ISSN : 2350-0743

www.ijramr.com

International Journal of Recent Advances in Multidisciplinary Research

Vol. 02, Issue 10, pp.0817-0821, October, 2015

REVIEW ARTICLE

VARIATION OF OUTPUT VOLTAGE THD FOR R AND RL LOADS FOR AN EFFICIENT DEVELOPED CASCADED MULTILEVEL CONFIGURATION WITH LESS NUMBER OF SWITCHES

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ARTICLE INFO

Article History:
Received 21st July 2015
Received in revised form
19th August, 2015
Accepted 26th September, 2015
Published online 31st October, 2015

Keywords:
Cascaded H Bridge Inverter,
Multilevel Neutral Point Inverter,
Multilevel Flying Capacitor Inverter,
Total Harmonic Distortion.

ABSTRACT

Multilevel inverter is a very popular in various fields like FACTS devices,HVDC systems, industrial drives,photovoltaic systems etc. It has a large number of advantages like low stress on switches,lower harmonics,low switching losses etc. There are different topologies available like neutral point or diode clamped inverter, flying capacitor inverter etc. each having numerous disadvantages and advantages. The efficiency of this inverter is greatly improved by minimising the number of switches of the configuration used. The paper takes into account a developed cascaded topology to reduce the number of switches and reduce the harmonics. To find the effectiveness of the developed cascaded topology in improvement of efficiency, a simulative study is done to evaluate the effect of topology with increasing voltage levels for R and RL loads.The configuration provides better harmonics with increasing levels for both kinds of loads. Simulations are done in MATLAB-Simulink.

INTRODUCTION

The Inverter is very familiar to all of us. In simple terms, it is a devise which converts Direct Current (DC) to Alternate Current (AC).We have lots of possibilities for this conversion. A variety of semiconductor configurations have helped in the development of better output waveforms by means of quality and shape. Multilevel inverters have evolved from simple two level inverters to produce waveforms which are more AC like. The AC output could better approximate a sine wave, if more than two voltage levels were available at the inverter output terminals with better output at each higher level. That is the reason multilevel inverters, although complex and costly, offers better performance. The purpose of multilevel converter is to give a high output power from medium voltage sources like solar panel, batteries, super capacitors etc. The multi-level inverter consists of several switches arranged in a particular manner. In the multi-level inverter the arrangement switches are very important and produce corresponding levels. The main advantage of multilevel inverters is that they improve the output waveform quality greatly by reducing the harmonic distortion. They can work with higher or lower switching frequency than the fundamental frequency and reduce the stress on switches. Disadvantages of multilevel inverter are that they often use a large number of semiconductor switches making the system costly andbulky. Also they require separate gate drive circuit for each switch used. The most familiar use of inverter is for emergency backup power in a home in the occasion of power failure or low voltage level. The inverter has a wide range of uses including in aircraft systems to convert a portion of the aircraft DC power to AC power.

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The AC power is used mainly for electrical amenities like lights, radar, radio, motor and other devices in such systems. The DC source is usually a controlled rectifier output or battery. It has many applications in FACTS devices, system, Industrial drives etc. Multilevel voltage source inverters have successfully been used and are an important alternative that competes with Pulse Width Modulation (PWM)-CSI in many classic applications like compressors, pumps, fans, rolling mills, and conveyors.

These processes are the most common medium-voltage applications of voltage source inverters in the industry today. This paper focusses on an energy efficient configuration which can act as an effective replacement for existing configurations due to its main advantage of reduced number of switches. Reduced number of switches means reduction in driver circuit, better voltage levels, improvement in size,space,cost and thereby betterment of efficiency of inverter. This paper analyses the effectiveness of cascaded topology in improvement of efficiency by simulative analysis. It can be used in photovoltaic applications and other renewable energy integration. The topology with reduced number of switches is analysed using Matlab-Simulink. The following section discusses the various topologies used and later sections describes the developed cascaded topology which is of interest to reduce number of switches and presents simulative analysis using this topology with various voltage levels.

DIFFERENT CONFIGURATIONS

Multilevel Diode Clamped/Neutral Point Inverter

One of the first configurations utilized in inverter applications is the multilevel diode clamped inverter. The inverter provides multiple voltage levels through connection of the phases to a series bank of capacitors. The advantage of this configuration is that diode transfers only a limited amount of voltage, thereby reducing the stress on other electrical devices. Also half of the input DC voltage is the maximum output voltage. This type of inverter gives high efficiency because the fundamental frequency is used for all the switching devices and it is a simple method, especially for back to back power transfer systems. The disadvantages of this configuration is it requires more number of clamping diodes is when number of output voltage level is high making it larger in size, cost and design. They are widely used in FACTS devices, motor drives, HVDC and HVAC applications (Waltrich and Barbi, 2010), (Hinago and Koizumi, 2010).

Multilevel Capacitor Clamped/Flying Capacitor Inverter

In order to make the inverter more efficient another configuration was developed eventually. It uses capacitors instead of using clamping diodes to hold the voltages to the desired value. The main concept of this inverter is to use capacitors instead of diodes. It is a series connection of capacitor clamped switching cells. The capacitors transfer the limited amount of voltage to electrical devices compared to diodes. In this inverter switching states are similar to the diode clamped inverter. Clamping diodes are not needed in this type of multilevel inverters. For higher levels use of filter becomes necessary. The output is half of the input DC voltage just as in previous configuration. It is the main drawback of the flying capacitor multi-level inverter. It can control both the reactive and active power flow. But due to the high frequency switching, switching losses will be a disadvantage. Control and cost of system also becomes difficult with increase of voltage levels. Capacitor Clamped Multi level Inverter are widely used in induction motor control, FACTS devices, converters etc. (Rodriguez, 2010), (Choi and Kang, 2009).

Cascaded Multicell Inverter, CMCI

Cascaded multilevel inverter is one of the most important and popular topology in the family of multilevel inverters. Multilevel inverters using this configuration do not need a coupling transformer to interface it with high power system. The cascaded H-bride multi-level inverter may use capacitors and switches and requires less number of components in each level which can be easily replicated. This topology consists of series of power conversion cells and power can be easily scaled and multiplied. The combination of capacitors and switches pair is called an H-bridge and requires separate input DC voltage for each H-bridge. It consists of H-bridge cells and each cell can provide the three different voltages like zero, positive DC and negative DC voltages for the basic unit. One of the advantages of this type of multi-level inverter is that it needs less number of components compared with diode clamped and flying capacitor inverters making it more desirable. The price and weight of the inverter are less than those of the two inverters discussed before.

Soft-switching is possible by some of the new switching methods which will reduce the losses. Multilevel cascade inverters are better as they eliminate the bulky transformer required in case of conventional multi-phase inverters, clamping diodes required in case of diode clamped inverters and flying capacitors required in case of flying capacitor inverters. But these require large number of isolated voltages to supply each module section. They are used in industrial drives, active filter circuits, power factor compensators, vehicle drives and control etc (Boora *et al*, 2009), (Babaei *et al*., 2006), (Ebrahim Babaei *et al*., 2002), (Kangarlu and Babaei, 2008).

Advanced H-bridge type inverter

Another configuration developed to compensate for the disadvantages is advanced H-Bridge configuration. Therefore at higher levels the overall cost and complexity of system reduces. This topology separates the circuit into two parts, one part is called level generation part and is used for generating output voltage levels in positive polarity. Level generation part requires high frequency switches to generate the required levels at the right time. The second part is named polarity generation part and is used for generating the negative polarity of the output voltage. This part is the low-frequency part and operating at line frequency or supply frequency. The second part of the circuit that is polarity generation part works similar to H-bride circuit in modular or cascaded configuration. Figure shows Schematic diagram of a single phase eleven level reversing voltage topology using the H Bridge.

This topology is highly modular because by duplicating the middle stage, the number of levels can be easily increased. This requires fewer switches and carrier signals in comparison to conventional inverters which is very appealing. It can also be applied to three phase system by duplicating the module. The main disadvantage is it uses isolated DC sources just as in cascaded topology. It should be noted that isolated power supplies avoid voltage balancing problems created by capacitors in previous two configurations. Advantages are that they have lesser number of switches compared to previous configurations and better harmonics elimination. Other disadvantages is that the system is bulky and need more space and is costly (Boora *et al*, 2009), (Kangarlu and Babaei, 2008), (Manjrekar and Lipo, 1998).

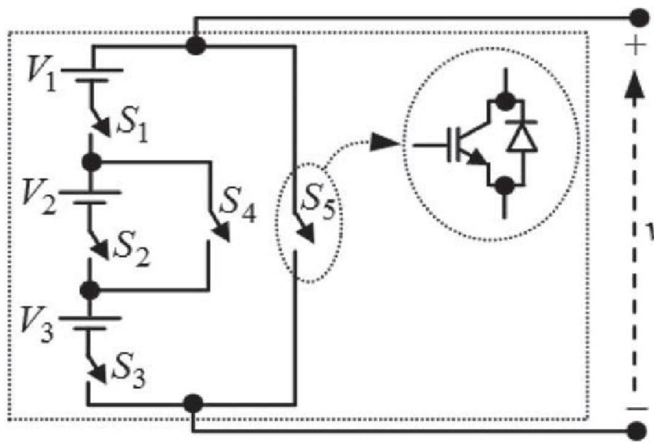


Figure 1.Basic unit of cascaded inverter (Boora *et al*., 2009)

Cascaded topology to reduce number of switches

An inverter topology has been used which has superior features over conventional topologies in terms of the required power switches and isolated DC supplies, control requirements, cost, and reliability. The basic unit for the cascaded multilevel inverter used is shown in Fig 1.The switching states for this unit is shown in Table 1.

Table 1. Switching States

State	Switch States					
	S_1	S_2	S_3	S_4	S_4	V_0
1	off	off	off	off	on	0
2	on	off	on	on	off	$V_1 + V_3$
3	on	on	on	on	off	$V_1 + V_2 + V_3$

By the series connection of several basic units, a cascaded multilevel inverter that only generatespositive levels at the output is utilised. Therefore, an H-bridge is added to the proposed inverter to generate all voltage levels that is positive levels and negative levels. level. The output voltage level of each unit is indicated by V_{01},V_{02}.,V_{03}.....V_{0n}.

Table 2. THD values for different voltage levels

Inverter	THD voltage(R load),%	THD voltage(RL load),%
9-level	12.91	10.19
11-level	10.17	8.12
15-level	7.37	5.75

The generated output voltage levels of the cascaded inverter are shown in Table 2. As aforementioned and according to Table 2, the cascaded inverter is shown in Fig 2 (a) is only able to generate positive levels at the output.

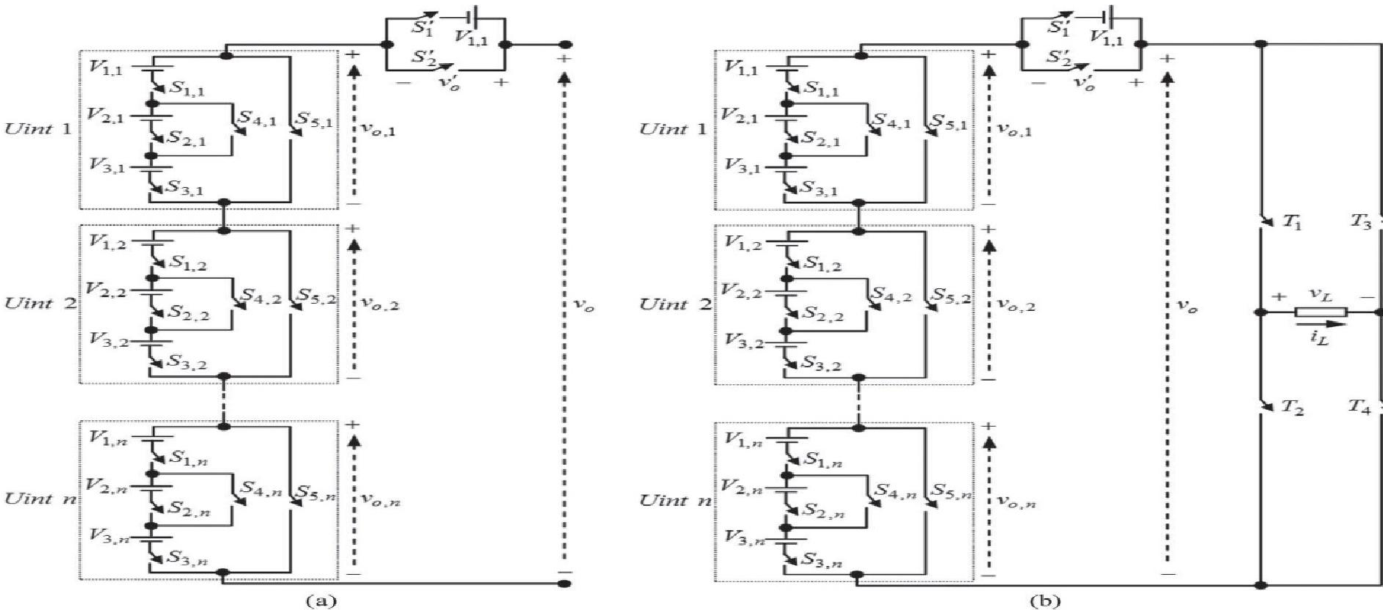


Figure 2. (a)n level cascaded topology (b)n level developed cascaded topolog

This inverter is called the developed cascaded multilevel inverter for convenience. By changing the magnitude of the dc voltage sources, we get different voltage levels at the output. The developed proposed inverter has better performance and needs minimum number of power electronic devices that lead to reduction in the installation space and total cost of the inverter. It can be studied for various voltage levels by changing the magnitude of DC voltage sources. Next section discuss the details of this better topology to improve efficiency (Kangarlu and Babaei, 2008), (Boora *et al*., 2009).

CASCADED TOPOLOGY TO REDUCE SWITCH NUMBER

To overcome the disadvantages of conventional topologies, developed cascaded topology discussed above is used. As shown in Fig 1 the basic unit is comprised of three dc voltage sources and five unidirectional power switches. Fig 3 shows the voltage values and corresponding switching states. As this inverter is able to generate all voltage levels except V_1, it is needed to use an additional dc voltage source with the amplitude of V_1 and two unidirectional switches that are connected in series with the cascaded topology. The developed cascaded inverter that is able to generate all levels is shown in Fig 2 (b). In this inverter, power switches S1 and S2 and DC voltage source have been used to produce the lowest output level V_1. The amplitude of this dc voltage source V_{dc} is considered V_1= V_{dc} which is equal to the minimum output

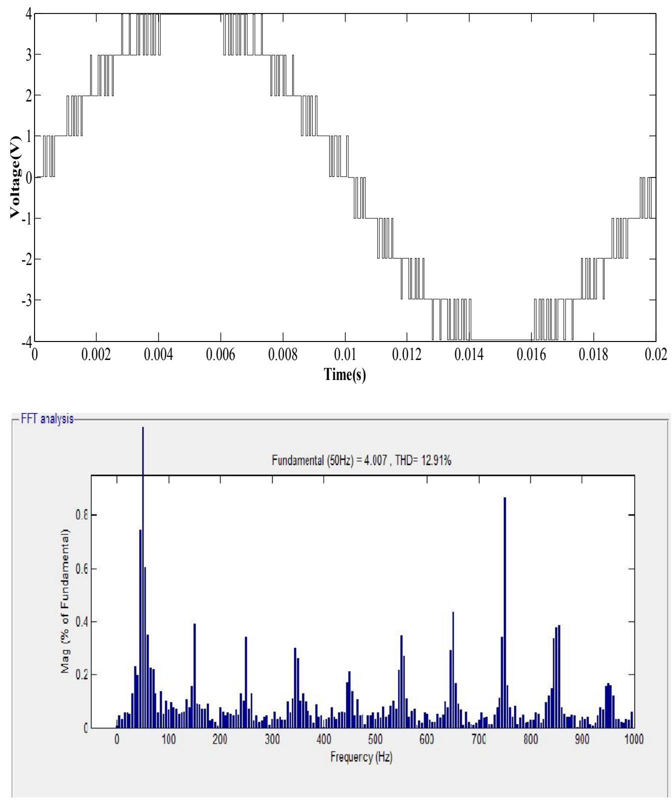


Fig 8(a). Nine level output waveform and THD

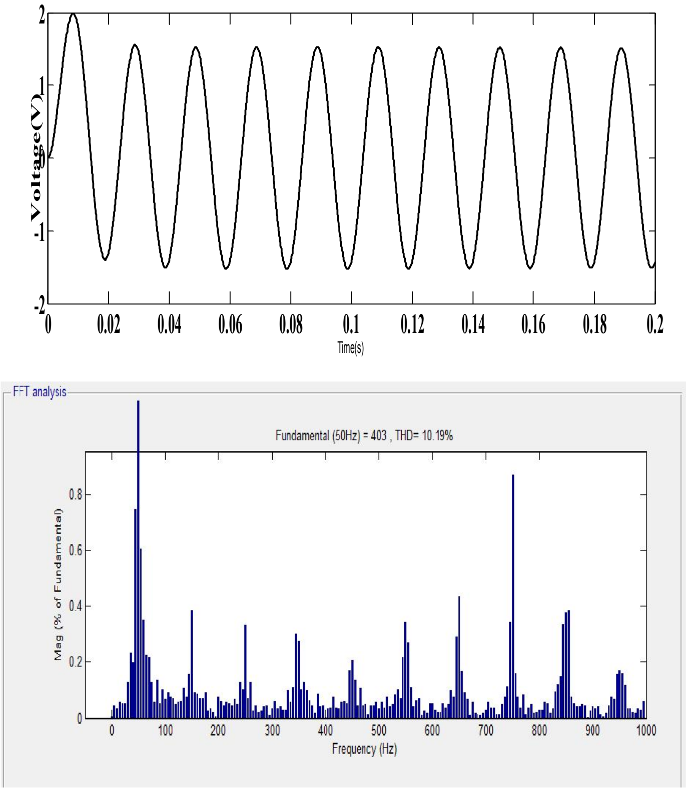


Fig 8(b). Nine level output waveform and THD with RL load

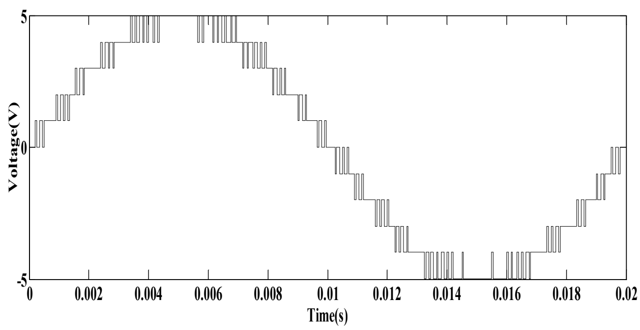
Therefore, an H-bridge with four switches is added to the cascaded topology. This inverter is called the developed cascaded multilevel inverter and is shown in Fig. 2(b).

If switches T1 and T4 are turned on, load voltage V_L.is equal to $+V_0$ and if power switches T2 and T3 are turned on, the load voltage will be $-V_0$.As unidirectional power switches are used in the developed cascaded multilevel inverter, the number of power switches is equal to the numbers of IGBTs, power diodes, and driver circuits.

Another main parameter in calculating the total cost of the inverter is the maximum amount of blocked voltage by the switches. If the values of the blocked voltage by the switches are reduced, the total cost of the inverter decreases as is obtained using this configuratio n (Boora *et al*, 2009).

Comparison of developed cascaded topology for various levelsfor r and rl loads

9 level, 11 level, 15 level and 19 level inverter using the above discussed cascaded topology was done. Results are shown in Table 3. Simulations were done in Matlab.



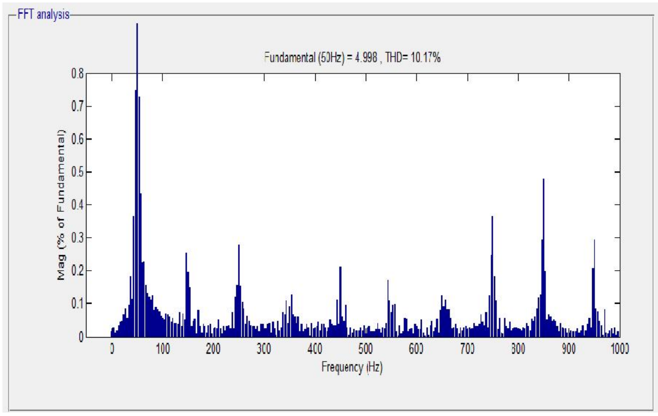


Fig 9 (a): Eleven level output waveform and THD

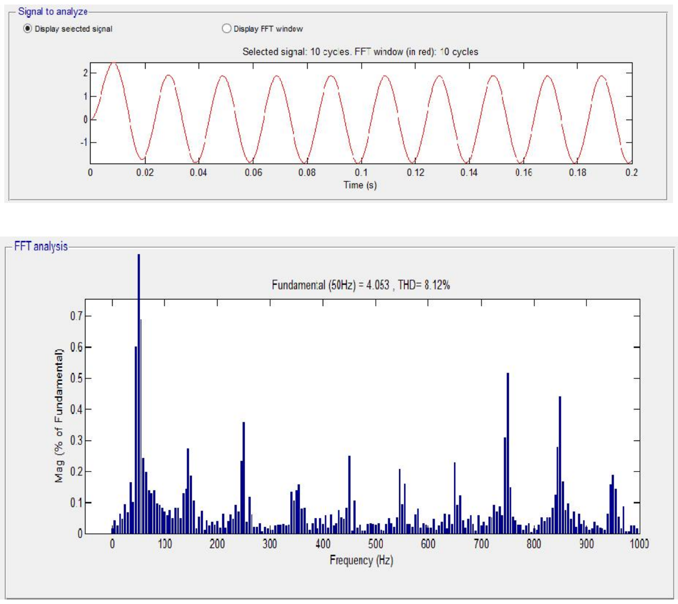
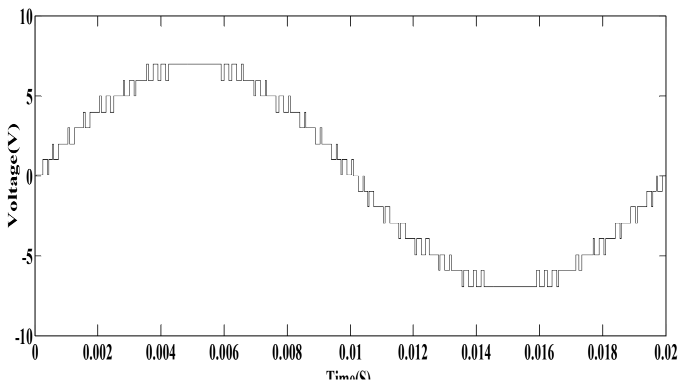


Fig 9 (b).Eleven level output waveform and THD with RL load

Figures 8 to 10 shows the voltage output waveforms of nine level, eleven level, fifteen level AND nineteen level inverter along with FFT report for R and RL loads.

The Table 2 shows the variation of THD with different voltage levels for r(124 ohms), RL (124 ohms,1mH) load .As can be clearly seen from the table the THD value decreases with increasing voltage level for both kinds of loads.



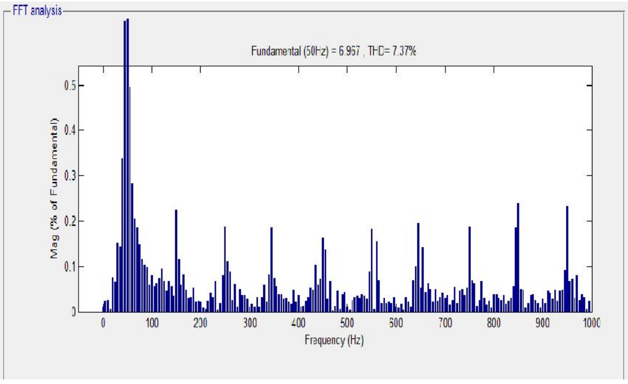


Figure10 (a) Fifteen level output waveform

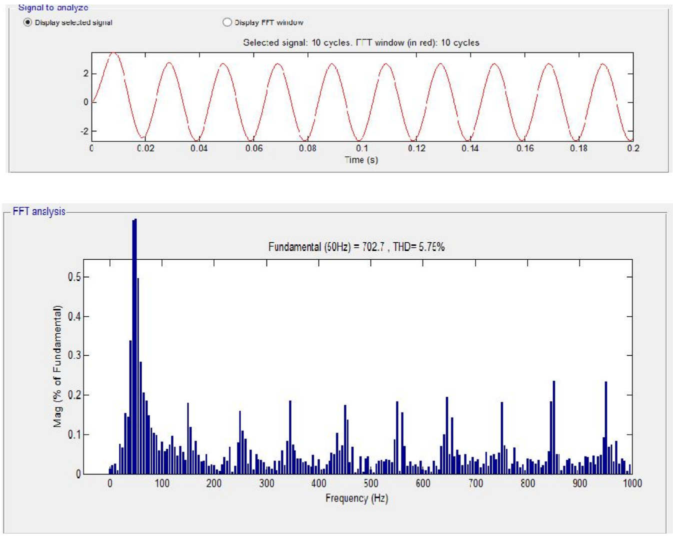


Figure10 (b) Fifteen level output waveform and THDWith RL load

Conclusion

Multilevel inverters have been used in many industrial applications like HVDC, FACTS, PV systems, UPS and Industrial drive applications. Instead of using other inverter topology, proposed topology is better for all these applications because it has less control complexities, less size and cost. It also reduces the THD of output to a great extend thus reduces the size of filter. As the level increases THD of Output reduces. It can be used in applications where quality of output is primary requirement. The simulation results shows the improvement of quality of voltage waveform as voltage level increases for resistive and inductive loads.

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