

# Nine Level MLI fed Single Phase Induction Motor Drive with Compressor Load Using Artificial Neural Network

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**Abstract** – Recent developments in power electronics and power semiconductor drives have improved AC-AC power conversion methods related to AC drives. Rectifier- multilevel inverters (MLIs) find their way in connecting AC source and induction motor. In AC compressor system, MLI fed induction motor is preferred because of low harmonic content. The Artificial neural network controller (ANNC) is employed for an MLI fed induction motor drive to improve the good dynamic response. The MLI also provides the better total harmonics distortion (THD). The proposed ANNC is compared with proportional integral (PI) and ANNC provides the superior performance compared with the PI controller. The proposed ANNC has been verified with MATLAB/Simulink and laboratory test has been done using the PIC16F84- microcontroller. Theoretical analysis, simulation and experimental results have established the feasibility of the developed ANNC.

**Keywords:** Multilevel Inverter, Induction motor, Artificial Neural Network, & SIMULINK

## 1. Introduction

Multilevel inverters (MLIs) based research has attracted much attention in this field of motor control and renewable application [1]-[3]. The most widely used single phase induction motor has advantages like rugged construction, reduced maintenance, reliability and more economy. By using power electronic controller, the speed of such motors can be controlled. The IGBT technology is widely employed in voltage regulation. The drawbacks are retardation of firing angle, higher harmonics and discontinuous power supply to the motor. Ahmed has presented a new AC drive with single phase induction motor [4]. Chopper type AC voltage regulator has been proposed by Mohamadeen *et al.*, [5] based on microprocessor. AC chopper fed single phase induction motor drive with improved control circuit has been presented by

Ahmed *et al.*, [6]. A practical PWM topology has been described by Ziogas *et al.*, [7]. This method suffers from high switching losses and stresses.

Controlling motor voltage by AC choppers by using symmetrical Pulse Width Modulation (PWM) technique has been discussed in [8]. A four switched circuit is used to adjust the AC power which in turn investigates basic circuit characteristics [9-10]. An improved version of single phase induction motor has characteristics affecting the frequency as well as the phase angle. Ample opportunities have paved the way for the development of medium voltage drives and distributed generations for the deployment of moderate and high capacity inverters. Pulse width modulation is characterized by the limitation of electromagnetic interferences and switching losses owing to high rate of change of voltage. The electromagnetic interference level is also increased.

These problems can be eradicated by selective harmonic elimination based optical pulse width modulation which is frequently employed in two level and higher level inverters to minimize both total harmonic distortion and switching frequency. Topologies of multilevel inverters have been proposed by Lai [11-15]. AC traction drive with 3 and 5 levels GTO inverter has been given by Steinke *et al.*, [16-17]. Medium voltage multi-level drives have been presented by Beinholt *et al.*, [18].

Generalized multilevel inverter and hybrid multilevel inverter have been proposed by Peng and Lipo [19-22]. Static VAR generator using multilevel VSC has been demonstrated by Peng *et al.*, [23]. Elimination of harmonics in multilevel inverter has been discussed by Tolbert [24]. Several DC sources are utilized by a multilevel inverter. DC sources can be interconnected or separated using different circuit topologies. Due to the complexity of the problem, certain assumptions such as the DC voltage sources are balanced, single switching

angle per voltage level have been made [25-26]. Multilevel inverter output voltage levels are limited due to low modulation index ranges. Higher harmonic distortion will result due to one switching per level scheme. Sun [27] has developed harmonic reduction equation by using Optimal PWM based on real time solution. Fuzzy logic application for variable speed drive has been presented by Tang [28]. Optimal PWM for seven level inverter has been given by Rathore *et al.*, [29]. Bharathiraja *et al.*, [30-31] have suggested a type of multilevel inverter asymmetrical having reduced number of switches and increased voltage levels to 12 or 24. The performance analyzed based MLI fed induction motor drive are presented F.Salem *et al.*, [32-34].

The above works cited from the literature do not deal with the ANN controlled nine level inverter fed induction motor drive (NLIMD). To the author's knowledge the comparison of PI and ANN controlled NLIMD systems is not presented. This work proposes ANN controller for multilevel inverter based induction motor drive to enhance the overall dynamic response. The induction motor drive performance is improved by employing a nine level inverter. Boost converters are added at the input to achieve power factor correction.

The proposed paper furnishes the following sections besides the introduction. Section 2 deals with the block diagram of the proposed MLI fed drive system. Section 3 presents mathematical analysis and section 4 discusses the design procedure. Section 5 analyses simulation results of the PI controller and ANN controller. Section 6 presents the experimental results and section 7 summarizes the work.

## 2. Proposed MLI Fed Drive System

The diagrammatic representation of the existing method is displayed in Fig.1. Fixed AC is converted into DC using uncontrolled rectifier. DC is converted into AC using inverter.

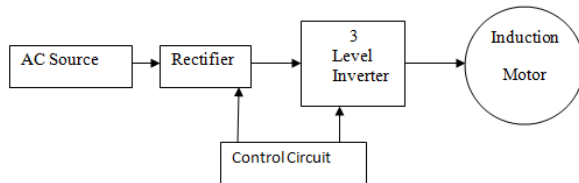


Fig.1. Block Diagram of Existing Module

The diagram of the proposed MLI fed induction motor drive is shown in Fig.2. The AC voltage is rectified using an uncontrolled rectifier and then two boost converters are used for power factor correction. The input for the MLI is fixed DC voltages. The output of the MLI is applied to the induction motor. The driving pulses required by the MLI are generated using the PIC16F84-microcontroller. Cascaded MLI is used to obtain nine-level output for driving the Induction motor.

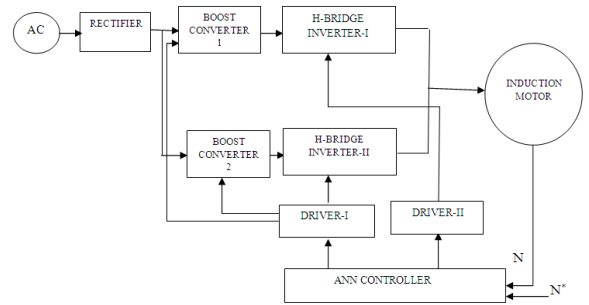


Fig.2. Proposed Block Diagram of the Induction Motor Drive System.

## 3. Mathematical Analysis

The output voltage is described as

$$V_o = \sum_{i=1}^n E_i S_i \quad (1)$$

where  $S_i$  is the switching function of the  $i^{\text{th}}$  node. It can have a value of zero or one.

The sum of the output voltages of the bridges implies the load voltages.

$$V_o = V_1 + V_2 \quad (2)$$

The stator current is

$$I_1 = \frac{V_1}{R_1 + jX_1 + R_{2s} + jX_{2s}} \quad (3)$$

The torque developed by the induction motor is

$$T = K \left( I_2^2 r_{2e} / s - I_2^2 r_{2e} / (2-s) \right) \quad (4)$$

where  $k$  is a constant,  $I_2$  denotes the rotor current,  $r_{2e}$  is the rotor resistance,  $s$  is the slip,  $N$  is the actual speed and  $N^*$  is the reference speed.

The elements of the boost converter are expressed as follows:

$$L = \frac{V_i D}{f_s I} \quad (5)$$

$$C = \frac{D}{2fR} \quad (6)$$

## 4. Design Procedure

Design procedure is added by obtaining the values of source voltage, rectifier output and operating frequency of the boost converter.

$$V_a = \frac{V_1}{(1-D)} \quad (7)$$

Efficiency of the boost converter is

$$\eta = \frac{V_2 I_2}{V_1 I_1} \quad (8)$$

The values of L and C are calculated by assuming the tolerance level for  $\Delta I$  and  $\Delta V$ .

$$\Delta V = \frac{V_2 D}{fL} \quad (9)$$

$$\Delta I = \frac{I_2 D}{fC} \quad (10)$$

There are sixteen operating modes in each cycle of multilevel inverter. The duration of each mode is  $T/16$ , where T is the time period.

## 5. Simulation results

A simulation circuit of nine-level MLI fed single phase induction motor drive using MATLAB is shown in Fig.3. The DC input voltages required at the input of the MLI are obtained from two rectifiers. Two uncontrolled rectifiers are used to obtain two different inputs required by the boost converters. The outputs of boost converters are applied to the respective bridges of multilevel inverter. The front end boost converter and simulation parameters are given in Table-1.

**Table 1: Simulation Parameters**

Parameter	Value
$V_{in}$	48V
$L_1$	100mH
$C_1$	3000 $\mu$ F
MOSFET	500V/8A
DIODE	230V/8A
$V_o$	150V

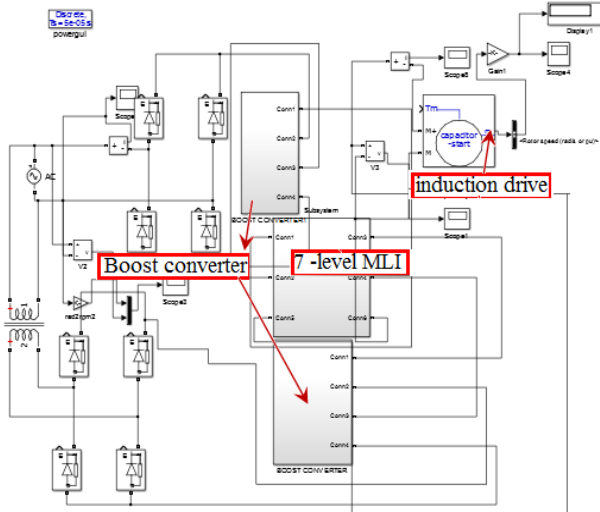


Fig.3. Simulink model of the open loop system with step change in load torque

The rectifier is operated to provide DC input voltages of the MLI and they are 50V and 150V. The corresponding output voltage of the inverter is shown in Fig.4. Here, the peak value of the MLI output is 150V which has four positive and four negative levels. The speed response of the induction motor is reduced to 1400 RPM, when the load torque is increased as shown in Fig.5.

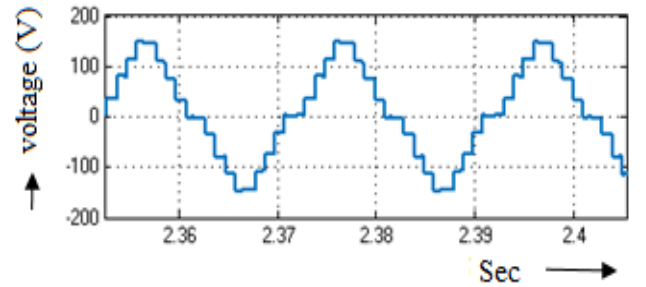


Fig.4 Simulation result of 9-MLI with open loop

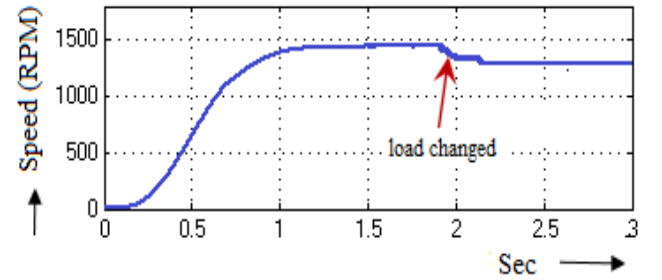


Fig.5 Speed response with before and after load change

Next, the PI controller based closed loop controlled MLI is verified with simulation. Here, the actual speed (1450 rpm) is compared with a reference speed. The error is applied to the PI controller, the output of PI controller is applied to a comparator, and the comparator modifies the pulse width applied to the boost converter.

Pulse width is modulated by maintaining a switching frequency of 20 KHz. The speed response is shown in Fig.6. The speed decreases from 1490RPM due to the increase in the load on the induction motor and then reaches normal value of 1490RPM by closed loop control. Here, the speed is settled with the setting time of 2.5 sec and steady state error of 15 RPM error speed.

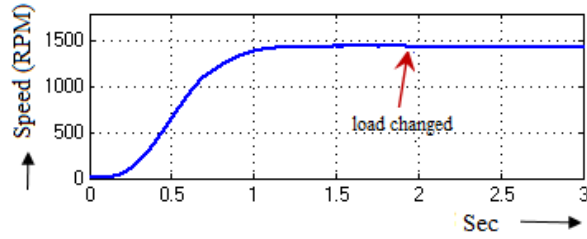


Fig.6. Speed response with before and after load change for PI controller based MLI fed induction motor

Next, the induction motor speed is trained with NN controller. The parameters of the PI controller are to be adjusted for every load condition since induction motor is a non-linear load. So the non linearity of the induction motor drive is handled by artificial neural network controller. Neural network controller is almost similar to human thinking and one of the intelligent controllers. The MATLAB simulation model of neural network controlled induction motor drive system is shown in Fig.7. The input signals to the ANN are error and its derivative. The output of neural network controller controls the pulse width applied to the power factor correction (PFC) circuit. The voltage applied to the Induction motor is shown in Fig.8 and the corresponding THD is 7.85%. The increase in the amplitude of voltage is due to the increase in the output of the boost converter. The current waveform is shown in Fig.9. The increases of load torque raise the load current. The speed response is shown in Fig.10. The speed is regulated by using the ANN controller.

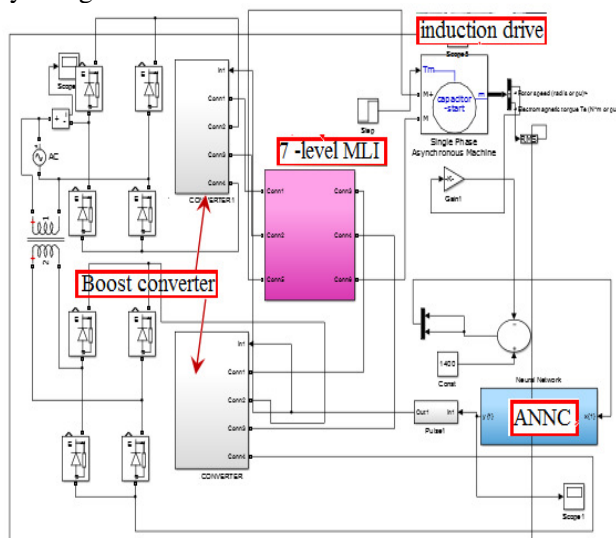


Fig.7 Simulink model of the closed loop system with ANN

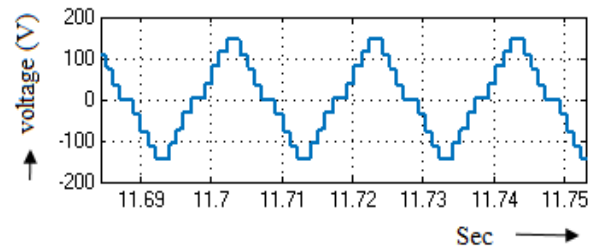


Fig.8 Simulation result of 9-MLI voltage waveform with closed loop system with ANN

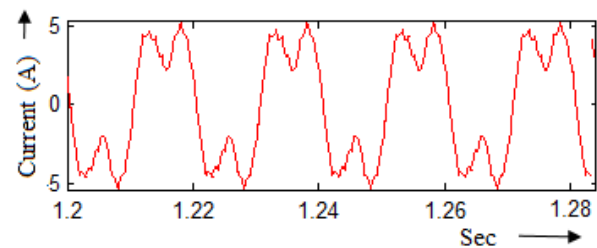


Fig.9 Simulation result of motor current waveform with closed loop system with ANN

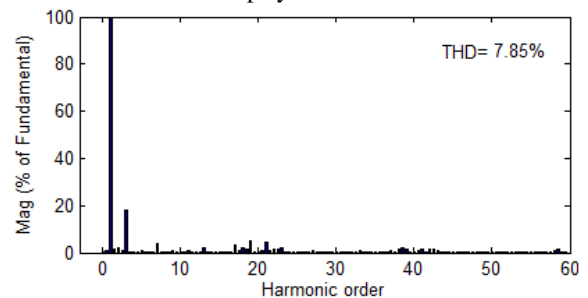


Fig.10 Simulation result of 9-MLI voltage THD

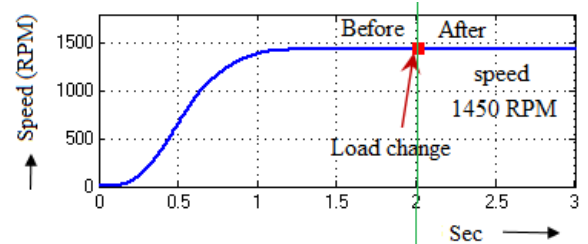


Fig.11 Speed response with before and after load change for closed loop system with ANN

The speed response of the neural network controlled system is smoother than that of the PI controlled system. The comparison of response with PI and the proposed neural network controllers is given in Table 2. It can be seen that the rise time,

peak time, settling time and steady state error are reduced by using neural network controller. The settling time is reduced from 2.65 to 0.2 secs by replacing the PI with the ANN controller. The steady state error is as small as 1RPM using ANN controller.

**Table 2: Comparison of Responses of PI and Proposed ANN Systems**

Controller	Rise time (s)	Peak time (s)	Setting time (s)	Steady state error (RPM)
PI	2.3	2.5	2.65	15
ANN	0.1	0.16	0.2	1

## 6. Hardware Results

The overall experimental system is depicted in Fig.12, and it includes the PIC16F84-microcontroller), a MOSFET (IRF540) based MLI and a single phase capacitor run induction motor drive. The power of the PMSM is 250W, the rating speed is 1500rpm, and the torque magnitude of the brake is adjustable in the range of 0.2 to 5N\*m. The parameters used in the hardware implementation are given in Table-3.

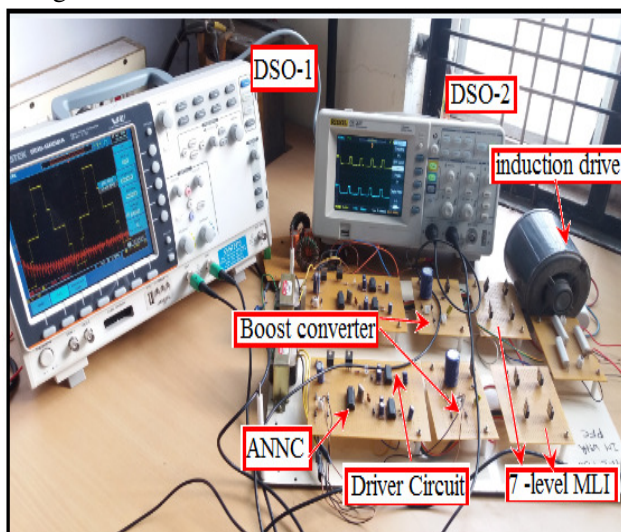


Fig.12. Hardware set-up of the proposed ANN based operated MLI fed induction motor drive

The DC input voltages  $V_{d1}$  and  $V_{d2}$  are delivered through uncontrolled rectifier through boost converter set. The MLI requires eight switches and

four drivers. The DC supply for the controller and the driver circuits is obtained using suitable voltage regulators. The control circuit and the power circuit are isolated by the driver circuit. The switching pulse of the inverter is shown in Fig.13. Initially motor is set at the speed of 1500 rpm with 1 Nm load torque and then the torque is increased to 2 Nm. Now the motor speed is maintained at 1500 rpm with the help of the ANN. Here the ANN is boosting the boost converter gain to catch the set speed as 1500rpm. Fig.14 shows the MLI output voltage and Fig.4 shows the harmonics spectra of MLI output voltage. Based on Fig.15, it seen that the inverter output THD is maintained less (7.4%).

**Table 3: Hardware Specifications**

S.No.	Name	Rating	Type
1	Capacitor	1000 $\mu$ F/25V	Electrolytic
2	Capacitor	47 $\mu$ F/63V	Electrolytic
3	Capacitor	104pf, 33pf	Disc
4	Capacitor	2200 $\mu$ F/63V	Electrolytic
5	Diode	IN4007-1000V	PN Junction
6	Inductance	10 $\mu$ H	Ferrite core
7	MOSFET (IR840)	500V, 8A	N-Channel
8	Resistor	1k	Quarter watt
9	Resistor	100E	5 Watts
10	Resistor	22E	5 Watts
11	Regulator	12V	L7812/TO3
12	Regulator	5V	L7805/TO220
13	IC	IR2110	Opto-coupler
14	PIC Controller	PIC16F84A	RISC
15	PCB	V105	General
16	Induction Motor	0.5 HP, 5A, 230 Volts, 1500RPM	Induction type, Non linear load

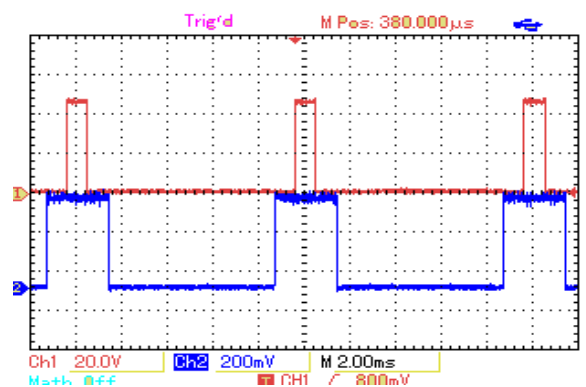


Fig. 13 Controlled MLI PWM pulses



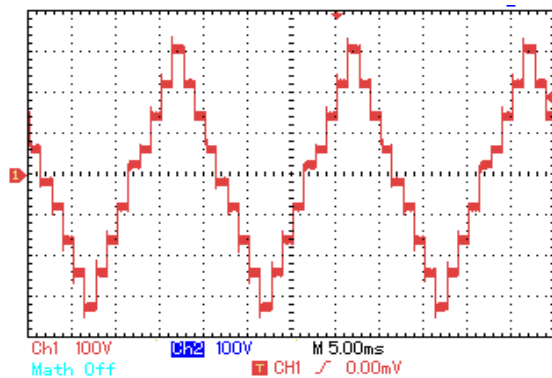


Fig.14 ANN operated 9-level MLI voltage waveform

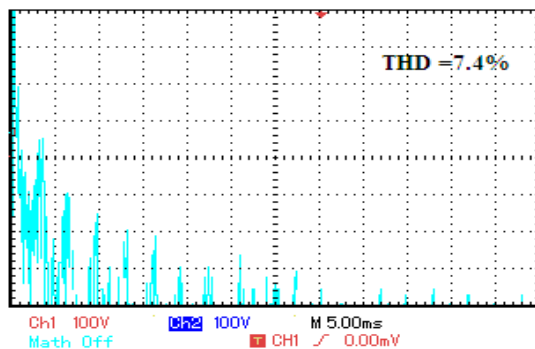


Fig.15 THD spectra of the ANNC operated MLI output voltage

The speed response of the motor is measured with tacho-generator. The speed response is similar to the simulation results changed with reduced setting time (1ms), which is less than  $\frac{1}{2}$  interval time of AC output signal. Based on the speed response the proposed ANNC hardware validation establishes that the proposed MLI fed induction drive system.

## 6. Conclusion:

Cascaded boost converter, multilevel inverter system has been designed and developed to obtain the advantages of power factor correction and THD reduction. In this paper, neural network controller based a nine level inverter has been presented for the control of single phase Induction motor drive. Simulation with controllers like the PI and the ANN under load variation has been performed using MATLAB. The results have indicated that the ANN controlled system is superior to the PI controlled system, since the settling time and steady state error have been drastically reduced. The neural network controller based system has produced output with less overshoot. The drive

system has advantages like reduced heating due to low harmonics and has improved power factor due to power factor correction. The hardware module has been fabricated, tested and the corresponding results have been presented. It has been observed that the experimental results are in agreement with the simulation results. The investigations on the fuzzy logic controlled drive will be done in the future. The response of the neural network controlled system will be compared with the fuzzy logic controlled system. The hardware can also be extended using the FPGA controlled system to enhance the switching frequency.

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