Performance Evalualtion of Three Phase Cascaded H-Bridge Multilevel Inverter Based on Multi Carrier PWM Techniques

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Objectives

♦ To design and implement the various 3-phase Multi level Inverter topologies available in the literature.

♦Analysis of various PWM techniques applied to cascaded H-Bridge MLI.

♦ Identification of benefits of over modulation range for all control schemes.

♦ To propose a new reference/carrier based PWM scheme.

♦ Comparing the performance of the proposed scheme with that of the existing control schemes.

Three phase Multi-level Inverters

Need for multi-level inverters-present problems

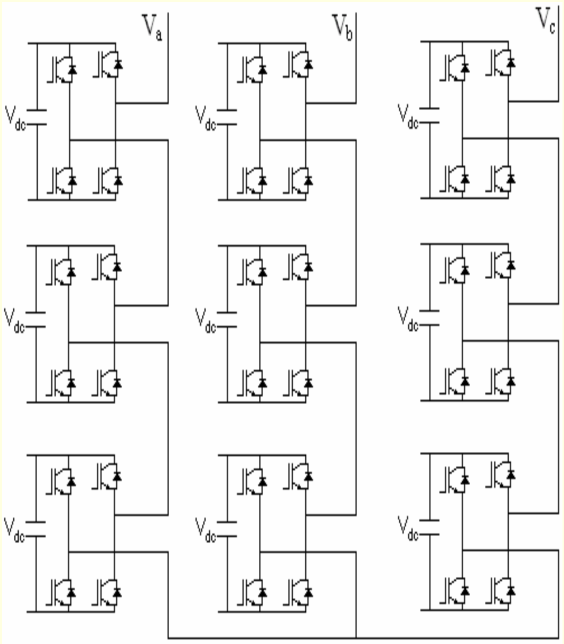
- Single devices can’t handle the V and I.
- Device voltage rating required 8-10kV - not available.
- Voltage handling capability problem.
- Poor Power quality due to harmonic distortions.
- High Switching losses

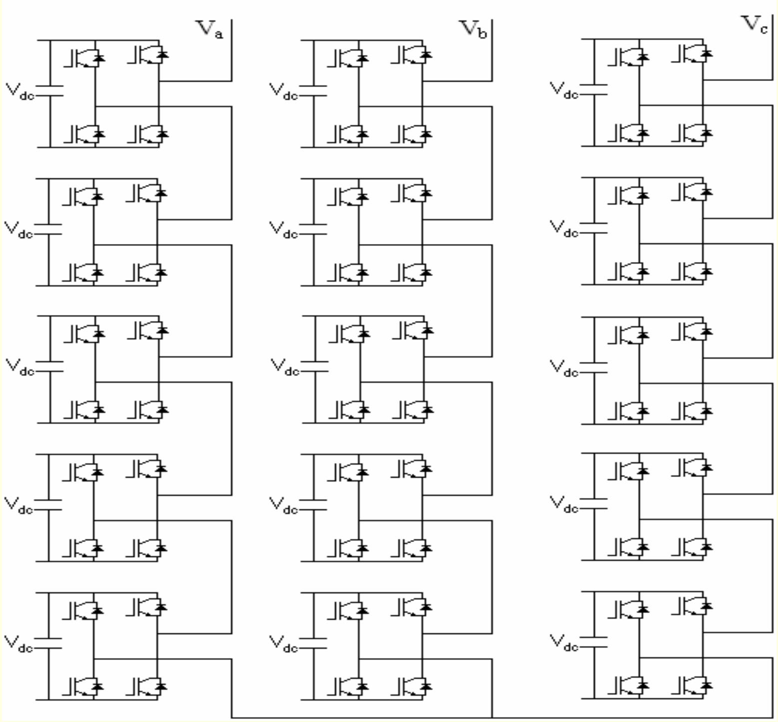
INVERTER TOPOLOGIES

- The are 3 basic types of multi-level inverter
  - Isolated H-bridge
  - Diode clamped inverter
  - Flying capacitor inverter

- Combinational Multilevel Topologies
  - Cascading Fundamental Topologies

Three phase Cascaded H-bridge MLI





- Each H-bridge must have an isolated DC supply - usually derived from an isolated AC supply via a diode bridge
- Each bridge can produce $+V_{dc}$, 0, $-V_{dc}$ independently
- With N bridges per phase, V_{AO} etc has 2N+1 levels and V_{AB} has 4N+1 levels

Merits and Demerits

Merits:

- Device voltage sharing is automatic because of the independent DC supplies. There is no restriction on switching pattern.

- With N devices (each capable of operating at voltage V_{dc}) per-phase, the circuit can produce an output varying between $\pm(N/2)*(V_{dc}/2)$. By using a lot of H-bridges, very high voltage converters can be made this way.

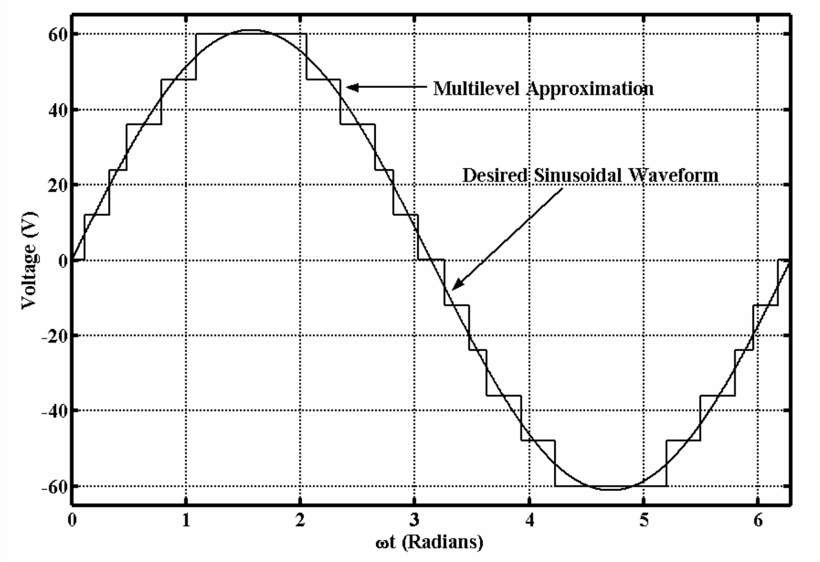
- The circuit is modular – this is an advantage for manufacture and maintenance.

Demerits:

- Each H-bridge needs an isolated DC supply compared to the other solutions which need only one supply.

Need for modulation schemes

- One pitfall of using multilevel inverters to approximate sinusoidal waveforms concern harmonics
- The multilevel switching schemes inherently provide the opportunity to eliminate certain higher order harmonics by varying the time at which certain switches are turned "on" and turned "off" (i.e. varying the switching angles)



Typical multilevel inverter output using five equal dc sources.

Pulse width modulation methods

The natural sampling techniques for a multilevel inverter are categorized into two and they are:

- Single-Carrier SPWM (SCSPWM) and
- Sub-Harmonic PWM (SHPWM)

Sub-Harmonic PWM is an exclusive control strategy for multilevel inverters and has further classifications. They are:

1. Carrier Disposition PWM methods

- Phase Disposition (PD)
- Alternative Phase Opposition Disposition (APOD)
- Phase Opposition Disposition (POD)

2. Phase Shifted Carrier PWM method (PSPWM)

Control Degrees Of Freedom

- **Frequency Modulation Index**

$$M_f = f_c / f_0$$

- **Amplitude Modulation Index**

$$M_a = A_0 / A_{cpp}$$

- **Angle Of Phase Displacement**

$$\phi = \sin^{-1}(A_c / A_m)$$

- **CDPWM**

$$M_a = (2A_0)/(n-1)A_c$$

$$M_f = f_c / f_0$$

- **PSPWM**

$$M_a = A_0 / A_{cpp}$$

$$\theta_c = 2\pi / M_f$$

$$\theta_{sh} = \theta_c /(n-1)$$

π

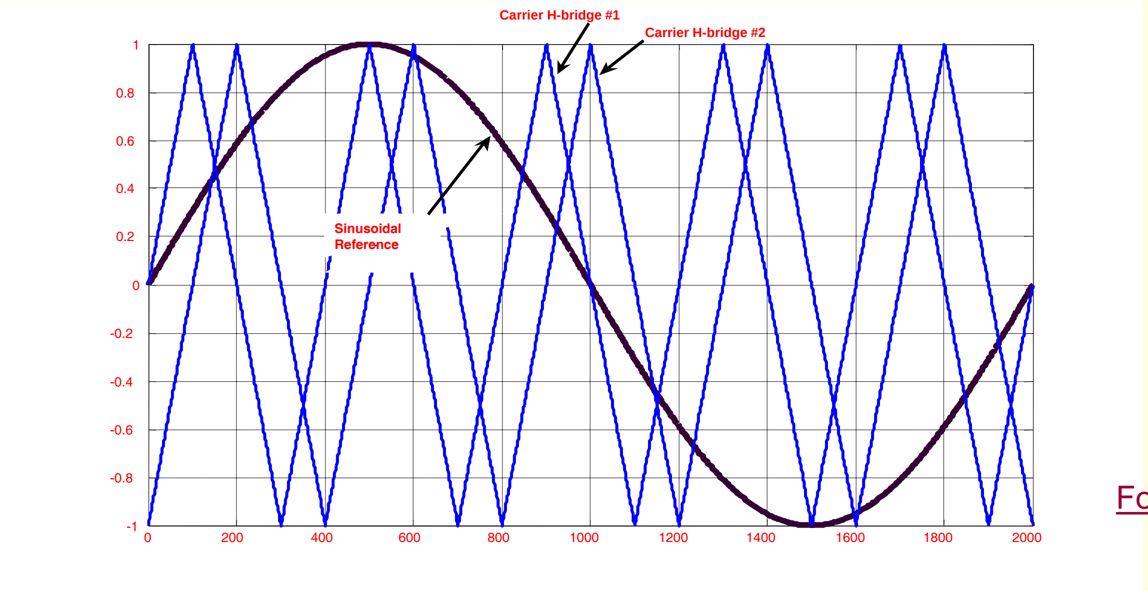
PSPWM

- Optimum harmonic cancellation is achieved, phase shifting each carrier by

(k-1)π/n, where, k is the kth inverter,

n is the number of series-connected single phase inverters

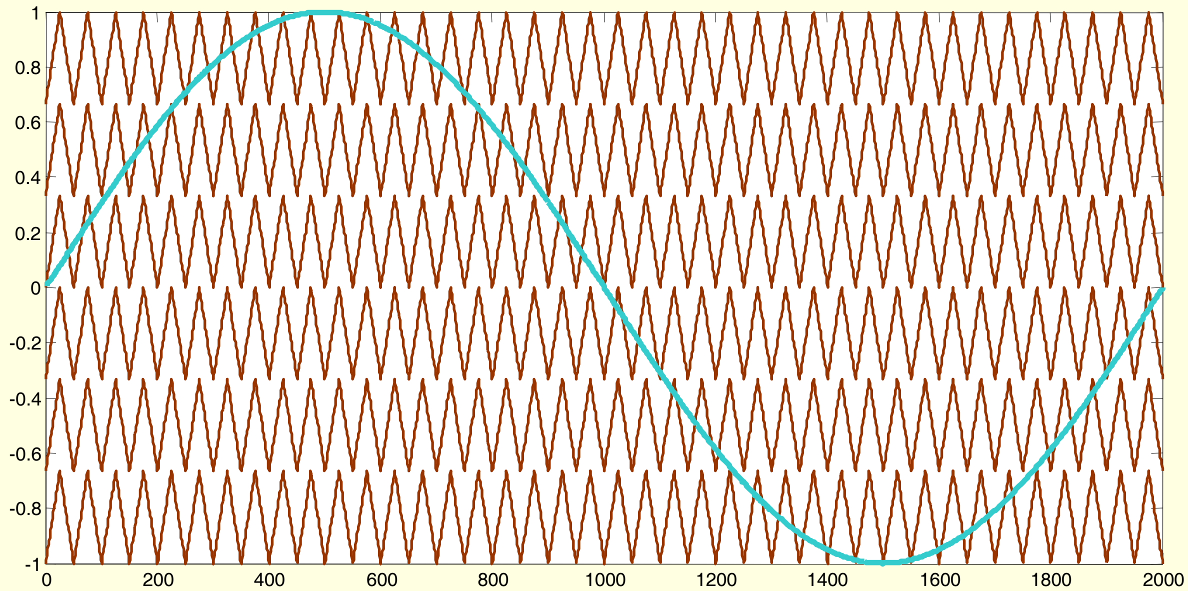
n= (L-1)/2 where L is the number of switched DC levels that can be achieved in each phase leg.



For example

PDPWM

- The carriers are in phase across all the bands.
- For this technique, significant harmonic energy is concentrated at the carrier frequency, but since it is a co-phasal component, it doesn't appear in the line-to-line voltage.

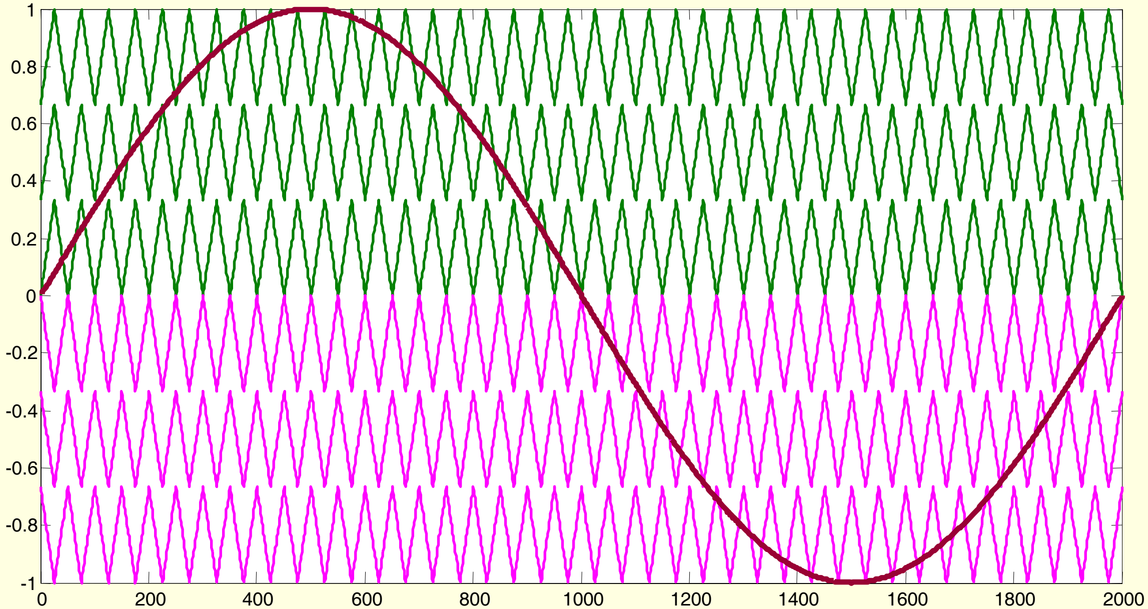


For example

PODPWM

- All the carriers above the zero reference are in phase and carriers below the zero reference are also in phase but are phase shifted by 180° with respect to that above zero reference.

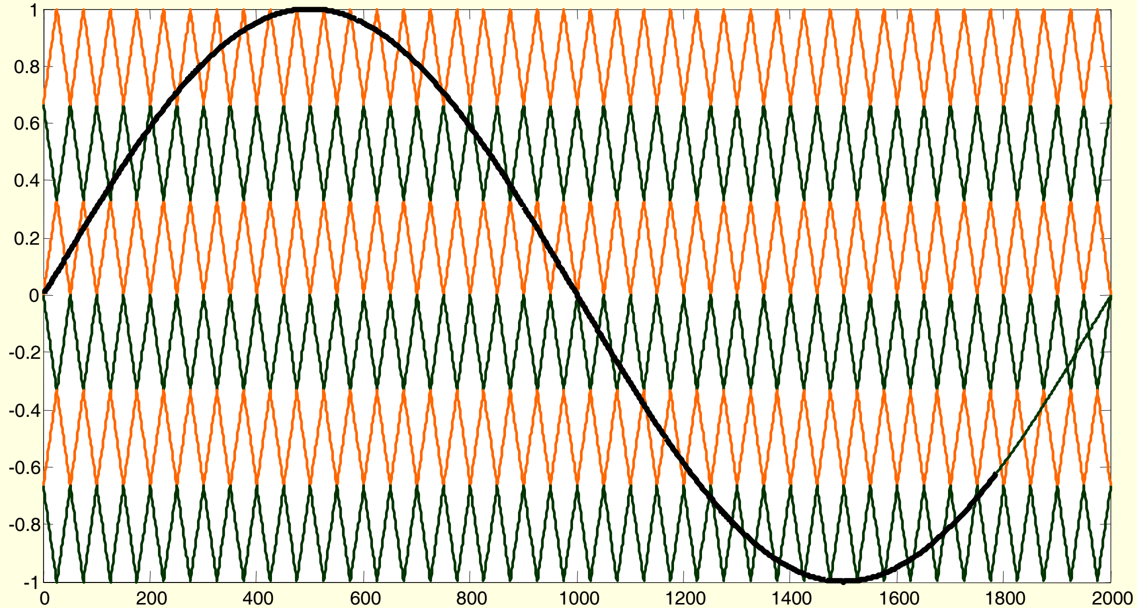
- The significant harmonics are located around the carrier frequency, for both the phase and line-to-line voltage waveform.



For example

APODPWM

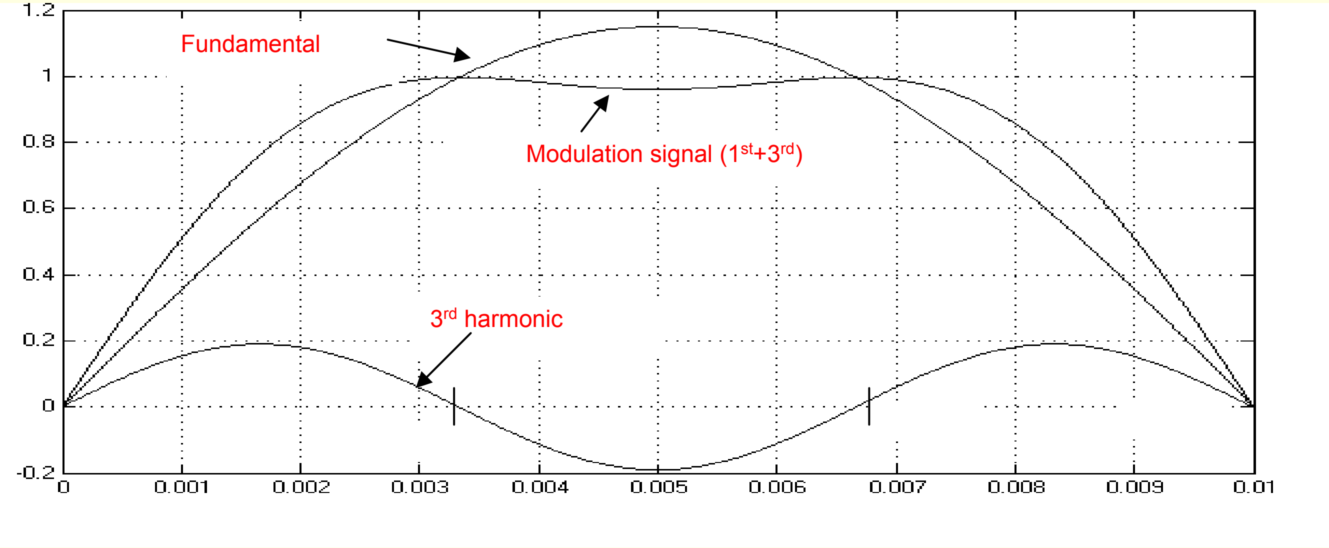
- Carriers in adjacent bands are phase displaced by 180°.
- With this method, the most significant harmonics are centered as sidebands around the carrier.



For example

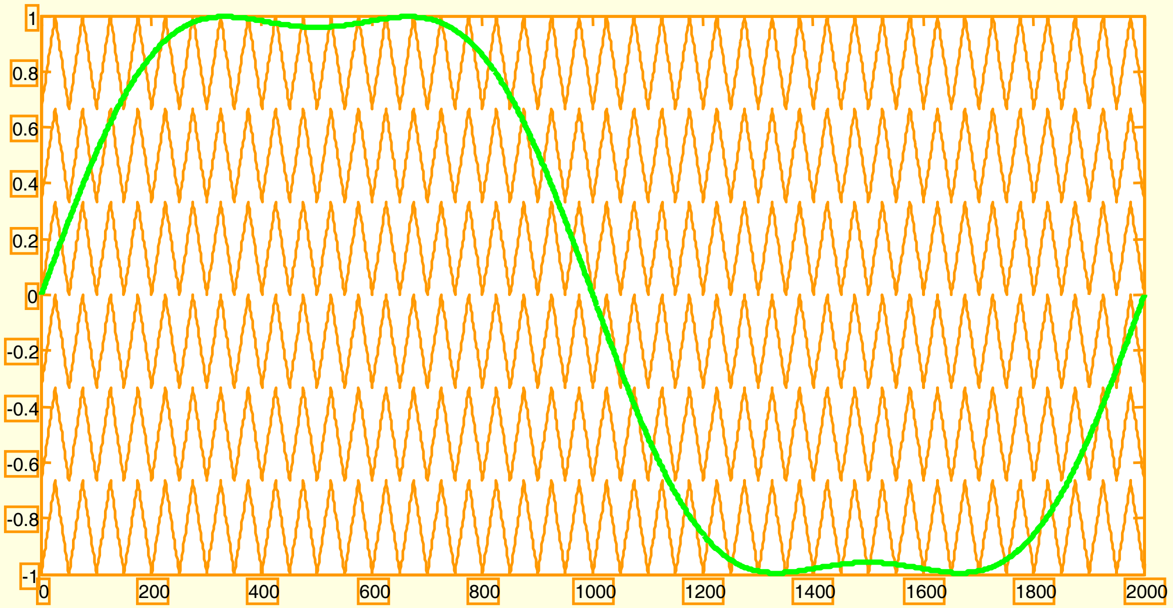
THIRD HARMONIC INJECTION

- For the third harmonic injected, reference values of the equation can be given as $y = 1.15\sin\theta + 1.15/6\sin3\theta$
- The resulting flat-topped waveform allows over-modulation (with respect to the original sine PWM technique) while maintaining excellent ac term and dc term spectra.



Advantages of THI-PWM

- This is an alternative to improve the fundamental voltage without entering the over modulation range.
- So, any carriers employed for this reference will enhance the fundamental by 15 percent without increasing the harmonics.



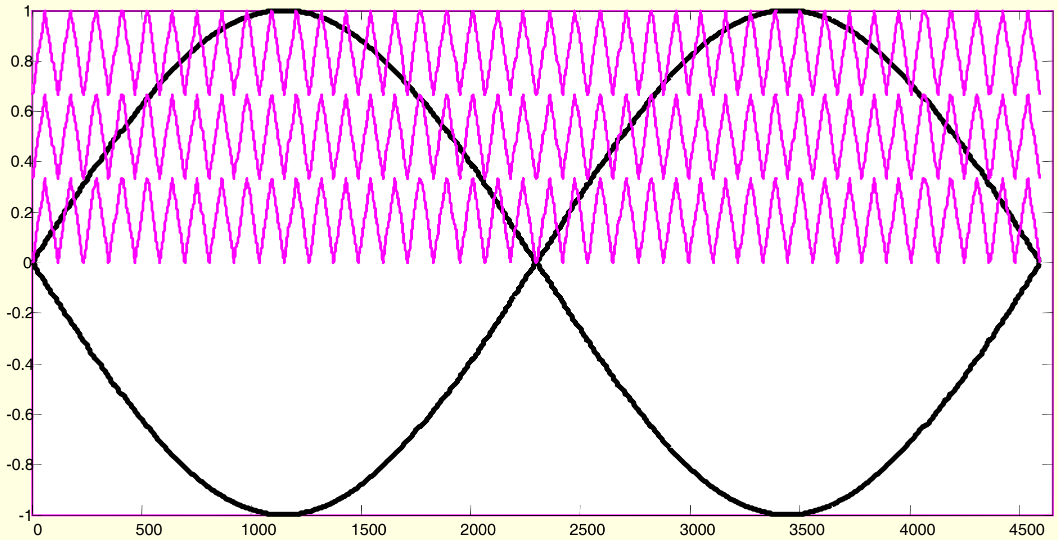
UNIPOLAR-MCPWM

- In this method a Unipolar multi carrier scheme is obtained by comparing the rectified sinusoidal reference or with two sine references (sine and 180^o phase shifted sine), with multi carriers positioned above the zero level.
- This scheme has the advantage of effectively doubling the switching frequency as far as the output harmonics are concerned, where the lowest harmonics appears as side bands of twice switching frequency.
- Here only n carriers are required for obtaining 2n+1 levels, unlike in above methods 2n+1 carriers are required.

UNIPOLAR-CDPWM

- Control degrees of freedom

$$M_a = \frac{A_r}{nA_c} \qquad M_f = \frac{f_c}{f_r}$$

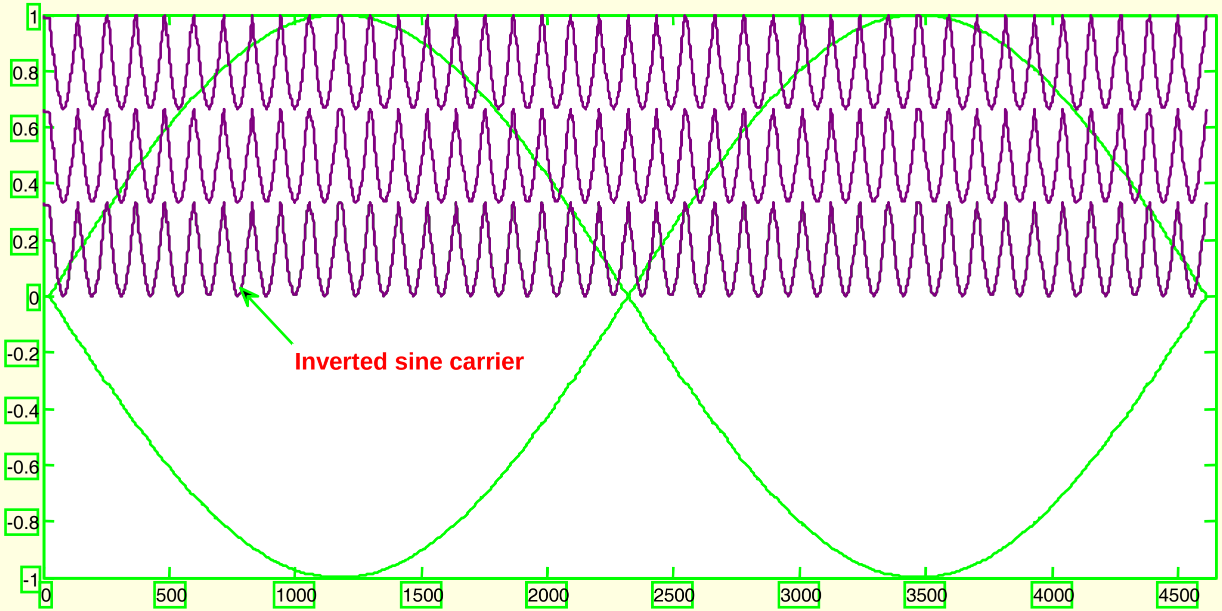


For example

UNIPOLAR-ISCPWM

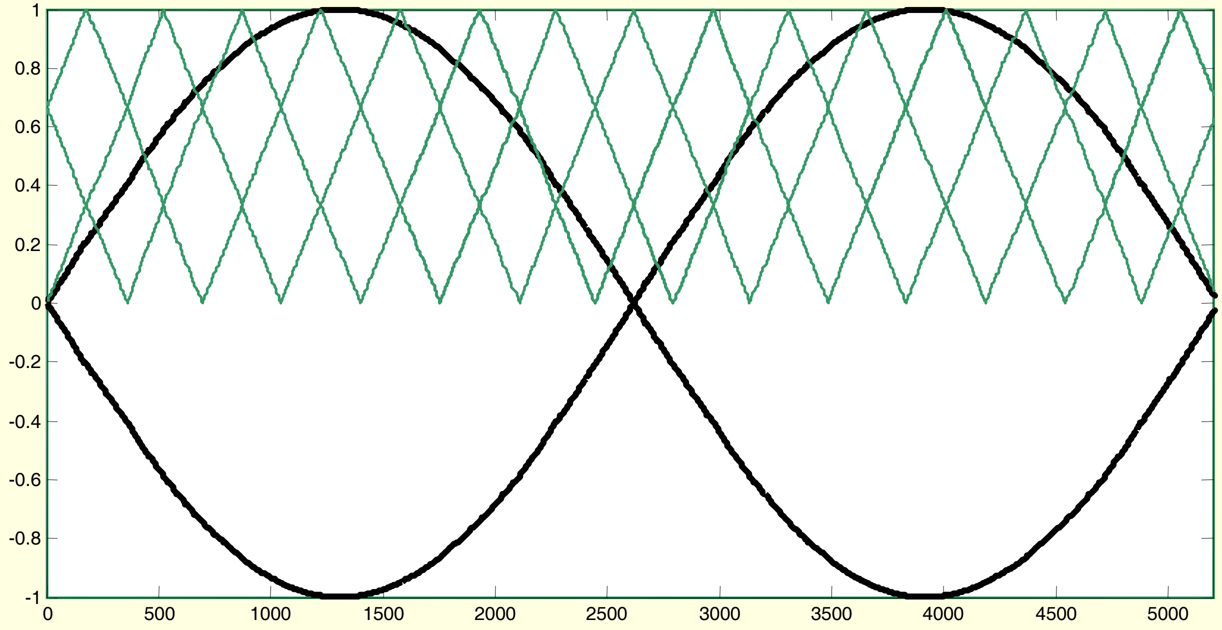
- The control scheme uses an inverted (high frequency) sine carrier that helps to maximize the output voltage for a given modulation index.

- Enhanced fundamental component demands greater pulse area. The difference in pulse widths (hence area) resulting from triangle wave and inverted sine wave with the low (output) frequency reference sine wave can be easily understood.



UNIPOLAR-PSPWM

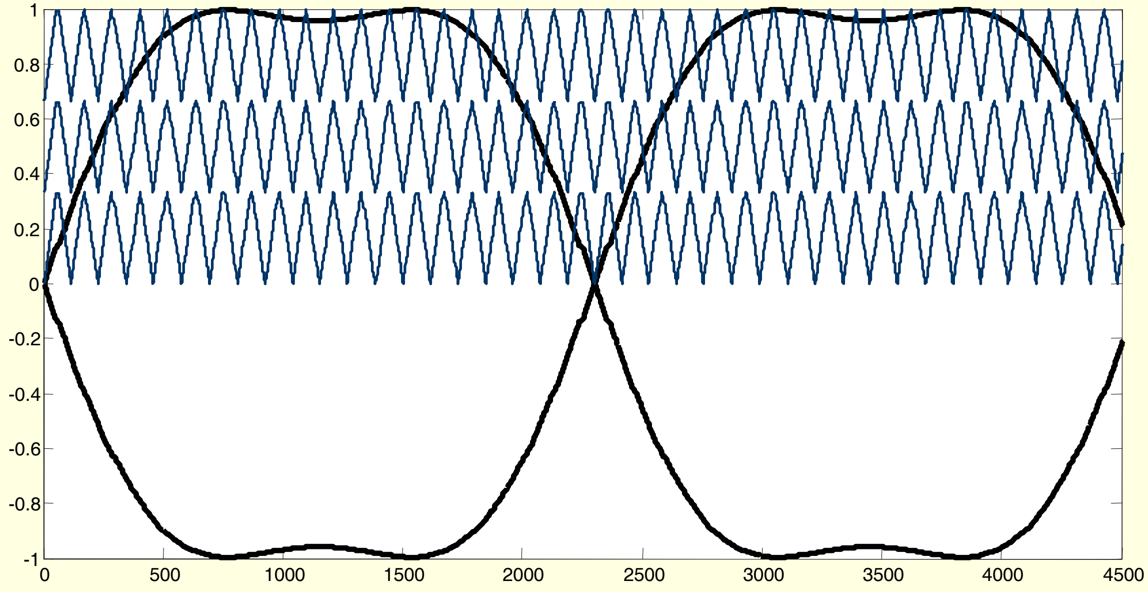
- In this method similar to above sinusoidal reference PSPWM, the carriers are phase shifted but all the carriers are arranged above the zero level.



UNIPOLAR-THIPWM

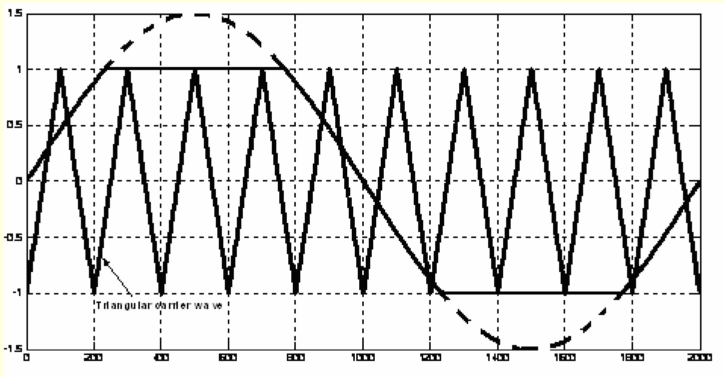
- Third Harmonic Injection unipolar PWM method is obtained by adding the third harmonic component to fundamental sine in right proportion and the obtained sine and 180° phase shifted ones are super imposed.

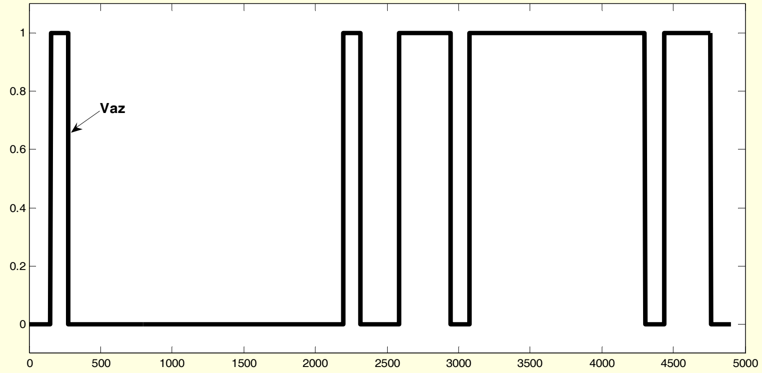
- The multi carriers used above are now compared by the obtained reference.



OVERMODULATION

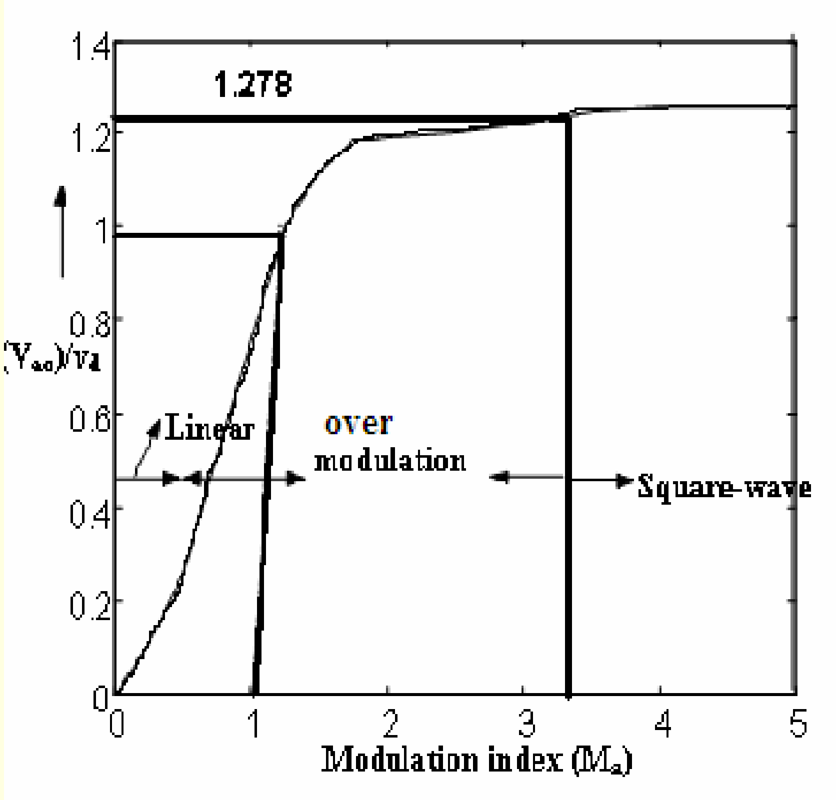
- In PWM overmodulation, the peaks of the control voltages are allowed to exceed the peak of the triangular waveform.
- Overmodulation is not intended to be a normal operating condition for a multilevel inverter, but in many applications there may be brief periods where the demanded output is sufficiently large for pulse-dropping to occur





Region of operation

- Unlike the linear region, in this mode of operation the fundamental frequency voltage magnitude does not increase proportionally with M_a.
- In the overmodulation region compared to the region with $M_a < 1.0$, more side band harmonics appear centered around the carrier frequencies, M_f and its multiples.



Simulation results

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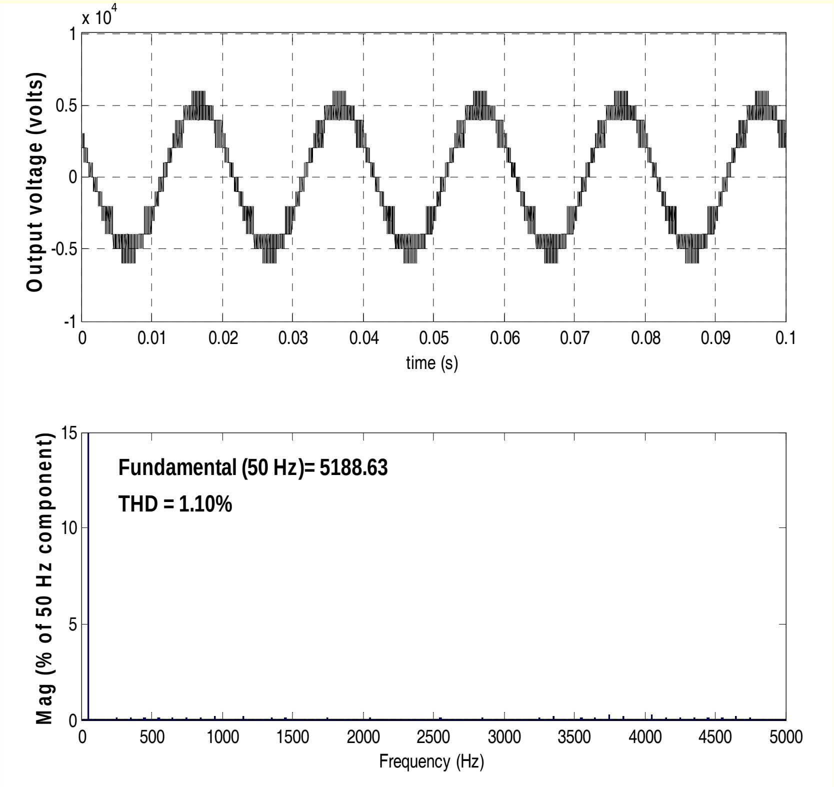
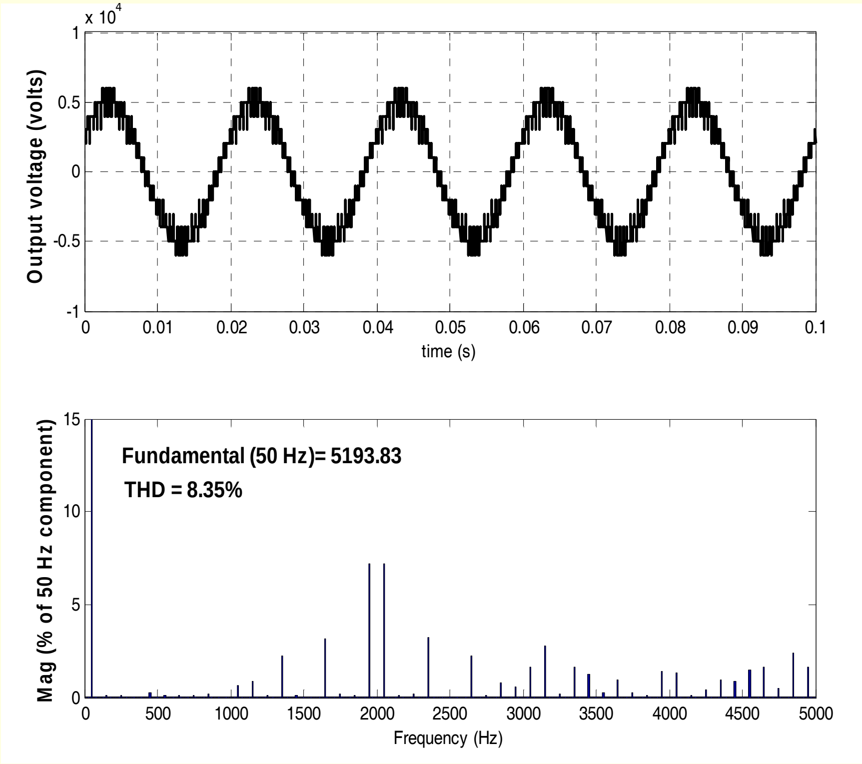
- Each module has a separate DC source of 1000V.
- The load is star connected RL load of 10ohm resistance and a 0.1H inductance

Connected in series.



Harmonic spectrum of MLI with PSPWM



Harmonic spectrum of MLI with PDPWM

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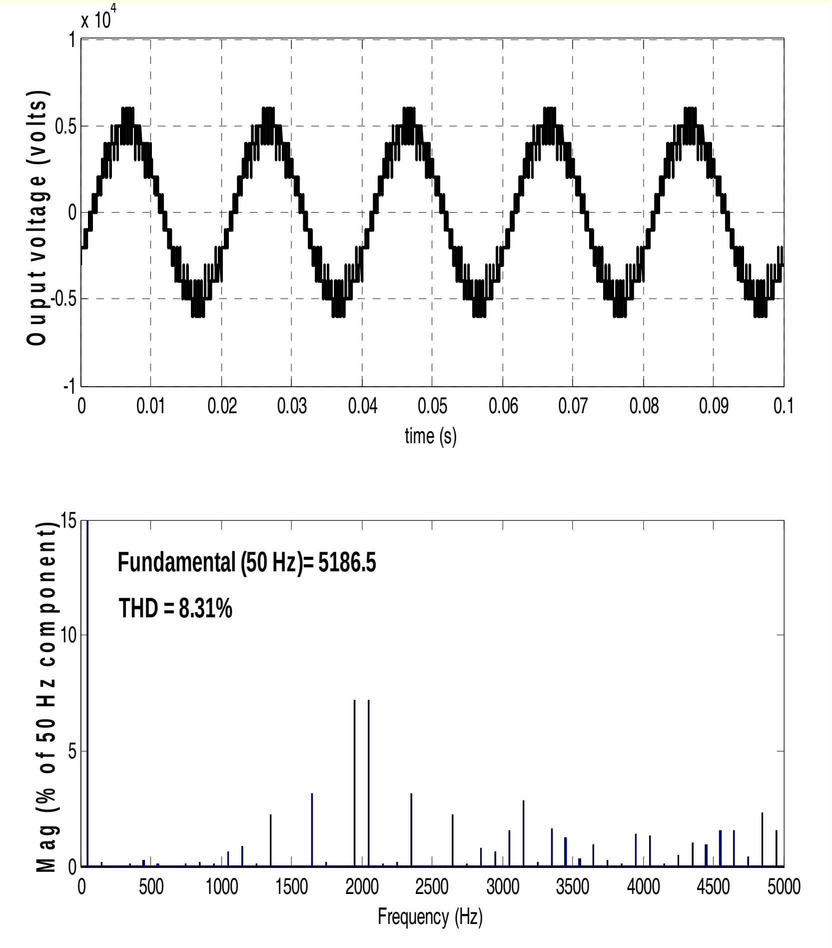
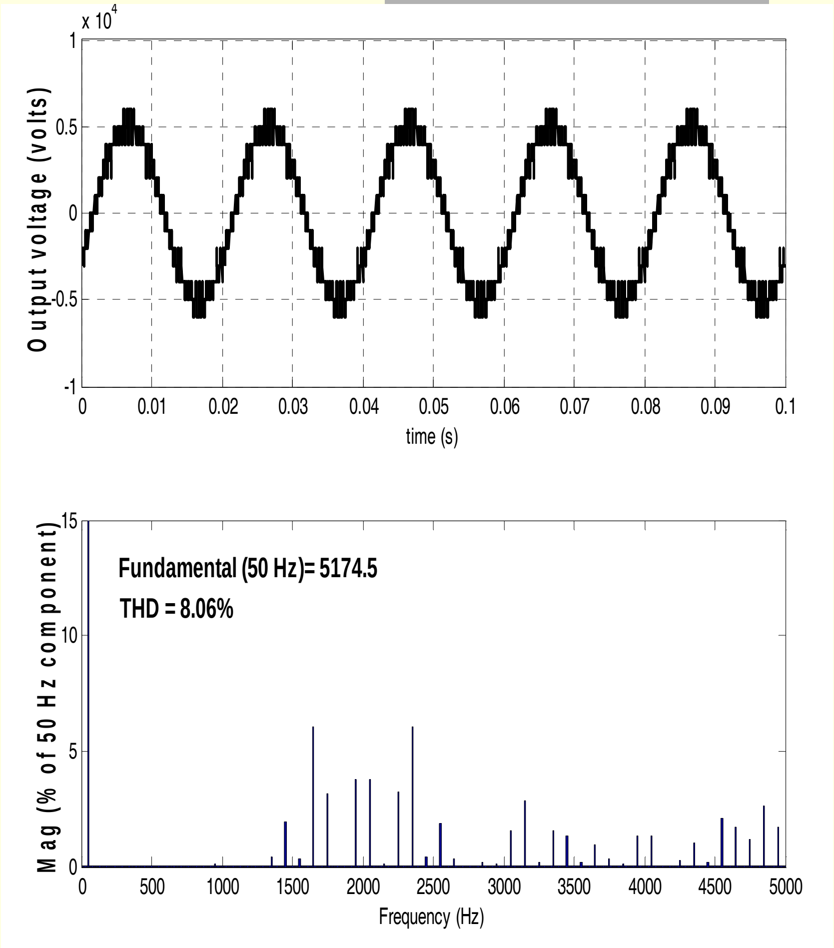


Harmonic spectrum of MLI with PODPWM



Harmonic spectrum of MLI with APODPWM

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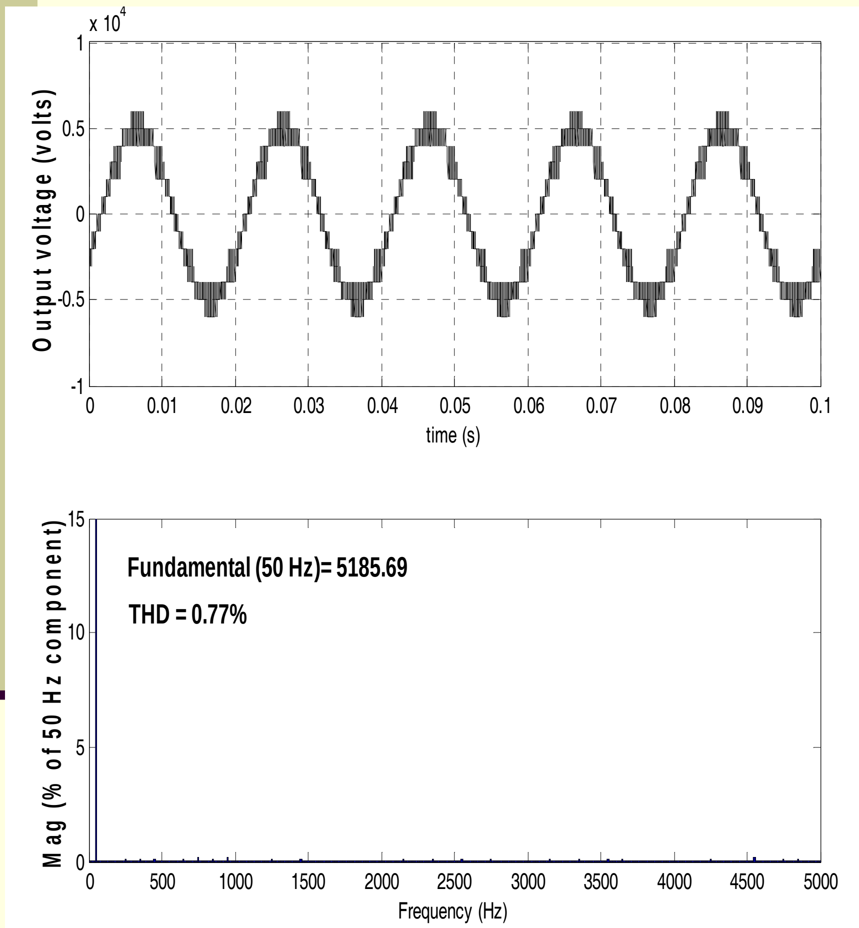
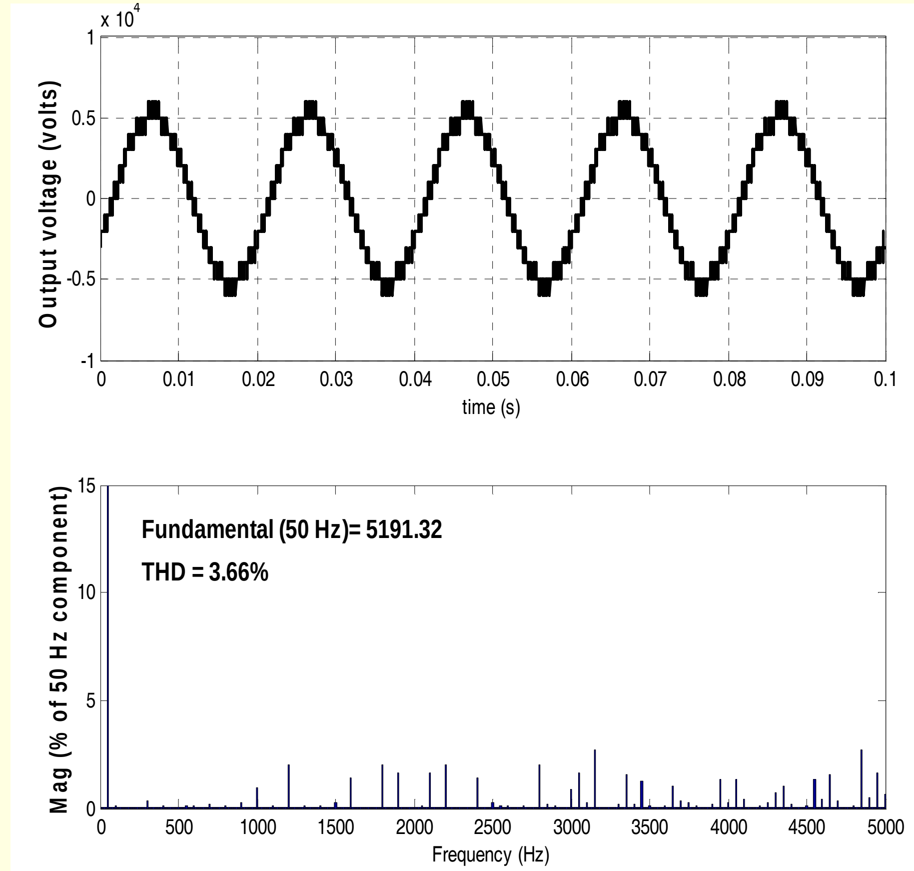
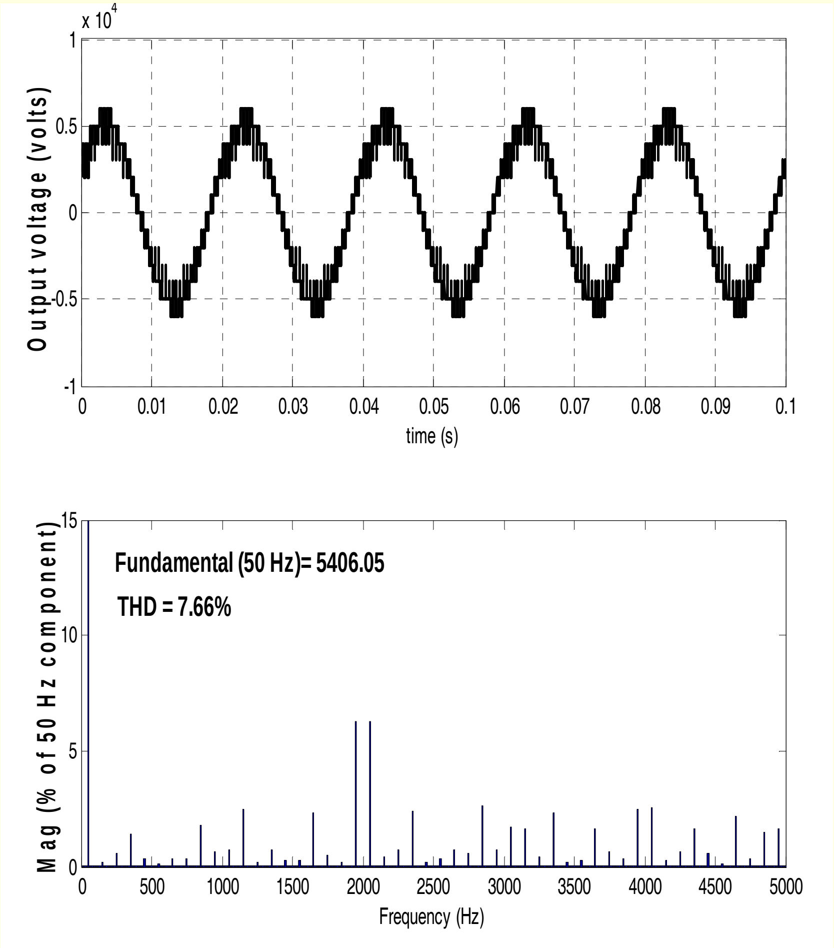


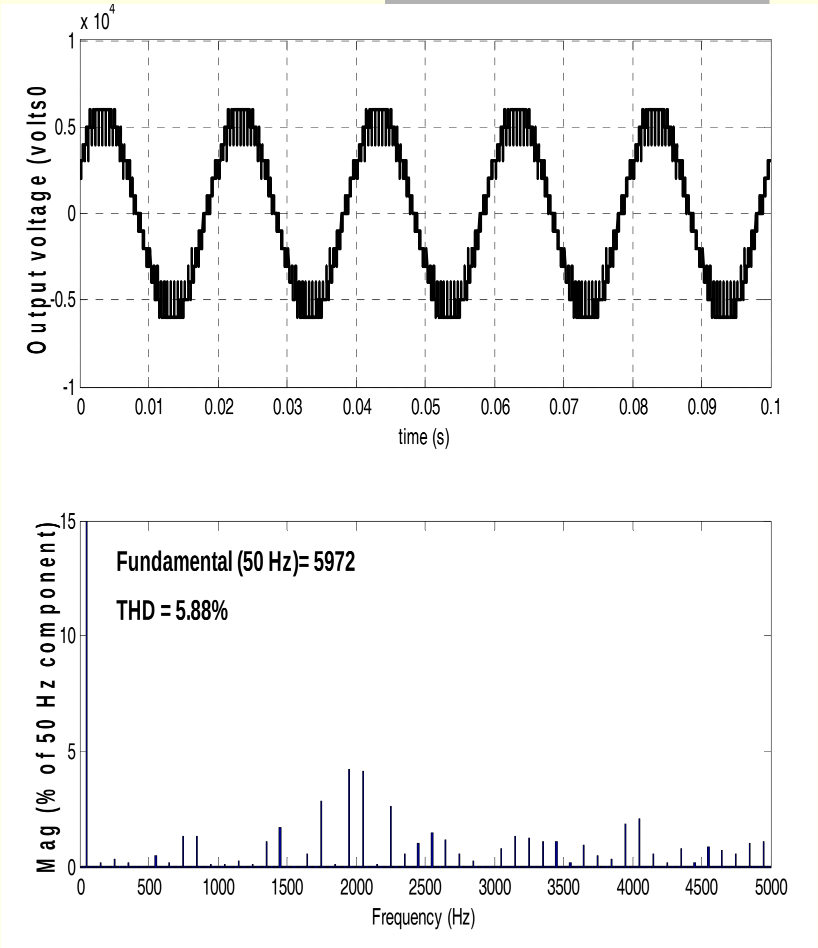
Harmonic spectrum of MLI with Unipolar-PSPWM



Harmonic spectrum of MLI with Unipolar-PDPWM



Harmonic spectrum of MLI with Unipolar-ISCPWM



Harmonic spectrum of MLI with Unipolar-THI-PDPWM

Comparison of results

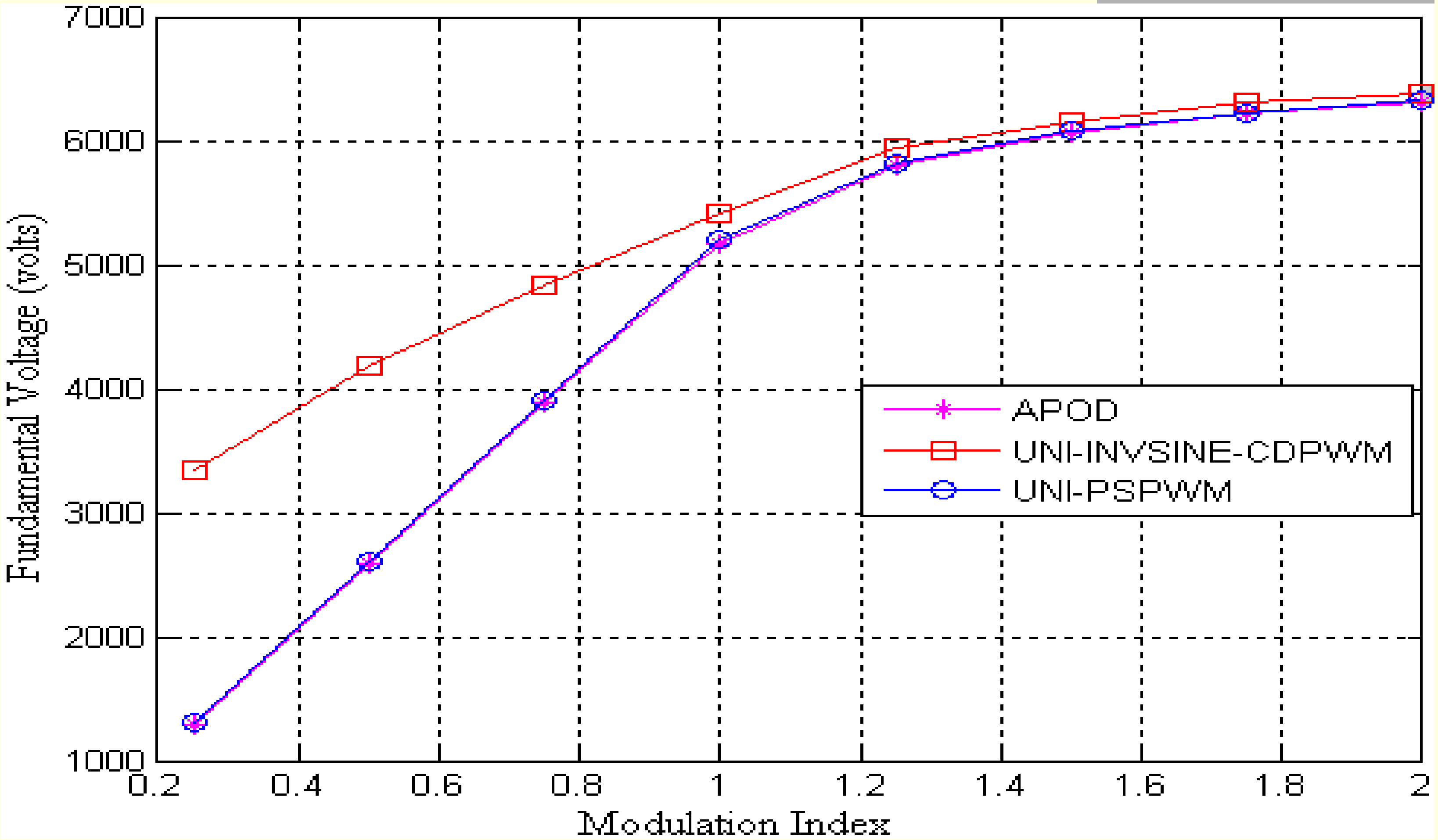
Table1 Summary of simulation results for three phase H-Bridge 3-cell multilevel inverter

PWM Technique	Voltage (volts)	THD (%)
PSPWM	5195	1.13
APOD	5170	8.06
POD	5206	8.31
PD	5189	8.35
Unipolar-MCPWM	5185	3.66
Unipolar-ISC	**5414**	**4.61**

Table2 Summary of simulation results for three phase H-Bridge 3-cell multilevel inverter with third harmonic injected reference

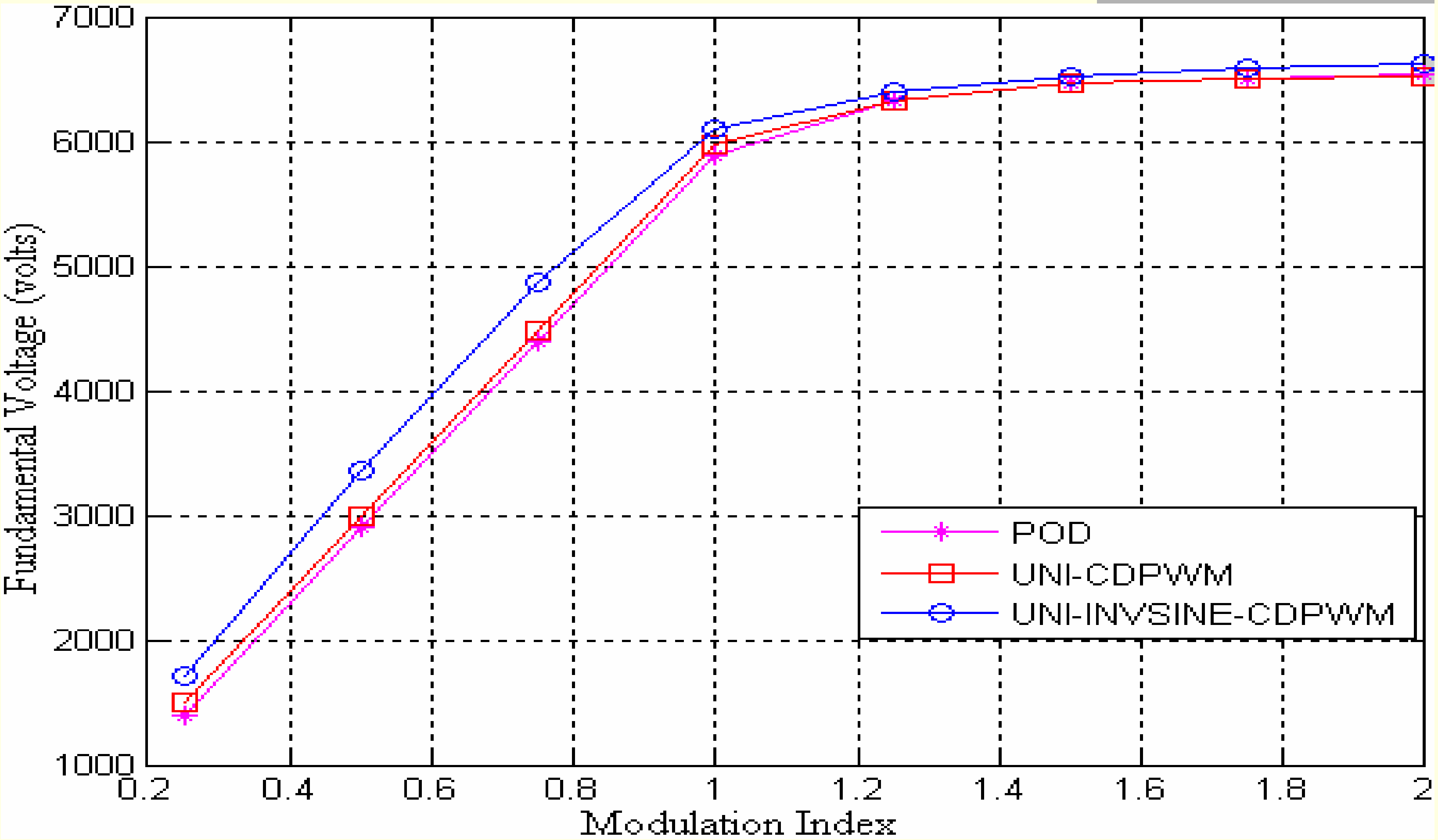
PWM Technique	Voltage (volts)	THD (%)
THI-POD	5991	5.78
THI-PD	5967	3.62
THI-APOD	5971	6.44
THI-Unipolar ISC	**6093**	**5.93**
THI-Unipolar MCPWM	5966	5.88

Ma Vs. Voltage



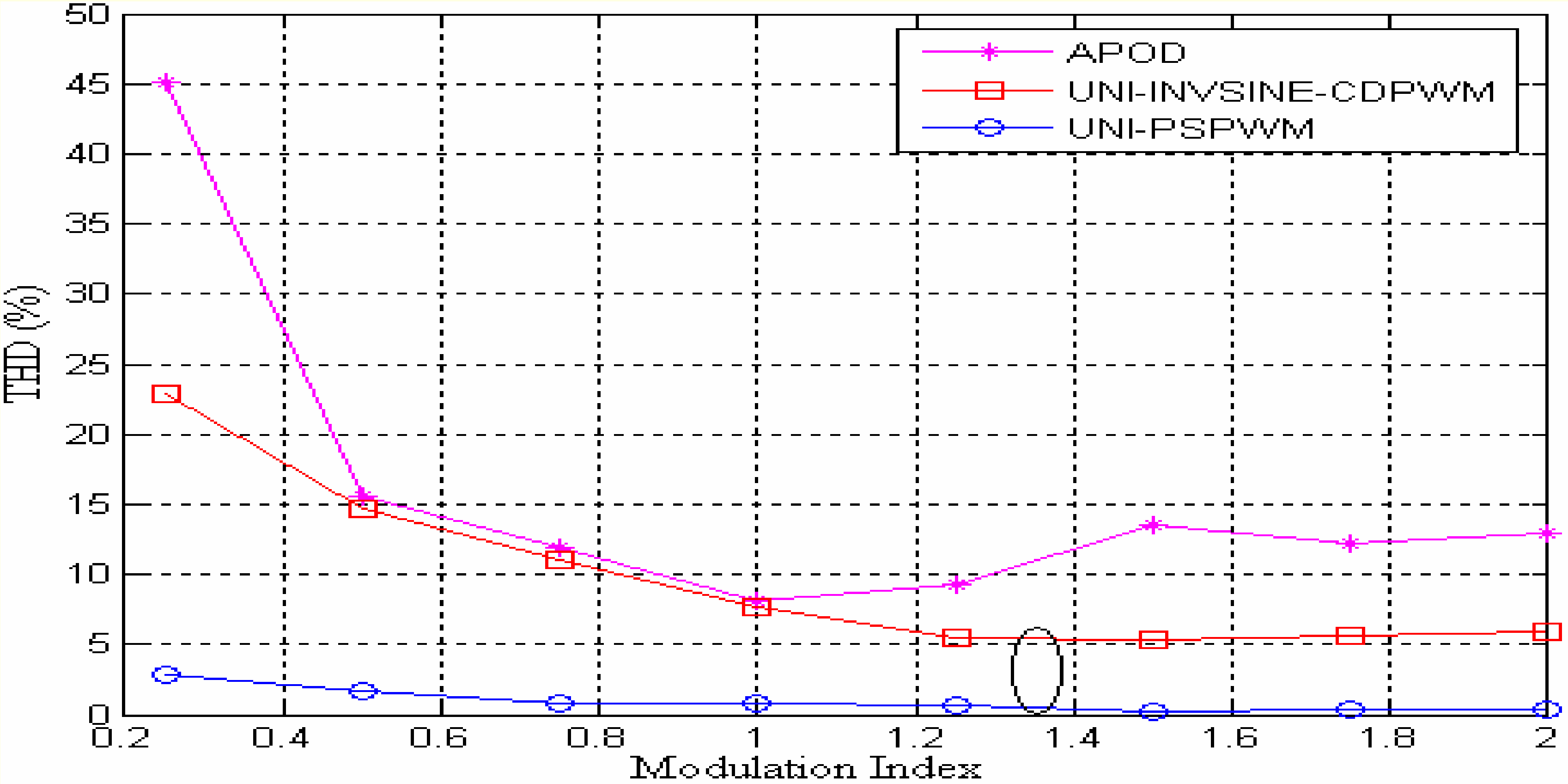
Comparison of conventional methods with unipolar--multicarrier PWM technique

Ma Vs. Voltage



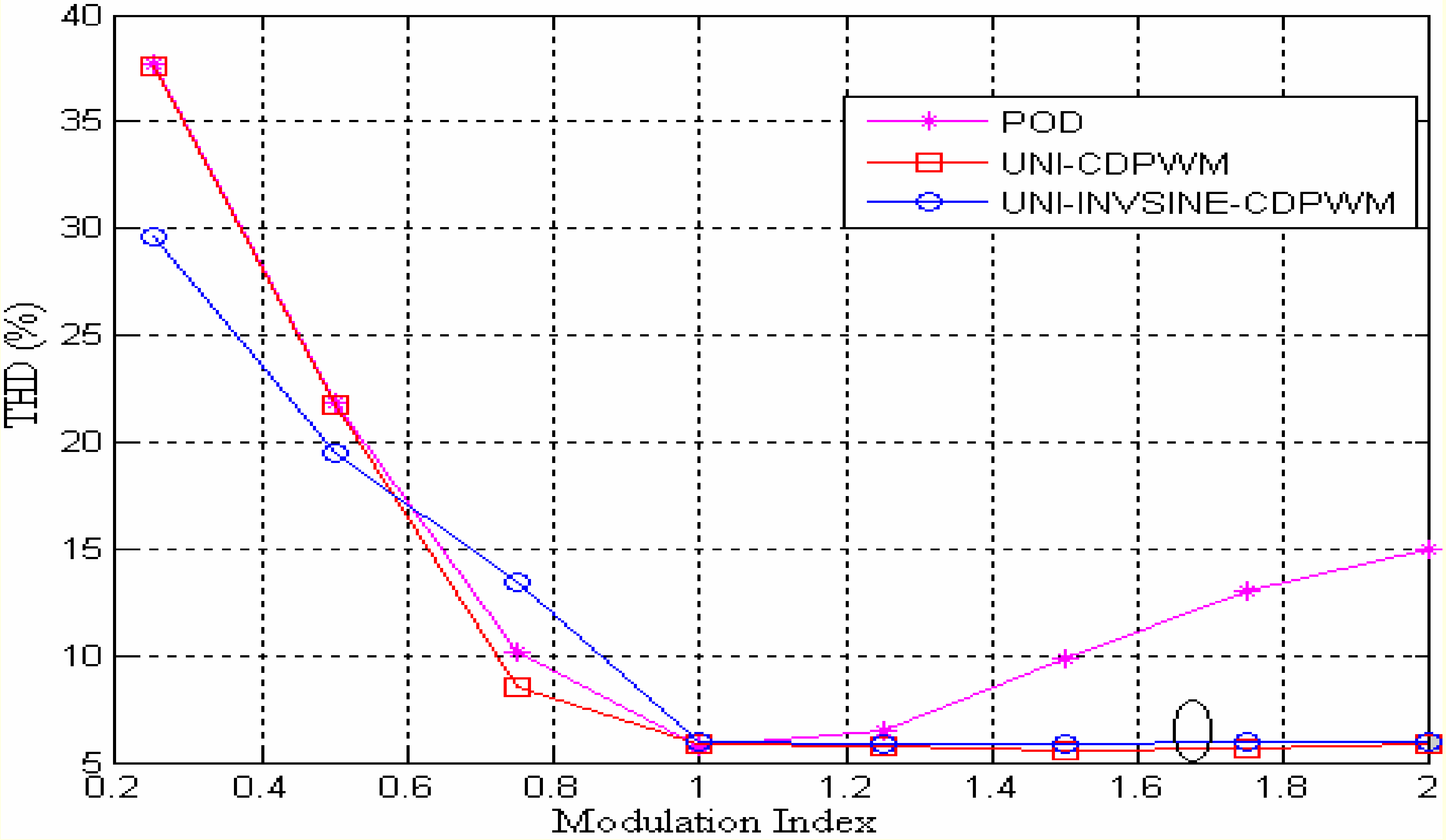
Comparison of conventional methods with unipolar--multicarrier PWM technique

M_a Vs. THD



Comparison of conventional methods with Unipolar-multicarrier PWM technique

M_a Vs. THD



Comparison of conventional methods with Unipolar-multicarrier PWM technique

CONCLUSIONS

- Three phase H-bridge 2-cell, 3-cell and 5-cell multilevel inverters are simulated using the conventional PWM techniques as well as the proposed PWM technique and the results were compared.
- The analyzed new technique has advantages compared to the already existing techniques available in the literature.
- The proposed unipolar-ISCPWM technique improves the fundamental voltage.
- The complexity of the pulse generation is reduced as the number of carriers is reduced to half compared to the already existing CDPWM techniques.
- Also M_a can be varied over a wide modulation range for the proposed unipolar-multicarrier PWM technique as the lower base band harmonics are shifted due to doubling effect and hence THD decreases with increase in Ma even greater than one.

QUERIES

Thank you