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A novel PWM technique for reduced switch count multilevel inverter in renewable power applications

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ABSTRACT

This paper described a novel pulse width modulation (PWM) technique in reduced switch count multilevel inverter (MLI) for renewable power applications. Therefore, the proposed technique finds a better solution in the multilevel inverters used for improving power quality, efficiency and reduction of switching and conduction losses. It produces a smoother sinusoidal output waveform with reduced total harmonic distortion (THD) using different modulation technique. The novel PWM technique consists of nearest level control (NLC) and level shift pulse width modulation (LSPWM). Normally semiconducting devices are added for increasing number of levels. It affects the power quality and efficiency due to losses. In this work, MLI topology with reduced number of switches count for NLC and LSPWM is presented. The single-phase and three-phase inverter configuration is used in proposed mythology. Detailed simulation results for 7-level inverter of single and three-phase inverters are presented in this paper. It is observed that NLC method is better efficiency and reduced THD than LSPWM for better utilization in renewable power applications.

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1. INTRODUCTION

Many grid-connected inverters have rarely investigated to utilization with renewable energy sources (RES) of energy. For the grid connection and the micro grid connected unit, several multilevel inverters (MLIs) have been successfully investigated [1]–[5]. The multilevel inverter is currently recommended for (L/M VA) applications applications without transformers and filters, as well as high-voltage (HVA) applications with a high-frequency transformer [6]. International regulations enable L/M VAs to operate in the absence of galvanic isolation; on the other hand, high voltage application necessitates the high frequencies transformers for isolation purposes [7]–[9]. High-frequency transformers are significantly smaller and lighter than fundamental frequency transformers. As a consequence, transformer less system are frequently used to describe multilevel inverters using the high-frequency transformers. In multilevel inverter, as output voltage levels increases the required filter requirement is decrease. As a consequence, today's multilevel inverters with higher output levels may operate without a filter or a transformer for low, medium and high VA and grid integration. As a result, system’s following parameters such as overall volume; size and the weight of the system are remarkably reduced [3], [10], [11].

In addition, as output voltage levels reduced in MLIs, the filter need reduces [12]. Consequently, recent, multilevel inverters with higher output voltage levels may operate not only filter less but also transformer less in low, medium, and high VA grid integration applications. This results in a significant minimization in the system's overall volume, weight, and total size [13], [14]. Flying capacitor (FC), diode-clamped, and cascaded H-bridge (CHB) are three traditional multilevel inverters methods often utilized for DC–AC conversion [15]–[18]. The fundamental disadvantage of traditional MLIs is the not only increased number of switches, gate drivers, and auxiliary components and DC voltage sources required for raise the output voltage steps. As a result, MLIs with fewer components and less complexity are being explored and analysed as a feasible alternative [19]. Presents an overview of several multilevel inverter methodologies with the goal of reducing switching device count. Modular multilevel converters have recently attracted much interest because they may be developed for higher voltage applications using a fundamental modular system framework [20], [21]. Asymmetric MLI design has been documented in different topologies [22].The key benefit of this architecture over CHB is that it has fewer components. The circuit becomes less difficult as the count of the switching devices is get significantly reduced. In addition, the system's costing and the size of system are get reduced. The fundamental restriction of this architecture is that it can only be implemented using symmetric voltage sources. Furthermore, the total of all functioning input DC sources equals the voltage stress across H-bridge switches. Another design, which requires bidirectional switches and has a higher component count than previous topologies, was developed with lower switching devices[23]. With the term cross-connected source based multilevel inverter (CCSMLI), the symmetrical and asymmetrical multilevel inverters topologies are a decreased count of system has been widely examined in this studies [24], [25].

The count of DC voltage sources and drives is not decreased with this topology, which is the biggest drawback. Similarly, Lesnicar and Marquardt [26] shows symmetrical and asymmetrical multilevel inverters with a less number of devices, but not with a less count of DC voltage sources and drivers. While reduces the count of components by using a sole DC power supply, this renders them inadequate to higher VA [27], [28]. Proposes another structure for symmetrical configurations with fewer components, but it needs bidirectional switching, increasing the fall, and maximizing the count of diodes inside this methodology [29]–[33]. Given work proposes, MLI for high, medium and low voltage level with the reduce switch count. Compare different multilevel inverters for the power loss, switching loss and total harmonic distortion (THD). Comprehensive analysis and working of the proposed system is described. Different renewable energy sources are compared for the grid connected system. Proposed study can improves the power quality, efficiency of the system and reduce power loss, switching loss, total harmonic distortion.

2. PROPOSED METHODOLOGY

In this work, multilevel inverter for optimal efficiency and power quality analysis is studied. Using different PWM technique power quality analysis done on the basis of THD, switching loss and conduction loss. Comparison of reduce switch count done by comparing proposed system with cascade H-bridge inverter, cross connected source based multilevel inverter and other MLI technique. Multilevel inverter is designed for high voltage, medium voltage, and low voltage applications. New multilevel inverter is designed from the present CCSMLI. This significantly lowers the count of the diode, DC source, driver circuit, capacitors. Also reduce the device size, switch count, gate drive, cost, switching loss of devices, total harmonic distortion, and maintenance of the system. Different pulse width modulation (PWM) techniques like nearest level control (NLC) and level shift pulse width modulation (LSPWM) are compared for the THD analysis[34]–[37]. Figure 1 shows the fundamental unit of the proposed MLI.

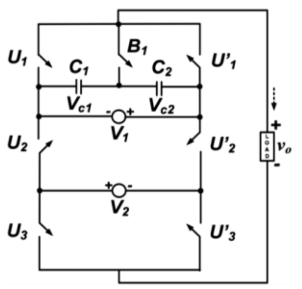

Figure 1. Schematic of proposed 7-level inverter MLI

Proposed MLI consist of one bidirectional switch, six unidirectional, switch, and two DC voltage sources. Voltage divider is used to maintain the constant voltage across the capacitor and reduce the count of DC voltage source. S1, S2, S3, S4, S5, S6 are the unidirectional switches and P1 is the bidirectional switch.

U1 and U2 is DC voltage source used. We can replace DC voltage source with the various renewable energy sources to analyse the system system performance. With the combination of DC sources U1:U2 in the ratio of 2 U:U, U:U, and 2 U:3 U. For (L/M VA) the fundamental unit of the proposed MLI is connected in series. The number of levels in the output can be raised in the recommended MLI by raising the capacitors count to 'n' with a 'n-1' bidirectional switch. For HVA the cascade connection of fundamental blocks of proposed MLI.

3. SIMULATION DIAGRAM AND RESULTS

3.1. Single-phase multilevel inverter

Figure 2 shows the simulation diagram of single -phase multilevel inverter. The output current of NLC and LSPWM technique of single-phase multilevel inverter is purely sine wave in Figures 3 and 4 respectively with few high-order harmonic to the steady operation. The value of output current is 20 amp.

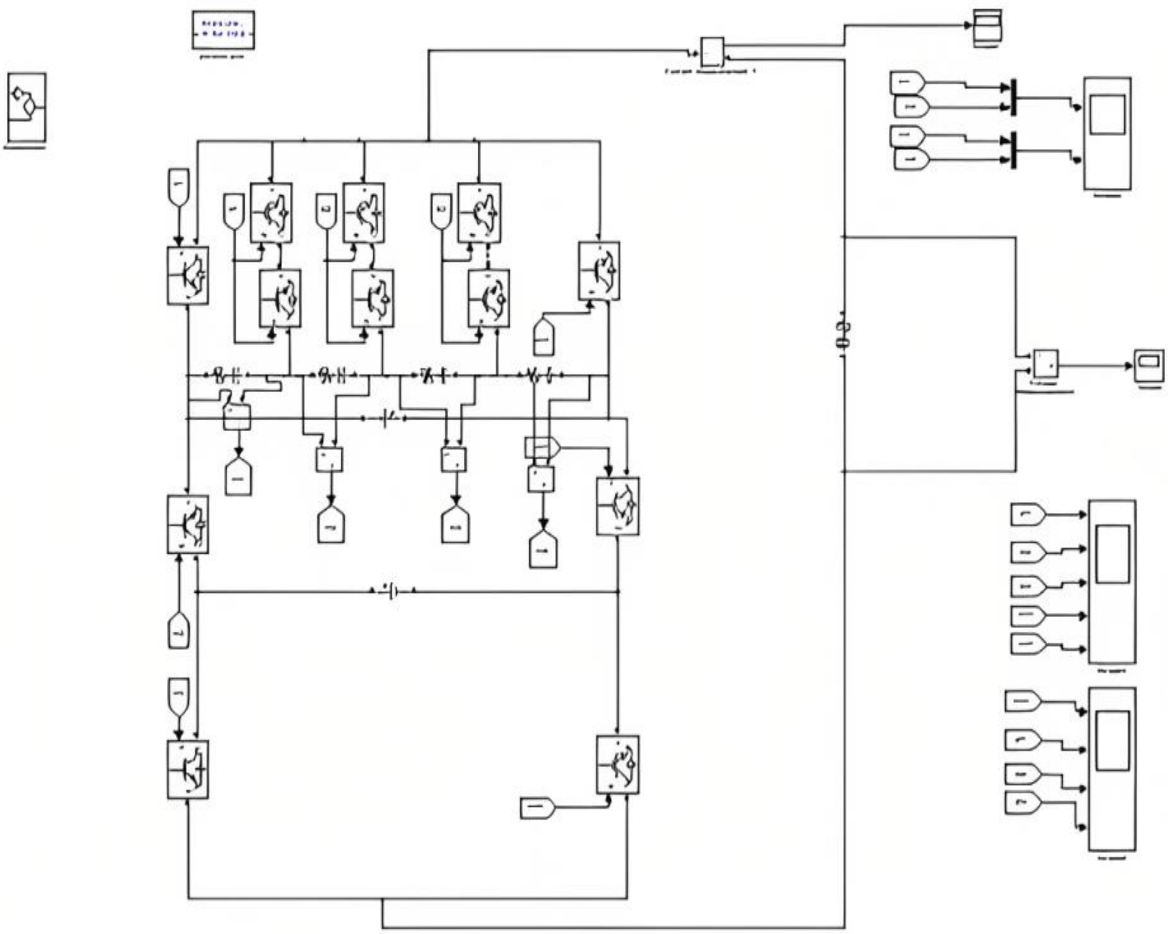

Figure 2. Simulation diagram of single-phase multilevel inverter

The output capacitor voltages of NLC and LSPWM technique of single-phase multilevel inverter is purely sine wave in Figures 5 and 6 respectively. The NLC capacitor voltages for single-phase is more than 20 V as compare to LSPWM capacitor voltages. The output-based voltages of NLC and LSPWM technique of single-phase multilevel inverter is purely sine wave in Figures 7 and 8 respectively. The NLC inverter base voltage is more than 300 V as compare to LSPWM. The THD analysis of NLC and LSPWM technique of single-phase multilevel inverter is purely sine wave in Figures 9 and 10 respectively with few high-order harmonic to the steady operation. The harmonics present in the output current of LSPWM techniques more as compare to NLC of single-phase multilevel inverter. The values are 4.84% in NLC and 6.98% in LSPWM techniques. It can be seen in Figures 9 and 10.

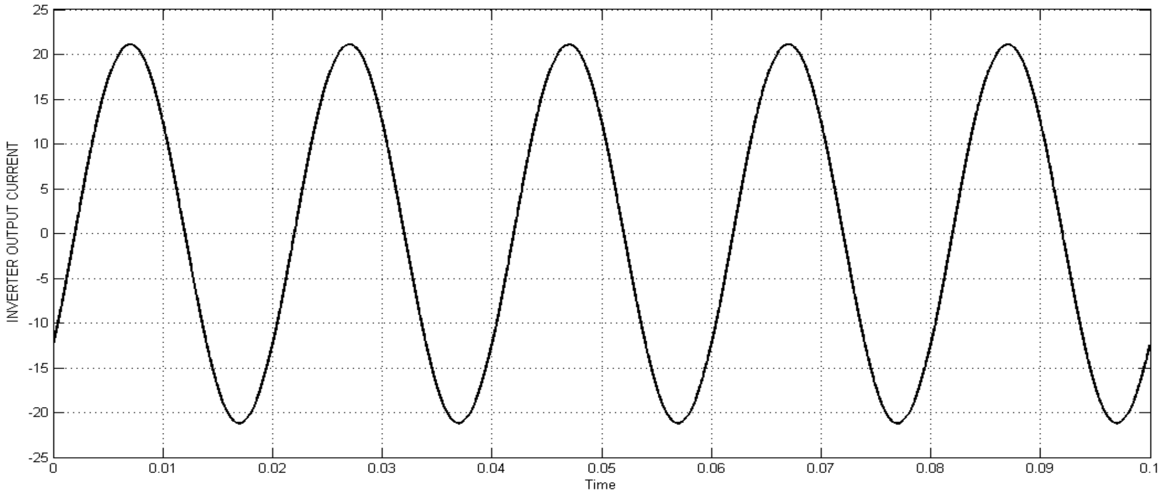

Figure 3. NLC inverter output current

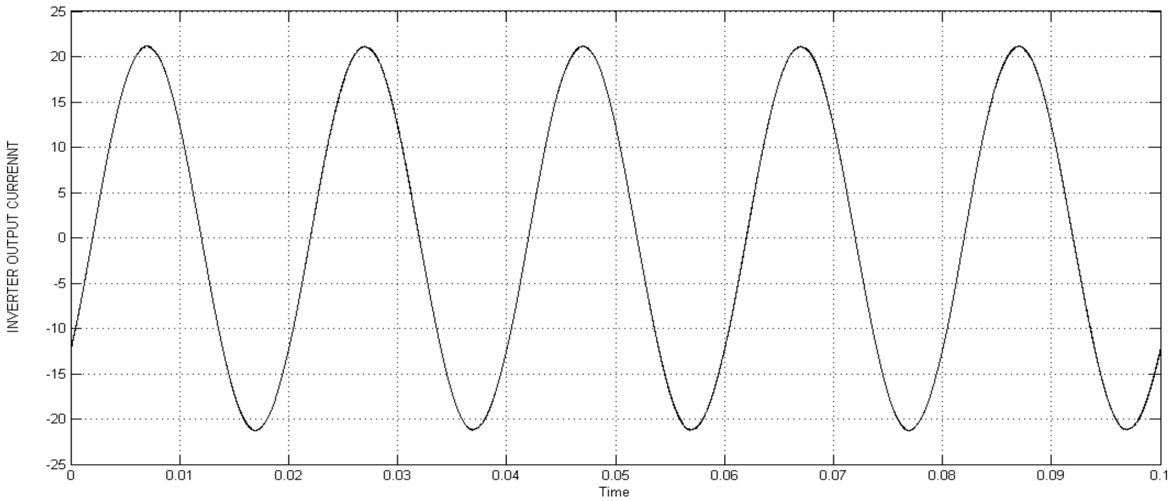

Figure 4. LSPWM inverter output current

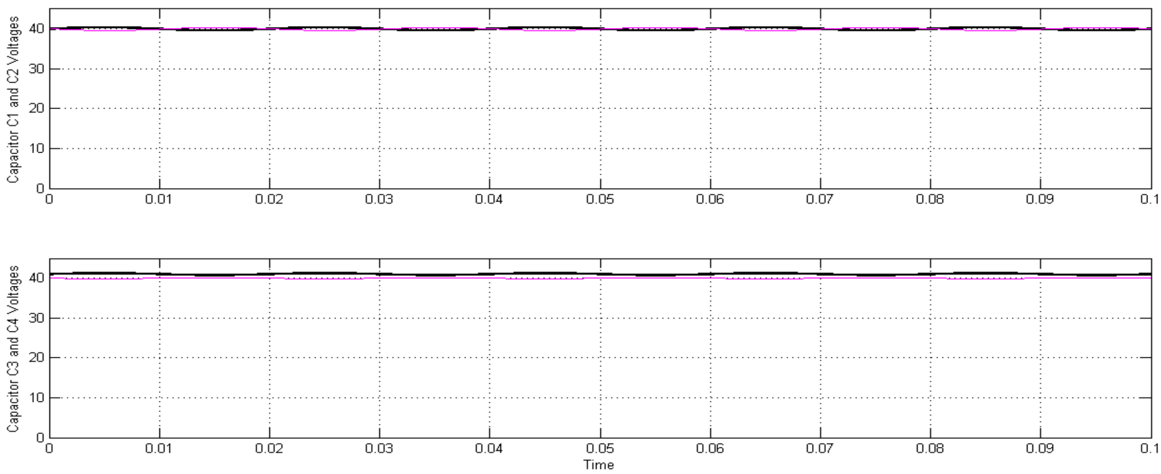

Figure 5. NLC capacitor voltages for single-phase

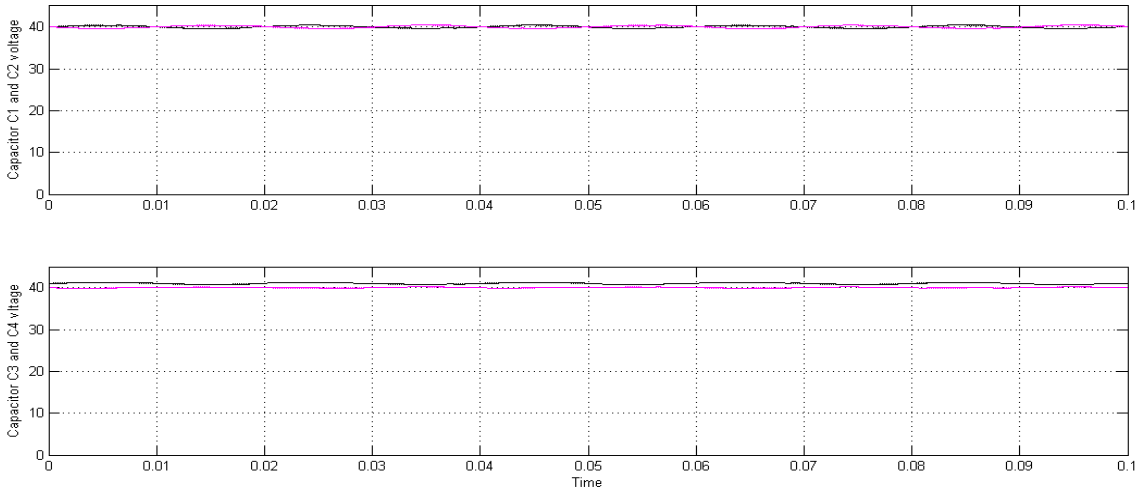

Figure 6. LSPWM capacitor voltages for single-phase

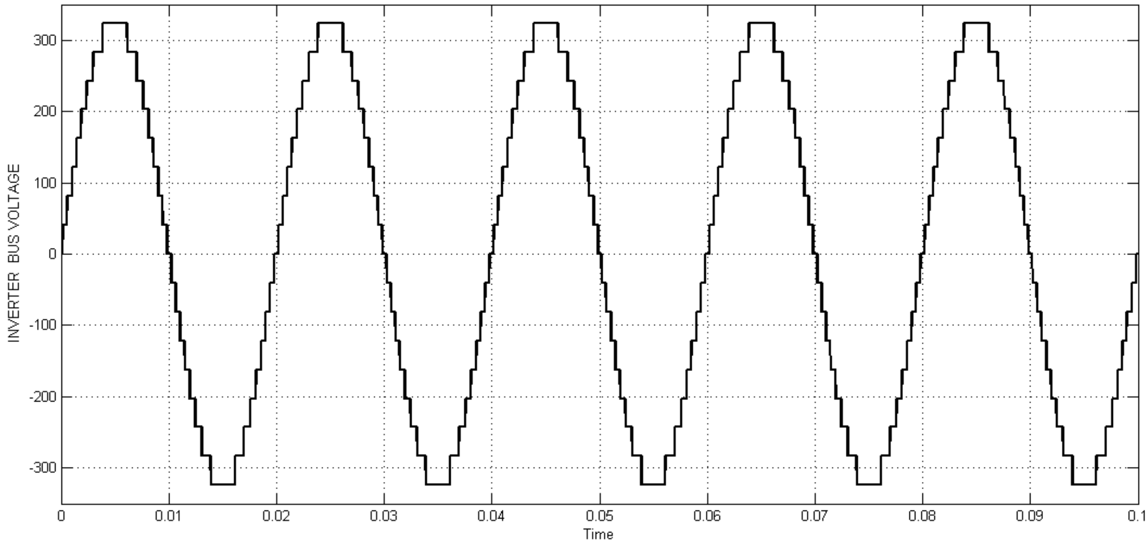

Figure 7. NLC inverter base voltage

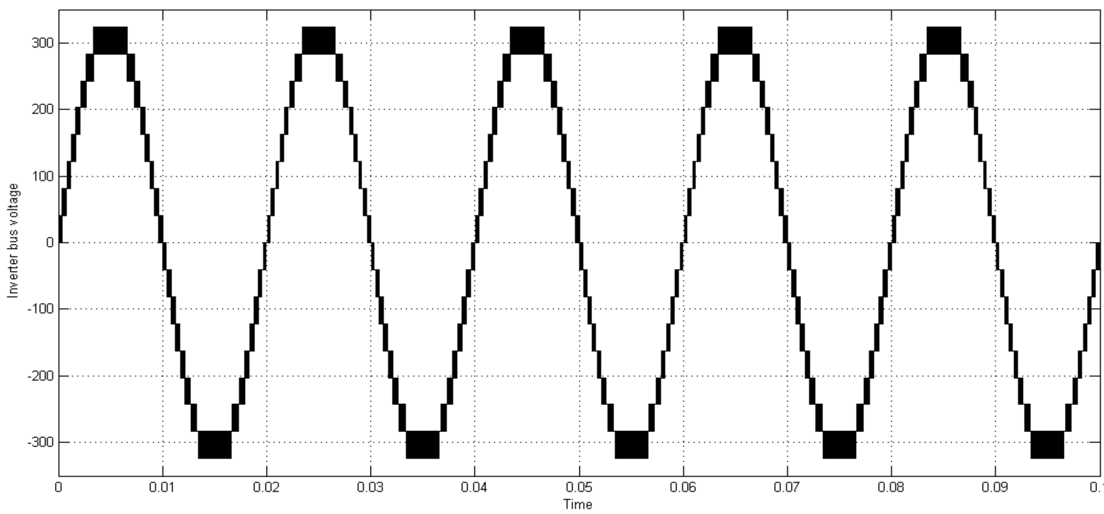

Figure 8. LSPWM inverter base voltage

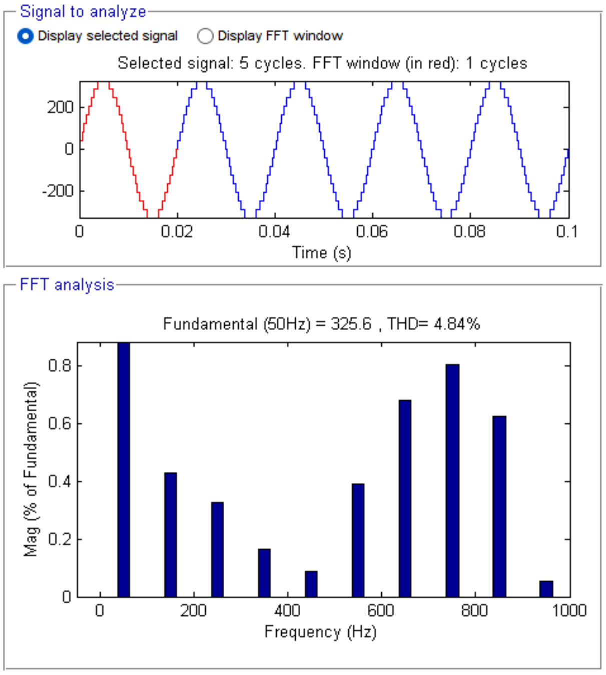

Figure 9. NLC THD analysis

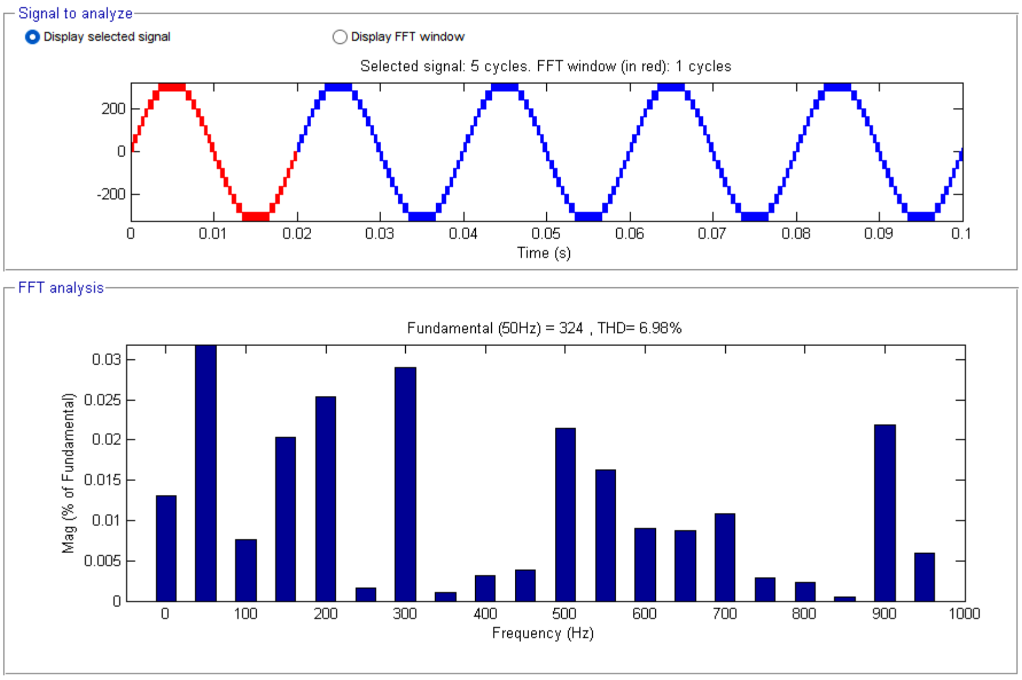

Figure 10. LSPWM THD analysis

3.2. Three-phase multilevel inverter

Figure 11 shows the simulation diagram of three-phase multilevel inverter. NLC capacitor voltages for three-phase shown in Figure 12. NLC and LSPWM inverter phase voltage, line to line voltage, output current for three-phase in Figures 13 and 14. The THD analysis of NLC and LSPWM technique of three-phase multilevel inverter is purely sine wave in Figures 15 and 16 respectively. The switching pattern of NLC and LSPWM for single-phase in Figures 17 and 18. Table 1 shows the simulation parameters and results. Table 2 shows THD analysis for single-phase and three-phase multilevel inverter.

Table 1. Simulation parameters and results

Application	Low/medium voltage		High voltage	
Phase	1−Φ	3−Φ	1−Φ	3−Φ
RMS voltage	$V_{L–N}$ = 240 V	$V_{L–L}$ =450 V	$V_{L–N}$=6.5 kV	$V_{L–L}$ =11 Kv
Mode	Symmetric		Asymmetric	
Irms	16 A		450 A	
Apparent output power	11 Kw		8 MW	
R–L load	25Ω, 55 Mh		25 Ω, 55 Mh	
Modulation technique	NLC		NLC	
Number of levels	17	29	19	33
Numberof switches/diodes/drivers/ DC supply/capacitors	12	36	24	72
Magnitude of each DC source	170 V		1950 V	
Switching device	MOSFET I_D = 20 A, V_{DS} = 500 V	IRFB20N50K	IGBT I_c=450, V_{CE}=3000 V	FF450R33T3E3_B5
THD	NLC 4.84	NLC 2.82	LSPWM 6.98	LSPWM 4.04

Table 2. THD analysis

THD	NLC	LSPWM
Inverter base voltage for single-phase multilevel inverter	4.84%	6.98%
Inverter base voltage for three-phase multilevel inverter	2.82%	4.04%

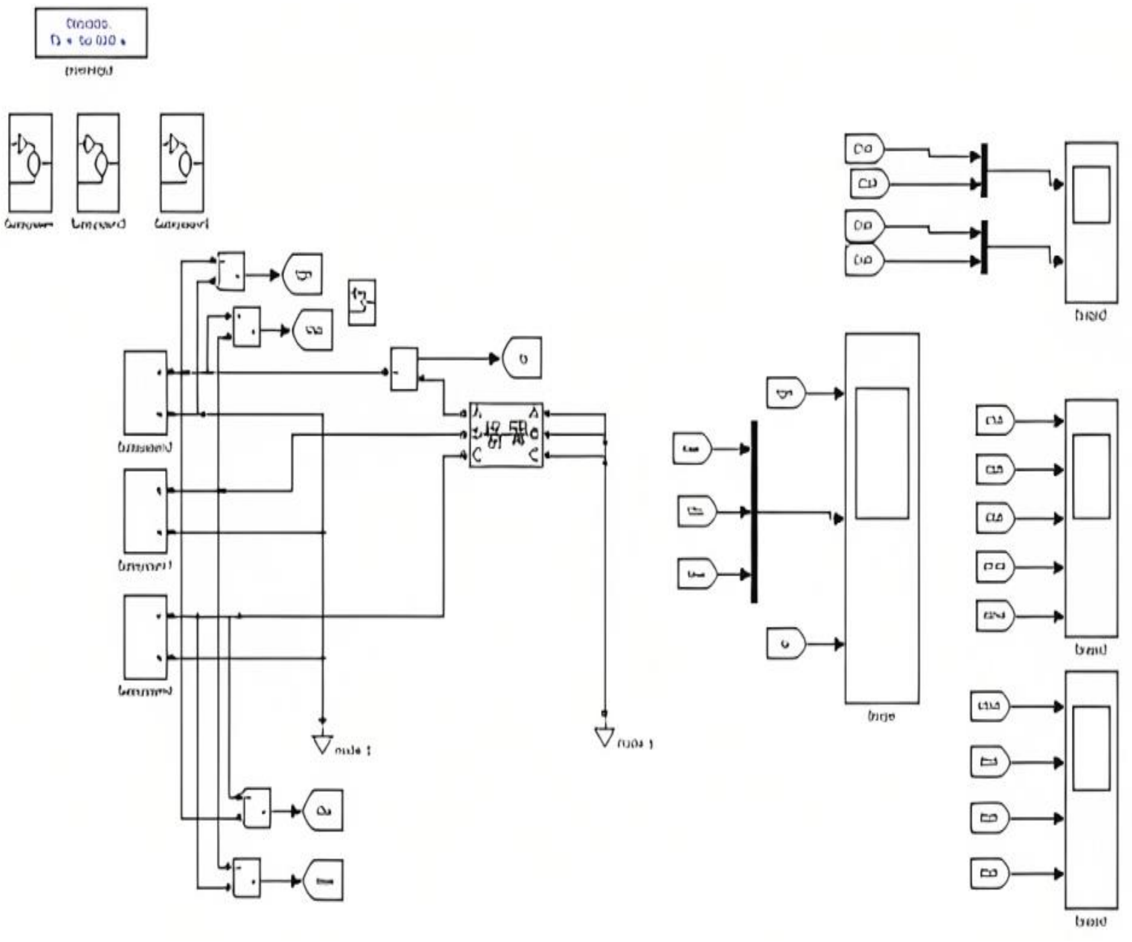

Figure 11. Simulation diagram of three-phase multilevel inverter

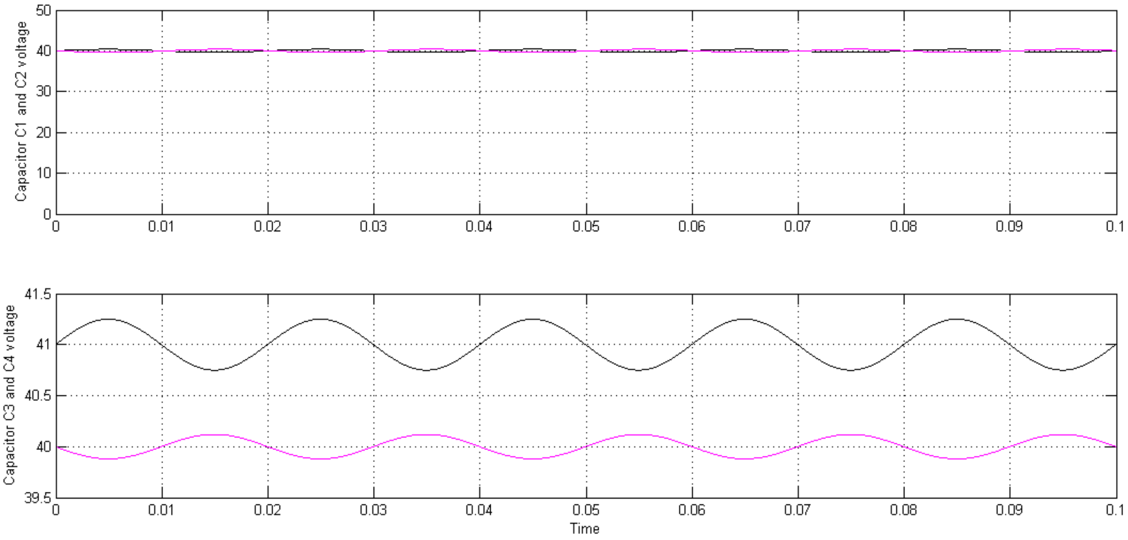

Figure 12. NLC capacitor voltages for three-phase

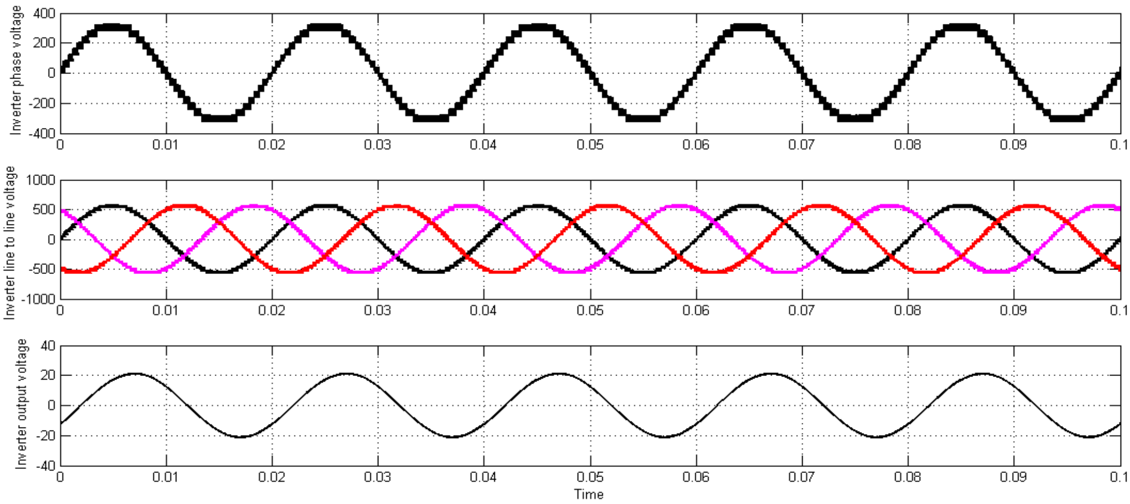

Figure 13. NLC inverter phase voltage, line voltage, and output current for three-phase

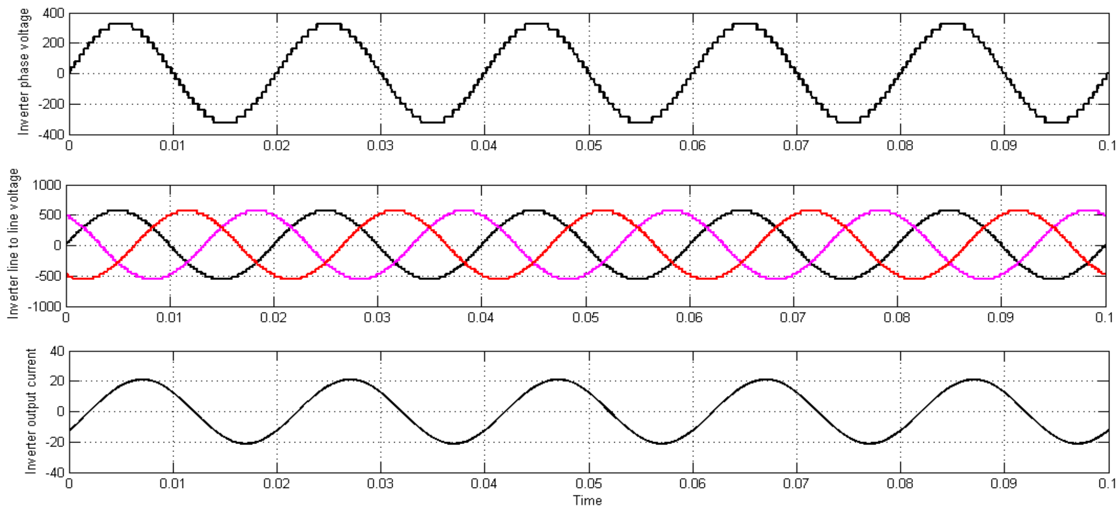

Figure 14. LSPWM inverter phase voltage, line voltage, and output current for three-phase

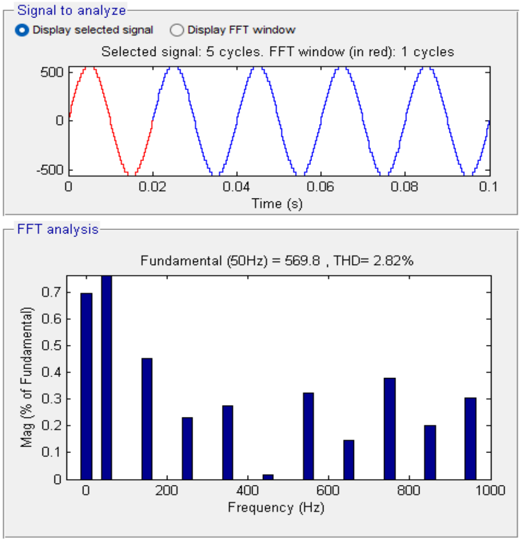

Figure 15. NLC THD for three-phase

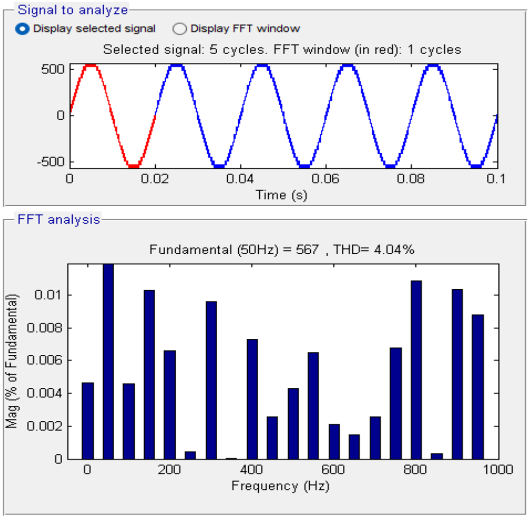

Figure 16. LSPWM THD for three-phase

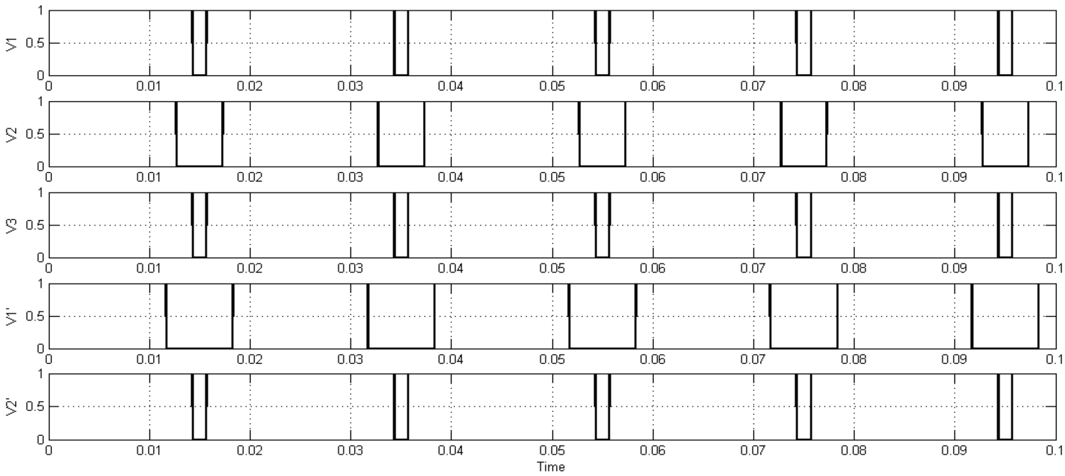

Figure 17. NLC switching pattern for single-phase

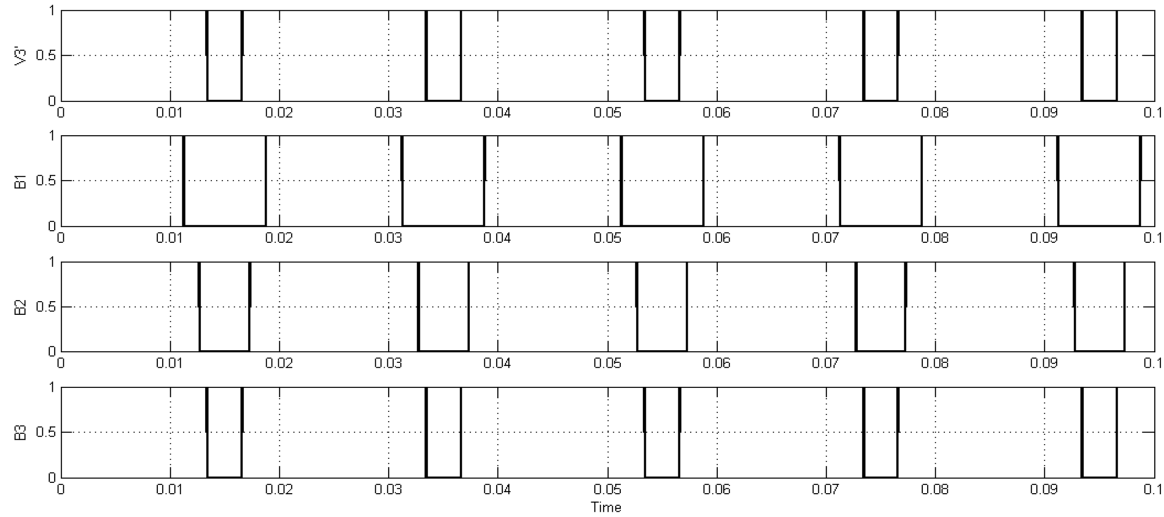

Figure 18. LSPWM switching pattern for single-phase

4. CONCLUSION

This paper proposed reduced switch count 7-level multilevel inverter (MLI) using NLC and LSPWM. It also improved power quality, efficiency and reduction of switching and conduction losses. The THD of three-phase voltage is less as compare to single-phase. Simulation show satisfactory performance of the proposed MLI, for grid interface, number switch count, switching losses and conduction losses. It was observed that NLC method is better efficiency and reduced THD than LSPWM for better utilisation in renewable power applications.

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