FUZZY BASED THREE-LEVEL MMC TOPOLOGY FOR DIRECT TORQUE CONTROL OF THREE PHASE INDUCTION MOTOR DRIVE WITH APOD-PWM TECHNIQUE

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ABSTRACT- This paper presents the controlling of induction motor by 3-level Modular Multilevel Converter (MMC) topology based on an Alternative Phase opposition Disposition Pulse Width Modulation (APOD-PWM) technique, with Fuzzy Logic Controller. In this paper comparison of PI controller and Fuzzy Logic Controller (FLC) was shown. This will results to decrease of THD content can be shown. The MMC is built up by identical, but individually controllable sub-modules. Therefore the converter can act as a controllable voltage source, with a large number of available discrete voltage steps. The deployment of Direct Torque Control using fuzzy logic in variable speed drive that is based on multilevel inverter has increased by researchers in the last few years. Our proposed approach is based on Simulator (MATLAB/SIMULINK) that is used to identify the performance of Direct Torque Control in terms of Speed, Torque, Transient response and the current ripple.

Index Terms- MMC-Modular multilevel converter, FLC-Fuzzy Logic Controller, DTC-Direct torque control.

INTRODUCTION

Multilevel inverter which plays an important role in the design of AC motor because it has efficient power quality, low switching losses, high voltage capability and good electromagnetic compatibility. For the outside applications where cabling the AC power for the desired location is impossible where constant or variable speed drive system is needed, the multilevel inverter gives a suitable solution. With more levels the output waveform of the inverter is much closer to the sinusoidal waveform [1]

For a VSC-HVDC transmission, the Modular Multilevel Converter (MMC) [3] is the preferred topology. MMCs combine a large number of individually-controlled sub-modules (cells) (see Fig. 1). They can generate high quality output voltage waveforms while maintaining a reduced switching frequency for each sub-module, therefore reducing the switching losses. Based on this concept, different manufacturers have proposed their specific solutions [2]–[4].

Over the past few years, there has been a significant effort towards addressing the technical challenges associated with the operation and control of the MMC as well as broadening its applications. This paper provides a better understanding of the MMC and comprehensive review on the most recent advances and contributions on the operational issues, modeling, control, and modulation techniques of the +MMC.

In the mid-80s, a strategy for control of induction machine emerged in the literature (Direct Torque Control) was proposed by T. Nougouchi and Depenbrock [4] - [5]. Sever offered by this technique as: [6] - [8]. The basic disadvantages of DTC scheme using hysteresis controllers are the variable switching frequency, the current and torque ripple. The movement of stator flux vector during the changes of cyclic sectors is responsible for creating notable edge oscillations of electromagnetic torque. Another great issue is the implementation of hysteresis controllers which requires a high sampling frequency. When an hysteresis controller is implemented using a digital signal processor (DSP) its operation is quite different to the analogue one. In the analogue operation the value of the electromagnetic torque and the magnitude of the stator flux are limited in the exact desirable hysteresis band. That means, the inverter can change state each time the torque or the flux magnitude are throwing the specified limits. On the other way, the digital implementation uses specific sample time on which the magnitudes of torque and flux are checked to be in the desirable limits. That means, very often, torque and flux can be out of the desirable limits until the next sampling period. For this reason, an undesirable torque and flux ripple is occurred. The performance of 3-phase induction motor with DTC was given in [9]-[13], when operated from MMC by using carrier-based Phase Opposition Disposition (POD PWM) technique.

This paper was implemented in Simulator (MATLAB/SIMULINK) that is used to identify the performance of Direct Torque Control in terms of Speed, Torque, Transient response and the current ripple of 3-phase induction motor. The proposed topology is of 3-level MMC with an Alternative Phase opposition Disposition Pulse Width Modulation (APOD-PWM) technique, in which both PI and Fuzzy controllers were used.

PROPOSED MMC TOPOLOGY

A new hybrid arm MMC topology is proposed with 100% unipolar cells in the arms that are connected to the grounding pole, and with 100 % bipolar cells in the arms that are away from the grounding pole.

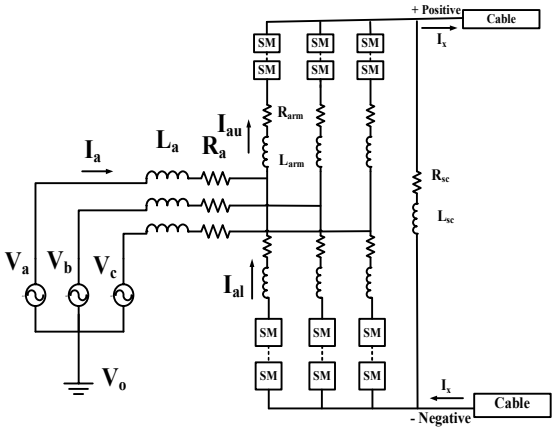

Fig.1 shows the basic topology of MMC

Fig. 1 shows a schematic diagram of a three-phase MMC. The MMC, as shown in Fig. 1, consists of two arms per phase leg where each arm comprises N series-connected, nominally identical SMs, and a series inductor Lo . While the SMs in each arm are controlled to generate the required ac phase voltage, the arm inductor suppresses the high-frequency components in the arm current.

Fundamental equations

The SMs of each phase have been grouped into two blocks with voltages V_{ua} (upper arm) and V_{la} (lower arm). The capacitor of each SM is kept charged with a voltage equal to DC voltage V_{DC} divided by the number of SMs of each arm n, Vc $= \frac{V_{DC}}{n}$.

The equation relating DC and AC voltage can be obtained through the upper arm, or the lower arm:

$$V_{oa} = \frac{V_{DC}}{2} - V_{ua} - L\,\frac{di_{ua}}{dt} \qquad (4)$$

$$V_{oa} = -\frac{V_{DC}}{2} + V_{la} + L\,\frac{di_{la}}{dt} \qquad (5)$$

For each of the arms, the currents are:

$$I_{ua} = \frac{I_a}{2} + \frac{I_{DC}}{3} + I_{za} \qquad (6)$$

$$I_{la} = -\frac{I_a}{2} + \frac{I_{DC}}{3} + I_{za} \qquad (7)$$

Where, I_{za}= circulating current

CONTROL AND MODULATION OF MMC

The control of voltages and currents of terminals are the primary issues in MMC. Thereby, both ac and dc voltages must be controlled. The controlled variable could change according to the research topic. In fact, energy exchange is provided by MMC between input and output stages with the help of SM capacitors whose average voltages must be controlled in steady-state operation [14]. Furthermore, the balancing of capacitor voltage, arm current control and suppressing of circulating currents are the considerable issues, which must be taken into account in design and operation of MMC. Depending on the applied PWM signals to the SMs, the capacitor voltage-balancing is realized [15].The detailed description of PWM techniques can be investigated in alternative publications as given in [16]–[17].

The energy exchange between input and output terminals can be done by SM capacitors whose capacitance can be controlled in steady state operation [18]-[19].When the MMC is constructed, the capacitance between capacitors, range of arms and its control and loss across the switches are to be considered for better operation. In recent studies [20]-[21], the principles and control scheme for variable speed AC motor drives with the MMC have been introduced.

Many research studies have been dedicated to the modulation of the MMC converter. The modularity and simple implementation of PWM-based modulation strategies make them the most suitable for MMC converters [22]. For the controlling of MMC various pulse width modulation (PWM) techniques were considered as carrier-based PWM (CB-PWM), nearest level modulation (NLM) and selective harmonic elimination (SHE) [23]. CB-PWM based technique was preferred because of its easy nature. Again CB-PWM was classified into Phase-Shifted Carrier Pulse Width Modulation (PSC-PWM), Phase Disposition Pulse Width Modulation (PD-PWM) and Alternative Phase opposition Disposition (APOD-PWM) techniques as well as Phase Opposition Disposition (POD PWM).

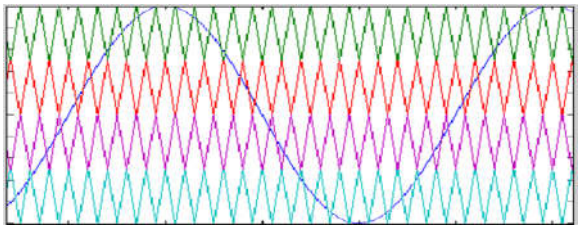

Fig.2 shows the carrier based APOD-PWM technique.

In carried based PWM ,the reference signal (sinusoidal, triangular, ramp.etc) are going to compare with the carrier signal (message signal) the gating pulses will generated and this generated pulses will trigger the switches in arms. The process of generating signal is called PWM technique.
In this paper an Alternative Phase Opposition Disposition PWM (APODPWM) strategy (Fig.2) was considered. This scheme uses in-phase and out of phase carrier waveforms alternatively.

FUZZY LOGIC CONTROLLER

Fuzzy logic idea is similar to the human being's feeling and inference process. Unlike classical control strategy, which is a point-to-point control, fuzzy logic control is a range-to-point or range-to-range control. The output of a fuzzy controller is derived from fuzzifications of both inputs and outputs using the associated membership functions. A crisp input will be converted to the different members of the associated membership functions based on its value. From this point of view, the output of a fuzzy logic controller is based on its memberships of the different membership functions, which can be considered as a range of inputs.

To implement fuzzy logic technique to a real application requires the following three steps:
1) **Fuzzification** – convert classical data or crisp data into fuzzy data or Membership Functions (MFs)
2) **Fuzzy Inference Process** – combine membership functions with the control rules to derive the fuzzy output
3) **Defuzzification** – use different methods to calculate each associated output and put them into a table: the lookup table. Pick up the output from the lookup table based on the current input during an application
Membership functions of input1.

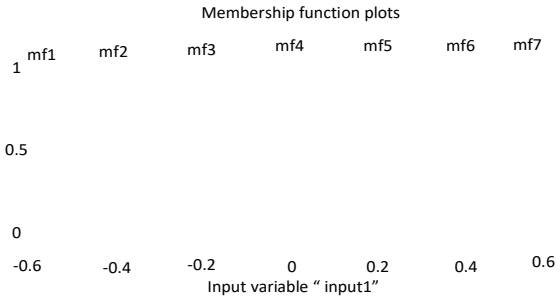

Fig.3 shows first MF

Membership functions of input2.

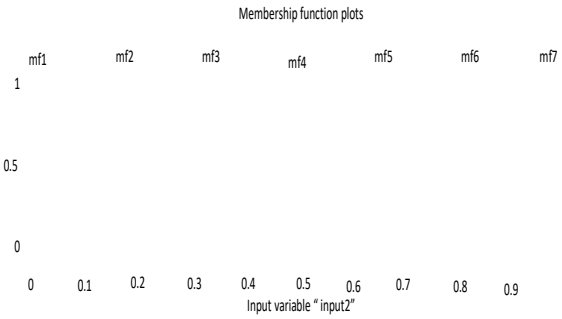

Fig.4 shows second MF

DIRECT TORQUE CONTROL METHOD

DTC of induction machine has increasingly become the best alternative to Field-Oriented Control methods. The configuration is much simpler than the vector control system due to the absence of coordinate transforms between stationary frame and synchronous frame and PI regulators. It also doesn't need a PWM and position encoder, which introduces delay and requires mechanical transducers respectively. DTC based drives are controlled in the manner of a closed loop system without using the current regulation loop. DTC scheme uses a stationary d-q reference frame (fixed to the stator) having its d -axis aligned with the stator q -axis. Torque and flux are controlled by the stator voltage space vector defined in this reference frame.

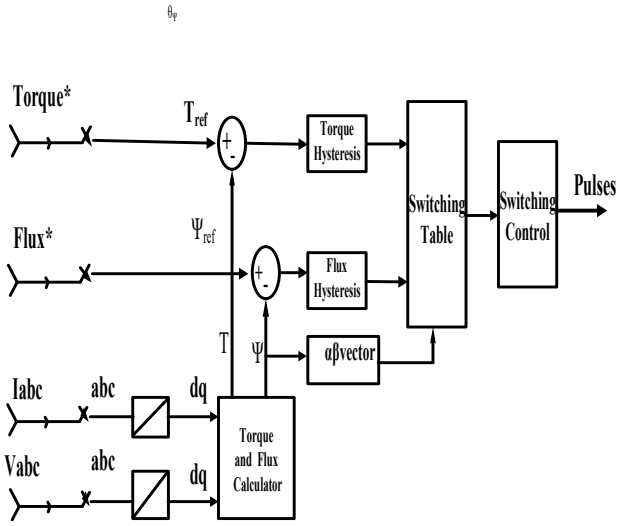

Fig.5 shows the DTC based circuit

Stator voltage is $u_s = R_s i_s + \frac{d}{dt}\lambda_s$..... (1).

To calculate torque

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

Stator linkage flux

$$\lambda_s = L_s i_s + L_m i_r = \frac{L_s}{L_m}(\lambda_r - \sigma L_r i_r) \dots\dots (3)$$

By using above equations torque and flux can be calculated.

The basic concept of DTC is to control directly the stator flux linkage (or rotor flux linkage or magnetizing flux linkage) and electromagnetic torque of machine simultaneously by the selection of optimum inverter switching modes. The use of a switching table for voltage vector selection provides fast response, low inverter switching frequency and low harmonic losses without the complex field orientation by restricting the flux and torque errors within respective flux and torque hysteresis bands with the optimum selection being made. The DTC controller comprises hysteresis controllers for flux and torque to select the switching voltage vector in order to maintain flux and torque between upper and lower limit

SIMULATION VIEW OF CIRCUIT

The values of induction motor were shown in TABLE-I.

TABLE-I: INDUCTION MOTOR DETAILS

PARAMETER	RATINGS
Nominal Power	2238VA
Voltage $_{line-line}$	220V
Stator Resistance (Rs)	0.435 ohm
Stator Inductance(Lls)	0.002 Henry
Rotor Resistance(Rr)	0.816 ohm
Rotor Inductance(Llr)	0.002 Henry

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

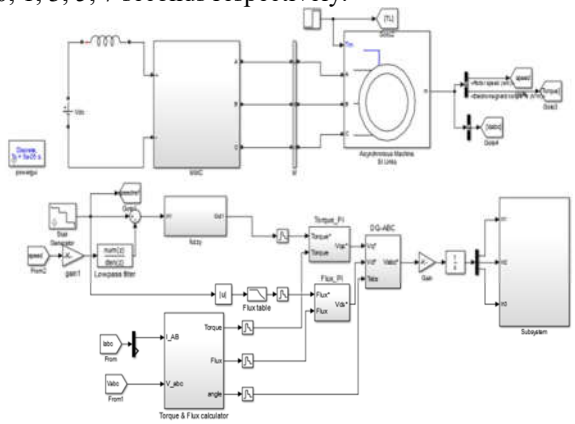

Fig.6 shows the simulation circuit

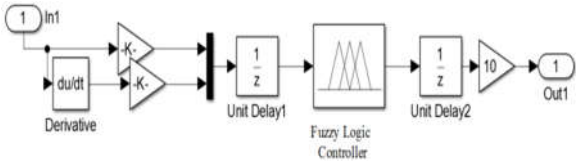

Fig.7 inside the Fuzzy sub system

TABLE-II: LIST OF PARAMETERS

parameter	Ratings
Voltage Source	250V
Inductor	0.005H

TABLE-III: CONTOLLER DETAILS

Controller	Gain values
Torque	Kp=1.5,K_I=100
Flux	Kp= 250,K_I=4000

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RESULTS AND DISCUSSION

PI CONTROLLER

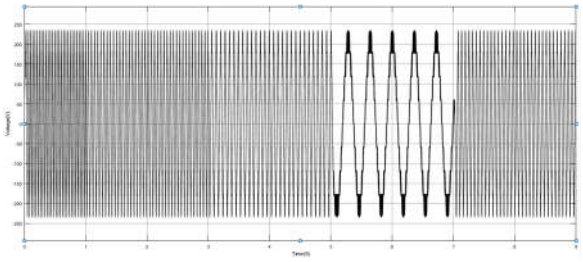


Fig.8 voltage across inverter

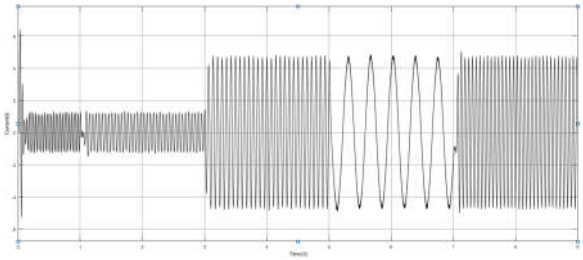


Fig.9 shows current at inverter

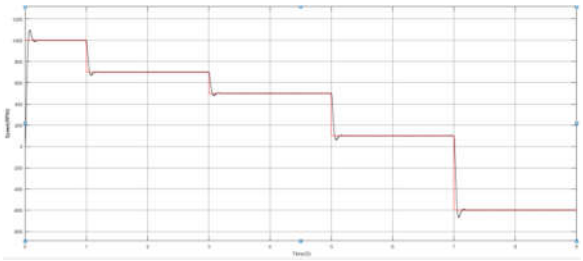


Fig.10 shows speed of induction motor.

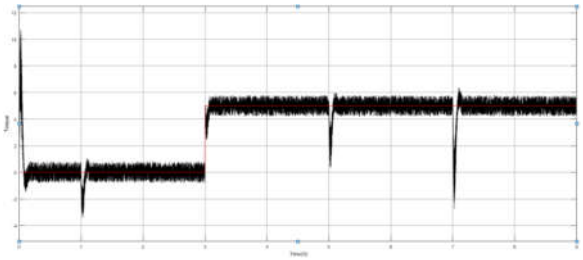
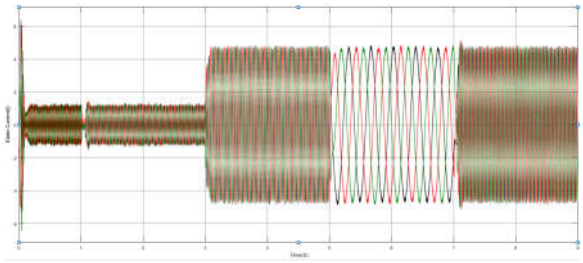


Fig.11 shows torque of induction motor.



``Fig.12 shows stator current of IM.

FUZZY LOGIC CONTROLLER

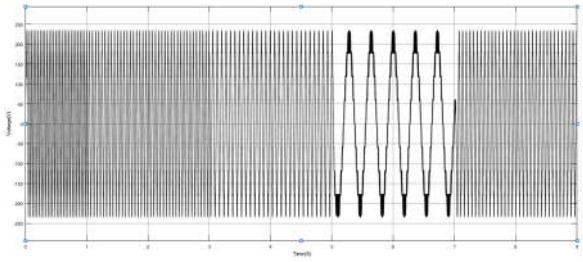


Fig.13 voltage across inverter

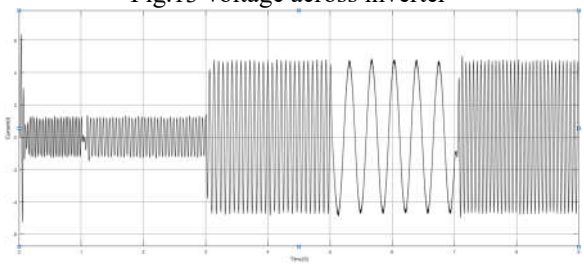


Fig.14 shows current at inverter

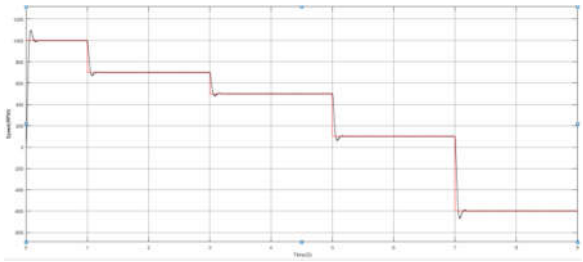


Fig.15 shows speed of induction motor.

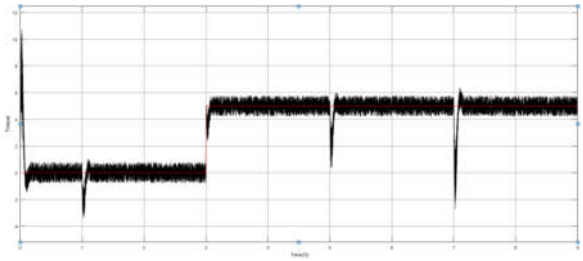


Fig.16 shows torque of induction motor.

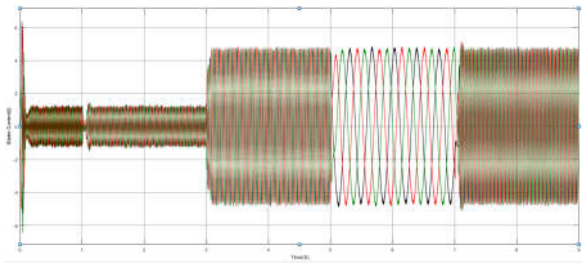


Fig.17 shows stator current of IM.

Results for both cases are looking same but while comparing with THD values, Fuzzy MMC is having

less percentage than PI MMC. For PI MMC the voltage THD value is 44.725, for Fuzzy THD is 41.005%. Maximum speed attained for Fuzzy MMC is 603.1 rpm, for PI MMC is 601.2 rpm

CONCLUSUION

Controlling of three-phase induction motor with both topologies of PI MMC and Fuzzy MMC was observed, and compared through MATLAB/SIMULATION. Fuzzy MMC topology is having high maximum speed attain value and low torque value and less harmonic content as compared with PI MMC topology. So Fuzzy MMC is having better performance.

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