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A Comparison Study Between Hysteresis and Sinusoidal Pulse Width Modulation for Induction Motor Drive

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Sinusoidal pwm (SPWM),
Three phase inverter,
Harmonics Analysis,
Simulink.

A B S T R A C T

In This paper compares the control strategies for three phase voltage source inverters, which have been the subject of extensive research in the last few years. Even if the inverter topologies that require the fewest switching elements yield the most efficient results, the switching technique that is as effective as the topology, at least. In addition, the inverter's selected switching technique will effectively suppress harmonic components while generating the optimal output voltage and current. To manage voltage source inverters, to regulate three phase voltage source inverters, several PWM approaches are frequently employed. Sinusoidal PWM and hysteresis band PWM are two examples of these techniques. MATLAB/SIMULINK has been used to model these modulation techniques that are applied in voltage source inverters to generate variable frequency and amplitude output voltage and current. Furthermore, a comparison is made between the overall harmonic distortions of the output voltages and current. Simulation tests have revealed that there is greater THD in the output current and voltages of voltage source inverter when sinusoidal pwm is used. Hysteresis band pwm has shown the ability to produce a lower overall harmonic distortion and more efficient output voltage and current.

1. Introduction

Asynchronous motors, also known as induction motors, are used in a spacious range of industrial applications due to their robustness, low cost, and high efficiency. One method of controlling the speed of an induction motor is to use pulse width modulation PWM techniques such as: Hysteresis PWM and Sinusoidal PWM.In hysteresis PWM, the actual motor current is continuously compared with a reference current. The power switches are toggled whenever the actual current reaches the hysteresis band limit (Fig.1). This method provides an excellent dynamic response as the control action is instantaneous. However, the switching frequency in this method is not constant and can result in acoustic noise.

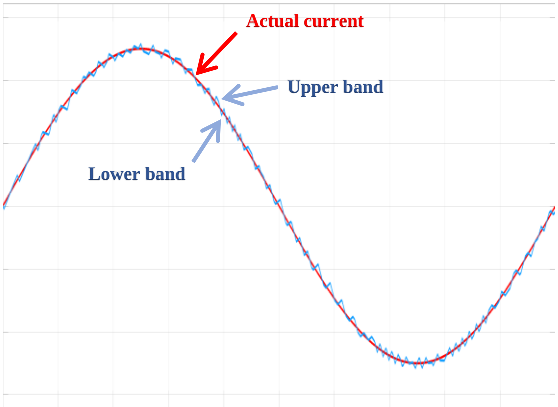

Fig.1. Hysteresis Current Control Band.

In sinusoidal PWM, a sinusoidal carrier wave is compared with a reference wave to create PWM signals (Fig.2). The modulating index (m) is established on the magnitude of the references signal, whose frequency defines the output frequency.The advantage of this method is that it has a constant switching frequency, which make the filtering of harmonics easier. However, its dynamic response is not as good as the hysteresis PWM .

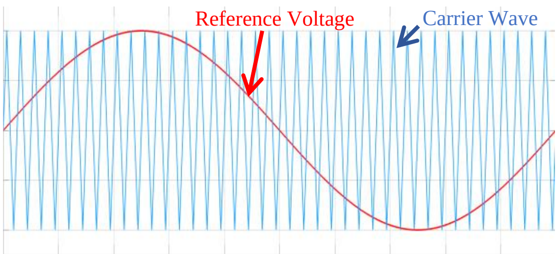

Fig.2. The intersection between Asin wave and triangle wave.

2. Control Techniques

As far as productivity and application go, the control method that produces the switching signals is fairly significant. Much of the energy produced is lost if the control mechanism is not effective. The effects of SPWM and HPWM control strategies on system performance are compared in this work.

2.1 Hysteresis Pulse Width Modulation

HBCPWM is simply a PWM approach that tracks the command current continually by the actual current within a predefined hysteresis range. It does this by using immediate feedback current control.

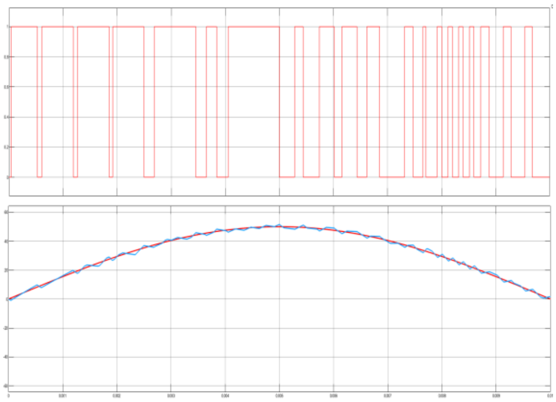

Fig. 3. Principle for Controlling Hysteresis Band Current.

Figure 3 depicts the working concept of a three phases full-bridge inverter applying HBCPWM.The control circuit produces a sine a reference current signal of designated frequency and amplitude, which is subsequently compared to the real phase current waveform. In a full-bridge setup, when the current exceeds a certain hysteresis range, the smaller switch is engaged while the higher switch is disengaged. The current subsequently diminishes, resulting in a variation in the final voltage from 0 Vd to 1 Vd. When the current attains the lower band limit, the top switch is engaged while the lowers switch is disengaged. By sequentially switching the upper and lower switches, or utilising a "bang-bang" control strategy, the system ensures that the real current signal conforms to the sine reference wave inside the hysteresis area. The inverter functions as a current source with controlled current ripple from peak to peak inside the hysteresis region, regardless of fluctuations in Vd, as seen in the flowchart in Fig. (6).
The (Fig. 4, Fig 5) illustrates the HBCPWM inverter control approach. Three phase current faults are the HBCPWM controller's inputs, and the PWM inverter's switching patterns are its outputs.

The normalization factor (shown in the photo as d) is employed to scale the HBCPWM controller'scurrent error input. The PS circuit is the one that divides the pulses for the IGBT in the upper and lower legs of the inverter.

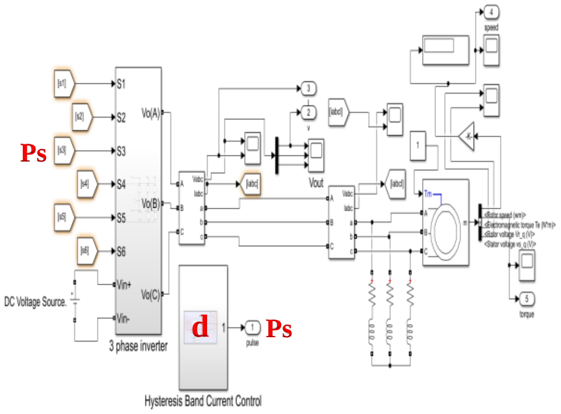

Fig. 4. Modulaing for 3-phase inverter with HBCPWM in Matlab/Simulink.

The inverter receives output pulses from the hysteresis current controller in the following ways:

Im,ref – d/Im | < d maintains the output pulse in a consistent state.

Im,ref – d/Im > d results in a high output pulse of

Im,ref – d/Im < -d output pulse low = 0

Here, d represents the hysteresis band, while m corresponds to the phases a, b, and c.

This scheme operates according to the following algorithm:

Im,ref(t) = Im,ref * sin(wt)

Upper boundary Iu equals Im,ref(t) plus I

Inferior range IL equals Im,ref(t) minus I, where I denotes the limit of the hysteresis band.

If Im exceeds Iu, then Vmo is equal to negative Vdc divided by 2. If I is less than IL, then Vmo equals Vdc divided by 2, where Vdc represents the inverter's DC input voltage, I denotes the load current, and m corresponds to phases a, b, and c.

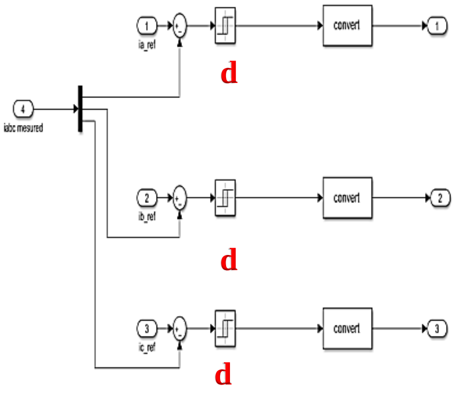

Fig. 5. Control block diagram for Hysteresis band current.

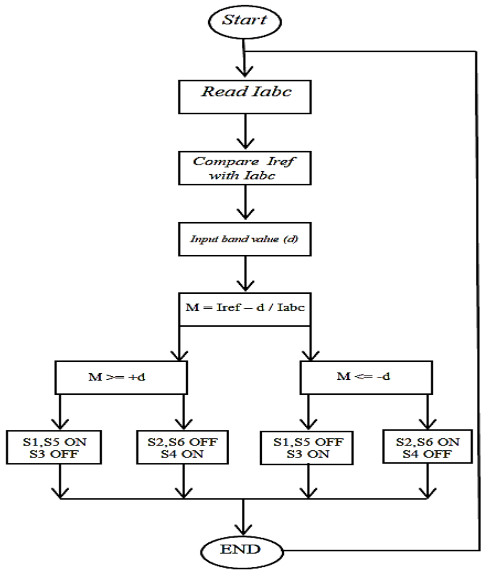

Fig. 6. Flowchart for HBCPWM.

2.2 Sinusoidal Pulse Width Modulation

Figure 7 illustrates the generation of switching signals through sinusoidal PWM. Three sinusoidal reference waves exist, each exhibiting a 120-degree phase shift: Vra, Vrb, and Vrc. The carrier wave Vcr (triangle wave) is compared apply the appropriate reference signal to produce the phase switching signals. The statuses for all switches (q1, q2, q3, q4, q5, and q6) shown in (Fig. 7) are derived from the comparison of the carrier signal with the reference signal. The switching components [q1, q4, q3, q6, q5, and q2] cannot simultaneously be in an open or closed.

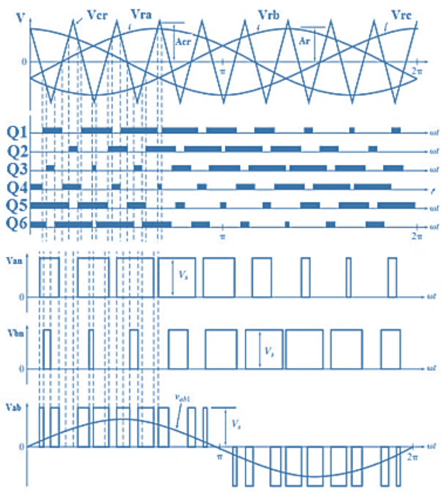

Fig. 7. Sinusoidal PWM For Three Phase Inverter.

Figure 7 delineates the situations as follows: while [Vcr > Vra], q1 is deactivated while q4 is engaged; similarly, when [Vcr < Vra], q1 is engaged and q4 is deactivated. Moreover, in the situation where

[Vcr > Vrb], q3 is deactivated while q6 is engaged; similarly, when [Vcr < Vrb], q3 is engaged and q6 is deactivated. In an alternative situation, when [Vcr > Vrc], q2 is deactivated while q5 is active; similarly, while [Vcr < Vrc], q2 becomes active and q5 is deactivated. To ascertain the reference voltages, Equation (1.1) can be used to regulate the signals.

$$Vr = A.sin(2\pi ft + \theta) \quad (1)$$

where Θ is the phase shift angle, ω = 2πf is the angular velocity, and A is the signal magnitude.

$$Vr = A.sin(\omega t + \theta) \quad (2)$$

The reference voltage V(a, b, c) can be found using the following equation:

$$Vra = A.sin(2\pi ft + 0^{\circ}) \quad (3)$$
$$Vrb = A.sin(2\pi ft - 120^{\circ}) \quad (4)$$
$$Vrc = A.sin(2\pi ft + 120^{\circ}) \quad (5)$$

The frequency of the reference signal dictates the frequency of the final voltage. The magnitude of the references signal dictates the index of modulation and the root mean square (rms) of the output voltage. Adjusting the modulation index enables you to change the root mean square value of the output voltage.

Figure 8 depicts the MATLAB/Simulink simulation of an SPWM circuit.

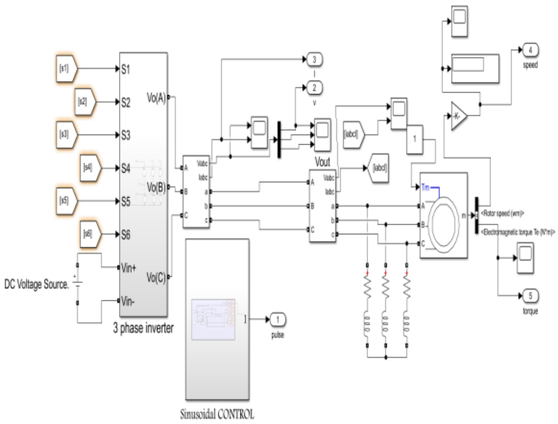

Fig. 8. Modulating for 3-phase inverter with SPWM in MATLAB/Simulink.

3. Simulation Results

HBCPWM and SPWM techniques have been applied to a three-phase Inverter. The band for HBCPWM is (d=1.55), the frequency for triangular wave is (2KHZ) for SPWM, Output pulses Fig 9(a,b), Output voltage Fig 9(c,d), and Output current Fig 9(e,f) graphs of HBCPWM and SPWM are given below, the parameters for a synchronous machine (400V, 50 HZ, 1430 RPM).

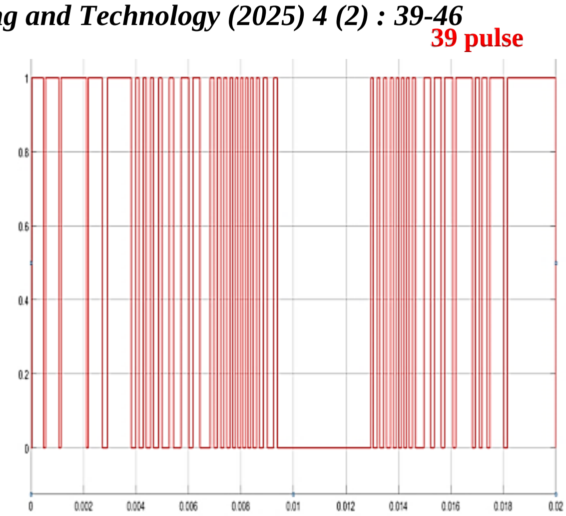

Fig. 9(a). HBCPWM Output 39 pulse for time 0.02s.

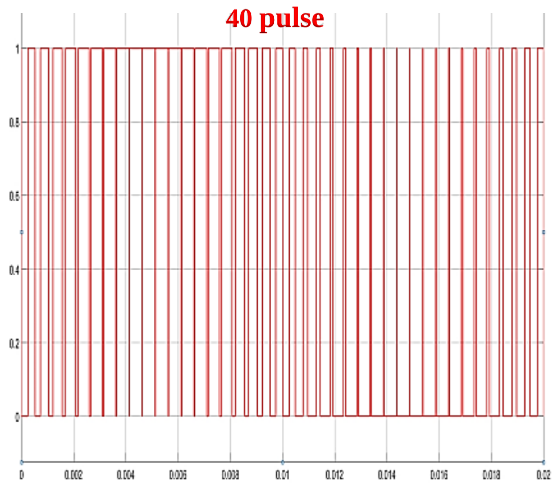

Fig. 9(b). SPWM Output 40 pulse for time 0.02s.

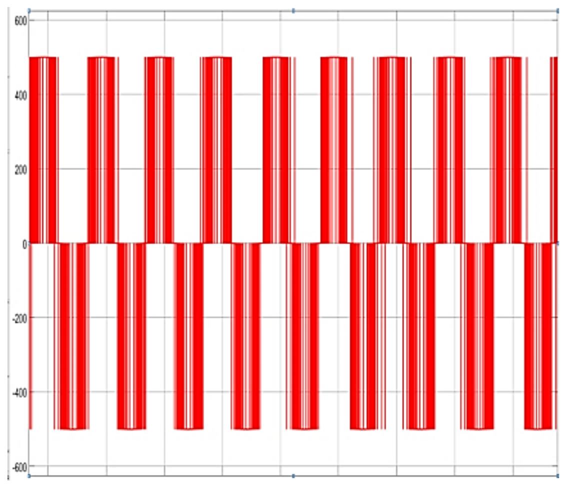

Fig. 9(c). HBCPWM Output Voltage.

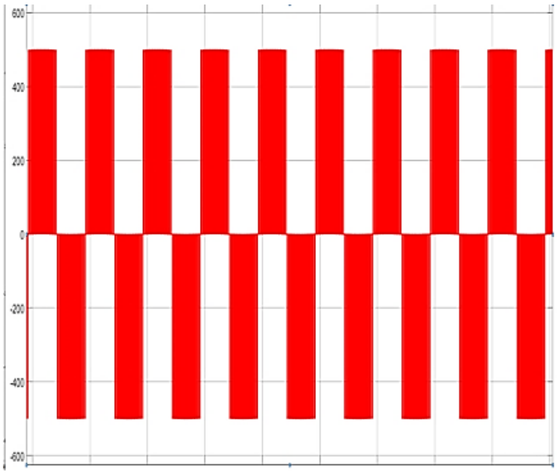

Fig. 9(d). SPWM Output Voltage.

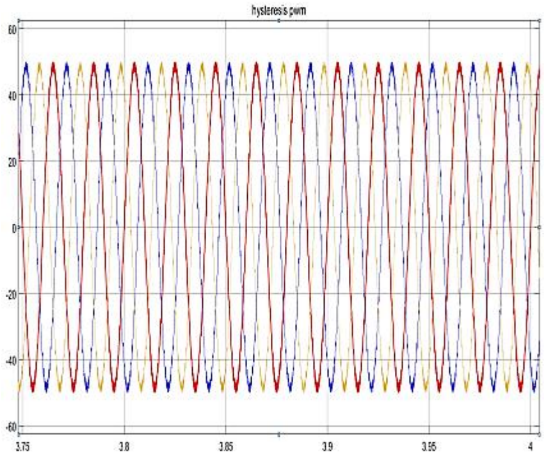

Fig. 9(e). HBCPWM Output Current.

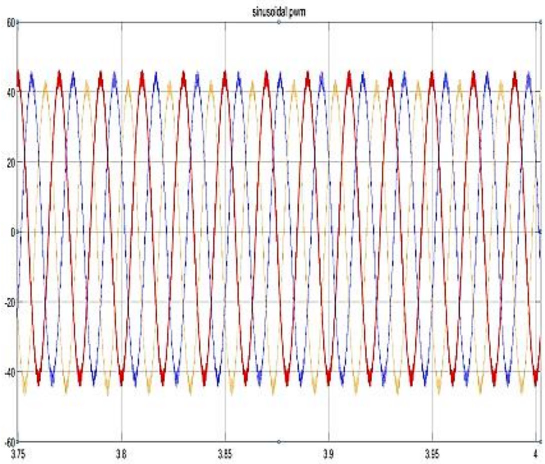

Fig. 9(f). SPWM Output Current.

As can be seen from the graphs below, the torque Figure 10(a,b) and speed Figure 10(c,d) of three phase synchronous machine.

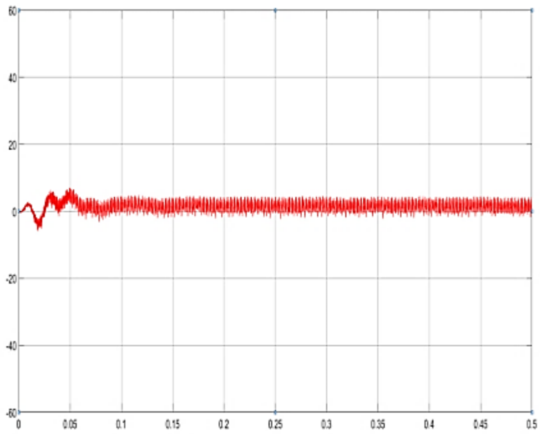

Fig. 10(a). Torque output of a synchronous machine using HBCPWM.

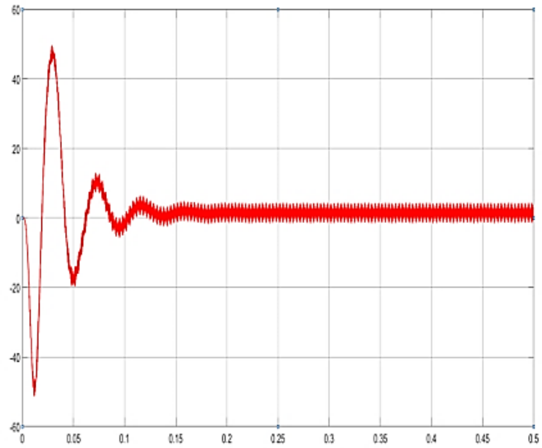

Fig. 10(b). Torque output of a synchronous machine using SPWM.

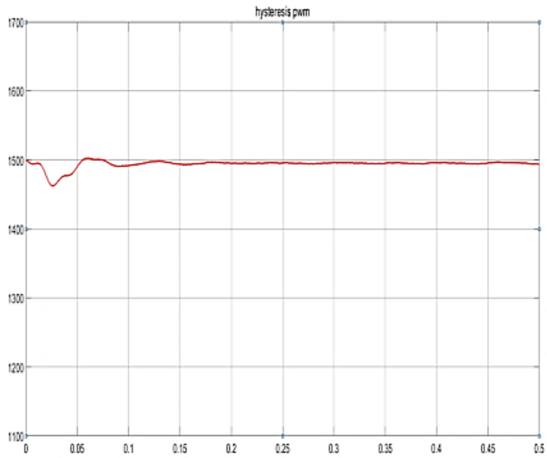

Fig. 10(c). Speed output of a synchronous machine using HBCPWM.

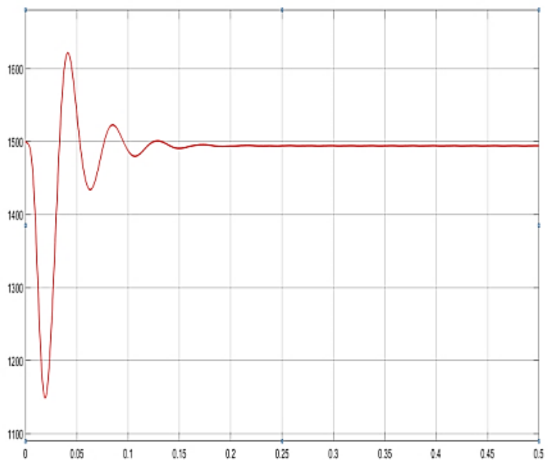

Fig. 10(d). Speed output of a synchronous machine using SPWM.

The three phase inverter's output voltages and currents' total harmonic distortion values and results are shown below. Figure 11(a, b, c, d), modulation index m=(0.5-1), Table (1), Figure 12(a, b).

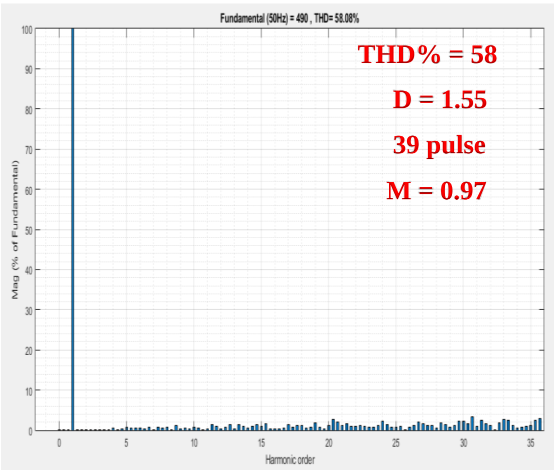

Fig 11(a): HBCPWM THD for Voltage.

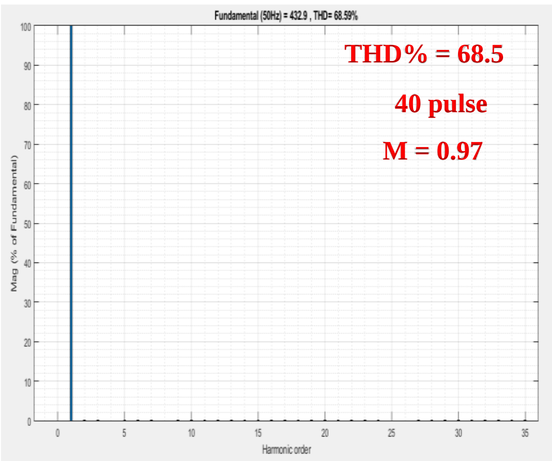

Fig. 11(b). SPWM THD for Voltage.

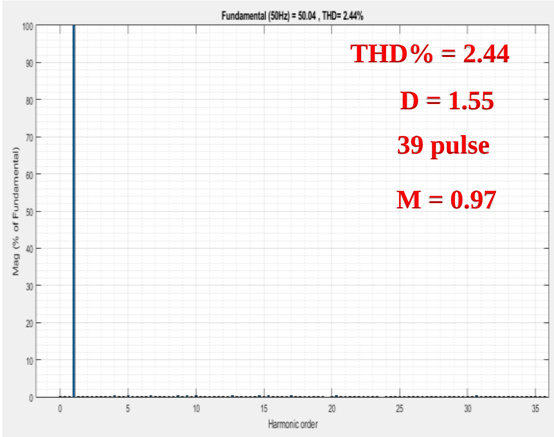

Fig. 11(c). HBCPWM THD for Current.

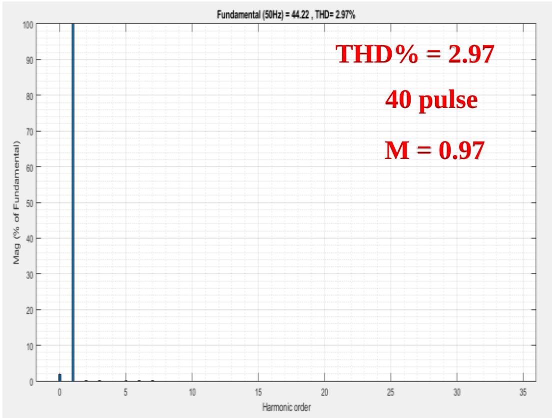

Fig. 11(d). SPWM THD for Current.

Table 1. Total Harmonic Distortion (THD), modulation index from 0.5 to 1, output voltage and current for different type of switching technique.

Switching Techniques	modulation index	THD%		Voltage (V)	Current (A)
		Voltage	Current		
HBCPWM	1	62.5	0.05	489.4	50
SPWM	1	68.5	2.97	432.9	44.2
HBCPWM	0.9	68	9.1	442.5	44.8
SPWM	0.9	79.5	2.99	389.8	39.8
HBCPWM	0.8	75.3	18.4	387.2	39.7
SPWM	0.8	91.5	3.09	346.3	35.3
HBCPWM	0.7	72.9	26.3	292.1	39.17
SPWM	0.7	104.9	3.26	303	30.9
HBCPWM	0.6	101.5	50.7	312.3	31.1
SPWM	0.6	120.5	3.49	259.5	26.5
HBCPWM	0.5	108.9	71.4	289.1	26.4
SPWM	0.5	139.3	3.76	216.4	22.1

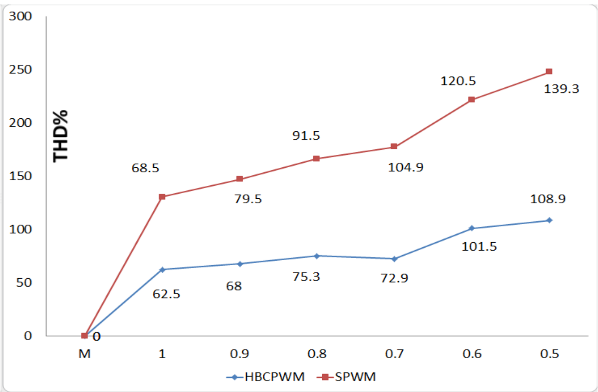

Fig. 12(a). Voltage THD curve between HBCPWM and SPWM.

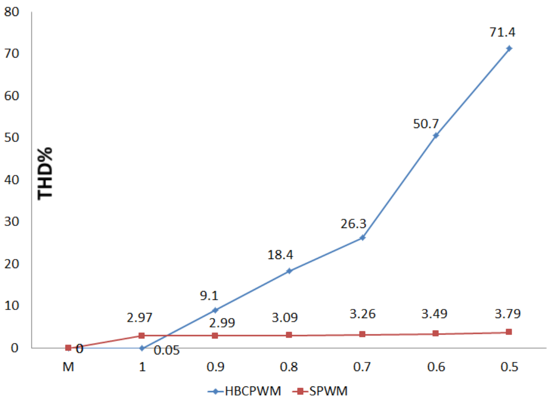

Fig. 12(b). Current THD curve between HBCPWM and SPWM.

4. Conclusion

This study compares and simulates the use of sinusoidal PWM and hysteresis band control PWM in MATLAB/SIMULINK to switch voltage source inverters. Figure 9(c), Figure 9(d), Figure 9(e) and Figure 9(f) exhibit output voltage and current graphs of the voltage source inverter switched by HBCPWM and SPWM. Analysis of the THD values of these voltages and currents shows that, for d = 1.55 and m = 0.97, the inverter's output voltage, which is controlled by HBCPWM has a THD value of 58%, the current has a THD value of 2.44%, the output voltage has a THD value of 68.5%, and the current has a THD value of 2.97% for the inverter controlled by SPWM.

Total harmonic distortion plays a significant role in power systems' power quality. This study compares the total harmonic distortion (THD) of switching voltage source inverters using the HBCPWM and SPWM approaches. Analysis revealed that the HBCPWM methodology is a more effective switching strategy in terms of power quality. In this way, this research serves as a baseline. The goal of this research is to determine the best switching strategy to lower harmonic rates to the lowest feasible level and to be able to transmit energy obtained from renewable energy resources as efficiently as possible.

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