UDC 621.314 https://doi.org/10.20998/2074-272X.2023.4.08

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Mitigation of harmonics for five level multilevel inverter with fuzzy logic controller

Introduction. *The advantages of a high-power quality waveform and a high voltage capability of multilevel inverters have made them increasingly popular in recent years. These inverters reduce harmonic distortion and improve the voltage output. Realistically speaking, as the number of voltage levels increases, so does the quality of the multilevel output-voltage waveform. When it comes to industrial power converters, these inverters are by far the most critical.* ***Novelty.*** *Multilevel cascade inverters can be used to convert multiple direct current sources into one direct current. These inverters have been getting a lot of attention recently for high-power applications. A cascade H-bridge multilevel inverter controller is proposed in this paper. A change in the pulse width of selective pulse width modulation modulates the output of the multilevel cascade inverter.* ***Purpose.*** *The total harmonic distortion can be reduced by using filters on controllers like PI and fuzzy logic controllers.* ***Methods.*** *The proposed topology is implemented with MATLAB/Simulink, using gating pulses and pulse width modulation methodology and fuzzy logic controllers. Moreover, the proposed model also has been validated and compared to the hardware system.* ***Results****. Total harmonic distortion, number of power switches, output voltage and number of DC sources are analyzed with conventional topologies.* ***Practical value.*** *The proposed topology has been very supportive for implementing photovoltaic based multilevel inverter, which is connected to large demand in grid and industry.* References 17, table 4, figures 9.

Key words: **cascade H-bridge multilevel inverters, fuzzy logic controller, selective pulse width modulation technique, total harmonic distortion.**

Вступ*. Переваги форми хвилі високої якості та високої напруги багаторівневих інверторів зробили їх дедалі популярнішими в останні роки. Ці інвертори зменшують гармонійні спотворення та покращують вихідну напругу. Насправді, зі збільшенням кількості рівнів напруги якість багаторівневого сигналу вихідної напруги зростає. Коли доходить до промислових перетворювачів енергії, ці інвертори, безумовно, є найважливішими.* ***Новизна****. Багаторівневі каскадні інвертори можуть використовуватися для перетворення кількох джерел постійного струму на один постійний струм. Останнім часом цим інверторам приділяється велика увага при використанні на великій потужності. У статті пропонується каскадний Н-мостовий багаторівневий інверторний регулятор. Зміна ширини імпульсу селективної широтно-імпульсної модуляції модулює вихідний сигнал каскадного багаторівневого інвертора.* ***Мета****. Загальне гармонічне спотворення можна зменшити, використовуючи фільтри на таких контролерах, як ПІ-контролери та контролери з нечіткою логікою.* ***Методи****. Запропонована топологія реалізована за допомогою MATLAB/Simulink з використанням стробуючих імпульсів та методології широтно-імпульсної модуляції, а також контролерів з нечіткою логікою. Крім того, запропонована модель також була перевірена та порівняна з апаратною системою.* ***Результати****. Загальне гармонічне спотворення, кількість силових ключів, вихідна напруга та кількість джерел постійного струму аналізуються за допомогою звичайних топологій.* ***Практична цінність****. Запропонована топологія дуже допомогла реалізувати багаторівневий інвертор на основі фотоелектричних систем, що пов'язано з великим попитом у мережах та промисловості.* Бібл. 17, табл. 4, рис. 9.

Ключові слова: **каскадні Н-мостові багаторівневі інвертори, нечіткий логічний регулятор, селективна широтно-імпульсна модуляція, повне гармонічне спотворення.**

1. Introduction. Modern power generation, transmission, distribution, and use systems all rely on the conversion of DC to AC power. Variable-frequency drives, static var compensators, uninterruptible power supply, induction heating, high-voltage DC power transmission, electric cars, air conditioning, and flexible AC transmission systems are just a few examples of their numerous applications. The demand for equipment with a megawatt rating has increased recently. The mega-watt class AC drives require a medium voltage network connecter. The above-stated reasons provide scope for multilevel inverters (MLIs) as a solution to work with higher voltage levels. A power semiconductor switch cannot be directly connected to a high voltage network due to the increase in demand for high-voltage, high-power inverters. As a result, MLIs have been developed and are now available for purchase. If the voltage sources are increased, a sinusoidal-like waveform appears at the output. The quality of the output waveform is improved while the total harmonic distortion (THD) is reduced by MLIs. Another advantage of MLIs is that they have lower switching losses [1-3]. In industrial drive systems, power electronic inverters are frequently employed. The limitations on voltage and current it is necessary to use series and parallel connections for power semiconductor devices. With the propensity to synthesize waveforms with a better harmonic spectrum and higher voltages, MLIs have gained more importance in literature in recent times [4]. Industrial applications include AC-power supplies, static var compensators, and drives. Diode-clamped (neutral-clamped), capacitor-clamped (flying capacitors), and cascaded inverters with separate DC sources have been suggested for MLIs [5-8]. Space vector modulation and selective pulse width modulation are other modulation and control strategies for MLIs. Using a MLI has the following advantages: These devices are excellent when it comes to distortion and voltage drop. Very little distortion occurs in the input current. The motor bearings aren't put under as much strain when the common voltage is reduced. The elimination of common voltages and a reduction in switching frequency are both possible with advanced modulation techniques. Two types of DC voltage source inverters exist for inverters that have DC voltage sources of the same or different amplitudes. Asymmetric cascaded MLIs provide more output levels than symmetric cascaded MLIs with a comparable number of power electronic devices because their DC voltage sources have different amplitudes. It is thus smaller and less expensive to use asymmetric MLIs [9-12].

Because the DC voltage sources are of equal magnitude, symmetric inverters require a large number of switches, insulated gate bipolar transistors (IGBTs), power diodes, and driver circuits. This problem can only be solved using an asymmetric MLI [13-16]. The disadvantages of bidirectional power switches will be magnified from a voltage perspective. Two IGBTs with dual anti-parallel diodes and a single driver circuit must be used to make a bidirectional switch. An anti-parallel diode is required for a unidirectional switch. It makes no difference which way a power switch is plugged in, whether it is a one-way or a two-way switch. Many asymmetric cascaded MLI has been proposed to increase the number of output levels. As a primary drawback, these inverters require high-voltage DC power sources. Using a new basic unit, a greater number of output levels can be generated with fewer electronic devices. A cascaded MLI is put forward by connecting several of the basic units that have been proposed. An H-bridge will be added to the inverter's output because only positive and negative voltages can be generated. One of the proposed cascaded MLIs has been developed. H-bridge and diode-clamped MLIs, as well as flying capacitances and fly inductors, are examples of topologies that can reduce harmonic distortion. Clamping diode inverter voltage control becomes more difficult as the number of levels increases. Voltage regulation of a flying capacitor MLI becomes increasingly challenging with more levels. The cascade multilevel [17] is the most efficient of the three topologies. Cascade MLIs have better performance, but they still fall short of IEEE standards as the data presented above shows. Using cascading MLIs and controllers, as well as the selective pulse width modulation technique, reduces THD. Different carrier waveforms are designed for the third and fifth levels of the project to reduce THD. Proportional and integral (PI) and fuzzy logic controllers (FLC) with filters is being used to further reduce harmonic distortion below IEEE standards of 5 %. Using these controllers, it is possible to reduce THD more effectively.

2. System configuration for existing PI, PI with filter controller. Figure 1 illustrates about schematic diagram for MLI with closed loop control scheme. Figure 2 depicts the simulation diagram of five level MLI with single phase system. An example of a five-level MLI's output can be seen in Figure 3. In order to get five level, six carrier signals and one reference signal has been used. Three levels are positive and the other three levels are negative and the left-over level is zero level and these voltages are obtained using different switching paths.

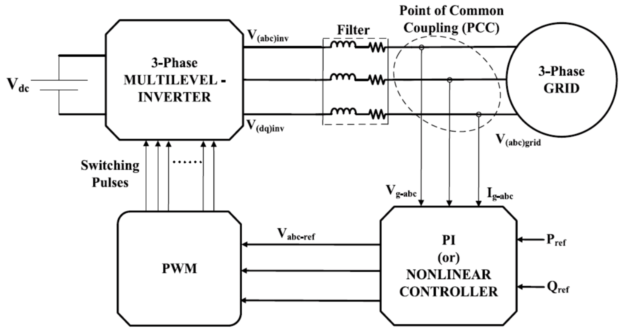

Fig. 1. Schematic diagram for MLI with closed loop control scheme

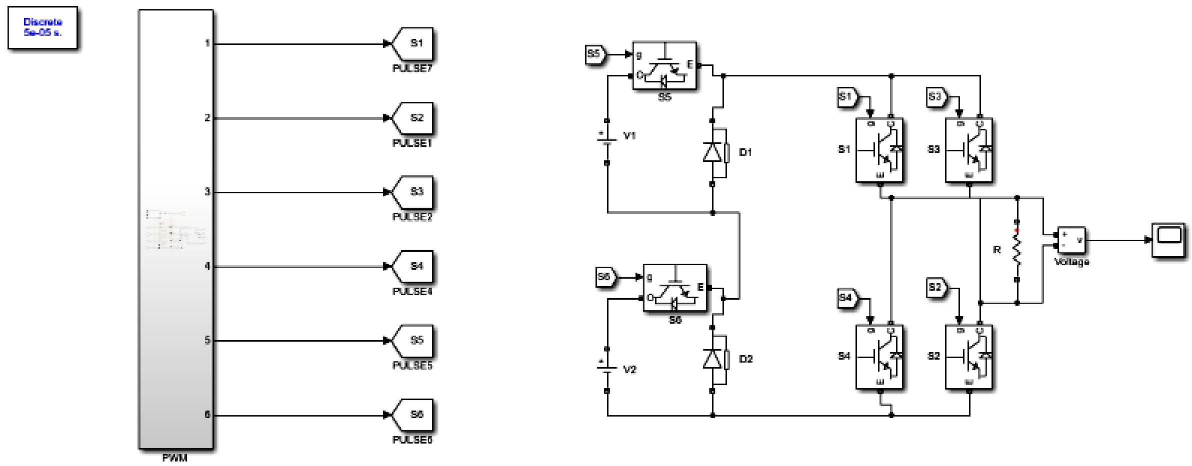

Fig. 2. Simulation diagram of five level MLI with single phase system

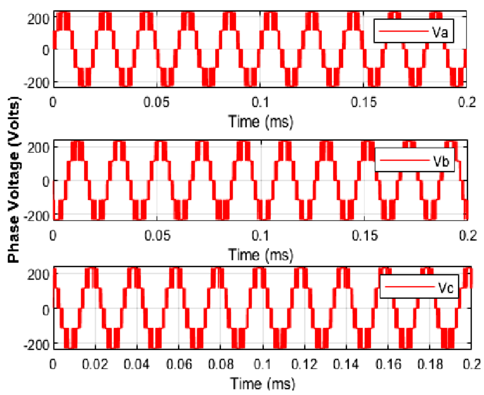

Fig. 3. Output of five level MLI

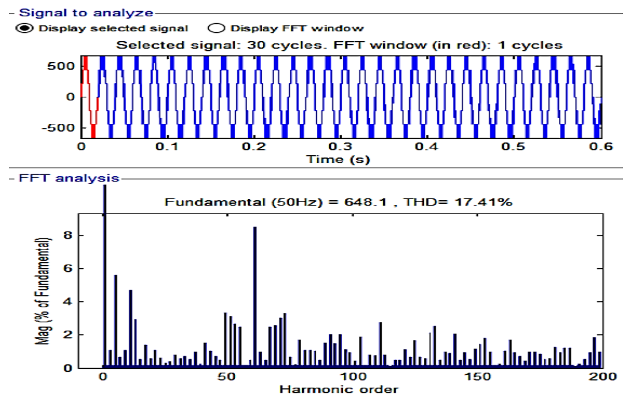

Fig. 4. Distortion level of five level MLI with PI controller

3. Results and discussion. Figure 4 shows MLI fast Fourier transform (FFT) analysis of five-level. Here the THD level obtained is 17.41 % for MLI with PI controller for a fundamental frequency of 50 Hz.

Figure 5 shows MLI FFT analysis of five-level. Here the THD level obtained is 6.56 % for MLI with PI controller and filter for a fundamental frequency of 50Hz.

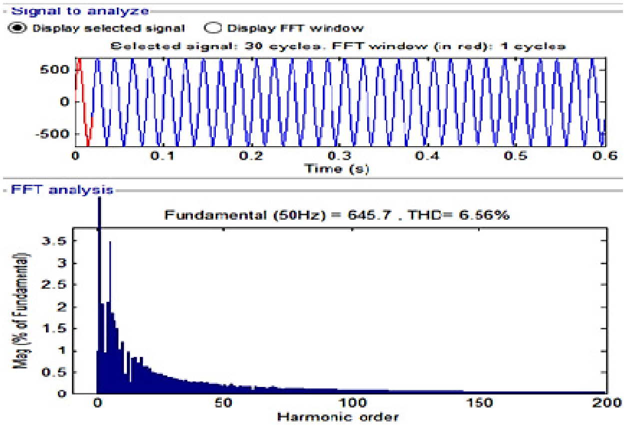

Fig. 5. Distortion level of PI controller with filter

Fuzzy logic is the application of conditional or rule-based logic to the transformation of an input space into an output space. It is a «fuzzy set» if the boundaries are ambiguous. The inclusion of elements with just a sliver of membership is permitted. It deals with difficult-to-define ideas (e.g., fast runner, hot weather). Being only a part of it is fine. Fudged set membership values range from 0 to 1, indicating the extent to which an object is a member of the collection. Input values in a fuzzy set range can be used to determine the appropriate membership value for a given membership functions. This type of multivalve logic is also known as a rule or condition because of the terminology used to describe the inputs and outputs of the multivalve devices. The schematic diagram of FLC is illustrated in Fig. 6.

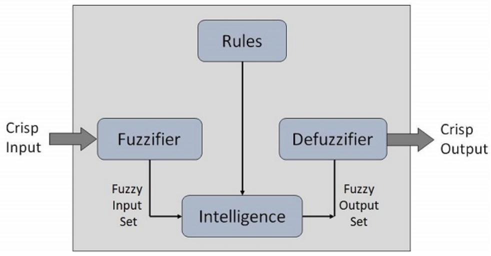

Fig. 6. Schematic diagram of FLC

Weightings, which can be added to each rule in the rule base, can be used to control how much a rule affects the output values. A rule's importance, reliability, or consistency can be assigned a numerical weighting. Depending on the results of other rules, these rule weightings can be either static or dynamic [14].

FLC in the fuzzy logic system is in charge of choosing the fuzzy rules that control it. Error (E) and error change (dE), which are inputs to the FLC system, are shown in the following diagram. Distortion level of FLC and filter for three membership functions is shown in Fig. 7.

Figure 7 shows FFT analysis of five level MLI with FLC and filter for three membership functions. Here the THD level obtained is 5.2 %

MATLAB/Simulink model of FLC is shown in Fig. 8. FLC'S output is determined solely by the rules set by the designer, and the controller does the rest. By doing this we can obtain desired output fuzzy logic system rules as follows in Table 1, where Ne – Negative, Ze – Zero, Pe – Positive, Me – Medium, Sm – Small, B – Big, as a result of implementing these fuzzy rules in a FLC, errors are smaller if the change in error is also smaller, so the output is smaller. If the value of error is negative (Ne) and the error change is zero, a medium result would be achieved which is illustrated in Table 2.

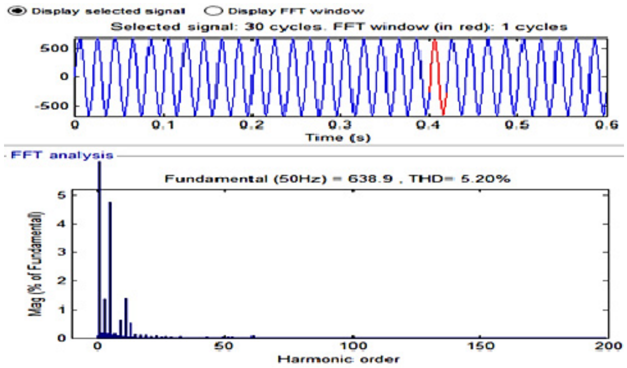

Fig. 7. Distortion level of FLC and filter for three membership functions

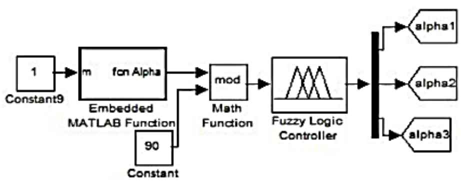

Fig. 8. MATLAB/Simulink of FLC

Table 1

Rules for three membership functions

		Change in error (dE=$\Delta E(t)$)		
		Ne	Ze	Pe
Error $E(t)$	Ne	Sm	Me	Sm
	Ze	Me	B	Me
	Pe	Sm	Me	Sm

Table 2

Rules for five membership functions

	Change in error				
Error	NeB	NeS	ZO	PeS	PeB
NeB	PeB	PeB	PeB	PeS	ZO
NeS	PeB	PeS	ZO	ZO	NeS
ZO	PeS	ZO	ZO	ZO	NeS
PeS	PeS	ZO	ZO	NeS	NeB
PeB	ZO	NeS	NeB	NeB	NeB

If the value of error is negative and the error change is positive, the output will be small. System could get a medium output with no errors or errors changing in a negative direction. A large output would be possible with no errors or errors changing in a negative direction. If the error value is zero and the change in error value is positive, the output would be medium. If the error value is positive and the error change value is negative, the output will be small. It is considered medium-sized when the error rate is more than 10 %.

Figure 9 shows FFT analysis of five level MLI with FLC and filter for five membership functions. Here the THD level obtained is 3.43 %.

Table 3 shows the comparison of THD levels for different controllers. The results show that FLC gives the better response when compared with conventional PI controller. Although the distortion is reduced to some extent when PI controller is used, but it is greatly reduced when Fuzzy controller is used. Table 4 gives the specifications of various parameters used in the simulation.

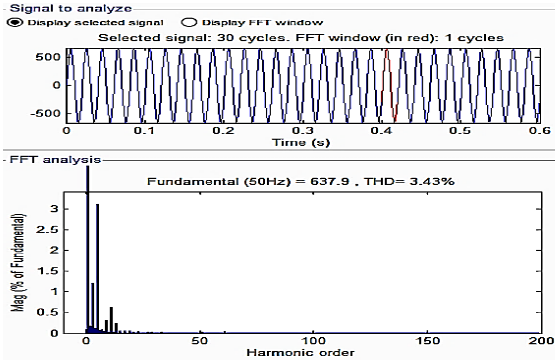

Fig. 9. Distortion level of FLC and filter for five membership functions

Table 3
Comparison of THD for different controllers

Controllers	THD, %
PI controller	17.74
PI controller with filter	6.56
Fuzzy controller with filter for three membership functions	5.20
Fuzzy controller with filter for five membership functions	3.43

Table 4
Specifications of parameters used in the Simulink models

Parameters	Specifications
Resistive load R, Ω	1
Inductive load L, mH	1
Frequency of carrier signal, Hz	1000
Frequency of reference signal, Hz	50
Proportional constant k_p	1.6
Integral constant k_i	36

4. Conclusions. The quality of multilayer output voltage waveform improves as the quantity of levels in a multilevel inverter grows. Different carrier waveforms are used for three and five levels of the project to reduce harmonic distortion. We used a multilevel inverter with a selective pulse width modulation technique to reduce harmonic distortion in five levels. PI and fuzzy logic controllers with filters have been added to the five-level multilevel inverter to further reduce the IEEE standards.

We can achieve from simulation results that total harmonic distortion levels can be reduced to less than 5 % by using the proposed PI and FLC controllers with filters on multilevel inverters. Due to these advantages in both technical and economic terms, it can be concluded that the proposed methodology will be beneficial in a wide range of industrial settings.

In the future, a sinusoidal pulse width modulation will be generated using other techniques for high-frequency applications by means of modified carriers using a fuzzy controller in order to reduce distortion as well as to improve the voltage. Then this proposed selective pulse width modulation will be applied to all types of inverters like voltage source and current source inverters. Previously only five level operations were done using the pulse width modulation technique. So, in the future, more than five-level will be achieved with other controllers. The verification of this inverter for lesser total harmonic distortion and higher frequencies can be done as a part of future work.

Conflict of interest. The authors declare that they have no conflicts of interest.

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Received 09.09.2022
Accepted 13.11.2022
Published 01.07.2023

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How to cite this article:
Sujatha M.S., Sreelakshmi S., Parimalasundar E., Suresh K. Mitigation of harmonics for five level multilevel inverter with fuzzy logic controller. *Electrical Engineering & Electromechanics*, 2023, no. 4, pp. 52-56. doi: https://doi.org/10.20998/2074-272X.2023.4.08