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Comparative Analysis of the PWM and SPWM on Three-Phase Inverter through Different Loads and Frequencies

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Abstract: This research paper aims to compare the total harmonic distortion (THD) of the three-phase inverters used in variable frequency drives (VFDs) and high-power applications such as HVDC power transmission and AC motor drive systems. THD causes electromechanical and thermal stresses on the system, and this study compares the results of Pulse Width Modulation (PWM) and Sinusoidal Pulse Width Modulation (SPWM) on the three-phase inverter under different loads and frequencies. The study is conducted using MATLAB/SIMULINK software and analyzes the THD of the three-phase inverter under the PWM and SPWM separately. The loads considered in this study include R, RL, RC, and RLC, while the frequencies include 10, 15, and 20 kHz. The results of the study show that SPWM produces a lower THD compared to the PWM, which indicates that the overall efficiency of the inverter is improved when the SPWM is used. This research is limited to fixed frequency and loads, and the study suggests that using the model predictive control (MPC) method may lead to even better results.

Keywords: Three-phase inverter; PWM; SPWM; THD; FFT.

1. Introduction

Both academics and industry have shown an increased interest in complex behavior in power converters [1]. DC power was used to convert to AC power using a motor generator set and rotary converter. David Prince coined the term “Inverter” in 1925. It is defined as the inverse of a rectifier. The new era of converters started and increased inverter application, after the invention of power electronics switches [2]. Comparative analysis is employed using different loads across the output of the inverter, the PWM and SPWM methods are used [3]. Currently, the use of polluting fossil fuels is discouraged and the use of renewable energy resources is encouraged. Inverters are essential to utilize these renewable energy resources because DC is the form in which most of the renewable energy is found [4]. According to related standards, the total harmonic distortion in the output current of the grid-connected inverter must be less than 5 percent, and each harmonic distortion must be less than 3 percent [5]. In voltage source inverter (VSI) sinusoidal pulse-width modulation (SPWM) is one of the simple techniques. The sinusoidal pulse width modulation simple control strategy technique is applied by comparing the three-phase modulated signals (known as reference signals) with a carrier signal. In this technique, switching frequency depends on carrier switching [6, 7]. With the invention of inverting switches, the harmonics performance of inverters has become a great challenge. As a result, minimizing the total harmonic distortion (THD) of high-voltage Inverters is highly desirable [8,9]. The inverter output signal is of high quality when it contains less harmonic distortion. To reduce the effect of harmonics on the inverter signal, there are several schemes used, such as PWM and SPWM techniques. These two techniques depend on the applications and the switching frequencies to produce a high-quality waveform with less THD. SPWM works with a high switching frequency and is a popular scheme utilized in industrial applications to produce a good quality of Power [10].

The converter operating at a high switching frequency results in power losses which may cause damage and decrease efficiency. It is, therefore, to compare the converter efficiency under different PWM techniques, for this, the most compatible modulation technique is determined. To do this, various techniques have been developed to reduce the harmonics in the output Voltage or Current [11,12]. In [13,14] author illustrated the comparative study of five distinct PWM approaches for the best induction motor drive. As the result, boosting SPWM performance and loading circumstances may also enhance THD performance. In [15], the authors presented the comparison of various scalar pulse width modulation (PWM) algorithms used in three-phase drives. In [16] author summarizes, that a low THD inverter ensures the greater performance of the equipment connected to the inverter's output. In [17] authors demonstrated that the SPWM and total harmonic pulse width modulation (PWM) approaches are superior to the space vector pulse width modulation method (SVPWM) when there is no overshoot at the intended speed and no larger load change over the current. In [18] author analysis based on total harmonic distortion (THD) in current, transient behavior, these two PWM approaches were used to investigate the three-phase VSI-supplied induction motor. In [19] the author used Matlab/Simulink software to simulate the three-phase five, seven, and nine levels, and it was found that this technique requires a greater number of switches. The speed of motors can be controlled using this method. In [20] the author presented the design and implementation of a 1kW SPWM-based inverter to convert the applied DC voltage from a photovoltaic array to a pure sinusoidal AC voltage. The simulation results are presented at the output of every section of the inverter, and the output after the filtration is a pure sine wave 220V AC with the desired frequency of 50Hz. In [21] authors' analysis, the control, and modeling of induction motors are examined, as well as the impacts of total current harmonic distortion on a variable speed using a PWM generated and the vector control approach. In [22], the authors have discussed that the generated voltage spectrum for five-level inverter topologies is much enhanced compared to the three classical topologies of three multilevel inverters. In [23], the authors have used two multilevel pulse width modulation (PWM) approaches to analysis: the multi-carrier sine PWM (MCSPWM) and space vector PWM (SVPWM), with results indicating that the SVPWM method is much better than the MCSPWM algorithms.

After a detailed study of the three-phase inverter and its techniques, most authors have applied loads at a fixed frequency to check which technique is better, but there is a lack of studies specifically using the three-phase inverter technique with different loads of varying frequencies. Therefore, the objective of this research is to analyze the three-phase inverter model comparatively by adding two techniques: one is PWM, and the other is SPWM supplying four varying loads that are R, RL, RC, and RLC separately at a different frequency of 10, 15 and 20 kHz, respectively. The study could be useful in revealing the usefulness of a three-phase inverter in various applications are industrial, High Voltage Direct Current (HVDC) Power Transmission systems, and variable frequency drive systems (VFD).

2. Design of Inverter

The inverter based on the modulation techniques is to controls the output Voltage or Current in terms of magnitude and frequency of the inverter. The magnitude is dependent on the modulation index, which is the ratio of the reference signal to the carrier signal. The index cannot be greater than one which means the reference signal cannot be greater than the carrier signal, if this happens your inverter cannot produce the gating Pulse. The modulation index decides the magnitude of the output Voltage and the frequency of the carrier signal decides the harmonic content present in the output voltages.

2.1 Proposed Model

This proposed concept uses 400 V DC input voltage and six IGBT switches to produce variable frequency power for industrial, HVDC Power transmission systems, and VFD applications with minimum total harmonic distortion (THD) shown in percentage by using Matlab Simulink software tool that is Fourier Fast Transform (FFT). The output voltage or current waveform is measured across the Y-connected variables load. The frequency of the switches is kept at 10, 15, and 20 kHz respectively whereas the reference frequency is 50 Hz. The Matlab/Simulink model is shown in Figure 1. All the data is taken from the Simulink software and presented in tabular format as shown in tables 1, 2, and 3

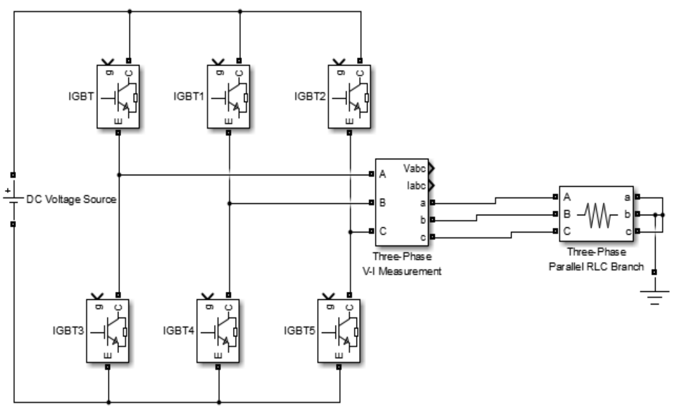

Figure 1. IGBT-Based 3-phase PWM Technique

2.2.1 PWM Technique

In pulse width modulation, modulation is done by using the carrier and reference signals. In this technique, the comparator is used by feeding mentioned two signals and the corresponding signals are generated based on the logic of the comparator. The reference wave is the desired signal output which may be a sine wave or a square wave. The carrier wave, on the other hand, is generally a saw tooth or triangular wave having a frequency significantly higher than that of the reference signal. The higher-order harmonics in the load current or voltage are eliminated using a series resistor, inductor, and capacitor respectively. A selected range of lower harmonics can be reduced by suitably choosing the number of pulses per half cycle. The model of this technique is shown in Figure 2.

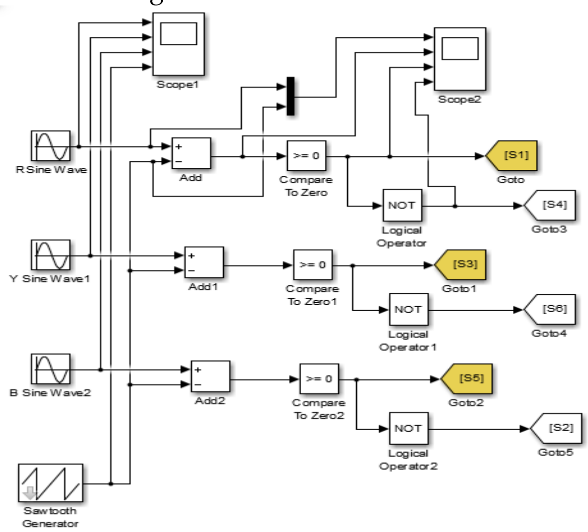

Figure 2. PWM Technique

2.2.2 SPWM Technique

This technique, sometimes known as triangular is particularly common in industrial applications. In the Sine Pulse Width Modulation, we are comparing two signals, one signal is sinusoidally known as a reference signal and the other one is a triangular signal known as a carrier signal. When the sinusoidal wave is greater than the carrier signal, we are getting the pulse at the output. These pulses are providing the IGBT or MOSFET of the Particular inverter and based on that get the output voltage or current.

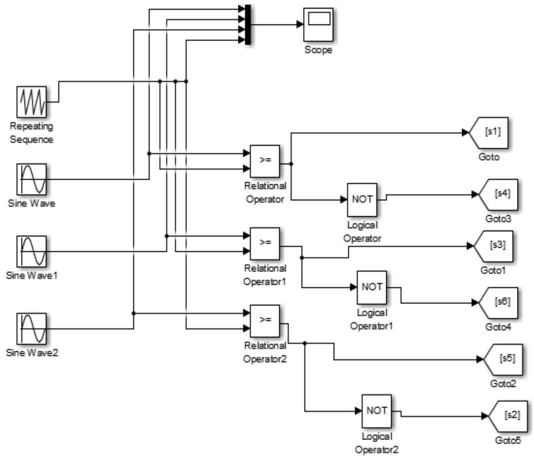

Figure 3. SPWM Technique

3. Result and Discussion

The proposed model is simulated in MATLAB/Simulink software presented in Figure 3.

In generated waveforms of Voltage and Current, the total harmonic distortion is shown in percentage in various loads under different cases using PWM and SPWM techniques. The generated waveforms are analyzed in a three-phase inverter in Figures 4, 5, and 6 at 10, 15, and 20 kHz switching frequencies respectively.

3.1. Case 1 Voltage and Current in Various loads at 10 kHz Frequency

In this case, we have comparatively analyzed two different techniques, one PWM and another SPWM respectively at 10 kHz frequency in various loads to check total harmonic distortion for the three-phase inverter.

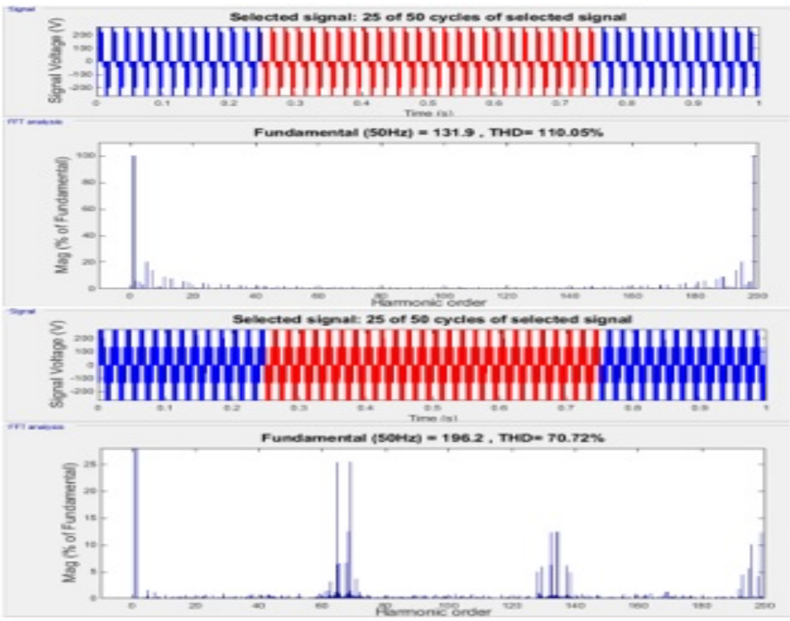

Figure 4. (a) Output Voltage of PWM and SPWM in R Load at 10 kHz

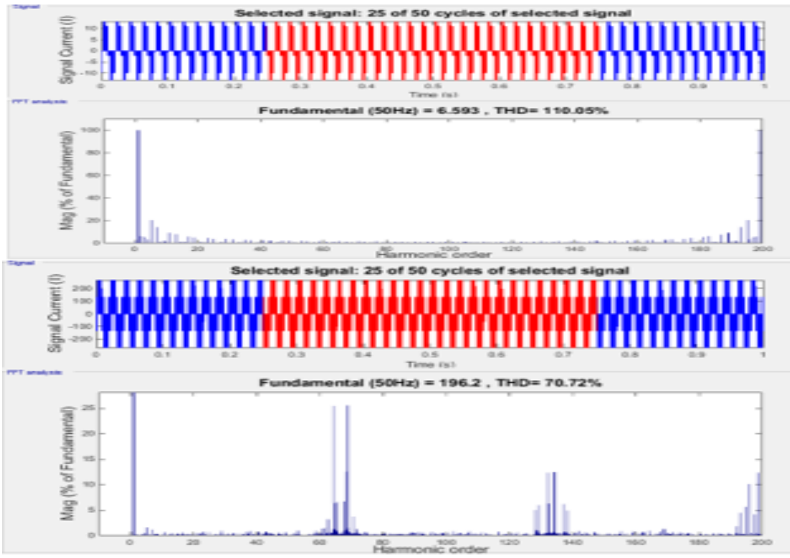

Figure 4. (b) Output Current of PWM and SPWM in R Load at 10 kHz

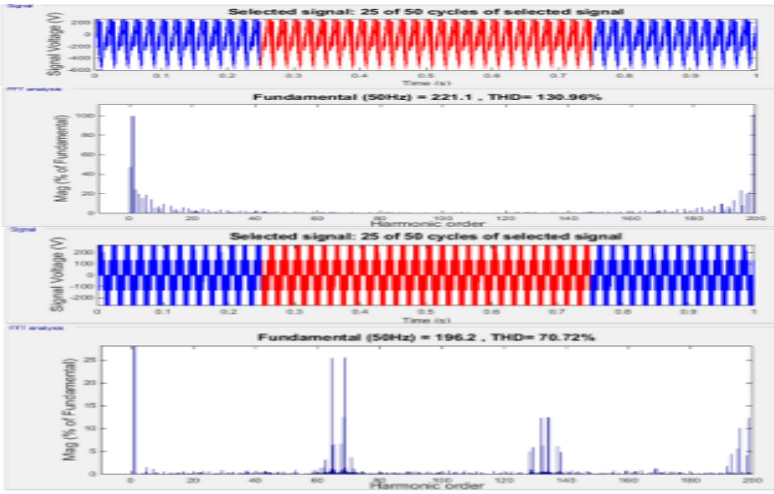

Figure 4. (c) Output Voltage of PWM and SPWM in RL Load at 10 kHz

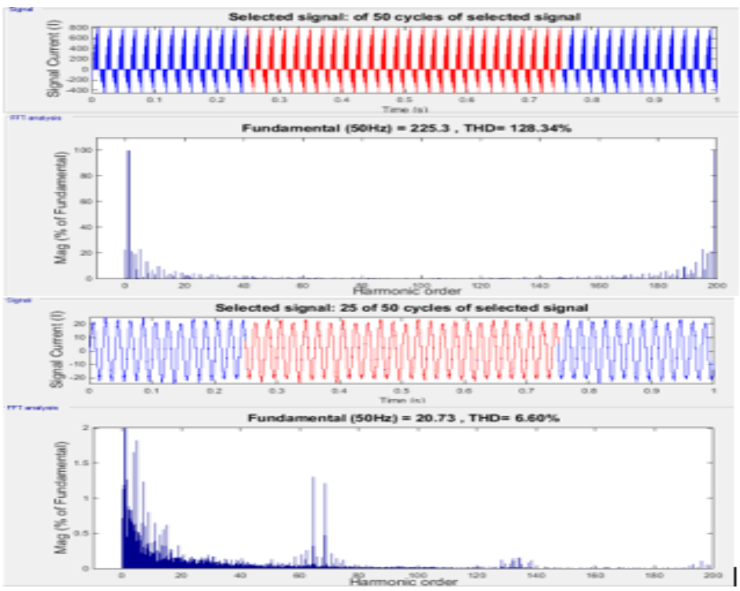

Figure 4. (d) Output Current of PWM and SPWM in RL Load at 10 kHz

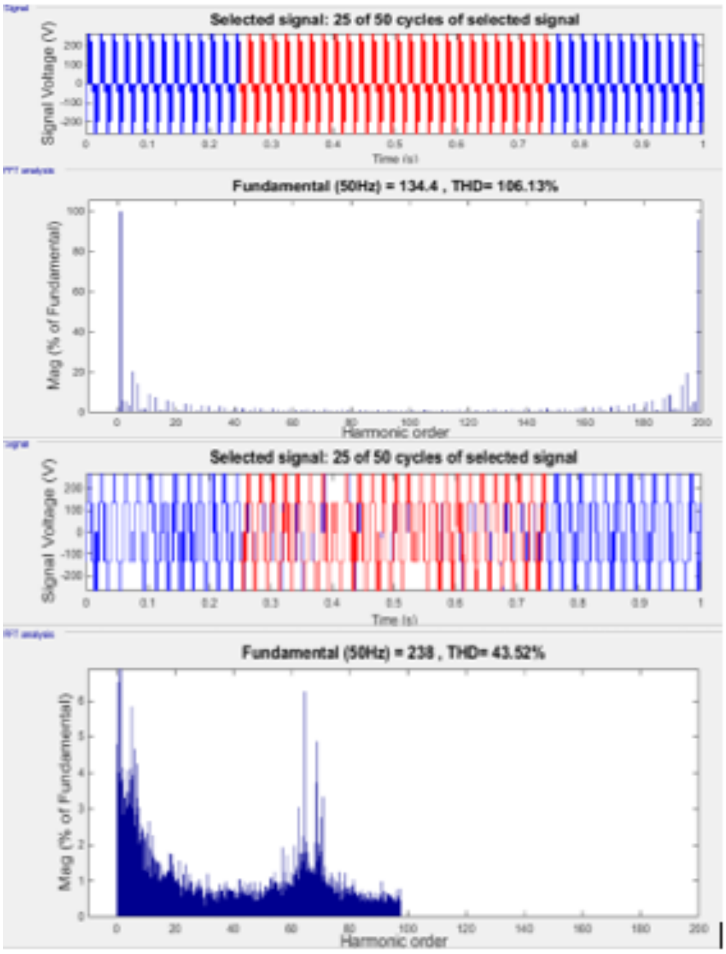

Figure 4. (e) Output Voltage of PWM and SPWM in RC Load at 10 kHz

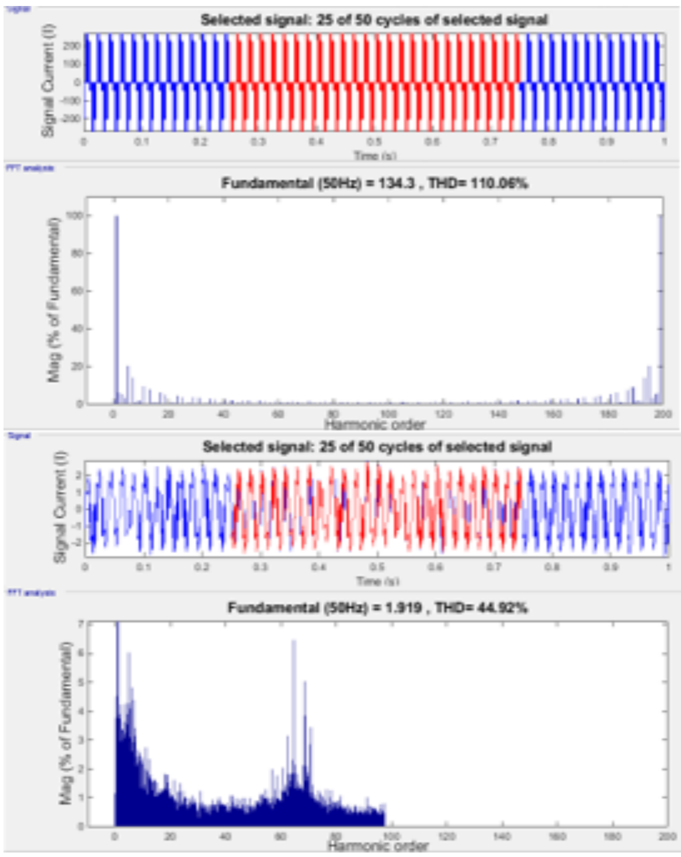

Figure 4. (f) Output Current of PWM and SPWM in RC Load at 10 kHz

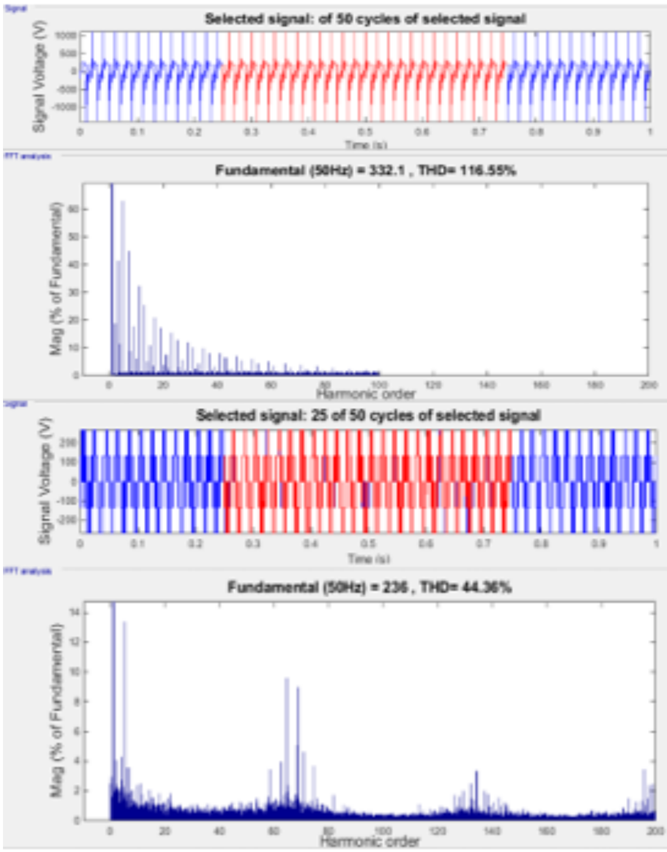

Figure 4. (g) Output Voltage of PWM and SPWM in RLC Load at 10 kHz

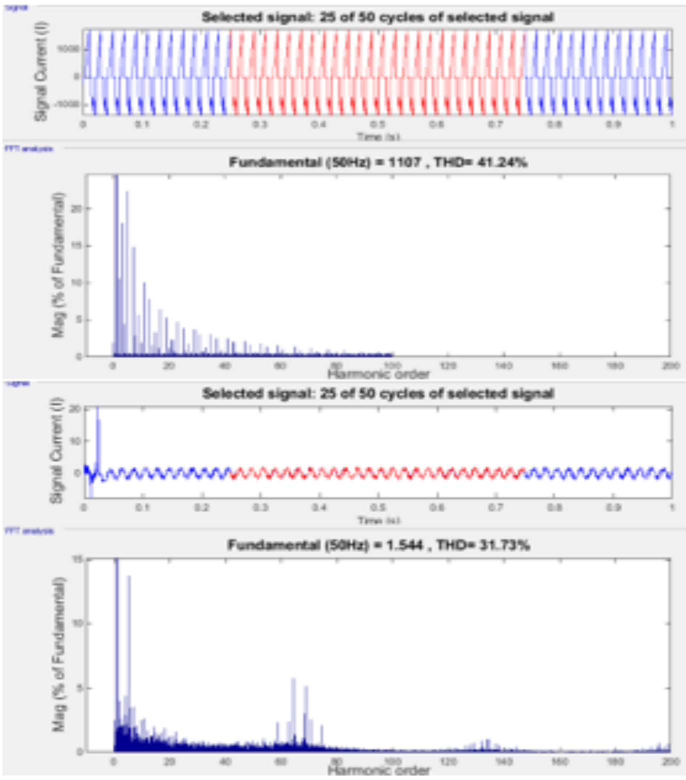

Figure 4. (h) Output Current of PWM and SPWM in RLC Load at 10 kHz

Hence it is clearly shown, that THD is found in the Output voltage and Current of 25 cycles of

50 cycles of the selected signal in all the loads at a switching frequency of 10 kHz, SPWM is much better than that PWM.

3.2 Case 2 Voltage and Current in Various loads at 15 kHz Frequency

In this case study similarly, we are analyzing the performance of the three-phase inverter based on THD at a frequency of 15 kHz in R, RL, RC, and RLC loads separately. For that, we are using PWM and SPWM techniques respectively.

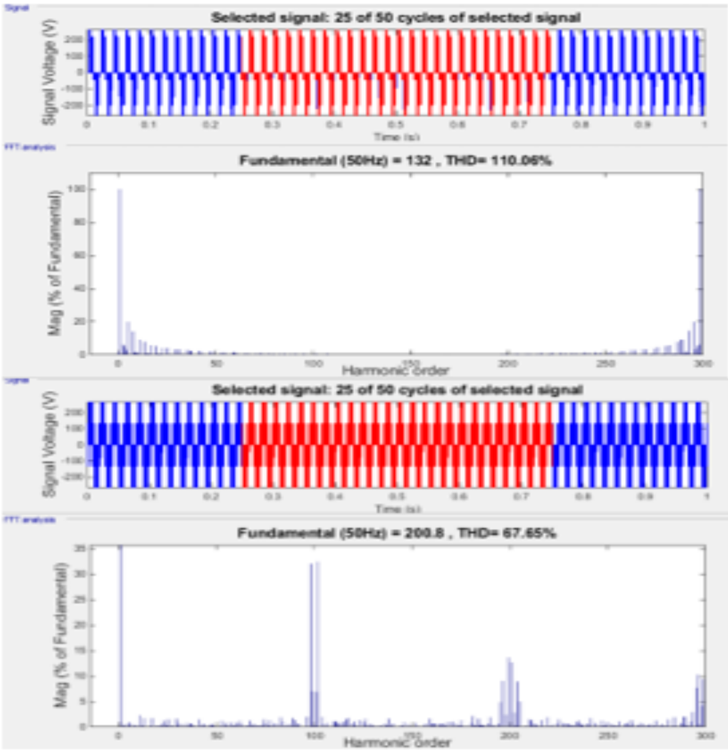

Figure 5. (a) Output Voltage of PWM and SPWM in R Load at 15 kHz

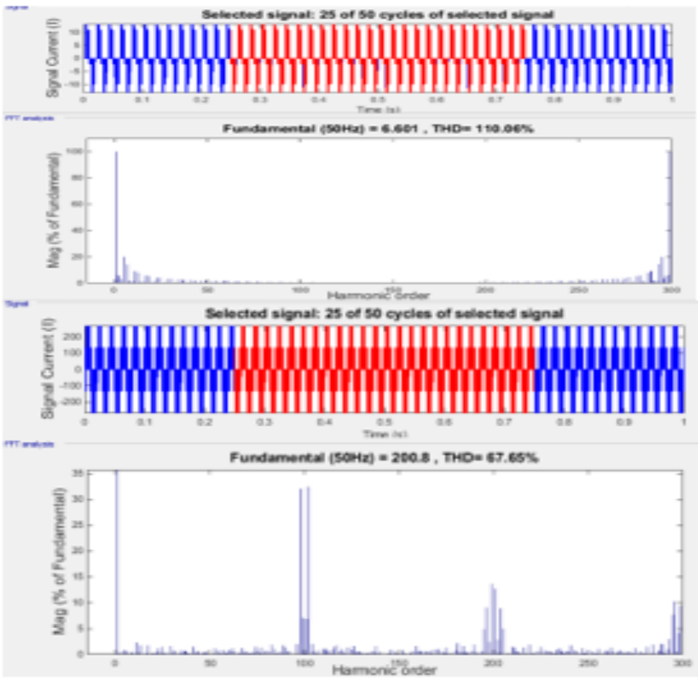

Figure 5. (b) Output Current of PWM and SPWM in R Load at 15 kHz

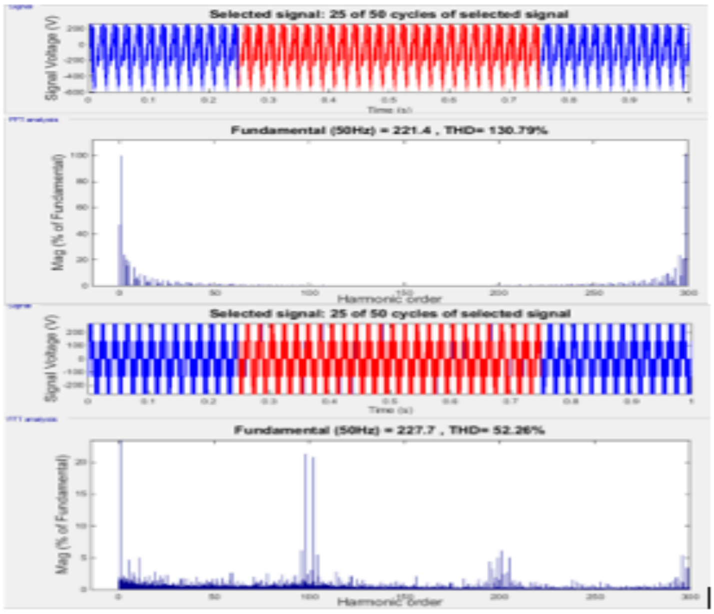

Figure 5. (c) Output Voltage of PWM and SPWM in RL Load at 15 kHz

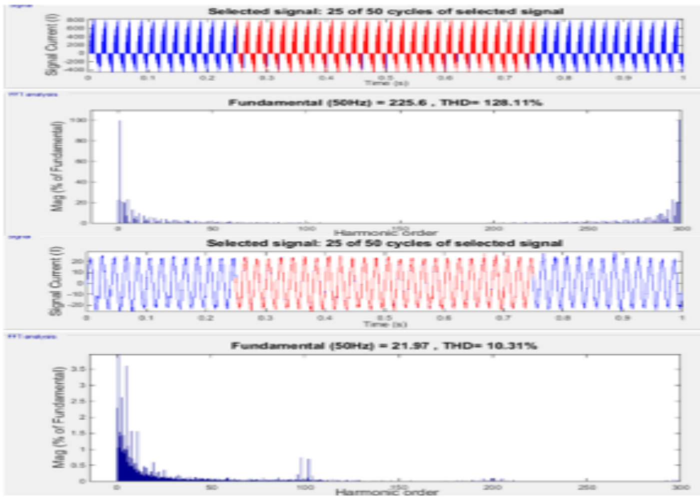

Figure 5. (d) Output Current of PWM and SPWM in RL Load at 15 kHz

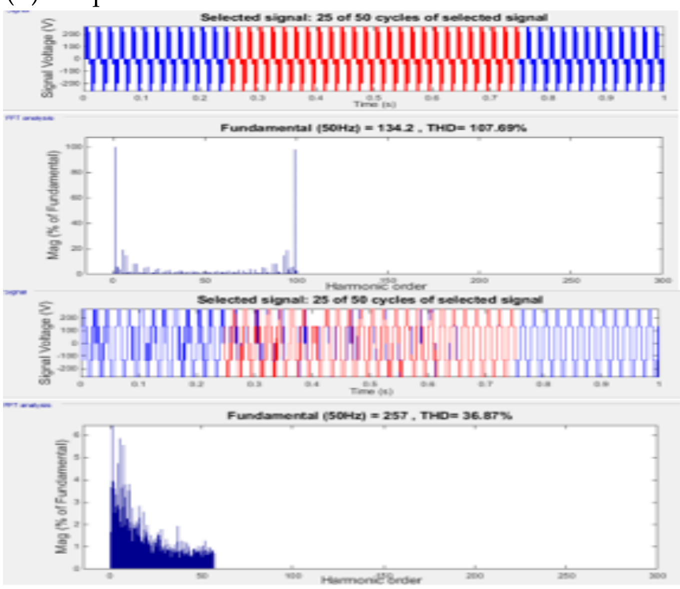

Figure 5. (e) Output Voltage of PWM and SPWM in RC Load at 15 kHz

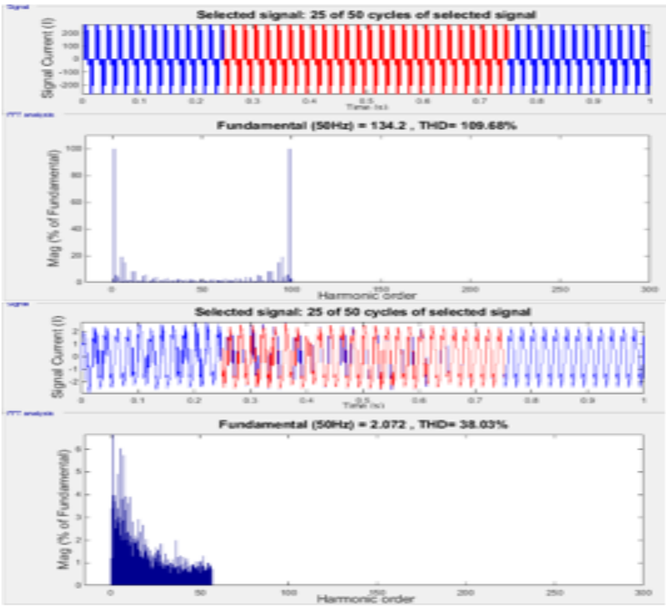

Figure 5. (f) Output Current of PWM and SPWM in RC Load at 15 kHz

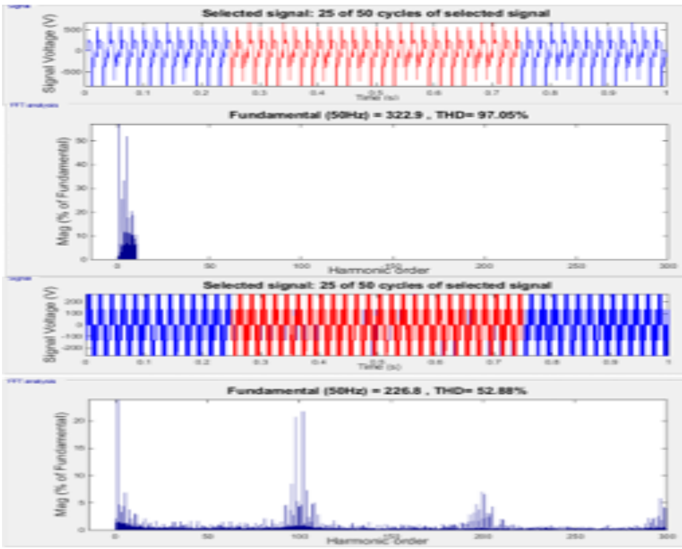

Figure 5. (g) Output Voltage of PWM and SPWM in RLC Load at 15 kHz

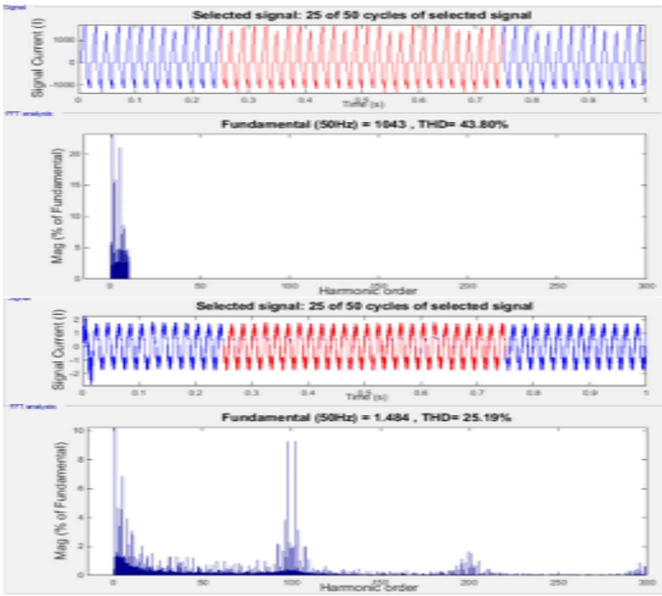

Figure 5. (h) Output Current of PWM and SPWM in RLC Load at 15 kHz

Hence it is clearly shown, that THD is found in the Output voltage and current of 25 cycles of 50 cycles of the selected signal in all the loads at a switching frequency of 15 kHz, SPWM is much better than that PWM.

3.3 Case 3 Voltage and Current in Various loads at 20 kHz Frequency

Similarly, in this case, study, we are analyzing the performance of the three-phase inverter based on THD at a frequency of 20 kHz in R, RL, RC, and RLC loads separately. For that, we are using PWM and SPWM techniques respectively.

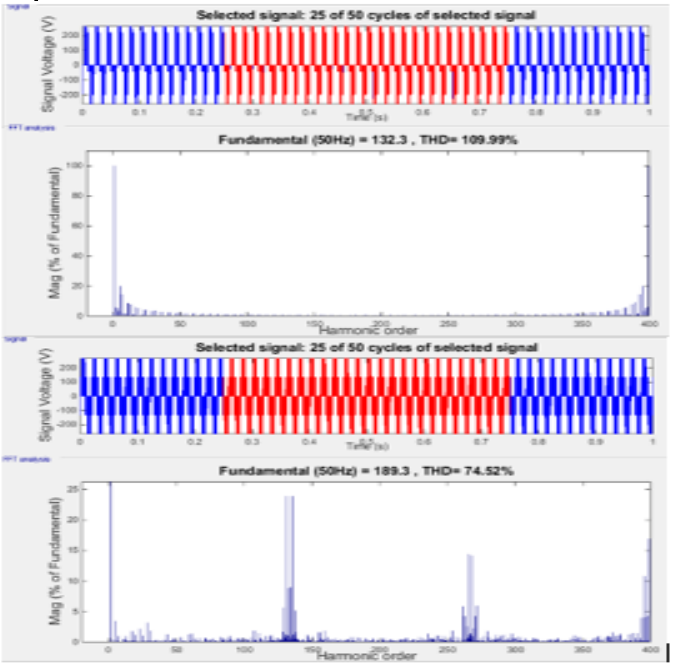

Figure 6. (a) Output Voltage of PWM and SPWM in R Load at 20 kHz

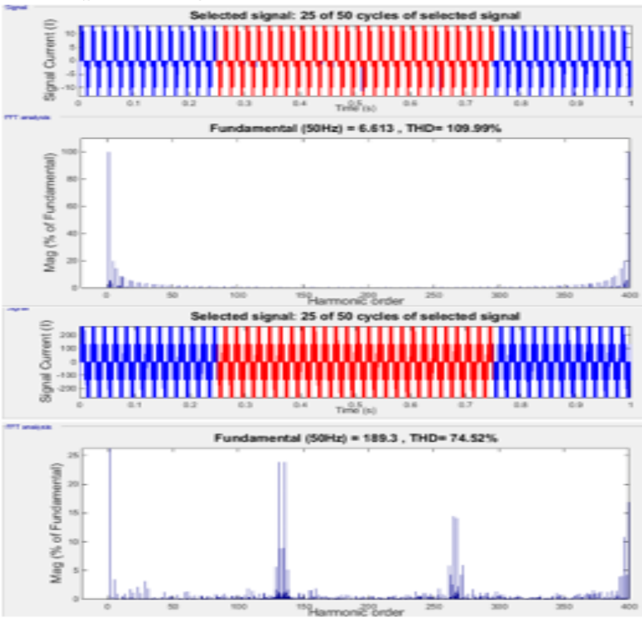

Figure 6. (b) Output Current of PWM and SPWM in R Load at 20 kHz

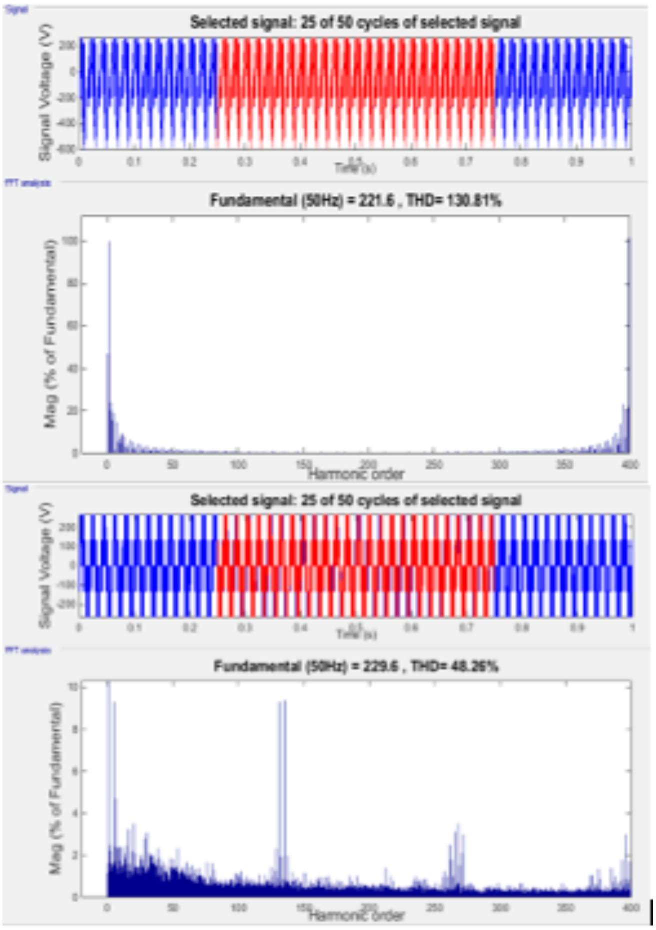

Figure 6. (c) Output Voltage of PWM and SPWM in RL Load at 20 kHz

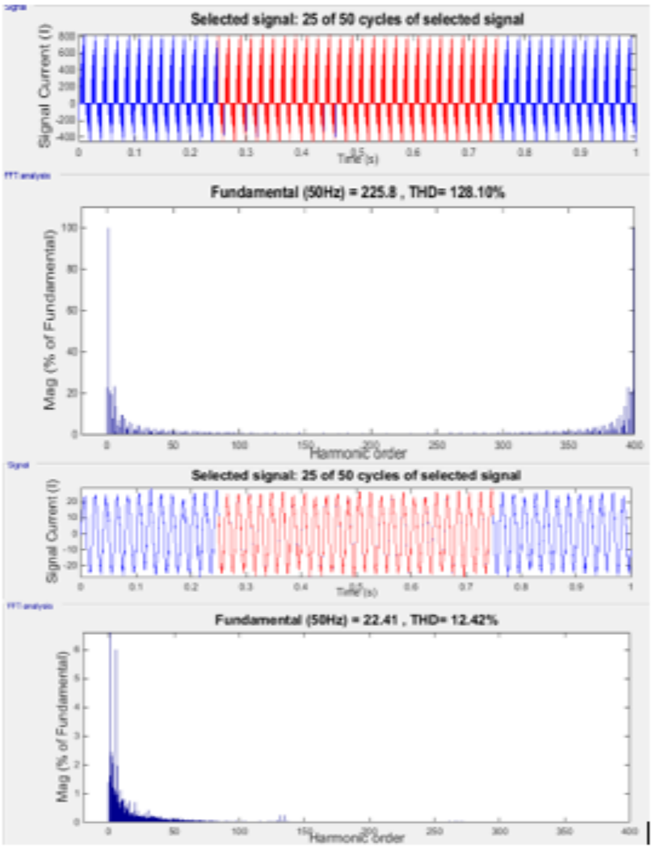

Figure 6. (d) Output Current of PWM and SPWM in RL Load at 20 kHz

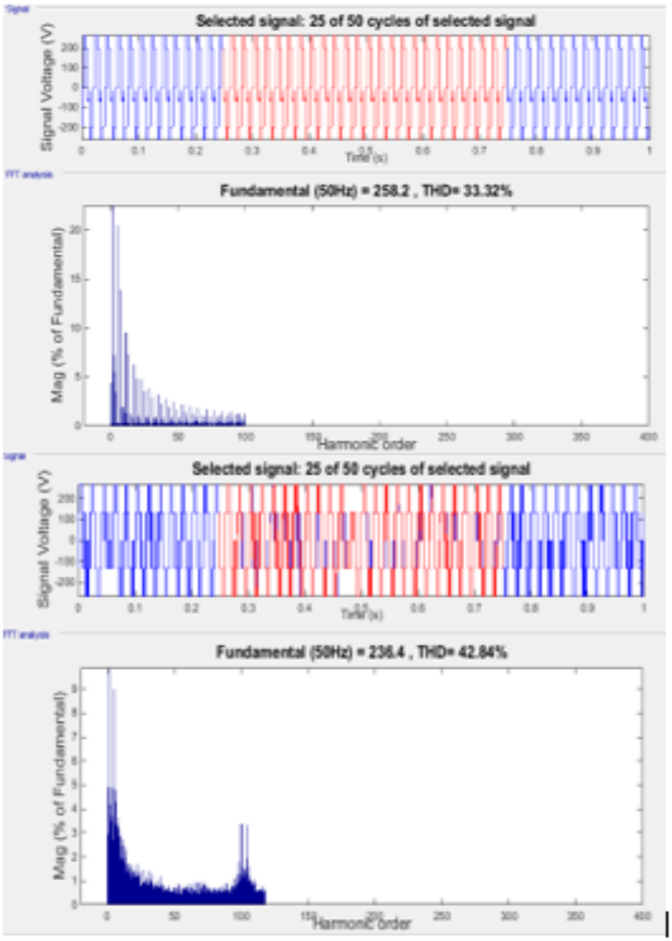

Figure 6. (e) Output Voltage of PWM and SPWM in RC Load at 20 kHz

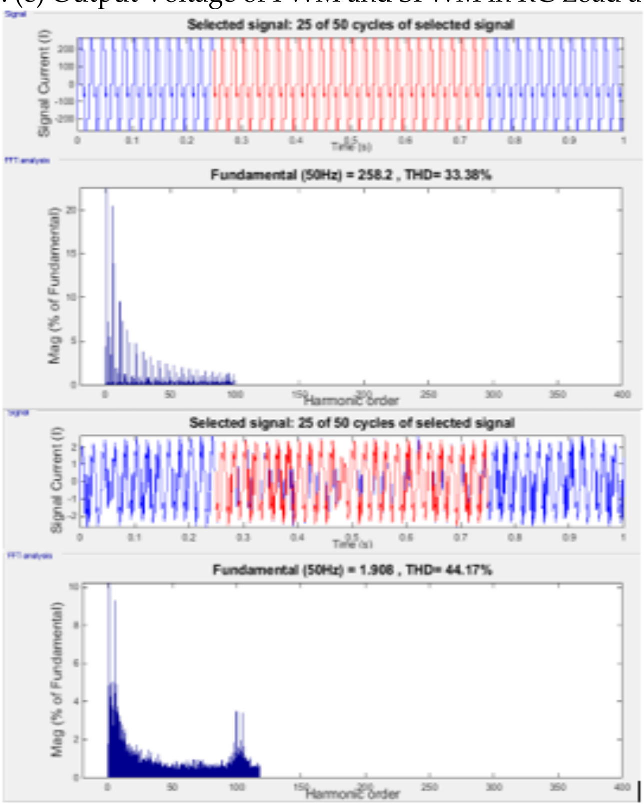

Figure 6. (f) Output Current of PWM and SPWM in RC Load at 20 kHz

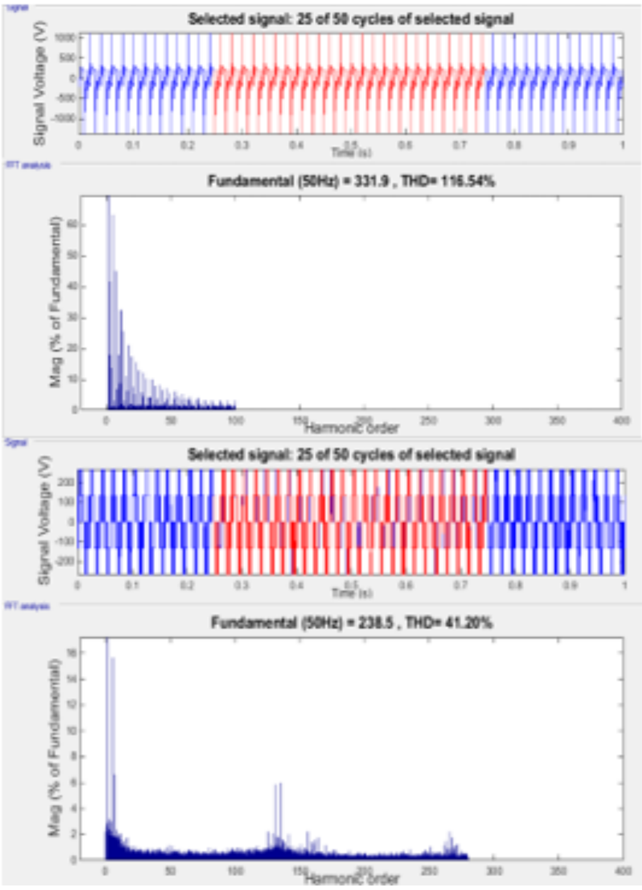

Figure 6. (g) Output Voltage of PWM and SPWM in RLC Load at 20 kHz

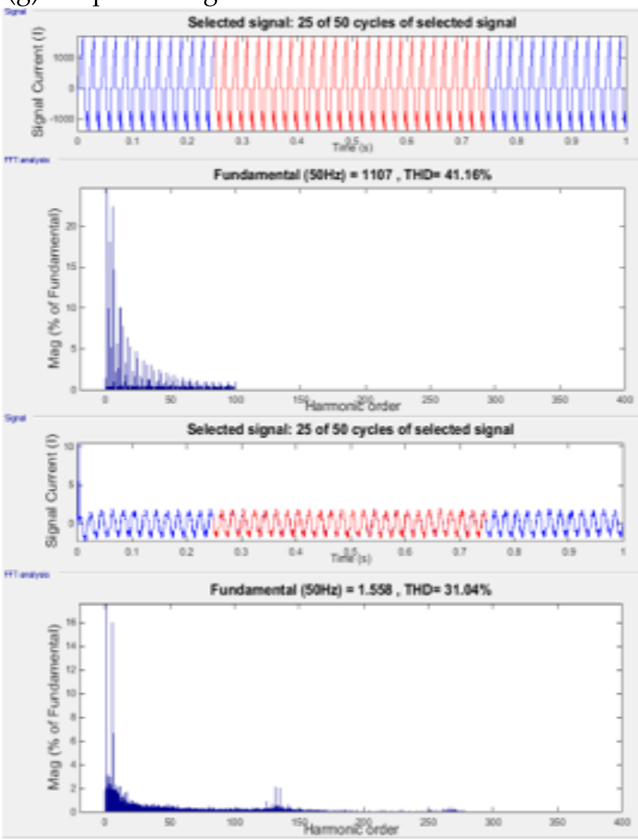

Figure 6. (h) Output Current of PWM and SPWM in RLC Load at 20 kHz

THD at a frequency of 20 kHz in R, RL, RC, and RLC loads separately. For that, we are using PWM and SPWM techniques respectively.

Hence it is clearly shown, that THD is found in the Output voltage and Current of 25 cycles of

50 cycles of the selected signal in all the loads at a switching frequency of 20 kHz, SPWM is much better than that PWM.

Our work is different from others in respect of loads and frequencies. In previous work, authors were taking only selective loads at a fixed frequency to check the performance of the three-phase inverter model in terms of THD in the output waveform of voltage respectively.

Table I show the THD at 10 kHz and the comparison between PWM and SPWM in various loads like R, RL, RC, and RLC separately to check the performance of the three-phase inverter. This helps in choosing a suitable technique.

Table 1. Total Harmonic Distortion (THD) for different types of loads and 10 kHz switching techniques

Load	Load Parameter	PWM		SPWM	
	Input DC Voltage	Output THD in %age at 10 kHz		Output THD in %age at 10 kHz	
		Voltage (V)	Current (I)	Voltage (V)	Current (I)
R	400 V	110.05	110.5	70.72	70.72
RL		130.96	128.4	57.72	6.6
RC		106.13	110.6	43.52	44.92
RLC		116.55	41.24	44.36	31.73

Table II shows the THD at 15 kHz and the comparison between PWM and SPWM in various loads like R, RL, RC, and RLC separately to check the performance of the three-phase inverter. This helps in choosing a suitable technique.

Table 2. Total harmonic distortion (THD) for different types of loads and 15 kHz switching techniques

Load	Load Parameter	PWM		SPWM	
	Input DC Voltage	Output THD in %age at 15 kHz		Output THD in %age at 15 kHz	
		Voltage (V)	Current (I)	Voltage (V)	Current (I)
R	400 V	110.06	110.6	67.65	67.65
RL		131.79	128.1	52.26	10.31
RC		107.69	109.6	36.87	38.03
RLC		97.05	43.80	52.68	25.19

Table III shows the THD at 20 kHz and the comparison between PWM and SPWM in various loads like R, RL, RC, and RLC separately to check the performance of the three-phase inverter. This helps in choosing a suitable technique.

Table 3. Total harmonic distortion (THD) for different types of loads and 20 kHz switching techniques

Load	Load Parameter	PWM	SPWM

	Input DC Voltage	Output THD in %age at 20 kHz		Output THD in %age at 20 kHz	
		Voltage (V)	Current (I)	Voltage (V)	Current (I)
R	400 V	109.99	109.9	74.52	74.52
RL		130.81	128.1	48.26	12.42
RC		42.87	44.17	33.32	33.38
RLC		116.54	41.16	41.20	31.04

When comparing the two methods, it is important to consider the benefits to the community. For example, the use of SPWM can reduce harmonic distortion in the power system and result in a more reliable power supply. This can benefit the community by providing more reliable power and reducing the risk of blackouts. Additionally, the use of SPWM can result in higher efficiency and reduced energy costs, which can benefit.

5. Conclusions

In this paper, the PWM and SPWM techniques are performed for R, RL, RC, and RLC loads under different switching frequencies, for example, 10, 15, and 20 kHz respectively. Both approaches are compared in terms of total harmonic distortion. Simulation shows that the SPWM is better than the PWM due to more THD in PWM. Therefore, the overall efficiency of the three-phase inverter is better under SPWM. The studies are limited to the PWM and SPWM techniques. However, the study may be further extended by using the model predictive control (MPC) method for better results.

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