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Comparison of Various Conversion Topologies for Offshore Wind Power Systems Connected to the Grid

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Abstract
This paper serves various simulations and results for different multilevel converters (MLCs) using offshore wind power installations with High Voltage Direct Current (HVDC) transmission networks. By simulating different converters for different levels, we can conclude the best suitable converter and levels for various MLC configurations and different control strategies to improve efficiency, performance, and reliability by reducing harmonics in offshore wind power systems. By selecting different parameters and different levels of converters. We can select the best suitable converter for offshore wind power systems. In this paper we are simulating different converters like the Cascade H bridge converter and multi-modular converter (MMC) and the concept of Cascade H bridge converter and multi-modular converter is explained. This paper delivers a complete simulation and results with a clear idea to reduce the harmonics and to boost up the efficiency of the converter for offshore wind power systems.

Keywords: *Multi-level converter (MLCs), Offshore Wind power plant, Multi Modular Converter (MMC), HVDC (High Voltage Direct Current)*

1. Introduction
A multi-level inverter is a type of power inverter that generates an output voltage with a greater number of levels compared to the two-level inverter. It increases the number of levels which gives a more accurate input AC waveform, which reduces the level of harmonic distortion in the output voltage. Multilevel inverters are probably used in renewable energy systems, such as solar power systems, and wind power systems, as well as in industrial and commercial applications where we require high-quality power (Figure 1). Multi-level inverters are mainly divided into three types:

1. Cascade H-Bridge Multi-level Inverter
2. Flying Capacitor Multi-Level Inverter
3. Multi Modular Converter

The Cascade H-bridge multi-level inverter can manage high power and complexity is less and even can use for high-power applications. The Flying Capacitor Multi-Level Inverter has very complex startup and poor switching efficiency. Multi modular converter structure creates a high-quality waveform since we can use in high-voltage applications. Modular converter gives improved performance and efficient solutions in power conversions and efficiency will be more than the other converters. Using a two-level inverter, we produce AC power from DC voltage. A two-level inverter provides +V/2 and -V/2 on the output and introduces two distinct voltages for the load. These two freshly created voltages are often switched to create an AC voltage. [1-4]

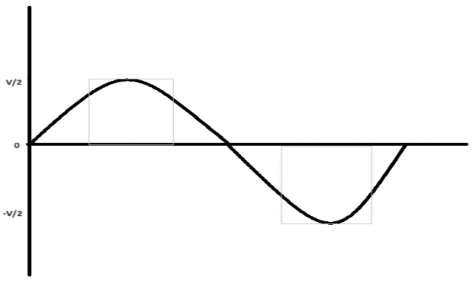

Figure 1 Two Level Voltages

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This type has some limitations as it causes disturbances in the output voltage (Figure 2). This type can be used but it creates some problems in some applications and we don't prefer distortion in the output voltage.

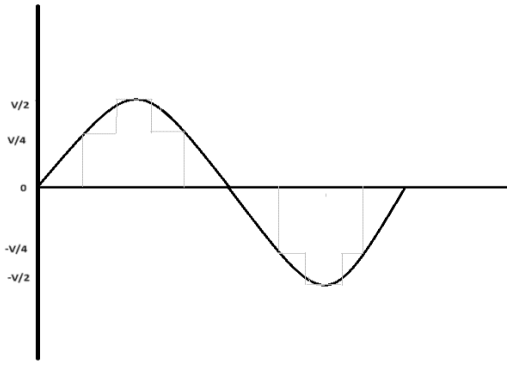

Figure 2 More than Two-Level Voltage

A two-level inverter is modified in a way by the multilevel inverter (MLI) idea. We produce a smoother stepped output waveform in the multilayer inverter. A combination of two or more voltage levels is used. The waveform gets smoother but gets more complex as the voltage levels rise. [6–10]

2. Multi Modular Converter

A multi-modular converter gives more efficient and flexible output and the conversion techniques are very flexible and it can be used in high power applications. The maintenance will be easy using individual modules and the working also reliable. Due to the multiple modules if one fails the rest modules operates without any delay it helps to easy scaling and maintenance (Figure 3 to 6). So that we can distribute the load evenly by reducing losses.

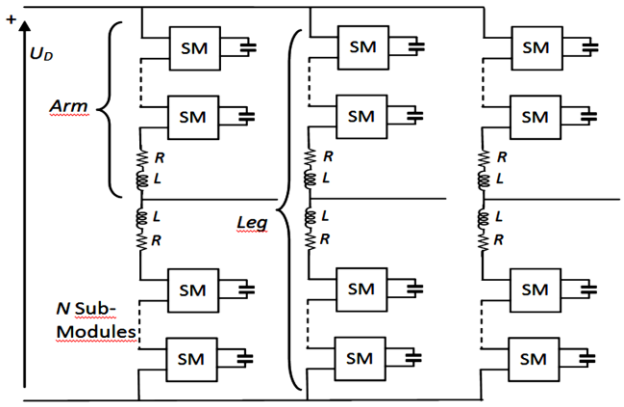

Figure 3 Three phase Multi Modular Converter

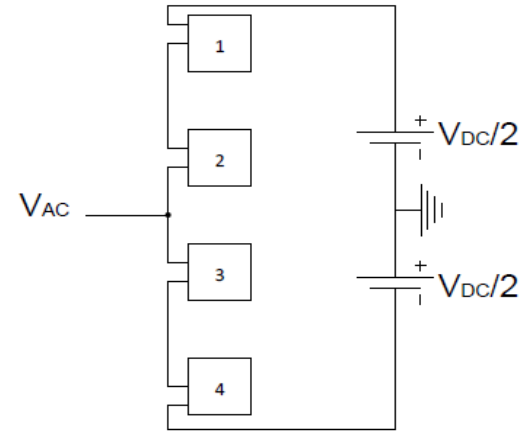

Figure 4 Schematic of One Phase of MMC

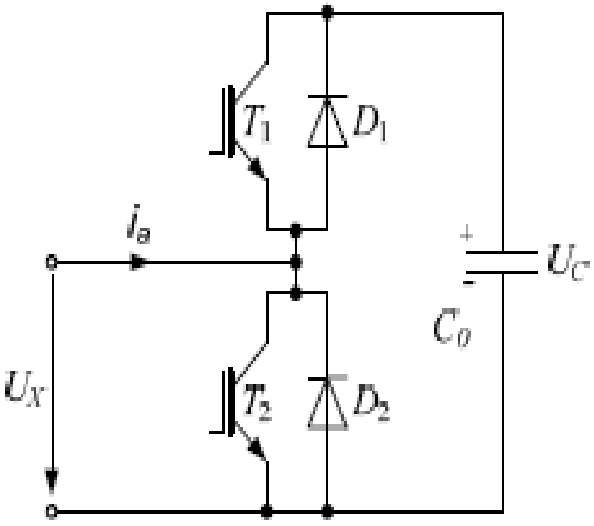

Figure 5 Schematic of Sub Module of MMC

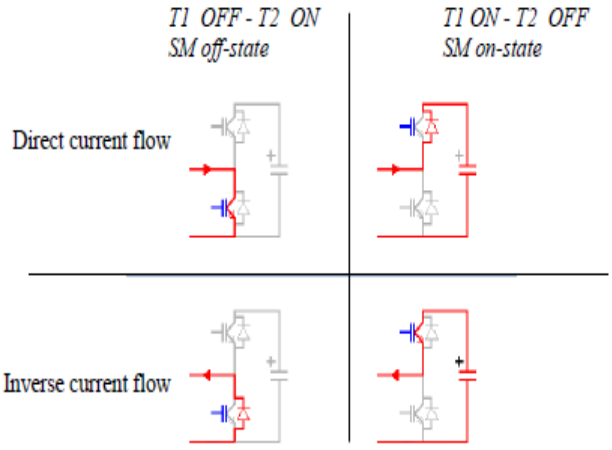

Figure 6 States of SM and Current Paths

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3. Simulation and Results

3.1. Two Level Inverter Without Filter

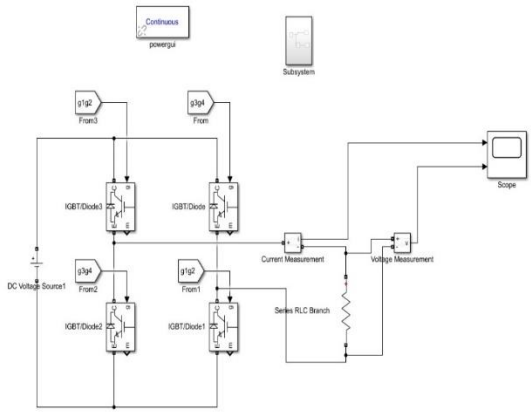

Figure 7 Two-Level Converter

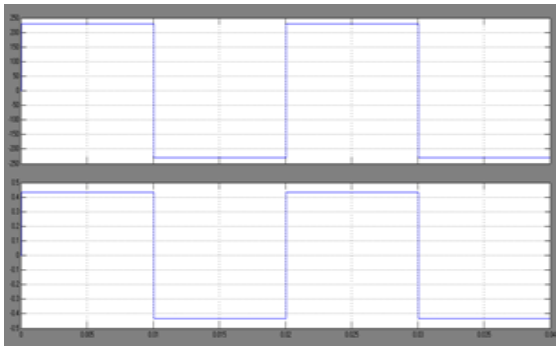

Figure 8 Two-Level Converter Output Voltage and Current

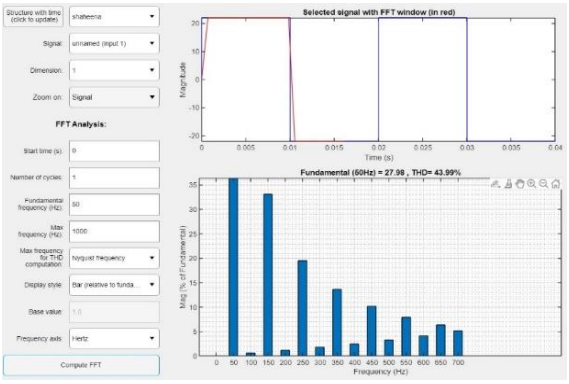

Figure 9 FFT Analysis

The output voltage of a two-level converter is a square wave that alternates between +Vdc and –Vdc (see Figure 7, 8). It can be seen from the FFT analysis (Figure 9) that the output voltage has a higher THD of 43.99% and more harmonics.

3.2. Two level inverter with filter

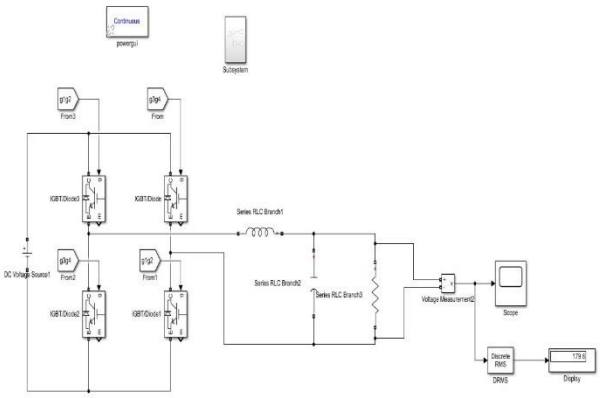

Figure 10 Two-Level Converter with Filter

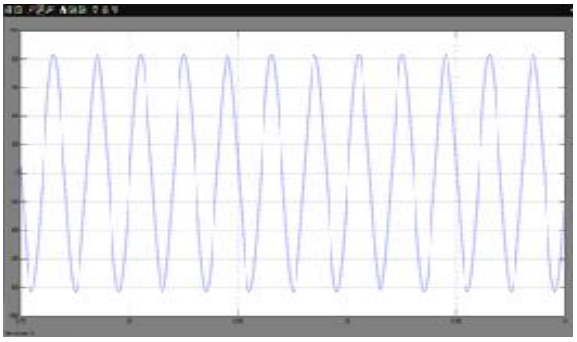

Figure 11 Output Voltage of Two-Level Converter with Filter

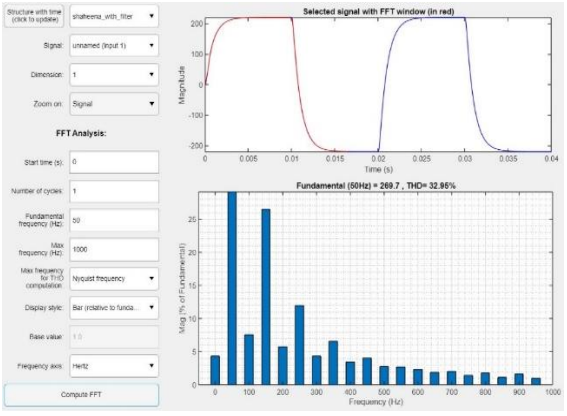

Figure 12 FFT Analysis

In the two-level converter (Refer Figure 10, 11) with filter the output voltage is square wave which switches between $+V_{dc}$ and $-V_{dc}$. From the FFT analysis (Figure 12) it is observed that the output voltage contains more harmonics and THD = 32.95%. [11-15]

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3.3. Cascaded 5 Level Inverter Without Filter

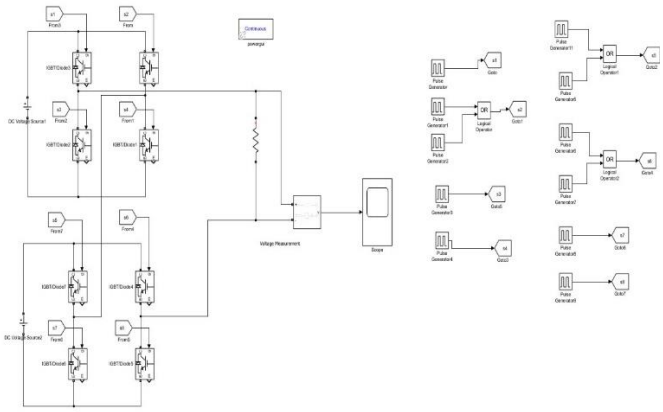

Figure 13 Five-level Cascaded Inverter without Filter

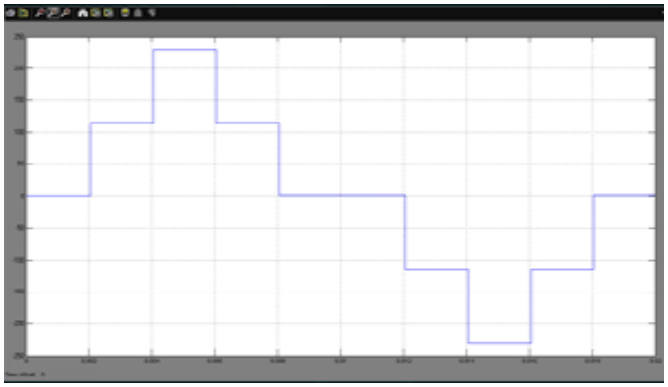

Figure 14 Output Voltage of Five-level Cascaded Inverter without Filter

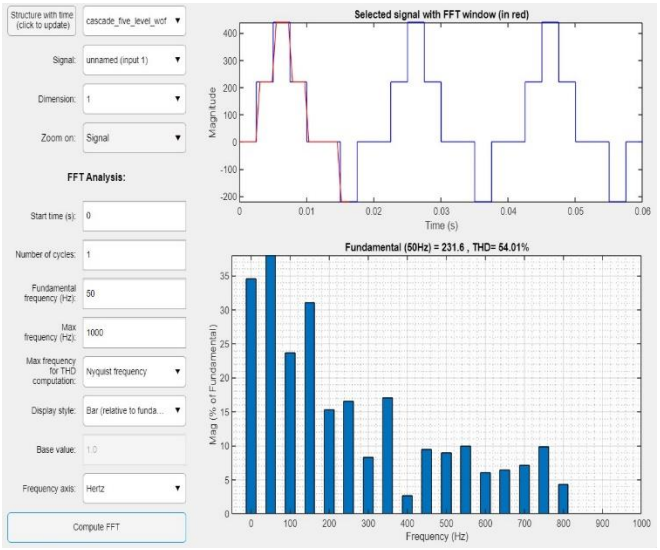

Figure 15 FFT Analysis of Five-level Cascaded Inverter without Filter

In five-level cascaded converter (Refer Figure 13, 14) the output voltage is step wave (+V, +2V, 0, -V, -2V). From the FFT analysis (Figure 15) it is noted that the output voltage contains lesser harmonics than the two-level converter and THD = 54.01%.

3.4. Cascaded 5 Level Inverter with Filter

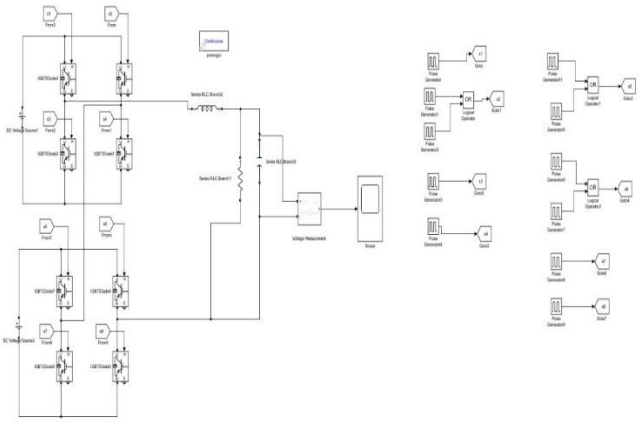

Figure 16 Five-level Cascaded Inverter with Filter

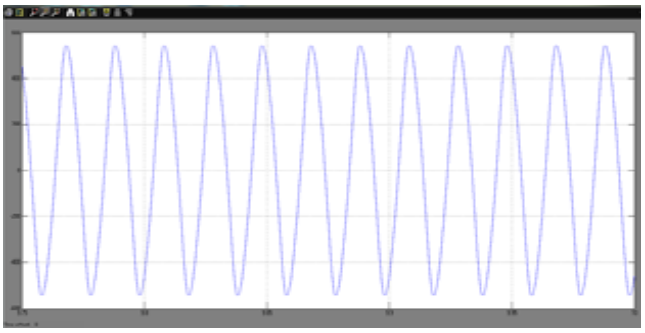

Figure 17 Output Voltage of Five-level Cascaded Inverter with Filter

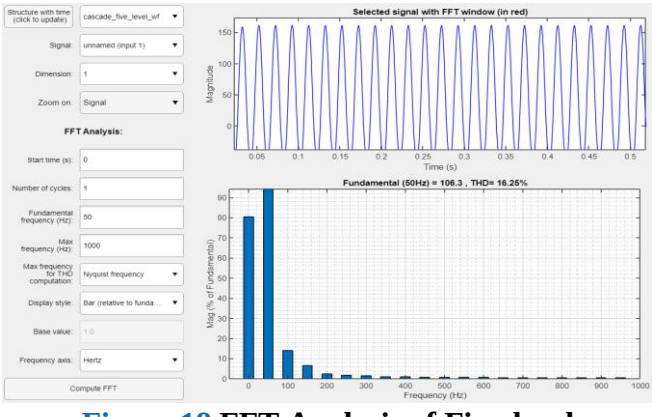

Figure 18 FFT Analysis of Five-level Cascaded Inverter with Filter

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The output voltage of the five-level cascaded converter with filter (see Figure 16, 17) is a step wave (+V, +2V, 0, -V, -2V). It can be shown from the FFT analysis (Figure 18) that the output voltage has a THD of 16.25% and fewer harmonics than a two-level converter.

3.5. Cascaded 7-Level Inverter Without Filter

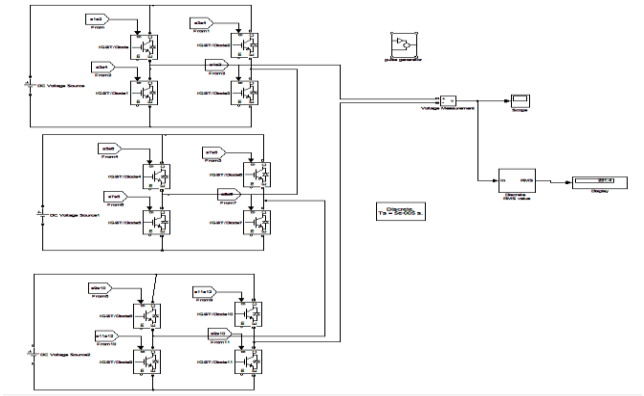

Figure 19 Seven-level Cascaded Inverter without Filter

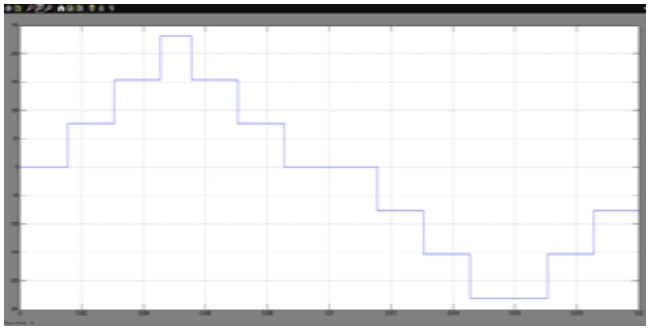

Figure 20 Output Voltage of Seven-level Cascaded Inverter without Filter

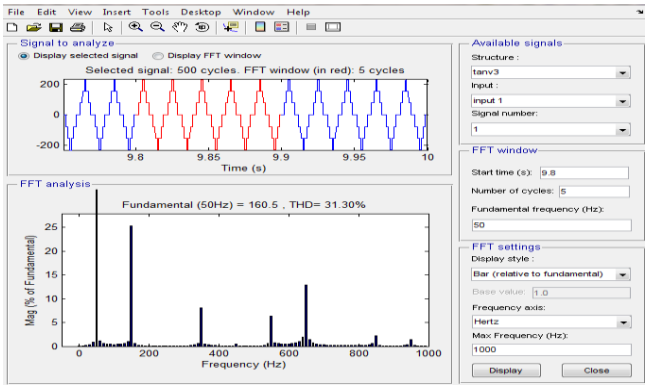

Figure 21 FFT Analysis of Seven-level Cascaded Inverter without Filter

Without a filter, the output voltage of a seven-level cascaded converter (see Figure 19, 20) is step wave (+V, +2V, +3V, 0, -V, -2V, -3V). The output voltage has fewer harmonics than the level-cascaded converter, according to the FFT analysis (Figure 21), and the THD is 31.30%. Because of this, it needs a smaller filter to remove both lower-order and higher-order harmonics than the five-level cascaded inverter. [16–20]

3.6. Cascaded 7-Level Inverter with Filter

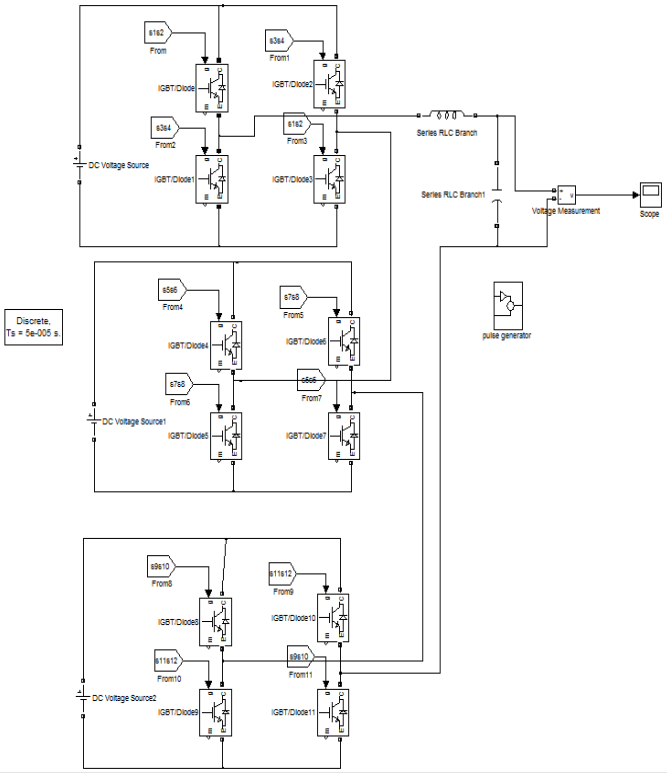

Figure 22 Seven-level Cascaded Inverter with Filter

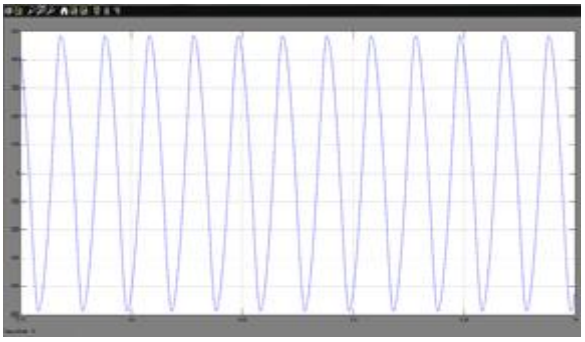

Figure 23 Output Voltage of Seven-level Cascaded Inverter with Filter

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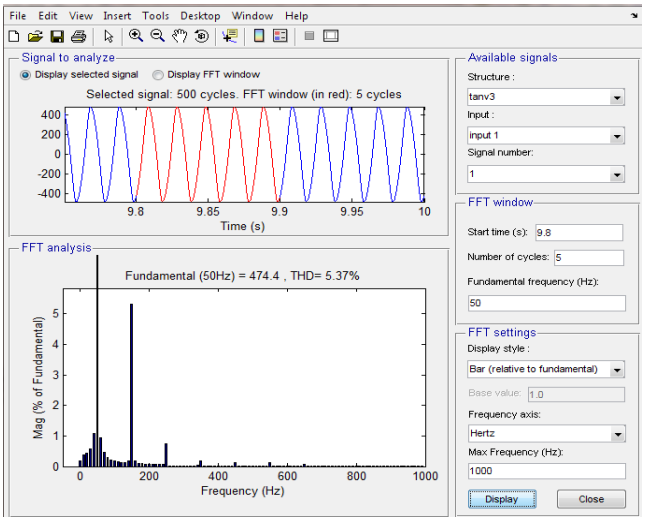

Figure 24 FFT Analysis of Seven-level Cascaded Inverter with Filter

The output voltage of a seven-level cascaded converter with a filter (see Figure 22, 23) is step wave (+V, +2V, +3V, 0, -V, -2V, -3V). The output voltage has fewer harmonics than the five-level cascaded converter, with THD = 5.37%, according to the FFT analysis (Figure 24). Therefore, to remove both lower-order and higher-order harmonics, a smaller filter is needed than a five-level cascaded inverter cascade. [21–25]

3.7. Five-level Multi Modular Inverter Without Filter

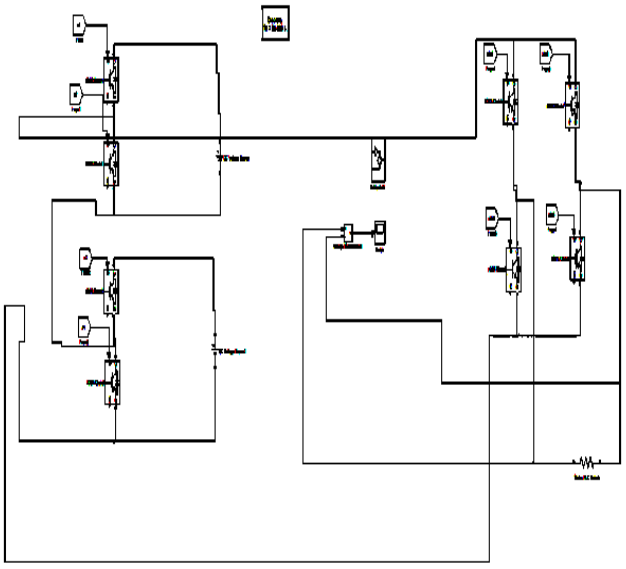

Figure 25 Five-level Multi Modular Inverter without Filter

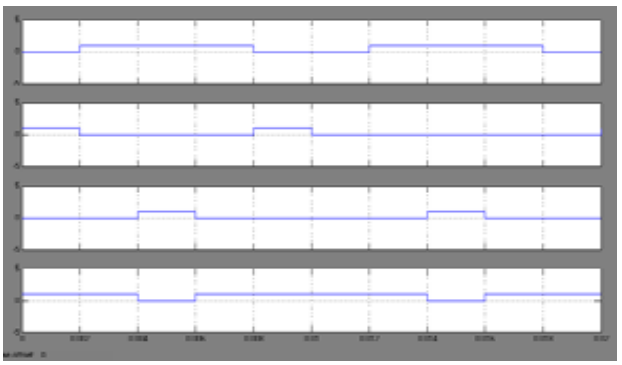

Figure 26 Pulses of Five-level Multi Modular Inverter without Filter

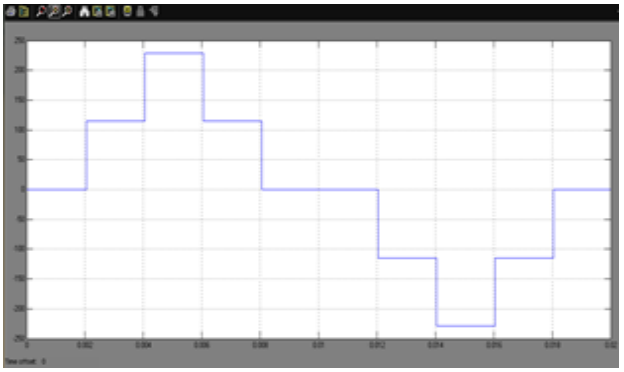

Figure 27 Output Voltage of Five-level Multi Modular Inverter without Filter

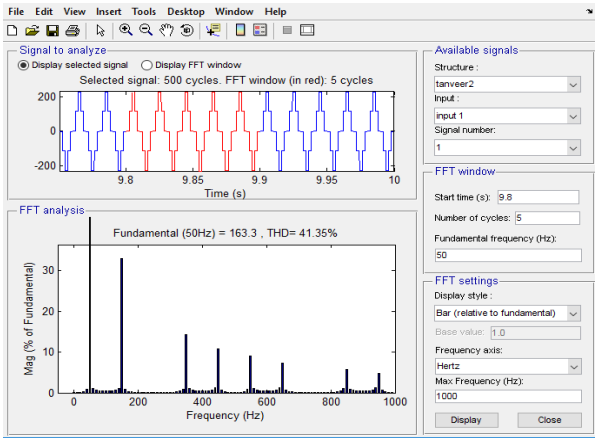

Figure 28 FFT Analysis of Five-level Multi Modular Inverter without Filter

In the five-level Multi Modular inverter (Refer Figure 25, 26, 27), the output voltage is step wave (+V, +2V, 0, -V, -2V). From the FFT analysis (Figure 28), it is observed that output voltage contains lesser harmonics than the two-level converter and THD = 41.35%. [26]

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3.8. Five-level Multi Modular Inverter with Filter

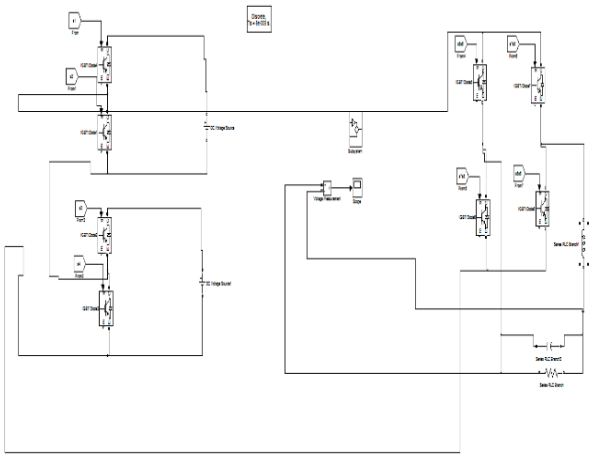

Figure 29 Five-level Multi Modular Inverter with Filter

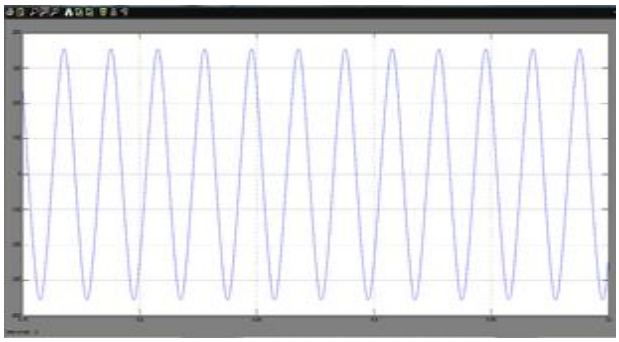

Figure 30 Output Voltage of Five-level Multi Modular Inverter with Filter

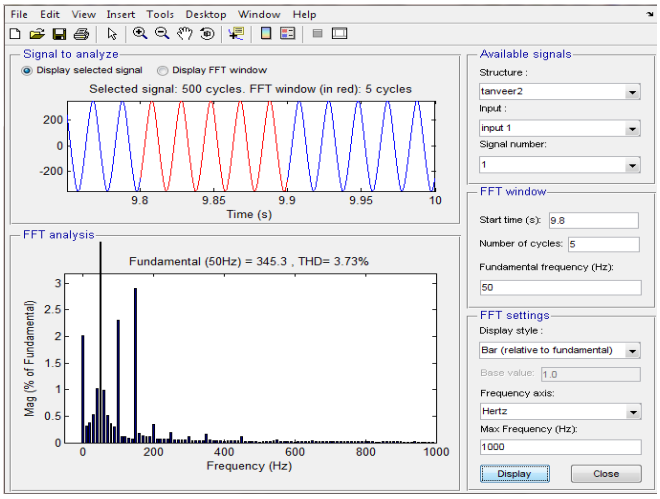

Figure 31 FFT Analysis of Five-level Multi Modular Inverter with Filter

In the five-level Multi Modular inverter (Refer to Figure 29, 30) with filter the output voltage is step wave (+V, +2V, 0, -V, -2V). From the FFT analysis (Figure 31) it is observed that output voltage contains lesser harmonics than the level converter and THD = 3.73%. Hence it requires a lesser size filter to eliminate lower-order and higher-order harmonics compared with the two-level inverter.

3.9. Seven-level Multi Modular Inverter Without Filter

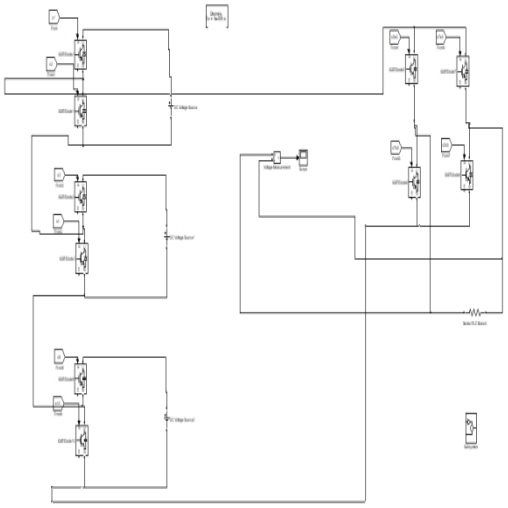

Figure 32 Seven-level Multi Modular Inverter without Filter

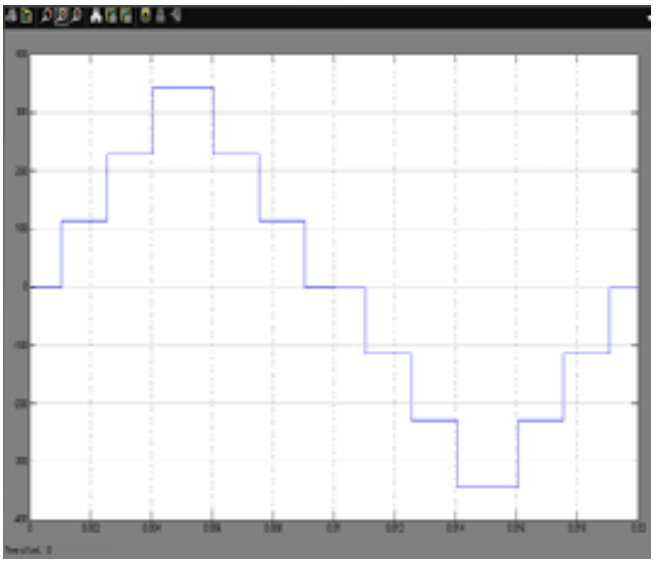

Figure 33 Output Voltage of Seven-level Multi Modular Inverter without Filter

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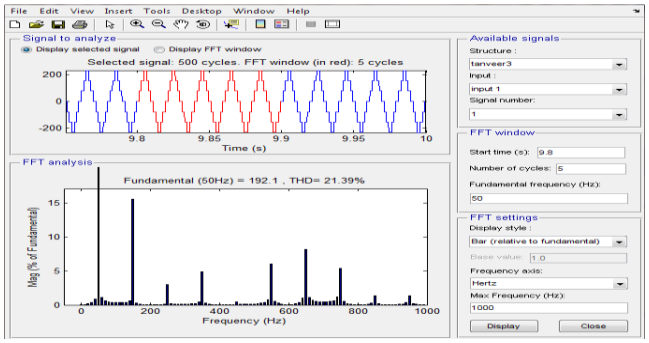

Figure 34 FFT Analysis of Seven-level Multi Modular Inverter without Filter

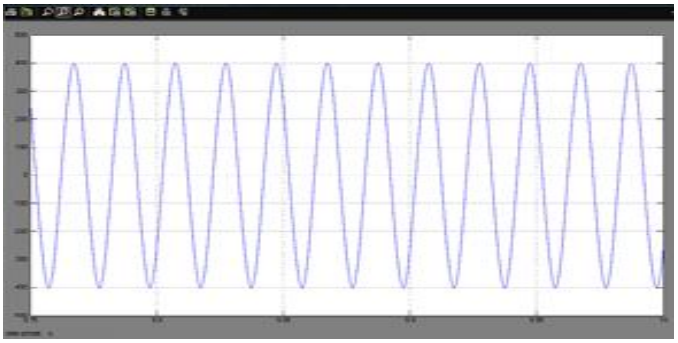

Figure 36 Output Voltage of Seven-level Multi Modular Inverter with Filter

In the Seven-level Multi Modular inverter (Refer to Figure 32, 33) converter the output voltage is step wave (+V, +2V, +3V, 0, -V, -2V, -3V). From the FFT (Figure 34) analysis it is noted that the output voltage includes lesser harmonics and THD = 21.39% than a five-level cascaded converter.

In the Seven-level Multi Modular inverter (Refer to Figure 35, 36) the output voltage is step wave (+V, +2V, +3V, 0, -V, -2V, -3V). From the FFT (Figure 37) analysis it is noted that the output voltage contains lesser harmonics and THD = 1.70% than a five-level cascaded converter.

3.10. Seven-level Multi Modular Inverter with Filter

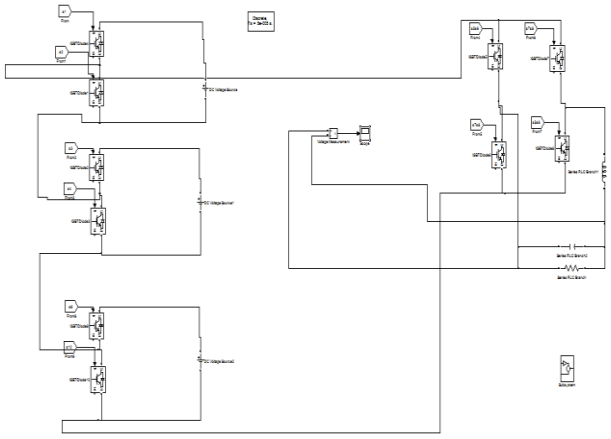

Figure 35 Seven-level Multi Modular Inverter with Filter

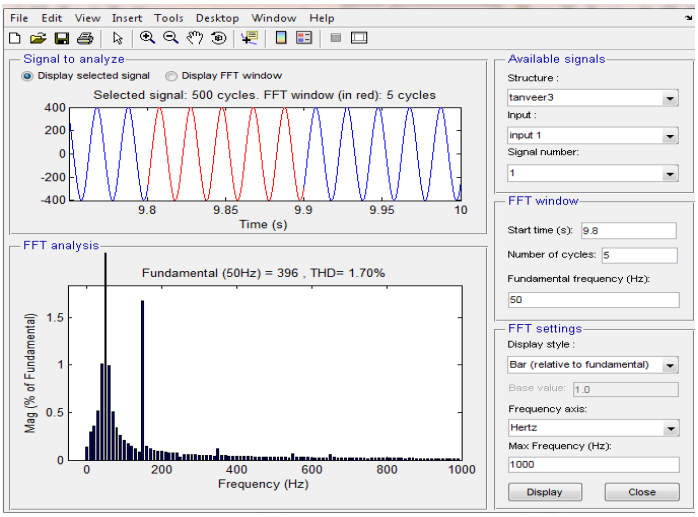

Figure 37 FFT Analysis of Seven-level Multi Modular Inverter with Filter

4. Comparison Of Converters

Table 1 Comparison of Converters without Filter

SI NO	Two level inverters	Five-level Cascaded inverter	Seven-level Cascaded inverter	Five-level Multi Modular inverter	Seven-level Multi Modular inverter
1	Vs=230V	VS=230V	VS=230V	VS=230V	VS=230V
2	V01=292.8	V01=163.9	V01=160.5	V01=163.3	V01=192.1
3	THD=43.99%	THD=54.01%	THD=31.30%	THD=41.35%	THD=21.39%

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Table 2 Comparison of Converters with Filter

SI NO	Two Level Inverters	Five-level Cascaded inverter	Seven-level Cascaded inverter	Five-level Multi Modular inverter	Seven-level Multi Modular inverter
1	Vs=230V	VS=230V	VS=230V	VS=230V	VS=230V
2	V01=812.6	V01=529.3	V01=474.4	V01=345.3	V01=396
3	THD=32.95%	THD=16.25%	THD=5.73%	THD=3.75%	THD=1.70%

Conclusion

In this paper comparison of cascaded and proposed new multi modular converter. Table 1 & 2 gives the comparison between converters without and with filter. From the above comparison we can conclude that seven-level modular multilevel inverter has control over the output voltage with lesser harmonics (within 5% which is acceptable according to IEEE standards) with lesser filter size and without PWM technique. Hence proposed modular multilevel inverter is preferred for weak AC system to improve power quality.

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