using MATLAB/Simulink. Maximum power extraction from the photovoltaic system was made easier by Perturb & Observe (P&O) MPPT, and motor stability was guaranteed by dual-stage current control and Proportional-Integral (PI) based Field-Oriented Control (FOC), which improved speed regulation. MMC switching is based on discrete pulse width modulation (PWM) has decreased total harmonic distortion (THD), producing a low THD of 3.25% and improved power quality. The simulation results validate the system's high efficiency and proper motor control with better power conversion. These demonstrate that MMC-fed IM drives are feasible for use in smart grid systems, industrial automation, and electric vehicles, among other renewable energy applications.

VI. FUTURE SCOPE

The proposed system lays a foundation for advanced renewable energy-driven motor drives. Future advancements encompass adaptive control strategies (AI, fuzzy logic) with improved dynamic performance and predictive current control of losses. Real-time implementation using FPGA/DSP will confirm the accurate and practical efficiency of the system, and grid integration with Battery Energy Storage Systems (BEES) will facilitate bidirectional power flow. Scalability and efficiency can be improved using multi-motor systems and high-order MMC configurations, which would make the system suitable for industrial and smart grid applications.

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