Fuzzy Logic Controller for Z-Source Cascaded Multilevel Inverter

M.Balachandran and N.P.Subramaniam

Abstract: This paper presents the control method, Fuzzy logic control (FLC) for Z-source Cascaded Multilevel Inverter. The Z-source converter overcome the conceptual and theoretical barriers and limitations of the traditional voltage-source converter and current-source converter and offers a new power conversion concept. Also the Fuzzy logic control method is applied to control the boosting dc voltage and to reduce the THD of the inverter output. A simulation model of conventional cascaded multilevel inverter and proposed Z-source cascaded multilevel inverter has been built in MATLAB/SIMULINK and its performance has been analyzed.

Keywords: **Cascaded multilevel inverter, MATLAB, fuzzy logic control, total harmonic distortion.**

I. INTRODUCTION

As described in [1], during the last fifteen years, fuzzy logic control (FLC) was successfully adopted. Few papers expose the use of FL in the control of ac converters chiefly for proportional–integral (PI) or sliding-mode current controller enhancement through gains adaptation [2]–[5]. Only a few papers, such as [6]–[9], proposed true FL controllers (FLCs).

In power electronics, the study of topologies with a less number of switches is an important topic because it may in power electronics since it may provide other options to reduce the cost of energy conversion process while preserving power quality [10]–[11].

There are two traditional converters: voltage-source (or voltage-fed) and current-source (or current-fed) converters. The voltage sources are battery, fuel-cell stack, diode rectifier, and/or capacitor.

The following conceptual and theoretical barriers and limitations are from V-source converter.

The inverter output voltage is restricted lower and cannot exceed the dc-rail voltage. And the dc-rail voltage has to be greater than the input voltage. A shoot-through problem may take place and demolish the devices. The shoot-through difficulty via electromagnetic interference (EMI) noise's improper gating-on is a major problem to the converter's stability.

I-source converter has conceptual and theoretical barriers and limitations as the follow.

The inverter output voltage has to be better than the input dc voltage that feeds the dc inductor. Otherwise the dc voltage supplied is always smaller than the input voltage. Even one of the upper bridge devices and one of the lower bridge devices have to be switching on and maintained on at any time. Or else, dc inductor will be an open circuited condition and demolish the semiconductor devices. The open circuit difficulty by EMI noise's improper gating-off is a major problem of the converter's consistency.

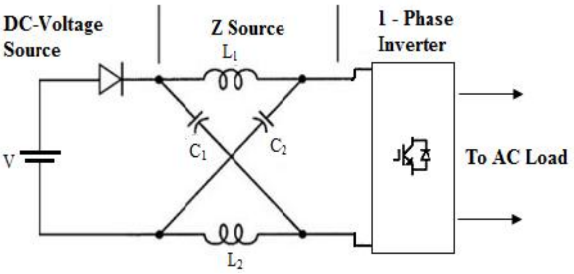

Fig. 1. General configuration of the Z-source inverter.

Additionally, common problems in the V-source and the I-source converters are discussed as the following.

Converters are either a boost converter or a buck converter and cannot be a buck–boost converter. That means converter output voltage range is restricted. The output may be greater or smaller than the converter input voltage. Their main circuits cannot be exchangeable between the V-source converter and the I-source converter [12].

To overcome the above problems, this paper explains an impedance-source (or impedance-fed or Z-source) power converter. Fuzzy logic control became a standard for the switching power. Fig.1 shows a general configuration of the Z-source inverter. The fuzzy logic control method is proposed for Z-source H-bridge cascaded multilevel inverter for the output of 15 levels. Simulation of the circuit configurations have been performed in MATLAB/SIMULINK. Finally, simulation results are presented, to verify the performance of the proposed inverter.

II. SWITCHING CONTROL

A. *Space Vector Pulse Width Modulation*

The space vector modulation (SVM) is an algorithm for the control of pulse width modulation (PWM). It is used for the creation of alternating current (AC) waveforms; most commonly to AC powered loads [13]-[15]. There are various variations of SVM that result in different quality and computational requirements. One active area of development is in the reduction of total harmonic distortion (THD) created by the rapid switching inherent to these algorithms [16]-[19].

B. *Fuzzy Logic Control*

The fuzzy logic approach has been objected of an

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increasing interest and has found application in many domains of control problem. In fuzzy logic concept, the transition is derived between membership and non-membership functions. Therefore, boundaries of fuzzy sets can be undefined and ambiguous, making it useful for approximate systems. The main advantages of fuzzy logic control method as compared to conventional control techniques resides on the fact that no mathematical model is required for controller design and also it does not suffer much from the stability problem but it needs the experts experience. Fuzzy logic can be considered as an alternative approach to conventional feedback control [20]. Fuzzy logic control is developed in this work to obtain desired output voltage and minimize the harmonics of the chosen inverter. The control action is determined in a fuzzy logic control through the evaluation of a set of simple linguistic rules.

III. SVM FOR Z-SOURCE CASCADED MULTILEVEL INVERTER

The concept of space voltage vectors corresponding to various switching states has been applied. Cascaded multilevel inverter consists of a series of H-bridge inverter. Z-source cascaded multilevel inverter is implemented with multiple DC sources to get 2^{n+1}-1 levels.

The topology has three unequal dc sources to generate an equal step fifteen level output. Inverter consists of three H-bridges as shown in Fig.2. H - Bridge (H_1) is connected to a dc source of 10V through Z-source components L_{11}, L_{12}, C_{11} and C_{12} and also R_1 and C_{13} controls the voltage spikes. The second bridge (H_2) is connected to a dc source of 20V through Z-source components L_{21}, L_{22}, C_{21} and C_{22} and also R_2 and C_{23} controls the voltage spikes. The third bridge (H_3) is connected to a dc source of 40V through Z-source components L_{31}, L_{32}, C_{31} and C_{32} and also R_3 and C_{33} controls the voltage spikes.

By suitably opening and closing the switches of H_1, the output voltage can be made equal to -10V or +10V similarly the output voltage of H_2 can be made equal to –20V or +20V. If H_1 and H_2 bridges are connected in series the output voltage can be made equal to -30 or +30, the out voltage of H_3 can be made equal to -40 or +40. If H_1 and H_3 bridges are connected in series the output voltage can be made equal to -50 or +50, when H_2 and H_3 bridges are connected in series the output voltage can be made equal to -60 or +60 and H_1, H_2 and H_3 bridges are connected in series, the output voltage can be made equal to -70 or +70. Therefore, the output voltage of the converter can have fifteen possible values -70V, -60V, -50V, -40V, -30V, -20V, -10V, 0V, +10V, +20V, +30V, +40V, +50V, +60V, and +70V. Therefore, the output voltage of the inverter has fifteen levels. The output voltage of the cascaded multilevel inverter is $V_{out.}$

The switching angles of the waveform will be adjusted to obtain the output voltage. The harmonics orders and magnitude depends upon the type of inverter and the control techniques. The harmonic spectra depend upon the switching frequency and the control method [21].

The general purpose of this multilevel inverter is to synthesize a desired voltage from several separate dc sources, like batteries, fuel cells, solar cells, and ultra capacitors [22]. The converter circuit consists of a single-phase structure of an inverter with separate dc sources. Each separate dc source is connected to a different Z-source component. Table I gives the comparison between conventional Z-source cascaded MLI and proposed Z-source cascaded inverter.

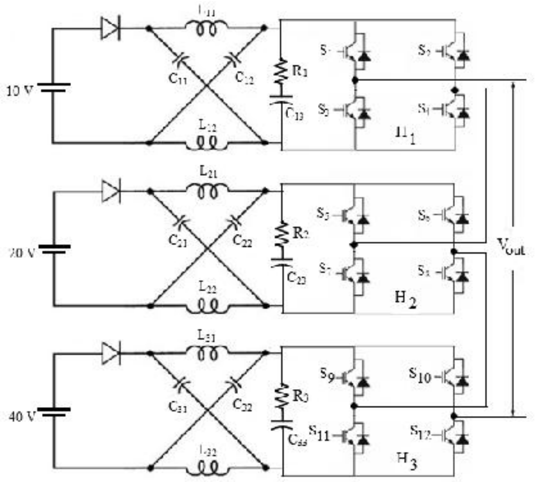

Fig. 2. Topology of a fifteen-level H-bridge cascaded multilevel inverter.

TABLE I. COMPARISON BETWEEN CONVENTIONAL Z-SOURCE MLI AND PROPOSED Z-SOURCE CASCADED MLI

Switching Method	Total number of switches used	Number of H-Bridges used	THD%
SVM	12	3	8.34%
Fuzzy logic			7.89%

IV. PROPOSED Z-SOURCE H-BRIDGE CASCADED MULTILEVEL INVERTER

An FLC, instead, does not require neither detailed knowledge of the process under control nor its precise description in terms of mathematical model and often, if well designed, outperforms more complex controllers because it adapts its outputs to the actual state of the system even without the use of observers.

TABLE II. INTERFACE RULES

ce e	IV+	III+	II+	I+	ZE	I-	II-	III-	IV-
NB	IV+	IV+	III+	II+	I+	ZE	I-	II-	III-
NS	IV+	IV+	III+	II+	I+	ZE	I-	II-	III-
ZE	IV+	III+	II+	I+	ZE	I-	II-	III-	IV-
PS	III+	II+	I+	ZE	I-	II-	III-	IV-	IV-
PB	III+	II+	I+	ZE	I-	II-	III-	IV-	IV-

FLC output can suppose nine different states, which an integer values bounded within the range [−4, 4]. The initial move during the FLC design is the formation of a knowledge base. Fuzzy rules, expressed in terms of statements, conditions, and actions. Starting from the condition "TRUE", a set of rules is defined for the errors. Then, conditions were defined accordingly, obtaining variable reactions. The type of membership functions (MFs) and number represent for the controller, achievable performance, memory space occupation, and execution speed [23]. The shape depends on the input data distribution. The most common shapes are the triangular, trapezoidal, or Gaussian ones. In this paper, triangular shapes were chosen for input and output MFs due to their satisfactory performance. Figs. 3 and 4 show the MFs chosen for the two input parameters. The labels “NB,” “NS,” “ZE,” “PS,” and “PB” used for error. Where “NB” is negative−big, “NS” is negative−small, and “ZE” is zero. The input error was assumed bounded within the range [−30, 30] V.

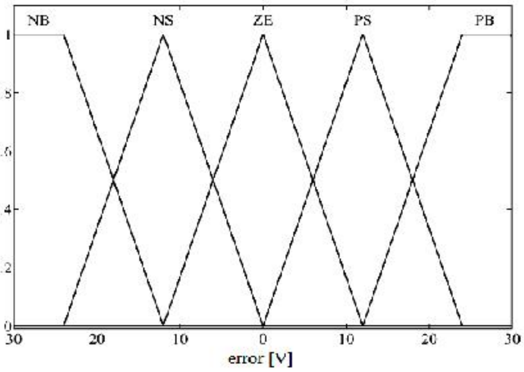

Fig. 3. Membership functions of error.

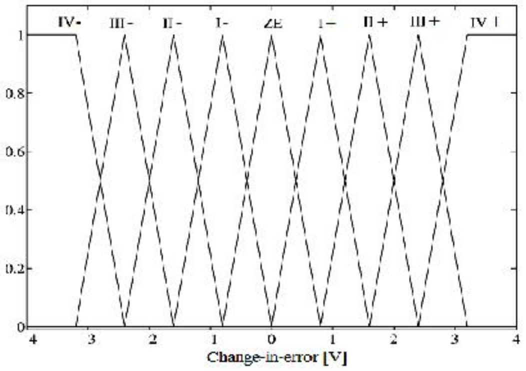

Fig. 4. Membership functions of change-in-error.

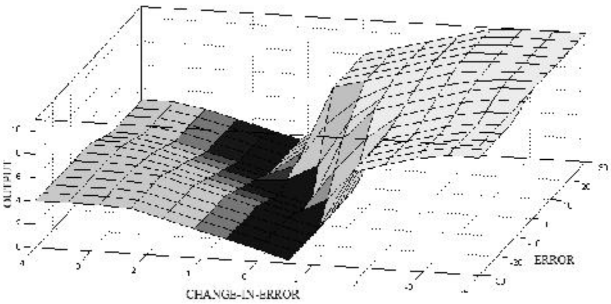

Fig. 5. 3-D image of interface rules.

The fuzzy set variables are *IV* −, *III*−, *II*−, *I*−, *ZE*, *I*+, *II*+, *III*+, and *IV* +. *Sugeno* system architecture, Prod or Probor (AND or OR) and weighted average methods were used in the inference engine, fuzzification method and in the defuzzification process, respectively.

It points out that a high number of fuzzy rules make sure both completeness and appropriate resolution of the controller. Therefore it gives high control accuracy. However, since both their type and quantity influence the fuzzy approximation error, a high number of rules may lead to an over parameterized system, thus reducing generalization capability and accuracy, and increasing execution time. The number of fuzzy rules depends on the number of input variables, system performance, the execution time, the chosen membership functions, the ease of construction, and the adaptability. A satisfactory level of performance was obtained after a tuning process, i.e., starting from some initial heuristic rules and gradually modifying their number and type. At the end of this process, the 45 inference rules summarized in Table II and shown in Fig. 5 were selected. In Fig. 5, the *x*-axis reports the possible values for error, the *y*-axis the possible values for change in error, and the *z*-axis the next state evaluated by the FLC.

V. SIMULATION OF CONVENTIONAL AND PROPOSED H-BRIDGE CASCADED MULTILEVEL INVERTER

The performance of the conventional Z-source H-bridge cascaded multilevel inverter is verified through the simulation results. For this inverter, space vector modulation control is used as conventional method and fuzzy logic control is used as proposed method to generate gate pulses to the inverter switches.

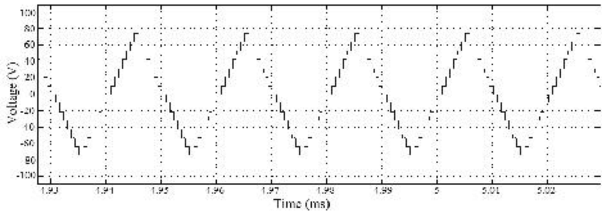

Fig. 6. Phase voltage of conventional Z-source cascaded MLI.

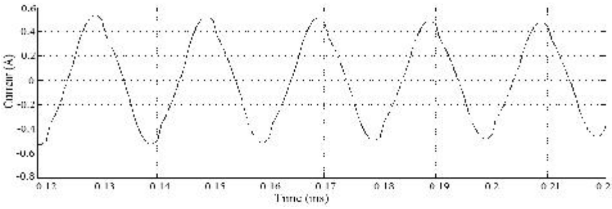

Fig. 7. Phase current of conventional Z-source cascaded MLI.

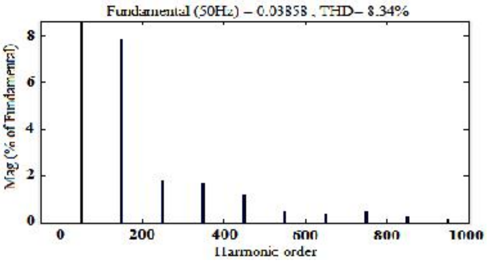

Fig. 8. FFT analysis of Z-source cascaded MLI.

The Fig.6 and Fig.7 show the phase voltage, and phase current of the Z-source H-bridge cascaded MLI. The output voltage has 15 levels. Fig.8 shows the FFT analysis of the inverter output voltage. THD value of the multi level inverter for the output voltage is 8.34%.

Fig.9 shows the gate pulses for the proposed Z-source cascaded MLI. Fig.10 and Fig.11 show the phase voltage, and phase current of the inverter. Fig.18 shows the FFT analysis of the inverter output voltage. THD value of the multi level inverter for the output voltage is 4.74%.

THD value of the inverter with proposed MLI is greatly reduced. And the performance of the voltage and current has been improved.

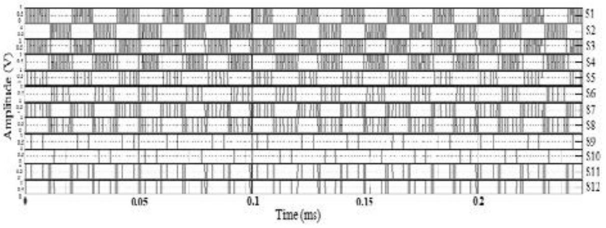

Fig. 9. Gate pulses for proposed Z-source cascaded MLI.

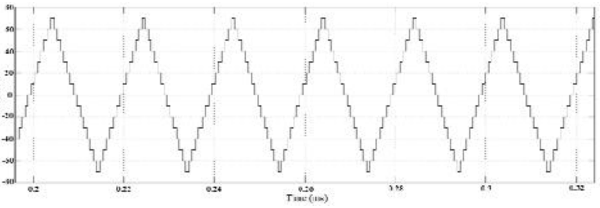

Fig. 10. Phase voltage of proposed Z-source cascaded MLI.

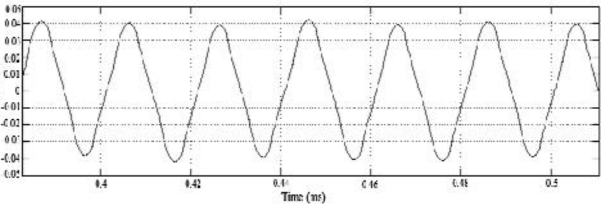

Fig. 11. Phase current of proposed Z-source cascaded MLI.

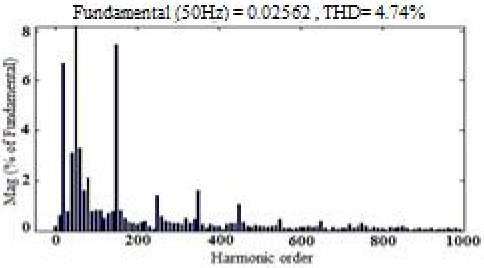

Fig. 12. FFT analysis of proposed Z-source cascaded MLI voltage.

Comparing both conventional method and proposed methods, THD value of proposed Z-source H-bridge cascaded MLI inverter using fuzzy logic controller is reduced to 4.74%. By reducing the harmonic contents the relative fundamental component has been increased. The RMS voltage has been improved. It is the better voltage compared to the conventional system. At the same time current ripple has been reduced to considerable quantity.

VI. CONCLUSION

It is concluded that a Z-Source H-bridge cascaded multilevel inverter gives high output voltage through its impedance network. Fuzzy logic control technique has been employed for Z-source cascaded MLI which gives an improved performance.FLC technique improves the inverter output profile by reducing the harmonic contents and increasing the relative fundamental component. The FFT spectrum gives the reduction in the harmonics of the output voltage. The performance of the proposed Z-source cascaded multilevel inverter has been compared with the conventional MLI. From the results, it is found that Z-source multilevel inverters with fuzzy logic control are implemented with cascaded MLI; the proposed method greatly reduces the THD and increases the converter efficiency when compared with conventional systems.

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