DFCM Converter with Different PWM Techniques for Harmonic Reduction

Rishana. N
PG student, Dept. of Electrical and Electronics
NSS College of Engineering, Palakkad
Email:rishanathusharam@gmail.com

Deepika Vasanthakumar
Assistant Professor, Dept. of Electrical and Electronics
NSS College of Engineering, Palakkad
Email:deepikavasanthakumar@rediff.com

Abstract: Multilevel inverters are widely used for medium and high-power applications due to the increase in the number of output voltage levels and its apparent frequency. Here, a new configuration of Flying Capacitor Multicell (FCM) converter is considered which is named as Double Flying Capacitor Multicell (DFCM) converter. When compared with conventional FCM this configuration gives doubled RMS value, increased number of output voltage levels, an improved output voltage frequency spectrum and cancels the midpoint of DC source. The main constructional difference of new FCM topology with conventional FCM converter is the two low frequency switches added in the source side and the remaining constraints are kept constant. This converter is controlled by a modified phase-shifted pulse width modulation in which two type of controlling is possible ie, either by using multiple carrier or by using multiple reference singals. The self-balancing property of the flying capacitor converter is maintained in the DFCM converter by using modified Pulse Width Modulation (PWM) technique with multiple carrier and multiple reference signals. The validity and effectiveness of DFCM converter with different PWM techniques are being verified by MATLAB simulink software.

Keywords: Flying Capacitor Multicell Converter (FCMC), Phase Shifted Pulse Width Modulation (PSPWM), Total Harmonic Distortion (THD).

I. INTRODUCTION

The multilevel inverters have been continuously developed in recent years due to the necessity of increase in power level for industrial applications. They are mainly used in high- power applications, such as high-power AC motor drives, active power filters, reactive power compensation, and FACTS devices. This is because of the capability of these converters to handle high voltage/power in the range of KV/MW [10]. They receive a wide acceptance in industry and energy systems because they enable the design of medium and high voltage systems with excellent output voltage quality. The main aim of any multilevel inverter based research is to choose a converter topology with a large number of voltage levels with minimum number of switching devices, reduced filter size and reduced harmonic distortion [1][2].

The term multilevel starts with the three-level converter. By increasing the number of levels in the converter, the output voltage has more steps generating a staircase waveform, which has a reduced harmonic distortion. However, a high number of levels increases the control complexity and introduces voltage imbalance problems [10]. Different cells and ways to interconnect them generate many topologies. The most common cells in multicell converters are the full-bridge and half-bridge. The half-bridge cells can generate only zero and positive voltages, so there is inevitably a DC component in the arm voltage. Among the different topologies for multilevel converters, multicell converters [3] features the highest degree of modularity and the lowest expense for redundancy due to the large number of cells they have, as well as the lowest harmonic content due to the large number of output voltage levels they produce.

Multilevel inverters are primarily classified into: diode clamped, flying capacitor, hybrid and cascaded H-bridge multilevel inverter. For higher number of voltage levels these converters have some limitations, mainly with clamping diodes and voltage balance of DC link capacitors. One of the main alternatives for these converters is the multicell converter topology, in which two or more switches are arranged to form a cell and the number of cells are depend on the output voltage level. Mainly there are 3 types of multicell configurations are available: flying capacitor, stacked and cascaded multicell converters. The main drawback of flying capacitor multilevel inverter is unbalancing of capacitor voltage and that problem is eliminated in case of FCM converter. By using modified phase shifted pulse width modulation the duty ratio of each cell kept constant so average flying capacitor current become zero. Thus the condition for self balancing of flying capacitor voltage is satisfied and additional requirement of flying capacitor voltage control is avoided. Double Flying Capacitor Multicell (DFCM) converter is a modification of FCM converter. By comparing DFCM converter with conventional multicell topologies the requirement of high frequency switches in DFCM converter is half of that in conventional multicell converters. The number of cells of DFCM converter is also half of that in FCM converter so the size of the converter is reduces. A single DC source is required as power supply for the operation of DFCM converter.

The commonly used sine PWM techniques are multi-carrier and muli-reference methods in which muti-carrier techniques are mostly used in multilevel inverters because of its simplicity. In three phase systems inorder to achieve voltage balancing multi-carrier PWM are preferred where the controlling of switching rates, shape and phase of the carrier signal is possible. Multi-reference single-carrier PWM technique is uses where the switching rate of all devices needs to be same. A comparative analysis of five level FCM converter and five level DFCM converter is given in this paper and different pulse width modulation techniques are also discussed with the help of MATLAB simulation.

II. FCM CONVERTER CONFIGURATIONS

A. Conventional FCM Converter:

A typical configuration of a 5 level conventional Flying Capacitor Multicell Converter (FCMC) is shown in Fig. 1, which is based on n cells which are connected in series to form required converter leg and can produce n+1 levels of output voltage.

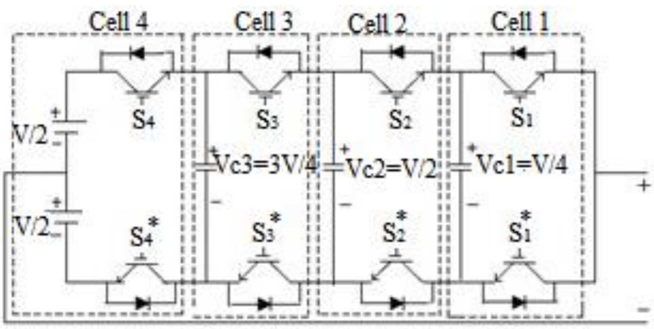

Fig. 1: 4-cell-5-level conventional FCM Converter

The positive and negative peak values of the output voltage lies at E. Each cell in FCMC offers a simple structure, which is made-up of one flying capacitor (FC) and a pair of power switches with complementary control signals. Every cell in the circuit is controlled with equal duty ratio so as to provide it a regular phase shifted progression along the cells. As the number of cells is increased, more levels of output voltage can be generated. In the conventional configuration of FCM converter, maximum value of positive and negative peaks of output voltage is half of the DC source voltage, i.e., V/2. The output voltage levels for different states of the switches are tabulated in Table.I.

Table.I State of power switches of the 4-cell-five-level FCMC

Output voltage	State of switches (S_4,S_3,S_2,S_1)	No.of states
+0.5V	(1,1,1,1)	1
+0.25V	(1,1,1,0)(1,1,0,1)(1,0,1,1)(0,1,1,1)	4
0	(1,1,0,0)(1,0,0,1)(0,0,1,1)(1,0,1,0)(0,0,1,1)(0,1,0,1)	6
-0.25V	(1,0,0,0)(0,1,0,0)(0,0,1,0)(0,0,0,1)	4
-0.5V	(0,0,0,0)	1

B. Double FCM Converter:

In Double FCM (DFCM) converter additional two low frequency switches, J and J* are used to obtain full value of the DC source voltage, E for positive and negative peaks of output voltage as shown in Fig. 2.. The main advantages of the DFCM converter, in comparison with FCM and stacked multicell converters, are doubling the RMS of output voltage and the number of output voltage levels and cancelling the midpoint of DC source. This progress is achieved by adding only two low- frequency switches to the conventional configuration of FCM converter, while the number of high frequency switches and capacitors, voltage ratings of capacitors and switches and the number of high-frequency switchings during a full cycle are kept constant. Also, the frequency spectrum of output voltage is improved and its THD is reduced significantly because of doubling the number of output voltage levels.

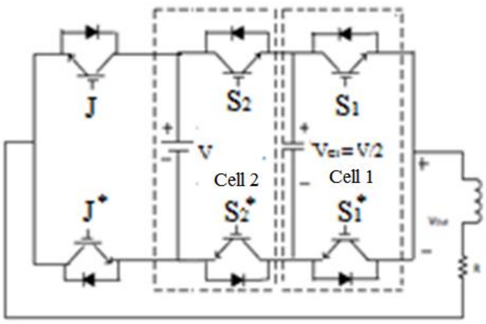

Fig. 2: Two-cell-five-level DFCM converter

Table.II Switching states of a 2 cell 5 level DFCM Converter

Output voltage	J	States of switches (S_2,S_1)	No.of states
+V	0	(1,1)	1
+V/2	0	(1,0)(0,1)	2
0	0	(0,0)	1
0	1	(1,1)	1
-V/2	1	(1,0)(0,1)	2
-V	1	(0,0)	1

For a DFCM Converter, a Modified Phase Shifted Pulsewidth Modulation Technique is used as the control strategy. Here the triangular carrier signals of individual cells are compared with a shifted reference wave so as to generate the switching pulses for individual cells. The modulation index is chosen to be 0.8. The low frequency switch J* is made on during the positive halfcycle and J is made on during the negative halfcycle. Different switching states of the high frequency as well as the low frequency switches in the DFCM converter configurations are shown in Table.II.

III. MODIFIED PWM TECHNIQUES

A. MULTI-CARRIER PWM:

In multi-carrier PWM method single-reference and two or more carriers are used. Carriers are with switching frequency and the reference is with fundamental frequency. Multi-carrier modulations are commonly used in 3 phase system inorder to achieve voltage balance. Here the control of switching rate, shape and phase of reference signal is possible. Multi-carrier system is simple and easy to implement. Fig. 3 represents the multi-carrier PWM technique and the generated pulses.

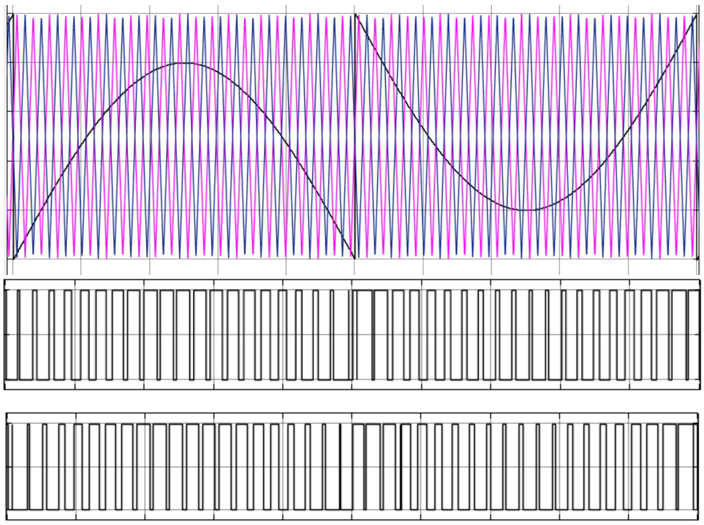

Fig. 3 Multi-Carrier PWM

B. MULTI-REFERENCE PWM:

Fig. 4 represents the multi-reference PWM technique and the generated pulses. Multi-reference PWM method is used where the switching rate of every switch needs to be constant. This PWM method is easy to program in microcontroller.

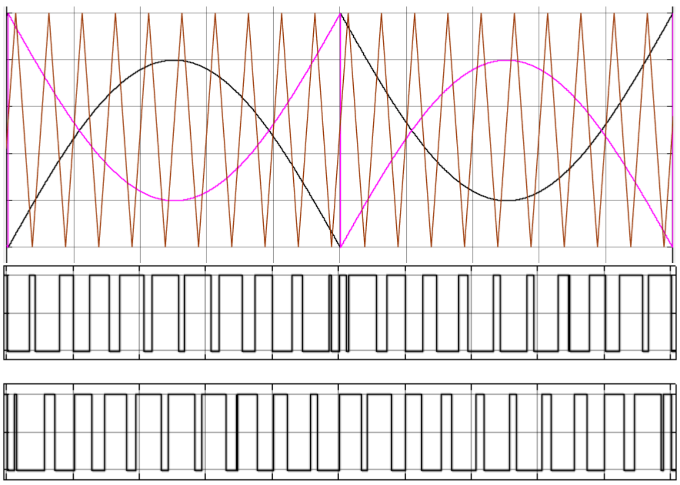

Fig. 4 Multi-Reference PWM

IV. SIMULATION RESULTS

Simulation of conventional FCM converter with sinusoidal PWM and DFCM converter with modified multi-carrier and multi-reference PWM is given in this paper. Simulation is performed to verify the effectiveness and performance of the converter. A basic Four-cell Five-level FCM converter is initially simulated and later on a Two- cell five-level DFCM converter is simulated. The simulation parameters which are considered are: DC Voltage 200V, switching frequency 700 Hz, Internal flying capacitors 1mF, Resistive loads 50Ω.

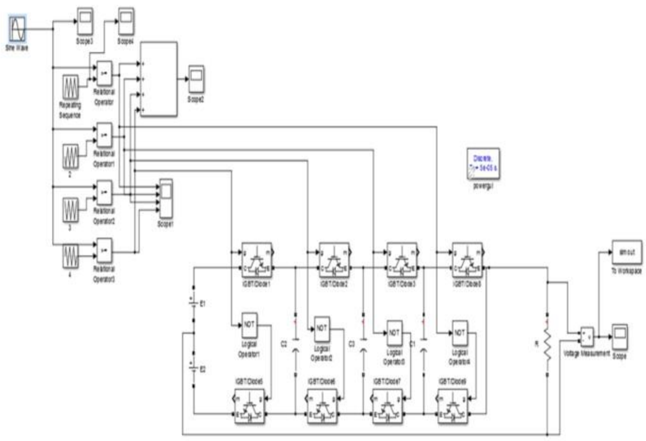

Fig. 5: Simulink Model for a conventional four cell five level FCM converter

Fig. 5 represents the simulation diagram of conventional four cell five level flying capacitor multicell converter. The four-cell-five-level FCM converter is controlled by PSPWM Technique and operated with a modulation index equal to 0.8 (M = 0.8). The converter load is resistive and the output voltage is shown in Fig. 6.

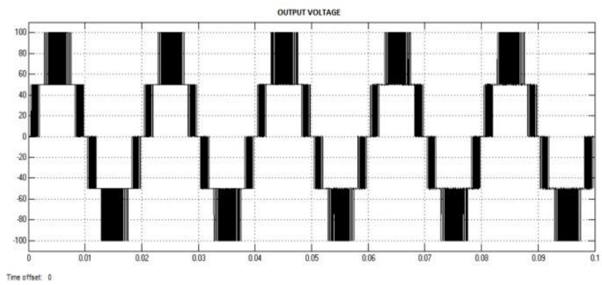

Fig. 6: Output Voltage for a 4cell 5level FCM Converter

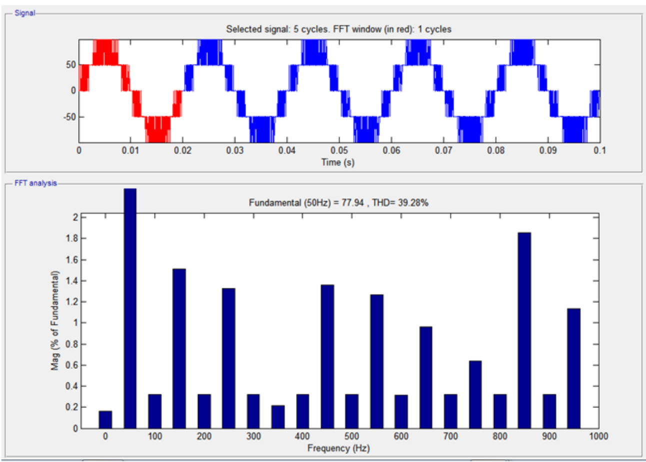

Fig. 7: FFT Analysis for 4 cell 5 level FCM

By using the above parameters simulation is done and five level output voltage is obtained with output voltage levels at +100V, +50V, 0V, -50V and -100V. The simulated five level converter has a voltage THD of 39.28 % which is shown in Fig. 7.

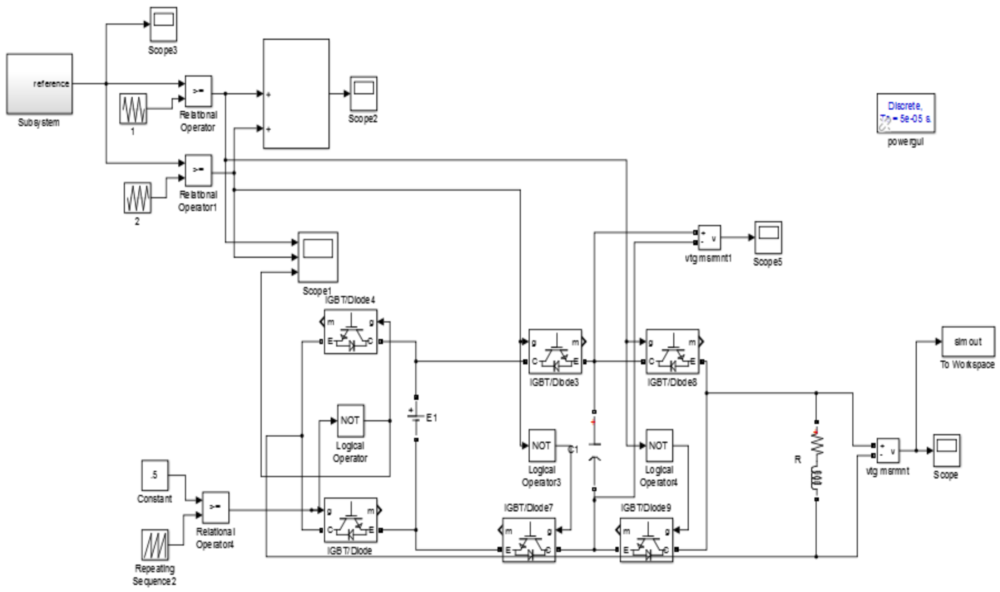

Fig. 8: Simulink Model for a two cell Five level DFCM Converter with multi carrier

Fig. 8 shows the simulink model for a two cell five level DFCM converter with multi carrier which is simulated with modulation index M=0.8 and modified phase shifted PWM Technique is employed. The load used is resistive-inductive load. The DFCM converter is controlled by a modified phase- shifted pulse width modulation. The reference signal for the generation of pulses is shown in Fig. 9.

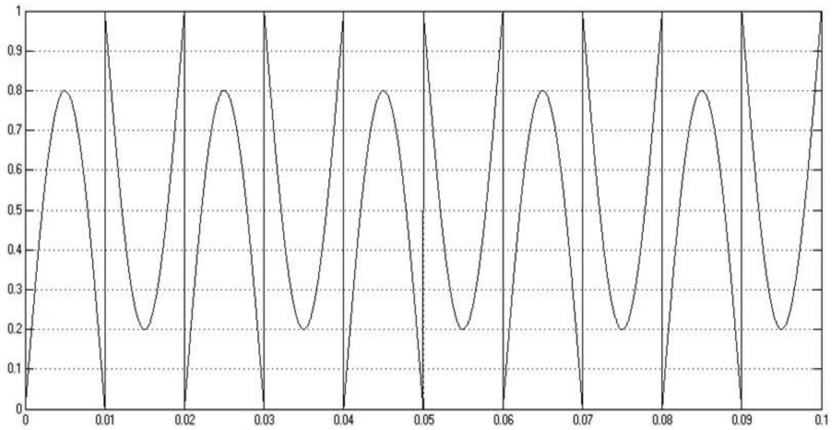

Fig. 9: Reference signal for the generation of pulses for the converter

Also, the frequency spectrum of output voltage is improved and its THD is reduced significantly because of doubling the number of output voltage levels. In the conventional configuration of FCM converter, maximum values of positive and negative peaks of output voltage are only half of the DC source voltage, i.e., E/2, while in the proposed DFCM converter, applying the switches J and J*, makes it possible to obtain full value of the DC source voltage, i.e., E for positive and negative peaks of output voltage. Here E is 200V. Hence a five level output voltage is achieved with voltage levels at 0, +100V, +200V, -100V and -200V. The output voltage obtained from the simulation is as shown in Fig. 10.

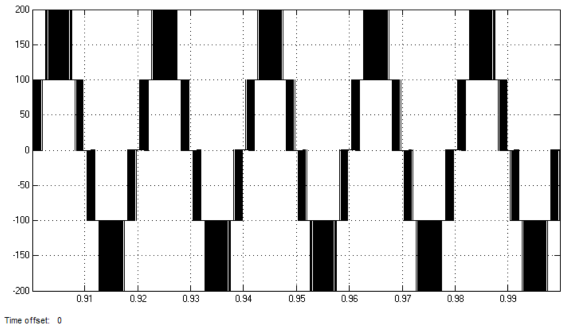

Fig. 10: Output voltage for a two cell five level DFCM Converter with multi carrier

Fig. 11 shows the simulink model for a two cell five level DFCM converter with multi reference which is simulated with modulation index M=0.8. The reference signals for the DFCM converter is shown in Fig. 12.

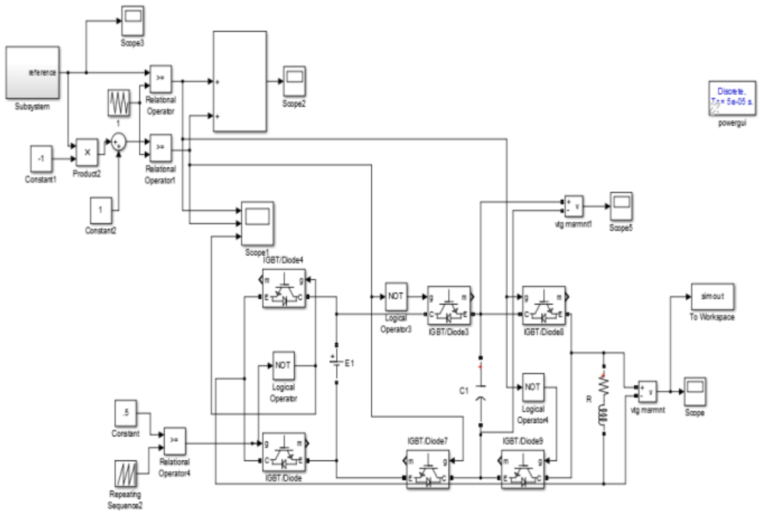

Fig. 11: Simulink Model for a two cell Five level DFCM Converter with multi reference

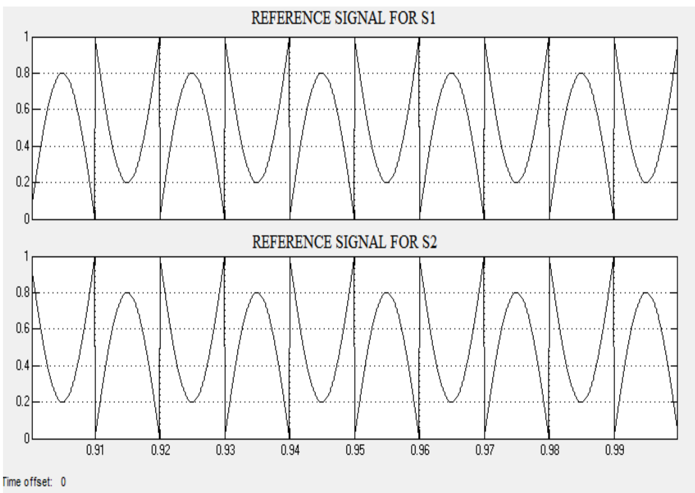

Fig. 12: Reference signals for the generation of pulses for the converter

The output voltage obtained from the simulation of DFCM converter with multi reference signal is shown in Fig. 13. FFT analysis of DFCM converter is as shown in Fig. 14. The THD for the DFCM Converter is 17.55%. When compared to conventional FCM topology with THD 39.28 %, the THD is significantly reduced to 21.73 %. Hence it is clear that when a

DFCM Converter is developed from conventional FCM Converter, the harmonic spectrum is improved and THD is reduced.

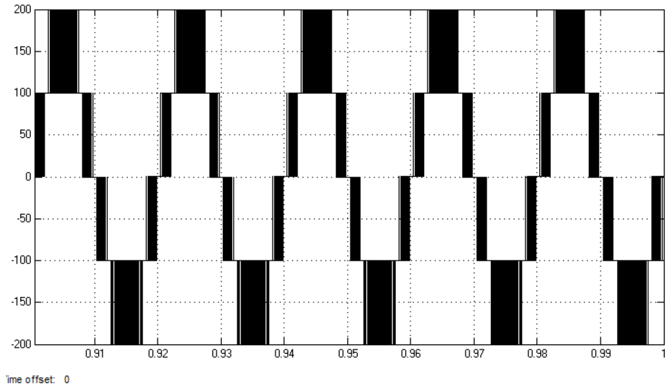

Fig. 13: Output voltage for a two cell five level DFCM Converter with multi reference

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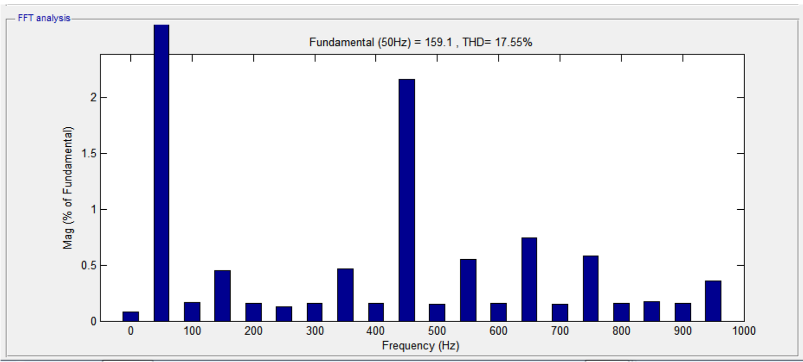

Fig. 14: FFT Analysis of DFCM Converter

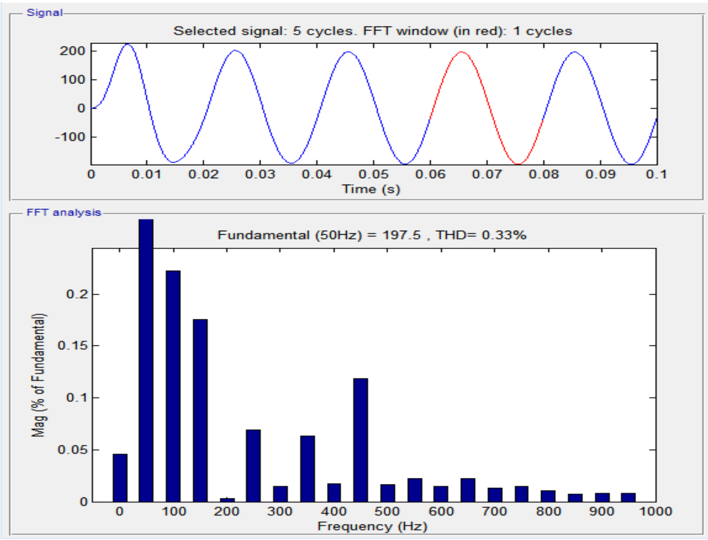

Fig. 15: FET Analysis of Filtered DFCM Converter

Moreover the RMS values of the output voltage as well as the number of voltage levels are also doubled. By using an LC filter the output voltage waveform becomes sinusoidal signal and the THD measured is considerably reduces to 0.33 % which is shown in Fig. 15.

V. CONCLUSION

A comparison between the conventional FCM converter and the DFCM converter was done by simulation using MATLAB simulink software also done the simulation of DFCM converter with multiple carrier as well as multiple reference PWM techniques. The output voltage of the DFCM converter has a THD of 17.55% which is 21.73% less than that of conventional multicell converter. By using multi-carrier and multi-reference PWM methods same output voltage with a reduced THD was observed. The THD of filtered DFCM converter output voltage is obtained as 0.33% which lies in the rage of IEEE standards. The self- balancing property of the FCM converter and transformerless operation are maintained in the DFCM converter since its control strategy is based on the modified PSPWM. Multi-carrier or muli-reference PWM techniques can be used for generating switching pulses depending upon the application. The DFCM converter has a good potential for high-power / high-voltage applications, such as high-power ac motor drives, active power filters, reactive power compensation, dynamic voltage restorer and FACTS devices.

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