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# EVALUATION OF THE PERFORMANCE OF DIFFERENT PWM TECHNIQUES USING HYBRID PWM TECHNIQUE FOR A VOLTAGE SOURCE INVERTER

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## ABSTRACT

A voltage source inverter (VSI) is a device that converts unidirectional voltage waveform into bidirectional voltage waveform. A VSI typically generates an AC output voltage that can vary in frequency, amplitude and phase angle depending on the control signals applied to it. This makes it useful for controlling the speed and direction of AC motors, connecting renewable energy sources like solar panels or wind turbines to the grid and providing stable AC power during power interruptions.

To control the output voltage and frequency of the inverter, Pulse Width Modulation (PWM) techniques are used. By adjusting the width of the pulses in PWM waveform, the average voltage delivered to the load can be controlled. Different PWM techniques are used to control the output voltage and frequency of the VSI. Some of them are sinusoidal pulse width modulation (SPWM), third harmonic injected pulse width modulation (THPWM), conventional space vector pulse width modulation (CSWPWM), etc. The above PWM techniques produce a cleaner output waveform with fewer harmonics, lower distortion and improve overall quality of the output voltage.

But these PWM techniques also have some limitations like increase in switching frequency, stress on power devices, switching and conduction losses etc. When switching and conduction losses are more in a voltage source inverter (VSI) it results in increased heating, higher voltage drop, increased stress in components and reduces efficiency. Total Harmonic Distortion (THD) is a measurement that quantifies the level of harmonic distortion present in electrical waveform. Increased THD results in reduced power quality, overheating, and reduced overall efficiency of system. Minimizing THD is essential to maintain the reliability, efficiency and safety of the system. To mitigate the total harmonic distortion (THD) and power losses of voltage source inverter a hybrid pulse width modulation technique is introduced in this project.

The hybrid PWM technique introduces a modified modulating signal along with newly shaped carrier signal. The proposed modulating signal consists of several signals like saturated triangular, sinusoidal, inverted triangular and 7th harmonic signal are mixed together in order to produce the proposed modulating signal. The project is extended by replacing a seventh (7th) harmonic in the modulating signal with eleventh (11th) harmonic signal. The modified modulating signal is designed to reduce the number of higher order harmonics in the output voltage waveforms. The performance of voltage source inverter with hybrid PWM technique is to be proved through simulation in MATLAB SIMULINK environment and decreases the total harmonic distortion (THD) as compared to the other existing PWM techniques with hybrid PWM technique.

## 1. INTRODUCTION

Hybrid Pulse Width Modulation (PWM) is a technique used in Voltage Source Inverters (VSIs) to control the output voltage by adjusting the width of the pulses in the PWM waveform. Due to the adjustment of width of pulses, the average voltage delivered to the load can be controlled. The controlled voltage is mostly used in the application of motor drives. Hybrid PWM helps to Improve the efficiency and performance of variable frequency drives. This technique enhances the speed control, torque response and overall reliability of motor drive systems in industries such as manufacturing, automotive and HVAC etc.

Voltage source inverters are widely used in many applications, including Industrial automation, grid integration of renewable energy systems, high Voltage DC power transmission, and uninterrupted power Supply (UPS) circuits etc. Power quality is a constant challenge for any kind of VSI based power system which mostly relies on the PWM Schemes used for inverters. But, these existing PWM schemes for Voltage source inverter suffer from high total harmonic distortion (THD).

To reduce the THD and increase the power quality, Hybrid pulse width modulation technique is used. This Hybrid PWM technique improves the efficiency, greater system reliability and enhance power quality. The Proposed Hybrid PWM technique introduces a modified modulating signal along with newly shaped carrier signal. The proposed modulating signal consists of several signals, saturated triangular, sinusoidal, inverted triangular and 7th harmonic or 11th harmonic signal are mixed in order to produce the proposed modulating signal. This modified modulating signal is designed to reduce the number of higher order harmonics in the output voltage waveforms.

Due to the modified modulating Signal and newly shaped carrier signal, the output voltage is cleaner with fewer harmonics. i.e., this Hybrid PWM can reduce the harmonic content in output voltage, than existing PWM techniques. Therefore, the performance and efficiency of the devices increases.

## 2. LITERATURE SURVEY

**1. Title:** ‘‘Three-phase boost-type grid-connected inverter,’’ IEEE Trans. Power Electron., vol. 23, no. 5, pp. 2301–2309, Sep. 2008.

**Author:** Y. Chen and K. Smedley

**Description:** Three-phase voltage source inverters (VSIs) have become a cornerstone technology in modern power electronics. Their ability to convert DC voltage to controllable AC voltage makes them ideal for a variety of applications. In variable frequency drives, VSIs adjust the frequency of the output power to precisely control the speed of AC motors. This is crucial for efficient operation in industrial settings. Furthermore, VSIs play a key role in integrating renewable energy sources like solar and wind into the power grid. They convert the DC output from these sources into grid-synchronized AC, enabling smooth integration. VSIs are also employed in high voltage DC (HVDC) transmission systems, where they efficiently convert AC to DC for long-distance power transmission with minimal losses. Finally, uninterruptible power supply (UPS) circuits utilize VSIs to provide backup power during outages. By storing DC energy and inverting it to AC during grid interruptions, VSIs ensure continuous operation of critical equipment. Overall, three-phase VSIs are a versatile and essential technology for various power conversion and control applications.

**2. Title:** ‘‘A new modulation technique to improve the performance of three phase inverters,’’ in Proc. IEEE Int. Conf. Appl. Supercond. Electromagn. Devices (ASEMD), Tianjin, China, Oct. 2020, pp. 1–2 [3].

**Author:** S. P. Biswas, M. S. Anower, M. R. Islam Sheikh, M. R. Islam, A. Z. Kouzani, and M. A. P. Mahmud

**Description:** One key parameter for evaluating the performance of Voltage Source Inverters (VSIs) is Total Harmonic Distortion (THD). Ideally, a VSI should output a pure AC waveform. However, traditional Pulse Width Modulation (PWM) techniques, such as Sinusoidal PWM (SPWM), Third Harmonic Injected PWM (THPWM), and Conventional Space Vector PWM (CSVPWM), introduce unwanted harmonic distortions into the output waveform. This distortion increases THD and reduces the overall power quality. These traditional PWM techniques achieve control by rapidly switching the inverter's power electronic devices. While effective, the inherent on-off nature of this switching process creates a stepped output waveform instead of a smooth sine wave. This stepping effect injects unwanted harmonic frequencies on top of the desired fundamental frequency, leading to higher THD. In essence, while traditional PWM techniques offer control functionality, they come at the cost of increased THD in the VSI's output. Minimizing THD is crucial for various reasons, including ensuring efficient power transmission, protecting sensitive equipment from damage, and complying with power quality standards.

**3. Title:** ‘‘A modular multilevel converter with an advanced PWM control technique for grid-tied photovoltaic system,’’ Energies, vol. 14, no. 2, p. 331, Jan. 2021 [19].

**Author:** S. Haq, S. P. Biswas, M. K. Hosain, M. A. Rahman, M. R. Islam, and S. Jahan

**Description:** Conventional Pulse Width Modulation (PWM) techniques, while widely used, introduce unwanted harmonic distortion into the output voltage. This distortion becomes especially problematic at high modulation indices. Researchers are exploring hybrid modulation methods that combine different PWM approaches. These hybrids aim to achieve a balance between minimizing harmonic distortion, maintaining good output voltage quality, and allowing for fast dynamic control of the output voltage – all crucial aspects for modern power electronics applications.

**4. Title:** ‘‘Carrier selection strategy of generalized discontinuous PWM method for current reduction in DC link capacitors of VSI,’’ IEEE Trans. Power Electron., vol. 37, no. 9, pp. 10428–10442, Sep. 2022 [24].

**Author:** J. Lee, M. Kim, and J. Park

**Description:** Studies on Voltage Source Inverters (VSIs) highlight the importance of Pulse Width Modulation (PWM) techniques in controlling power output and minimizing unwanted harmonics. However, traditional PWM methods can result in high Total Harmonic Distortion (THD) and reduced efficiency. Research suggests that a hybrid PWM

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technique is a promising solution. By combining different PWM approaches, the hybrid technique can achieve a significant reduction in THD, leading to a cleaner output waveform and improved overall system efficiency. This improvement in efficiency translates to lower power losses within the VSI itself.

**5. Title:** ''Investigation of the impact of different PWM techniques on rectifier-inverter fed induction motor drive,'' in Proc. Australas. Universities Power Eng. Conf. (AUPEC), Hobart, TAS, Australia, Dec. 2020, pp. 1–6 [25].

**Author:** S. P. Biswas, M. S. Anower, M. R. I. Sheikh, M. R. Islam, and K. M. Muttaqi

**Description:** Studies on Voltage Source Inverters (VSIs) highlight the importance of Pulse Width Modulation (PWM) techniques in controlling power semiconductor switches and ensuring power quality. A conventional concern for VSIs is high Total Harmonic Distortion (THD) which can reduce efficiency. Research suggests that a hybrid PWM technique is a promising solution. This method minimizes THD by combining a modified control signal with a specially crafted carrier signal. This reduction in THD leads to lower power losses in the VSI, thus improving overall system efficiency.

## 3. PROPOSED SYSTEM

### 3.1 Implementation of Hybrid PWM:

**3.1.1** Generation of Modified modulating signal:

Saturated triangular, Sinusoidal, inverted triangular and 7th or 11th harmonic signals are mixed together in order to produce modulating signal. In this process we have to saturate the triangular signal, to generate modulating signal.

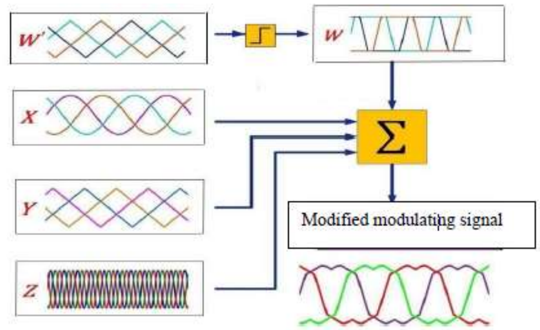


**Fig 3.1: Block diagram for generation of Modified modulating signal**

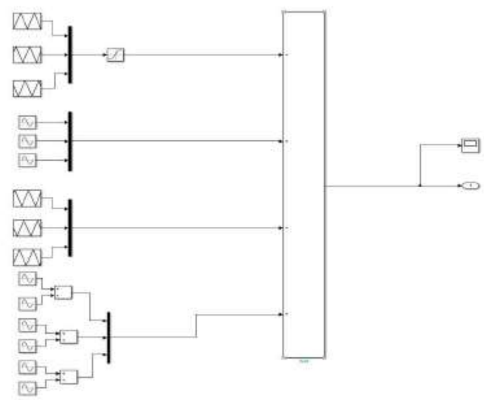

**Fig 3.2: Simulation model for generation of Modified modulating signal**

- **Triangular signal:** A waveform that rises linearly from a minimum value to a maximum value and then falls linearly back to a minimum Value, Forming a Triangular shape.
- **Sinusoidal Signal:** It also known as Sine wave. A waveform that oscillates periodically over a time, forming a sinusoidal signal.
- **Inverted triangular:** An Inverted Triangular signal is essentially the opposite of the regular triangular signal. It forms an inverted

triangular shape and shares similar characteristics with regular triangular signal.

- **7th Harmonic signal:** A 7th harmonic signal refers to a signal whose frequency is seven times that of a fundamental frequency.

- **11th Harmonic signal:** A 11th harmonic signal refers to a signal whose frequency is eleven times that of a fundamental frequency. **3.2.2** Generation of carrier signal:

**3.1.2 Generation of carrier signal:**

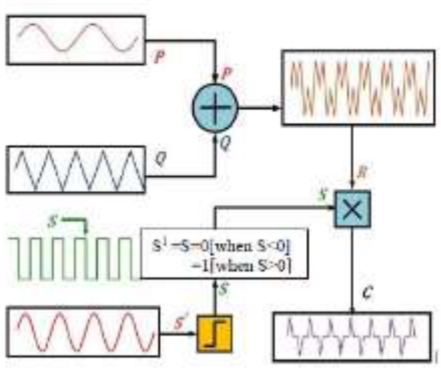


**Fig 3.3: Block diagram for generation of Carrier signal**

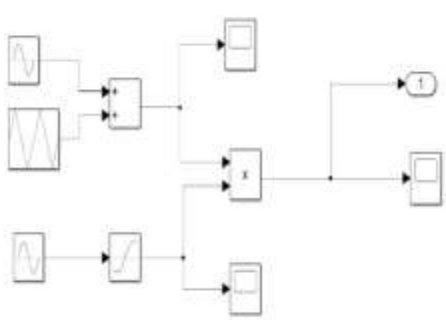

**Fig 3.4: Simulation model for generation of Carrier signal**

A Sinusoidal wave(P) and triangular wave(Q) is produced having triple the frequency of the sinusoidal signal (P) is added to generate the signal (R).

**R=P+Q**

After that sinusoidal signal(S1) having double the frequency of signal P and then S1 compared to zero to generate the signal S.

**S1=S= 0 [when S<0]**

**= 1 [when S>0]**

Finally, the signals R and S are multiplied to generate the proposed carrier signal 'C'

**C=R*S**

This Carrier signal is a high-frequency periodic waveform, used as a reference to encode the formation in pulse width modulation. Due to the high frequency of carrier signal, it can be more efficiently amplified and transmitted through the circuits or systems.

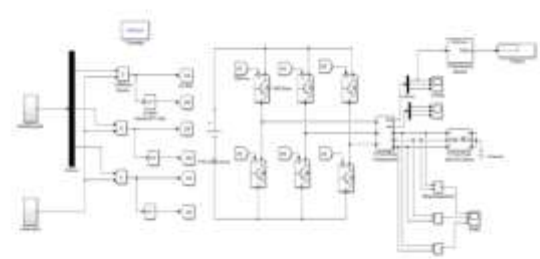

**Fig 3.5: Three phase VSI with HYBRID PWM [7th harmonic injected] (without LC filter)**

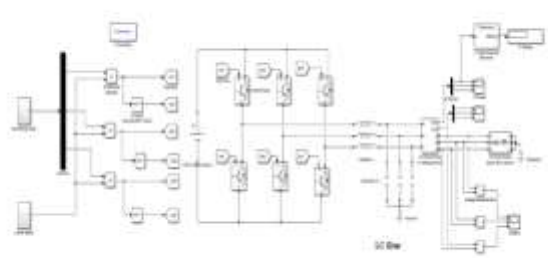

Fig 3.6: Three phase VSI with HYBRID PWM [7th harmonic injected] (with LC filter)

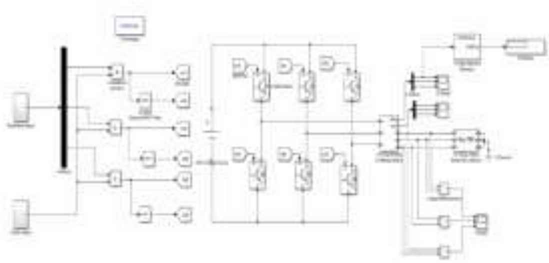

Fig 3.7: Three phase VSI with HYBRID PWM [11th harmonic injected] (without LC filter)

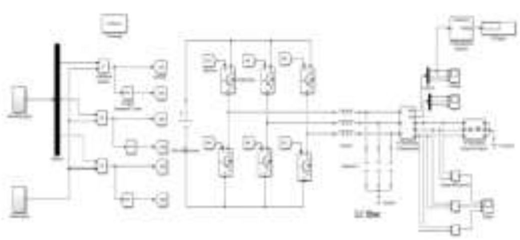

**Fig 3.8: Three phase VSI with HYBRID PWM [11th harmonic injected] (with LC filter)**

### 3.3 Comparison of modulating signal with carrier signal:

The modified modulating simal is compared with the newly shaped carrier signal at every instant. During the comparison of modulating and carrier signals, produce the gate pulses for the IGBTS of the VSI. When amplitude of the modulating signal is greater than the amplitude of the carrier signal, the gate pulse will be high.

On the contrary, when the amplitude of the modulating signal is less than amplitude of carrier signal, the gate pulse will be low. The proposed carrier signal generates more symmetrical gate pulses. The pulse symmetry plays a vital role in overall performance of VSI. Therefore, more Symmetrical gate pulses are desired as it reduces the harmonic distortion. This is the superiority of the proposed hybrid PWM technique compared to existing PWM techniques.

**Hybrid PWM Based VSI:**

The VSI consists of six IGBT switches which are named as S1, S3, S5, S4, S6 and S2 respectively. The DC input voltage is chosen as 400V. The LC filter is used in between the VSI and load to suppress harmonics. The switch pairs should not be turned ON simultaneously to avoid the short circuiting of DC Source. Three modulating signals (Ma, Mb, and Mc) are compared to a high frequency carrier signal to generate the gate pulse for the IGBTs. More symmetrical gate pulses plays a key role to increase the performance of voltage source inverter.

**Benefits of Hybrid PWM:**

- **Enhanced harmonic reduction:** By utilizing multiple signals in the generation of modulating signal, hybrid PWM can effectively reduce harmonic distortion, resulting in cleaner output waveforms and improve the system performance.

- **Increased Efficiency**: Due to the presence of lesser harmonics in output voltage, the power quality increases and efficiency is also increases.

- **Flexibility:** Hybrid PWM allows for adaptability to various load conditions and system requirements, offering flexibility in achieving optimal performance.

- **Reduce Electromagnetic Interference (EMI):** Minimizing harmonics through hybrid PWM helps mitigate EMI, ensure compliance with regulatory standards and improving system reliability.

- **Improve Voltage and Current Control:** In Hybrid PWM enables precise control of output voltage and current. Enhance control capabilities Contribute to better system stability, response time and transient performance. Accurate voltage and current regulation are essential for maintaining system integrity and protecting sensitive components from over voltage and over current conditions.

**Applications of Hybrid PWM Based VSI:**

- Motor Drives
- Uninterrupted power supply circuits
- Grid Integration of Renewable energy systems
- High Voltage DC (HVDC) power transmissions
- Electric vehicles and Hybrid electric vehicles
- Grid-Tied Inverters
- Induction Heating
- Industrial automation. etc.

## 4. RESULTS

### 4.1 Results with HYBRID PWM technique:

**Table 4.1.1: Output voltage THD of Hybrid PWM (7th)**

| FREQUENCY | Hybrid PWM (7th) | |
|---|---|---|
| | Non filtered voltage THD (%) | Filtered voltage THD (%) |
| 1KHz | 38.32 | 0.8735 |
| 5KHz | 35.18 | 0.9327 |
| 10KHz | 35.28 | 0.9422 |
| 15KHz | 35.21 | 0.7974 |
| 20KHz | 35.51 | 0.9702 |

**Description:**

The frequency is switched from 1 KHz to 20 KHz in the steps of 5 KHz to observe the THD percentage of filtered voltage and unfiltered voltage for hybrid PWM technique (7th harmonic). It is observed that the THD% is comparatively very less in the filtered voltage condition. For the non-filtered voltage, THD percentage varies from 38.3% to 35.18%. For the filtered voltage, THD varies from 0.9702% to 0.7974%. The hybrid PWM technique (7th harmonic) is a significant important with respect to THD as compared to existing PWM techniques.

**Table 4.1.2: Output voltage THD of Hybrid PWM (11th)**

| FREQUENCY | Hybrid PWM (11th) | |
|---|---|---|
| | Non filtered voltage THD (%) | Filtered voltage THD (%) |
| 1KHz | 37.48 | 0.7541 |
| 5KHz | 33.95 | 0.6926 |
| 10KHz | 33.95 | 0.5721 |
| 15KHz | 33.95 | 0.3574 |
| 20KHz | 33.94 | 0.8233 |

**Description:**

The frequency is switched from 1 KHz to 20 KHz in the steps of 5 KHz to observe the THD percentage of filtered voltage and unfiltered voltage for hybrid PWM technique (11th harmonic). It is observed that the THD% is comparatively very less in the filtered voltage condition. For the non-filtered voltage, THD percentage varies from 37.48% to 33.94 For the filtered voltage, THD varies from 0.8233% to 0.3574%. The hybrid PWM technique (11th harmonic) is a significant improvement with respect to THD as compared to existing PWM techniques and hybrid PWM technique (7th harmonic).

### 4.2. Comparison of HYBRID PWM technique with existing PWM techniques

The benefit of a hybrid PWM technique in reducing Total Harmonic Distortion (THD) compared to traditional techniques like SPWM, THPWM, and CSVPWM.

The THD percentage of the output voltage is measured under two conditions:

• Filtered voltage (presumably after passing through a filter to remove unwanted harmonics)

• Unfiltered voltage (directly from the converter output)

Following five PWM techniques are simulated and compared:

• SPWM (Sinusoidal PWM) - A common PWM technique

• THPWM (Third harmonic injected PWM) - Another PWM technique by injecting third harmonic in reference wave.

• CSVPWM (Conventional SVPWM) - A more advanced PWM technique based on space vector modulation

• Hybrid PWM technique (7th harmonic injected)

• Hybrid PWM technique (11th harmonic injected)

**Conclusion:** The final claim is that the hybrid PWM technique consistently produced a lower THD percentage for both filtered and unfiltered voltages compared to the other techniques. The project suggests that the proposed hybrid PWM technique is a significant improvement for reducing THD in the output voltage of a power converter. This can be beneficial for various applications where cleaner power is desired.

### 4.3. Tabular columns

**Table 4.3.1: Comparison of output voltage THD of different PWM techniques**

| Frequency | SPWM | | THPWM | | CSVPWM | | HYBRID PWM 7th harmonic injected | | HYBRID PWM 11th harmonic injected | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Non filtered voltage THD (%) | Filtered voltage THD (%) | Non filtered voltage THD (%) | Filtered voltage THD (%) | Non filtered voltage THD (%) | Filtered voltage THD (%) | Non filtered voltage THD (%) | Filtered voltage THD (%) | Non filtered voltage THD (%) | Filtered voltage THD (%) |
| **1KHz** | 68.21 | 3.739 | 54.22 | 3.114 | 51.32 | 1.109 | 38.32 | 0.8735 | 37.48 | 0.7541 |
| **5KHz** | 69.31 | 2.275 | 58.03 | 3.73 | 49.38 | 1.789 | 33.18 | 0.9327 | 33.95 | 0.6926 |
| **10KHz** | 72.78 | 5.547 | 58.54 | 4.206 | 52.24 | 1.978 | 33.28 | 0.9422 | 33.95 | 0.5721 |
| **15KHz** | 69.67 | 1.105 | 57.87 | 2.809 | 53.20 | 2.942 | 33.21 | 0.7934 | 33.95 | 0.3574 |
| **20KHz** | 69.15 | 2.192 | 59.38 | 2.531 | 54.95 | 2.511 | 35.51 | 0.9702 | 33.94 | 0.8233 |

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**4.4. THD graphs**

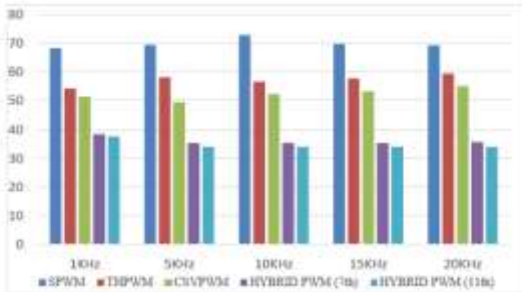


**Fig 4.4.1: Non-filtered voltage THD (%) of different PWM techniques**

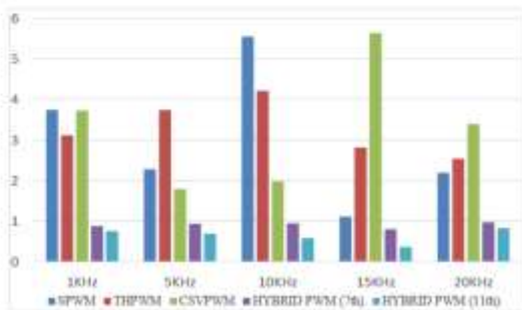


**Fig 4.4.2: Filtered voltage THD (%) of different PWM techniques**

**4.5. Final comparison**

The frequency is switched from 1 KHz to 20 KHz in the steps of 5 KHz to observe the THD percentage of filtered voltage and unfiltered voltage for SPWM, THPWM, CSVPWM and hybrid PWM technique (7th & 11th harmonic). It is observed that the THD% is comparatively very less in the hybrid PWM technique in both filtered and un-filtered condition.

The proposed hybrid PWM technique is a significant improvement with respect to THD as compared to existing PWM techniques and hybrid PWM technique (7th harmonic and 11th harmonic injection).

## 5. CONCLUSION

### 5.1 CONCLUSION

A voltage source inverter (VSI) is a device that changes a constant DC voltage to an AC voltage with variable magnitude and frequency. It is also known as a voltage-fed inverter (VFI). A VSI generates an AC output voltage that can vary in frequency and amplitude depending on the control signal applied to it.

To control the output voltage of the inverter, Pulse Width Modulation (PWM) techniques are used. By adjusting the width of the pulses in PWM waveform, the average voltage delivered to the load can be controlled. Different PWM techniques are used to control the output voltage of the VSI. A larger pulse width results in higher average voltage, while a shorter pulse width results in lower average voltage. Different PWM techniques are used to control the output voltage and frequency of the VSI. Some of the common PWM techniques are SPWM, THPWM, CSVPWM etc.

Sinusoidal pulse width modulation (SPWM) is a pulse width modulation (PWM) technique that compares a sinusoidal AC voltage reference with a high-frequency triangular carrier wave. The frequency is switched from 1 KHz to 20 KHz in the steps of 5 KHz to observe the THD percentage of filtered voltage and unfiltered voltage for SPWM. For the non-filtered voltage, THD percentage varies from 72.78% to 68.21%. For the filtered voltage, THD varies from 5.547% to 1.105%.

Third harmonic injected PWM (THPWM) is a modulation technique that adds a third harmonic signal to a fundamental sine wave. The triangular signal acts as carrier signal. The main

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purpose of adding a third harmonic into the sine triangle PWM is to increase the DC bus voltage utilization of the converter and reduction of THD. The frequency is switched from 1 KHz to 20 KHz in the steps of 5 KHz to observe the THD percentage of filtered voltage and unfiltered voltage for THPWM. For the non-filtered voltage, THD percentage varies from 59.38% to 54.22%. For the filtered voltage, THD varies from 4.206% to 2.531%.

Conventional space vector PWM, also known as space vector pulse width modulation (SVPWM), is a technique that generates a fundamental sine wave to provide higher voltage to the motor, lower total harmonic distortion, and controls the number of short pulses in the PWM waveform. The frequency is switched from 1 KHz to 20 KHz in the steps of 5 KHz to observe the THD percentage of filtered voltage and unfiltered voltage for CSVPWM. For the non-filtered voltage, THD percentage varies from 54.95% to 49.38%. For the filtered voltage, THD varies from 2.942% to 1.109%.

To mitigate the total harmonic distortion (THD) of voltage source inverter a hybrid pulse width modulation technique is introduced. The hybrid PWM technique introduces a modified modulating signal along with newly shaped carrier signal. The proposed modulating signal consists of several signals like saturated triangular, sinusoidal, inverted triangular and 7th harmonic signal are mixed together in order to produce the proposed modulating signal. The project is extended by replacing a seventh (7th) harmonic in the modulating signal with eleventh (11th) harmonic signal. For proposed hybrid PWM technique with 7th harmonic the non-filtered voltage THD varies from 38.3% to 35.18% and the filtered voltage THD varies from 0.9702% to 0.7974% and with 11th harmonic the non-filtered voltage THD varies from 37.48% to 33.94% and the filtered voltage THD varies from 0.8233% to 0.3574%.

While comparing the THD values of different PWM techniques, it is observed that the proposed hybrid PWM technique has given a significant improvement with respect to the THD values. Due to the decrease in the THD values, cleaner output voltage is produced, power quality is improved, losses are decreased and efficiency is increased.

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