Design And Analysis Of Different Multi-Level Inverter Topologies For Single Phase Im Drive

N Bharath Kumar[1], T Ch Anil Kumar[2], Haqqani Arshad[3], DSNMRAO[4]

[1] Department of Electrical and Electronics Engineering, Vignan's Foundation for Science, Technology and Research, Guntur-522213, AP, India
[2] Department of Mechanical Engineering, Vignan's Foundation for Science, Technology and Research, Guntur-522213, AP, India
[3]Yanbu Industrial College, Yanbu, Western Region, Saudi Arabia.
[4] Department of Electrical and Electronics Engineering, Gokaraju Rangaraju Institute of Technology and Science, Hyderabad-500090, Telangana, India

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Abstract
A PWM technique can be used to increase the level of the converter voltage. The duty ratio of PWM controller plays a major role in controlling the step-up converter operation to obtain the required output level. The output of the boost converter is converter into AC by using the Inverter and fed to the induction motor (IM). The operation of the IM is mainly based on the suitable choice of converter-inverter system. Inverter operation is controlled by a PWM switching technique. This paper mainly deals with the photovoltaic (PV) integration of Voltage Multiplier circuit and an inverter fed IM drive. Solar energy from the renewable resource is the primary source for the converter circuit. In renewable energy applications, a new high step-up converter is used to boost up the input variable low-voltage. Converter doubles the input voltage by using a voltage multiplier circuit. The proposed model is designed and simulation is done and the output waveforms are plotted.

Keywords: Multi-level Inverter, Voltage-Doubler circuit, Boost Converter, Induction Motor, PV Integration.

1. INTRODUCTION

The Voltage Doubler circuit mainly uses the principle of the Boost converter in closed-loop since it yields better efficiency for the considered system. During the DC-AC conversion process, multi-level inverters (Aneesh Kumar, Poddar, & Ganesan, 2015; Boby et al., 2016; Roshankumar et al., 2012) will reduce the harmonics. Nowadays, from medium level to high power level implementations the multilevel inverters (Chowdhury, Wheeler, Patel, & Gerada, 2016; Mukherjee & Poddar, 2010; SDMIT (Organization), Institute of Electrical and Electronics Engineers. Bangalore Section, & Institute of Electrical and Electronics Engineers, n.d.) are the best choice to reduce harmonics in the system by increasing the inverter levels. Presently, Photovoltaic (PV) system of solar energy is one of the alternative resources to provide the electrical energy to the system (Boby et al., 2018; Chaitanya, Patnaik, & Murthy, 2017; Yadav, Gopakumar, Raj, et al., 2019). The major disadvantage of the PV system is its installation cost. To improve the efficiency of the system and to reduce the installation cost, a PE interface is required. This paper mainly deals with the effective operation of the high step-up converter fed IM using different levels of inverter operation. In this modern developing world the demand for power is increasing every year by 2%. The demands have to compensate, by moving towards a renewable form of power generation. Grid integration is necessary for all stand-alone operations as the sustainable energy resources are not producing continuous power to the load due to nature. Direct current generator sources are numerously available and they produce power at different frequencies and at different voltage levels. In a wind turbine, solar and fuel cells are found some disparity. So, for needs of standard value, some necessary power and frequency conversions (Krishna Raj et al., 2019; Singhai, Pandey, Singh, Inverter, & Multiple, 2018; Yadav, Gopakumar, Krishna Raj, et al., 2019) are required and they should be compatible with commercial and domestic power supply. A power conditioner is required to fulfill this power conversion.

2. VOLTAGE MULTIPLIER WITH BOOST CONVERTER CIRCUIT

The voltage multiplier circuit with Boost converter topology is shown in Fig. 1. The voltage multiplier is also called as voltage doubler circuit or voltage coupled inductor.This voltage multiplier is using in boost converter circuit as it can yield high voltage gain. By using soft-switching technique, we can decrease the stress in the switches and also diminish the switching losses. So the output voltage gain of the system also increases. A voltage multiplier with a coupled inductor increases the overall gain of the system. To compensate the losses in the inductor the soft-switching techniques are used and these techniques also improve the voltage gain of the converter and decrease the converter losses.

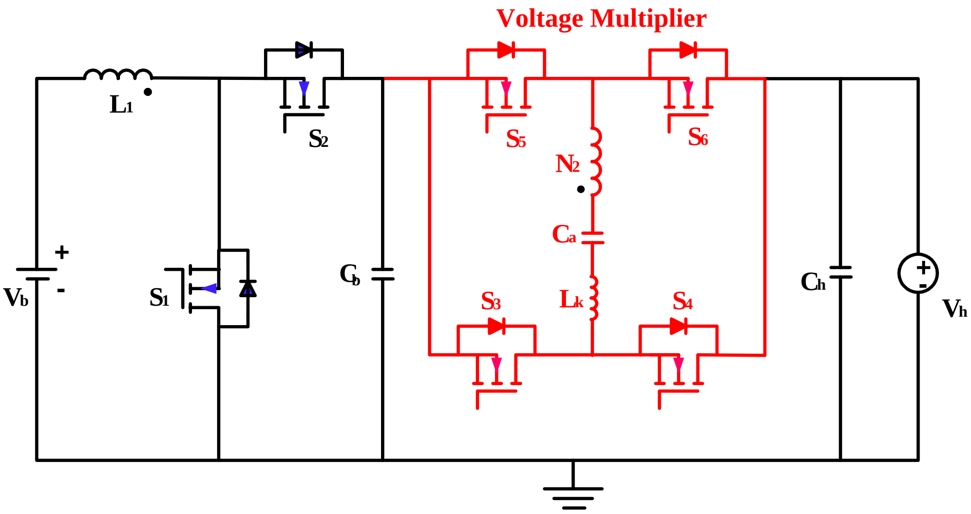

Figure 1. Step-up converter integrated with voltage multiplier

3. IMPLEMENTED TECHNOLOGY

The implemented converter topology explains the photovoltaic (PV) integrated high step-up converter with cascade H-bridge multilevel inverters for three-level, five-level, seven-level, nine-level, and eleven-level topologies for single phase IM drive for water pumping applications. In present days the key sources are the renewable energy sources for PV integrated step-up converter, with multilevel inverters to improve the number of levels to get the inverter voltage in pure sinusoidal form and increases the given input voltage by step up converter. The converter output gain improves by voltage doubler circuit. The step-up converter voltage is given as input to the single-phase 3-level cascade H-bridge multilevel inverter to converter the source voltage from DC-AC for single phase IM drive applications. The major advantage of the cascaded H-bridge multilevel inverter consists of less number of components, the size of the circuit is small, and PWM control technique is applied. The output voltage level of the 3- level inverter switching sequence is shown in Table 1.

Table 1. Three-level cascade H-bridge multilevel inverter switching sequence operation

Output voltage levels	Switching sequence operation			
	T_a	T_b	T_c	T_d
V_{dc}	1	1	0	0
0	1	0	1	0
$-V_{dc}$	0	0	1	1

The PV integrated high step-up DC-DC converter with 5-level cascade H-bridge multilevel inverter fed IM is obtained by connecting two inverters in series. The step-up converter voltage is given to the 5-level inverter. The 5-level multi-level inverter consists of two input voltage sources which are fed by the independent voltage sources. The voltage in the 5-level inverter is the sum of the individual voltages of the voltage sources. The 5-level inverter total voltage value is given by equation (1).

$$V = \frac{V_{dc}}{2} + \frac{V_{dc}}{2} \quad (1)$$

Table 2. Switching operation of 5-level H-bridge multilevel inverter

Output voltage levels	**Switching sequence operation**							
	$\mathbf{T_a}$	$\mathbf{T_b}$	$\mathbf{T_c}$	$\mathbf{T_d}$	$\mathbf{T_a'}$	$\mathbf{T_b'}$	$\mathbf{T_c'}$	$\mathbf{T_d'}$
$\frac{V_{dc}}{2}$	1	1	0	0	0	0	0	0
V_{dc}	1	1	0	0	1	1	0	0
0	1	0	1	0	1	0	1	0

$-\frac{V_{dc}}{2}$	0	0	1	1	0	0	1	1
$-V_{dc}$	0	0	1	1	0	0	0	0

The first inverter voltage is represented by $\frac{V_{dc}}{2}$ and another multilevel inverter voltage value is also represented by $\frac{V_{dc}}{2}$. The output voltage level sequence of the 5-level inverter consists of five output voltage levels such as $\frac{V_{dc}}{2}$, V, 0,-V, $\frac{-V_{dc}}{2}$ and the switching sequence operation is given in Table 2.

To obtain 7-level H-bridge multilevel inverter, connect three multilevel inverters in series. Three different voltage levels are operated at three different voltage sources. The 7-level inverter overall voltage is represented by the equation (2).

$$V = \frac{V_{dc}}{3} + \frac{V_{dc}}{3} + \frac{V_{dc}}{3} \qquad (2)$$

Table 3. The operating sequence of the 7-level inverter.

Output Voltage Levels	Switching Sequence Operation											
	T_a	T_b	T_c	T_d	T_a'	T_b'	T_c'	T_d'	T_a''	T_b''	T_c''	T_d''
$\frac{2V_{dc}}{3}$	1	1	0	0	0	1	0	1	0	1	0	1
$\frac{V_{dc}}{3}$	1	1	0	0	1	1	0	0	0	1	0	1
V_{dc}	1	1	0	0	1	1	0	0	0	1	0	1
0	0	1	0	1	0	1	0	1	0	1	0	0
$-\frac{2V_{dc}}{3}$	0	1	0	1	0	1	0	1	1	1	0	0
$-\frac{V_{dc}}{3}$	0	1	0	1	0	0	1	1	0	0	1	1
$-V_{dc}$	0	0	1	1	0	0	1	1	0	0	1	1

The three different voltage sources of the inverter are represented by $\frac{V_{dc}}{2}$. The voltage level of the 7-level inverter consists of seven output voltage levels those seven levels are denoted $\frac{V_{dc}}{3}, \frac{2V_{dc}}{3}, V_{dc}, 0, \frac{-V_{dc}}{3}, \frac{-2V_{dc}}{3}, -V_{dc}$and the switching sequence operation of 7-level inverter is given in Table 3.

The 9-level inverter is obtained by connecting four inverters in cascade. The overall voltage of the 9-level inverter is the sum of all the individual voltage levels. The output voltage value of the 9-level inverter is given by equation (3)

$$V = \frac{V_{dc}}{3} + \frac{V_{dc}}{3} + \frac{V_{dc}}{3} + \frac{V_{dc}}{3} \qquad (3)$$

When comparing the 3-level and 11-level inverters the THD is decreased, the harmonics also reduced and the pure sine wave is obtained. Five inverters are connected in cascade to obtain the 11-level inverter.

4. RESULTS AND DISCUSSION

The PV panel output voltage is shown in Figure 2(a). The output value of the PV panel voltage is 48V. This voltage is given as input to the converter.

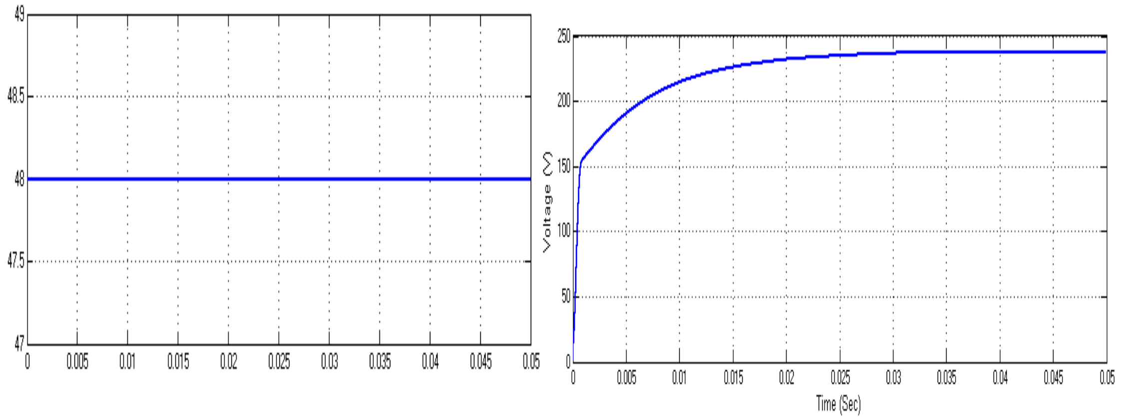

Figure 2(a). PV input voltage **Figure 2(b). Converter output voltage**

Figure 2. PV input voltage and converter output voltages

The converter output voltage with the coupled inductor is shown in Figure 3. The converter voltage value is 230V. Figure 3(a) shows the simulation waveform of the inductor primary voltage V_{N1}. The value of the primary voltage multiplier is 48V.

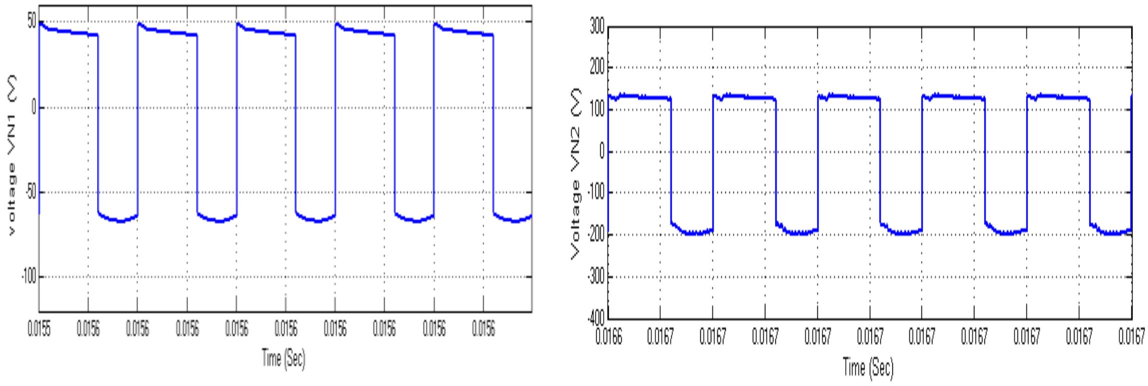

Figure 3(a). Primary voltage V_{N1}(V) **Figure 3(b). Secondary voltage V_{N2}(V)**

Figure 3. Voltage multiplier primary and secondary voltages V_{N1}(V) and V_{N2} (V)

The output waveform of the secondary side voltage multiplier is shown in Figure 4(b). The inductor voltage value is 144V.

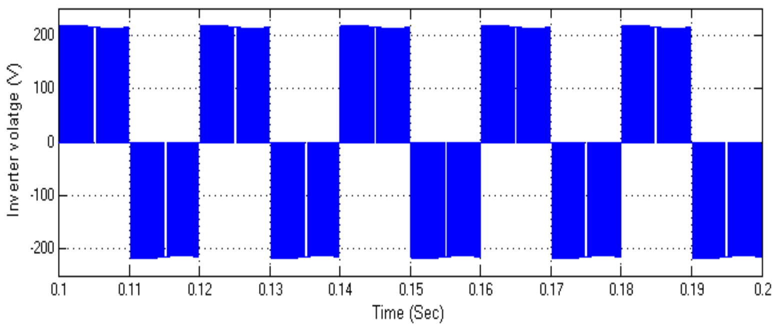

Figure 4(a). Output voltage

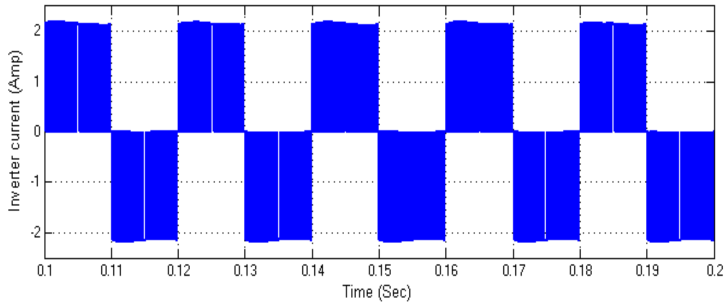

Figure 4(b). Output current

Figure 4. Output voltage and current values of the 3-level inverter

The output voltage waveform of the 3-level inverter is shown in Figure 4(a). The voltage value of the 3-level converter is 230V. The current waveform of the 3-level inverter is shown in Figure 4(b) and the IM speed, torque and current waveforms are shown in Figure 5. The THD plot of the 3-level inverter is shown in Figure 6. The output THD value for the 3-level inverter is 52.37%.

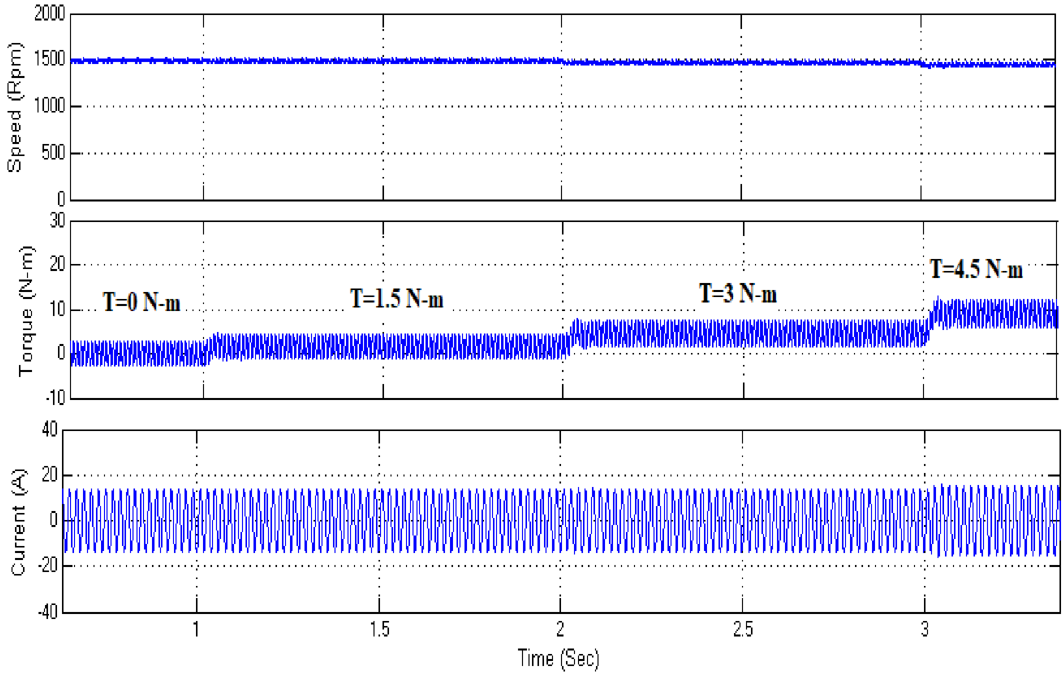

Figure 5. Output waveforms of speed, torque, and current.

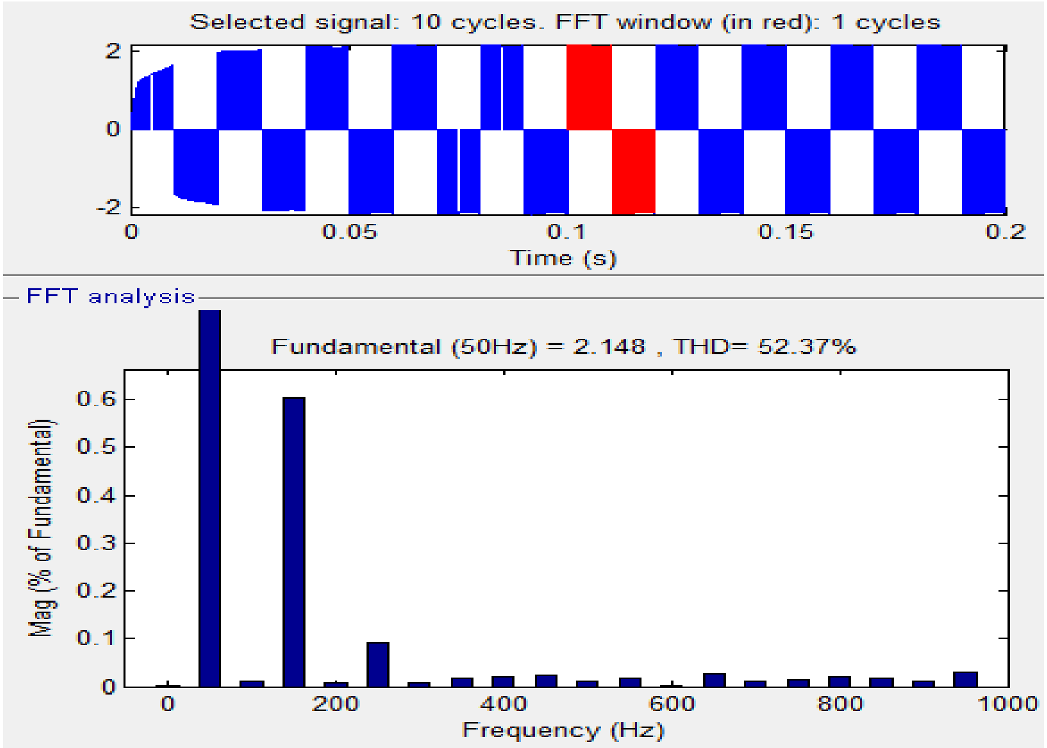

Figure 6. Three-level inverter THD

The output voltage and current waveforms of the 5-level inverter are shown in Figure 7. The output voltage value of the inverter is 230V.

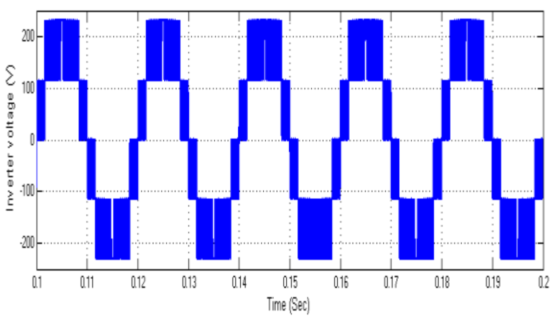

Figure 7(a). Output voltage.

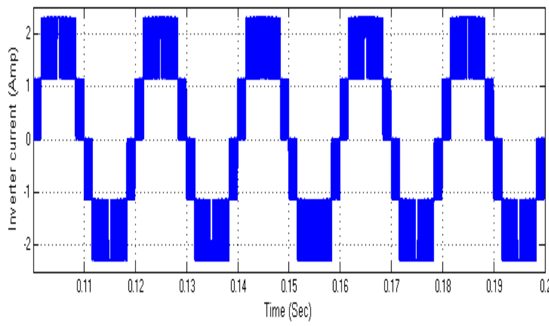

Figure 7(b). Output current

Figure 7. Output Voltage and current of the 5-level inverter

The IM speed, torque, and current waveforms are shown in Figure 8 for five-level inverter. The THD plot of the 5-level inverter is shown in Figure 9. The THD value of 5-level inverter is 26.4%. When compared to the 3-level inverter, %THD value reduces in 5-level inverter.

The voltage and current output waveforms of the 7-level inverter are shown in Figure 10. The voltage value of inverter is 230V.

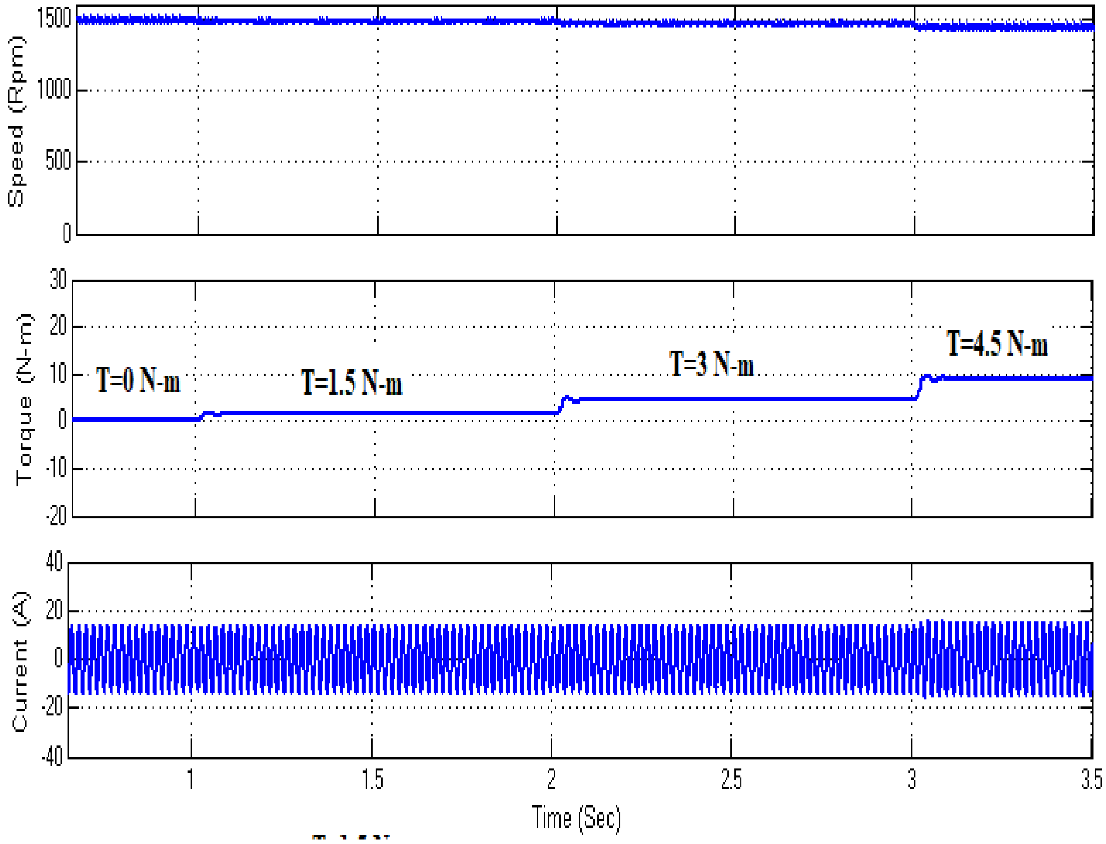

Figure 8. Output waveforms of speed, torque, and current.

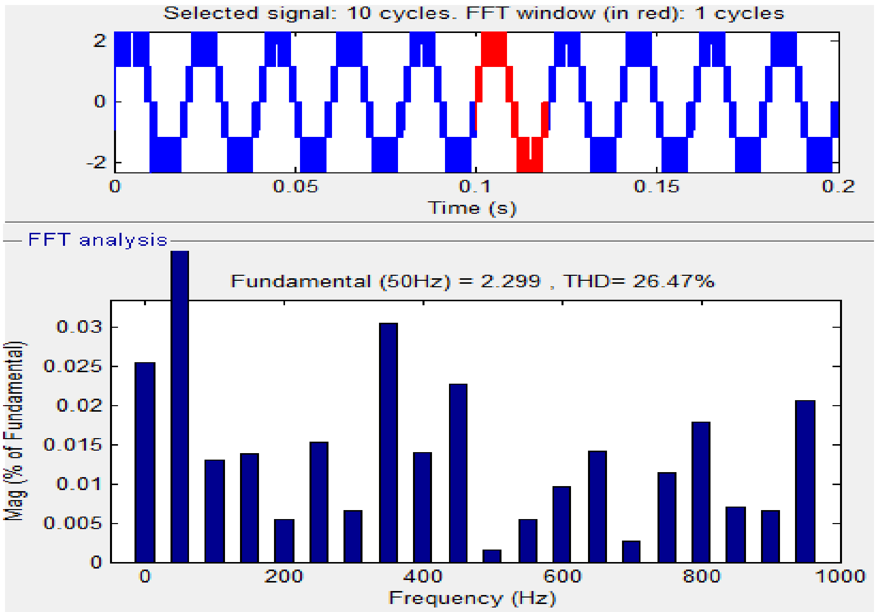

Figure 9. THD plot 5-level H inverter source current

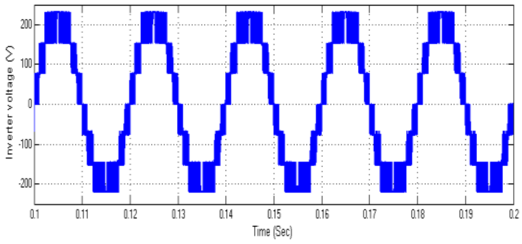

Figure 10(a). Output voltage

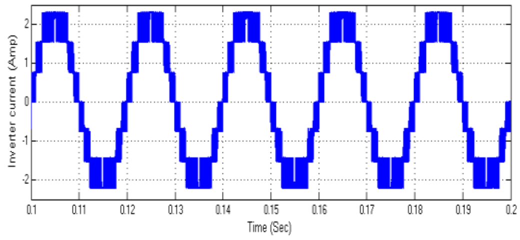

Figure 10(b). Output current

Figure 10. Seven-level inverter output voltage and current

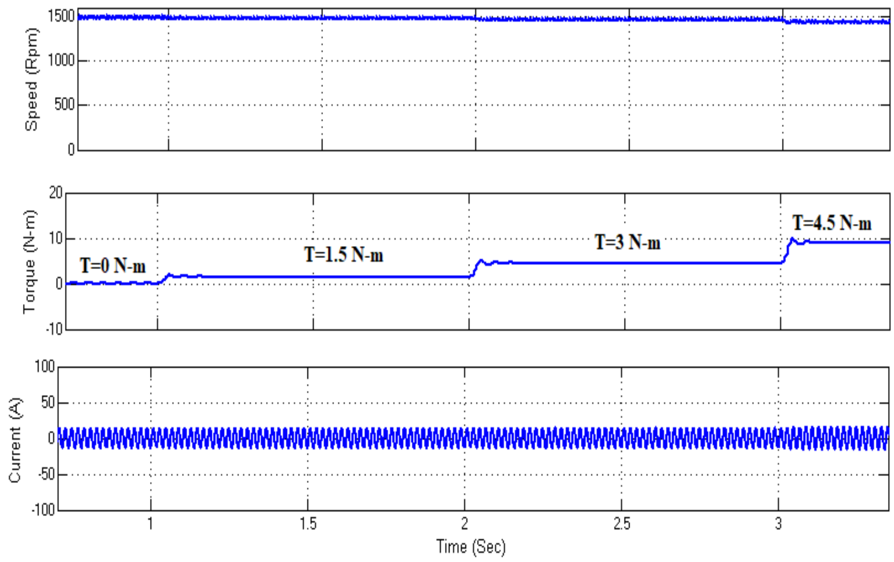

Figure 11. Output waveforms of speed, torque, and current.

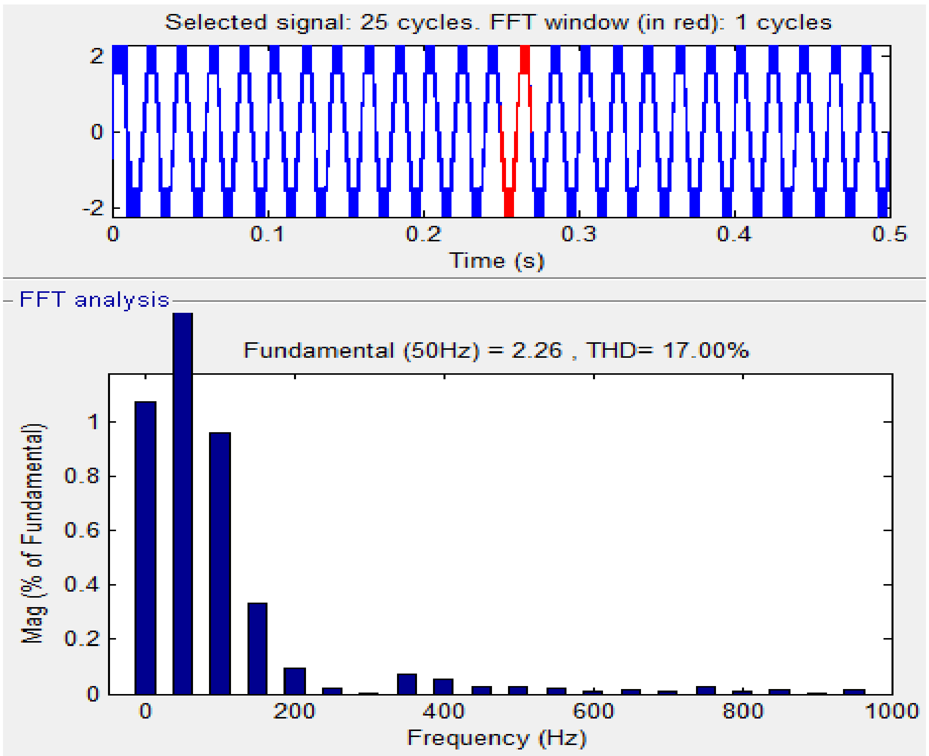

Figure 12. THD plot of 7-level H-bridge multilevel inverter

The waveforms of the IM speed, torque and current are shown in Figure 11 and the %THD plot for 7-level H-bridge multilevel inverter is shown in Figure 12. The THD value of the 7-level inverter is 16.99%. The 7-level H-bridge inverter %THD value is decreased when compared to the %THD value of 3-level, 5-level H-bridge inverters.

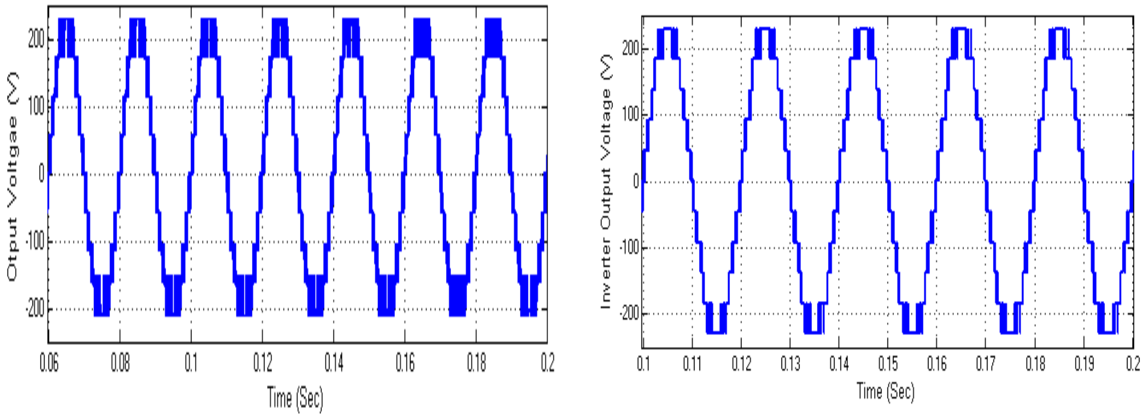

Figure 13(a). Output voltage **Figure 13(b). Output current**

Figure 13. Nine-level inverter output voltage and current

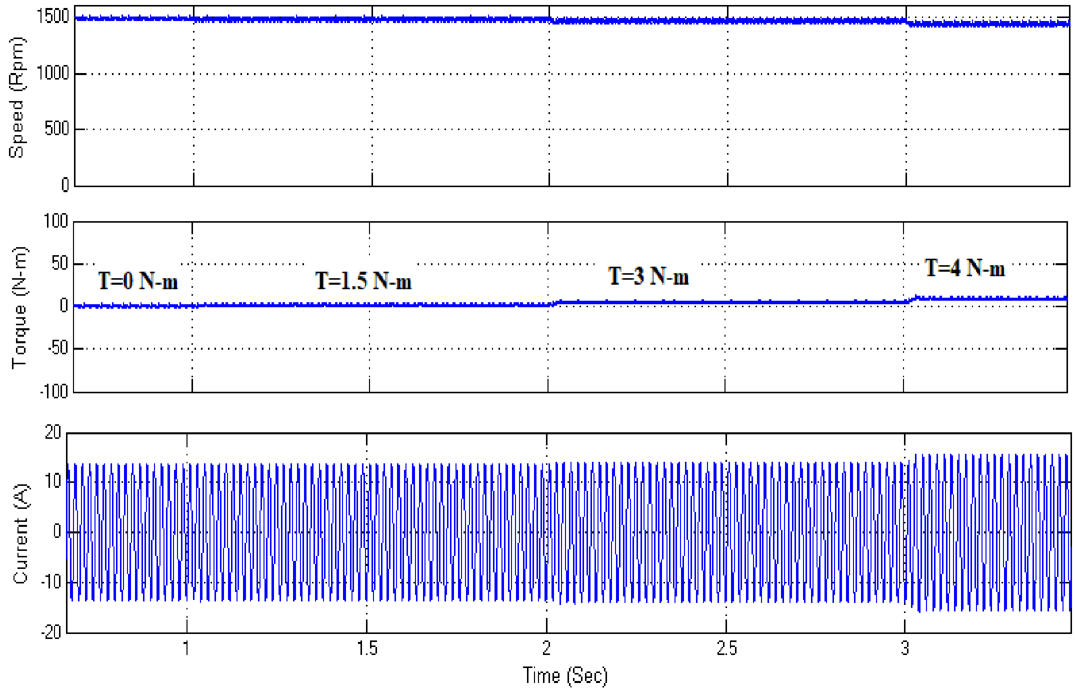

Figure 14. Output waveforms of speed, torque, and current at different loading conditions of 9-level inverter

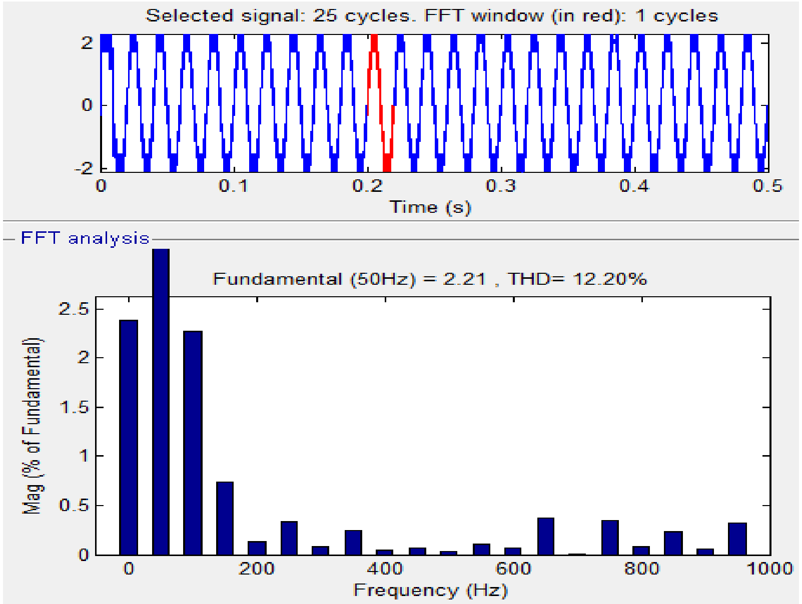

Figure 15. Source current THD plot for 9-level inverter

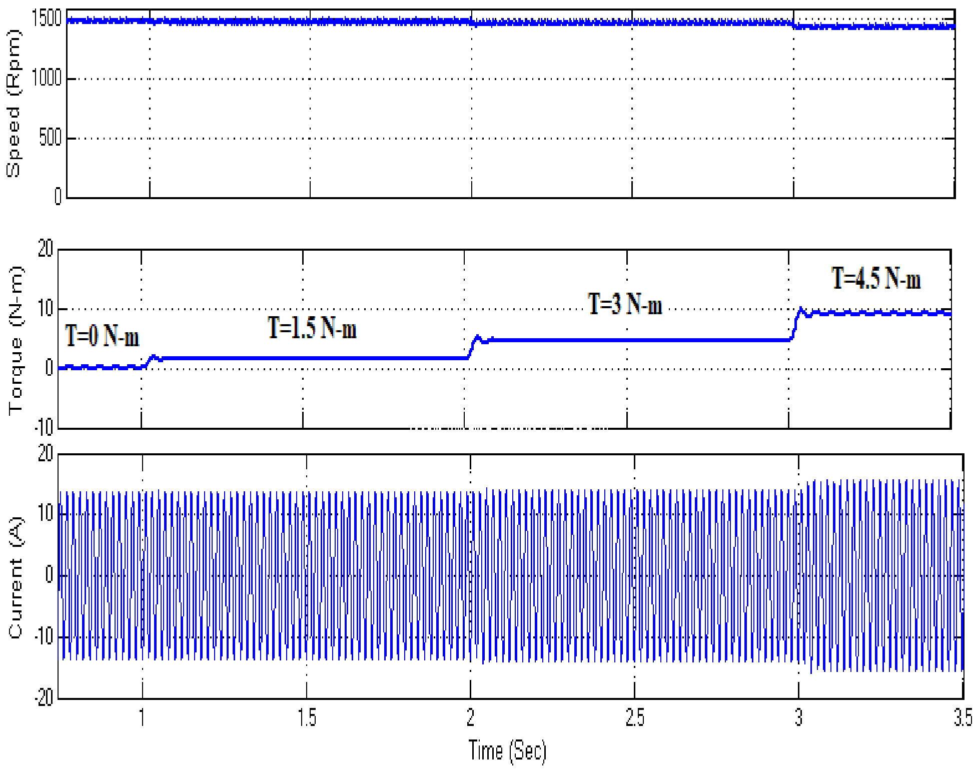

Figure 16. Output waveform for Speed, Torque and Current at different loading conditions 11-level inverter

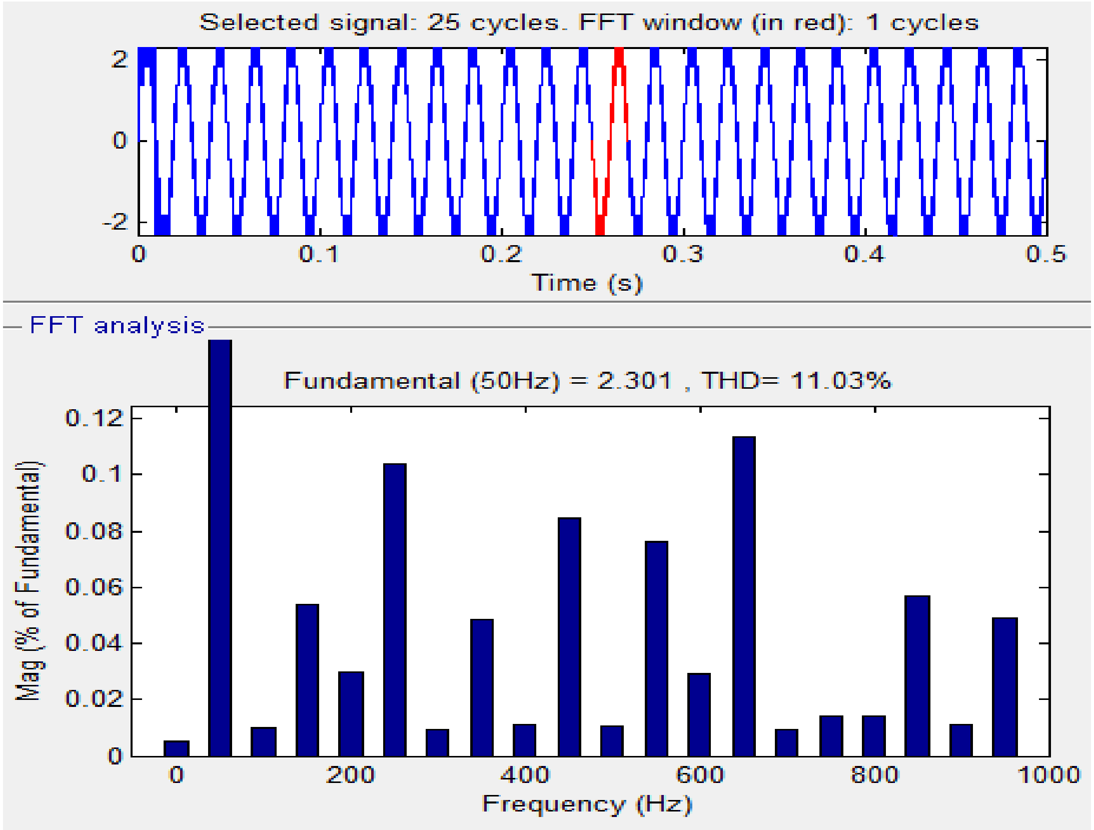

Figure 17. Eleven-level inverter source current THD plot

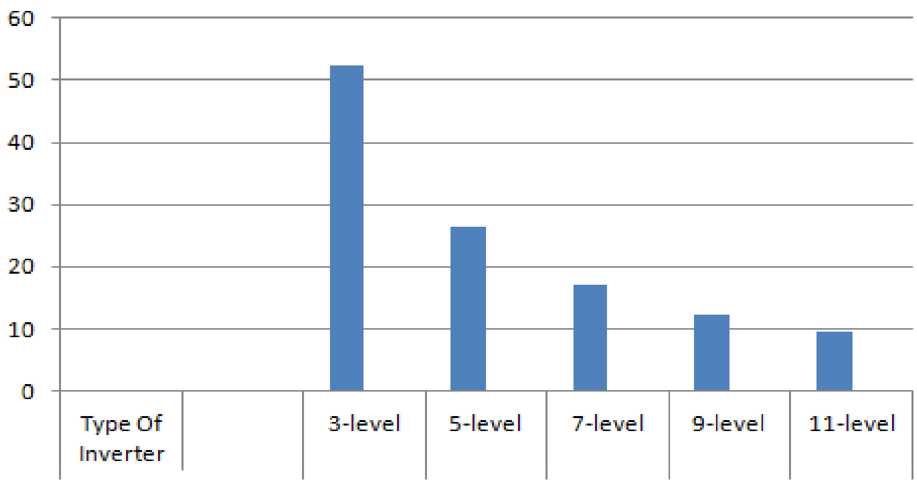

Figure 18. Graphical representation of source current THD at different levels

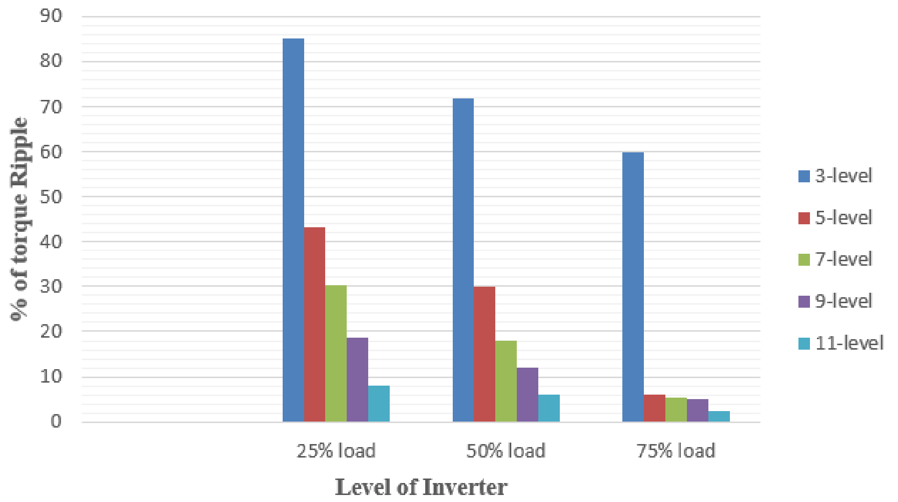

Figure 19. Graphical representation of %torque ripple at different loading condition with different levels

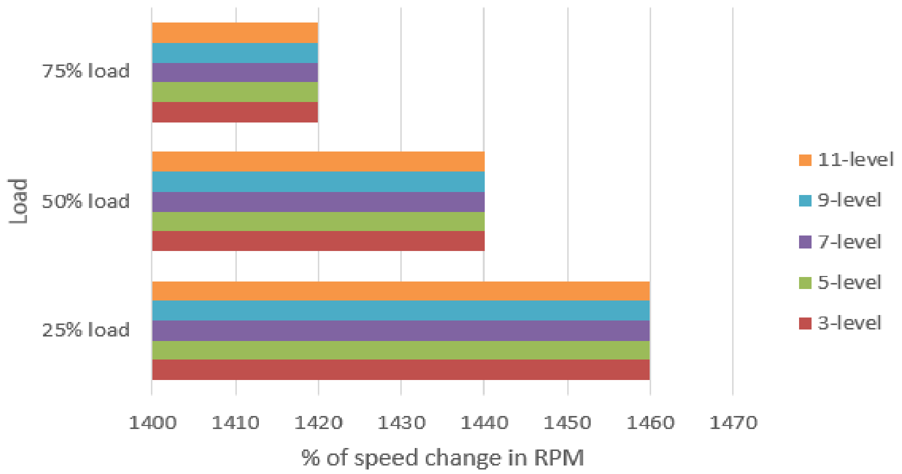

Figure 20. Representation of speed at different loading conditions with different multilevel inverters

Table 4. The %THD comparison of different multilevel inverters

S.No.	Type of inverter	%THD
1	3-level	52.37
2	5-level	26.47
3	7-level	16.99
4	9-level	12
5	11-level	11.9

Table 5. %THD comparison of different multilevel inverters (3, 5, 7, 9 and 11-level inverters) and torque ripples at different loading conditions

Type Of Inverter	% current THD	%Torque Ripple at Different Loading Conditions		
		25%	50%	75%
3-level	52.37	85%	72%	60%
5-level	26.47	43.3%	30%	6%
7-level	16.99	30.3%	18%	5.3%
9-level	12.15	18.7%	11.9%	4.9%
11-level	9.58	8%	6.2%	2.3%

Table 6. The %THD comparison of different multilevel inverters fed induction motor speed

Type Of Inverter	Speed Change at different Loading conditions			
	No Load	25%	50%	75%
3-level	1500	1460	1440	1420
5-level	1500	1460	1440	1420
7-level	1500	1460	1440	1420
9-level	1500	1460	1440	1420
11-level	1500	1460	1440	1420

5. CONCLUSION

The proposed converter is flexible to use as PV based step-up converter for multilevel inverter fed single phase IM drive applications. In this paper the simulation analysis of the proposed converter with different multilevel inverter topologies are discussed and the output waveforms are plotted. The Simulation analysis of PWM control based DC-DC converter integrated with 3, 5, 7, 9, and 11- level inverter's feeding a single-phase IM drive for water pumping applications is also presented. The THD analysis of the different multi-level inverter topologies are shown in simulation results and also shown that the THD is reduced even though the disturbances are increasing.

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