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Comparison between GA and NR method for selective harmonic elimination in a MLI with reduced number of components

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ABSTRACT:
Multilevel inverters (MLIs) are the most popular DC-AC converters for the medium voltage and high power applications. In this paper, a MLI with minimum number of switching components with two varieties of DC voltage sources is taken. This MLI provides a higher number of output voltage levels with lower switching components compared to conventional MLIs. MLIs with low total harmonic distortion (THD) are beneficial for medium and high voltage applications. To eliminate desired harmonics in this MLI, selective harmonic elimination (SHE) techniqueis used. Using genetic algorithm (GA) and traditional Newton Raphson (NR) algorithm switching angles are calculated. A significant reduction in harmonics is achieved in the GA based approach compared with NR approach. Simulation of this MLI is done in MATLAB/Simulink.

I. INTRODUCTION:

The Two-level inverters are those which convert DC power to AC power at a desired output voltage and frequency and produce an output voltage with levels either 0 or $\pm$V. In the inverter switches operate at high switching frequency sothey have high switching losses and rating constraints for high power and voltage applications. Inverters also face harmonic distortion, EMI and high $\frac{dv}{dt}$ stress[1]. Because of these difficulties, it is difficult to interface PE switch directly to high and medium voltage grid. So the MLI topology concept arises in 1975.

The MLIs have drawn tremendous interest in industrial applications, transportation, renewable energy, reactive power compensation, uninterruptible power supply (UPS), high voltage DC (HVDC), variable frequency drives, in pumps, conveyors, electric vehicles, FACTs devices etc. Conventional MLIs classified as diode clamped (DC) MLI, flying capacitor (FC) MLI, cascaded H-bridge (CHB) MLI [1], [2]. In [2] the generalized MLI topology and its deduction to other MLI topologies are explained.

The conventional MLIs have applications with different power and voltage ratings with their advantages and disadvantages. The disadvantage includes high number of switches,capacitors and DC voltage sources required for MLI to get higher levels. To overcome all these problems, several new topologies are designed for MLI and their control have been introduced in [3]-[5]. This paper adopts MLI topology from [6].

To get better output voltage waveform with low THD, need to go for optimization techniques. Selective harmonic elimination technique is taken in this paper for harmonic reduction. In [7] various algorithms are proposed for selective harmonic elimination technique to calculate the switching angles for harmonic reduction. From various algorithms in [7] the traditional NR approach [8-9], GA approach [10-16] are taken to get optimized switching angles. Comparison between NR method and GA are given in [17].

In this paper the main aim is to get higher number of levels at the output voltage of MLI with less number of switches and having reduced harmonic content in output waveform.

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II. THE PROPOSED MLI:

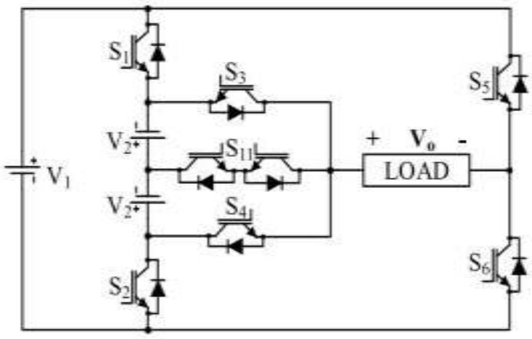

Figure 1: The Proposed MLI with 11-level at output.

S1	S2	S3	S4	S5	S6	S11	V0
ON	OFF	ON	OFF	ON	OFF	OFF	0
ON	OFF	ON	OFF	OFF	ON	OFF	V1
ON	OFF	OFF	OFF	ON	OFF	ON	V2
ON	OFF	OFF	OFF	OFF	ON	ON	V1+V2
ON	OFF	OFF	ON	ON	OFF	OFF	2V2
ON	OFF	OFF	ON	OFF	ON	OFF	V1+2V2
OFF	ON	OFF	ON	OFF	ON	OFF	0
OFF	ON	OFF	ON	ON	OFF	OFF	-V1
OFF	ON	OFF	OFF	OFF	ON	ON	-V2
OFF	ON	OFF	OFF	ON	OFF	ON	-V1-V2
OFF	ON	ON	OFF	OFF	ON	OFF	-2V2
OFF	ON	ON	OFF	ON	OFF	OFF	-V1-2V2

Table1:Switching table of the MLI.

Fig.1 shows the adopted basic unit from the MLI topology in [6]. This MLI Consists of three DC voltage sources and six unidirectional switches and one bidirectional switch. S_{11}isthe bidirectional switch and all the remaining switches are unidirectional switches. In the MLI, outer switch pairs are (S_1,S_2) and (S_5,S_6)and inner switches are S_3,S_4,S_{11}. Outer switch pair should be operated in complementary mode means if one switch is turned ON the other switch should be turned OFF. In inner switches only one switch should be turned ON at each level. In this MLI only two varieties of DC voltage sources and 8 switches are used to achieve 11 levels at the output. Switching table for this topology shown in Table 1.

III. SELECTIVE HARMONIC ELIMINATION (SHE):

Selective harmonic elimination technique is the best technique for eliminating lower order harmonics. By mitigating the harmonics can avoid the resonance.

The Fourier analysis for fig 2 is as follows

$$V_0(t) = a_o + \sum_{n=1}^{\infty}(a_n \cos(n\omega t) + b_n \sin(n\omega t))$$

This staircase output voltage waveform has quarter wave symmetry so, even harmonics are zero, $a_0 = 0$, $a_n = 0$ and sine terms of odd harmonics are present.

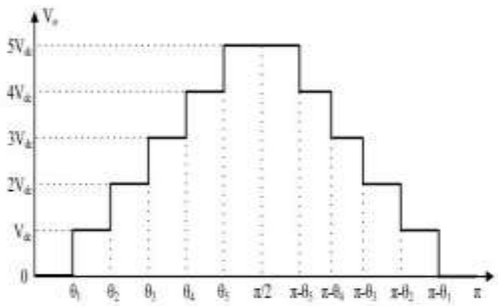

Figure2: 11 level staircase output voltage waveform.

$$a_0 = \frac{1}{T}\int_0^T V_0(t)dt = 0$$

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$$a_n = \frac{2}{T}\int_0^T V_0(t)\cos(n\omega t)\,dt = 0$$

So,

$$V_0(t) = \sum_{i=1,3,5....}^{n} b_n \sin(n\alpha_i)$$

b_n can be expressed as

$$b_n = \frac{4V_{dc}}{n\pi}\sum_{i=1,3,5....}^{n} \cos(n\alpha_i)$$

K=$\frac{N_{level}-1}{2}$; M = $\frac{V_{o1}}{KV_{dc}}$; $0 \le M \le 1$

Where M = modulation index; K= number of switching angles required to reduce harmonics and also the factor of the maximum output voltage value.

To eliminate $3^{rd}, 5^{th}, 7^{th}, 9^{th}$ harmonics 5 switching angles required. The firing angles $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5$ are calculated using the following equations

$$b_1 = \frac{4V_{dc}}{\pi}(\cos\theta_1 + \cos\theta_2 + \cos\theta_3 + \cos\theta_4 + \cos\theta_5) = V_{o1}$$

$$b_1 = \cos\theta_1 + \cos\theta_2 + \cos\theta_3 + \cos\theta_4 + \cos\theta_5 = \frac{5\pi M}{4}$$

$$b_3 = \cos3\theta_1 + \cos3\theta_2 + \cos3\theta_3 + \cos3\theta_4 + \cos3\theta_5 = 0$$

$$b_5 = \cos5\theta_1 + \cos5\theta_2 + \cos5\theta_3 + \cos5\theta_4 + \cos5\theta_5 = 0$$

$$b_7 = \cos7\theta_1 + \cos7\theta_2 + \cos7\theta_3 + \cos7\theta_4 + \cos7\theta_5 = 0$$

$$b_9 = \cos9\theta_1 + \cos9\theta_2 + \cos9\theta_3 + \cos9\theta_4 + \cos9\theta_5 = 0$$

And the firing angles should be calculated by maintaining the relationship $0 < \theta_1 < \theta_2 < \theta_3 < \theta_4 < \theta_5 < \frac{\pi}{2}$.

By maintaining the above relationship and solving the above nonlinear transcendental equations firing angles can be calculated. For this purpose two techniques are studied.

IV. NEWTON RAPHSON APPROACH:

NR method is an iterative method to solve nonlinear equations. It is based on linear approximation principle. The selective harmonic elimination technique has nonlinear transcendental equations. First, initial guess of random values has to be taken then it converges to optimum solution after certain iterations.

If x_0 is the first random value, and is not the optimum solution then x_0 is further improved by this equation

$$x_{n+1} = x_n - \frac{f(x)}{\frac{d}{dx}f(x)}$$

The switching angles depend on the determination of modulation index (M).The switching angles calculated by NR method for M=0.8 are $\theta_1 = 13.7875^\circ, \theta_2 = 34.6366^\circ, \theta_3 = 46.866^\circ, \theta_4 = 67.4985^\circ, \theta_5 = 79.6939^\circ$

V. GENETIC ALGORITHM APPROACH:

GA is taken from Darwins theory about evolution. This algorithm starts with population which is the set of solutions (Represented by chromosomes). The solutions taken from one population are used to form new population. If the new population solution is better than old one then it has to be selected to form new solution (called as offspring). According to their fitness function, if it is more suitable then there may be greater chance to reproduce. This has to be repeated until some condition should be satisfied.

GA is implemented in MATLAB using GA tool box. For GA tool box, has to define fitness function, number of variables and constraints. In population, population size and initial population and initial range have to be defined.

The switching angles calculated by GA using GA tool box are

$$\theta_1 = 6.778^\circ, \theta_2 = 15.907^\circ, \theta_3 = 31.219^\circ, \theta_4 = 41.532^\circ, \theta_5 = 63.031^\circ$$

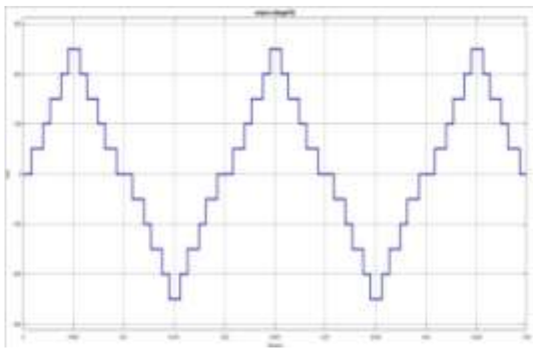

Figure 3: The output voltage waveform of the MLI, which is given pulses according to the switching angles calculated by NR-method

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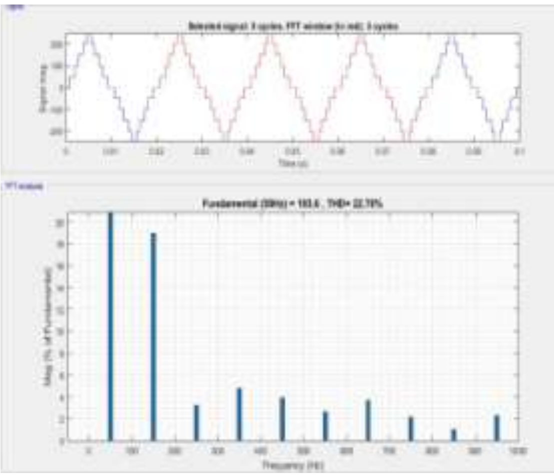

Figure 4: FFT of output voltage waveform of the MLI, which is given pulses according to switching angles calculated by NR-method

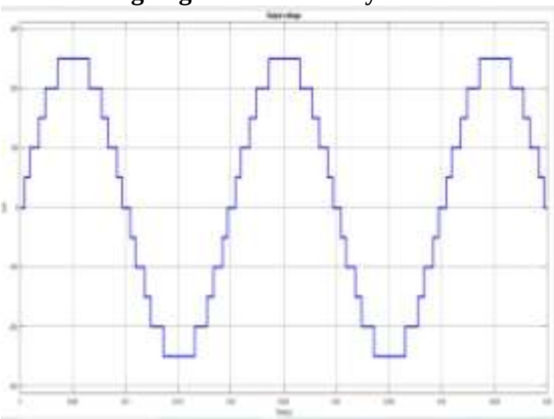

Figure 5:The output voltage waveform of the MLI, which is given pulses according to the switching angles calculated by GA

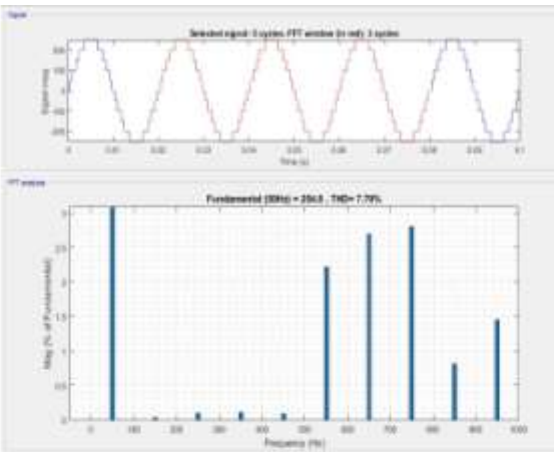

Figure 6: FFT of output voltage waveform of the MLI, which is given pulses according to switching angles calculated by GA

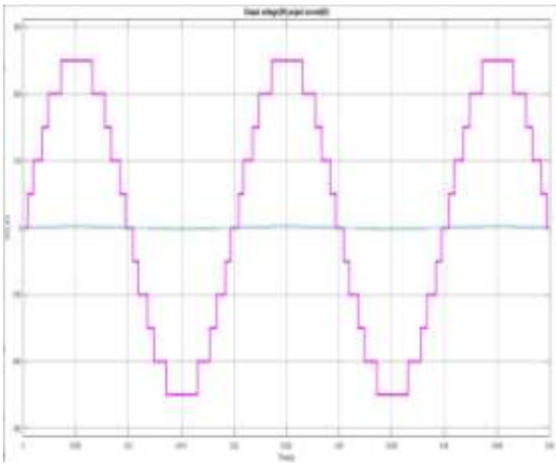

Figure 7: The output voltage and current waveforms of the MLI with R-load (GA)

Figure 8: The zoomed view of output current waveform of the MLI with R-Load (GA)

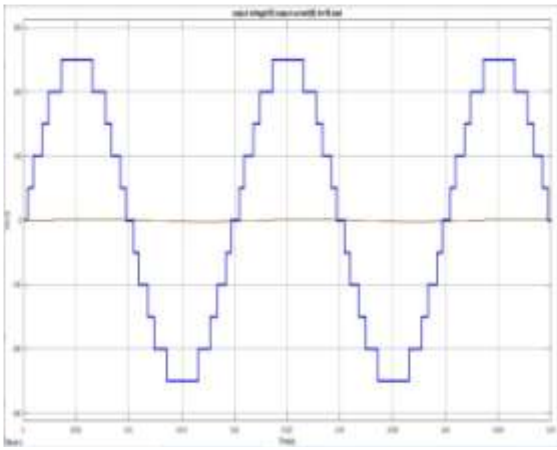

Figure 9: output voltage and current wave forms of the MLI with RL-Load (GA)

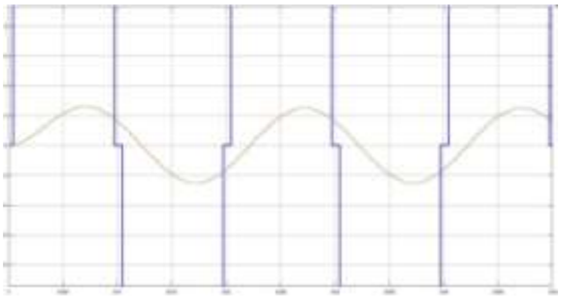

Figure 10: The zoomed view of output current waveform of the MLI with RL-load (GA)

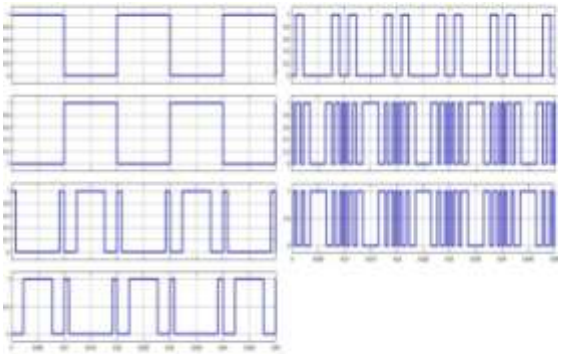

Figure 11:Switching pulses for switches S1, S2, S3, S4, S11, S5, S6 respectively.

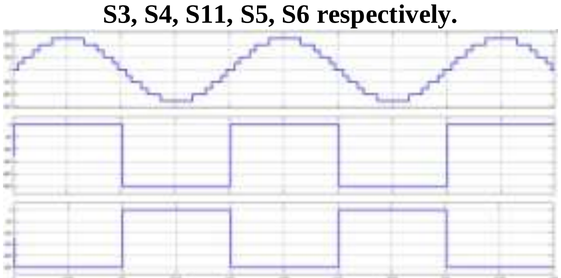

Figure 12: Output voltage and voltage stress across switches S1, S2 respectively

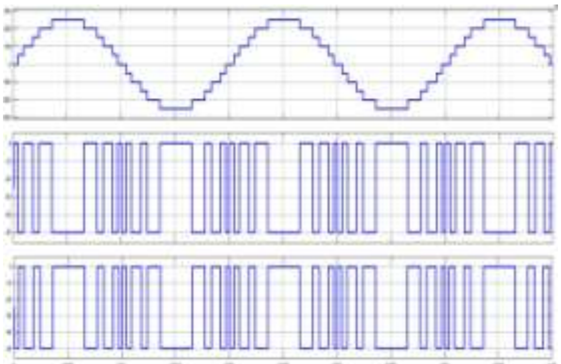

Figure 13: Output voltage and voltage stress across switches S5, S6 respectively.

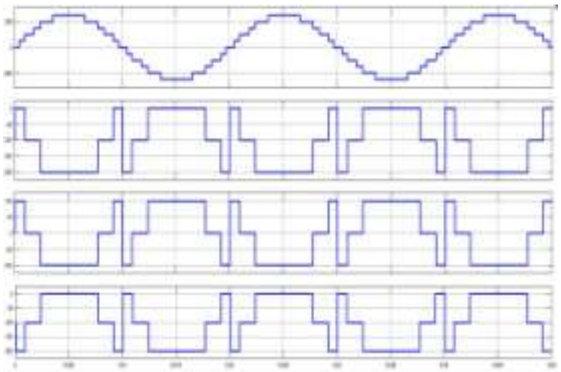

Figure 14:Output voltage and voltage stress across switches S3, S11, S4 respectively.

VI. SIMULATION RESULTS:

The proposed MLI is taken for the generation of 11 levels at the output. The MLI is constructed in MATLAB/SIMULINK, and pulses are given according to the switching angles calculated by NR method. For inputs $V_1 = 50V, V_2 = 100V$ and load R=100 ohms, obtained maximum output voltage is 250V and the output voltage waveform is shown in Fig.3. The FFT of the output voltage waveform is shown in Fig.4. For the same inputs and load, the MLI is given switching pulses according to the switching angles calculated by GA. The maximum output voltage obtained is 250 V and the output voltage waveform is shown in Fig.5.The FFTof the output voltage waveform is shown in Fig.6. The MLI is given R load first then RL load and which is pulsed with switching angles calculated by GA.When the MLI is simulated with inputs $V_1 = 50V, V_2 = 100V$ and the load R=100ohms the resulted output voltage and output current waveforms are shown in Fig.7. Maximum output voltage obtained is 250V and maximum output current obtained is 2.5A. The zoomed view of output current is shown in Fig.8.When the MLI is simulated with inputs $V_1 = 50V, V_2 = 100V$ and the loadR=80 ohms and L=200mH the resulted output voltage and output current waveforms are shown in Fig.9. The zoomed view of output current is shown in Fig.10.The waveforms of the gate pulses which are given to the switches of the MLI are shown in Fig.11. Voltage stresses across the switches of the MLI along with the output voltage waveform are shown in Fig.12, Fig.13, Fig.14.

VII. COMPARISIONS:

1. When switching angles calculated by NR method are given as pulses to the pulse generator of the MLI, the obtained THD=22.7%. The THD value is given in Fig.5.

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2. When switching angles calculated by GA are given as pulses to the pulse generator of the MLI, the obtained THD=7.79%. The THD value is given in Fig.6.
3. According to the THD's obtained by both the methods, the better harmonic reduction achieved by GA approach compared with NR method.
4. Duty cycle (%) for each switch of the MLI by both the methods is

SWITCHES	N.R (%)	GA (%)
S1	50	50
S2	50	50
S3	31.74	35.76
S4	31.74	35.76
S5	50	50
S6	50	50
S11	36.51	28.47

5. Different topologies with number of switches, number of DC sources and number of capacitors are used to obtain output voltage levels are given below

Topologies	**No of switches**	**No of DC sources**	**No of capacitors**	**No of levels**
Cascaded H bridge	20	5	0	11
[3]	10	0	5	11
[4]	10	4	0	11
[5]	10	4	0	17
Proposed topology	8	3	0	11

VIII. CONCLUSION:

In this paper the proposed MLI topology has reduced number of switches and only two varieties of DC voltage sources. The main objective of this paper is to get high levels of output voltage with less number of components and with less harmonic distortion. To give pulses to the MLI and to reduce harmonics SHE technique is used. For that purpose here NR and GA methods are taken. Here GA has given minimum THD compared with NR method. 3^{rd}, 5^{th}, 7^{th}, 9^{th} harmonics reduction is more significant with GA compared with NR method.

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