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Elimination of Lower Order Harmonics in Modified Reduced Switched 7-Level MultilevelInverter Using Artificial Neural Network

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Abstract: Multilevel inverters, or MLIs, are finding increasing use in electric vehicles, drives, renewable energy systems, and other applications. The best power conversion and stepped output are provided by Multilevel Inverters (MLI). Selective harmonic elimination pulse width modulation, or SHEPWM, is a modulation technique that is commonly used to eliminate low-order harmonics from the output waveform of MLIs. This paper solves the transcendental nonlinear output equations of multilayer inverters (MLI) using Newton Raphson's (NR) approach. The suggested reduced switched Multilevel Inverter uses the NR technique. Additionally, lower harmonics (such as the third, fifth, seventh, etc.) S that are more dangerous and challenging to eliminate using filters are being decreased through the use of artificial neural networks (ANNs) in the proposed reduced switched 7 levels MLI. The THD comparison in the proposed reduced switched 7 levels MLI is done between PWM, SHE-NR, and SHE-ANN. The comparison and outcome are displayed in MATLAB simulation results. This paper also emphasizes the creation of a modified multilevel inverter and itssignificance. This work aims to encourage and direct society toward the development of an affordable, efficient multilevel inverter that combines the capabilities of various converters documented in the literature.

Keywords: *Multilevel Inverter (MLI), Selective Harmonic Elimination (SHE), Newton Raphson (NR), Artificial NeuralNetwork (ANN).*

I. Introduction

When the number of levels at the output side of a multilayer inverter increases, the output becomes more sinusoidal, but a significant number of switches are needed. As the number of levels rises, THD gradually falls, but controller circuit complexity and system complexity eventually rise as well. Total stress, TSV, and switching loss all drop with fewer switching components, and THD can be significantly reduced with the right modulation and control strategies. [1][2]

There are five sections in the paper: 1. The proposed reduced switching seven-level MLI is operational. 2. To reduce the lower order harmonics, the Selective Harmonics Elimination Technique was introduced. 3. The proposed reduced switching 7 levels MLI uses NR-SHE. 4 Artificial Neural Network (ANN) Evolution in the Reduced Switched 7 Levels MLI Proposed. 5. Simulation and Outcomes.

II. Operation Of Proposed ReducedSwitched 7 Levels Mli

Proposed reduced switching 7-level MLI is shown in Figure 1. The level generating unit creates the levels, and the H-bridge creates the polarity in the output waveform. The following formula can be used to count the number of switches in a conventional H-bridge cascaded MLI.

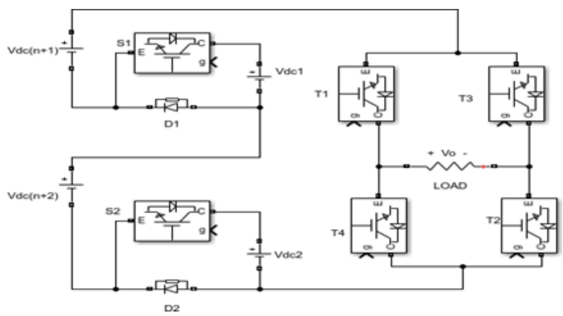

Fig.1 Proposed Reduced switch 7 level MLI

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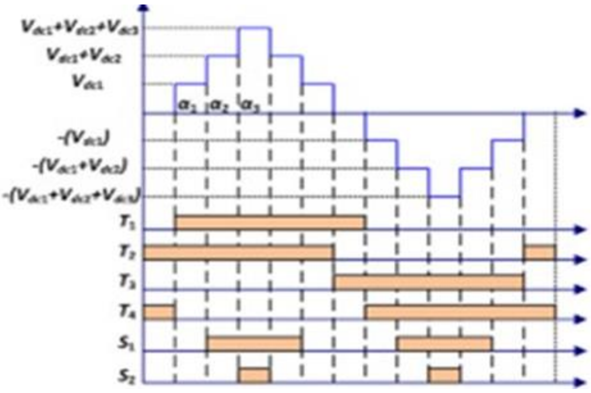

Fig. 2 Output waveform of 7 level MLI

For N=3

$$L = 2N + 1 = 2(3) + 1 = 7$$

$$S = 2(L - 1) = 2(7 - 1) = 12$$

L stands for level, N for cells, and S for switches. Therefore, in order to generate 7 levels at the output side using a cascade H-bridge, a total of 12 switches are needed. On the other hand, utilizing the suggested MLI circuit, the total number of switches is lowered to 7 according to the computation below.[3]

$$L = 3N + 1 = 7$$

$$S = N + 4 = 2 + 4 = 6$$

Applying the proper phase delay and pulse width from table II, switching angles are determined for each switch using the switching pattern displayed in table I.

III. Modulation Techniques

High switching frequency and low switching frequency modulation techniques are the two main types. While nearest level control (NLC), space vector control, and selective harmonics elimination are examples of fundamental frequency approaches, high switching frequency methods include SPWM, space vector modulation, trapezoidal modulation, and so forth.[4] Modulation techniques with higher switching frequencies decrease filter size but increase switching losses. Basic frequency modulation techniques provide a smaller switching loss but call for a larger filter size. Despite this, the objective of various modulation techniques is to minimize the output voltage's total harmonic distortion. Conversely, THD is the sum of the effects of each individual harmonic component, which implies the overall influence of all harmonic components in a waveform.

Large magnitude individual harmonic components can be eliminated to improve voltage quality and lower THD in the waveform. All harmonics can be individually controlled only with the selective harmonic elimination technique (SHE).

One of the basic methods of frequency modulation is selective harmonic elimination, which reduces switching loss and completely eliminates the desired low-order harmonics through the solution of non-linear equations. You can use this technique to minimize any harmonic present in the waveform. Any inverter with an infinite number of levels can use this technique. SHE or SHEPWM are some more names for it.[5]

TABLE I. SWITCHING TABLE FOR PROPOSED SEVEN LEVELS MLI

switches	0	V	2V	3V	2V	V	0	-V	-2V	-3V	-2V	-V	0
T1	0	1	1	1	1	1	1	0	0	0	0	0	0
T2	1	1	1	1	1	1	0	0	0	0	0	0	1
T3	0	0	0	0	0	0	1	1	1	1	1	1	0
T4	1	0	0	0	0	0	0	1	1	1	1	1	1
S1	0	0	1	1	1	0	0	0	1	1	1	0	0
S2	0	0	0	1	0	0	0	0	0	1	0	0	0

TABLE II. SWITCHING ANGEL CALCULATION

Switches	Phase Delay	Pulse Width	OR	Phase Delay	Pulse Width
T1	$(30 * 0.002)/360$	$(6/12) * 100$	NO	--	--
T2	0	$(6/12) * 100$	NO	--	--
T3	$(180 * 0.002)/360$	$(6/12) * 100$	NO	--	--

T4	0	(1⁄12) ∗ 100	YES	(210 ∗ 0.002)/360	(5⁄12) ∗ 100
S1	(60 ∗ 0.002)/360	(3⁄12) ∗ 100	YES	(240 ∗ 0.002)/360	(3⁄12) ∗ 100
S2	(90 ∗ 0.002)/360	(1⁄12) ∗ 100	YES	(270 ∗ 0.002)/360	(1⁄12) ∗ 100

IV.The Newton Raphson Based Selective Harmonic Elimination Technique

In order to identify the best switching angles for eliminating particular low-order harmonics, nonlinear transcendental equations are solved using the basic frequency Selective Harmonic elimination (SHE) technique [6]. In this sense, the Newton Raphson (NR) method is used to solve the optimal switching angle of transcendental equations describing the fundamental and harmonic component.[7]

The following Fourier series equation can be used to explain the quarter-wave symmetry output waveform of MLIs, as their output waveform is a staircase. [8]

$V(wt) = \sum_{n=1}^{\infty}(A_n \sin \mathrm{wt} + B_n \cos \mathrm{wt})$[9]…(1)

Due to the quarter symmetry in the waveform, the even harmonics are cancelled and only odd harmonics remain in the equation. Therefore, the output voltage can be reduced to the following equation.[10]

$\mathrm{V(wt)} = \sum_{n=1}^{\infty} An \sin(\mathrm{nwt})$…..(2)

$where B_n = 0$

The amplitude of the nth harmonic is representedby

$An = \frac{4V}{n\pi}\sum_{k=1}^{r}(\cos \mathrm{n}\alpha\mathrm{k})$……(3)

where r is the quantity of switching angles present in the initial quadrant. where αk is the Kth switching angle and V is the nominal dc voltage. Now, using a MATLAB script file, the following steps are simulated to get the switching angles in order to get the optimal angle from the above equation for eliminating the 3rd, 5th, 7th, 11th, and 13th harmonics.

$\mathrm{V}(wt) = \frac{4V}{n\pi}\sum_{n=1,3,5}^{\infty}(\cos(\mathrm{n}\alpha_1) + \cos(\mathrm{n}\alpha_2) + \cos(\mathrm{n}\alpha_3) + \cos(\mathrm{n}\alpha_4) + \cos(\mathrm{n}\alpha_5))\sin(\mathrm{nwt})$…….(4)

In Step: 1

$$\cos(\alpha_1) - \cos(\alpha_2) + \cos(\alpha_3) - \cos(\alpha_4) + \cos(\alpha_5) = 0.85(\pi/4)$$

$$\cos(3\alpha_1) - \cos(3\alpha_2) + \cos(3\alpha_3) - \cos(3\alpha_4) + \cos(3\alpha_5) = 0$$

$$\cos(5\alpha_1) - \cos(5\alpha_2) + \cos(5\alpha_3) - \cos(5\alpha_4) + \cos(5\alpha_5) = 0$$

$$\cos(7\alpha_1) - \cos(7\alpha_2) + \cos(7\alpha_3) - \cos(7\alpha_4) + \cos(7\alpha_5) = 0$$

$$\cos(9\alpha_1) - \cos(9\alpha_2) + \cos(9\alpha_3) - \cos(9\alpha_4) + \cos(9\alpha_5) = 0$$

Step: 2

$$\alpha^j = \left[[\alpha_1^j \quad \alpha_2^j \quad \alpha_3^j \quad \alpha_4^j \quad \alpha_5^j]\right]^T$$

Step: 3

$$F^j = \begin{bmatrix} \cos(\alpha_1{}^j) - \cos(\alpha_2{}^j) + \cos(\alpha_3^j) - \cos(\alpha_4^j) + \cos(\alpha_5^j) \\ \cos(3\alpha_1^j) - \cos(3\alpha_2^j) + \cos(3\alpha_3^j) - \cos(3\alpha_4^j) + \cos(3\alpha_5^j) \\ \cos(5\alpha_1^j) - \cos(5\alpha_2^j) + \cos(5\alpha_3^j) - \cos(5\alpha_4^j) + \cos(5\alpha_5^j) \\ \cos(7\alpha_1^j) - \cos(7\alpha_2^j) + \cos(7\alpha_3^j) - \cos(7\alpha_4^j) + \cos(7\alpha_5^j) \\ \cos(9\alpha_1^j) - \cos(9\alpha_2^j) + \cos(9\alpha_3^j) - \cos(9\alpha_4^j) + \cos(9\alpha_5^j) \end{bmatrix}$$

Step: 4

$$\left[\frac{\partial f}{\partial \alpha}\right]^j = \begin{bmatrix} -\sin(\alpha_1^j) + \sin(\alpha_2^j) - \sin(\alpha_3^j) + \sin(\alpha_4^j) - \sin(\alpha_5^j) \\ -3\sin(3\alpha_1^j) + 3\sin(3\alpha_2^j) - 3\sin(3\alpha_3^j) + 3\sin(3\alpha_4^j) - 3\sin(3\alpha_5^j) \\ -5\sin(5\alpha_1^j) + 5\sin(5\alpha_2^j) - 5\sin(5\alpha_3^j) + 5\sin(5\alpha_4^j) - 5\sin(5\alpha_5^j) \\ -7\sin(7\alpha_1^j) + 7\sin(7\alpha_2^j) - 7\sin(7\alpha_3^j) + 7\sin(7\alpha_4^j) - 7\sin(7\alpha_5^j) \\ -9\sin(9\alpha_1^j) + 9\sin(9\alpha_2^j) - 9\sin(9\alpha_3^j) + 9\sin(9\alpha_4^j) - 9\sin(9\alpha_5^j) \end{bmatrix}$$

Step: 5

$$T = \left[\frac{(0.85)\pi}{4} \quad 0 \quad 0 \quad 0 \quad 0\right]^T$$

Step: 6

$$f(\alpha) = T$$

In order to determine the gating pulses initiative, point, it is necessary to compute the iteration values α1 to α5 for the third, fifth, seventh, eleventh, and thirteenth harmonics.

Iterative computation has the drawback of requiring additional computational work and sometimes making the answer harder to perform in real time. The numerical techniques yield just one solution and are sensitive to the beginning parameters. It offers no understanding of the different solution sets. NR is unable to generate a precise pulse position due to the nonlinearity. The results of this procedure are more intricate and need more time. Moreover, several modulation indexes could not be solved by this strategy.[12]

One hidden layer, s outputs, each of which represents a switching angle, and a single input neuron fed by the modulation index comprise the artificial neural network (ANN) that will be utilized to produce the ideal switching angles. The 3rd, 5th, 7th, 11th, and 13th harmonics, among others, provided by equation (5), must be eliminated with this set of angles.[4]

The ANN is trained using the Mean Square Error (MSE) back-propagation algorithm between the output and the target value. [14] The training set of the network was generated offline by the Newton-Raphson method for solving nonlinear equations (3). MATLAB programming is used to develop this approach, which speeds up and simplifies the procedure. The output pattern is driven by a series of forward calculations carried out step-by-step by the ANN when it receives a set of input data. By adjusting the weights one at a time, starting with the output layer, the gradient descent approach is utilized to minimize the mean square error (MSE) produced for the set of input patterns. [15] The m-file program is used to implement the ANN control algorithm. Following the training phase's conclusion, the generated ANN can be utilized to produce the inverter's control sequence, as depicted in Figure 3.

V.The Evolution Of Artificial NeuralNETWORK

An alternative method involves training artificial neural networks (ANNs) to recognize switching patterns, which can subsequently be utilized to determine the ideal inverter switching angles.[13] The objective of the current work is to solve the SHE equations using ANN in order to propose an ANN-based SHE technique for regulating a seven-level inverter.

In order to cancel the third, fifth, seventh, eleventh, and thirteenth harmonics and regulate the fundamental of the AC output voltage supplied by the taken into consideration inverter, the feed-forward neural network is utilized to create switching angles based on the SHE technique.

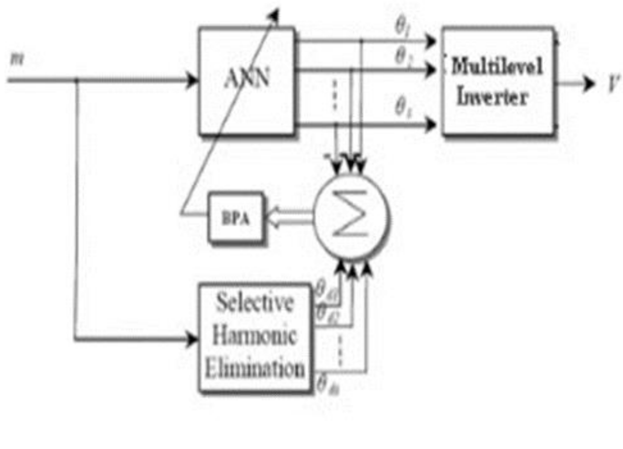

Fig. 3 Back Propagation Algorithm [15]

The most harmful harmonics, the third harmonic and its multiple, which cause excessive current production and equipment overheating, are eliminated by the suggested ANN-SHE. In Table No. III, the switching angels produced by the ANN are enumerated.

VI.Simulation And Result

The suggested 7-level reduced switches MLI's Simulink circuit schematic is displayed in Figure 4. Phase delay and pulse width are applied in Table 2 to determine the output voltage and switching pattern, respectively, which are displayed in Figures 5 and 6.

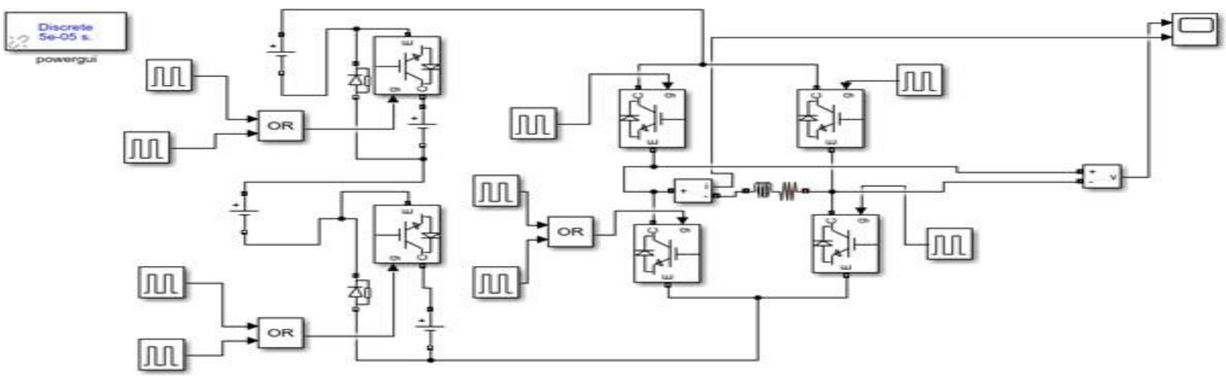

Fig. 4 MATLAB Simulation Circuit diagram for 7 levels MLIs

When NR- SHE is applied, Figure 7 shows the gate pulses from 0◦ -180◦ and 180◦ - 360◦. After getting the gate pulses MLI will remove the harmonics. All gate pulses shown in figure 7 for the modulation index 8.5.

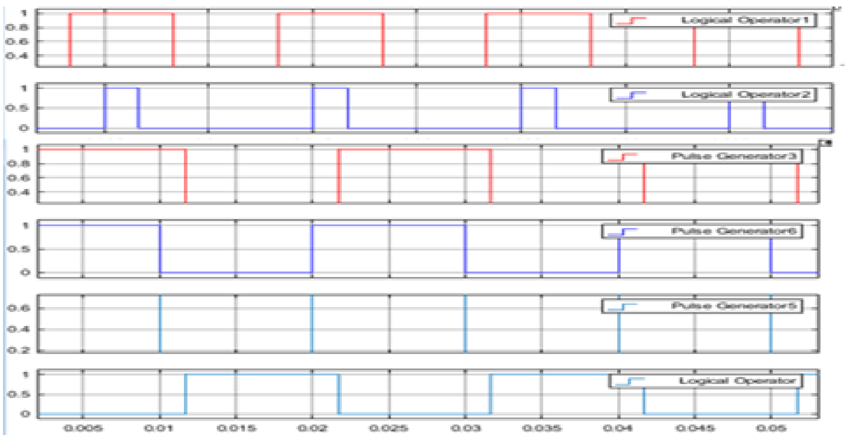

Fig .5 Switching Pattern calculated in table 2

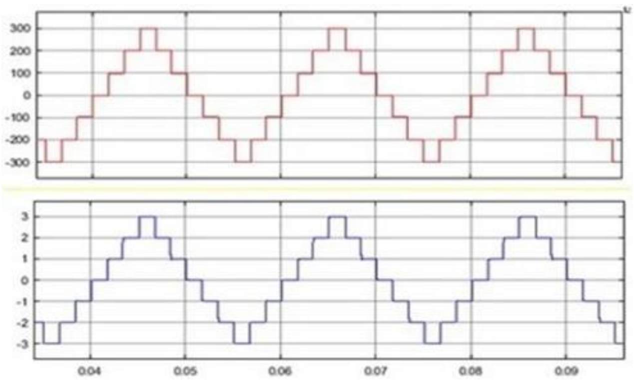

Fig. 6 Output voltage waveform

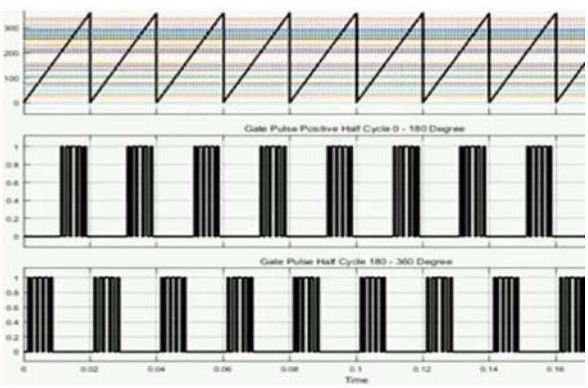

Fig 7. Gate pulses for 0° -180° and 180° -360

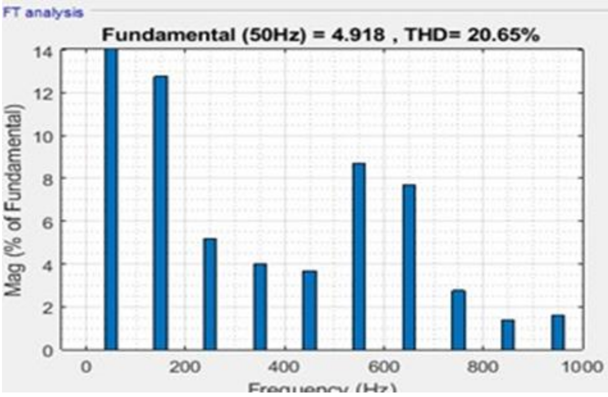

Fig.8 FFT analysis without NR (by obtained angels in table 2)

In Figure 8 THD is 20.65% that is obtained by applying switching angels as calculated in table 2.Figure 9 shows 12.86% THD by applying NR -SHE.

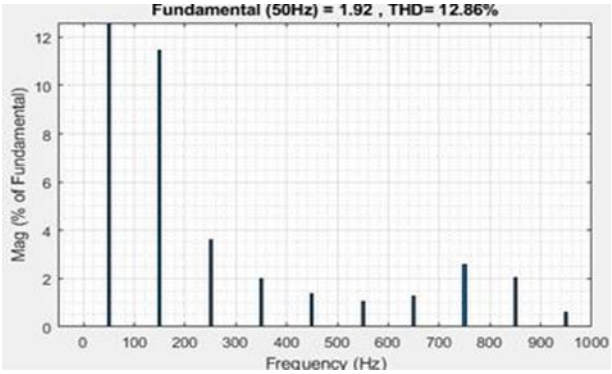

Fig 9. Waveform of NR-SHE for 7 levels MLI

TABLE III. SWITCHING ANGELS GENERATED BY ANN

Modulation Index (M)	Θ1(rad)	Θ2(rad)	Θ3(rad)	Θ4(rad)	Θ5(rad)
0.6	32.18	38.35	52.45	70.23	78.45
0.75	26.27	32.54	42.51	59.54	63.66
0.8	17.63	24.54	32.75	47.25	58.54
0.85	14.85	21.24	27.25	38.25	42.85
0.9	11.77	16.21	19.32	23.69	30.40

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In figure 10 obtained THD by ANN-SHE is 1.38%

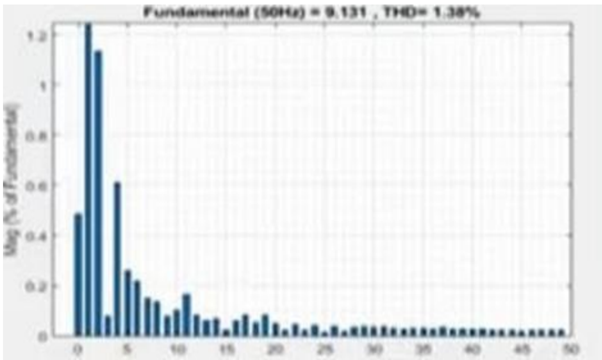

Fig 10.FFT analysis of THD of ANN-SHE

VII. Conclusion

To cancel the third, fifth, seventh, eleventh, and thirteenth harmonics, the switching angles for a seven-level inverter are computed in the first section of the paper using pulse width and phase delay. Next, the SHE method with NR is applied in the suggested MLI. Lastly, for any modulation index value, an artificial neural network (ANN) is trained offline to replicate these switching angles without any restrictions. This research aimed to examine the total harmonic distortion among all suggested topologies (PWM, SHE-NR, and SHE-ANN) in the seven-level reduced HB-MLI. All of the aforementioned topologies are simulated using MATLAB Simulink in order to examine the generated parameters. The ANNs technique is an optimization tool that offers decreased THD when compared to NR. Also, number of components used in proposed 7 levels MLI is less as compared to conventional 7 levels cascade MLI so this work aims to encourage and direct society toward the development of an affordable, efficient multilevel inverter.

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