PWM MODULATION REPORT

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Contents

1. Abstract

This report presents a comprehensive comparison of three distinct modulation techniques employed in power electronics: Sinusoidal Pulse Width Modulation (SPWM), Space Vector Modulation (SVM), and Discontinuous Pulse Width Modulation (DPWM). The primary aim is to scrutinize the performance of these techniques in various scenarios, considering their response to overmodulation, harmonic distortion analysis, and handling of symmetric and asymmetric updates. Furthermore, the Fast Fourier Transform (FFT) of the modulated signals is examined to provide insights into the spectral characteristics of each technique.

The report provides a concise theoretical comparison of the different modulation techniques, complemented by illustrative plots that offer an in-depth understanding of the distinctions between them.

2. Modulation Techniques

In the realm of pulse width modulation (PWM) techniques for controlling power electronic systems, several methods have been developed to achieve high-quality output waveforms and efficient energy conversion. This section will provide a comparative analysis of commonly used PWM techniques: Sinusoidal Pulse Width Modulation (SPWM), Third Harmonic Injection (THI), Space Vector Modulation (SVM), and Discontinuous PWM (DPWM). Each of these techniques has its own characteristics, advantages, and limitations, making them suitable for different applications based on specific requirements.

- **Sinusoidal Pulse Width Modulation (SPWM)**

SPWM is a widely utilized PWM technique that generates a PWM signal by comparing a reference sinusoidal waveform with a high-frequency carrier signal. The key concept behind SPWM is to vary the pulse width of the carrier signal to approximate the desired sinusoidal waveform. This technique is relatively simple to implement and provides good harmonic performance. However, SPWM suffers from higher switching losses due to its continuous variation of the pulse width.

- **Third Harmonic Injection (THI)**

THI is a technique used to reduce or eliminate specific harmonics in the output waveform by adding a third harmonic component to the reference waveform before the PWM comparison. This effectively shifts the dominant harmonics to higher frequencies, making it easier to filter them out. THI is particularly effective for applications where specific harmonic distortion reduction is required, such as grid-tied inverters. However, THI may introduce additional complexity due to the need for precise harmonic injection.

- **Space Vector Modulation (SVM)**

SVM is a more advanced PWM technique that provides better utilization of DC link voltage and reduced harmonic distortion compared to conventional methods. It operates in a two-dimensional space involving the amplitude and angle of a reference vector representing the desired output voltage (Alpha-Beta frame). SVM can achieve maximum utilization of DC voltage and, as a result, improved efficiency. It also enables balanced distribution of switching losses among the switching devices. SVM, however, is more complex to implement than basic SPWM and may require more computation resources.

- **Discontinuous PWM (DPWM)**

DPWM is a technique that intentionally introduces short periods of zero voltage between active switching intervals. This approach aims to reduce voltage overshoot and minimize switching losses, especially in applications where fast transient responses are important. DPWM has the advantage of reducing voltage stress on components and may lead to better efficiency and reliability. However, it can also increase harmonic distortion due to the discontinuous nature of the output waveform.

- **Comparison**

i. Harmonic Performance
   - SPWM and SVM offer good harmonic performance, with SVM typically having a slight edge due to its better utilization of the DC link voltage.
   - THI can effectively mitigate specific harmonics, but it may not provide overall lower harmonic distortion compared to SVM or SPWM.
   - DPWM might introduce higher harmonics due to its discontinuous nature, impacting harmonic performance.

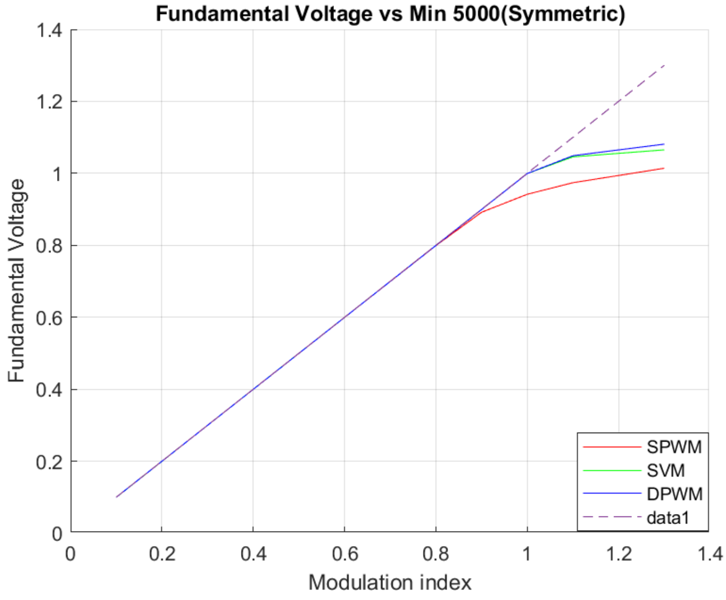
ii. Efficiency
   - SVM and DPWM tend to offer better efficiency due to their optimized switching patterns, leading to reduced losses.
   - SPWM may have slightly higher switching losses due to continuous pulse-width modulation.

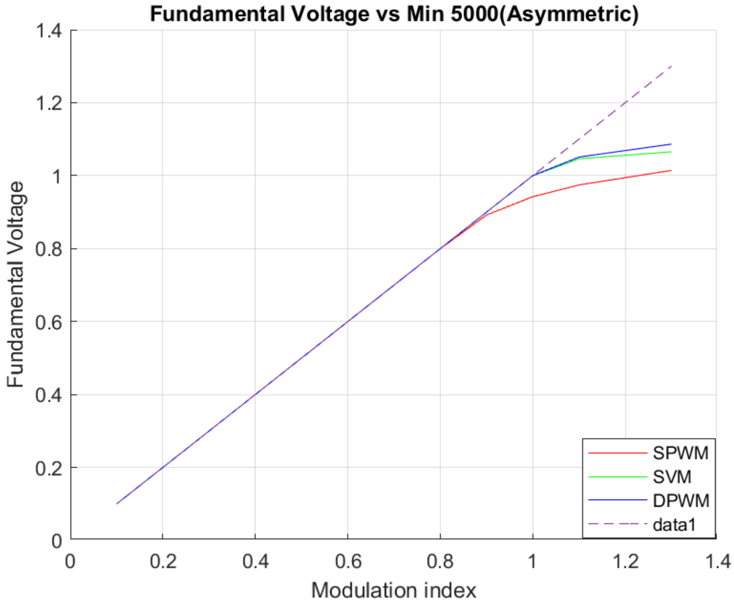
iii. Complexity
   - SPWM is the simplest to implement, making it suitable for applications where complexity is a concern.
   - THI introduces an additional layer of complexity due to harmonic injection requirements.
   - SVM and DPWM are more complex but have better efficiency.

The choice between SPWM, THI, SVM, and DPWM depends on the specific requirements of the application, including harmonic performance, efficiency, complexity, and transient response.

3. Simulation Results

Fundamental voltage vs Modulation input (Symmetric Vs Asymmetric) 5000Hz

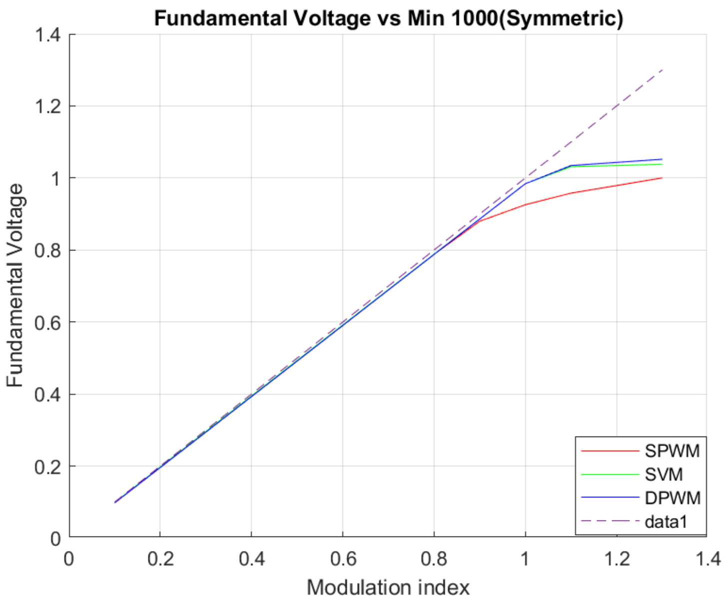


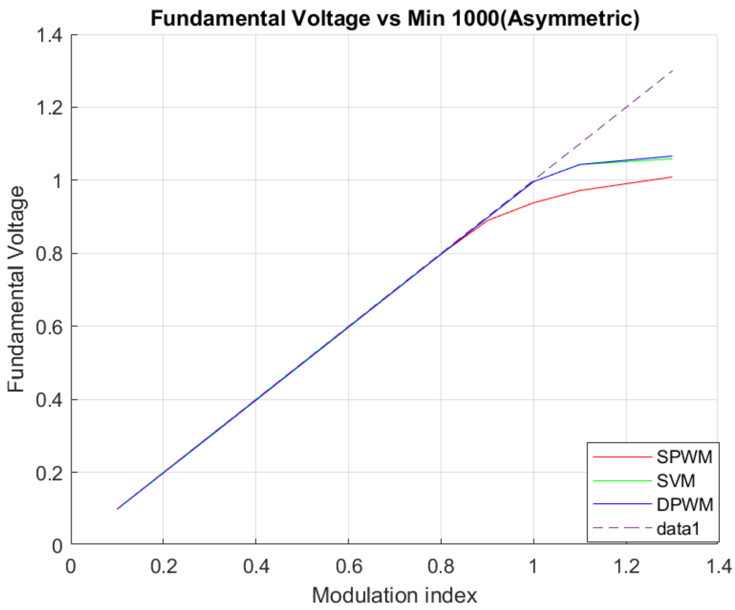


Comment:

The SVM and DPWM1 techniques extend beyond the linear region at modulation index 1, whereas the SPWM reaches this point earlier. As a result, the linear region available for SVM and DPWM1 is greater compared to SPWM, allowing for a more utilization of the DC source. This observation corresponds to the reference of Vdc/sqrt (3), DPWM exhibits a slight edge over SVM in the over modulation region. This advantage comes from DPWM's optimized switching distribution.

Fundamental voltage vs Modulation input (Symmetric Vs Asymmetric) 1000Hz





Comment:

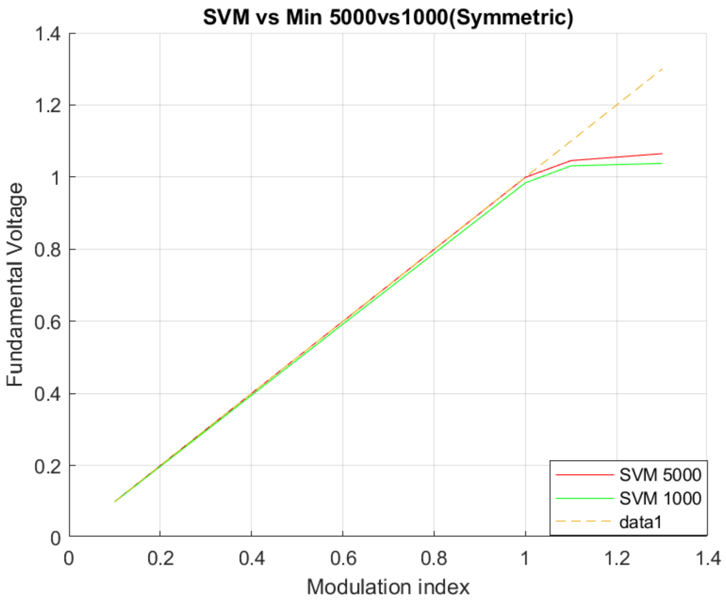
The same as previous figure but when the switching frequency decreases, the fundamental voltage output in the symmetric case deviates slightly from the ideal output, as predicted. However, in asymmetric cases, the reduction in switching frequency can be handled using asymmetric sampling. Thus, enhancing the output voltage and bringing it closer to the ideal within the linear region. It’s important to note that asymmetry increases the CPU load due to the signal being double-symmetrically sampled, which adds to computational overhead.

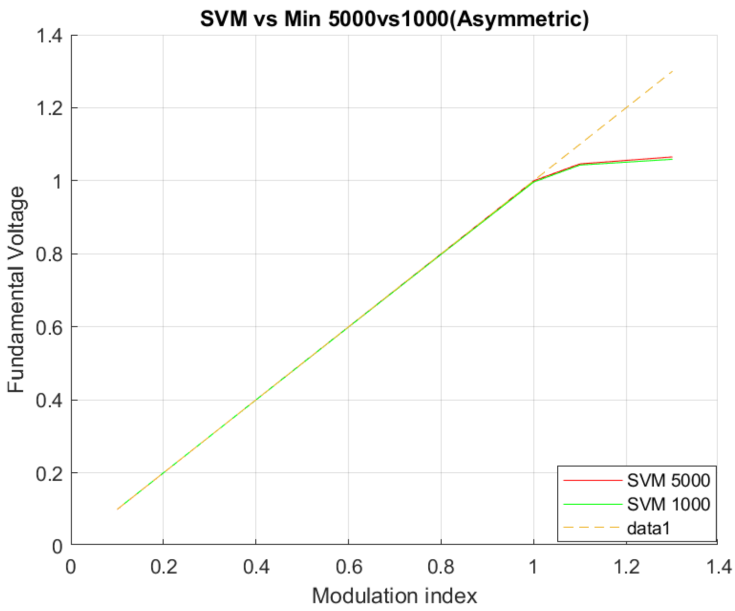
Fundamental voltage vs Modulation input (Symmetric Vs Asymmetric) (SPWM)

Comment:

SPWM exits the linear region prior to modulation reaching one. As evident in the figure, when employing asymmetry, the difference between 5000 Hz and 1000 Hz is minimal. This indicates that asymmetry outperforms symmetry, as it brings the output closer to resembling the higher switching frequency output.

Fundamental voltage vs Modulation input (Symmetric Vs Asymmetric) (SVM)

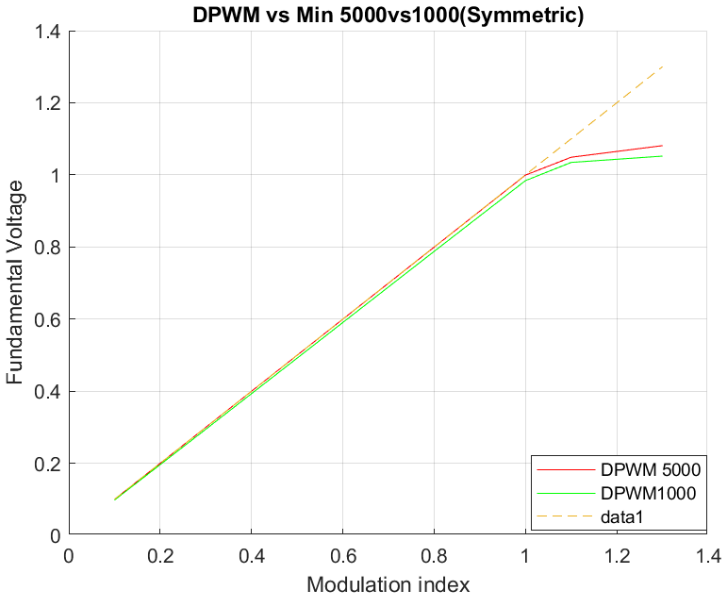


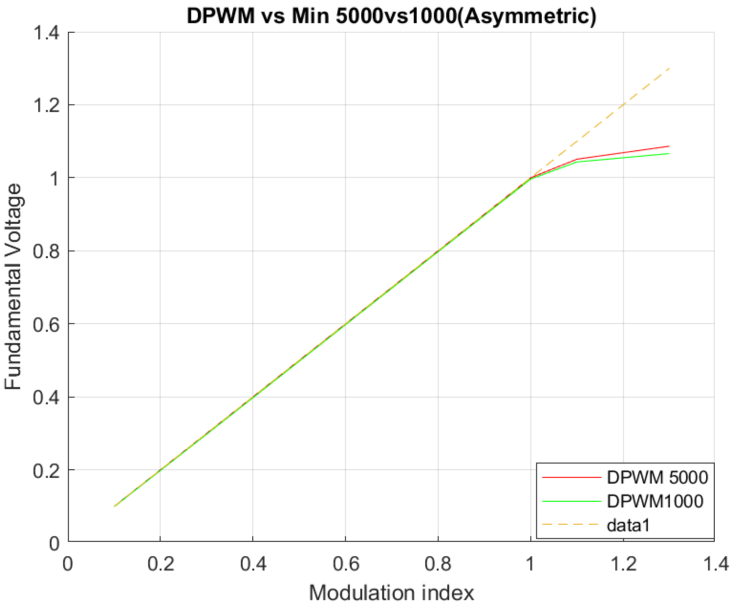


Comment:

In SVM, the nonlinear region initiates after the modulation index corresponds to our reference point (Modulation=1). Like the previous observation, asymmetry makes the lower pulse ratio output to be near to the higher pulse ratio output in the non-linear region, effectively mitigating the difference.

Fundamental voltage vs Modulation input (Symmetric Vs Asymmetric) (DPWM1)

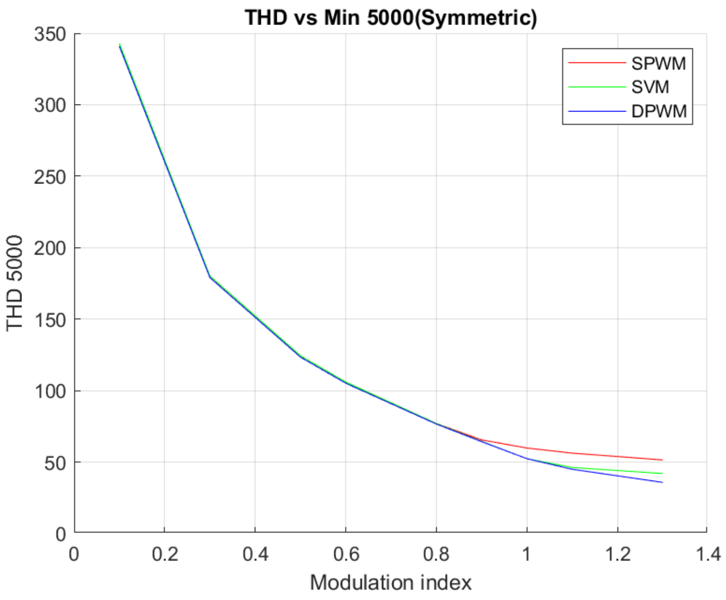


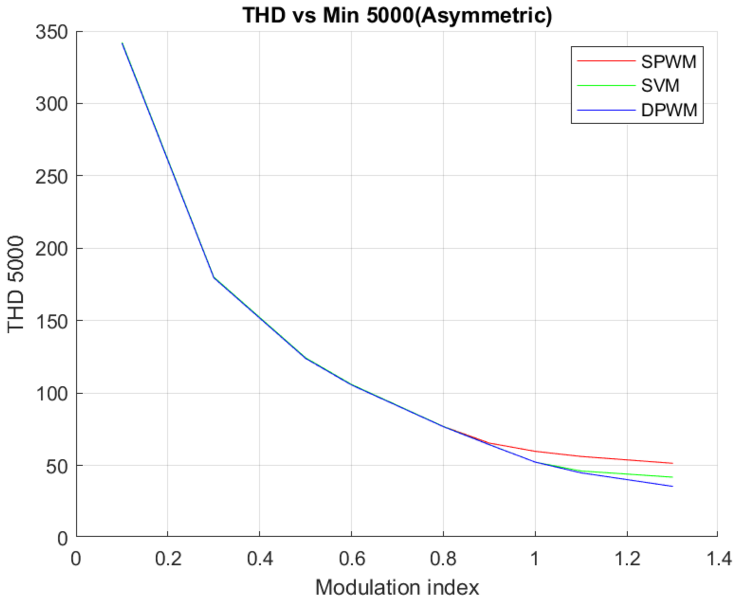


Comment:

DPWM and SVM share similarities as they can be seen as equivalent techniques. However, the distinction lies in DPWM's clamping at maximum and minimum values. DPWM has lower switching frequency losses compared to SVM.

THD (%) vs Modulation input (Symmetric Vs Asymmetric) 5000Hz

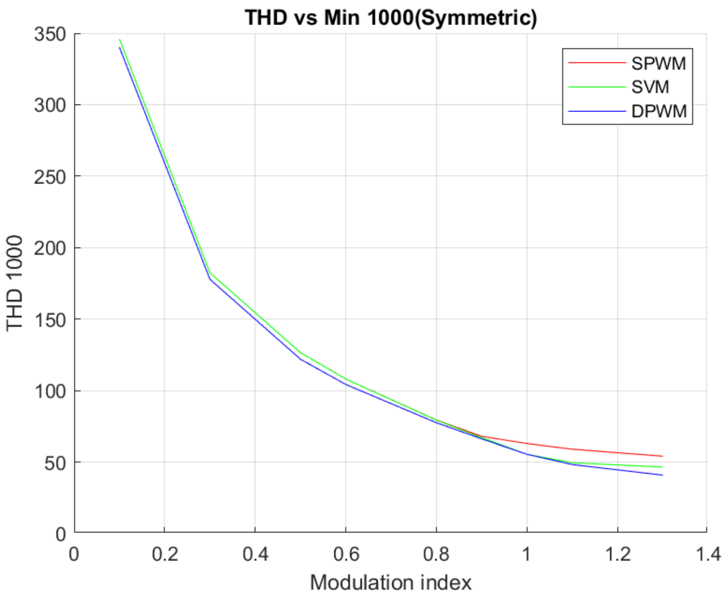


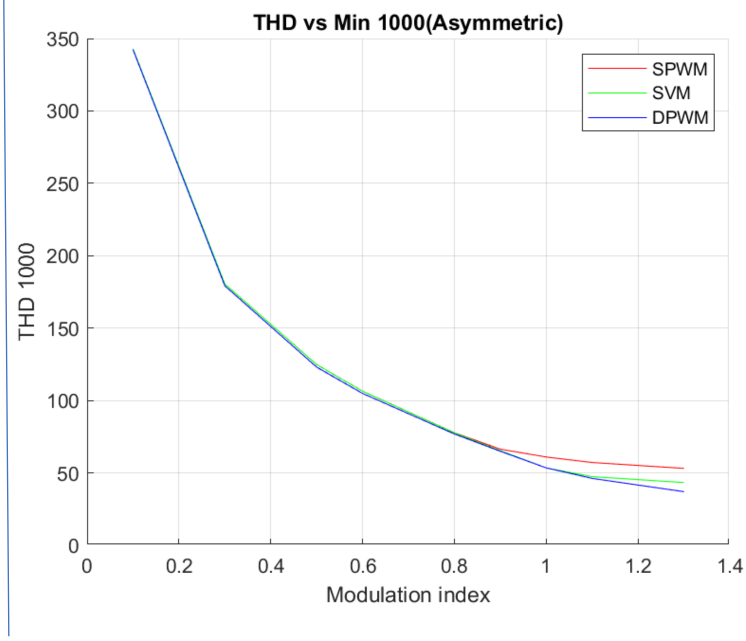


Comment:

In the figure, we can see that when the modulation index is low, the total harmonic distortion (THD) is high for all modulation techniques, and it's quite similar. As the modulation index increases and we reach the point of the end of linear region, THD goes down. But, when we go into the nonlinear region for SPWM, SVM, and DPWM, the THD goes up again because the lower-order harmonics start to appear. So, the best technique at the non-linear region for the lower THD is DPWM.

THD (%) vs Modulation input (Symmetric Vs Asymmetric) 1000Hz

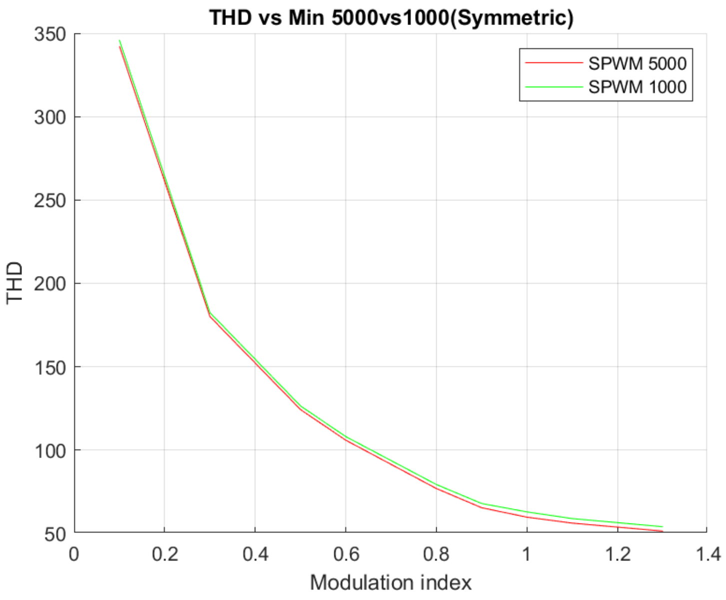


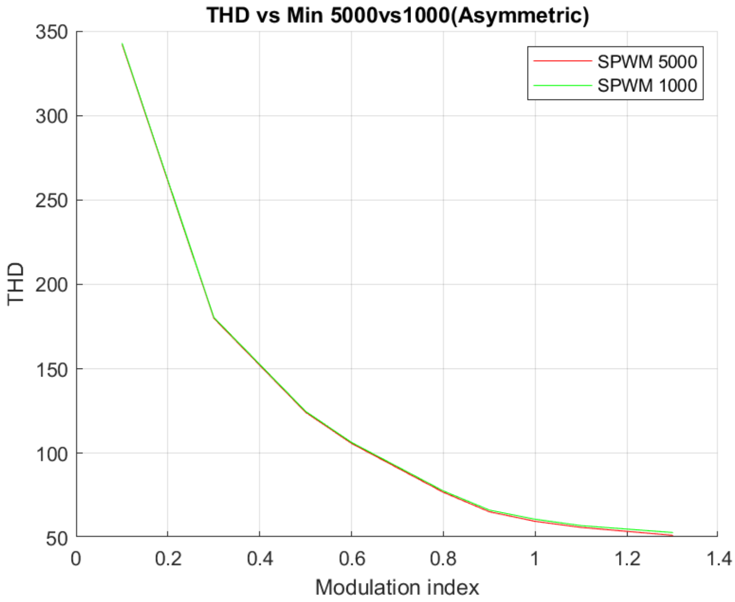


Comment:

The same as previous figure but the asymmetric make the THD to be like the high pulse ration without increasing the switching frequency just increasing the update rate of the input and the THD should increase again at the non-linear region.

THD (%) vs Modulation input (Symmetric Vs Asymmetric) (SPWM)

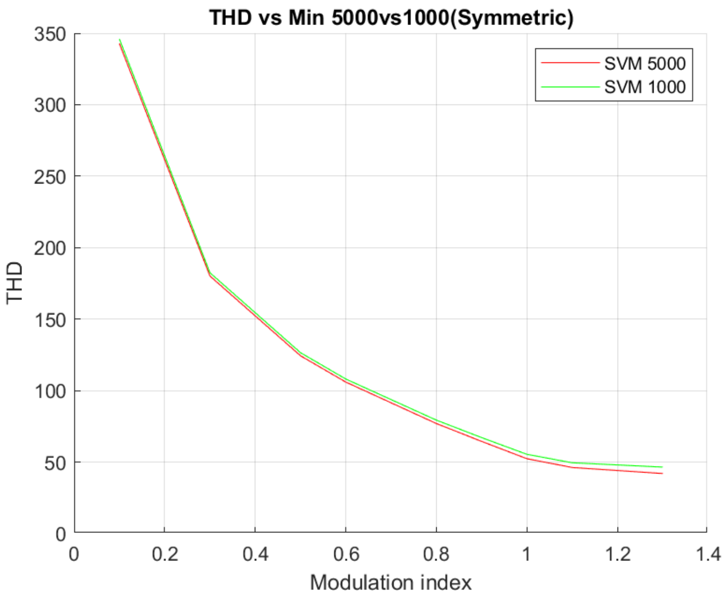


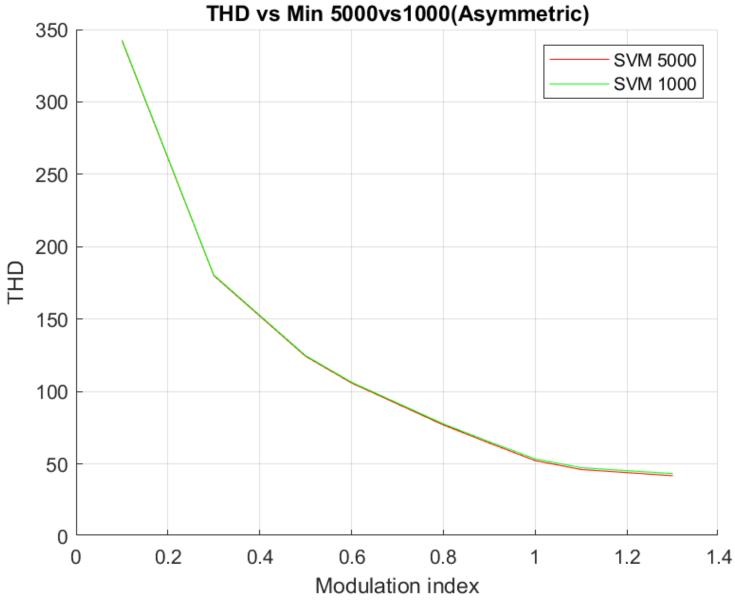


Comment:

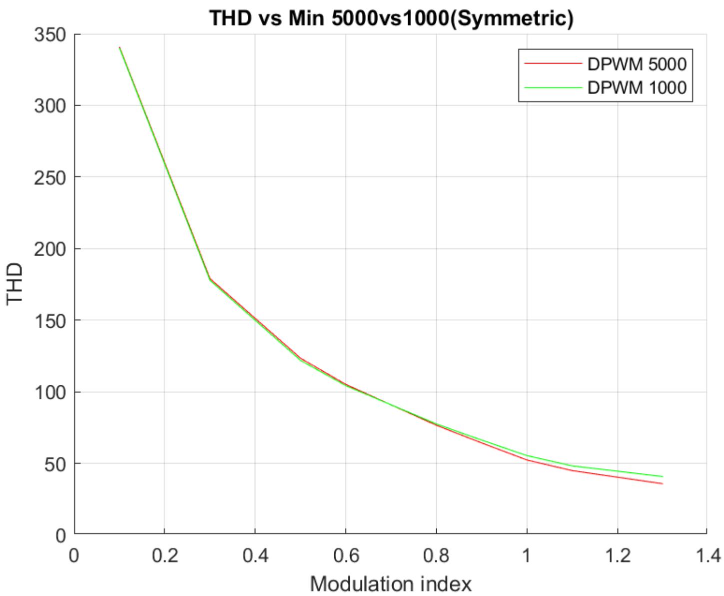
The THD should increase again after the nonlinear region at point cause the low order harmonics appears due to the over modulation.

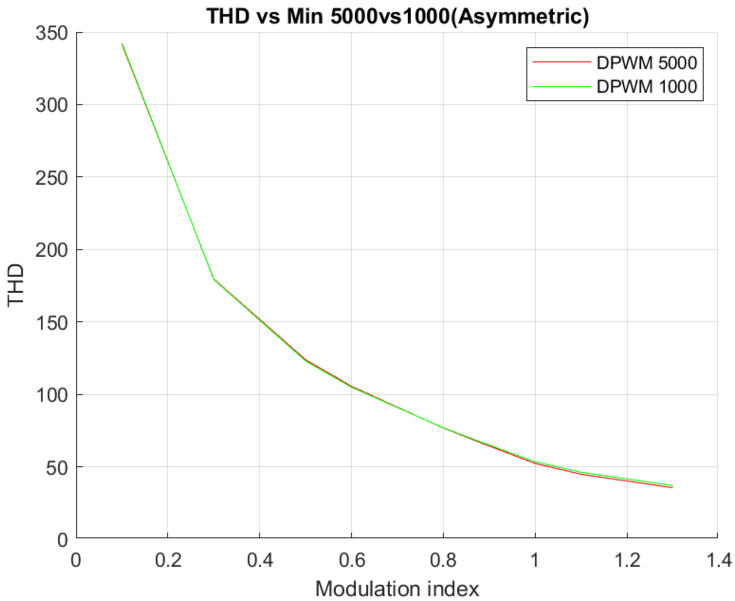
THD (%) vs Modulation input (Symmetric Vs Asymmetric) (SVM)





THD (%) vs Modulation input (Symmetric Vs Asymmetric) (DPWM1)

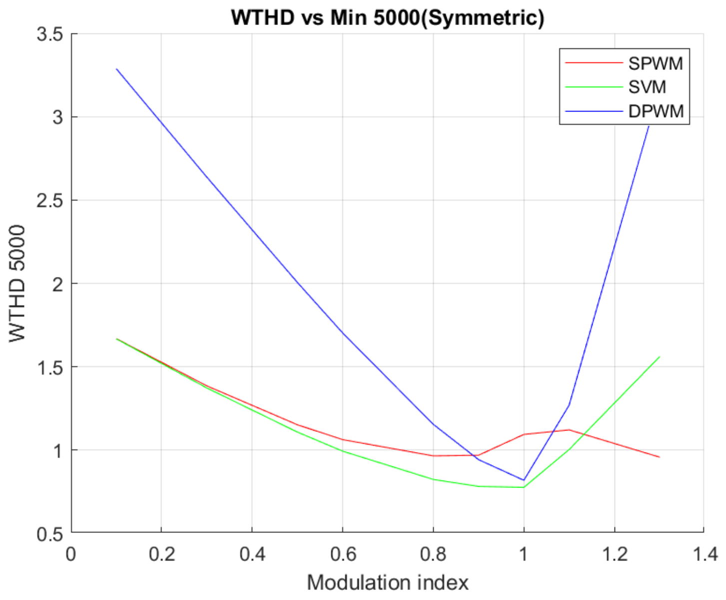


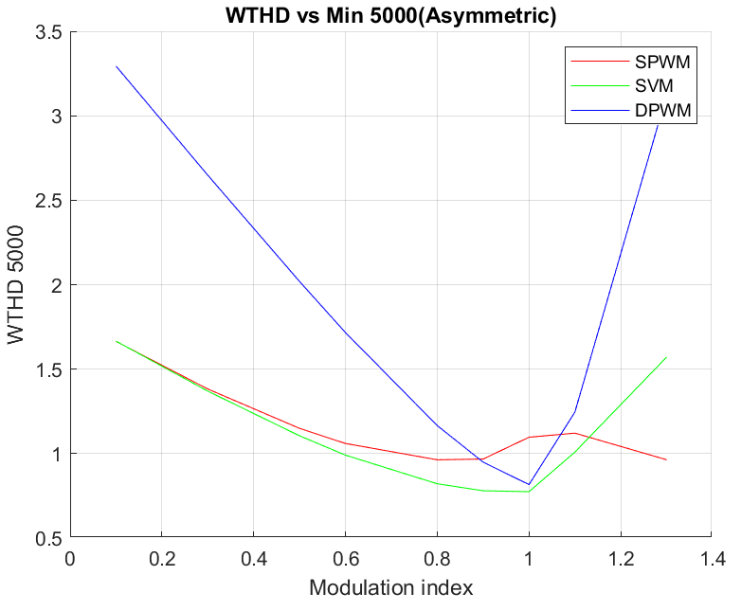


Comment:

THD decreases as we approach a modulation index of 1, but it should then increase afterwards at non-linear region.

WTHD (%) vs Modulation input (Symmetric Vs Asymmetric) 5000Hz

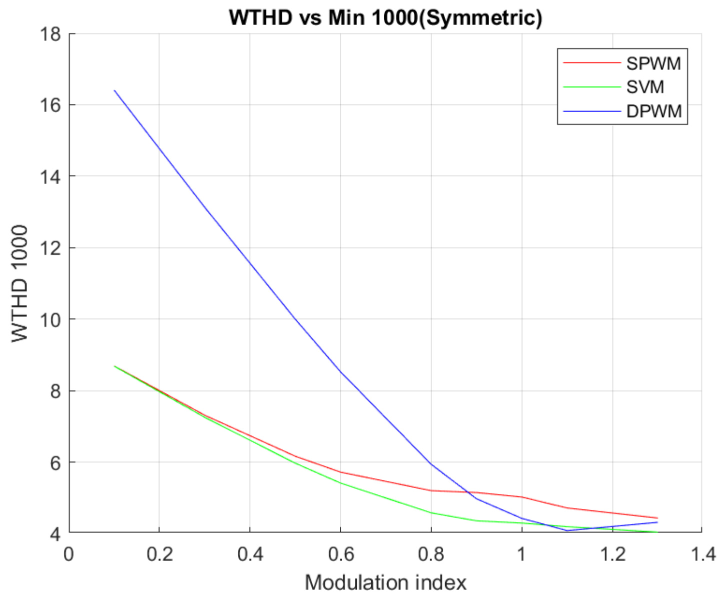


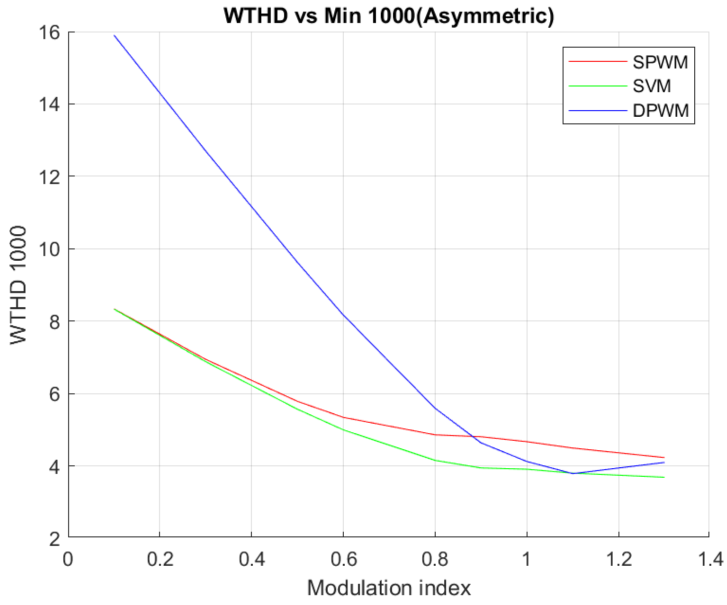


Comment:

The Weighted Total Harmonic Distortion (WTHD) goes up when the modulation index is low and goes down as the modulation index gets higher, reaching its lowest point at the point which the overmodulation starts to occur. But then, it goes up again because of the appearance of low-order harmonics, which have a bigger impact due to their harmonic indices. SVM is the best according to the WTHD in the linear region.

WTHD (%) vs Modulation input (Symmetric Vs Asymmetric) 1000Hz

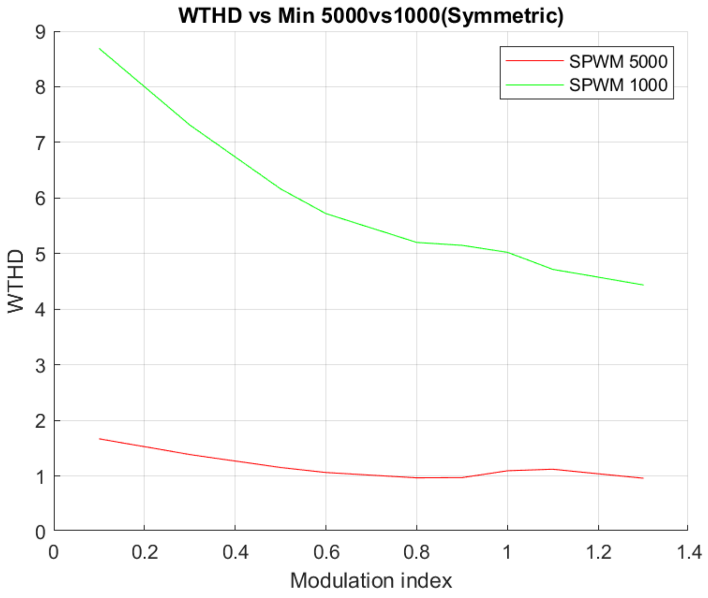


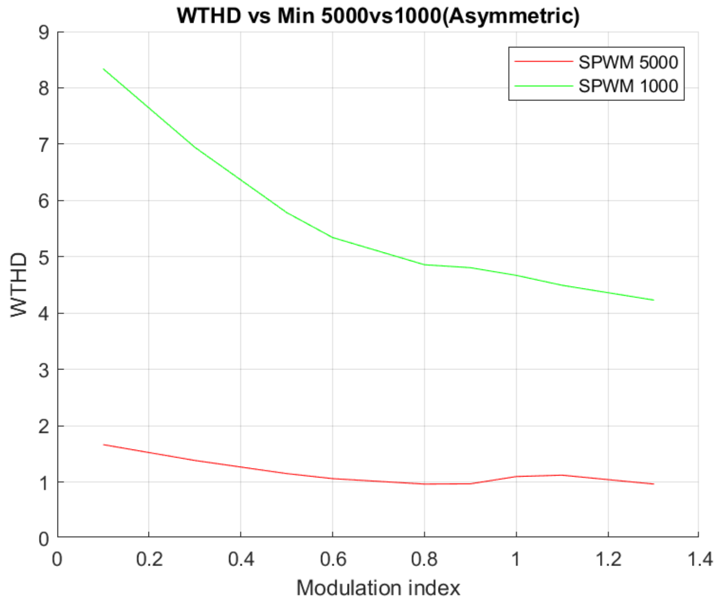


Comment:

The figure shows that in symmetric cases, the WTHD decreases as the modulation index rises. However, the WTHD increases again due to the presence of low-order harmonics. In asymmetric scenarios, the decrease in WTHD is similar, but the transition is smoother, resembling the effect of higher switching frequencies.

WTHD (%) vs Modulation input (Symmetric Vs Asymmetric) (SPWM)

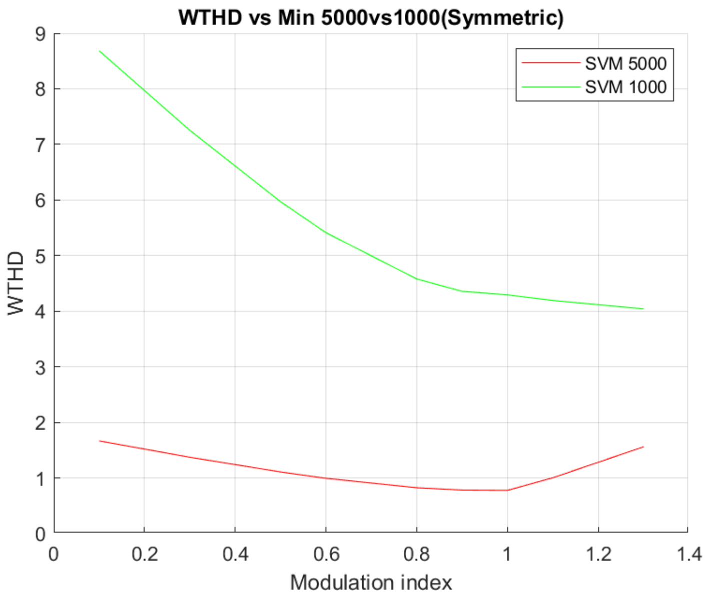


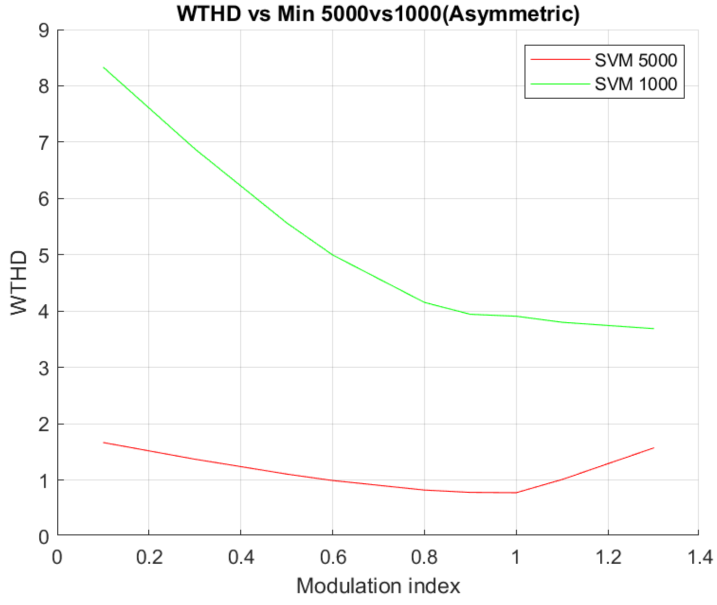


Comment:

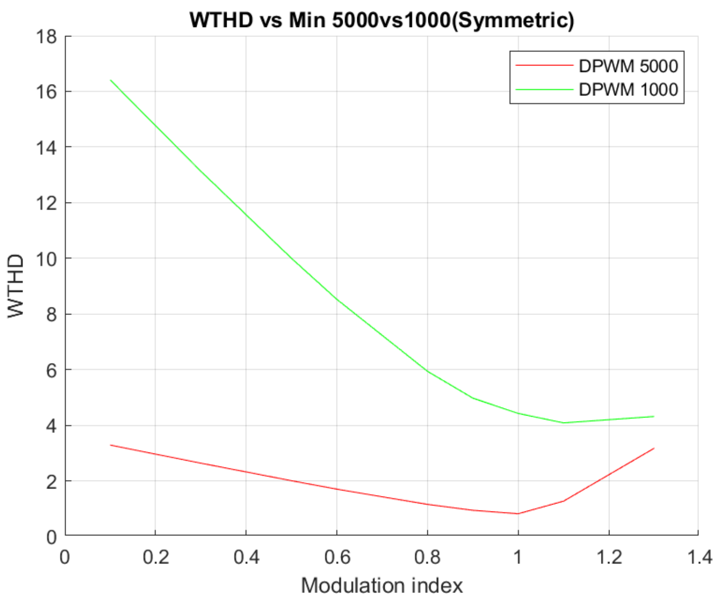
As the pulse ratio increases, the WTHD also increases, particularly at lower modulation indices. However, as the modulation index increases, The WTHD starts decreasing because, at lower modulation indices, we start seeing low-order harmonics. These harmonics have smaller harmonic indexes, which have a stronger effect on the WTHD value.

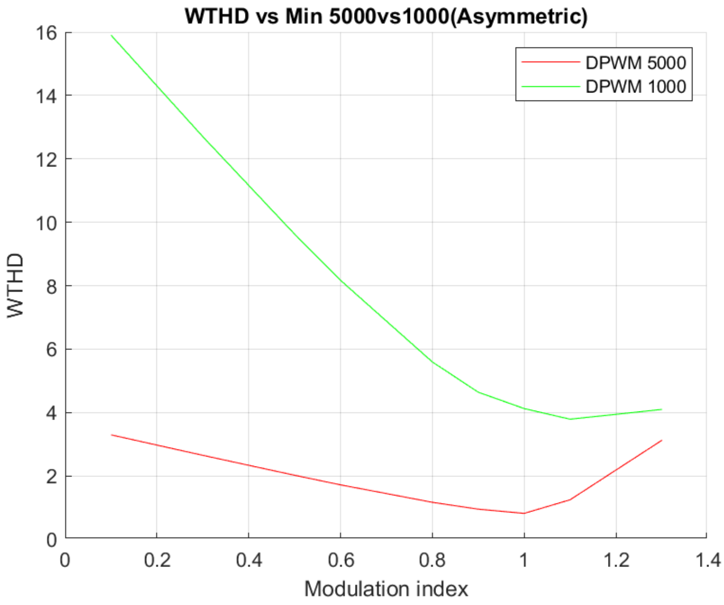
WTHD (%) vs Modulation input (Symmetric Vs Asymmetric) (SVM)





WTHD (%) vs Modulation input (Symmetric Vs Asymmetric) (DPWM1)

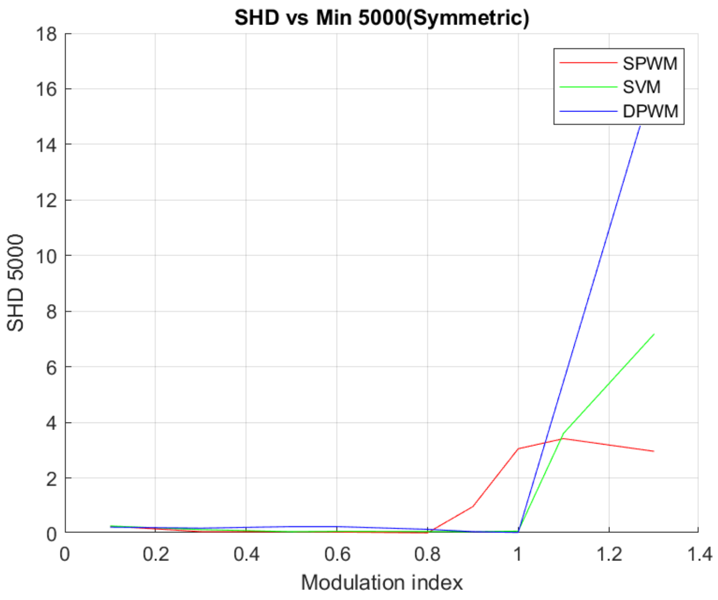


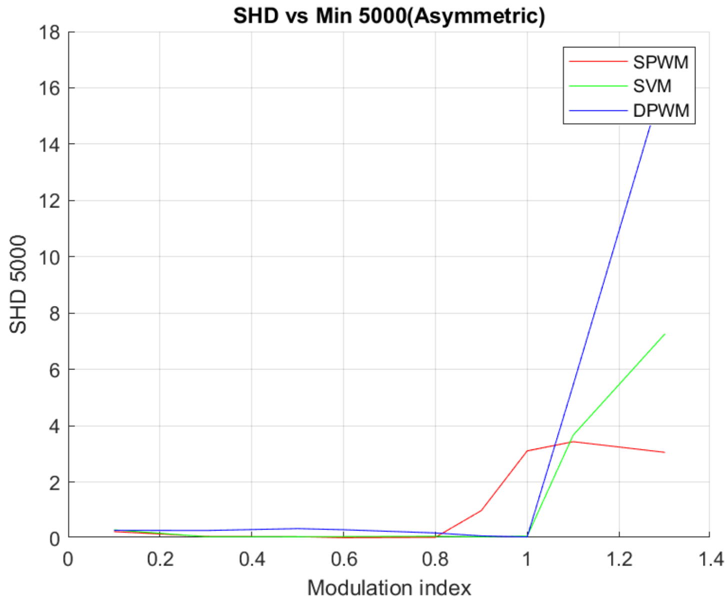


Comment:

As the SPMW when the switching frequency increases the WTHD of the SVM or DPWM increases because higher switching frequencies often lead to shorter intervals between switching transitions. These shorter intervals may limit the system's ability to respond to rapid changes effectively, resulting in increased distortion and higher harmonic content in the output signal, thus leading to a higher WTHD value.

SHD (%) vs Modulation input (Symmetric Vs Asymmetric) 5000Hz

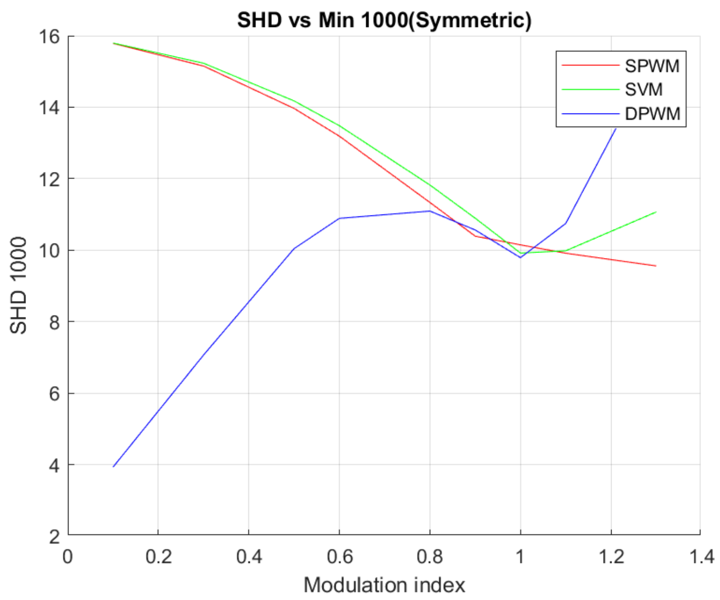


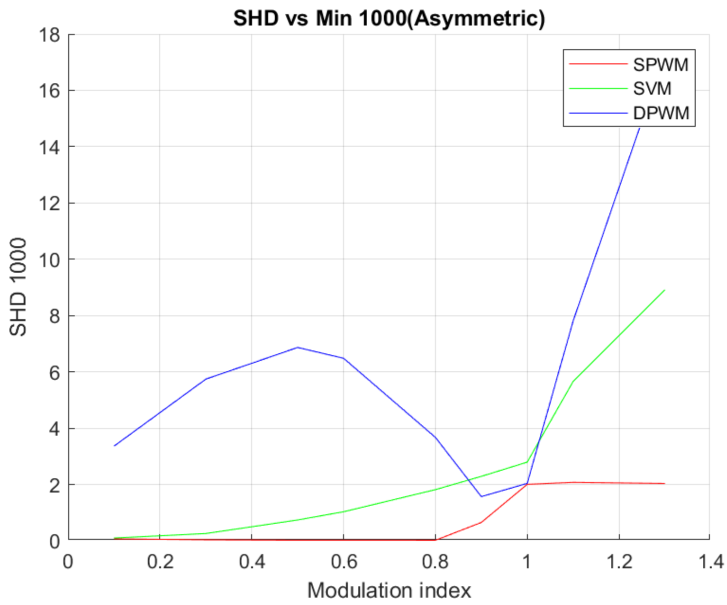


Comment:

In the linear region for the three modulation techniques, the SHD value remains very low because the lower-order harmonics are not present. However, in the non-linear region, the emergence of these low-order harmonics impacts the SHD. In the overmodulation region, DPWM exhibits the highest SHD, primarily due to its clamping approach at maximum and minimum values. This technique, coupled with overmodulation, brings DPWM closer to the characteristics of a square wave – known for its unfavorable low-order harmonics. The difference between symmetric and asymmetric don't appear here cause its high pulse ratio.

SHD (%) vs Modulation input (Symmetric Vs Asymmetric) 1000Hz

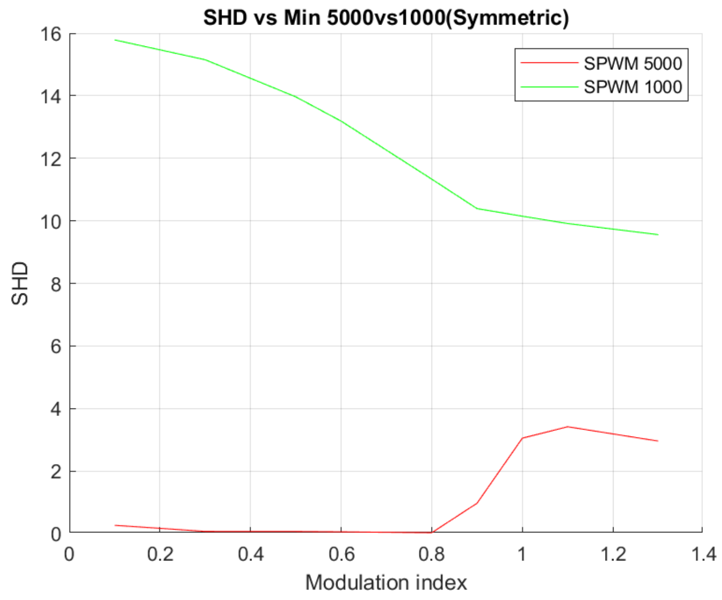


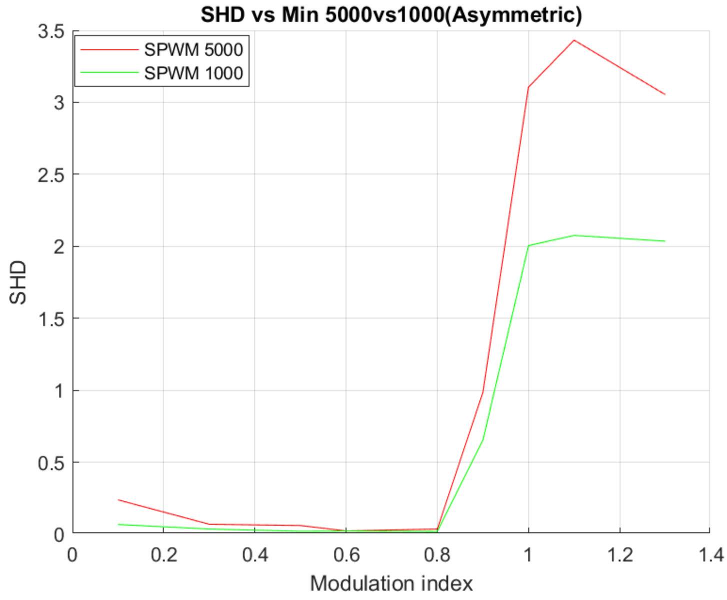


Comment:

When the pulse ratio is low, the lower-order harmonics become more prominent compared to higher pulse ratios. This happens because these harmonics show up closer to the fundamental frequency when the pulse ratio is low.

SHD (%) vs Modulation input (Symmetric Vs Asymmetric) (SPWM)

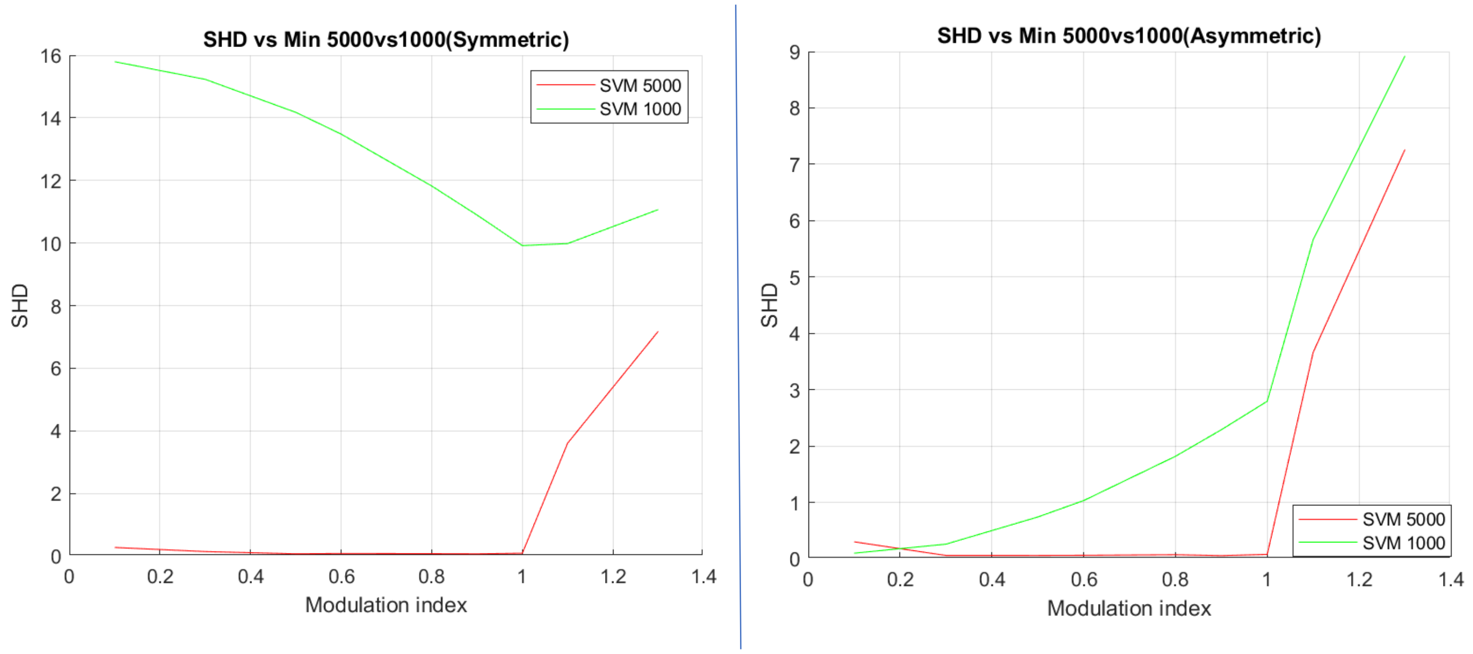




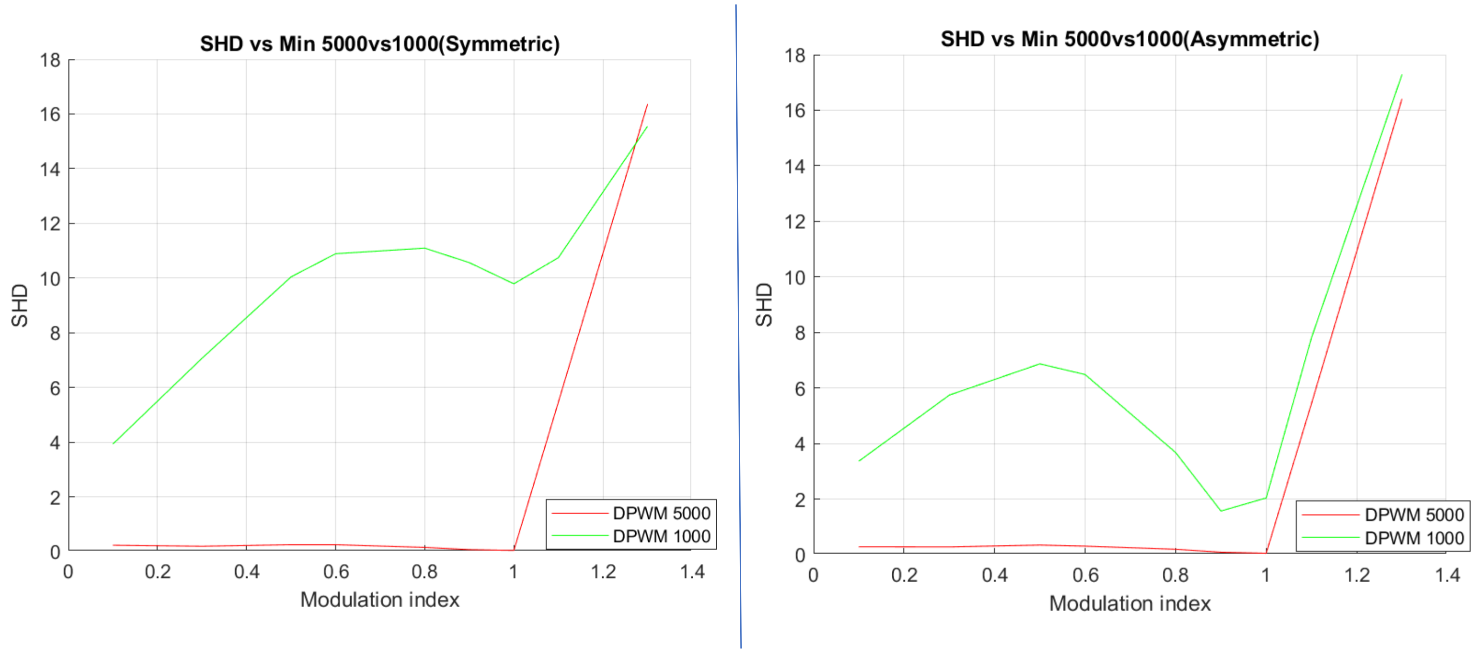
Comment:

The STD is less at higher pulse ratios because the low-order harmonics are not as close to the main frequency. But when using asymmetric techniques, the value becomes even smaller. It's like making the frequency seem doubled, even though we're only updating it twice without changing the switching frequency. This makes the STD go down even more.

SHD (%) vs Modulation input (Symmetric Vs Asymmetric) (SVM)



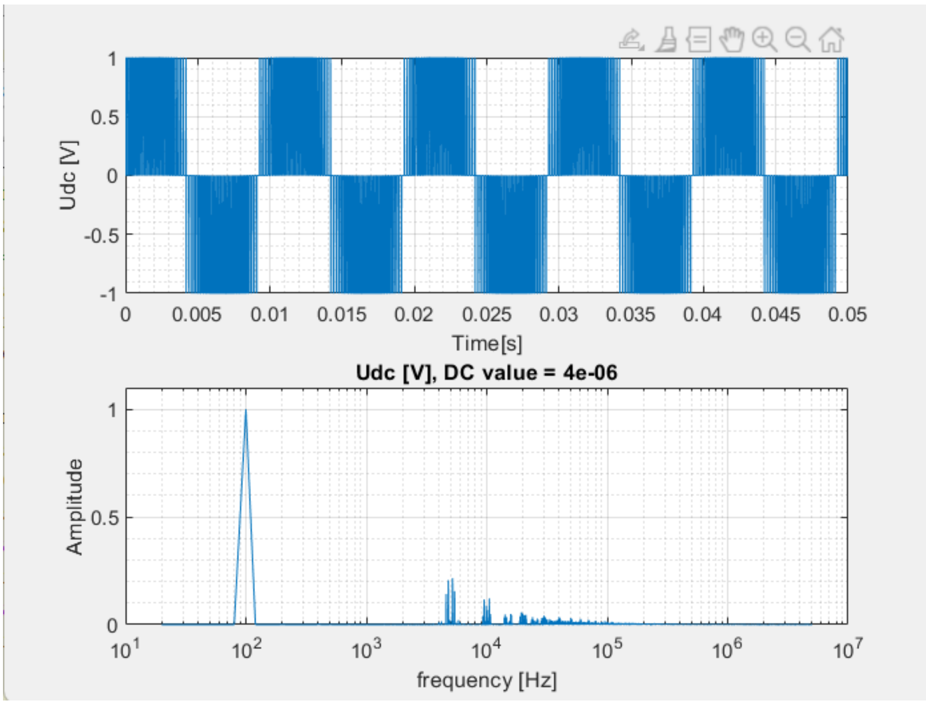
SHD vs Modulation input (Symmetric Vs Asymmetric) (DPWM1)



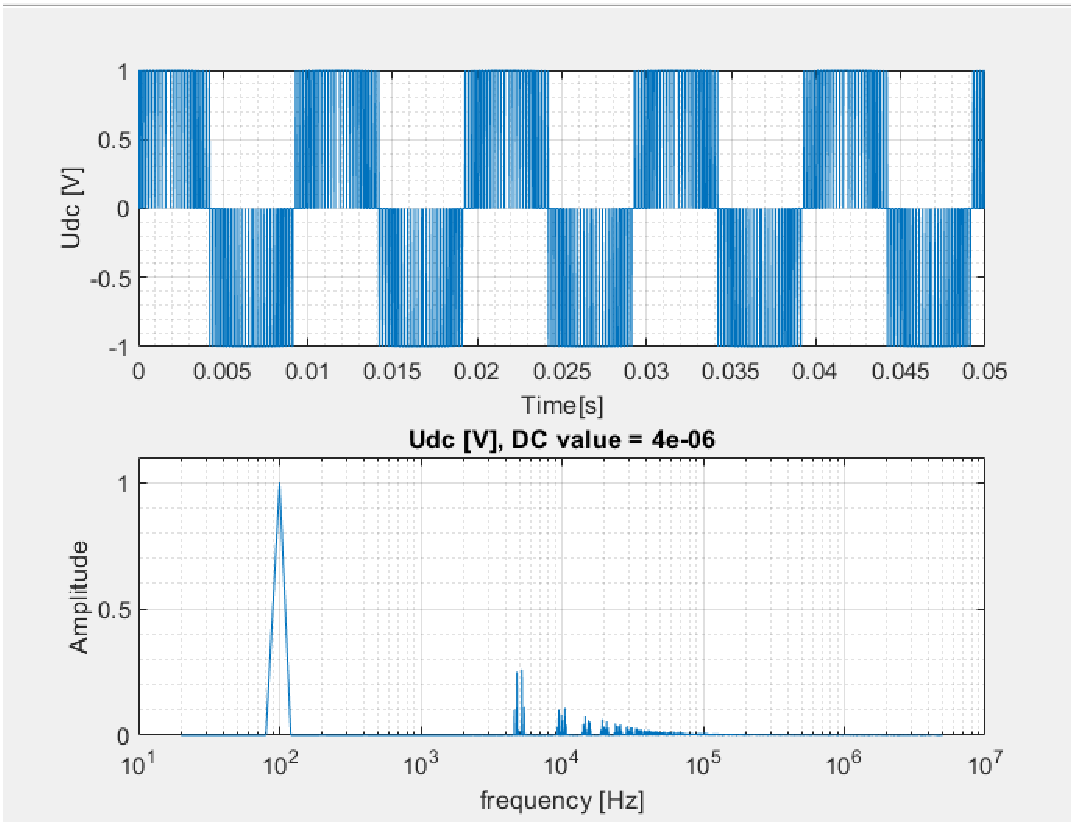
Comment:

The STD works better with high pulse ratios since, in the linear region, the harmonics are far from the fundamental frequency. Yet, in the non-linear region, low-order harmonics start to show up, causing the STD to rise as the modulation index increases. This pattern continues into the overmodulation region. Asymmetry affects low pulse ratios more than high ones. It helps lower the SHD by pushing the harmonics farther from the main frequency.

FFT for SVM



FFT for DPWM



4. About the Code

The code can compute the fundamental voltage, THD, WTHD, and SHD for the SPWM, SVM, and DPWM models, both symmetric and asymmetric in sampling. Afterward, it creates plots to facilitate comparisons among them. Users can input the fundamental frequency and two distinct switching frequencies (which are shown as plot names and legends for 1000Hz and 5000Hz). However, the code is adaptable to other frequencies and organizes the output accordingly. Furthermore, users can provide any number of modulation indices, and the code will carry out calculations and generate output for each modulation index specified.

Future work involves enhancing the code to accommodate various switching frequencies and generate corresponding plots, similar to how it handles modulation indices. This enhancement will make the code versatile, allowing users to input any number of switching frequencies for analysis and plotting.