International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-3, February 2020

Fuzzy Logic Based Control of Multilevel Inverter for Railway Traction System

Jaydeep Lakwal, Manisha Dubey

Abstract: ***This research especially focus on Railway Traction System of Electrical Multiple Units (EMUs) and illustrate the approaching of an Asymmetric Cascaded H-bridge (ACHB) 9-level MLI controlled by the Fuzzy Logic Controller (FLC) to enhance the quality of output by sinking the harmonic contents in the output result. As in the railway, traction system desires high power and voltage for its operation. So it is proficient to utilize recent introduced Multilevel Inverter (MLI) instead of Conventional Inverter. MLI which is discussed here uses two H-bridge modules with unequal DC sources and it is competent to generate multilevel results at output side. Here proposed MLI uses limited semiconductor switches and voltage source. Therefore expenditure and dimensions of the system is condensed. Thus the system effectiveness will enhance. Simulation has done by MATLAB software to authenticate the performance and functional study of proposed MLI. The simulated output shows very favourable result. Comparison has been made between the two (Conventional and Multilevel) power circuit configurations.***

Keywords: Multilevel Inverter, Electric Multiple Unit, Fuzzy Logic Controller, Asymmetric Cascaded H-bridge.

I. INTRODUCTION

Nowadays, more and more high/medium voltage inverters are having industrial use; especially medium voltage inverters are useful for many applications, such as offshore wind farms, various power quality applications, etc. Recently, a bundle of research in the field of MLI has made, like applications such as Photo Voltaic System, STATCOM, Industrial drives and High Voltage Direct Current (HVDC) [1–7]. On the other hand, research work on Railway Traction Systems is relatively limited [8-11].

This research article mainly discuss the traction system of the Railway EMUs, here the EMUs are receiving 25 kV/50 Hz single phase AC supply through Pantograph equipped at the top of EMUs. Railway grid has 3-phase supply, and these 3-phase supplies are to be distributed to different sections with single phase at each section. As discussed earlier that EMUs are getting single phase supply through pantograph. In the EMU, this supply is sent to transformer through pantograph. This step-down transformer has converted this 25KV AC supply to 1800V AC supply. Now with the use of Converter and Inverter, this single phase supply is converted to 3-phase supply. And it is then fed to traction motors. Nowadays these conversion is took place through conventional inverter. In this paper, objective is to change the conventional inverter into recent efficient Multilevel Inverter (MLI). In modern years, MLIs have become more prominent for industrialist and researchers because of their advantages over conventional Inverters. It gives better-quality output waveforms, minimum Total Harmonic Distortion (THD), reduced filter size and minor EMI. The most widespread topologies of MLIs are as follows: 1) Cascaded H-bridge MLI, 2) Neutral clamped (diode clamped) MLI [12] and 3) Flying clamped (Capacitor clamped) MLI [13].

The controlling of CHB MLI is quite easy with respect to other MLIs since it doesn't want flying capacitors and clamping diodes for step-up levels.

Qualitative Performance of the MLIs is mainly handled by the modulation strategies. There are some widespread pulse width modulation (PWM) strategies like sinusoidal PWM, multicarrier PWM, selective harmonics elimination and space vector PWM for the cascaded H-bridge MLI.

In the presented paper, by the intention of improving the performance of output waveform and minimize the number of switching components, driver circuits, and reduces the complete expenses of power circuit configuration of EMUs, an ACHB MLI is presented in power circuit of EMUs for the replacement of Conventional Inverter in EMUs. The proposed MLI circuit configuration is comparing with conventional circuit topologies on diverse points of investigation like number of IGBT switching components, number of DC voltage source and choice of the magnitude of DC voltage source. Lastly, the outcome of presented MLI circuit topology in generating all projected levels of output with 9-step MLI is confirmed by simulation through MATLAB software.

The presented research article is ordered in following manner: Section II describes the research background, Section III describes the main power circuit configuration, Section IV describes the FLC, and Section V displays the simulation results. Section VI describes comparison between proposed MLI topology and conventional topologies, followed by conclusion in the Section VII.

II. RESEARCH BACKGROUND

This part of the paper describes short details of the research articles on MLI and FLC.

Revised Manuscript Received on February 05, 2020.
* Correspondence Author
Jaydeep Lakwal*, Electrical Engg. Department, Maulana Azad National Institute of Technology, Bhopal, India. Email: lakwal.jaydeep@gmail.com
Manisha Dubey, Electrical Engg. Department, Maulana Azad National Institute of Technology, Bhopal, India. Email: manishadubedy6@gmail.com

Retrieval Number: C5609029320/2020©BEIESP
DOI: 10.35940/ijeat.C5609.029320
Journal Website: www.ijeat.org

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Now a day's developments in high power converter for industry and traction applications, it has MLI with its various topology and control techniques which snatches the industrial market. Investigation done on cascaded H-bridge MLI [14-22]. Comprehensive reviews are mentioned in [23-27]. There is various modulation strategies used for MLIs. Few once are Sinusoidal PWM, Space Vector Modulation (SVM), Selective Harmonic Elimination (SHE), and Multicarrier PWM.

PID based control technique is the most admirable control strategy [28]. It is largely accepted controller for process control systems model because of its significant effectiveness and ease of execution. This control technique is extensively used for industrial control processes [29-30].

Conventional control techniques have deprived performances in consideration with industrialized process systems; these are sturdily non-linear in nature. Superior performance is to be received from recently invented control methods [31].

The modern computational techniques, like Artificial Neural Network (ANN) and Fuzzy Logic Controller (FLC) are effectively used for numerous technical research articles and industrial practices [32].

A. Fuzzy based controller Technique

Fuzzy based logic controller is simply being useful for various industrial applications [33]. The huge benefit is the opportunity to establish the awareness of human experts regarding suitable command on plant through controller [34].

FL based controller gives a proper technique of translating subjective and inaccurate human information into various control methods, so as to generate improved system behaviour by the development and submission of information [35].

Rahul Malhotra et al [36] describes that FLC optimises the data of the boiler's steam flow. The comparative analysis depicted the superior results of FLC with respect to PID controller.

Sahil Chandan et al [37] describe the comparative study of the outcome of PID controller and FLC. The outcome of the PID controller is oscillatory in nature which may harm the control system. While on the contrary side, outcome of the fuzzy logic controller does not have any unsafe oscillations in the transient period.

Gaurav et al [38] describes the comparative study of the performance of FLC and PID controller by MATLAB and comparison is conclude with different time domain variables in order to verify that PID controller has slow response and large overshoot as compare to the fuzzy logic controller.

Jelenka [39] in their study investigated the FLC for process based control system. Process control variables were formed. A multi valued FLC system is constructed. A computer based system of the FLC is generated for rate of flow of distillation and control of quality by rate of flow of refluxes as manipulated parameter. Input/output data generates the FLC system. This control model performed quite satisfactory for wide working range and useful for controlling of online process. The obtained outcome shows that distillation plant controls the state parameters efficiently.

III. MAIN POWER CIRCUIT CONFIGURATION

To run motors in the Railway Traction system is mainly depends on the circuit configuration. The Main Circuit Configuration of EMUs which is appropriate to operate either 1500V DC or 25 KV AC systems. Configuration components are as follows:

- Pantograph: for receiving DC or Ac supply
- Surge Arrestor: In order to protect from voltage surge
- Voltage sensing device: Sensing voltage and giving feedback to the electronic system.
- AC DC changeover Switch: Switch of changeover as per availability of supply.
- Vacuum Circuit Breaker: On/Off switch used for AC supply
- High Speed Circuit Breaker: On/Off switch used for DC supply.
- Traction Transformer: Step-down Transformer
- DC link Capacitor: For availability of stable DC supply
- Converters: AC-DC-4-quadrant chopper, PWM Inverters and brake chopper.

Fig. 1 depicted the power circuit of an EMU in block diagram form.

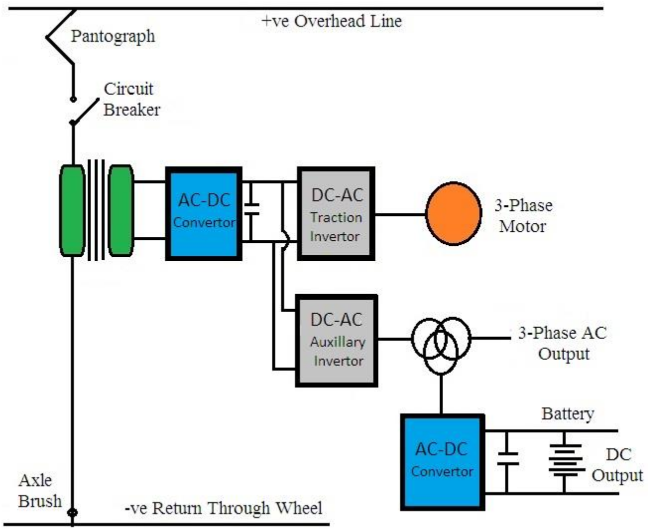

Fig. 1. Power circuit of an EMU in generalised form.

A. Conventional Inverter for EMU Power Circuit

DC-AC Converter has been used in Railway Traction system of EMUs is conventional by nature, which is conventional 3- phase inverter. As depicted in fig. 2. Main circuit configuration of EMU is getting single phase 25kV AC supply from substation, and it is given to a traction transformer which has two windings at secondary side. Traction Transformer is Step-down in nature. Output voltage of traction transformer is sent to 4-quadrant chopper. Then output of Convertor is sent to DC link circuit. Here DC link circuit is consisting of capacitors and inductors, in series and parallel combination respectively. DC link output is sent to inverter, a 3-phase DC-AC inverter. Output result of the inverter is connected with load by use of High rated LC filter in order to create supply for load which is free from harmonic.

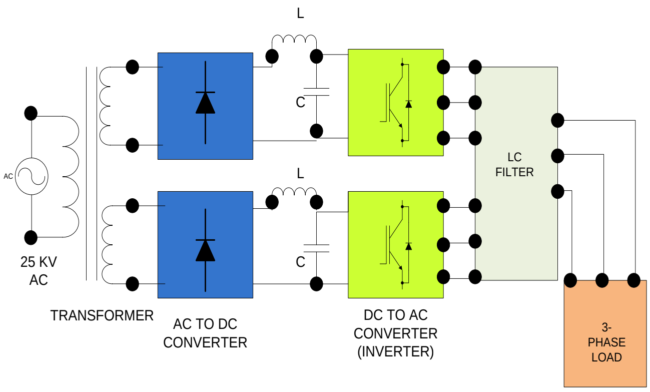

Fig. 2.Conventional Inverter for Power Circuit of EMU

B. Asymmetric Cascaded Multilevel Inverter for EMU Power Circuit

EMUs of Railways can use multilevel inverter for their Traction system. Three Single phases ACHB MLI is combined to make 3-phase MLI as given in fig. 3. Proposed circuit configuration shows that 25kV AC single phase supply from substation is received through pantograph and sent to traction transformer of EMU traction system. It is Step-down transformer having two secondary windings. Output result of traction transformer is sent to 4-quadrant chopper followed by DC connection circuit. DC connection circuit is having capacitors and inductors in series-parallel form. Output of DC connection circuit is sent to inverters. It consists of three single phase MLI. ACHB type MLI Topology adopted here. LC filter is not consumed for connection of load with output of MLI.

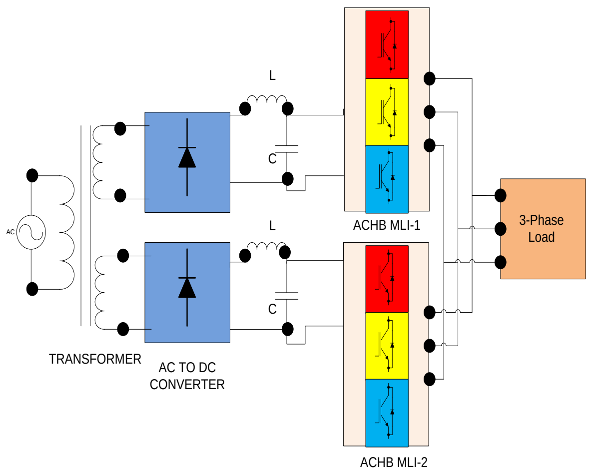

Fig. 3. ACHB-MLI for EMU Power Circuit

C. Asymmetric Cascaded H-bridge Multilevel Inverter

Fig. 4. shows the module based structure of the proposed MLI; it comprises of two modules of Cascaded H-bridge MLI. Asymmetric nature is given here in its input DC supply. The DC supply of these two modules has different magnitudes. First module has DC supply of 150V and it has 4 switches as S_{a1}, S_{a2}, S_{a3}, S_{a4}. Whereas Second module has DC supply of 50V and it has 4 switches as S_{b1}, S_{b2}, S_{b3}, S_{b4}. As asymmetric ratio is 1:3, thus ACHB MLI can generate 9-level at the output result from the topology. The switching pattern of 9-level ($\pm Vdc$, $\pm 3/4Vdc$, $\pm 1/2Vdc$ $\pm 1/4Vdc$, 0) voltage output is shown in Table I.

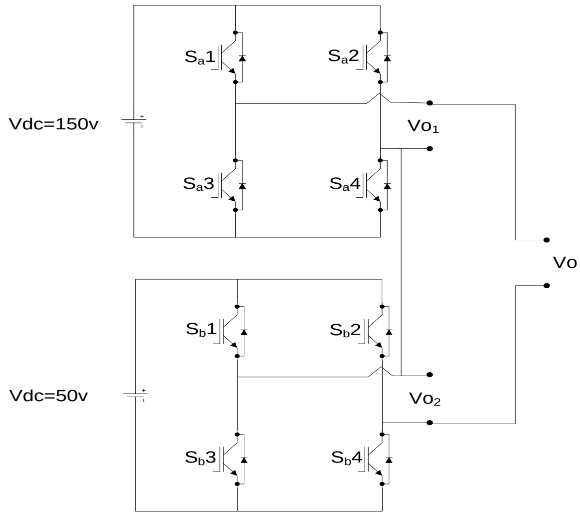

Fig. 4. Circuit diagram of ACHB-MLI

Table-I: Output voltage of 9-level ACHB MLI

Sa1	Sa2	Sa3	Sa4	Sb1	Sb2	Sb3	Sb4	Van
1	0	0	1	1	0	0	1	$+V_{DC}$
1	0	0	1	1	1	0	0	$+3/4\ V_{DC}$
1	0	0	1	0	1	1	0	$+1/2\ V_{DC}$
1	1	0	0	1	0	0	1	$+1/4\ V_{DC}$
1	1	0	0	1	1	0	0	0
0	0	1	1	0	1	1	0	$-1/4\ V_{DC}$
0	1	1	0	1	0	0	1	$-1/2\ V_{DC}$
0	1	1	0	0	0	1	1	$-3/4\ V_{DC}$
0	1	1	0	0	1	1	0	$-V_{DC}$

In the proposed ACHB MLI composition, the number of levels (N_{level}), number of switching components (N_{switch}) and number of separate DC source (N_c), are considered as:

$$N_{Step} = 2(n+2)+1$$

$$N_{Switch} = 2(n+2)$$

$$N_C = 2n \quad (1)$$

IV. FUZZY LOGIC CONTROLLER

Fuzzy logic controller implements algorithms which are knowledge based and it uses experiences of operators. Non-linear systems are more useful for this type of control strategy. Fuzzy logic controller is implemented here in this circuit configuration for obtaining desired quality output voltage waveform and minimum harmonics of the proposed ACHB MLI. In FLC controlling action is resolute through the assessment of easy language based rules. Full understanding of the process is required for the development of the rules.

Retrieval Number: C5609029320/2020©BEIESP
DOI: 10.35940/ijeat.C5609.029320
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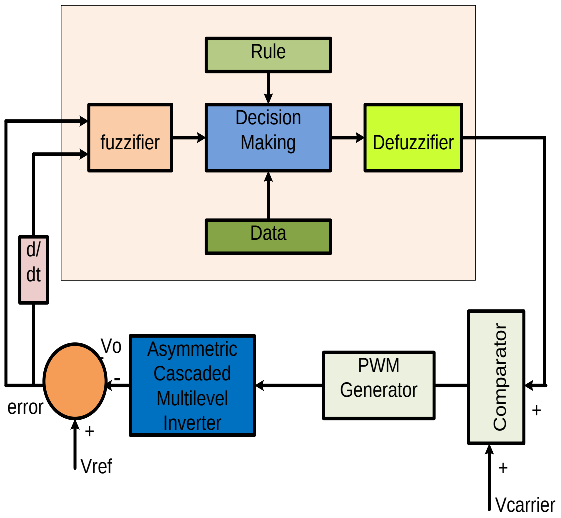


Fig. 5. Scheme of FLC for ACHB-MLI

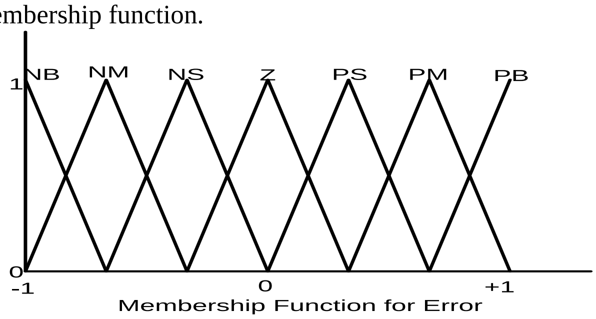
FLC is divided into five sub-parts as shown in Fig. 5. These sub-parts are as follows: Fuzzifier, Defuzzifier, rule, Decision Making and Data. The functional arrangement of fuzzy logic control scheme is composed as follows:

A. Inputs-Output: Identification

The FLC inputs which are used for this scheme consists of current error also change of that current error. Here error is actually the disparity between desired reference voltage (Vref) and actual voltage (Vo). And change of error is the difference of current error and next preceded error. Output of FLC is the compensating signal. It is an updated modulation signal obtained which will be sent to PWM generator for generation of gating signal. IGBT switching components of the MLI are triggered through these gating signals.

B. Inputs and Output: Fuzzification

The inputs- output signals of the FLC does not quantized in a classical manner where as each input or output signal is assigned a "membership function" for each fuzzy set. Each input signal has been mapped into several fuzzy sets with different shapes. Output signal is also mapped into several fuzzy regions with different shapes (for Mamdani type of fuzzy systems). For proposed MLI, seven fuzzy sets has to be adopted which are triangular in shapes. These are shown in Fig. 6. Error signals, change in error signals and compensating signals are defined from the library of fuzzy membership function.



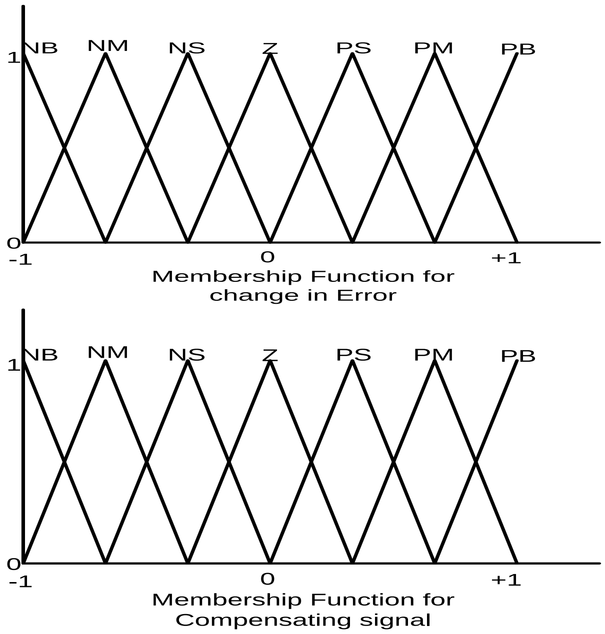


Fig. 6. Membership functions

C. Table for Rules and Mechanism of Inference

The beginning of FLC rules for proposed MLI is conceptualised by the following criteria:

- If the proposed MLI output changes far-off from the system reference value, the compensating signal does change the modulating signal with large value so as to carry the output to the reference value quickly.
- If the proposed MLI output is moving toward reference point, a little modification in modulating signal will be enough.
- If the output of the proposed MLI is close to the reference value and is moving toward it speedily, the modulating signal must have to be reserved stable so that further deviation can avoided.
- If reference point is achieved and the proposed MLI output is still varying, the modulating signal must have to be altered with small value so as to avoid the output from deviating far- away.
- If the reference value is achieved and the output of the proposed MLI is stable, the modulating signal remains unaffected.
- If the output of the proposed MLI is higher than reference point, signal of modulation has amplitude must be reduced and vice versa.

As per above given scheme, Table II describes rule base for FLC.

Table-II: Inference Rules for FLC

e/d/de	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NM	NS	Z	PS	PM
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PM	PM	PB
PM	NS	Z	PS	PM	PM	PB	PB

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e/d/de	NB	NM	NS	Z	PS	PM	PB
PB	Z	PS	PM	PM	PB	PB	PB
e/d/de	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	Z

D. Defuzzification

A crisp control signal is created after the defuzzification of fuzzy sets. Bisector of area method is used to calculate a crisp value for every change in modulating signal.

V. EMU Power Circuit with ACHB MLI and FLC

This research article shows the potential of a EMU power circuit governed by the fuzzy logic controller using ACHB MLI. As shown in Fig. 5, block diagram of FLC with ACHB MLI consists of FLC model, ACHB MLI model which is a symbol for whole EMU power circuit, PWM Generator, summer and comparator. Its implementation is initiated with use of signal generator of reference voltage which is striking frequency, amplitude and phase. Here FLC has signal of feedback and its output signal is continuous waveform send to block of driver for MLI. These are functions of conditional statement creating discrete signals on behalf of gate pulse of the ACHB MLI.

The variable at the input of FLC:

- The differentiation for signals of reference and actual as *AVdiff* = Vref –Vout.

The signal of output for FLC is send to MLI driver for gating signal. Here are different eleven states for the output of FLC. A knowledge base was generated initially during the design process of FLC, (i.e. rules of fuzzy, behaviour, articulated through statements and situations). Starting since situation "TRUE" (i.e., condition has established), error signal created by the formation of set of rules. Afterwards situations were formed by getting variable reactions. Type and quantity of membership functions (MFs) represents a solution for the FLC. Data allocation of input is responsible for Shape of MFs and the time of implementation and accurateness of tracking are influenced by its shape. Fig. 6 and 7 shows the MFs adopted in favour of two inputs. Denotation "NB," "NM," "NS," "ZE," "PS," "PM," and "PB" are adopted for error signal =AVdiff and for other variable also. Here: "NB" = negative-big, "NM" = negative-medium, "NS" = negative-small, "ZE" = zero, and so others. In this research article, the type and quantity of the FLC rules were determined according to study prepared by changing the type and number of rules.

Logics were proposed for crafting the rules of inference:

- If AVdiff signal is equivalent to ZE, the present condition is right, and the MLI brings its present state.
- As an essential state, if AVdiff is positive (Vout > Vref), the MLI state should be squashed; if AVdiff is negative (Vout < Vref), the MLI state should be improved.

In this research article, Model of simulation is designed with MATLAB software. Figs. 5 depicted the configuration of closed loop for 9-level ACHB MLI. Feedback of output signal is send to summer for comparing the output signal along with reference signal in order to get error signal. Here two input signals are used in FLC, one is error signal and other one is derivative of this error signal. The task of the FLC is to translate the observed inputs which are crisp in nature into sets of fuzzy by process of fuzzification, afterward the sets of fuzzy is processed with the help of fuzzy rules and fuzzy inference system help to perform evaluation mechanism. A set of fuzzy is again generated as an Output from the fuzzy inference system, afterwards by the process of defuzzification these are again transformed to output signal which is crisp in nature. The above generated output is compared along with carrier wave which is triangular in nature to create gate pulses for driver circuit of the 9-level ACHB MLI.

VI. RESULTS OF SIMULATION

In the research article, MATLAB software has used in order to simulate EMU power circuit configuration with two topologies (Conventional and MLI. For the simulation purpose RL load has been taken. As this configuration is for Railway traction purpose so firstly 3-phase output waveform of both topologies is depicted in Fig. 7 and Fig. 8. Afterward DC link voltage waveform which is input for inverter and phase voltages of inverters of both the topologies is shown is Fig. 9 and Fig. 10. And Total harmonic distortion analysis is shown for both the topologies in Fig. 11 and Fig. 12.

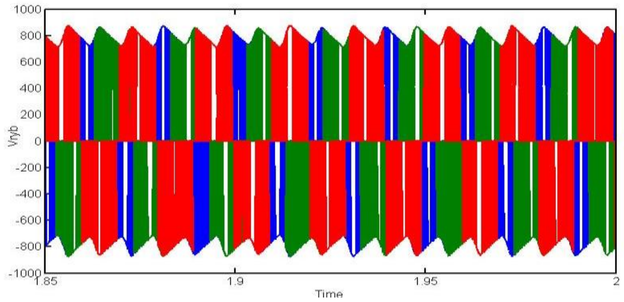

Fig. 7. 3-ph waveform of voltage for conventional configuration

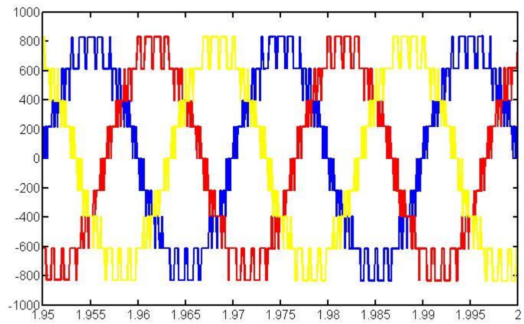

Fig. 8. 3-phase waveform of voltage for MLI configuration

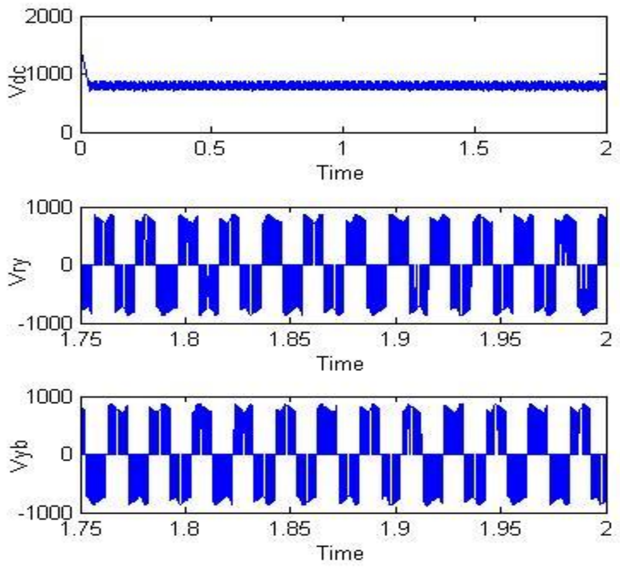

Fig. 9. Vdc, Vry and Vyb waveform of conventional configuration

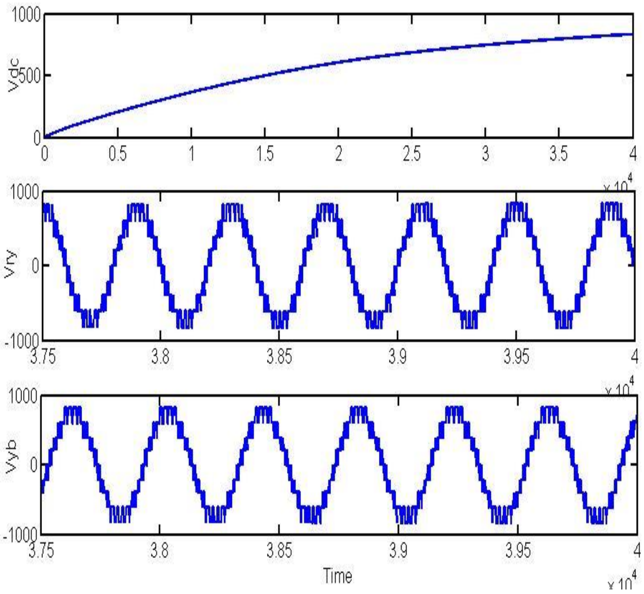

Fig. 10. Vdc, Vry and Vyb waveform of MLI configuration

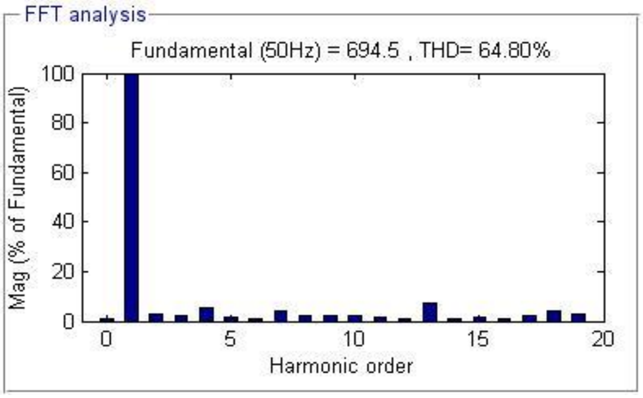

Fig. 11. THD analysis of conventional configuration

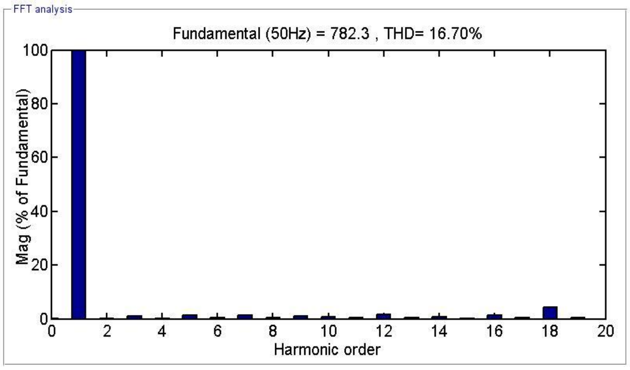

Fig. 12. THD analysis of conventional configuration

VII. CONCLUSION

An EMU power circuit with ACHB MLI configuration for Railway traction system based on fuzzy logic-closed loop controller is investigated. An ACHB MLI structure used minimum quantity of power electronic switches for generation of 9-level output. The operation and performance of the FLC based EMU power circuit with ACHB MLI is validated through MATLAB simulation software. From the THD analysis it is concludes that MLI configuration is ¼ more efficient than conventional inverter configuration. The performances of FLC-based MLI configuration have been assessed, and the results display the effectiveness of this controller configuration. Based on the performance study, it is conclude that FLC-based proposed railway traction system gives better performance.

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AUTHORS PROFILE

Jaydeep Lakwal was born in Ujjain, India, on 19th July 1989. He received B.Tech and M.Tech. degrees I 2011 and 2013 respectively. He is currently working as Senior Section Engineer at Indian Railway and pursuing part time Ph.D. from Maulana Azad National Institute of Technology, Bhopal, India. His research interests include power electronics, Multilevel Inverter and Fuzzy Logic systems.

Manisha Dubey was born in Jabalpur, India, on 15th December 1968. She was received B.E. (electrical), M.Tech. (Power systems), and Ph.D. (electrical engineering) degrees in 1990, 1997, and 2006, respectively.
She is working as a Professor at the Department of Electrical Engineering, National Institute of Technology, Bhopal, India. Her research interests include power systems, genetic algorithms, fuzzy logic systems and application of soft computing techniques in power system dynamics and control. Dr. Dubey is the life member of the IE and the ISTE.