A new high voltage asymmetrical 27 level bidirectional multilevel converter with V/F control for locomotive WAP-7D using ANFIS

Ms.J.SUGANTHI VINODHINI [1], Dr.R.SAMUEL RAJESH BABU[2]
[1]Research Scholar,Sathyabama Institute of Science and Technology,Chennai,,giri_vino@rediffmail.com
[2]Associate Professor, Department of Electronics and Instrumentation,Sathyabama Institute of Science and Technology, Chennai, drsamuelrajeshbabu@gmail.com

***Abstract*- In all the High power applications the multilevel inverters grasp attractive highlights utilization of more switches in the conventional arrangement represents a barrier to its wide range application. Multilevel inverters are getting to be progressively well known for high-control applications due to their expanded power ratings. SPWM technique was carried out for the bidirectional multilevel converter using the binary and trinary method. There are few investigations that really talk about or assess the evaluation of three phase Induction motor drives related with Bidirectional multilevel inverter. The regenerative in the locomotive Induction motor usefully employed for regenerating the voltage above the synchronous speed. In this paper the electromagnetic torque and speed of the drive was directly controlled by the Artificial neuro -fuzzy inference system process. Simulation was carried out in the entire region of the proposed drive for speed, torque, voltage and braking effort in the traction motor and also results are compared with the Artificial neuro -fuzzy inference system with the open loop using MATLAB simulink software. THD value for the R-L load was standard as per IEEE standard (below 5%) this proposed system simulated 3.69% as THD.**

***Keywords*: Pulse width modulation , Fuzzy neural networks ,Regeneration engineering,Power semiconductor switches,Traction motors**

I. INTRODUCTION

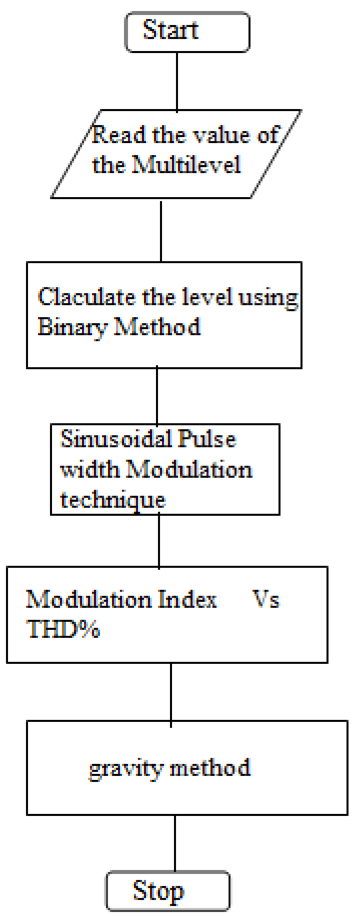
Bidirectional multilevel VSI are acutely examined for high-control applications [1] &[2] and standard drives for medium-voltage applications for standard drives have plainly accessible [3]&[4].In some industrial applications more levels are need to improve the output voltage for this purpose some multilevel inverter are expanding number of levels has a tendency thereby decrease the power converter general unwavering quality what's more, proficiency. Arrangements with a higher number of yield voltage levels have the ability to combine waveforms with a superior consonant range and to restrict the induction motor winding stress. Then again, arrangements with a low number of voltage levels either require a fairly extensive and need filters to restrain the induction motor winding stress, or must be utilized with induction motor that do withstand such stress. Several studies and reviews are undertaken towards improving the efficiency of the multilevel inverter. In some of the case studies regarding increase in the voltage level many improved topologies and to improve the voltage resolution the input of the multilevel inverter was carried out with the symmetrical and asymmetrical phenomenon[5].In recent studies the focus on multilevel inverter to improve the voltage level with less THD ,So the studies are mainly focused on controlling the strategies of the semiconductor switches like MOSFET, IGT and MESFET[6].Recently the asymmetrical multilevel inverter was examined using several H bridges with various pulse width modulation technique to produce a quality voltage for the industrial drives[7] .In general all the AC drives are operated by the direct Torque control method for the high efficiency in the control strategies[8].DTC for hybrid 2 level multilevel inverter was studied for the symmetrical and asymmetrical inverter for the sinusoidal output voltage[9]

Large scale industrial applications are mainly variable in the speed of the motors like constant and variable speed. In locomotive both DC and AC drives was carried out but due to disadvantages over the DC drives in all the high speed locomotive this ACC drives was utilized. Majorly the locomotive should run with a constant speed for a time and this was not possible in DC motor, so this can be overcome by the AC induction drive. Mani methods are come across in the industrial drive to control the speed dint he stator and rotor side of the AC motors[10].In this world most of the renewable energy was utilized and this techniques Variable voltage variable frequency(VVVF) drive will be most suitable for speed control with high efficiency in all the large scale industries.

In Locomotive WAP-7 the regenerative braking gives more productivity to the recovering the power from the three phase squirrel cage induction motor [11]. To apply those regenerative braking, Inverter is sufficient however in this paper the bidirectional converter is designed and utilized to store the regenerative source as DC in the battery. This regenerative braking helps the engine under overheating in the phenomenon by sending the kinetic energy back to the source which was put away in the rotor of the Induction motor. So this VVVF technique is valuable for the regenerative system in Locomotives.

In Bidirectional Multilevel converter the motor drives with the real power flow but in terms of inverter another Static VAR compensator only the reactive power is used for the induction motor drive. In all the investigations regarding the rectifier-inverter three five level was carried out using PWM switching controller were utilized [12]&[13].In this paper the analysis of bidirectional multilevel converter was carried out, by the performance of the regenerative braking in the induction motor for some period of constant time DC was stored in the battery through the designed converter.

Work flow:



New Novelty of the proposed system:

In this proposed system the output of the multilevel inverter voltage is generated with 12 power semiconductor switches compared with the conventional multilevel inverter. Binary method is used to calculate the level and the number of power semiconductor switches used in this propose system. ANFIS gives a stability output by increasing the modulation Index .The Total harmonic distortion is reduced in this proposed system below the IEEE standard value.

II. OVERHAULING OF LOCOMOTIVES IN INDIA

Indian railways already going deeply by manufacturing with better reliability and high speed locomotives. The Rajdhani and Shatabdi expresses was running by the WAP- 7 locomotive. They provided the statement during this budget meeting that WAP- 7D with dual breaks is still undergoing for experimentation. The WAP- 7D implementation to our Indian locomotive should be speeded up. Still 2016 this process was under experimentation. This paper gives the analysis of the bidirectional multilevel converter to rut the AC drive in locomotive with 27 level voltage with reduced number of power switches with lower harmonic distortion.

III. MULTILEVEL INVERTERS

Multilevel converters are initially used for the traction application which it doesn't use only for higher power ratings and also it was utilized by the small scale industries for their long time applications. In all the renewable energy this multilevel converter was utilized for the low power generation [14].For High power applications the inverter has been designed with the series power switches. During the transient operation and steady state process this series switches allows higher unequal voltages [15].Due to the higher voltage problem the multilevel converter was designed with less number of DC sources and power switches [16]. 3 level, 5 level and 7 level has been investigated using Various PWM switching control for the multilevel converter [17]. The proposed bidirectional multilevel Converter overcomes all the problems which were faced by the conventional multilevel inverter. During the regenerative braking operation in three phase Induction motor the slip goes to negative thereby the regenerative voltage was flow towards the converter and thus the multilevel converter acts as a rectifier and stores the energy in the form of DC voltage in batteries.

IV. ASYMMETRICAL BIDIRECTIONAL CASCADED H - BRIDGE MULTILEVEL CONVERTER ANALYSIS

Solar cells can be utilized as asymmetrical DC voltage source for the multilevel Converter [18] .For the locomotive induction motor the proposed multilevel Cascaded H bridge converter will be suitable during the variable speed operation. The main advantage of this proposed multilevel converter are modular in terms of protection ,modulation and control.Fig.(1) shows the topology of the 27 level cascaded H bridge Multilevel converter with the asymmetrical DC voltages for the three bridges. In this topology only 12 switches are used and also the input DC sources are used from the solar cell for the three Cascaded H –bridges. From the designed multilevel converter the output is the sum of the three voltages produced form the three cascaded H –bridges.

$$V_0(t) = V_{0,1}(t) + V_{0,2}(t) + V_{0,3}(t) \quad …….. \quad (1)$$

The ouput voltage of the multilevel converter also carried out by the various cells performing individually in the switching states.

$$V0(t) = \sum_{i=1}^{n}(\alpha i - 1)V_{dc;i}$$

$\alpha_i = 0,1,2,……$

…………………. (2)

Where V_{dc} is the input Asymmetrical DC voltage which can e utilized form the solar cells.

The asymmetrical multilevel converter provides 27 level of voltages with three different DC sources. These Levels are increased by the SPWM techniques by controlling the power IGBT switches. The angels are calculated by the Newton-Rapson (N-R) method [19] and many investigations are done on angle calculation for the switching techniques. The Binary and Trinary method for the multilevel converter suits to produce a quality output for the Locomotive WAP-7D.This modulation was carried out by the binary method to improve the quality of the various parameters.

Table.1.Parmeters for the proposed 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D simulation.

Parameters	Binary	Normal Converter	Proposed 27 level
N_b(Number of Bridges)	$2^{N_b+1}-1$	15	27
DC Sources	N_b	3	3
Switches Number	$4N_b$	12	12
$V_{0\,pu}$	$2^{N_b}-1$	7	13

The maximum output voltage for the asymmetrical in case of binary the voltage level increased from the equation (2).

$$V_{o\,ma} = \sum_{i=1}^{n} V_{dc;i}$$

The above equation can be written as for binary it was rewritten as

$$V_{0\,pu} = (2^{N_b+1}-1)\,V_{dc} \quad …………. (3)$$

If $V_{dc,i} = 2^{i-1}V_{dc}$ $\quad i=1,2,3,…N_b$

equation (3) shows for the proposed Bidirectional Multilevel converter has maximum magnitude output voltage and level also increase by reviewing with the other PO, POD and APOD techniques [20].

V. OPERATION FOR PROPOSED ASYMMETRICAL 27 LEVEL BIDIRECTIONAL CASCADED H - BRIDGE MULTILEVEL CONVERTER

Existing Topology for the multilevel Inverter: In conventional and other existing topology still finding the effectiveness in the drive for high power applications. In conventional topology more number of power switches needed to yield the sinusoidal output voltage for AC drives [21].In 7 level with minimum number of 9, 7, 6 and 5 switches but the THD value for the R-L load was not in the standard as per IEEE (below 5%).Nearly the existing topology focusing on the devices but still distortion is more in the output side of the multilevel inverter. The proposed topology gives a valuable cost and high efficiency for the High power applications and the design was simple with the binary method of pulse generating to the power switches. It has 12 IGBT switches and Three DC source which was utilized from the solar energy (Photovoltaic cells).

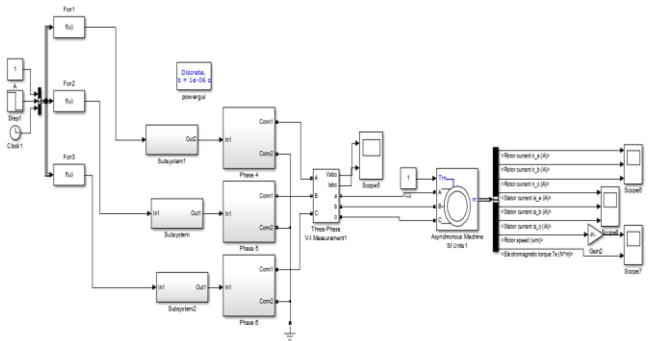


Fig.1.Proposed 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D simulation.

27 level bidirectional multilevel converter was shown in Fig(1) with the high efficiency Low harmonic distortion 11 level multilevel inverter was propose for the static VAR compensation without bidirectional mode of operation. The control scheme of the proposed converter was Sinusoidal Pulse width modulation technique using the binary method and this method proves a very effective for high switching frequencies. In this proposed 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D the switching frequencies for each power switches was taken as in time period of t=0.07s.

VI. IGBT SWITCHING OPERATION

In 27 level 3φ bidirectional multilevel inverter with regenerative braking 12 IGBT's used to create the yield for the three phase Induction motor in Locomotive and the SPWM modulation technique using Binary method utilized for the asymmetrical converter to trigger the switches. The different DC voltages are utilized from the solar power. Three voltage used for the H –bridge Converter is V1 = 18V, V2 = 54V, V3 = 162V and the control circuit was analyzed under MAT Lab. The power semiconductor switches were S1,S2,S3,S4,S5,S6,S7,S8,S9,S10,S11 and S12.For introductory level the voltage was taken as 0v. For 2nd level , switches S2,S3 and S5,S8 and S11,S12 are taken has 1 in computerized it taken has ON. So with the SPWM technique the yield Voltage from the converter crosses for 1st level to 2nd level. So the level was increased by changing the asymmetrical input voltage by changing the switching frequencies.

1: 'U_Phase 1/V3=162V
2: 'U_Phase 1/V2=54V
3: 'U_Phase 2/V1=18V
4: 'U_Phase 1/V1=18V
5: 'U_Phase 2/V2=54V
6: 'U_Phase 3/V3=162V
7: 'U_Phase 3/V2=54V
8: 'U_Phase 3/V1=18V
9: 'U_Phase 2/V3=162V

Table.2.Switching control for the proposed 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D simulation

Levels	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
0	0FF	0FF	ON	ON	0FF	0FF	ON	ON	0FF	0FF	ON	ON
1	ON	0FF	0FF	ON	0FF	0FF	ON	ON	0FF	0FF	ON	ON
2	0FF	ON	ON	0FF	ON	0FF	0FF	ON	0FF	0FF	ON	ON
3	0FF	0FF	ON	ON	ON	0FF	0FF	ON	0FF	0FF	ON	ON
4	ON	0FF	0FF	ON	ON	0FF	0FF	ON	0FF	0FF	ON	ON
5	0FF	ON	ON	0FF	0FF	0FF	ON	ON	0FF	0FF	ON	ON
6	0FF	0FF	ON	ON	0FF	0FF	ON	ON	ON	0FF	0FF	ON
7	ON	0FF	0FF	ON	0FF	0FF	ON	ON	ON	0FF	0FF	ON
8	0FF	ON	ON	0FF	ON	0FF	0FF	ON	ON	0FF	0FF	ON
9	0FF	0FF	ON	ON	ON	0FF	0FF	ON	ON	0FF	0FF	ON
10	ON	0FF	0FF	ON	ON	0FF	0FF	ON	ON	0FF	0FF	ON
11	0FF	ON	ON	0FF	0FF	ON	ON	0FF	0FF	ON	0FF	ON
12	0FF	ON	ON	0FF	0FF	0FF	0FF	ON	0FF	0FF	ON	ON
13	ON	0FF	0FF	ON	0FF	ON	0FF	ON	ON	0FF	0FF	ON
-1	0FF	ON	ON	0FF	0FF	0FF	ON	ON	0FF	0FF	ON	ON
-2	ON	0FF	0FF	ON	0FF	ON	ON	0FF	0FF	0FF	ON	ON
-3	0FF	0FF	ON	ON	0FF	ON	ON	0FF	0FF	0FF	ON	ON
-4	0FF	ON	ON	0FF	0FF	ON	ON	0FF	0FF	0FF	ON	ON
-5	ON	0FF	0FF	ON	0FF	0FF	ON	ON	0FF	ON	ON	0FF
6	0FF	0FF	ON	ON	0FF	0FF	ON	ON	0FF	ON	ON	0FF
-7	0FF	ON	ON	0FF	0FF	0FF	ON	ON	0FF	ON	ON	0FF
-8	ON	0FF	0FF	ON	0FF	ON	ON	0FF	0FF	ON	ON	0FF
-9	0FF	0FF	ON	ON	0FF	ON	ON	0FF	0FF	ON	ON	0FF
-10	0FF	ON	ON	0FF	0FF	ON	ON	0FF	0FF	ON	ON	0FF
-11	ON	0FF	0FF	ON	0FF	0FF	0FF	ON	ON	0FF	0FF	ON
-12	0FF	ON	ON	0FF	0FF	0FF	0FF	ON	ON	0FF	0FF	ON
-13	0FF	0FF	ON	ON	0FF	0FF	0FF	ON	ON	0FF	0FF	ON

VII. DC INPUT VOLTAGE SOURCES(PV) FOR THE PROPOSED 27 LEVEL OPERATION

The proposed 27 level multilevel converter has 12 IGBT switches and three DC sources. The total input voltage to the inverter is DC 234 v and this was asymmetrical where V1 = 18V, V2 = 54V, V3 = 162V and three cascaded H-bridges were used. To increase the level of the output voltage the switches must get trigged by the SPWM techniques with t=0.07seconds.For level 1 the IGBT switches S1, S4, S7, S8, S11 andS12 are trigged by the modulated Sinusoidal pulses with the carrier signal with input DC voltage as (+18) from the given Table(3).For 234v all the DC sources gets active and the switches S1, S4, S5, S8, S9, S12 are triggered.

Table.3.levels and DC voltages for the proposed 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D simulation.

Level	DC voltage Source(V)	Output Voltage(V)
1	V_1	+18
2	$V_2 - V_1$	+36
3	V_2	+54
4	$V_1 + V_2$	+72
5	$2 V_2 - V_1$	+90
6	$V_3 - V_2$	+108
7	$V_1 + V_3 - V_2$	+126
8	$-V_1 + V_3$	+144
9	V_3	+162
10	V_1+V_3	+180
11	$-V_1 + V_3 + V_2$	+198
12	V_3+V_2	+216
13	$V_1+V_3+ V_2$	+234
-1	$-V_1$	-18
-2	$-V_2 + V_1$	-36
-3	$-V_2$	-54
-4	$-V_1 - V_2$	-72
-5	$-2 V_2 + V_1$	-90
-6	$-V_3 + V_2$	-108
-7	$-V_1 - V_3 + V_2$	-126
-8	$V_1 - V_3$	-144
-9	$-V_3$	-162
-10	$-V_1-V_3$	-180
-11	$V_1 - V_3 - V_2$	-198
-12	$-V_3-V_2$	-216
-13	$-(V_1+V_3+ V_2)$	-234

VIII. MODULATION TECHNIQUE AND MODULATION INDEX

Existing Topology: In conventional multilevel inverter leads to the higher order harmonics due to the lower switching frequencies in the power switches and also the PWM technique was utilized for the modulation technique. I t can be seen that the large number of pulse width adopted over the fundamental components during the operation of the drives. The other topologies like diode clamped multilevel inverter and Flying capacitor multilevel inverter is very difficult to produce the real power to the AC drive because the passive element capacitors are discharge or overcharge without any control circuit. The main disadvantage of the other multilevel existing system while increasing the level in output the number of clamping diodes in diode clamped multilevel inverter and number of capacitors in Flying capacitor multilevel inverter also increased and the circuit become more complicated to work under the dynamic processes[22].

Modulation Index connects the output of the fundamental voltage with the DC link voltage of the inverter. The level of the output voltage(phase to ground) was increased by increasing the Modulation index ,the ratio of the modulation index shows the magnitude of the modulating signal and the carrier signal which operates the power switches in the multilevel inverters.

In the proposed bidirectional multilevel converter Sinusoidal Pulse width Modulation technique achieve the standard level for the three phase Induction motor for all the output duty cycle in sinusoidal way. The plan, in its rearranged frame, includes examination of high frequencies. In the proposed technique the high frequency carrier triangular waves was compared with the modulated sinusoidal signal. Phase disposition, Phase opposition and Alternate POD are the techniques used in the multilevel inverter [23].In asymmetrical the binary and trinary method improves the RMS voltage and also the total harmonic distortion was reduced in this proposed system. In the Table (4) the modulation index was increased where the output voltage level increased and the THD value gets reduced and up to 5% below it was analyzed for the locomotive Converter.

Table.4.Various Modulation Index for the proposed 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D simulation

Modulation Index	Phase to Ground Volt(V)	THD%
0.2	90	9.28
0.4	110	7.98
0.6	150	5.74
0.8	200	4.39
1	234	3.69

In asymmetrical the binary and trinary method improves the RMS voltage and also the total harmonic distortion was reduced in this proposed system. In Table (4) shows the modulation index was increased where the output voltage level increased and the THD value gets reduced and up to 5% below it was analyzed for the locomotive Converter.

IX. DESIGN OF PROPOSED 27 LEVEL BIDIRECTIONAL MULTILEVEL CONVERTER WITH ANFIS

I. ADAPTIVE NERO FUZZY INFERENCE SYSTEM(ANFIS)

In this proposed system the ANFIS demonstrated by using the MATLAB(r2013a). Neural and Fuzzy logic system combine as a frame work of Neuro-Fuzzy network. Neural system gives a structural framework by the neural networks by framing the IF AND THEN rules of reasoning and thinking. In all the non linear system there must a control parameters and this can be achieved by the Fuzzy Inference system through the neural networks [24] & [25]. Adaptive neuro fuzzy inference system (ANFIS) is the proposed controller design to control the electromagnetic torque by the proposed bidirectional multilevel converter by the Fuzzy and Neural network structure.

The main functional blocks present in the ANFIS a. Rule b. Data c. Unit with Decision making d. Interfacing Fuzzification e. Interfacing defuzzification. All the five functional blocks are generate by the network layers.

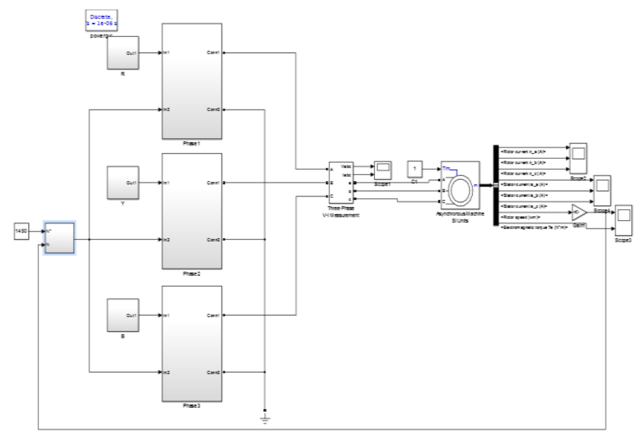


Fig.2.Proposed 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D simulation with ANFIS.

Network Layer 1: It's a triangular function is called as Fuzzy membership where the layer 1 is composed of the computing nodes.

Network Layer 2: The minimum value inputs are selected by this Layer.

Network Layer 3: This layer standardizes each contribution concerning the others.

Network Layer 4: The output from this layer is the linear function and it acts as a input of the ANFIS signal.

This ANFIS has better flexibility for wide range of all control applications.

X. CONTROLLER DESIGN FOR THE PROPOSED 27 LEVEL BIDIRECTIONAL MULTILEVEL CONVERTER

A controller is a gadget which controls each and every activity in the framework deciding. From the control framework purpose of see, it is conveying security to the framework when there is a unsettling influence, in this way protecting the device from further harms.

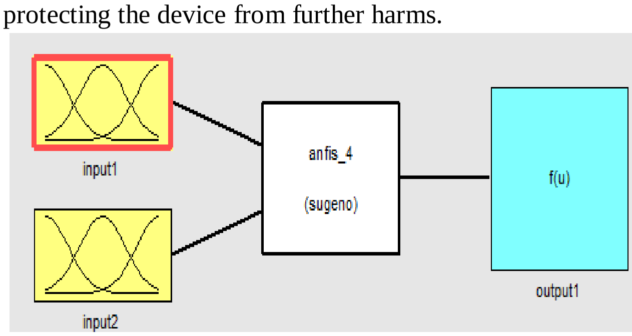


Fig.3. FIS properties for the proposed 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D .

It might be equipment based controller or a product based controller or a blend of both. In this proposed design ANFIS, the improvement of the control technique for control of different parameters of the Induction motor, for example, the voltage, current speed, torque, and is exhibited utilizing the ANFIS control system.

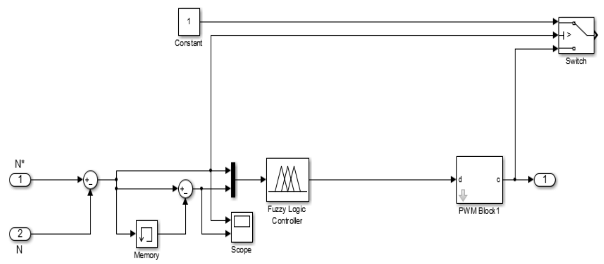


Fig.4. Subsystem of the ANFIS 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D simulation

XI. ANFIS RULES

The basic developed structure for the proposed system mainly consists of

- Fuzzification,
- Rule base
- Neural network and
- Defuzzyfication

The input of the ANFIS is mainly error and change in error modeled by the equation for the proposed syetem

$e(f)=\omega_{ref}- \omega_r$

Δ e(f)= e(f)- e(f-1)

Where e(f) is the error , e(f-1) change error , reference speed ω_{ref} and ω_r is the actual rotor speed in the Induction motor. The first lock is the fuzzification which converters all the inputs into linguistic output variables and feed to the Rule based function block. Total set of 25 rules were framed for the proposed 27 level bidirectional multilevel converter.

I. IF AND THEN RULES for the Proposed converter to control the rated the speed of the motor in Locomotive WAP-7D

Table .5. IF AND THEN rules for the Proposed converter to control the rated the speed of the motor in Locomotive WAP-7D

IF	INPUT1	AND	INPUT2	THEN	OUTPUT
IF	NB	AND	NB	THEN	ZE
IF	NB	AND	NS	THEN	NS
IF	NB	AND	ZE	THEN	NB
IF	NB	AND	PS	THEN	NB
IF	NB	AND	PB	THEN	NB
IF	NS	AND	NB	THEN	ZE
IF	NS	AND	NS	THEN	NS
IF	NS	AND	ZE	THEN	NB
IF	NS	AND	PS	THEN	NS
IF	NS	AND	PB	THEN	NB
IF	ZE	AND	NB	THEN	PB
IF	ZE	AND	NS	THEN	PA
IF	ZE	AND	ZE	THEN	ZE
IF	ZE	AND	PS	THEN	NS
IF	ZE	AND	PB	THEN	NB
IF	PS	AND	NB	THEN	PB
IF	PS	AND	NS	THEN	PS
IF	PS	AND	ZE	THEN	PS
IF	PS	AND	PS	THEN	ZE
IF	PS	AND	PB	THEN	NS
IF	PB	AND	NB	THEN	PB
IF	PB	AND	NS	THEN	PB
IF	PB	AND	ZE	THEN	PB
IF	PB	AND	PS	THEN	PS
IF	PB	AND	PB	THEN	ZE

The above 25 set of rules are given to the neural block and this lock selects the proper rules by the back propagation algorithm. These rules are properly selected and triggered the neural to get the optimal output for the proposed system.

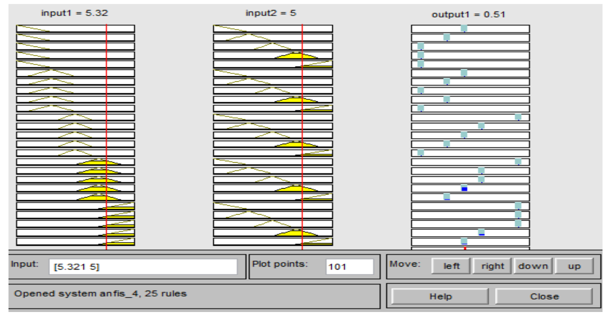


Fig.5. Rules for FIS for the Proposed converter to control the rated the speed of the motor in Locomotive WAP-7D

The defuzzification system is the main block to get the numeric information from the fuzzy logic information which holds the fuzzy sets. In this proposed work by the gravity method is chosen for the defuzzification to retrieve the numeric data from the fuzzy sets

Table.6. Error e (f) and the change in error signal e (f-1) for the Proposed converter to control the rated the speed of the motor in Locomotive WAP-7D

Error	Change In Error	output
0	0	0.498
1.28	1.55	0.488
2.2	2.27	0.497
3.3	3.36	0.5
4.59	4.45	0.504
5.32	5	0.51
6.97	6.45	0.522
7.34	7.18	0.508
8.26	8.45	0.5
9.54	9.18	0.5
9.91	9.91	0.5
-1.65	-1.36	0.389
-2.39	-2.45	0.377
-3.12	-3.36	0.351
-4.4	-4.82	0.365
-5.69	-5.91	0.401
-6.79	-6.45	0.423
-7.52	-7.18	0.453
-8.81	-8.27	0.5
-9.72	-9	0.5
-10	-10	0.5

This system maintains the stability by giving the error signal which in turn converts into the normal sets. The above table(6) the error e (f) and the change in error signal e (f-1)from the positive above 8v the output remain 0.5 and the error e (f) and change in error e (f-1) above 8v in negative region the output remains 0.5

.

II. SURFACE VIEW FOR THE ANFIS CONTROLLER

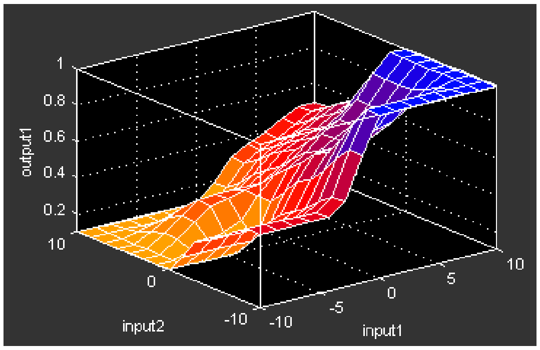


Fig.6. Surface viewer for the ANFIS controller for the Proposed converter to control the rated the speed of the motor in Locomotive WAP-7D

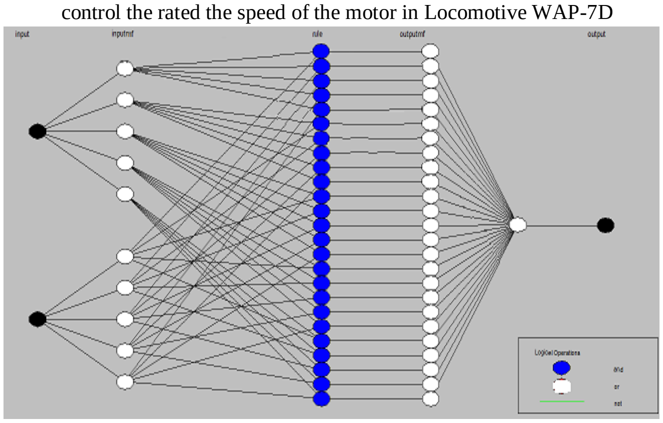


Fig.7. ANFIS structure for the Proposed converter to control the rated the speed of the motor in Locomotive WAP-7D

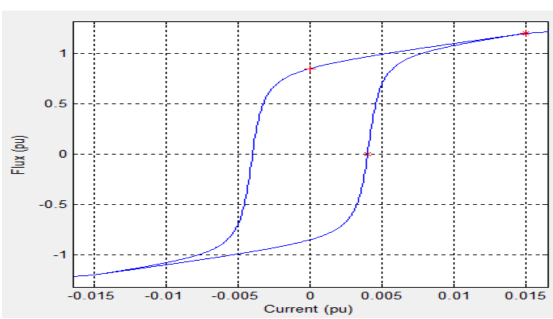


Fig.8. Hysteresis loop for the proposed converter to control the rated the speed of the motor in Locomotive WAP-7D

12. SIMULATION RESULTS FOR THE 27 LEVEL BIDIRECTIONAL MULTILEVEL CONVERTER FOR WITHOUT CONTROLLER MODULATION INDEX =1 AND WITH CONTROLLER (ANFIS)

Modulation Index =1

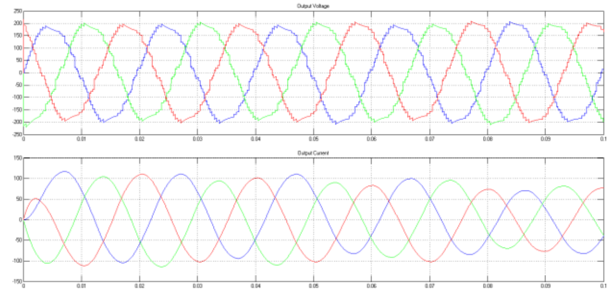


Fig.9.Converter output performance(Voltage and Current) of 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D with Modulation Index =1

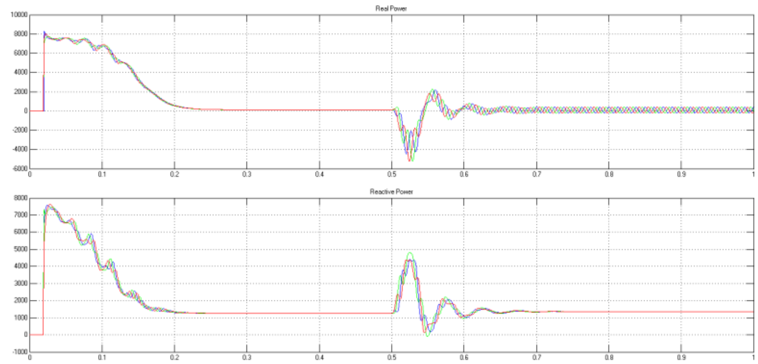


Fig.10.Real and Reactive Power for the Converter output of 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D with Modulation Index =1

III. ROTOR AND STATOR CURRENT FOR THE PROPOSED WITHOUT AND WITH CONTROLLER

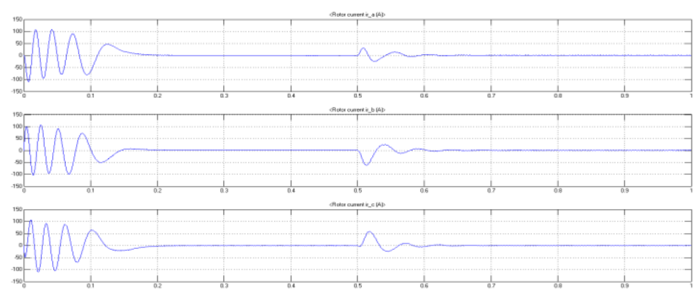


Fig.11.Rotor current for the three phase Ia, Ib and Ic of 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D for Modulation Index =1 without controller

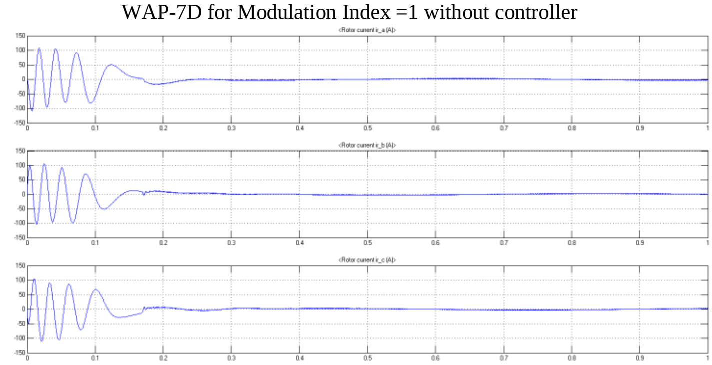


Fig.12.Rotor current for the three phase Ia, Ib and Ic of 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D with Modulation Index =1 with ANFIS

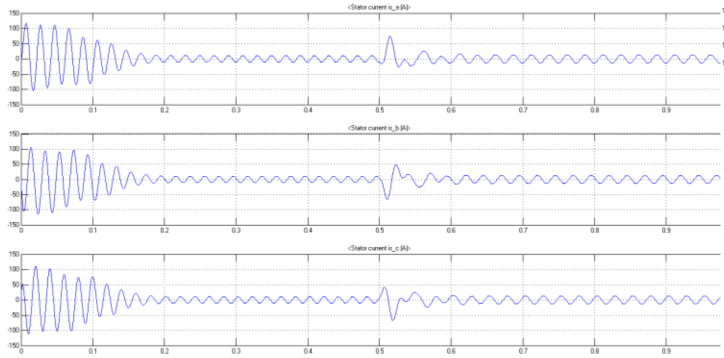


Fig.13.Stator Current for the Three phases Ia, Ib and Ic of 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D for Modulation Index =1 without controller

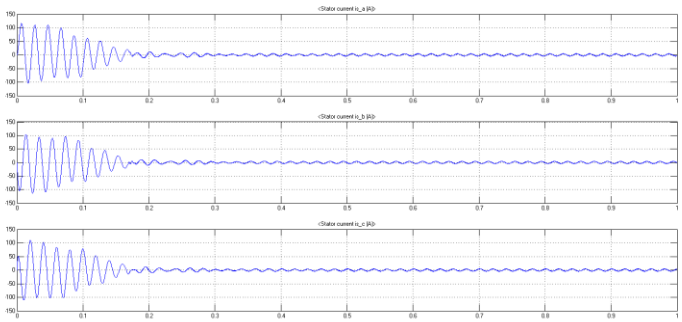


Fig.14.Stator Current for the Three phases Ia, Ib and Ic of 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D for Modulation Index =1 with ANFIS

IV. SPEED AND ELECTROMAGNETIC TORQUE CURVE FOR THE PROPOSED WITHOUT AND WITH CONTROLLER

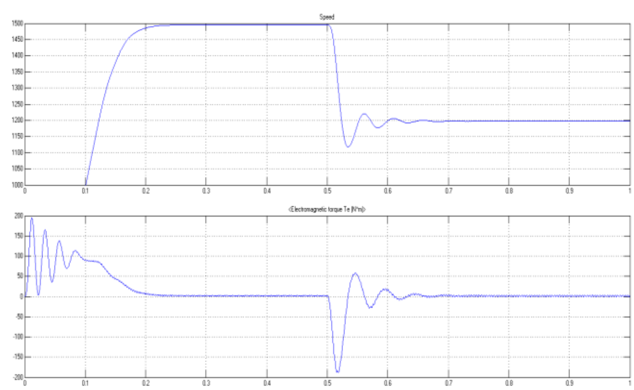


Fig.15.Speed and Torque Curve of 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D for Modulation Index =1 without controller

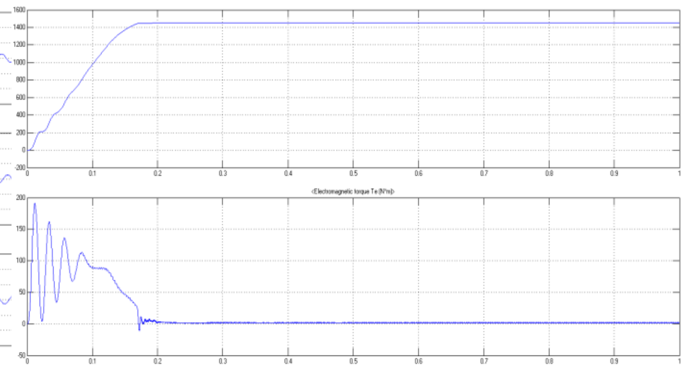


Fig.16.Speed and Torque Curve of 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D for Modulation Index =1 with ANFIS

V. TOTAL HARMOIC DISTOTRTION FOR THE PROPOSED OF 27 LEVEL BIDIRECTIONAL MULTILEVEL CONVERTER FED THREE PHASE INDUCTION MOTOR FOR THE LOCOMOTIVE WAP-7D

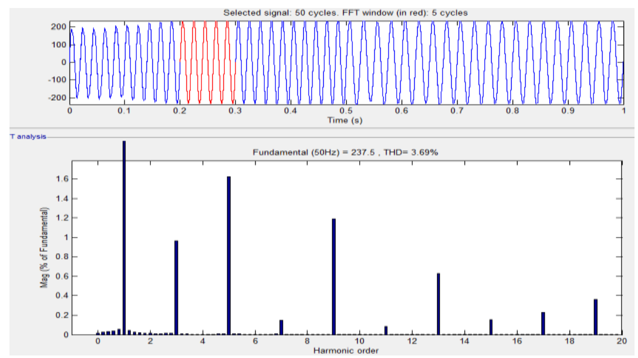


Fig.17.Total Harmonic Distortion(THD) for 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D with Modulation Index =1

12 ANALYTICAL ANALYSIS OVER THE EXPERIMENTAL FOR THE PROPOSED 27 LEVEL BIDIRECTIONAL MULTILEVEL CONVERTER FED THREE PHASE INDUCTION MOTOR FOR THE LOCOMOTIVE WAP-7D WITH MODULATION INDEX =1

THD $=1\sum_{i=1}^{n}\sqrt{Vrms^2}$/Fundamental Voltage Odd Harmonics (3^{rd}, 5^{th}, 7^{th} ….) ………………4

THD for te modulation index =1 shows in the FFT analysis using MATLA is 4.65% and hence the equation (4) shows the RMS voltage of the harmonics and the fundamental voltage in analysis prove the simulation value of the THD.

Sampling time = 1e-06 s

Samples per cycle = 20000

DC component = 0.02919

Fundamental = 237.5 peak (167.9 rms)

THD = 3.69%

THD=Square root$(184.6^2+180^2+191^2+179^2+190^2+181^2+176^2)/167.9$

THD=616.4/167.9

THD=4.49%

From the above the THD value calculated 4.49% and analyzed by the simulation 3.69% for the 27 level bidirectional multilevel converter fed Three phase induction motor for the Locomotive WAP-7D with Modulation Index =1

13 COMPARISON ON MODULATION INDEX AND SPEED OF THE INDUCTION MOTOR FOR THE PROPOSED TOPOLOGY

27 level was analyzed for various modulation index and variable frequency to control the speed of the Induction motor.

Table.7.Various modulation index, Speed and Voltage for the proposed system

Modulation Index	Phase to Ground Volt(V)	Time(sec)	Speed(rpm)
0.2	90	0.9	1100
0.4	110	0.75	1200
0.6	150	0.6	1350
0.8	200	0.3	1450
1	234	0.15	1500

14 REGENERATIVE BRAKING

In railway the CLW works hauled the 6000hp capacity motor for 24 coach train. It is buildup by the microprocessor based technology for the trouble shooting purpose and the salient feature of this it can regenerate the voltage while braking and this power was transferred to the catenary. In this proposed 27 level the regenerated voltage is again rectified and converted as DC voltage and stored in the batteries. For the motoring operation the phase angle between the stator current and voltage should less than 90˚ and for the regenerative braking operation (generator) this stator and voltage and currents angle should e above 90˚.The below Table (8) shows that above the synchronous speed the motoring operation was changed to the generating operation by applying a break for some period of time.

Table.8.Regenerated DC voltage from the proposed system

Frequency(Hz)	Speed(rpm)	Regenerated DC Voltage(v)Phase 1	Time(sec)
60	1650	234	0.15
50	1500		

15 AC TO DC FORM THE REGENERATIVE BRAKING OF THE THREE PHASE INDUCTION MOTOR IN LOCOMOTIVE WAP-7D-SIMULATION RESULTS

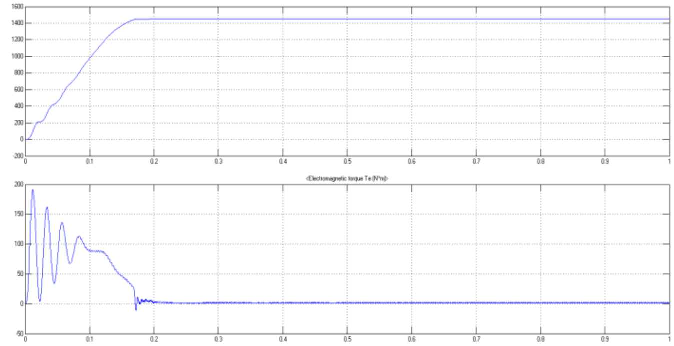


Fig.18.Speed and Torques Curve for the modulation index =1(0.15sec) with same speed (simulation)

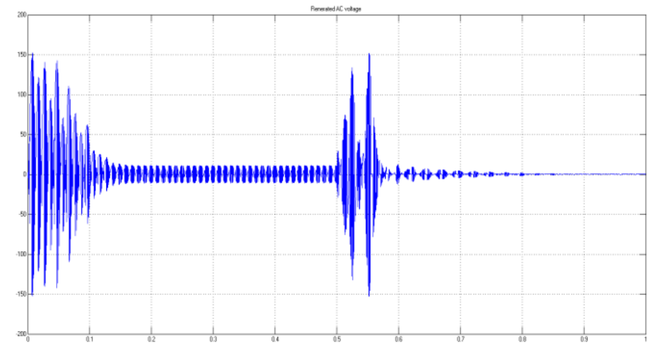


Fig.19.Regenerated AC voltage from 0.15s in the Three phase Induction motor

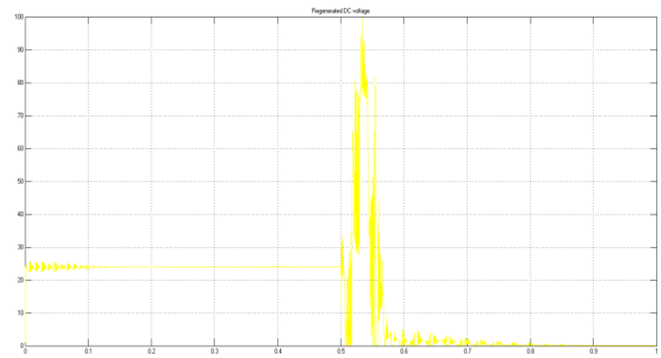


Fig.20.Regenerated AC-DC voltage from 0.15s

In locomotive from one station to the other station the speed of the induction motor should maintain same speed which should above the rated speed. During that condition voltage was regenerated by making the slip has negative. The Fig(19) shows the amount of voltage was regenerated as AC and the Fig(20) shows the AC regenerated voltage from the time 0.15s its storing DC voltage by the same 27 level multilevel inverter with the same number of power switches without short circuiting problem.

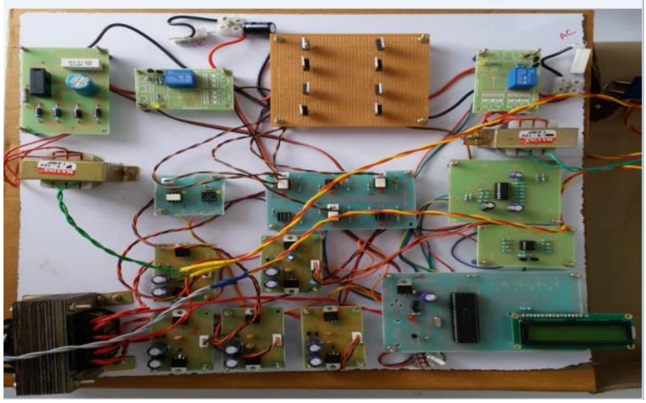


Fig.21.Hardware for the Single phase Bidirectional Multilevel Inverter for locomotive.

16 CONCLUSION

This paper has presented a complete analysis of the 27 level bidirectional multilevel converter with regenerative braking of locomotive WAP-7D.Locomotive Ac drive is majorly utilized that the DC motor due to the ratio of power to weight is higher in the AC drives. The output without the controller takes more time to settle to stable which was noted by the simulation results. Due to the ANFIS the rotor and stator current was controlled and also the speed was settled quickly for the rated speed compared with the open loop system. This research work shows the regenerative braking and the ANFIS is used to control the output voltage. The performance of the proposed system is quite satisfactory since the output can be controlled easily for traction AC motor in locomotives. In future this bidirectional inverter can be used with new algorithms to control the output as well as to reduce the total harmonic distortions in locomotives for traction motor. Mainly this paper shows the regeneration in the Induction motor during the regenerating braking operation in the locomotive above the synchronous speed. This proposed 27 level bidirectional multilevel converter was achieved the regenerated voltage from AC to DC.80% of the Indian railway Locomotives are working in the AC drive. By comparing the value of the total harmonic distortion the cascaded H bridge inverter gives good efficiency and less THD .So this inverter suits for the locomotive WAP-7D.Hence the cost, size, EMI and EMC problems are very less in the cascaded H –bridge Inverter. The proposed system has many advantages for Indian railway locomotive applications. In all the aspect for locomotive the results shows ANFIS gives good stabilization and reliability with faster settling time.

The proposed system shows potential topology because of its features.

- It has higher number of voltage levels.
- It has less number of devices compared with the other topologies.
- Switching techniques is comparatively gives higher switching frequency for the power switches.
- Photovoltaic panels are used for the asymmetrical DC voltages.
- ANFIS gives a faster settling time with the controlled electromagnetic torque.
- Bidirectional is achieved in this proposed topology.
- Regenerative braking is utilized from the Induction motor of locomotive.

Acknowledgments:

I would like to thank my God, parents, Guide Dr.Samuel Rajesh Babu, Husband Mr. Giridharan , Friend Mr.Raj kumar and who are really helped in all aspects to fulfill my goal through this research. Really thankful to the Rayapuram Loco, Chennai who helped for the in plant visit for my research in locomotive WAP-7D.

Appendix:

A1: Three phase Squirrel Cage Induction Motor

Specifications: 460 V, 60 Hz, 50 HP, 1800 rpm

Reference Frame: Stationary

3-Phase 2 pair of poles,

Mechanical Input: Torque Tm

Rotor type: Squirrel Cage type IM

[Pn(VA),Vn(Vrms),fn(Hz)] = [0.5*746, 430, 50]

Stator resistance and inductance= [0.435, 0.002]

Rotor resistance and inductance= [0.816, 0.002]

Mutual inductance= 69.31e-3

REFERENCES

[1]L. G. Franquelo, J. Rodriguez, J. I. Leon, S. Kouro, R. Portillo, and M. A.M. Prats, “The age of multilevel converters arrives,” IEEE Ind. Electron.Mag., vol. 2, no. 2, pp. 28–39, Jun. 2008.

[2] J. Rodriguez, L. G. Franquelo, S. Kouro, J. I. Leon, R. C. Portillo, M. A.M. Prats, and M. A. Perez, “Multilevel converters: An enabling technologyfor high-power applications,” Proc. IEEE, vol. 97, no. 11, pp. 1786–1817,Nov. 2009.

[3] M. F. Escalante, J. C. Vannier, and A. Arzande, “Flying capacitor multilevel inverters and DTC motor drive applications,” IEEE Trans. Ind.Electron., vol. 49, no. 4, pp. 805–815, Aug. 2002.

[4] T. Ishida, K. Matsuse, T. Miyamoto, K. Sasagawa, and L. Huang, “Fundamental characteristics of five-level double converters with adjustable DC voltages for induction motor drives,” IEEE Trans. Ind. Electron., vol. 49,no. 4, pp. 775–782, Aug. 2002.

[5] Y. S. Lai and F. S. Shyu, “Topology for hybrid multilevel inverter,” IEEE Proc. Electr. Power Appl., vol. 149, no. 6, pp. 449–458, Nov. 2002.

[6] C. Rech and J. R. Pinheiro, “Impact of hybrid multilevel modulation strategies on input and output harmonic performance,” IEEE Trans. Power Electron., vol. 22, no. 3, pp. 967–977, May 2007.

[7] M. Veenstra and A. Rufer, “Control of a hybrid asymmetric multilevel inverter for competitive medium-voltage industrial drives,” IEEE Trans. Ind. Appl., vol. 41, no. 2, pp. 655–664, Mar./Apr. 2005.

[8] D. Casadei, F. Profumo, G. Serra, and A. Tani, “FOC and DTC: Two viable schemes for induction motors torque control,” IEEE Trans. Power Electron., vol. 17, no. 5, pp. 779–787, Sep. 2002.

[9] Farid Khoucha, Mouna Soumia Lagoun, Abdelaziz Kheloui, and Mohamed El Hachemi Benbouzid A Comparison of Symmetrical and Asymmetrical Three-Phase H-Bridge Multilevel Inverter for DTC Induction Motor Drives, IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 26, NO. 1, MARCH 2011

[10]Mr. Aung Zaw Latt, Dr.Ni Ni Win,"Variable speed drive of single phase induction motor using frequency Control method",International conference on education technology and computer 2009,pp. 30-34[222]

[11]Course on three phase technology in trs application indian railways indian railways institute of electrical engineering NASIK ROAD18th August, 2010.

[12]J.K.Steinke,"Control Strategy for a three phase ac traction drive with three level GTO PWM inverte"PESC,1988,pp.431-438

[13]J.Zhang,"High performance control of a three level IGBT inverter fed ac drive,"Conf.Rec.of IEEE IAS Annual Meeting,1995,pp 22-28

[14] H. Stemmler. Power electronics in electric traction applications. IEEE conference of Industrial Electronics, Control and Instrumentation, IECON'93, 2:7 07 – 713, 1993.

[15] In-Dong Kim, Eui-Cheol Nho, , Heung-Geun Kim, , and Jong Sun Ko,. 'A Generalized Undeland Snubber for Flying Capacitor Multilevel Inverter and Converter".IEEE transactions on industrial electronics, vol. 51, no. 6, December 2004.

[16] R. H. Baker and L. H. Bannister, "Electric Power Converter," U.S. Patent 3 867 643, Feb. 1975.

[17]M. Klabunde, Y. Zhao, T.A. Lipo, "Current control of a 3-level rectifier inverter drive system,".Conf Rec. of IEEE IAS Annual Meeting, 1994, PP. 2348-2356.

[18]F.Z.Peng,J.S.Lai,J.W.McKeever,J.Van Covereing,"A multilevel voltage –source inverter with separate DC source for static VAR generation,"IEEEteans.Industry Applications,Vol 32, no.5,sep,1966.pp1130-1138.

[19] Yousefpoor, N., S.H. Fathi, N. Farokhnia and H.A. Abyaneh, 2012. Total harmonic distortion minimization applied directly on the line-to-line voltage of multilevel inverters. IEEE T. Ind. Electron., 59(1): 373-380.

[20] Holmes, D.G, McGrath, B.P. "Multi carrier PWM strategies for multilevel inverters" Industrial Electronics, IEEE Transactions, Vol. 49, issue:4, pp.858-867, Aug 2002.

[21] P. Palanivel and S. S. Dash, "Analysis of THD and output voltage performance for cascaded multilevel inverter using carrier pulse width modulation techniques," IET Power Electronics, vol. 4, no. 8, pp. 951–958, 2011.

[22] Rodriguez J, Jih-Sheng Lai, Fang Zheng Peng. Multilevel inverters: a survey of topologies, controls, and applications. IEEE Trans Indus Electron 2002; 49(4): 724–38.

[23] Xiaoming Yuan and Ivo Barbi, "Fundamentals of a New Diode Clamping Multilevel Inverter," IEEE Trans. on Power Electronics, Vol.15, No.4, pp.711- 718, 2000.

[24] A.K. AI-Othman and Tamer H. Abdel hamid., "Elimination of Harmonics in Multilevel Inverters with Non-Equal DC Sources Using PSO.," Elsevier Energy Conversion and Management, 2009.

[25] Jang J. ANFIS: adaptive network-based fuzzy inference systems. IEEE Trans Syst Man Cybern 1993;23:665–85