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Nine level Double Flying Capacitor Multicell Converter Based on Phase Shifting Technique

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ABSTRACT: Multicell converter are a very interesting alternative for medium and high power drives. This paper presents a new configuration of double flying capacitor (DFCM) converter. The main advantages of the proposed converter in comparison with FCM and stacked multicell converter are doubling the rms and the number of output voltage levels, improving the output voltage frequency spectrum, and cancelling the midpoint of dc source. This can be obtained by adding two low frequency switches to the conventional configuration of FCM converter while the number of high-frequency switches and capacitors, voltage rating of capacitors and switches, and the number of high frequency switchings during a full cycle are kept constant. The control strategy is controlled by a modified phase-shifted pulse width modulation. The circuit is simulated using PSIM. The simulation results are presented to validate the effectiveness and advantages of the proposed configuration as well as its control strategy.

KEYWORDS: Double Flying Capacitor Multicell (DFCM) converter, Flying Capacitor Multicell (FCM) converter, Neutral point clamped (NPC) converter, Phase Shifted technique in MATLAB (PSIM)

I. INTRODUCTION

Multicell converter have been continuously developed in recent years due to the necessity of increase in power level of industrial applications, especially high-power applications, such as high-power ac motor drives, active power filters, reactive power compensation, and FACTS devices. The main reason is the capability of these topologies to handle voltage/power in the range of kilovolts/megawatts due to recent developments in the area of high-power semiconductor. The commutation of the switches permits the addition of the capacitors voltages and generates high voltage at the output, while the power semiconductors must withstand only reduced voltages.

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 increase the control complexity and introduce voltage imbalance problems.

The neutral point clamped (NPC) converter, presented in the early 1980s is now a standard topology in industry on its three-level version. However, for a high number of levels, this topology presents some problems, mainly with the clamping diodes and the balance of the dc-link capacitors. An alternative for the NPC converter are the multicell topologies. Different cells used in olden days are the cascaded multicell (CM), the flying capacitor multicell (FCM) with its sub topology and stacked multicell (SM) converters.

The FCM converter uses a series connection of “cells” comprising a flying capacitor and its associated complimentary switch pair and produces a switched voltage that is the sum of the individual cell states. The SM converter stacks two FCM converters together with the upper stack switching only when a positive output is required and the lower stack switching only when a negative output is required.

The proposed configuration, called double FCM (DFCM) converter, the output voltage levels and rms value of output

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voltage are double in comparison with FCM and SM converters; this progress is achieved by applying only two additional low-frequency switches, which work with low-switching frequency, and are generally switched twice during a full cycle of the fundamental output voltage. In this project the double flying capacitor multicell converter is used to get the desired nine level stepped outputs. Two low frequency switches are used. MOSFET is used as switches. By using this THD can be calculated. It can also used in many applications.

II. TYPES OF MULTICELL CONVERTER

One of the major limitations of the multilevel converters is the voltage unbalance between different levels. The technique to balance the voltage between different levels normally involves voltage clamping or capacitor charge control. Three recently developed multilevel voltage source converters are diode-clamp, flying capacitor and cascaded-inverters with separate dc sources.

A) Diode- Clamp Multilevel Converter

An m-level diode – clamp converter typically consists of m-1 capacitors on the dc bus and produces m levels of the phase voltage. When the number of levels is high enough, harmonic content will be low enough to avoid the need for filters. Efficiency is high because all devices are switched at the fundamental frequency. Reactive power flow can be controlled. Excessive clamping diodes are required when the number of the levels is high. It is difficult to do real power flow control for the individual converter. The features of diode clamp multilevel converter are high voltage rating required for blocking diodes, unequal device rating, and capacitor voltage unbalance.

B) Multilevel Converter Using Flying Capacitors

The voltage level is similar to that of the diode-clamp converter. The phase voltage of an m-level converter has m levels including the reference level. The voltage mixture in a flying-capacitor converter has more flexibility than a diode-clamp converter. The features are Large amount of storage capacitors provides extra ride through capabilities during power outage. Provides switch combination redundancy for balancing different voltage levels. Both real and reactive power flow can be controlled making a possible voltage source converter candidate for high voltage dc transmission. The drawback is High-level systems are more difficult to package and more expensive with the required bulky capacitors. The inverter control will be very complicated and the switching frequency and switching losses will be high for real power transmission.

C) Multilevel Converter Using Cascaded-Inverter with Separate DC Sources

Requires the least number of components among all multilevel converters to achieve the same number of voltage levels. Modularized circuit layout and packaging is possible because each level has the same structure and there are no extra clamping diodes or voltage balancing capacitors. The drawback is it needs separate dc sources for real power conversions, and thus its applications are somewhat limited. It is used in high voltage and high-power applications.

D) Flying Capacitor Multicell Converter

Figure.1 shows the $2n$ -cell FCM converter is composed of $4n$ switches forming $2n$ -commutation cells controlled with equal duty cycles and phase shifted of π/n and $2n - 1$ flying capacitors with the same capacitance. As a result, the electrical stresses on each switch are reduced and more equally distributed as each switch must withstand E/n volts. The output voltage of $2n$ -cell FCM converter has $2n + 1$ level and its frequency spectrum has the harmonics around the $(2nkf\text{switching})$ th harmonic, where k and $f\text{switching}$ are the integer number and the switching frequency, respectively. All capacitors see similar current waveforms and have the same capacitance to obtain the same voltage ripple, but their dc voltage ratings are different and equal to $E/n, 2E/n, \dots, (2n - 1)E/n$,

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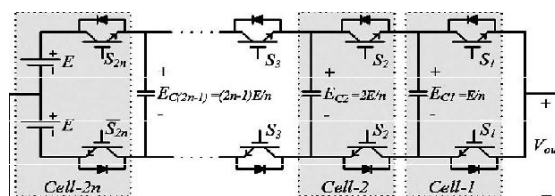


Fig. 1 FCM converter

Main advantages of a FCM converter over a CM converter are that the FCM converter does not require a complex input transformer and in the case of internal fault of one cell, the maximum output voltage remains constant, but the number of levels decreases to as follows:

$$L_f = L - f \quad (1)$$

where f is the number of faulty cells.

E) Stacked Multicell Converter

An alternative topology based on the FCM converter is the SM converter; this structure uses an $m \times n$ cells array to increase the number of output voltage levels. The main advantages of this configuration are that the number of combinations to obtain a desired voltage level is increased (redundancy), and the voltage ratings of capacitors and stored energy in the flying capacitors as well as the semiconductor losses are reduced. However, it requires the same number of capacitors and semiconductors in comparison with the equivalent FCM converter for the same number of output voltage levels.

F) DFCM Converter

Figure.2a shows the circuit diagram and the waveform of the DFCM converter. In the conventional four-cell-five-level FCM converter, the control strategy is based on the PSPWM and the output voltage is shown. Two low-frequency switches (J, J') are added to the conventional configuration of FCM converter and the new four-cell-nine-level converter, called DFCM converter, is proposed. Two additional switches work with low-switching frequency, and generally, are switched twice during a full cycle of the fundamental output voltage, while the switch J is ON for negative output voltage and the switch J' is ON for positive output voltage. 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. As shown in fig, this achievement causes to double the rms value of output voltage and the number of output voltage levels. The effect of switch J is a negative shift of the voltage V_{AN} , equal to $-E$, in the second half cycle to form the output voltage V_{out} . As a result, the reference signal must be shifted one positive unit in the second half cycle to offset negative shift of the voltage V_{AN} made by switch J , as shown.

The main advantages of the proposed converter, in comparison with FCM and SM converters, are doubling the rms of output voltage and the number of output voltage levels and canceling 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 switching 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.

International Journal of Innovative Research in Science, Engineering and Technology

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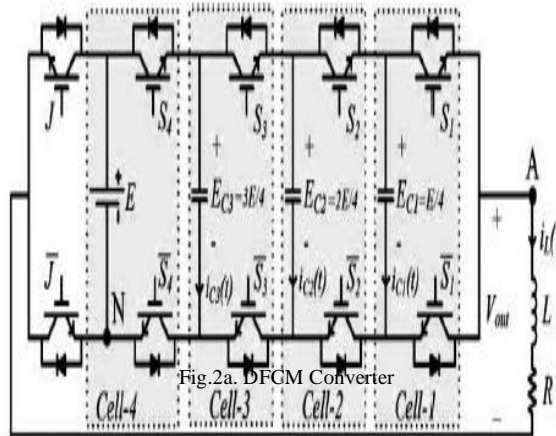


Fig.2a. DFCM Converter

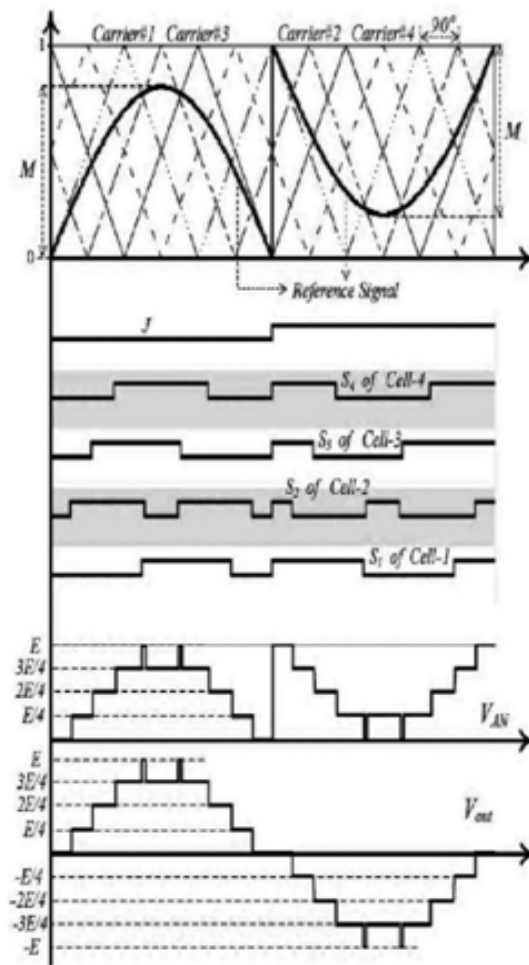


Fig 2b.Characteristics of DFCM Converter

TABLE I SWITCHING FREQUENCY TABLE

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

Output Voltage Level	State		No. of states
	J	(S_1, S_3, S_2, S_4)	
$+E$	0	(1,1,1,1)	1
$+\frac{3}{4}E$	0	(1,1,1,0), (1,1,0,1), (1,0,1,1), (0,1,1,1)	4
$+\frac{2}{4}E$	0	(1,1,0,0), (1,0,0,1), (0,0,1,1), (0,1,1,0)	4
$+\frac{1}{4}E$	0	(1,0,0,0), (0,1,0,0), (0,0,1,0), (0,0,0,1)	4
0	0	(0,0,0,0)	2
	1	(1,1,1,1)	
$-\frac{1}{4}E$	1	(0,1,1,1), (1,0,1,1), (1,1,0,1), (1,1,1,0)	4
$-\frac{2}{4}E$	1	(1,1,0,0), (1,0,0,1), (0,0,1,1), (0,1,1,0)	4
$-\frac{3}{4}E$	1	(0,0,0,1), (0,0,1,0), (0,1,0,0), (1,0,0,0)	4
$-E$	1	(0,0,0,0)	1

III. ABOUT THE SWITCHES

MOSFET is used as a two low frequency switches to get the nine level stepped output. The triggering pulses are given to each switch between 0 to 360 degree. A MOSFET is a voltage-controlled device and requires only a small input current. The switching speed is very high and the times are of the order of nanoseconds. The turn-on is the time that is required to charge the input capacitance to threshold voltage level. The turn-off time is the time required for the input capacitance to discharge from the overdrive gate voltage to the pinch-off region.

IV. SIMULATION RESULT

PSIM is a simulation package specifically designed for power electronics and motor control. With fast simulation and friendly user interface, PSIM provides a powerful simulation environment for power electronics, analog and digital control, and motor drive system studies. The PSIM simulation package consists of three programs: circuit schematic program PSIM, PSIM simulator, and waveform processing program SIMVIEW1. The simulation environment is illustrated as follows.

A) To Simulating a Circuit

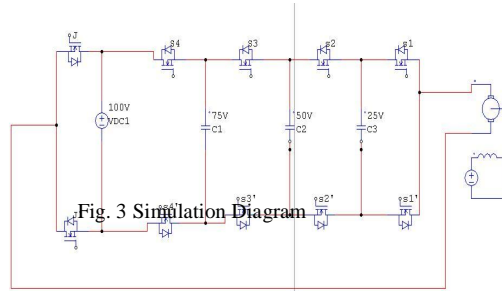
To simulate the sample one-quadrant chopper circuit "chop.sch": - Start PSIM. Choose **Open** from the **File** menu to load the file "chop.sch". - From the **Simulate** menu, choose **Run PSIM** to start the simulation. The simulation results will be saved to File "chop.txt". Any warning messages occurred in the simulation will be saved to File "message.doc". - If the option **Auto-run SIMVIEW** is not selected in the **Options** menu, from the **Simulate** menu, choose **Run SIMVIEW** to start SIMVIEW. If the option **Auto-run SIMVIEW** is selected, SIMVIEW will be launched automatically. In SIMVIEW, select curves for display.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

B) Simulation Diagram for Nine level DFCM Converter



C) Output Waveform

From the proposed simulation circuit the output waveform is obtained as follow

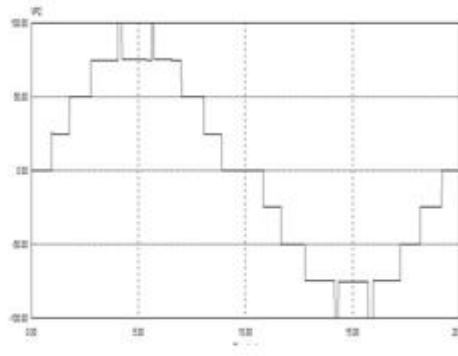


Fig. 4 Simulation Diagram

D) Output Waveform for the Dc Motor

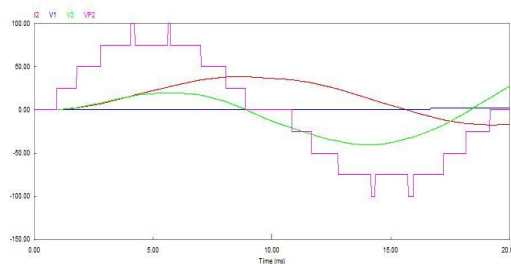


Fig. 5 Output waveform

- I2 - Output current
- VP2 - Ninelevel stepped output
- V2 - Output voltage
- V1 - Input voltage

From the output waveform, the dc motor is operated in Safe Operating Area (SOA) and the performance of the motor is

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Vol. 4, Issue 8, August 2015

to be increased.

E) Simulation Diagram for Control Strategy

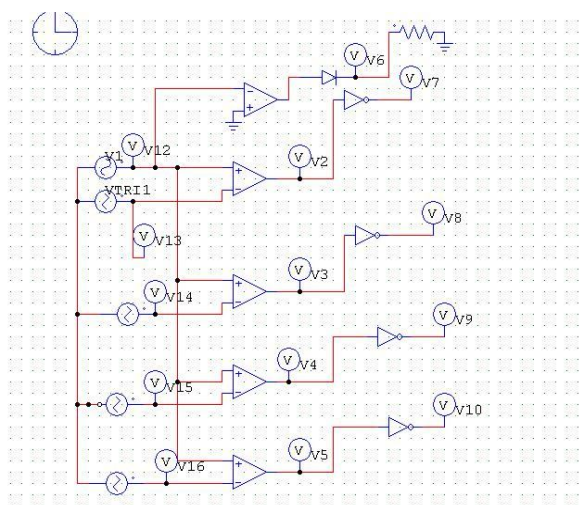


Fig. 6 Simulation diagram

F) Output Waveform for the Above Circuit

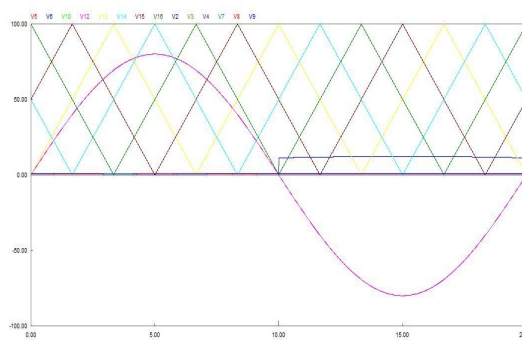


Fig. 7 Output diagram

V. CONCLUSION

Multicell converters are very interesting for high-power/high voltage applications and considerably improve the output voltage frequency spectrum. In comparison with FCM and SM converters, the main advantages of the proposed converter are doubling the rms of output voltage and the number of output voltage levels and canceling the midpoint of dc source. This progress is achieved by adding only two low-frequency switches to the conventional configuration of the FCM converter, while the number of the high frequency switches and capacitors, voltage ratings of capacitors and switches, and the number of high-frequency switching during a full cycle are kept constant. Two additional switches work with low-switching frequency and are generally switched twice during a full cycle of the fundamental output voltage. Also, the frequency spectrum of the output voltage is improved and its THD is reduced significantly because of doubling the number of output voltage levels. This proposed converter make good potential for high-power/high-voltage application, such as high-power ac motor drives, active power filters, reactive power

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

compensation, dynamic voltage restorer and FACTS devices, while the connection of three separate single-phase DFCM converters must be in one of the mentioned methods.

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