

THREE PHASE GENERALIZED 63 LEVEL MULTILEVEL INVERTER FED INDUCTION MOTOR DRIVE WITH INTELLIGENT CONTROLLERS

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Abstract : Multilevel inverters play a pivotal role for smooth functioning of AC drives, pumps, UPS, railway locomotives, grid connected photovoltaic systems and are grabbed attention by many researchers mainly because of their minimal harmonic distortion and production of good quality output power compared to conventional two level inverters. Against this back drop this paper presents 63 level optimal structured single phase multilevel inverter by means of fewer switches and Sinusoidal Pulse Width Modulation- (SPWM) technique used according to the requirements the switches were operated. In the next step three phase optimal cascaded 63 level multilevel inverter with same SPWM controlling technique is implemented. In the consequent step closed loop optimal cascaded high level multilevel inverter feeding induction motor (IM) drive with Fuzzy Logic Controller (FLC) has been designed. To further better performance with same drive, replace FLC with Adaptive Neuro Fuzzy Inference System (ANFIS) controller by verifying voltage, current, distortion and speed- torque under no load and ON load conditions. By following the above mentioned methods the proposed drive of validity has been proved with MATLAB/SIMULINK.

Index terms: Multilevel inverter, Induction motor, FLC, ANFIS, THD, Speed, Torque.

I. INTRODUCTION

The multilevel inverters (MLIs) are consisting of power semiconductor switches arranged in such a manner with number of DC voltage sources used for generating alternating wave form with different steps of voltage levels. When compared to classical two level inverters these MLIs [1-2] have tremendous features such as low switching losses, low electromagnetic interference, and minimum distortion, reduced dv/dt stress on load and quality output waveform. If number of levels are improved in output waveform that leads to decrease total harmonic distortion. Another advantage of MLIs is high voltage requirement is achieved by connecting modules of MLIs in a series manner. The applications of MLIs are UPS, speed control of AC drives, HVDC system, reactive power compensators and smart grid with PV system. Generally classical MLIs are categorized into three types (i) Neutral point or diode clamped MLIs [3] (ii) Flying or fixed capacitor MLIs [4] (iii) Cascaded multilevel inverters [5]. With above classical MLIs some other topologies are symmetric & asymmetric multilevel inverters [6-7], hybrid type MLIs with combination of diode clamped and flying capacitor. The performance investigation for four - Switch three phase Inverter with PI and FLC was implemented [8]. A control technique was implemented with new neural network applicable to induction motor [9]. An induction motor had been controlled by using direct torque control method with sophisticated lookup tables based on neural networks. Common mode voltage can be minimized using novel space vector PWM with direct torque control feeding induction motor [10]. Acoustical noise was reduced by using random operated SVPWM for induction motor with direct torque control technique.

Initially in industry applications three phase inverter with six switches were used which were not suitable for medium and high voltage or power requirements due to high switching losses, controlling technique complexity and low quality output. To avoid such problems, classical multilevel inverters were designed and implemented. Problems in classical MLIs were - more switching devices, DC sources with high standing voltages and distortion. Most of the industrial requirements three phase induction motors were used due to their simple construction and ruggedness. Ancient days speed control AC motor done with three phase voltage source inverter (VSI) but this drive speed torque performance was very poor. In order to improve drive performance, classical MLIs were replaced in place of VSIs.

Still to improve performance of AC motor drives an optimal structured 63 level MLI is proposed with minimum required count of switches and DC sources through sinusoidal pulse width modulation control technique for proper operation switches. The proposed MLI produces very low switching losses, low off state voltage drops and minimum total harmonic distortion-(THD) due to the cause of almost sinusoidal output wave form at output with more levels. The proposed MLI control of induction motor drive through FLC is compared with proposed MLI feeding induction motor drive with ANFIS controller for achieving better speed torque performance.

II. DESIGN OF OPTIMAL CASCADED HIGH LEVEL MULTILEVEL INVERTER

The proposed optimal cascaded 63 level MLI is shown in figure 1 which is designed with series connection of ‘u’ number of sub units to achieve more steps of voltage levels in output waveform. Each sub unit contains two switches with one DC source. A number of output levels in voltage wave form decided based on quantity of DC sources applied in every one sub division of proposed MLI. If all ‘s’ number of DC sources values are same then low levels are obtained in output but with different values of DC sources with ratio of 1:2:4:8:16 applied to respective sub units, more number of levels are achieved in output.

$$N_{SWITCH} = 2u + 4, \text{ when } s = 1$$

$$= u(s + 2), \text{ when } s \geq 2 \tag{1}$$

$$N_{DRIVER} = N_{SWITCH} \tag{2}$$

$$N_{IGBT} = 2us + 4 \tag{3}$$

$$N_{SOURCE} = u * s \tag{4}$$

$$V_{DC,1} = V_{DC,2} = \dots = V_{DC,u} \tag{5}$$

$$N_{LEVEL} = 2u + 1, \text{ If DC sources equal} \tag{6}$$

$$V_{DC,J} = (s + 1)^{(J+1)} V_{DC,1} \tag{7}$$

where $J = 1, 2, 3, \dots, u$

$$N_{LEVEL} = 2^{(u+1)} - 1, \text{ If DC sources unequal} \tag{8}$$

Where $V_{DC,J}$, N_{SWITCH} , N_{DRIVER} , N_{IGBT} , N_{SOURCE} , N_{LEVEL} are the DC voltage of J^{th} Sub unit, No. Of switches, No. Of switches’ drivers, No. of IGBTs and total No. of Sources for proposed MLI. The Series connected sub units of proposed MLI produces only zero and positive levels of output. An H bridge linked with series combination of sub units to obtain negative levels in addition to positive levels and zero level. The positive levels of output voltages are obtained during the ON condition of ‘H₁’ and ‘H₄’ devices in the H-Bridge and negative levels of output voltages are achieved for ON position of ‘H₂’ and ‘H₃’ in the H-Bridge

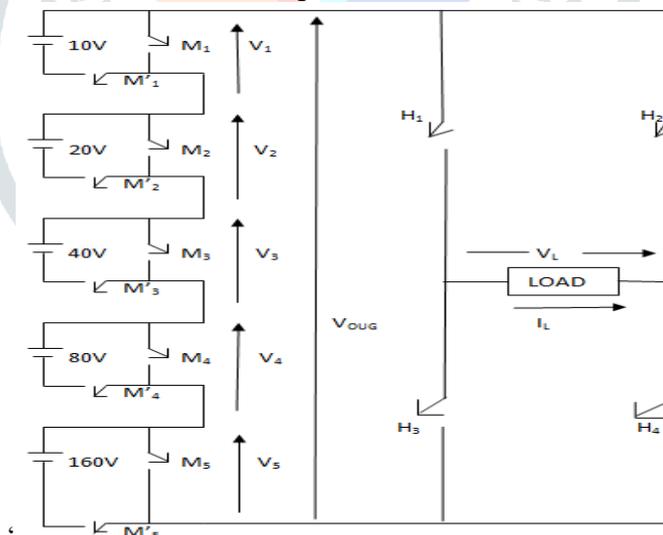


Figure 1.Single phase proposed optimal cascaded 63 level MLI

Table 1.ON state switching patterns for 63 level proposed optimal MLI

| Voltage (PU) | Switches to be Conduct | Level Num. |
|--------------|---------------------------------------|------------|
| +31 | M'1 , M'2 , M'3 , M'4 , M'5 , H1 , H4 | 1 |
| +30 | M1 , M'2 , M'3 , M'4 , M'5 , H1 , H4 | 2 |
| +29 | M'1 , M2 , M'3 , M'4 , M'5 , H1 , H4 | 3 |
| +28 | M1 , M2 , M'3 , M'4 , M'5 , H1 , H4 | 4 |
| +27 | M'1 , M'2 , M3 , M'4 , M'5 , H1 , H4 | 5 |
| +26 | M1 , M'2 , M3 , M'4 , M'5 , H1 , H4 | 6 |
| +25 | M'1 , M2 , M3 , M'4 , M'5 , H1 , H4 | 7 |
| +24 | M1 , M2 , M3 , M'4 , M'5 , H1 , H4 | 8 |
| +23 | M'1 , M'2 , M'3 , M4 , M'5 , H1 , H4 | 9 |

| | | |
|-----|--|----|
| +22 | $M_1, M'_2, M'_3, M_4, M'_5, H_1, H_4$ | 10 |
| +21 | $M'_1, M_2, M'_3, M_4, M'_5, H_1, H_4$ | 11 |
| +20 | $M_1, M_2, M'_3, M_4, M'_5, H_1, H_4$ | 12 |
| +19 | $M'_1, M'_2, M_3, M_4, M'_5, H_1, H_4$ | 13 |
| +18 | $M_1, M'_2, M_3, M_4, M'_5, H_1, H_4$ | 14 |
| +17 | $M'_1, M_2, M_3, M_4, M'_5, H_1, H_4$ | 15 |
| +16 | $M_1, M_2, M_3, M_4, M'_5, H_1, H_4$ | 16 |
| +15 | $M'_1, M'_2, M'_3, M'_4, M_5, H_1, H_4$ | 17 |
| +14 | $M_1, M'_2, M'_3, M'_4, M_5, H_1, H_4$ | 18 |
| +13 | $M'_1, M_2, M'_3, M'_4, M_5, H_1, H_4$ | 19 |
| +12 | $M_1, M_2, M'_3, M'_4, M_5, H_1, H_4$ | 20 |
| +11 | $M'_1, M'_2, M_3, M'_4, M_5, H_1, H_4$ | 21 |
| +10 | $M_1, M'_2, M_3, M'_4, M_5, H_1, H_4$ | 22 |
| +9 | $M'_1, M_2, M_3, M'_4, M_5, H_1, H_4$ | 23 |
| +8 | $M_1, M_2, M_3, M'_4, M_5, H_1, H_4$ | 24 |
| +7 | $M'_1, M'_2, M'_3, M_4, M_5, H_1, H_4$ | 25 |
| +6 | $M_1, M'_2, M'_3, M_4, M_5, H_1, H_4$ | 26 |
| +5 | $M'_1, M_2, M'_3, M_4, M_5, H_1, H_4$ | 27 |
| +4 | $M_1, M_2, M'_3, M_4, M_5, H_1, H_4$ | 28 |
| +3 | $M'_1, M'_2, M_3, M_4, M_5, H_1, H_4$ | 29 |
| +2 | $M_1, M'_2, M_3, M_4, M_5, H_1, H_4$ | 30 |
| +1 | $M'_1, M_2, M_3, M_4, M_5, H_1, H_4$ | 31 |
| 0 | M_1, M_2, M_3, M_4, M_5 | 32 |
| -31 | $M'_1, M'_2, M'_3, M'_4, M'_5, H_2, H_3$ | 33 |
| -30 | $M_1, M'_2, M'_3, M'_4, M'_5, H_2, H_3$ | 34 |
| -29 | $M'_1, M_2, M'_3, M'_4, M'_5, H_2, H_3$ | 35 |
| -28 | $M_1, M_2, M'_3, M'_4, M'_5, H_2, H_3$ | 36 |
| -27 | $M'_1, M'_2, M_3, M'_4, M'_5, H_2, H_3$ | 37 |
| -26 | $M_1, M'_2, M_3, M'_4, M'_5, H_2, H_3$ | 38 |
| -25 | $M'_1, M_2, M_3, M'_4, M'_5, H_2, H_3$ | 39 |
| -24 | $M_1, M_2, M_3, M'_4, M'_5, H_2, H_3$ | 40 |
| -23 | $M'_1, M'_2, M'_3, M_4, M'_5, H_2, H_3$ | 41 |
| -22 | $M_1, M'_2, M'_3, M_4, M'_5, H_2, H_3$ | 42 |
| -21 | $M'_1, M_2, M'_3, M_4, M'_5, H_2, H_3$ | 43 |
| -20 | $M_1, M_2, M'_3, M_4, M'_5, H_2, H_3$ | 44 |
| -19 | $M'_1, M'_2, M_3, M_4, M'_5, H_2, H_3$ | 45 |
| -18 | $M_1, M'_2, M_3, M_4, M'_5, H_2, H_3$ | 46 |
| -17 | $M'_1, M_2, M_3, M_4, M'_5, H_2, H_3$ | 47 |
| -16 | $M_1, M_2, M_3, M_4, M'_5, H_2, H_3$ | 48 |
| -15 | $M'_1, M'_2, M'_3, M'_4, M_5, H_2, H_3$ | 49 |
| -14 | $M_1, M'_2, M'_3, M'_4, M_5, H_2, H_3$ | 50 |
| -13 | $M'_1, M_2, M'_3, M'_4, M_5, H_2, H_3$ | 51 |
| -12 | $M_1, M_2, M'_3, M'_4, M_5, H_2, H_3$ | 52 |
| -11 | $M'_1, M'_2, M_3, M'_4, M_5, H_2, H_3$ | 53 |
| -10 | $M_1, M'_2, M_3, M'_4, M_5, H_2, H_3$ | 54 |
| -9 | $M'_1, M_2, M_3, M'_4, M_5, H_2, H_3$ | 55 |
| -8 | $M_1, M_2, M_3, M'_4, M_5, H_2, H_3$ | 56 |
| -7 | $M'_1, M'_2, M'_3, M_4, M_5, H_2, H_3$ | 57 |
| -6 | $M_1, M'_2, M'_3, M_4, M_5, H_2, H_3$ | 58 |
| -5 | $M'_1, M_2, M'_3, M_4, M_5, H_2, H_3$ | 59 |
| -4 | $M_1, M_2, M'_3, M_4, M_5, H_2, H_3$ | 60 |
| -3 | $M'_1, M'_2, M_3, M_4, M_5, H_2, H_3$ | 61 |
| -2 | $M_1, M'_2, M_3, M_4, M_5, H_2, H_3$ | 62 |
| -1 | $M'_1, M_2, M_3, M_4, M_5, H_2, H_3$ | 63 |

Table 1 shows the corresponding switches should be ON for producing various output voltage levels of proposed optimal 63 level MLI shown in figure 1. To get output level as 1 or voltage P.U as +31 the following switches $M'_1, M'_2, M'_3, M'_4, M'_5, H_1, H_4$ should be in ON condition. Similarly $M'_1, M_2, M_3, M_4, M_5, H_1, H_4$ should be ON to get output level as +1PU or 31 level. Suppose to achieve level 33 or P.U voltage is -31 switches $M'_1, M'_2, M'_3, M'_4, M'_5, H_2, H_3$ need to be conducting state. Likewise M_1, M_2, M_3, M_4, M_5 switching devices required to turn ON for zero P.U voltage or 32 level output. In order to get 63 level or -1 P.U voltage the following switches $M'_1, M_2, M_3, M_4, M_5, H_2, H_3$ should be ON. Similarly based on level number or PU unit voltage above table 2 said respective switches are in ON state.

III. DESIGN OF PROPOSED INDUCTION MOTOR DRIVE

The proposed MLI is extended as three phase 63 level optimal MLI is with star connection of three individual single phase 63 optimal MLIs. Hence the designed three phase optimal MLI is feeding with IM with different controllers for improving drive performance.

Electro Magnetic Torque equation

$$T_e = J \frac{d\omega_r}{dt} + B\omega_r + T_L \tag{9}$$

J-Moment of inertia; ω_r -Rotor speed (rad/sec),

B-friction coefficient, T_L -Load torque

Induction motor rotor speed equation

$$\omega_r = \omega_s (1-S) \tag{10}$$

Synchronous speed (rad /sec)

$$\omega_s = 2\pi N_s / 60 \tag{11}$$

Synchronous speed (rev/min)

$$N_s = 120f / p \tag{12}$$

Slip of induction motor

$$S = (\omega_s - \omega_r) / \omega_s \tag{13}$$

‘S’ means Slip of induction motor, ‘f’ is frequency of supply to stator of IM, ‘p’ means poles number of magnets.

3.1 Closed loop control of optimal MLI fed IM drive with FLC

The operation of FLC shown in figure 2 depends on linguistic rules IF, AND & THEN operators. The importance of FLC is to make the induction motor actual current, voltage, speed and torque equals to given reference values of the same .There are two inputs given to FLC one is error in voltage ‘ ΔV ’ and second is change in error voltage ‘ ΔE ’ and with five membership functions such as ‘NL’ negative low, ‘NH’ negative high, ‘PL’ positive low, ‘PH’ positive high, ‘ZE’ zero equal. By using above said five membership functions, 25 rules are made in FLC for reducing error between actual and reference values as shown in table 2 for improving presentation of projected optimal MLI fed induction motor drive. The 63 level MLI feeding induction drive controlled by FLC block diagram is as shown in figure 4 by replacing ANFIS with FLC. The input to the FLC is the difference in voltage between reference value and actual value obtained from MLI. The function of FLC controller is to decrease the steady state and transient error in voltage and the same as input to the induction motor for improving drive performance.

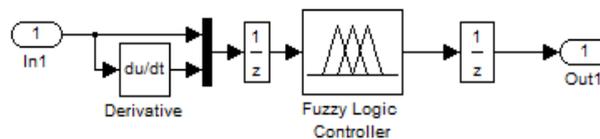


Figure 2. Fuzzy logic controller implementation in drive
Table 2. Rules for FLC

| S.No | Rule |
|------|---|
| 1 | IF (ΔV is NH) AND (ΔE is NH) THEN (ERROR is ZE) |
| 2 | IF (ΔV is NH) AND (ΔE is NL) THEN (ERROR is NL) |
| 3 | IF (ΔV is NH) AND (ΔE is ZE) THEN (ERROR is NH) |
| 4 | IF (ΔV is NH) AND (ΔE is PL) THEN (ERROR is NH) |
| 5 | IF (ΔV is NH) AND (ΔE is PH) THEN (ERROR is NH) |
| 6 | IF (ΔV is NL) AND (ΔE is NH) THEN (ERROR is PL) |
| 7 | IF (ΔV is NL) AND (ΔE is NL) THEN (ERROR is ZE) |
| 8 | IF (ΔV is NL) AND (ΔE is ZE) THEN (ERROR is NL) |
| 9 | IF (ΔV is NL) AND (ΔE is PL) THEN (ERROR is NH) |
| 10 | IF (ΔV is NL) AND (ΔE is PH) THEN (ERROR is NH) |
| 11 | IF (ΔV is ZE) AND (ΔE is NH) THEN (ERROR is PH) |
| 12 | IF (ΔV is ZE) AND (ΔE is NL) THEN (ERROR is PL) |
| 13 | IF (ΔV is ZE) AND (ΔE is ZE) THEN (ERROR is ZE) |
| 14 | IF (ΔV is ZE) AND (ΔE is PL) THEN (ERROR is NL) |
| 15 | IF (ΔV is ZE) AND (ΔE is PH) THEN (ERROR is NH) |
| 16 | IF (ΔV is PL) AND (ΔE is NH) THEN (ERROR is PH) |
| 17 | IF (ΔV is PL) AND (ΔE is NL) THEN (ERROR is PH) |
| 18 | IF (ΔV is PL) AND (ΔE is ZE) THEN (ERROR is PL) |
| 19 | IF (ΔV is PL) AND (ΔE is PL) THEN (ERROR is ZE) |
| 20 | IF (ΔV is PL) AND (ΔE is PH) THEN (ERROR is NL) |

| | |
|----|---|
| 21 | IF (ΔV is PH) AND (ΔE is NH) THEN (ERROR is PH) |
| 22 | IF (ΔV is PH) AND (ΔE is NL) THEN (ERROR is PH) |
| 23 | IF (ΔV is PH) AND (ΔE is ZE) THEN (ERROR is PH) |
| 24 | IF (ΔV is PH) AND (ΔE is PL) THEN (ERROR is PL) |
| 25 | IF (ΔV is PH) AND (ΔE is PH) THEN (ERROR is ZE) |

In the above table 2 ' ΔV ' means voltage error as input 1; ' ΔE ' means change in voltage error as input 2, 'ERROR' means output voltage error.

3.2 Closed loop control of optimal MLI fed IM drive with ANFIS

In figure 4, proposed novel three phase 63 level MLI is connected to three phase induction motor with ANFIS in closed loop control system. In proposed drive the three phase inverter is implemented with three single phase 63 level MLIs. When compared to closed loop drive with fuzzy logic controller, the proposed closed loop drive with ANFIS controller offers better performance in case of THD in voltage and current, Speed and Torque control. 'V' is the reference voltage (310 volts) is compared with actual voltage from proposed MLI and the error is applied as input to the ANFIS. The function of ANFIS shown in figure 3 in the proposed drive is minimized error and improves the drive performance.

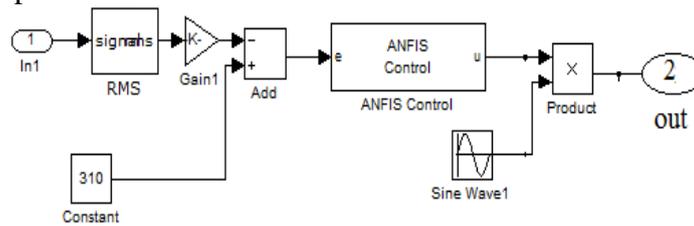
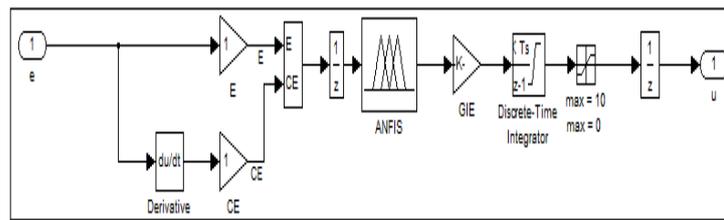


Figure 3 (a) Simulation model of ANFIS implementation in drive



ANFIS control

Figure 3(b) ANFIS controller internal representation; E –Error in voltage, CE-Change in error voltage.

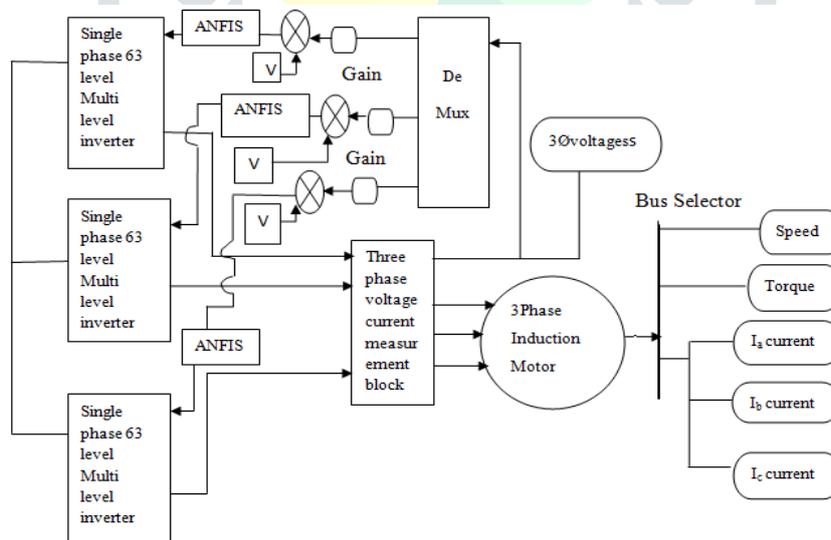


Figure 4 Closed loop control 3 Phase IM fed by three phase 63 level MLI through ANFIS controller.

IV. RESULTS AND DISCUSSION

4.1 Proposed single phase optimal 63 level MLI

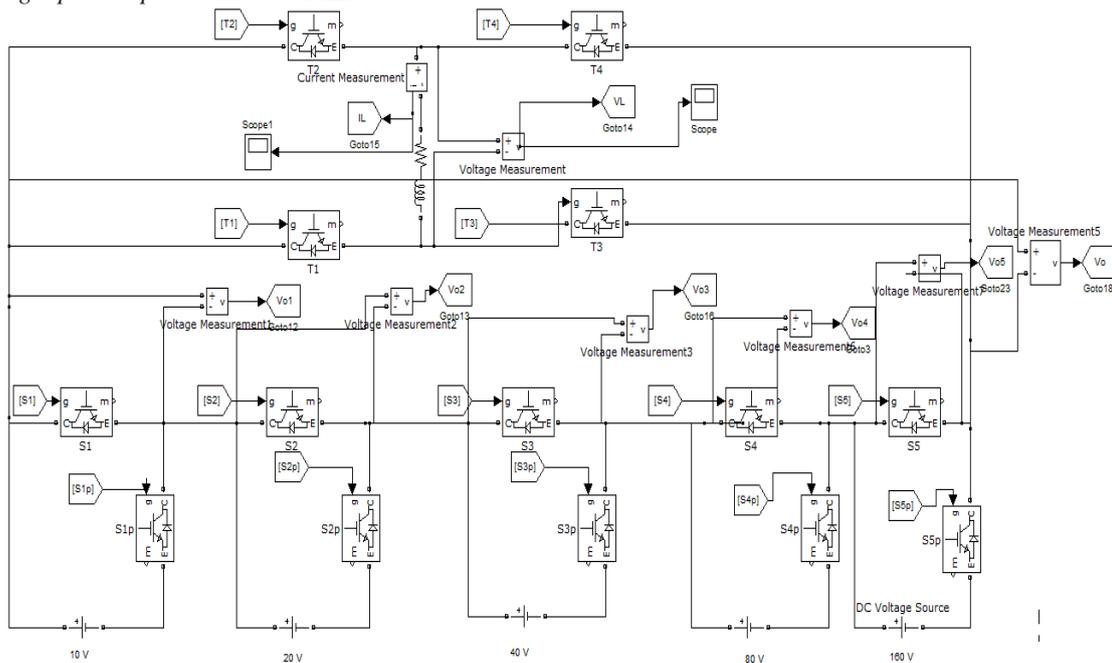


Figure 5(a) Simulation model of single phase optimal 63 level MLI

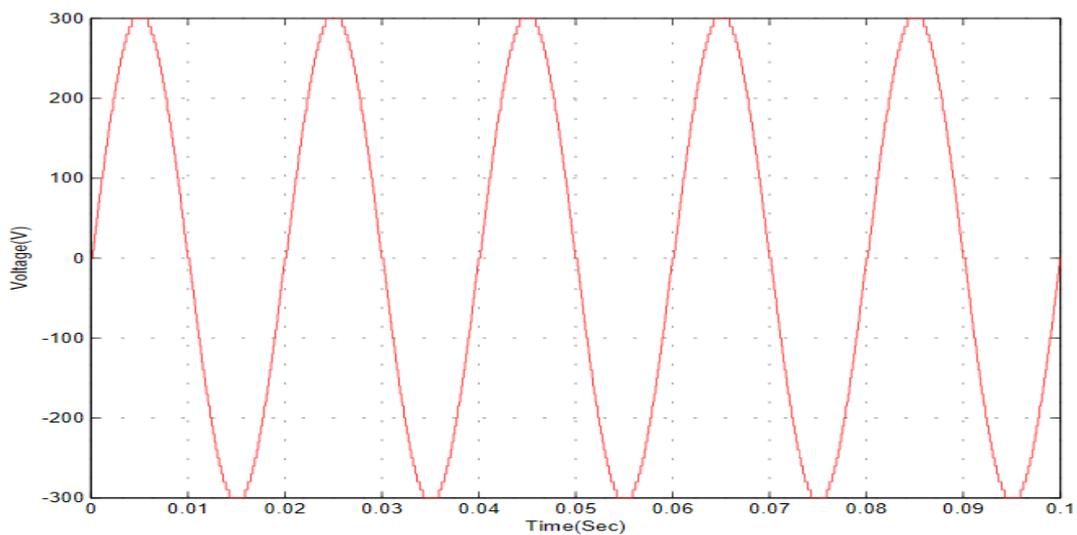


Figure 5 (b) Output voltage of the 63 level single phase proposed optimal MLI

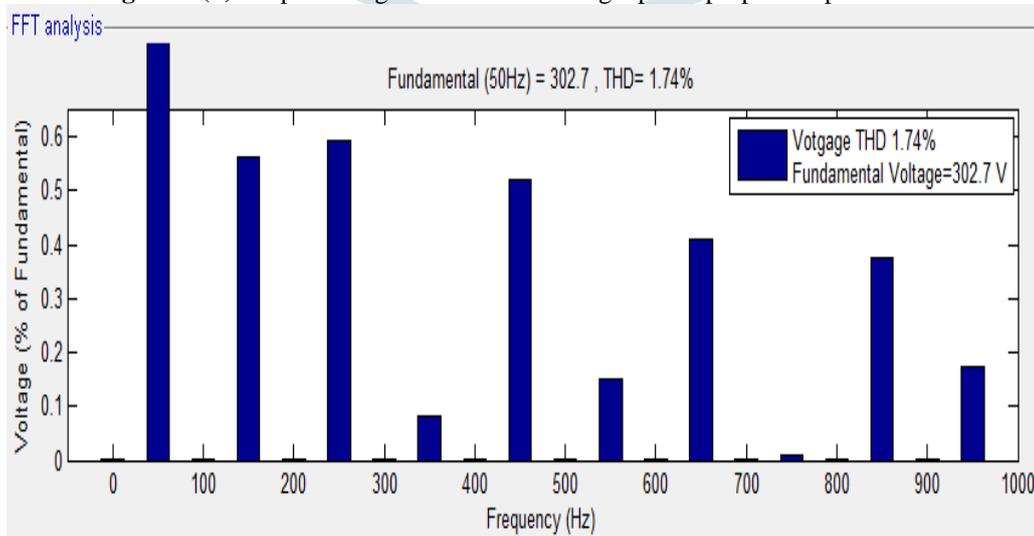


Figure 5(c) THD (1.74%) in voltage of 63 level single phase proposed optimal MLI

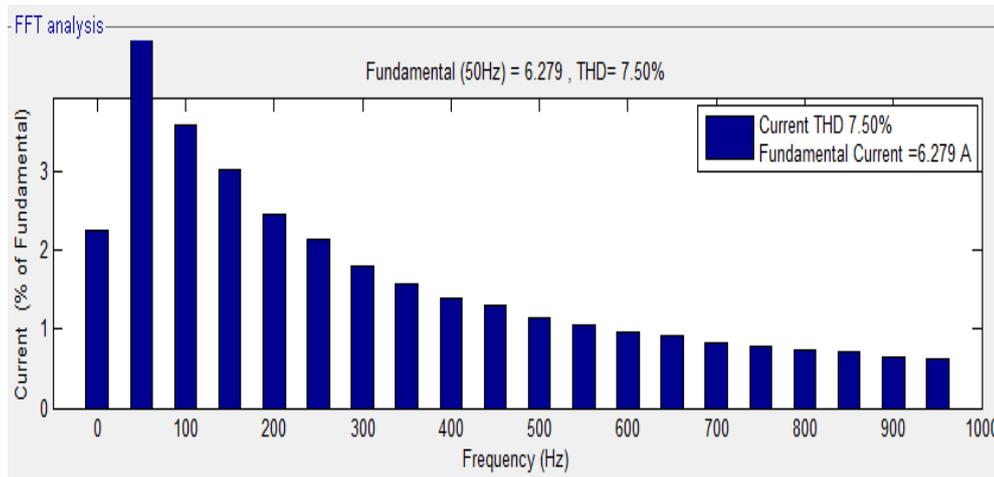


Figure 5 (d) THD (6.70%) in current of 63 level single phase proposed optimal MLI

4.2. Closed loop control of IM drive with FLC

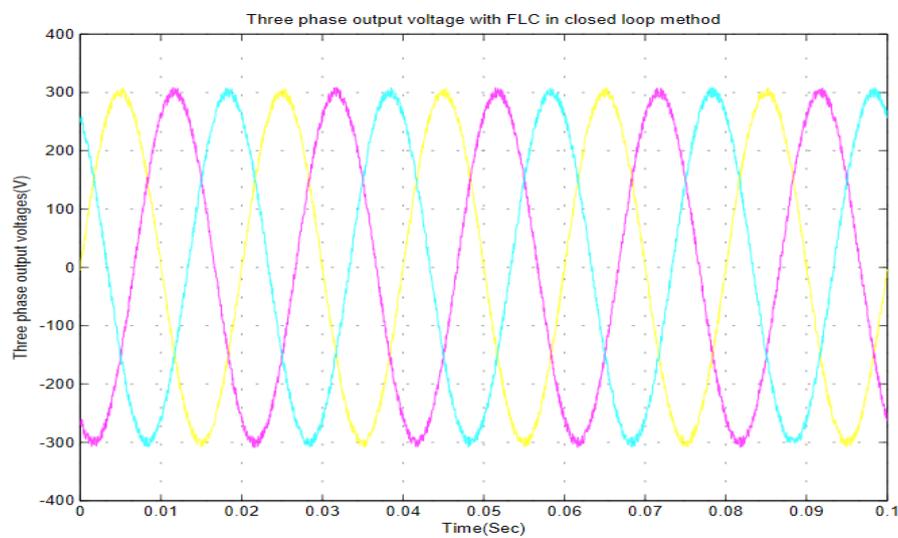


Figure 6 (a) Three phase output voltages of MLI drive with FLC

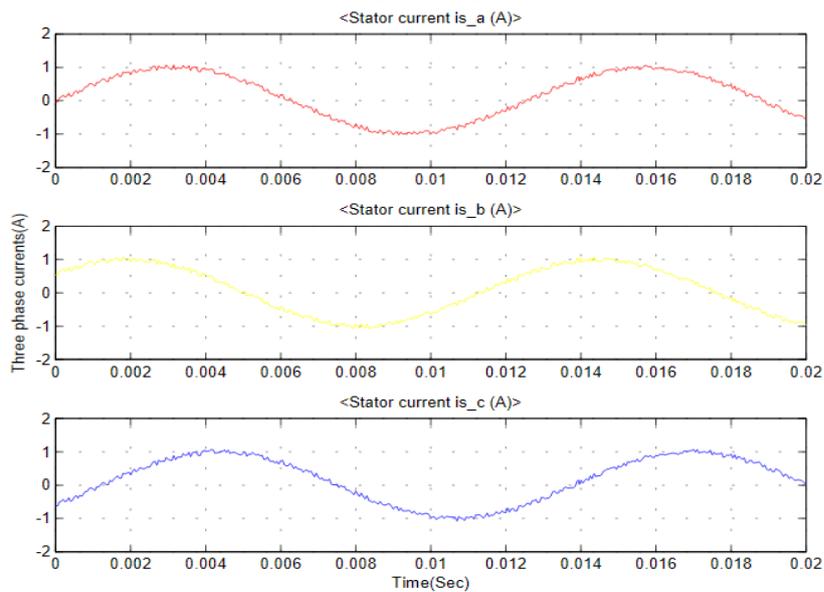


Figure 6 (b) Three phase stator currents of MLI drive with FLC

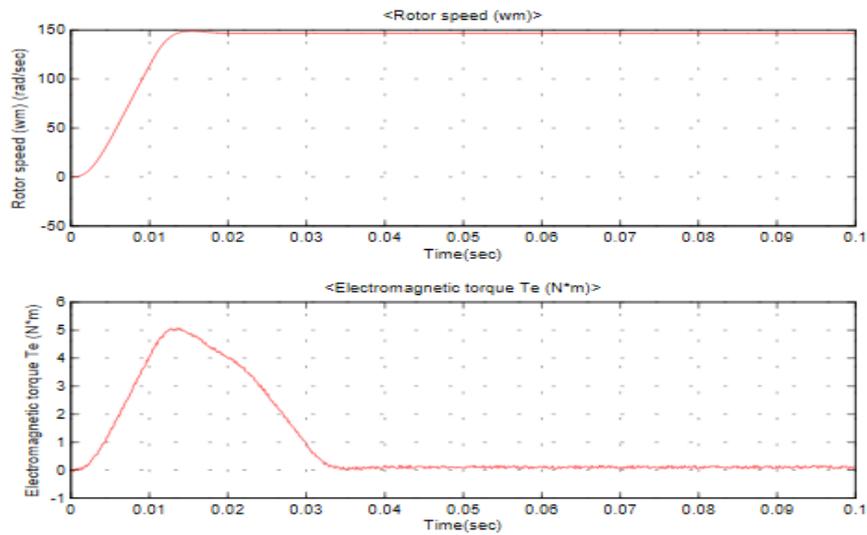


Figure 6(c) Rotor Speed and torque under no load condition of MLI drive with FLC

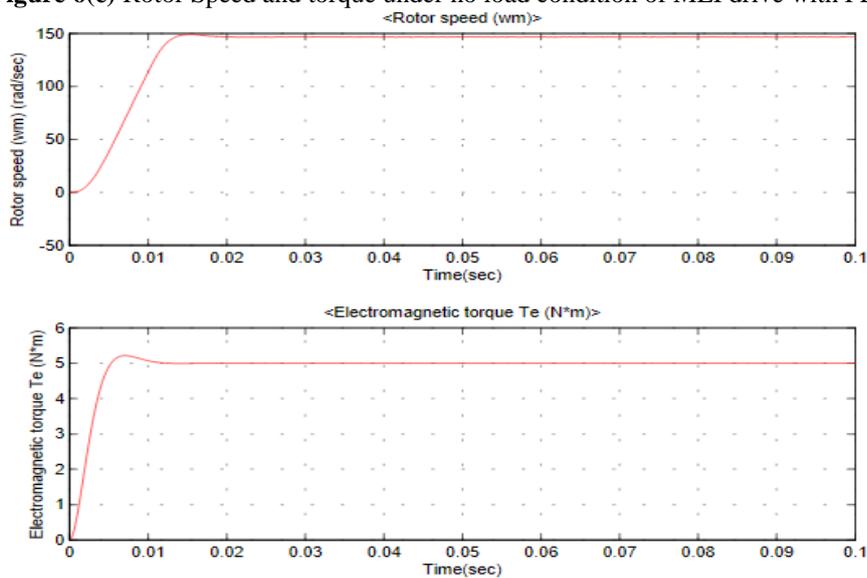


Figure 6(d) Rotor Speed and torque under applied load (6 Nm) condition of MLI drive with FLC

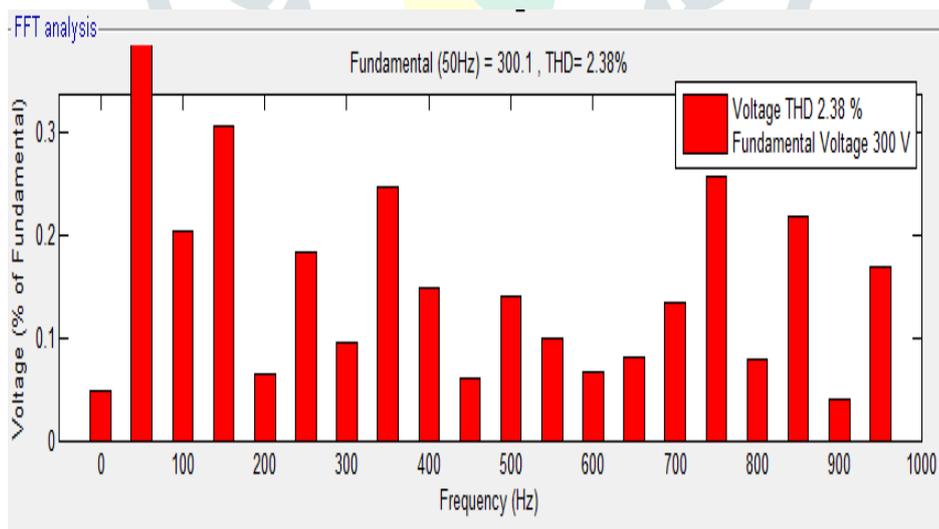


Figure 6(e) %THD of three phase voltages of MLI drive with FLC

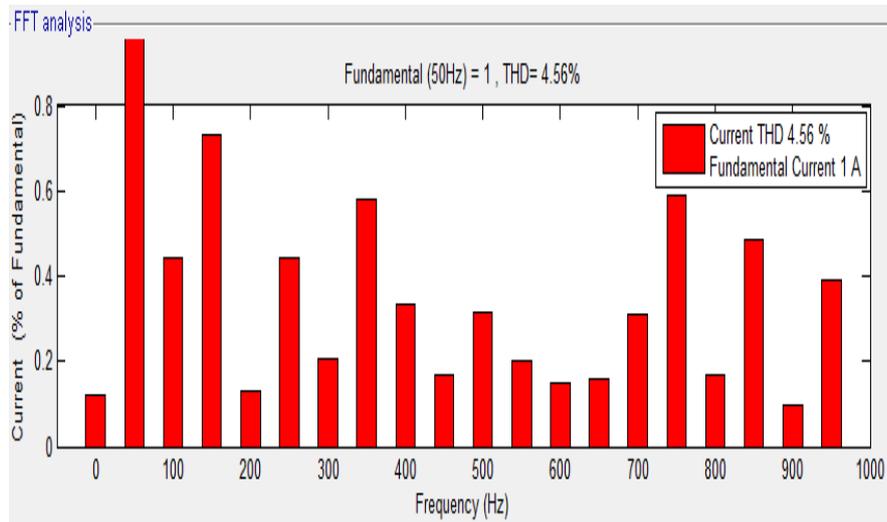


Figure 6(f) % THD of three phase currents of MLI drive with FLC

4.3. Closed loop control of IM drive through ANFIS

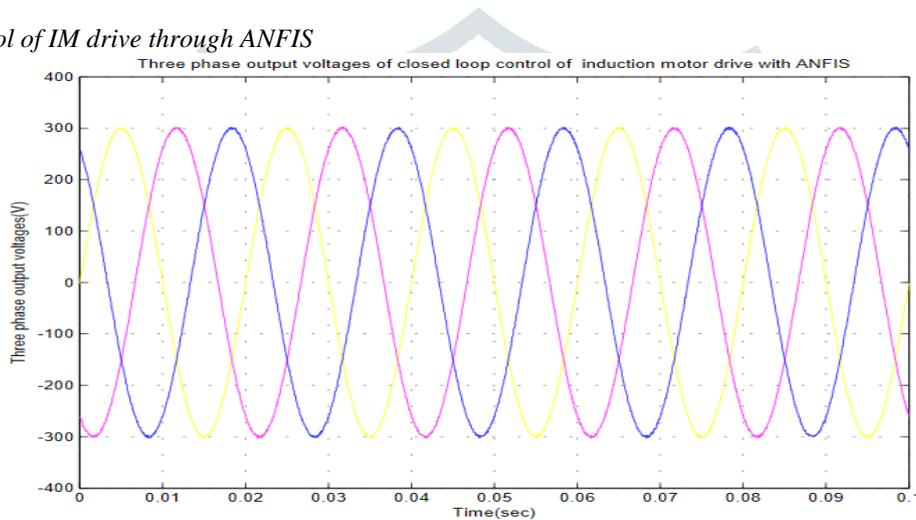


Figure 7 (a) Three phase output voltages of MLI drive with ANFIS

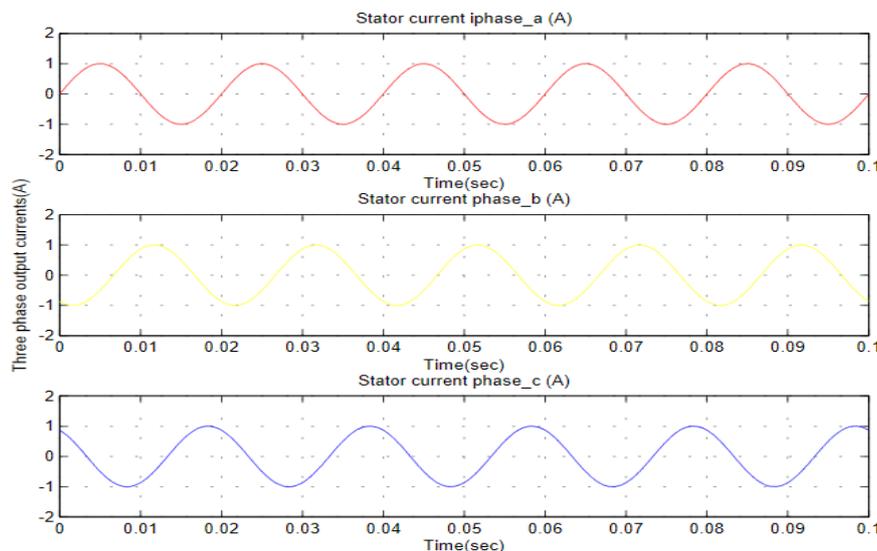


Figure 7 (b) Three phase stator currents of MLI drive with ANFIS

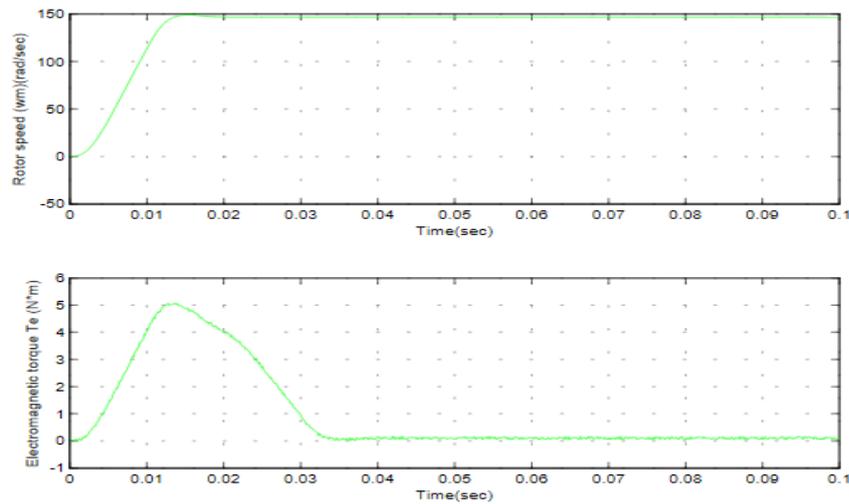


Figure 7(c) Rotor Speed and torque under no load condition of MLI drive with ANFIS

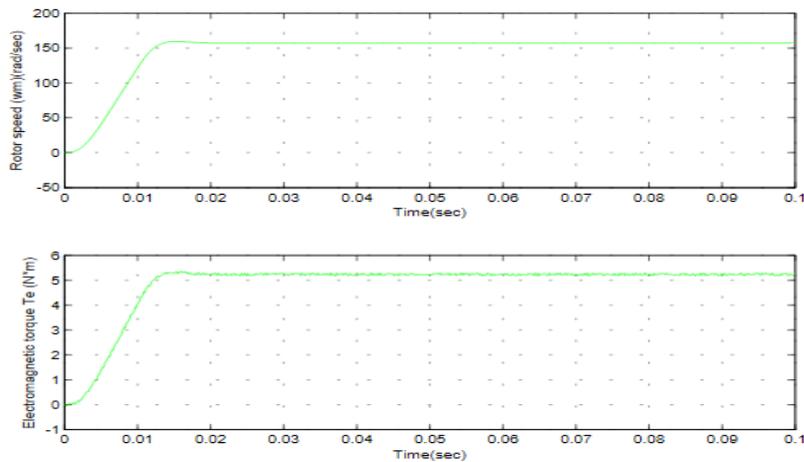


Figure 7(d) Rotor Speed and torque under applied load (6 Nm) condition of MLI drive with ANFIS

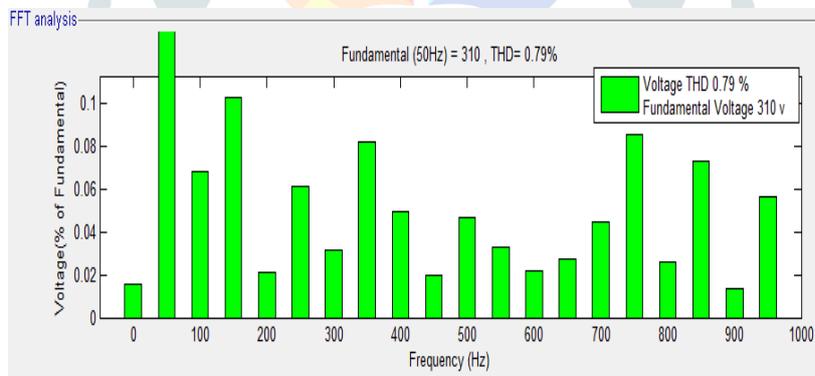


Figure 7(e) %THD of three phase voltages of MLI drive with ANFIS

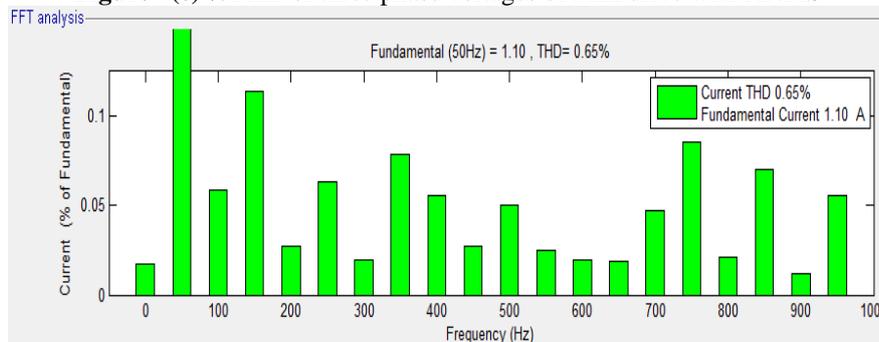


Figure 7(f) %THD of three phase currents of MLI drive with ANFIS

In above analysis Matlab/Simulink model of 63 level single phase proposed optimal MLI is shown in figure 5(a). Simulation results at output voltage waveform given in figure 5(b). THD of output voltage as 1.74% shown in figure 5(c). THD of output current as 7.50% as shown in figure 5(d). Closed loop control of 3 phase 63 level MLI fed induction motor drive using FLC three phase output voltages shown in figure 6(a). Three phase

stator currents given in figure 6(b). Speed versus torque under no load condition shown in figure 6(c). Rotor Speed and torque under applied load (6 Nm) condition shown in figure 6(d) %THD of three phase voltages is 2.38% shown in figure 6(e). %THD of three phase currents is 4.56% shown in figure 6(f). Closed loop control of 3 phase 63 level MLI fed induction motor drive using ANFIS waveforms regarding -Three phase output voltages shown in figure 7 (a). Three phase stator currents shown in figure 7 (b). Rotor Speed and torque under no load condition shown in figure 7 (c). Rotor speed and torque under applied load (6 Nm) condition shown in figure 7 (d). %THD of three phase voltages is 0.79% shown in figure 7 (e). %THD of three phase currents is 0.65% shown in figure 7(f). Therefore in the proposed drive using ANFIS produces more fundamental voltage and current, better speed torque control and less THD in voltage and current when compared to drive with FLC in closed loop control system as shown in table 3.

As the number of levels was increased by using proposed 63 level MLI the output quality also be improved. The proposed 63 level MLI cost is less than existing high level MLI due to cause of less number of switching devices and drivers used in proposed MLI. Similarly proposed MLI offers minimum switching, power losses and low voltage drops. Thus by using this proposed MLI with control of Induction motor drive produces better performance

Table 3 Comparisons between closed loop 63 level MLI fed Induction motor drive through FLC Controller and ANFIS

| Parameters | Closed loop control of optimal MLI fed IM drive with FLC | Closed loop control of optimal MLI fed IM drive with ANFIS |
|------------------------|--|--|
| %THD Voltage | 2.38 | 0.79 |
| Fundamental voltage(V) | 300 | 310 |
| %THD current | 4.56 | 0.65 |
| Fundamental current(A) | 1.00 | 1.10 |
| Speed(rad/sec) | 147 | 154 |
| Torque (Nm) | 5.2 | 5.8 |

Table 4 Induction motor specifications

| Configuration and Parameters | |
|-------------------------------|---------------|
| Mechanical input | Torque(Nm) |
| Rotor type | Squirrel cage |
| Reference frame | rotor |
| Rotor resistance(R_r) | 0.21 Ω |
| Rotor Inductance(L_{lr}) | 1.62mH |
| Stator resistance(R_s) | 0.66 Ω |
| Stator Inductance(L_{ls}) | 1.6mH |
| Mutual Inductance | 38.8mH |
| Friction factor | 0 N-ms |
| Power(P_o) | 1.5KW |
| Voltage(V_{ph}) | 310V |
| Frequency | 50 Hz |
| Inertia(J) | 0.08Kgm |
| Pole Pairs(P) | 2 |

V. CONCLUSION

The proposed three phase optimal 63 level MLI is designed by using three individual single phase multi-level inverters. Proposed optimal MLI is the asymmetrical type which has been inducted with SPWM control technique. The extend part of closed loop control method the drive has been controlled and influenced by a FLC controller after that with ANFIS controller. Simulation results show that proposed drive produces more fundamental voltage and current, low THD in voltage and current and better speed torque control when it was controlled by ANFIS.

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