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Performance Analysis of Modular Multilevel Converter (MMC) with Continuous and Discontinuous Pulse Width Modulation (PWM)

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ABSTRACT: Modular structured multilevel inverter is very attractive in high voltage and high power applications. This inverter has a few advantages. First, by using a multilevel structure, the stress on each switching device can be reduced MMC can handle higher voltage without using an expensive and bulky step-up transformer in various application. This paper offers a performance comparison of various multicarrier continuous and discontinuous pulse width modulations (PWM) Techniques for the control of the modular multilevel converter (MMC). Selection of the carrier frequency and the multi-carrier PWM method is an important design question for the MMC topology. The paper makes an effort to apply some continuous and discontinuous modulating of MMC this comprehensive simulation has been done in MATLAB.

Keywords: Modular converter, continuous and discontinuous pulse width modulations (PWM) Techniques.

I.INTRODUCTION

The progress of high-power high-voltage power electronic equipment for various medium- to high-voltage applications Continues to benefit from the advancement of the high-powerFully-controlled semiconductors [1]. Applications for such Equipment include motor drives, traction systems [1], high Voltage direct current (HVDC) power transmission [2], flexible alternating current transmission systems (FACTS) such as static compensators (STATCOMs) to mention just few [3]. As the level of power and voltage needs to be increased for many applications, the rapid development of multilevel voltage source converters (VSCs) over the last three decades has resulted, for instance, in many successful commercially viable HVDC systems [2]. In multilevel converters, the staircase Approximation of the sinusoidal waveform with numerous DC Sources is used, effectively reducing the total harmonic Distortion (THD) of the output voltage [1-2].The MMC [11-14] interesting multilevel converter providing various advantages, such as modular construction, multilevel waveform with a large number of steps and fault management [12]. An MMC can be configured using half- or full-bridge. circuits and their associated capacitors. The use of a number of full-bridge Sub-modules cascaded to create phase-legs result in an AC/ACConverter [13]. Similarly the uses of half-bridge sub-modules, or DC-choppers, cascaded in phase-legs are a DC/AC converter. The latter converter topology can also operate in a back-to back configuration for HVDC power transmission or motor Control, without the need of a large DC-side capacitor. This reduces the cost of the converter andincreases its reliability. However, limited information is available in the open technical literature about the performance of many well-knownPWM techniques [8] tocontrol the converter operation. Moreover, it is important to report the effects of the control method to a number of variables such as: the synthesis of the voltage waveform, the charging and discharging of the floating capacitors, the total harmonic distortion and associated switching losses

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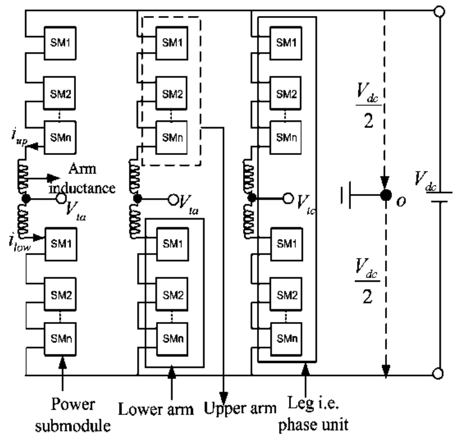

Fig 1.Topology of three phase MMC

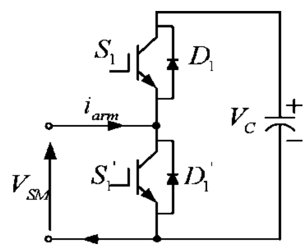

Fig.2.Structure of sub module(SM)

The objective of this paper is to contribute to the Understanding of the operation and performance of the MMC Topology under Continuous and Discontinuous PWM techniques. PWM applies a pulse train of fixed amplitude and frequency only the width is varied in proportion to an input voltage In PWM technique the power semiconductor switches are turned ON and turn OFF several times during HALF cycles and output voltage is controlled by changing the width pulse.

II. LITERATURE SURVEY

The idea behind doing this project is taken from different research papers presented in various conferences and IEEE transactions. I had gone through a number of research papers to obtain the basic knowledge about this research. I have taken different innovative idea from all these sources and I have applied those in research paper.

The multilevel inverters have drawn tremendous interest in the power industry. Modular structured multilevel inverter is very attractive in high voltage and high power application. It mayeasier to produce a high voltage, high power inverter with the multilevel structure because of the way in which device voltage stresses are controlled in thestructure [1]. By using multilevel structure, the stress on each switching device can be reduced proportional to the number of levels of the multilevel inverter. Thus, the inverter can handle higher voltage without using an expensive and bulky step-up transformer in various applications. As the number of inverter output voltage levels is increased, harmonics content of the output voltage waveform decreases significantly enough to avoid the need of bulky filters [7,9,10]. The multilevel inverter has drawn tremendous interest in the power industry. This inverter is very attractive in high-voltage and high-power applications. This inverter has a few advantages [16]. It may easier to produce a high-power and high-voltage inverter with the multilevel structure because of the way in which device voltage stresses are controlled in the structure. Increasing the number of voltage levels in the inverter without requiring higher ratings on individual devices can increase the power rating [11-13].

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The stress on each switching device can be reduced proportional to the number of levels of the multilevel inverter, thus the inverter can handle higher voltage without using an expensive and bulky step-up transformer in various application. As the number of voltage levels increases, the harmonic content of the output voltage waveform decreases significantly enough to avoid the need of bulky filters [2,6]. The topological structure of multilevel inverter must have less switching devices as far as possible, be capable of withstanding very high input voltage for high-power application and have lower switching frequency for each switching device [16].

III.MODULAR MULTILEVEL CONVERTERS

Fig.1 shows the three-phase MMC with n sub-module in each arm. There are two arms in each phase, which are positive-arm and negative arm. The no. of levels in the output of the phase – leg depends not only on the no. of sub-modules in the arm of the topology but also on the way the converter leg depends not only on the no. of sub-modules in the arm of the topology but also on the way the converter leg is modulated. Output line-to-neutral voltage has n+1 levels if topology consisting of 'n' sub-modules per arm (2n per phase leg). The no. of sub-modules that are continuously connected in the whole phase leg remains constant and equal to n, meaning that n-upper + n-lower = n(where n-upper and n-lower are the sub-modules connected in the upper and lower arm respectively). When carrier phase-shifted SPWM is adopted, 2n sub-modules in each phase leg have 2n triangular waveforms with the same frequency but a phase difference of 3600/2n, thus output line-to-neutral voltage has 2n+1 levels. Fig. 2 is a single SM structure. The SM output voltage VSM has two values; VSM = VC, when the upper switch is on and the lower one is off; or VSM = 0 when the lower switch is on and the upper switch is off. This means each SM has only two states in normal operations: switched on or switched off. Output voltage and the states of charge on DC–side capacitor are listed in table 1.
Each of the arms of the topology can be seen as a voltage source, and the voltage of the arm is given by eq. [16].

$$V_{arm} = \sum_{i=1}^{n} S_{armi} V_{SMarmi} + L\frac{di_{arm}}{dt}$$

'SM' is OFF when S1=0, S2=1, 'SM' is ON when S1=1, S2=0

TABLE I

OUTPUT AND CHARGING STATE OF A SUB-MODULE

S1	S1'	D1	D1'	Current direction	Capacitor state	Output voltage
OFF	ON	OFF	OFF	$i_{arm}>0$	Unchanged	0
OFF	OFF	OFF	ON	$i_{arm}<0$	Unchanged	0
OFF	OFF	ON	OFF	$i_{arm}>0$	Charging	v_c
ON	OFF	OFF	OFF	$i_{arm}<0$	Discharging	v_c

IV.MULTICARRIER CONTINEOUS AND DISCONTINEOUS PWM TECHNIQUES.

PWM applies a pulse train of fixed amplitude and frequency only the width is varied in proportion to an input voltage In PWM technique the power semiconductor switches are turned ON and turn OFF several times during HALF cycles and output voltage is controlled by changing the width pulse N= number of carriers (n-1), Modulation index=Am/N'Ac Where N= (n-1)/2, Where n= number of levels Frequency of reference wave is 5o Hz and frequency of carrier is 2khz.We made comparing of reference wave and carrier wave its result is pure PWM for switching of switches for 3 level no. carriers requires two and for 5 level no. of carrier requires 4 upper two and lowers two. By using this technique we are giving the switching pulse to switches. The multicarrier PWM techniques are based on a single Modulating or reference signal, which in most cases is Sinusoidal. This reference waveform is compared and

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sampled through a number of triangular waveforms and for this reason the PWM techniques considered here are called multicarrier PWM techniques. They can be categorized as follows:

A. Phase disposition (PD) [7]
In the phase-disposition method all triangular carriers are in Phase the significant line-to-line voltage harmonics are presented as sidebands around the carrier frequency as the theory suggests.

B. Phase opposition disposition (POD) [7]
In POD, the positive and negative carriers are in phase, but between them, there is a phase shift of 180 degrees as shown in Fig. 4(b). Significant harmonics are presented, similarly to PD, as sidebands around the carrier frequency.

C. Alternative phase opposition disposition (APOD) [7]
In APOD, carrier signals are alternately displaced 180Degrees between them as shown in Fig.4(c). Similarly to the Previous two carrier disposition methods, sidebands to theCarrier frequency is presented as the most significant harmonics.The PD, POD and APOD control methods have theProperty of producing signals with significantly lower Switching frequency than the carrier frequency. The linear or continuous modulating functions are co-sinusoidalmodulating functions (CMF), Harmonics modulating function (HMF), and Trapezoidal modulating function (TMF) and non-linear or discontinuous modulating functions are Non-linear modulating function NLMF-1, NLMF-2, NLMF-3. [15]

CMF: $F1(\alpha) = \frac{1}{2}\cos(\alpha)$
HMF: $F1(\alpha) = F1(\alpha) = \frac{1}{\sqrt{3}}[\cos(\alpha)\text{-}\frac{1}{6}\cos(3\alpha)$

TMF:

$$F1(\alpha) = \begin{cases} 0.5 & \text{if} -60^o \le \alpha < 60^o \\ 1.5 - \frac{\alpha}{60^o} & \text{if } 60^o \le \alpha < 120^o \\ -0.5 & \text{if } 120^o \le \alpha < 240^o \\ \frac{\alpha}{60^o} - 4.5 & \text{if } 240^o \le \alpha < 300^o \end{cases}$$

LMF-1:

$F1(m1\alpha) =$

$$\begin{cases} 0.5 & \text{if} -30^o \le \alpha < 30^o \\ m\cos(\alpha - 30^o) - 0.5 & \text{if } 30^o \le \alpha < 90^o \\ m\cos(\alpha + 30^o) + 0.5 & \text{if } 90^o \le \alpha < 150^o \\ -0.5 & \text{if} 150^o \le \alpha < 210^o \\ m\cos(\alpha - 30^o) + 0.5 & \text{if } 210^o \le \alpha < 270^o \\ m\cos(\alpha + 30^o) - 0.5 & \text{if } 270^o \le \alpha < 330^o \end{cases}$$

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NLMF-2:

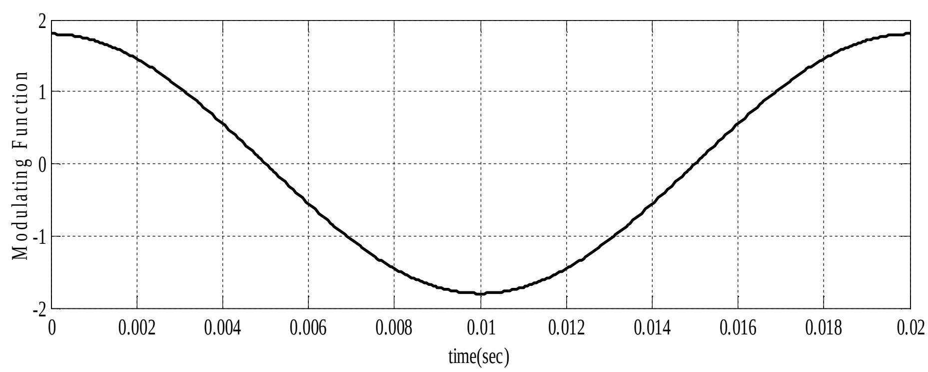
F1(m1α) =

$$\begin{cases} m\cos(\alpha-30^o) - 0.5 & \text{if } 0^o \le \alpha < 30^o \text{ or } 90^o \le \alpha < 120^o \\ 0.5 & \text{if } 30^o \le \alpha < 60^o \text{ or } 300^o \le \alpha < 330^o \\ m\cos(\alpha+30^o) + 0.5 & \text{if } 60^o \le \alpha < 90^o \text{ or } 150^o \le \alpha < 180^o \\ -0.5 & \text{if } 120^o \le \alpha < 150^o \text{ or } 210^o \le \alpha < 240^o \\ m\cos(\alpha-30^o) + 0.5 & \text{if } 180^o \le \alpha < 210^o \text{ or } 270^o \le \alpha < 300^o \\ m\cos(\alpha+30^o) - 0.5 & \text{if } 240^o \le \alpha < 270^o \text{ or } 330^o \le \alpha < 360^o \end{cases}$$

NLMF-3:

F1(m1α) =

$$\begin{cases} m\left[\cos(\alpha-30^o) - \frac{2.25}{\pi}\right] + 0.25 & \text{if } 0^o \le \alpha < 120^o \\ -0.5 & \text{if } 120^o \le \alpha < 240^o \\ m\left[\cos(\alpha+30^o) - \frac{2.25}{\pi}\right] + 0.25 & \text{if } 240^o \le \alpha < 360^o \end{cases}$$



(a)Co-sinusoidal modulating function

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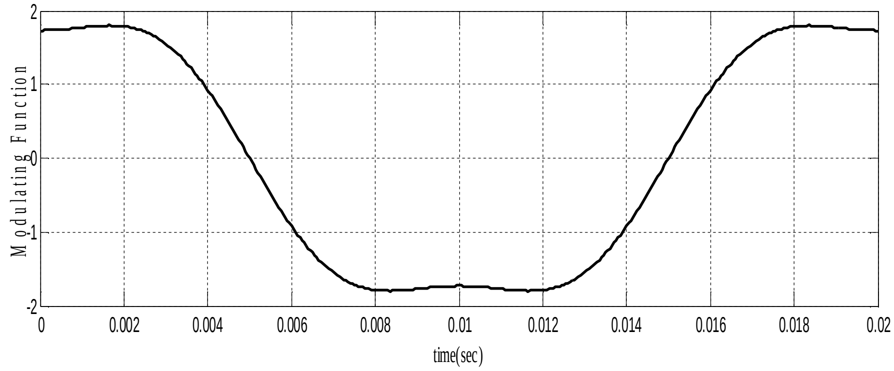
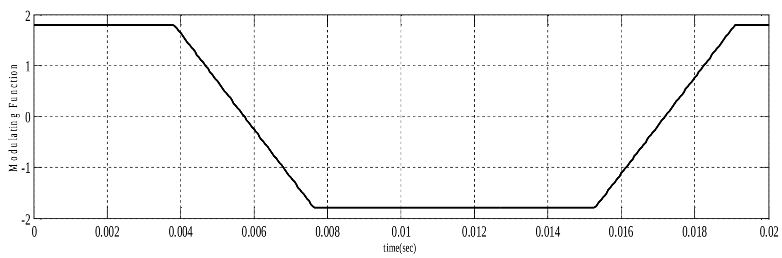
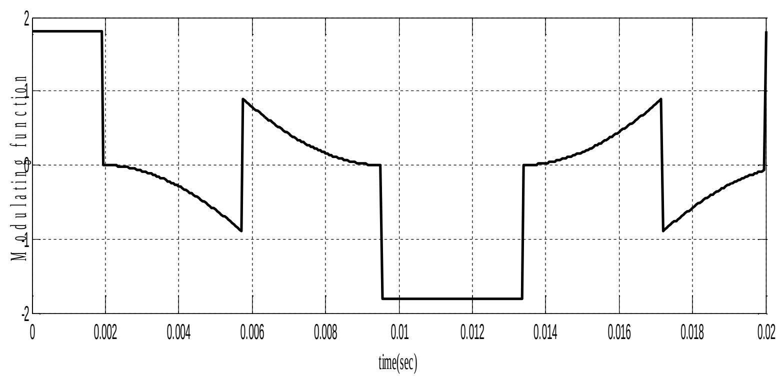


(b)Harmonic modulating function



(c)Trapezoidal modulating function



(d)Nonlinear modulating function-1

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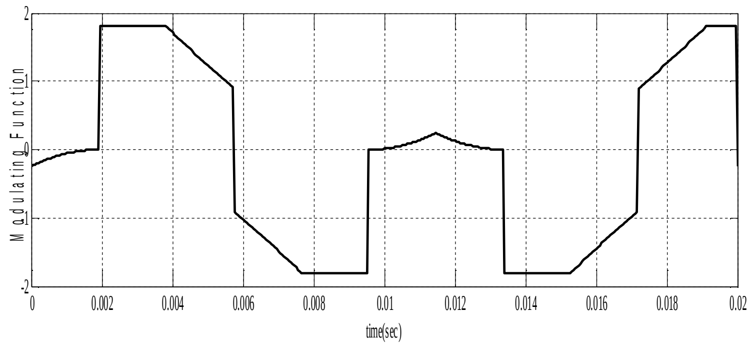
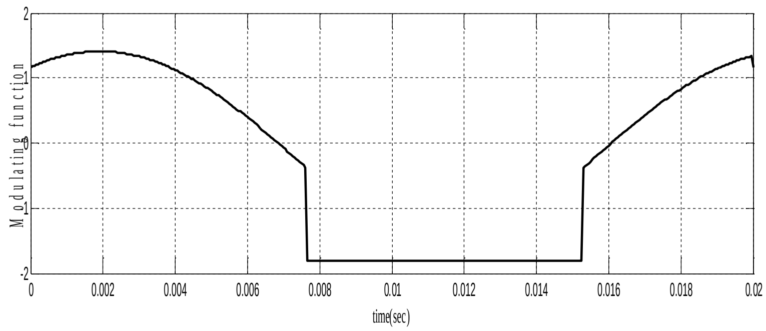
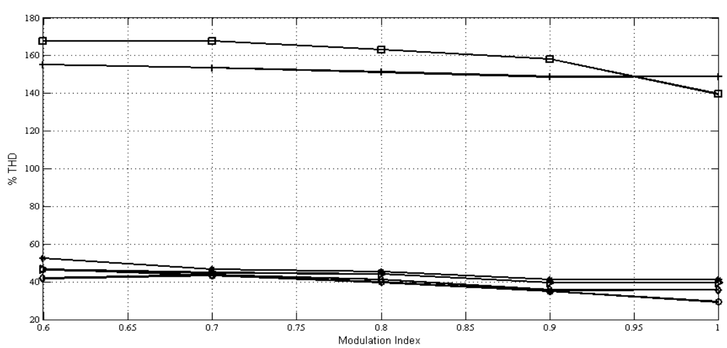


(e)Nonlinear modulating function-2



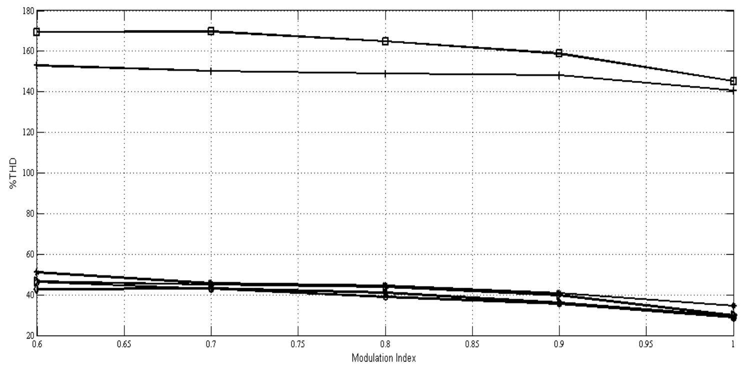
(f)Nonlinear modulating function-3

V. SIMULATION RESULTS



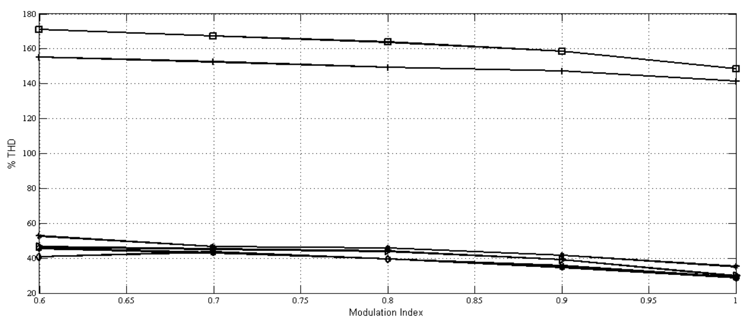
(a) APOD (THD)

The above results shows the percentage of THD of MMC verses different modulation index for different continuous and discontinues waveforms and Alternate Phase opposite disposition carrier waveform, where all carriers are alternatively in opposition, each carriers is phase shifted by 1800 from its adjacent carrier.



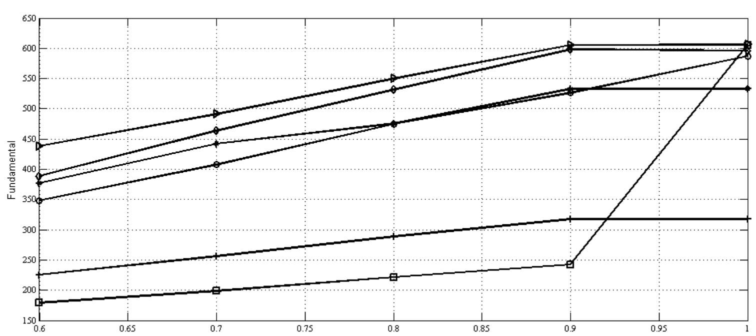
(b)PD (THD)

The above results shows the percentage of THD of MMC verses different modulation index for different continuous and discontinues waveforms and Phase disposition carrier waveform, where all carriers are in phase.



(c)POD (THD)

The above results shows the percentage of THD of MMC verses different modulation index for different continuous and discontinues waveforms and Phase opposite disposition carrier waveform, where all carriers above the zero value reference are in phase among them but in opposition with those below.



(d) APOD (Fundamental)

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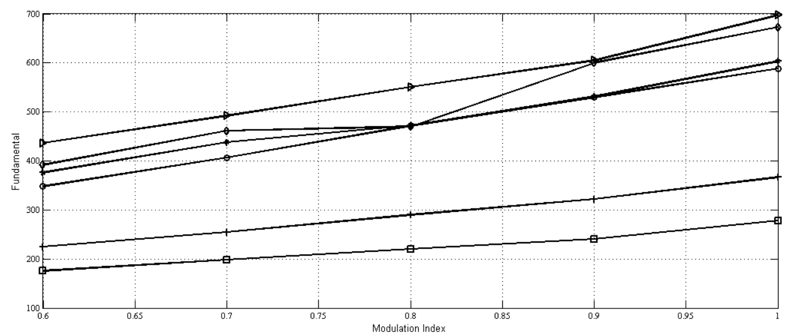
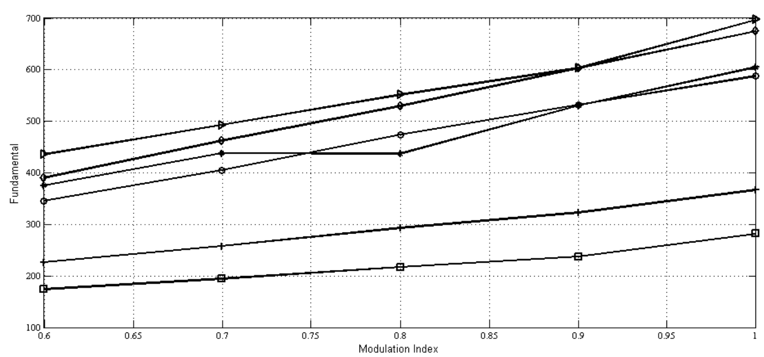
The above results shows the fundamental value reference wave of MMC verses different modulation index for different continuous and discontinues waveforms and Alternate Phase opposite disposition carrier waveform



(e) PD (Fundamental)

The above results shows the fundamental value reference wave of MMC verses different modulation index for different continuous and discontinues waveforms and Phase disposition carrier waveform.



(f)POD (Fundamental)

The above results show the fundamental value reference wave of MMC verses different modulation index for different continuous and discontinues waveforms and Phase opposite disposition carrier waveform.

Different graph of THD verses Different Modulation index shown in figures. Fig 4(a) shows the characteristics of APOD in terms of THD verses Modulation index. . Fig 4(b) shows the characteristics of PD in terms of THD verses Modulation index. . Fig 4(c) shows the characteristics of POD in terms of THD verses Modulation index. . Fig 4(d) shows the characteristics of APOD in terms of Fundamental verses Modulation index. . Fig 4(e) shows the characteristics of PD in terms of Fundamental verses Modulation index. . Fig 4(f) shows the characteristics of POD in terms of Fundamental verses Modulation index. Where CMF is represented by '○', HMF is represented by '◇', Where TMF is represented by ▷ Where NLMF-1, NLMF-2, NLMF-3, is represented by '□' '+', '*'.

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Table II

Modulation Index	0.6 THD %	0.6 Fundamental	0.7 THD %	0.7 Fundamental	0.8 THD %	0.8 Fundamental	0.9 THD %	0.9 Fundamental	1 THD %	1 Fundamental
Alternate Phase Opposite Disposition										
CMF	46.63	348	43.37	407.3	39.75	474.8	35.01	526.2	29.30	586.8
HMF	41.85	388.8	43.53	463.7	41.25	531.3	35.63	598.1	35.63	598.1
TMF	46.44	438.1	44.78	491	44.05	550	39.52	605.6	39.52	605.6
NLMF-1	167.81	178.9	167.70	198.6	163.14	221.2	158.09	242.3	139.52	607.6
NLMF-2	155.15	225.7	153.56	256.2	151.21	288.8	148.85	317.3	148.85	317.3
NLMF-3	52.45	377.1	46.61	441.9	95.41	475.5	41.19	532.8	41.19	532.8
Phase Disposition										
CMF	45.57	347.7	43	407	39.54	471.6	34.81	529.5	28.69	588
HMF	40.87	391.9	43.40	461.2	39.63	470.2	35.62	600.4	28.84	673
TMF	46.42	436.8	45.14	492.1	44	550.9	39.16	604.7	29.67	697
NLMF-1	171.17	175.3	167.34	198.4	163.84	220.2	158.51	240.3	148.63	278
NLMF-2	155.15	225	152.61	254.6	149.49	289.6	147.35	322.3	141.46	366.7
NLMF-3	52.60	376	46.54	437.8	45.72	472.1	41.65	531	35.12	603
Phase Opposite Disposition										
CMF	46.11	345.5	42.94	405.2	38.87	473.8	35.59	532	28.76	587.6
HMF	42.74	390.4	43.03	462.1	41.01	529.6	36	603.3	29.28	675
TMF	46.33	435.4	44.94	492.8	43.64	551.2	39.64	603.4	29.65	697
NLMF-1	169.46	174.3	169.64	194.2	164.80	217	159.82	237.7	145.27	281.8
NLMF-2	153	226.5	150.18	257.9	149.06	292.9	148.07	322.8	140.59	367.1
NLMF-3	50.98	375.2	45.56	438.3	44.58	473.1	40.83	530.7	34.56	604.8

HARMONICS ANALYSIS OF APOD, PD AND POD WITH CONTINUOUS AND DISCONTINUNUOS MULTICARRIER WAVEFORM

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VI.CONCLUSION

The modular multilevel converter and different multi-carrier continuous and discontinuous PWM techniques.Have been discussed in this paper. THD and harmonic spectrum, from simulations with the MATLAB software have been reported. Comparison of the typical multicarrier continuous and discontinuous PWM techniques. the simulation results which are shown in fig IV(a) to IV(d) and Table II shows that multi-carrier discontinuous PWM methods gives more harmonics distortion in the output voltage because it does not cut often to carrier signal, while continuous modulation methods gives less distortion in the output voltage because the reference waveform is continuous and cuts to more points in the carrier waveform. The distortion in the output voltage is given without filter. Discontinuous modulation though gives high distortion, it gives low switching losses. Simulation results acknowledge the above opinions.

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BIOGRAPHY

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