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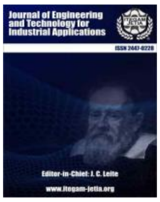

**RESEARCH ARTICLE OPEN ACCESS**

# DTC OF A 5 LEVEL MMC FED 3-Φ INDUCTION MOTOR WITH PI AND FLC USING CBAPOD PWM TECHNIQUE

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## ABSTRACT

Industrial motor drives, particularly three phase induction motor drives, have been adopting Modular Multilevel Converters (MMC). MMC is utilized in the design of power and control circuits to give the appropriate switching sequences that yield the corresponding output voltage levels. This paper describes the Alternate Phase opposition Disposition Pulse Width Modulation (APOD-PWM) method and fuzzy logic controller used to regulate the 5-level MMC topology of an induction motor. The MMC's switching mechanism is essential for enhancing the induction motor drive's power quality. The converter can be used as a source of controlled voltage because it has numerous distinct voltage levels accessible. Researchers have improved the application of fuzzy logic for Direct Torque Control (DTC) in variable speed drives that rely on multilevel inverters in the past few years. The MATLAB/SIMULINK simulator is the foundation of our suggested method, which measures the effectiveness of direct torque control with respect to ripple in current, speed, torque, and transient response. Both the fuzzy logic controllers (FLC) as well as the PID controller were compared in this study. THD content will significantly decrease as a result of this.

## I. INTRODUCTION

Power electronic converters, such as multilevel inverters, are essential of the development of AC motors due to their excellent power abilities, reduced switching losses, and effective electrical performance, strong electromagnetic compatibility, and decreased output waveform harmonic content. Multilevel inverters provide a viable option for outdoor applications where it is not possible to cable AC power to the desired area and at which a driving unit with a fixed or varying speed is needed. Output waveforms inverter becomes significantly more similar to the sinusoidal waveform [1].

First described by [2], the Modular Multilevel Converter (MMC) is an architecture that offers benefits for high power utilizations. It is appropriate for HVDC of excellent performance [3]. Additionally, motor drives and STATCOM employ it [4],[5].
T. Nougouchi and Depenbrock [6],[7] developed the direct torque control approach for induction machine control, which was first published in the literature in the middle of the 1980s. The following severity is provided by this method: [8-10]. The disadvantages of a DTC system with hysteresis controllers are torque ripple, current, and variable switching frequency.

Because of their straightforward design and excellent performance under a variety of operating circumstances, PI-type controllers are the most often used controller in industrial applications [11]. The key issue with that controller is the proper selection of PI gains, as well as the fact that employing fixed gains may result in the controller failing to provide the appropriate control performance when plant characteristics and operating conditions change [12].

In [13-17], the performance of a 3-phase induction motor with DTC was reported when it was operated from MMC using the carrier-based Phase Opposition Disposition (POD PWM) approach. In [18],[19], 3-Level MMC employed a Fuzzy Logic Controller in conjunction with APOD-PWM technique. The current work used a simulator (MATLAB/SIMULINK) to determine the ripples in current, dynamic responsiveness, torque, and speed of a 3-Φ induction motor with DTC. The proposed architecture is a 5-level MMC with APOD-PWM strategy, which incorporates and combines both PI and fuzzy controllers.

## II. PROPOSED MMC TOPOLOGY

As a unique hybrid arm multipolar cell topology, 100% of the arms' unipolar cells are connected to the grounding pole and 100% of the arms' bipolar cells are detached (Figure 1).

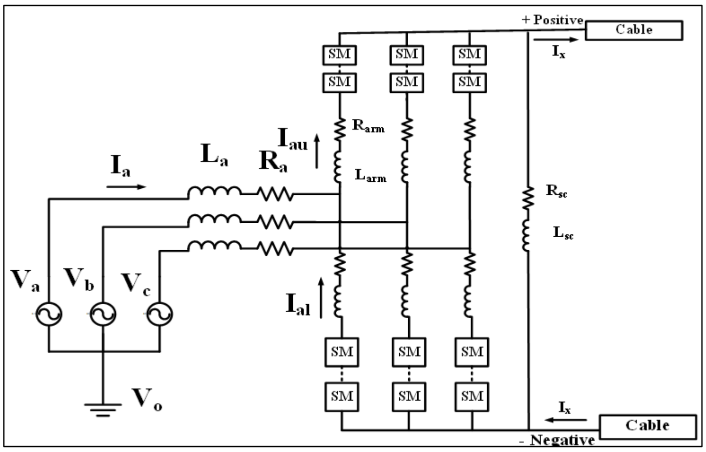

Figure 1: Depicts MMC's fundamental topology.
Source: Authors, (2024).

**Basic formulas**

All phase's SMs are arranged into two blocks according to the voltages Vla (lower arm) and Vua (upper arm). Per SM's capacitor is maintained full at a voltage of Vc = $V_{DC}/n$.

The equations connecting DC and AC voltage can be found using an upper or lower arm:

$$V_{oa} = \frac{V_{DC}}{2} - V_{ua} - L\,\frac{di_{ua}}{dt} \tag{1}$$

$$V_{oa} = -\frac{V_{DC}}{2} + V_{la} + L\,\frac{di_{la}}{dt} \tag{2}$$

For each of the arms, the currents are:

$$I_{ua} = \frac{I_a}{2} + \frac{I_{DC}}{3} + I_{za} \tag{3}$$

$$I_{la} = -\frac{I_a}{2} + \frac{I_{DC}}{3} + I_{za} \tag{4}$$

Where, $I_{za}$= circulating current

## III. CONTROL AND MODULATION OF MMC

The regulation of terminal voltage as well as current is one of MMC's main challenges. Controlling both the ac and dc voltages is therefore essential.

The controlled variable may vary based on the subject of the investigation. MMC enable energy exchange between the input and output stages [20]. Further, significant considerations that must be made in the design and operation of MMC include arm current management, suppressing circulating currents, and balancing capacitor voltage [21]. Alternative research as listed in [22],[23] provide an extensive discussion of PWM approaches.

Several studies have been carried out [24-28] on the modulation of the MMC converter. PWM-based modulation techniques are most suited for MMC converters due to their modularity and simplicity of implementation. For MMC control, several pulse width modulation (PWM) approaches were examined [29].

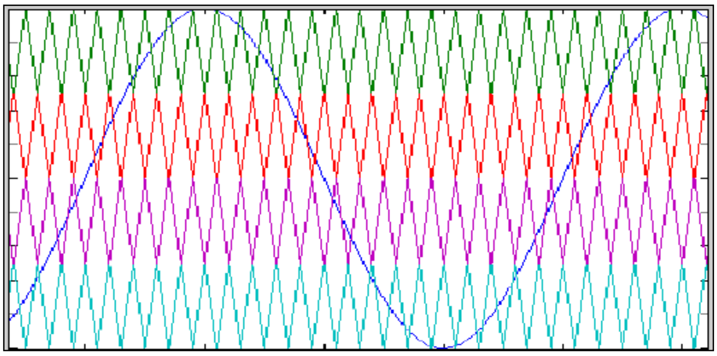

Figure 2: Illustrates the carrier-based APOD-PWM method.
Source: Authors, (2024).

The carry signal (message signal) and a reference signal (sinusoidal, triangle, ramp, etc.) are compared when carried-based PWM is used. This results in the generation of gating pulses, which in turn activate the switches on the arms. PWM technique refers to the signal generation process. An Alternative Phase Opposition Disposition PWM (APODPWM) technique (Figure 2) was taken into consideration in this work. This system alternates between using out-of-phase and in-phase carrier waveforms.

## IV. FUZZY LOGIC CONTROLLER

The concept of fuzzy logic is comparable to human senses and cognition. For the fuzzy logic approach to be used in a real usage, the three steps that follow need to be completed:

1. The process of converting crispy or traditional information into fuzzy data, also known as Membership Functions (MFs), is called fuzziness.
2. Fuzzy Synthesis Procedure: Blend control constraints and functions for membership to produce the fuzzy outcome.
3. Defuzzification is: Various techniques are applied to determine each related result, which is then arranged in an array known as a lookup table.

According to the information being provided, choose the appropriate output from the lookup table for an application. The electromagnetic torque error is fizzed using five fuzzy subsets: Negative Big (NB), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Big (PB). Figure 3 (a) shows an assessment of their membership functions. Three fuzzy subsets of the error of flux are fuzzy: Negative (N), Zero (Z), and Positive (P). Figure 3(b) provides an assessment of their membership functions.

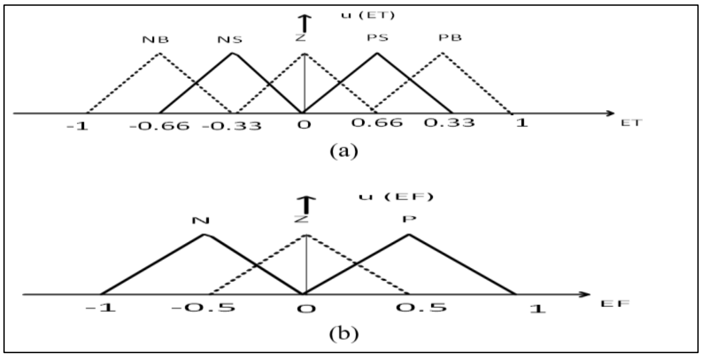

Figure 3. Fuzzy membership functions for input variables (error of torque and flow).
Source: Authors, (2024).

## V. DIRECT TORQUE CONTROL

DTC for induction machines is becoming the superior substitute for field-oriented control techniques. In comparison to the vector control system, the configuration is significantly less complicated because PI regulators and positional conversions between synchronous and stationary frames are not included. Additionally, it does not require a position encoder or PWM, which add latency and call for mechanical transducers, respectively. DTC-based drives don't use the current regulation loop; instead, they are managed similarly to a closed loop system (Figure 4).

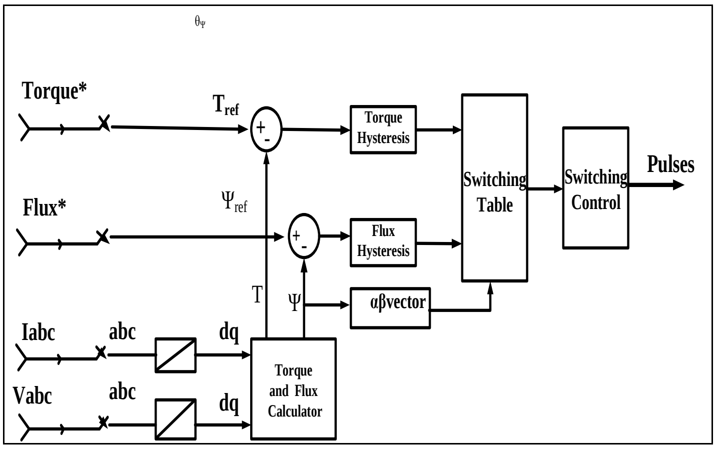

Figure 4: DTC based circuit.
Source: Authors, (2024).

Stator voltage is $u_s = R_s i_s + \frac{d}{dt}\lambda_s$ (5)

To calculate torque

$$T_e = \frac{3}{2} p_n \lambda_s * i_s \qquad (6)$$

Stator linkage flux

$$\lambda_s = L_s i_s + L_m i_r = \frac{L_s}{L_m}(\lambda_r - \sigma L_r i_r) \qquad (7)$$

It's possible to calculate torque and flux using the formulae above.

The fundamental idea of DTC is to concurrently select the best inverter switching modes and directly manage the machine's electromagnetic torque and stator flux linkage.

## VI. SIMULATION VIEW OF CIRCUIT

The values of induction motor were shown in Table 1.

Table 1: Induction Motor Details.

| Parameter | Rating |
|---|---|
| Nominal power | 2237VA |
| Voltage $_{Line-Line}$ | 220V |
| Stator resistance | 0.436Ω |
| Stator inductance | 0.003H |
| Rotor resistance | 0.818Ω |
| Rotor inductance | 0.003H |

Source: Authors, (2024).

Speed was considered as 1000, 700, 500, 100, -600 at 0, 1, 3, 5, 7 seconds respectively.

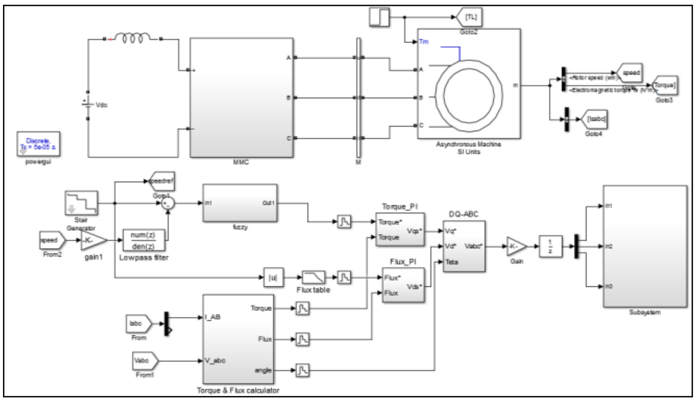

Figure 5: The simulation circuit.
Source: Authors, (2024).

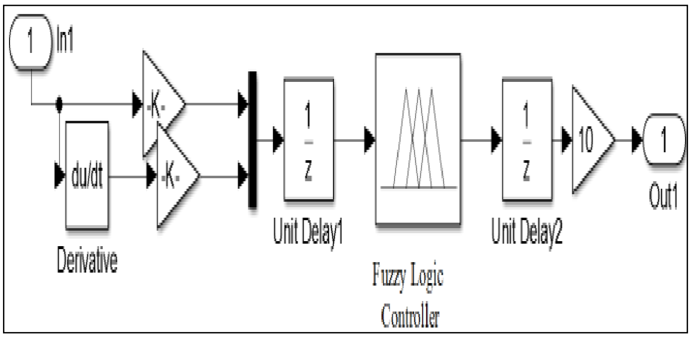

Figure 6: Inside the Fuzzy sub system.
Source: Authors, (2024).

Table 2: Controller details.

| Controller | Gain Value |
|---|---|
| Torque | $K_P$ =1.3, $K_I$ = 100 |
| Flux | $K_P$ =200, $K_I$ = 3000 |

Source: Authors, (2024).

## VII. RESULTS AND DISCUSSION

PI CONTROLLER

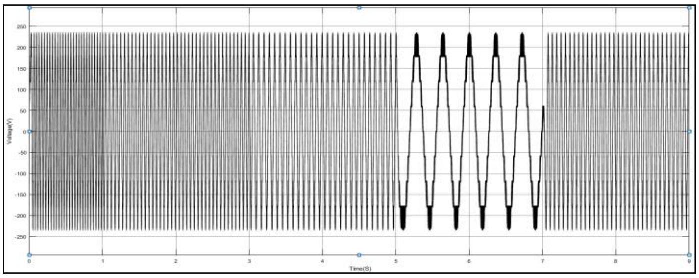

Figure 7: Voltage across inverter.
Source: Authors, (2024).

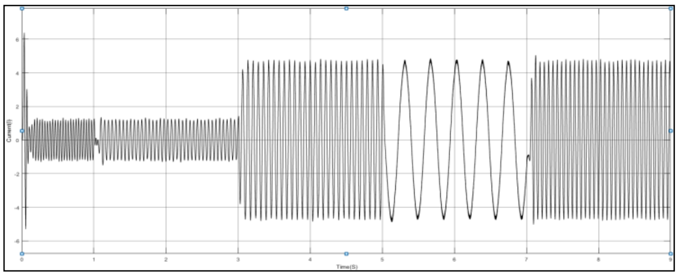

Figure 8: Current of inverter.
Source: Authors, (2024).

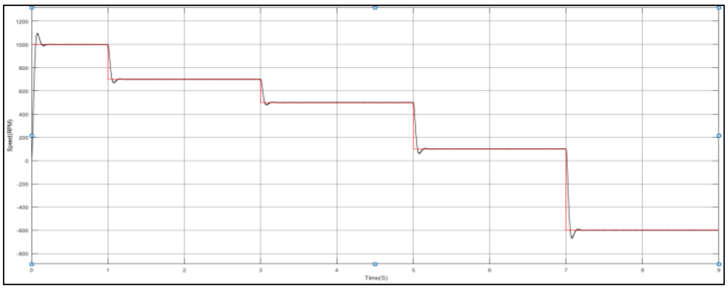

Figure 9: Speed of induction motor.
Source: Authors, (2024).

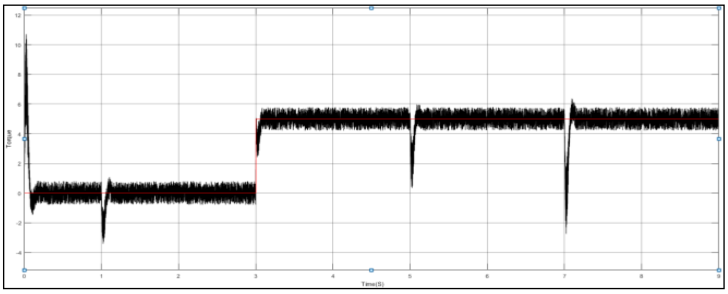

Figure 10: Torque of induction motor.
Source: Authors, (2024).

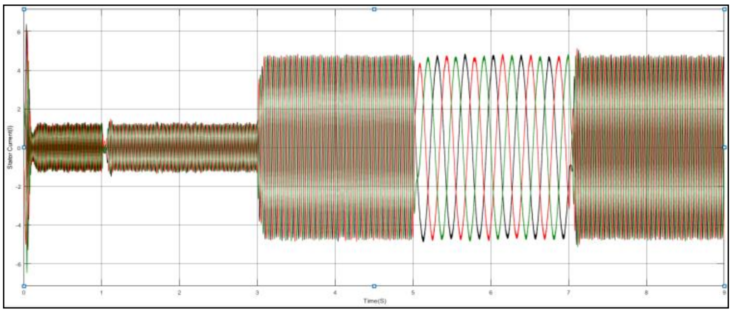

Figure 11: Stator current of motor.
Source: Authors, (2024).

FUZZY LOGIC CONTROLLER

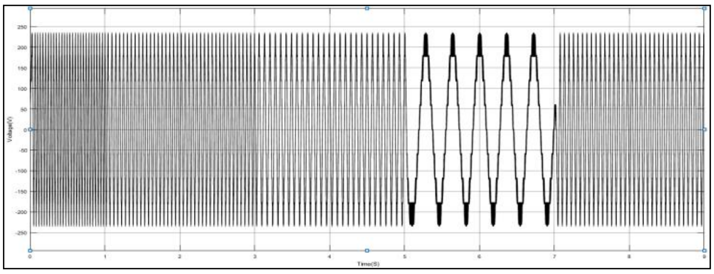

Figure 12: Voltage across inverter.
Source: Authors, (2024).

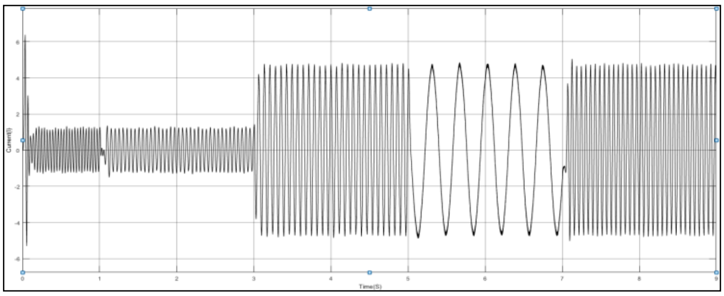

Figure 13: Current at inverter.
Source: Authors, (2024).

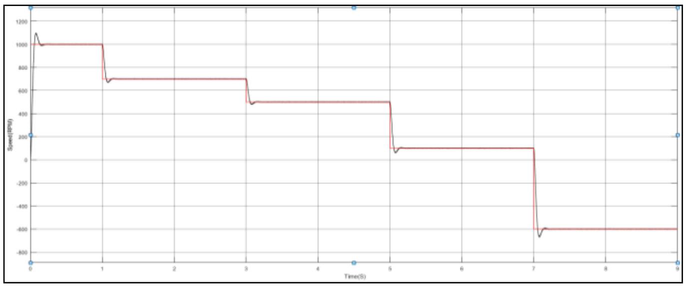

Figure 14: Speed of induction motor.
Source: Authors, (2024).

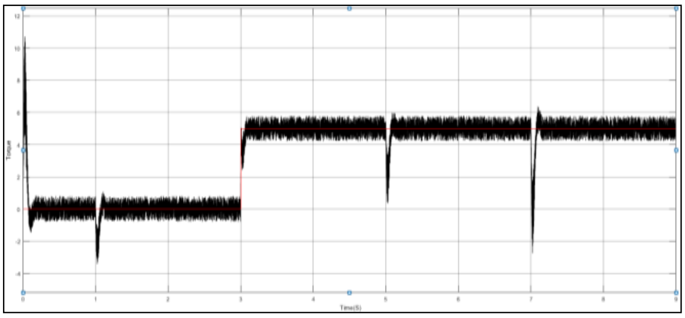

Figure 15: Torque of induction motor.
Source: Authors, (2024).

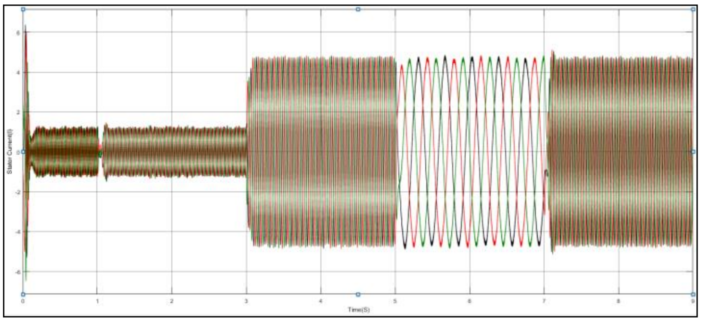

Figure 16: Stator current of induction motor.
Source: Authors, (2024).

The results seem to be the same for both scenarios, yet the Fuzzy MMC has a smaller percentage than the PI MMC when compared to THD values. The voltage THD value for PI MMC is 5.28%, while the fuzzy THD value is 4.52%. The maximum speed achieved with Fuzzy MMC is 997.28 rpm and with PI MMC is 996.46 rpm.

Table 3: Performance Comparison.

| S. No | Parameter | 5-L MMC | 5-L F MMC |
|---|---|---|---|
| 1 | Voltage (V) | 246.43 | 246.43 |
| 2 | Current(A) | 4.45 | 4.45 |
| 3 | Speed (rpm) | 996.46 | 997.28 |
| 4 | Torque (N-m) | 5.08 | 5.06 |
| 5 | Stator Current(A) | 4.39 | 4.32 |
| 6 | THD | 5.28% | 4.52% |
| 7 | current ripple(p.u) | 0.12 | 0.02 |
| 8 | torque ripple(p.u) | 0.001 | 0.0003 |
| 9 | Peak Time(s) | 0.073 | 0.03 |
| 10 | Settling Time(s) | 0.154 | 0.102 |

Source: Authors, (2024).

## VIII. CONCLUSUION

Employing MATLAB/SIMULATION, the application of fuzzy MMC and PI MMC topology to the control of a three-phase induction motor was observed and compared. Fuzzy MMC topology performs better than PI MMC topology because it has a higher maximum speed attain value, a lower torque value, and less harmonic content.

## IX. AUTHORS'S CONTRIBUTION

**Conceptualization:** Sriramulu Naik Mudhavath, Kesana Gopikrishna, Venkat Anjani Kumar. G
**Methodology:** Sriramulu Naik Mudhavath, Kesana Gopikrishna, Venkat Anjani Kumar. G
**Investigation:** Sriramulu Naik Mudhavath, Kesana Gopikrishna, Venkat Anjani Kumar. G
**Discussion of results:** Sriramulu Naik Mudhavath, Kesana Gopikrishna, Venkat Anjani Kumar. G
**Writing – Original Draft:** Sriramulu Naik Mudhavath, Kesana Gopikrishna, Venkat Anjani Kumar. G
**Writing – Review and Editing:** Sriramulu Naik Mudhavath, Kesana Gopikrishna, Venkat Anjani Kumar. G
**Resources:** Sriramulu Naik Mudhavath, Kesana Gopikrishna, Venkat Anjani Kumar. G
**Supervision:** Sriramulu Naik Mudhavath, Kesana Gopikrishna, Venkat Anjani Kumar. G
**Approval of the final text:** Sriramulu Naik Mudhavath, Kesana Gopikrishna, Venkat Anjani Kumar. G
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