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Analysis And Comparison Of Flying Capacitor And Modular Multilevel Converters Using SPWM

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Abstract: ***Multilevel inverters are considered as one of the best solutions for high power and medium voltage applications due to their reduced THD, dv/dt stresses, lower switching frequency, reduced EMI and EMC issues etc. This paper presents the analysis and comparison of three level Flying Capacitor (FC) or Capacitor Clamped multilevel inverter and Modular Multilevel Converter (MMCs) topologies. For the topologies mentioned above the simulations were carried out for resistive load. The PWM used here is Sinusoidal Pulse Width Modulation (SPWM) and the multicarrier modulation used here is Phase shifted PWM. By comparing the THDs the advantages of Modular Multilevel Converter over the conventional Multilevel inverter is confirmed. The simulations are performed using MATLAB/SIMULINK software and the results are presented.***

Keywords: Multilevel inverters(MLI), SPWM, Flying Capacitor(FC), THD, Modular Multilevel Converter (MMC).

I. INTRODUCTION

Inverter is a device which converts DC power to AC power at desired voltage and frequency level. They are mainly classified into (a) Voltage source and (b) Current source inverters. The voltage source inverters are again classified into

- ✓ Single level inverters
- ✓ Multilevel inverters

On the basis of single and multiple DC sources the multilevel inverters are broadly classified into[1]-[2]:

- ✓ Diode clamped or Neutral clamped
- ✓ Flying capacitor or Capacitor clamped
- ✓ Cascaded multilevel inverters.

Multilevel inverters consist of an array of power semiconductor devices and capacitor voltage sources and the output of which generates voltages with stepped waveforms. The function of multilevel inverters is to synthesize desired voltages from several levels of DC voltages [3]. The multilevel inverters draw input with low distortion. They can operate with lower switching frequency with lesser harmonics and reduced dv/dt stresses. In the multilevel inverters a sine wave can be approximated to a stepped waveform having larger number of steps. As the number of levels increases the output waveform has more number of steps so the harmonic distortion reduces. They can operate at both fundamental and high switching frequency PWM. The various applications of multilevel inverters are in industrial medium voltage motor drives, traction drive systems, FACTS, utility interface for renewable energy systems etc. The main drawback of the flying capacitor multilevel inverter is that the output voltage is reduced to half of the input DC voltage. And also it requires more capacitance than the equivalent diode clamped multilevel inverter.

Now a day's Modular Multilevel Converter become an alternative to the conventional multilevel inverters in medium and high voltage applications. It is a combination of the cascaded and flying capacitor multilevel inverters. It consists of series connected half bridges with dc capacitors called sub modules. Each phase leg consists of one upper arm and lower arm connected between the dc terminal. The various advantages of Modular Multilevel Converters over the conventional multilevel inverters are:

- ✓ Modular construction
- ✓ It can be extendable to any number of levels and capacitor voltage balance is attainable.
- ✓ As the number of levels increases output filters and interface transformers can be eliminated. Therefore reduction in cost.

The multicarrier PWM technique used in the Flying capacitor and Modular Multilevel Converter mentioned here is the Phase Shifted PWM. In this technique for an m level inverter (m-1) carriers are required.The phase shift may vary according to the level of the inverter.Figure 1 shows the phase shifted PWM for single phase three level

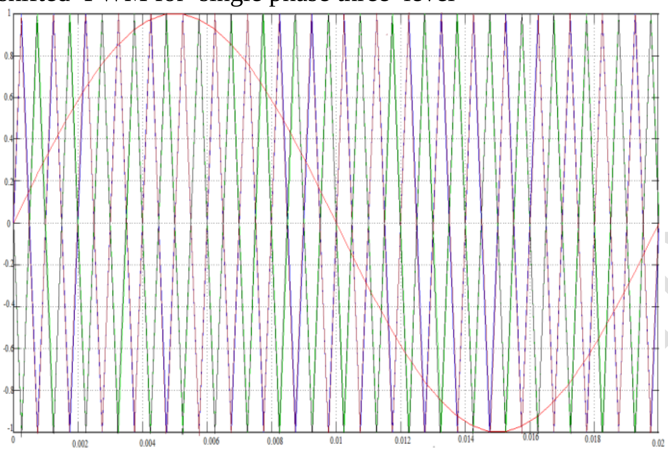

Figure 1: Phase shifted PWM for three level inverter

inverter.Let ϕ_s be the phase shift and is given by:

$$\phi s = \frac{360}{m-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where m is the number of levels.Since the topologies mentioned here are for three level therefore the phase hift between the two carriers are 180^0 apart.

II. REVIEW OF FLYING CAPACITOR AND MODULAR MULTILEVEL CONVERTER

A. FLYING CAPACITOR MULTILEVEL INVERTER

The topology of three phase three level flying capacitor multilevel inverter is shown in figure 1[10].It is also called as Capacitor Clamped or Imprecated cell inverter. It is similar to that of diode clamped multilevel inverter. The only difference is that here the clamping diodes are replaced by flying capacitors. The flying capacitor is also called as imprecated cell inverter. The flying capacitor is so called because the capacitors float with respect to earth's potential. In flying capacitor multilevel inverters the switching combination or states which produce the same phase voltage level will be referred to as a redundant switching state. This topology consists of twelve switches. Each leg consists of four switches that is (m-1) switches where m is the number of levels. Considering A phase the switches Sa_1 and Sa_4 are complementary, and the other complementary pairs are Sa_2 and Sa_3For m levels 2(m-1) switches (m-1) dc bus capacitance and (m-1)(m-2)/2 balancing capacitors per phase are required. Considering A phase for obtaining a positive voltage switches Sa_1 and Sa_2 are ON and for negative voltages switches Sa_3 and Sa_4 are ON.As compared to the Diode clamped multilevel inverter here an extra switching state is possible, that is the zero level can be obtained in two ways. Either switches Sa_1 and Sa_3 are operated or switches Sa_2 and Sa_4 are operated.

The PWM used here is Sinusoidal PWM. Let Va, Vb and Vc be the three phase reference voltages which are displaced at 120^0 apart.

$$V_a = V_m \sin(\omega t) \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$V_b = V_m \sin(\omega t - \tfrac{2\pi}{3}) \ldots\ldots\ldots\ldots(3)$$

$$V_b = V_m \sin(\omega t + \tfrac{2\pi}{3}) \ldots\ldots\ldots\ldots(4)$$

The frequency of carrier is 10 kHz. The carriers for the first and second switches, second and fourth switches are 180^0 out of phase. Figure 2 shows the three level flying capacitor multilevel inverter. The switching pulses are in such a way that the complementary pairs are switches (Sa_1,Sa_4) and (Sa_2,Sa_3).

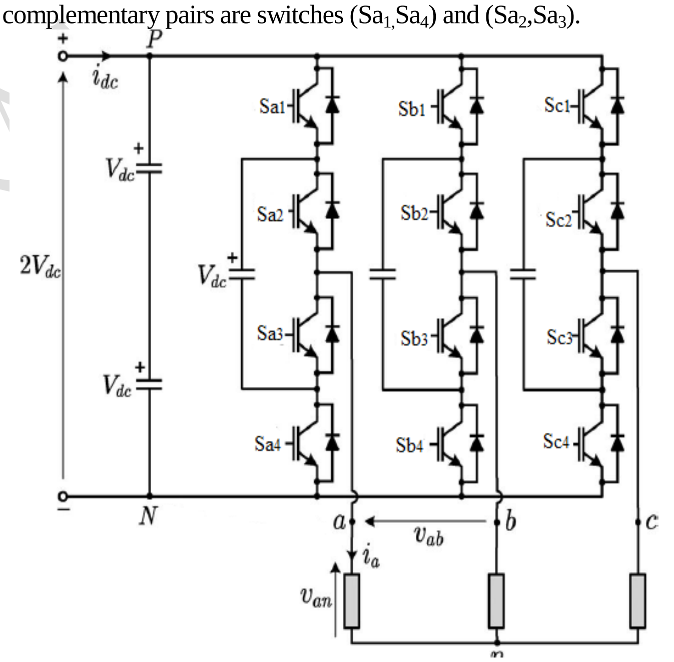

Figure 2: Three level Flying capacitor multilevel inverter

The advantages of Flying Capacitor multilevel inverters are:

- ✓ For a high m level the use of filters is unnecessary.
- ✓ Use of active and reactive power flow is possible.
- ✓ It eliminates the clamping diode problems present in the diode clamped multilevel topologies
- ✓ It limits the dv/dt stresses across the devices.

B. MODULAR MULTILEVEL CONVERTER

Figure 3 shows the schematic of a three phase modular multilevel converter[9]. It consists of a number of series connected half bridges with dc capacitors called sub modules. Each phase leg consists of two arms, one upper

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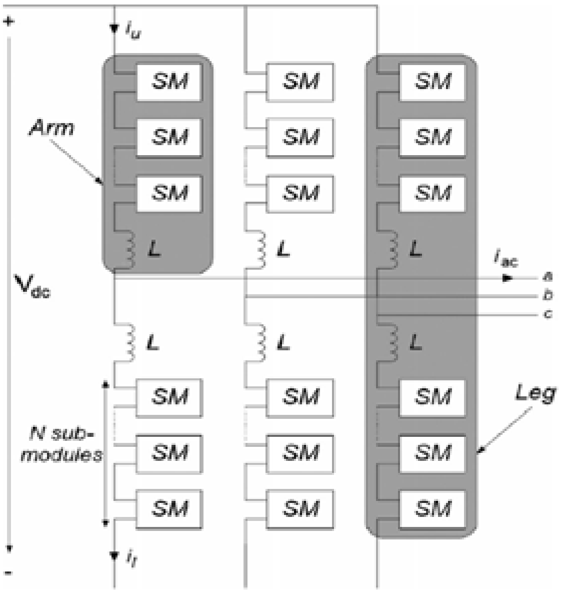

Figure 3: Three phase modular multilevel converter

and one lower arm. Each arm consists of N number of sub modules. Each sub module is a simple chopper cell consists of two complementary switches that is one main switch and an auxiliary switch. Figure 4 shows the schematic of one phase of three level modular multilevel converter. Each phase consists of four main and four auxiliary switches. Here Sa_1,Sa_2,Sa_3,Sa_4 are the main and Sx_1,Sx_2,Sx_3,Sx_4 are the auxiliary switches respectively. Considering A phase the complementary pairs are(Sa_1,Sx_1),(Sa_2,Sx_2),(Sa_3,Sx_3) and (Sa_4,Sx_4).Each instant four switches will be conducting, two from the main and two from the auxiliary.

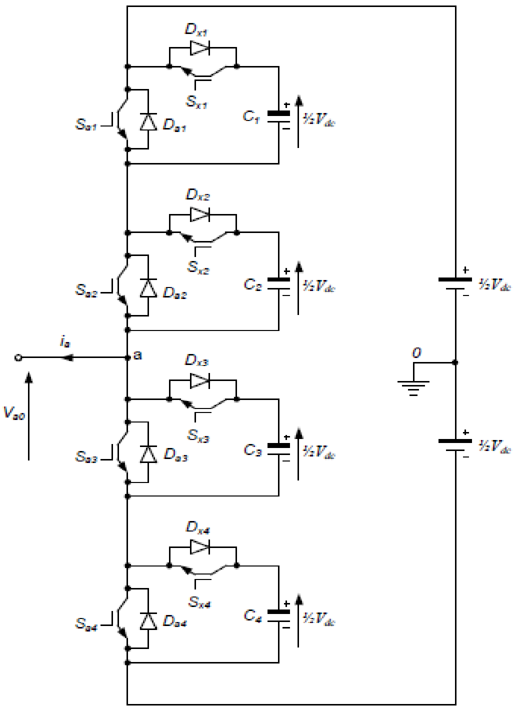

Figure 4: One phase of three level modular multilevel converter

For obtaining positive voltage the upper switches Sa_1, Sa_2 and the lower auxiliary switches Sx_3 and Sx_4 are conducting. For negative voltages the switches Sa_3, Sa_4 and the auxiliary switches Sx_1 and Sx_2 are conducting. The zero level can be obtained in four ways:

(a)Turn ON switches Sa_1,Sa_3, Sx_2 and Sx_4
(b)Turn ON switches Sa_2,Sa_3, Sx_1 and Sx_4
(c)Turn ON switches Sa_2,Sa_4, Sx_1 and Sx_3
(d)Turn ON switches Sa_1,Sa_4, Sx_2 and Sx_3

The PWM used here is Sinusoidal PWM. For this three sine waves which are displaced at 120^0 apart having amplitude of 1V and frequency 50 Hz is compared with two carriers which are displaced at 180^0 apart and having an amplitude of 1V and frequency 10 kHz per phase are fed to the comparator and the corresponding pulses are fed to the switches. Considering A phase the sine reference and first carrier are compared and the pulses are fed to switches Sa_1 and Sx_4 and the complementary pulses are fed to Sa_4 and Sx_1.Then the second carrier which are displaced at 180^0 apart with the first carrier and the sine reference are compared and the pulses are fed to switches Sa_2 and Sx_3 and the complementary pulses are fed to switches Sa_3 and Sx_2.

III. RESULTS AND DISCUSSION

The comparison of three level flying capacitor and modular multilevel converters for resistive loads are conducted using MATLAB/SIMULINK. Here the sinusoidal pulse width modulation (SPWM) with switching frequency of 10 KHz is used as the basic modulation for both the converters. The input to both the converters are 800V.

A. FLYING CAPACITOR MULTILEVEL INVERTER

Figure 5 shows the simulation circuit of flying capacitor multilevel inverter for resistive load. Figure 6 shows the

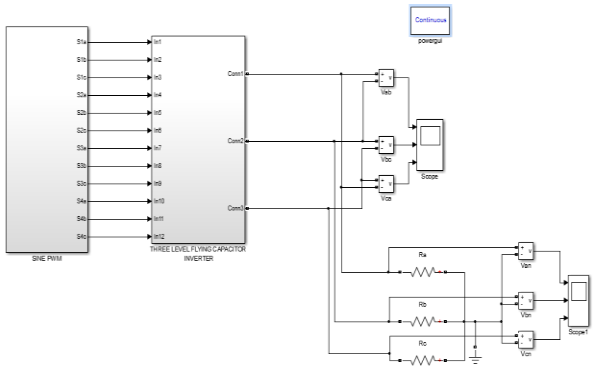

Figure 5: Simulation circuit of flying capacitor multilevel inverter

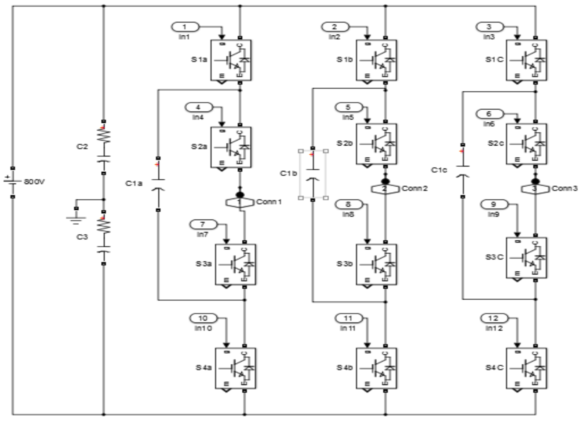

Figure 6: Simulink model of three level flying capacitor multilevel inverter

simulink model of three level flying capacitor multilevel inverter. Figure 7 shows the Sinusoidal PWM.

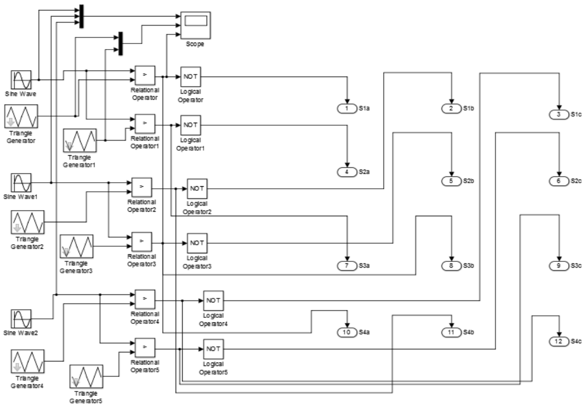

Figure 7: Sinusoidal PWM

Figure 8 shows the A phase switching pulses and PWM input. Figure 9 shows the line voltage and Figure 10 shows the phase voltage of flying capacitor multilevel inverter.

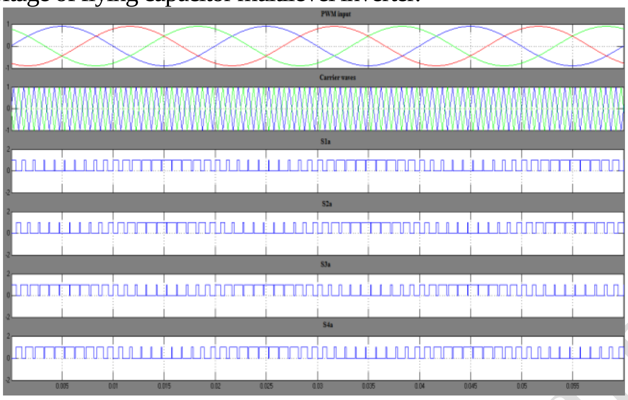

Figure 8: PWM input and switching pulses for A phase

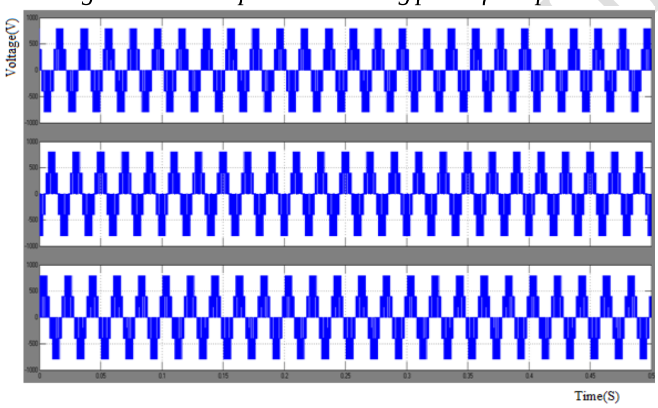

Figure 9: Line voltage

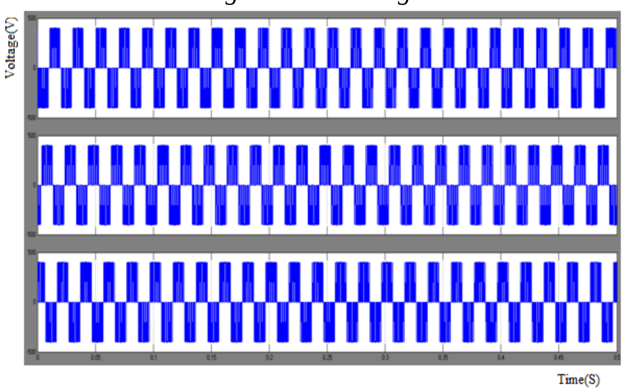

Figure 10: Phase voltage

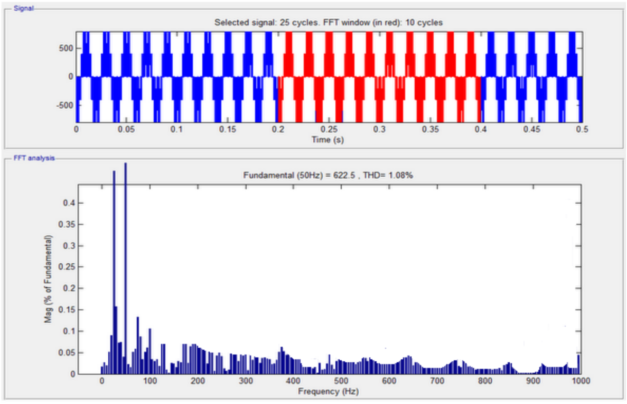

Figure 11: Line voltage THD

Figure 11 and Figure 12 shows the line and phase voltage THDs respectively. And their THD values are found to be 1.08% and 1.33% respectively.

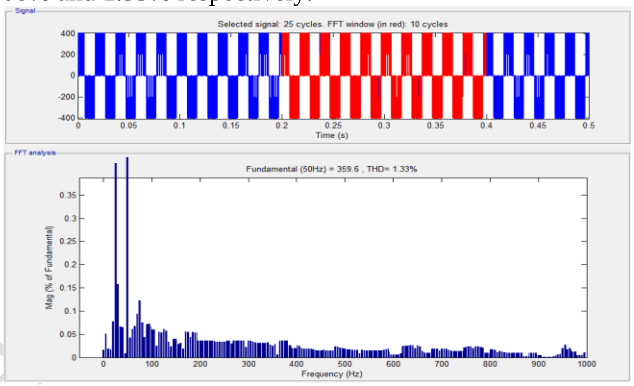

Figure 11: Phase voltage THD

B. MODULAR MULTILEVEL CONVERTER.

Figure 12 shows the simulation circuit of modular multilevel converter for resistive load. Figure 13 shows the Simulink model of three level modular multilevel converter.

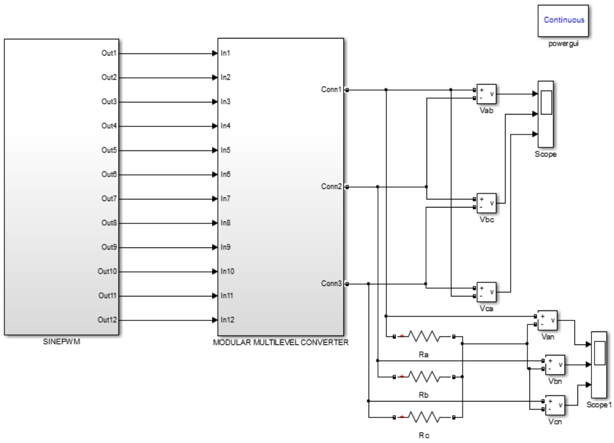

Figure 12: Simulation circuit of modular multilevel converter

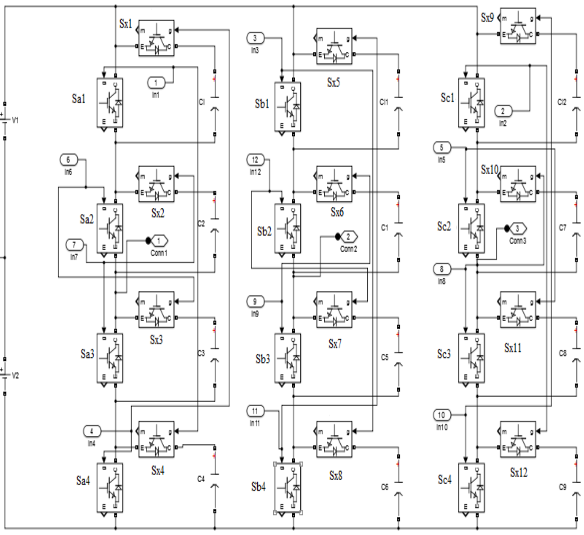

Figure 13: Simulink model of three level modular multilevel converter

Figure 14 shows the sinusoidal PWM. Figure 15 shows the PWM input and the switching pulses. Figure 16 shows the line voltage and Figure 17 shows the output phase voltage. Figure 18 and Figure 19 shows the line volage and phase voltage THDs respectively and the values are 0.66% and 0.66% respectively.

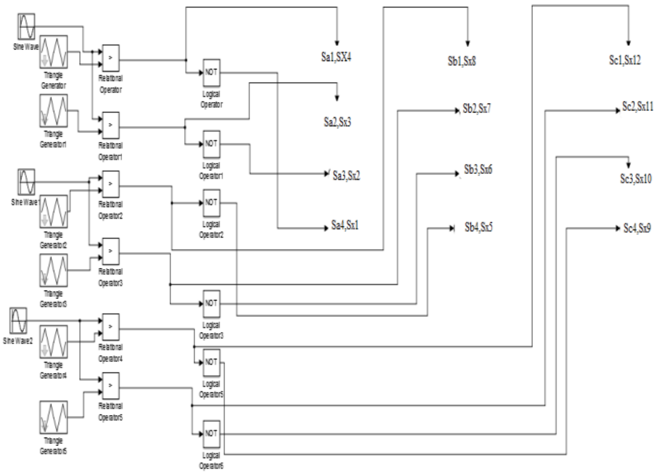

Figure 14 Sinusoidal PWM

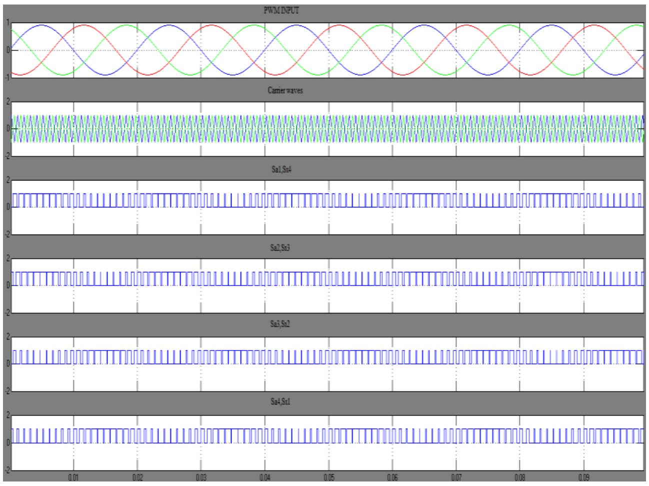

Figure 15: PWM input and switching pulses

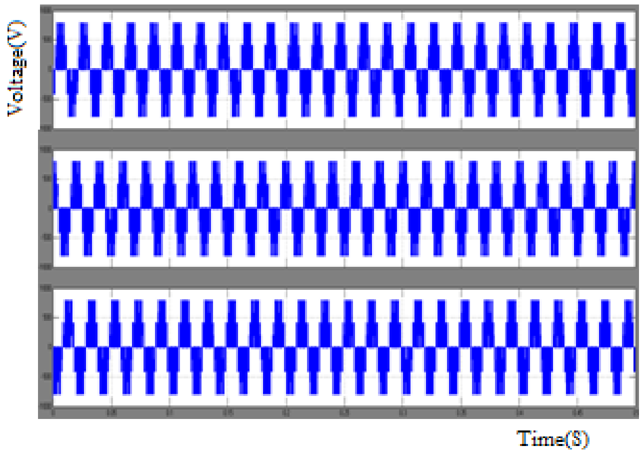

Figure 16: Line voltage

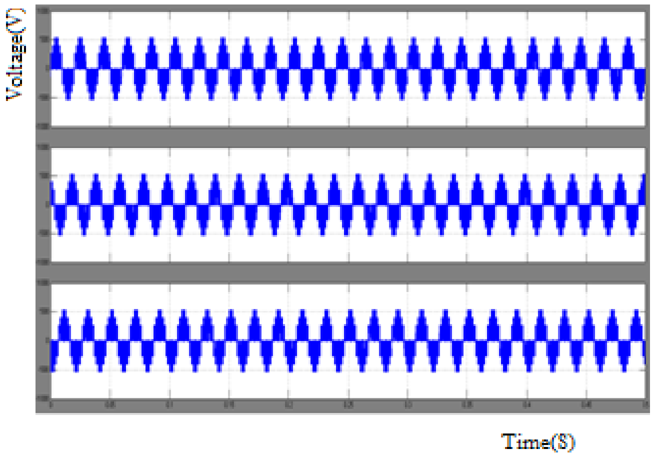

Figure 17: Phase voltage

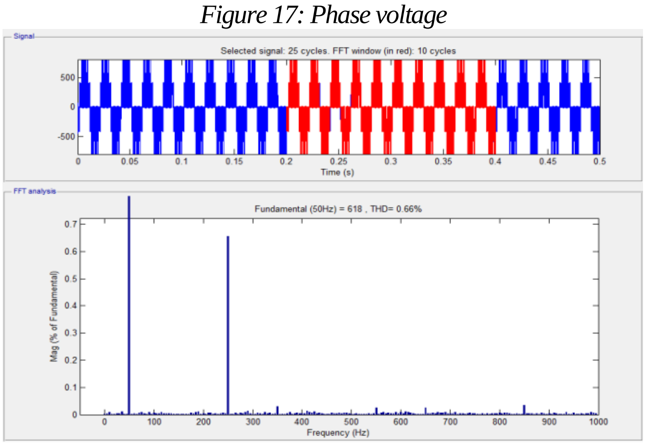

Figure 18: Line voltage THD

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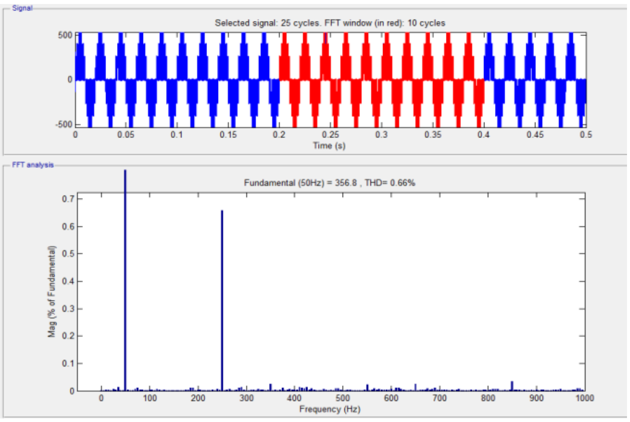

Figure 19: Phase voltage THD

Sl No.	Topology	Voltage THD(%)	
		Line voltage	Phase voltage
1	Three level Flying capacitor Multilevel inverter	1.08	1.33
2	Three level Modular Multilevel Converter	0.66	0.66

Table 1: Comparison of voltage THD for various multilevel converter topologies

Table 1 shows the comparison of THD values of Flying capacitor and Modular Multilevel Converter topologies and from the table given above it is clear that the Total Harmonic Distortion decreases when moving from Flying capacitor to Modular Multilevel Converter.

IV. CONCLUSION

The simulation of three level Flying capacitor and Modular Multilevel Converters was carried out using Sinusoidal PWM. It also explains the multi carrier phase shifted pulse width modulation. The performance of the converters was analysed using MATLAB/SIMULINK. From the above results obtained the advantages of the Modular Multilevel Converter over the Flying capacitor multilevel inverter is confirmed.

REFERENCES

[1] P. K. Chaturvedi, S. Jain, Pramod Agrawal " Modeling, Simulation and, Analysis of Three level Neutral Point Clamped inverter using mat lab/ Simulink/Power System Blockst"

[2] G. Bhuvaneshwari and Nagaraju "Multilevel inverters – a comparative study" vol .51 No.2 Mar – Apr 2005.

[3] Tolbert. L. M and Pend. F. Z, "Multilevel Converter as a Utility Interface for Renewable Energy Systems," IEEE Power Engineering Society Meeting, Vol. 2, pp. 1271-1274, 2000.

[4] J. Rodriguez, J. S. Lai, and F. Z. Peng, "Multilevel inverters: A survey of topologies, controls and applications," IEEE Transactions of Industrial Electronics, vol.49, no. 4, pp. 724-738, Aug. 2002

[5] Akhila. A, Manju Ann Mathews, "Simulation and Analysis of Diode clamped and Modular Multilevel Inverters Using SPWM," *International Journal of Advanced Research in Electrical Electronics and Instrumentation Engineering Trends and Technology,vol.5,no.6,pp.4677-4686,Jun. 2016.*

[6] [6] Bose BK. "Power electronics—an emerging technology". IEEE Transactions on Industrial Electronics, vol.36, no.3, pp. 403–12, Aug 1989.

[7] B. Urmila, D. Subbarayudu, "Multilevel inverters: A comparative study of pulse width modulation techniques," International Journal of Scientific and Engineering Research, vol. 1, issue 3, pp. 1-5, Dec. 2010.

[8] J. Rodriguez, S. Bernet, B. Wu, J. O. Pontt, and S. Kouro, "Multilevel voltage source converter topologies for industrial medium-voltage drives," IEEE Transactions on Industrial Electronics, vol. 54, no.6, pp. 2930-2942, Dec. 2007.

[9] Kalle Ilves, Antonios Antonopoulost, Staffan Norrga, Hans-Peter Nee "A New Modulation Method for the Modular Multilevel Converter Allowing Fundamental Switching Frequency," IEEE Trans. Power Electron., vol. 27, no. 8, pp. 3482–3494, Aug. 2012.

[10] JoseRodriguez, Leopoldo.G.Franquelo, SamirKouro, Jose.I.Leon, Ramon.C.Portil "Multilevel Converters an Enabling Technology for High power Applications," IEEE Trans. Ind. Applicat., vol. 97, no. 11, pp. 1786-1816,Nov 2009.